The Mzimvubu Water Project:

Baseline indicators for long-term impact monitoring

Report to the

WATER RESEARCH COMMISSION

by

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EXECUTIVE SUMMARY

BACKGROUND

The Mzimvubu River is the largest undeveloped river in South Africa, despite having high potential for development. In recognitions of this, the South African government announced plans to build two multipurpose storage dams in Tsitsa River, one of the largest tributaries to the Mzimvubu. The Ntabelanga dam will largely be used for irrigation (2 686 ha) and potable water whilst the smaller Laleni dam, 20 km downstream of Ntabelanga, will predominantly be used for generation of hydroelectricity. Collectively the dams and associated infrastructure is called the Mzimvubu Water Project (MWP). Government hopes that the MWP will stimulate economic development and promote job creation through rejuvenation of the agricultural sector, hydropower, water transfer and tourism.

Despite the recognised benefits of dams, dam development raises important questions of social and environmental sustainability. The success of a dam project does not only depend on technical feasibility but also sociological feasibility. Success is increasingly being measured by the extent to which the project coheres with specific social and environmental dynamics in the local area – in the short-, medium- and long-term. Studies have shown that a failure to pay close attention to specific socio-cultural dynamics in the local area could expose the project to invidious local resistance, if not immediately, then certainly in the long run. Indeed, difficulties could arise even though local residents appeared to have initially welcomed the project.

In addition the environmental impact, in the short-, medium- and long-term determines the long-term sustainability of a dam project. A large body of literature exists on the environmental impacts (both positive and negative) of dam construction. Nevertheless, because every river is unique in terms of its morphology, the landscapes it flows through and the species it supports, the impacts of dam construction on ecosystems will also be unique.

Therefore, a ''*dam [dam construction] can be regarded as a huge, long-term and largely irreversible environmental experiment without a control*" (McCully, 2001:31). It is crucial to establish a baseline of conditions *prior* to development in order to measure the impact of such development on the environment, economy and sociological dynamics. In recognition of this, the WRC funded a short-term consultancy project with the title '*Conceptualising long-term monitoring to capture environmental, agricultural and socio-economic impacts of the Mzimvubu Water Project in the Tsitsa River*'. In the latter, several aspects which should be monitored in the long term were identified. These then became the objectives of the current research and are summarised below. The overall aim of this interdisciplinary project was to construct a baseline of environmental, agricultural and socio-economic intersections associated with the MWP.

OBJECTIVES

1) **To quantify water quality at selected locations in the Ntabelanga valley**

Water quality criteria are scientific and technical information provided for a particular water quality constituent in the form of numerical data and/or narrative descriptions of its effects on the fitness of water for a particular use. The water quality in the Tsitsa River is likely to change both at spatial and temporal scales once the dam wall is closed. Water quality was assessed over four seasons at twenty fixed sites; eight sites in the Tsitsa River, seven from tributaries to the Tsitsa River and five were from the taps/ground water from villages most likely to be affected by the dam development. Turbidity levels in the Tsitsa River and its tributaries were above recommended levels average levels of 4.88 and 4.64 (10 sample times) for the Tsitsa River and tributaries respectively. Other water quality indicators such as pH, Total Dissolved Solids, Alkalinity, Chloride and Phosphates were however present at acceptable levels at all the sites during all the sampling times. Identification and quantification of influences (natural or anthropogenic inputs) and understanding the contaminant sources is crucial to planning, mitigation and clean-up process and to establish future management strategies. The water quality should therefore be monitored on a continuous basis following the inception of the MWP.

2) **To determine the potential pollution from dry-sanitation systems**

In developing countries, many households use on-site dry sanitation systems (also known as pit latrines) which generally lack a physical barrier, such as concrete, between stored excreta and soil and/or groundwater. As in many developing areas, water for domestic use in the Ntabelanga areas is derived from groundwater and streamwater. In the Ntabelanga area 56% of the households rely on pit latrines and several of these sanitation systems are located around the Ntabelanga dam footprint. There is a concern that, with the rise in the groundwater level associated with impoundment, water sources can become contaminated through these systems. Four sites located close to the inundation footprint and near a tributary to the Tsitsa River were identified. A hydropedological transect survey was conducted at each site to conceptualise the hydrological behaviour, followed by measurements of key hydraulic properties of the soils. Samples were collected of representative horizons to determine the total coliform, total bacteria and *E.coli* contents of the soils as well as that of the tributary. Results show high levels of various microbial indicators with spatial variation (vertical and horizontal) which support the hydropedological interpretations. The migration of rates and quantities of faecal bacteria from these four sites, as well as other pit-latrines, to surface and groundwater sources should be determined in future studies.

3) To characterise stream geomorphology at selected locations in the Tsitsa River

Fluvial systems are dynamic systems in which variables in a catchment and river channels affect the morphology of river reaches. South African rivers are increasingly being exposed to stresses from a combination of factors, one of the most prevalent being the impacts of dams which result in varying sediment yields and flow regimes. The sediment load combined with flow characteristics for respective river channels provides the physical habitat for aquatic ecosystems. The damming of the Tsitsa River, through the construction of the Ntabelanga Dam, will change the overall downstream geomorphology. This creates an opportunity for research in the pre-construction window. Over two years this Masters project focused on monitoring the current condition of the Tsitsa River by completing a baseline survey of the channel geomorphology. Five sites were established in variable reaches of the Tsitsa River, proximal to the proposed Ntabelanga Dam. In each of these sites features such as the nature of the substrate (topography and roughness), distribution of clasts, turbidity, suspended sediment concentration and slope of flow were measured at various temporal intervals. This baseline study provides a set of data about the current geomorphic condition of selected sites in the Tsitsa River as well as seasonal variations in flow hydraulics against which post-impoundment impacts can be assessed.

4) To describe aquatic biodiversity at selected locations in the Tsitsa River

The natural and land use processes within a river catchment play a pivotal role in ecosystem health and have a dominant influence on habitats within a river as well as its biological diversity. It has been recognised by many authors that increased sedimentation and turbidity have a direct impact on ecological health in fluvial systems. Anthropogenic impacts, such as impoundments can augment the amount of sediment entering fluvial systems resulting in a marked change in both aquatic habitats and associated biota. The physical habitat was described at selected locations in the Tsitsa River under current conditions using the SAS analysis. From this a physical habitat score was created which accounted for seasonal changes as well. The physical score was based on, *inter alia*, temperature, EC, pH, Dissolved Oxygen, P concentrations, occurrence of macroinvertebrates and a Hydromorphological Index of Biodiversity (HMID). In addition macroinvertebrates were classified into orders and related to their sensitivity to habitat change. Documenting seasonal changes in the Tsitsa River will hopefully aid a better understanding of the current processes at work between sediment characteristics and river habitats. Post dam impacts can be monitored at all the sites to quantify the impact of the development. After dam construction, one of the sites, above the dam inundation, can still be used as a monitoring point for rehabilitation effectiveness in upstream catchment areas.

5) To characterise natural vegetation on representative landscape positions in the Ntabelanga area

Plant diversity, composition and utilisation within the Tsitsa river catchment area in the Eastern Cape Province were examined in relation to how the planned dam development will impact livelihood needs of the local people. Before such major land use changes are implemented, there is need to evaluate the perceptions of the residents, current land use practices and the changing socio-economic framework. The household was therefore chosen as the unit of analysis. The different livelihood needs in the study area revolving around plant biodiversity were identified, including their land, useful plant species, crops, grazing land and the corresponding impacts likely to be caused by the planned dam were demarcated for a detailed analysis. This study utilised the participatory rural appraisal (PRA) methods, emphasising in-depth discussions with 21 participants. Documenting such contextual details is essential to understand and meet the local community's expectations from an ethnobotanical research and also as part of establishing a broader, contextual framework necessary to understand the complex relationships between people and the plant resources around them. This ethnobotanical research was complemented by several ecological techniques aimed at assessing plant species diversity, composition and rangeland condition. At least six distinct vegetation units and the associated species were identified and discussed. Nine different uses of plants were also recorded in the area, namely beverage, cereal and crafts (one species each), ornamental, live fence or hedge (three species each), edible tubers or roots (six species), vegetables (nine species), fruits (16 species) and herbal medicines (28 species). Useful plant species were mentioned by at least 50% of the participants. Three grass species generally regarded as highly palatable were recorded in study area with eight species regarded as moderately to poorly palatable. Dry matter yield increased from 94.4±8.0 to 341.5±26.8 kg/ha from crest areas to the valley bottom on the periphery of Tsitsa River. The vegetation sites and interviews can be used as baseline to which changes in floral diversity, composition and utilisation is measured.

6) To quantify soil quality of representative soils and cultivated fields in the Ntabelanga area

The proposed dam will result in alteration of land uses (e.g. conversion of dryland crop production to irrigated fields). These changes will invariably result changes in the soil quality and it is therefore necessary to quantify soil quality prior to construction. The Soil Management Assessment Framework (SMAF) as non-linear indexing tool to assess soil functioning and hence soil quality. SMAF was created for farmers and their advisors in evaluating the ongoing management activities. SMAF assessments were conducted on soils from 19 different sites. Ten of these sites were located on cultivated fields of the Lower Sinxaku village and another on fields demarcated for irrigation near the KuGubengxa village. The remaining eight sites were located on the same plots where vegetation assessments were conducted. Indicators used in the SMAF analysis included Organic Carbon (OC), Microbial Biomass Carbon (MBC), phosphorous (P), exchangeable potassium (K), pH, aggregate stability and bulk density. Soil Quality Index (SQI) ranged from 50.4% in KuGubengxa to 97.8% in one of the community garden in Lower Sinxaku, highlighting the importance of different management practices on soil quality. In general the rangelands had lower SQI values than cultivated fields. These SMAF scores serve as valuable baseline data for future comparisons of soil quality, not only to determine the impacts of land-use change but also on the effectiveness of rehabilitation practices.

7) To characterise carbon stocks and wetland water regimes

The soils under the dam footprint will change from a carbon sink to a carbon source once inundated. Since decomposition of carbon will occur under anaerobic conditions, large quantities of Greenhouse Gases (GHG's), and especially methane can be released following dam construction. It is therefore necessary to quantify carbon stocks under the proposed Ntabelanga dam footprint and estimate the GHG associated with the development. Closing of the Tsitsa River will also impact flow regimes and consequently wetlands downstream of the proposed dam. These impacts need to be quantified to estimate the true environmental cost of the project. Carbon stocks were calculated following a digital soil mapping approach. A soil association map of the dam footprint were created. Five soil associations were identified based on re-grouping of 14 soil forms occurring in the study area. The associations are Duplex, Semi-duplex, Apedal, Wet and Shallow. Soil Organic Carbon (SOC) contents of these soil associations were then determined and, based on the area covered by different associations, total soil carbon stocks calculated. The total SOC under the 3 780 ha footprint is 262 733 tonnes, or approximately 70 t ha^{-1}. The SOC is relatively low when compared to other similar environments due to chemical and physical degradation in the area.

Wetlands below the proposed Ntabelanga dam were identified using desktop analysis. Since the independent Environmental Impact Assessment (EIA) focussed on identification and characterisation of wetlands under the dam footprint. A representative wetland below the dam footprint was instrumented with piezometers, soils were classified and the hydromorphology of the soils described. Shortly after the installation the instruments were stolen. An indirect approach whereby satellite images between 2002 and 2016 of a large wetland, directly below the Ntabelanga dam were studied. The area of surface water was determined for five different time-steps and correlations between the surface water area, rainfall and streamflow were determined. Poor correlations between short term cumulative rainfall (<6 months) and surface water area exists. A very good positive correlation ($R^2 = 0.92$) between 12 month cumulative rainfall and surface water area suggests that the water contents of the wetlands are a factor of seasonal precipitation and not particular events. The lack of any significant correlation between streamflow characteristics (including streamflow on the image date and long term maximum flow) indicate the water regimes of the wetlands are not impacted directly by the streams. These findings further indicate the wetlands below the dam are not gaining water from the stream but are in fact feeding the stream (losing wetlands). The impact of the dam on wetland water regimes will therefore be restricted to streambed incisioning directly below the dam wall. Deepening of the streambed will result in lowering of water tables in the wetland and therefore alter water regimes.

8) To describe the dominant agricultural practices and quantify yields of selected crops

One of the anticipated benefits of the MWP is the rejuvenation of agriculture. With this in mind it was important to describe existing agricultural practices and quantify yields/productiveness of dominant practices. These descriptions and quantifications can then be used to evaluate the contribution of the proposed development to rejuvenation in agriculture. A socio-physical approach was used. Interviews with 300+ respondents were conducted in five villages which will be impacted by the dam in different ways. An addition 21 interviews were held with farmers who were actively involved in agriculture. Yield samples from 10 representative fields were collected during two growing seasons and up-scaled for comparison purposes. Maize yields during the two seasons ranged between 0.83 $t.ha^{-1}$ and 2.67 $t.ha^{-1}$. Even the highest yield was only 49% of the potential yield based on soil and climatic conditions. The interviewed farmers attributed poor yields to unreliable rainfall, lack of labour and lack of external inputs as the main reasons. The farmer with the highest yield (who notably also had highest SMAF score), is actively improving his soils through incorporation of decomposed animal manure. Timely access to good quality seeds, fertilisers and extension services (to the right farmers) as well as in-field rainwater harvesting might be a more cost-effective approach to improve agricultural production in the area, instead of large scale irrigation. Future work should expand the yield gap approach to identify constraints to agricultural production in other areas impacted by the MWP.

9) **To capture social-economic perceptions, hopes and fears dynamics in selected villages associated with the MWP**

This report is a sequel to several qualitative studies by the research team in selected Ntabelanga Dam communities. The sociological aspects of those studies revealed, among other things, narratives of hope, fear, and even disdain, with regard to the proposed dam – especially disdain about the modes of public participation community engagement so far adopted by the state (or consultants acting on its behalf). The survey, conducted over a two-week period in November/December 2016, focused on six key themes: (a) Respondent demographics, (b) Livelihoods and socio-economic activities, (c) Social network and social capital, (d) Formal and informal safety nets, (e) Social amenities: availability, access and community satisfaction, and (f) Ecological indicators, risk and vulnerability. Its main purpose was to generate a baseline of quantitative metrics against which the short-, medium-, and long-term, impact of the Ntabelanga can be measured. It is a snapshot of the dam communities before the first bricks of the dam walls are laid, and against which to make sense of progress, or otherwise, vis-à-vis the promise of a new lease of life in the affected communities. Five communities were selected for the baseline survey – and they were the same communities in which earlier (qualitative) phases of the study were conducted, namely: Emqokolweni (with particular attention to the dam inlet section of Ngxoto), Lower Sinxaku, Ngqongweni, Ndzebe and Ndibanisweni Administrative Area (AA). The survey data are presented in full in this report. They reveal, in the main, that if the dividends of the Ntabelanga dam are currently imagined (by the state) in mostly economic terms, the economic status quo in the communities is daunting in itself. However, there are social, cultural and ecological dynamics that the dam will impact, one way or another, and because of the sensitivities embedded in these dynamics, such impact must be carefully monitored. Will the dam make a difference, positively or negatively, in the affected communities? This baseline survey report offers a modest basis for embarking on a systematic, multi-year analysis of the dam-community-environment nexus, that, ultimately, will yield an answer to the question just posed.

A UNIVERSE OF INTERACTIONS AND INTERSECTIONS

A dam project, such as the one proposed for Ntabelanga, can support a vision of rural renewal, as propagated by the state and its agencies. A major dam can become a galvanising basis for skills development and entrepreneurships – besides making possible easy access to potable water and water for general household use, and bolstering job creation and occupational and skills enhancement. All this can translate to improved household income and a better quality of life for community members in the long run. Members of the five selected communities recognise these potentials, and in some ways, are willing to embrace them. These putative benefits could, however, come at a huge cost, if local concerns and certain community dynamics are not recognised and taken on board early in the dam development process. In the various communities – with the exception, perhaps, of Ndibanisweni AA, which is located too far away from the dam to be directly adversely affected – the dam has clear socio-economic, agricultural and environmental aspects that intersect in distinct, sometimes adverse, ways. For instance, the study reveals a clear possibility of social displacement, and people have been made to contemplate this possibility. What this indicates is that a 'redevelopment' of the area is inevitable; but this is bound to entail interventions in the agricultural sector, including, perhaps, a tinkering with grazing areas, grazing regimes and even the number and demographics of people involved in agriculture. Such new realities could impact one way or another on household income, but will definitely impact on the quality of human dwelling and instigate a new sense of space and place. Indeed, community members picture the future utilising grim phrases such as being "killed", being "torn down", and being "thrown away". These are metaphors of future-shock which contradict their otherwise supportive narratives about possible dam-induced rural renewal. Furthermore, while the putative potable, agricultural and industrial water supply benefit of the proposed dam is acknowledged, a crucial segment of the community – sangomas, who are generally regarded as important custodians of local knowledge – has sounded a word of caution about the devastating implications of water inundation on both the mystical ecology and the spiritual and cultural well-being of the community. From their perspective, a dam might signify development and modernisation for the living, but the living cannot function without the guidance of ancestors and spirits – and water inundation is a bad omen for spiritual activities and ultimately for the reciprocal relationship between the world of the living and the abode of ancestors. Thus, cultural issues intersect directly with environmental aspects of a big dam. Almost in the same vein, easy access to drinking water – a clear dam benefit – is counterpoised by the possibility of dam inundation. It could lead to resource losses, deficits and deprivations. In a socio-economically depressed area where families have very limited access to arable farm plots (1-3 ha on average), and where 49% of residents depend on welfare grants, 22% of the labour force subsist on piece jobs and 11% of the adult population are supported by family members, resource losses arising from dam inundation cannot be viewed as a challenge that has simple remedies: the intersection of environmental and socio-economic aspects of the project must be closely watched. In the Ntabelanga area, therefore, a big dam project is a distinct source of hope and dread. Social cohesion seems quite high in the study communities and is partly indicated by 'social capital, which in turn, is indicated by the preponderance of grassroots associations. These include burial societies, women's clubs, neighbourhood associations, hometown associations, men's clubs, youth clubs, cooperatives, stokvels, and churches – with burial societies identified by an overwhelming majority of survey respondents as being by far the most popular, and men's clubs and cooperatives the least popular. The possibility exists that a 're-development' of the area (through new agricultural interventions) and access to new income sources could impact membership of, and people's commitment to, these grassroots associations in different ways. However, there is a sense that factors such as potential social displacement could adversely affect the functioning of such associations. Community cohesion is caught in these possibilities. The matrix of intersections does not end there. There is the issue of social deviance. Awareness by survey respondents of issues such as alcohol abuse, drug abuse and domestic violence currently stand at 82%, 51% and 54% respectively. While these mirror the communities' high unemployment statistic (72%), it would be of interest to see how possible improvements in income (linked to the proposed dam's job-creation potential) would affect these indices. In the final analysis, the question to which researchers must constantly seek answers is: to what extent can a dam project change the quality of social existence in South Africa's rural communities?

CONCLUSION

The South African government's pronouncements concerning the Ntabelanga dam is unequivocal about the dam's potential to bring about rural renewal in, at the very least, the surrounding communities – through hydropower, irrigated, modernised and commercial agriculture, ecotourism and multifarious job-creation opportunities that these bring. Indeed, if there is one idiom that underpins the state's investment in this project, it is an economic one. What has emerged from qualitative data obtained in the five selected communities and a quantitative survey of community members – is that a dam is a multivalent investment, but, in the case of the Ntabelanga dam, one which the state appears to view in an overwhelmingly beneficial way. From the findings of this study, it is of utmost importance to adopt a holistic view of the dam communities and, thus, to view the dam's impacts as being potentially more than just economic and more than simply beneficial.

RECOMMENDATIONS FOR FUTURE RESEARCH

The present study was designed principally to establish a baseline of environmental, agricultural and socio-economic data that would aid the long-term impact monitoring of the Ntabelanga dam. Empirical data from the study communities brought out in bold relief important dynamics that clearly are crucial for the long-term monitoring effort – and the sustainability of the dam. These include space-place dynamics, but especially the disaffection felt by many in the study communities about the "sidelining" of community members during the initial phases of the project. The fact that the dam construction has not begun as of the time of concluding the present study is perhaps something positive, as a crucial, more sociological, phase of the study can now be enacted. It should focus on possibilities of community-based impact monitoring of the Ntabelanga dam, with a key emphasis on uncovering a strategy for empowering affected communities to themselves "monitor" and "measure" how the dam affects them.

CAPACITY BUILDING AND TECHNOLOGY TRANSFER

The following students benefited from K5/2433:

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Peer reviewed publications from K5/2433

1. Parwada, C. & Van Tol, J.J. 2018. Effects of litter quality on macroaggregates reformation and soil stability in different soil horizons. *Environment, Development and Sustainability*. https://doi.org/10.1007/s10668-018-0089-z
2. Akpan, W. van Tol, JJ, Malambile, M & Nqalo, N. 2017. Science, ethnoscience and a dam: (Mis)reading the potential impacts of the Ntabelanga Dam, South Africa. *In* Akpan, W & Moyo, P. (eds.) Revisiting Environmental and Natural resource questions in Sub-Saharan Africa. Cambridge Scholars Publishers. 1 – 24.
3. Maroyi, A. 2017. Assessment of Useful Plants in the Catchment Area of the Proposed Ntabelanga Dam in the Eastern Cape Province, South Africa. *The Scientific World Journal* doi.org/10.1155/2017/3763607.
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10. Parwada, C & Van Tol, J.J. 2017. Litter quality effects on soil stability and erodibility of selected South African soils *Global Advanced Research Journal of Agricultural Science*, 6, 181-187.
11. Parwada, C. & Van Tol, J.J. Litter quality influence on soil splash rates and organic carbon dynamics in top soil horizons. **Accepted in:** *WaterSA.*
12. Mamera, M. & Van Tol, J.J. Application of hydropedological information to conceptualise pollution migration from dry sanitation systems in the Ntabelanga area, South Africa. **Accepted in:** *Air, Soil and Water Research.*

Several other manuscripts are being prepared. Findings were also presented as seven papers at national conferences.

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TABLE OF CONTENTS

EXECUTIVE SUMMARY III
ACKNOWLEDGEMENTS XIV
TABLE OF CONTENTS XV
LIST OF FIGURES XX
LIST OF TABLES XXVI
LIST OF ABBREVIATIONS XXXI
1 INTRODUCTION 1
1.1 Aim and objectives 2
2 ENVIRONMENTAL DESCRIPTION OF THE STUDY AREA 5
2.1 The Ntabelanga Study Area 6
2.2 Description of Environmental Situation 11
Climatic Information 11
Streamflow in the Tsitsa River 15
Soils 17
Vegetation, Wetlands and Natural Forests 30
2.3 Studied communities 32
3 METHODOLOGICAL NOTES 34
3.1 Introduction 34
3.2 Water quality monitoring 34
Sampling sites 34
Materials 36
Analytical procedure 37
Data processing and analysis 37
3.3 Pollution from latrines 37
Site selection 37
Hydropedological conceptualisation and microbial sampling 39
3.4 Stream channel geomorphology 41
Monitoring Sites 41
Physical Variables 41
3.5 Aquatic biodiversity 48
Materials and methods 48
Statistical Analyses 55
Patch Scale Analyses 56
3.6 Vegetative analysis 57
Research approach 57
3.7 Assessment of grazing potential 62
3.8 Assessment of soil quality, yields and yield gaps 62
Soil quality 62
Soil Management Assessment Framework 62
Yield measurements 64
3.9 Carbon stocks and wetland water regimes 65

Estimation of carbon stocks 65
Wetland water regimes 66
3.10 Methods of sociological data collections 68
Community survey – Instrument and themes 68
Survey sampling procedure 71
Focus group discussion (FGD), in-depth interview and field observation 71
A note on research ethics 71
4 WATER QUALITY 73
4.1 Water Quality Guidelines 74
Fitness for use category 74
Combined fitness for use 75
4.2 Results and discussion 76
Water Quality indicators (parameters) 79
Stream flow vs. Water Quality 83
4.3 Conclusion and continuous monitoring actions 85
5 POTENTIAL POLLUTION FROM DRY-SANITATION SYTEMS 86
5.1 Introduction 86
5.2 Results 88
Soil morphology 88
Soil physical properties 91
Hydropedological behaviour 92
Microbial biomass 96
5.3 Conclusions and recommendations for future monitoring 98
6 STREAM CHANNEL GEOMORPHOLOGY 100
6.1 Introduction 100
6.2 Results and Discussion 102
Desktop Analysis 102
Physical Variables 106
Flow Hydraulics 119
6.3 Concluding remarks and recommendations for future monitoring 125
7 MONITORING AQUATIC BIODIVERSITY AND HABITAT CONDITIONS 126
7.1 Introduction 126
7.2 Results and Discussion 127
Habitat quality 127
Biological Variables 134
7.3 Concluding Remarks and recommendations for future monitoring 154
8 VEGETATION DIVERSITY, COMPOSITION AND UTILISATION 155
8.1 Introduction 155
8.2 Results and discussion 155
Plant diversity and composition 155
Impact of dam construction on plant diversity and composition 161
Useful plant species 165

State of grazing land in Ntabelanga area 169
Impact of dam construction on grazing potential 170
8.3 Conclusion and recommendations for future monitoring 172
9 SOIL QUALITY 173
9.1 Soil Management Assessment Framework (SMAF) to evaluate soil quality 173
SMAF Assessment procedure 173
9.2 Results and discussion 176
Soil classification 176
Soil chemical and physical properties 177
SMAF assessments 180
9.3 Conclusions and recommendations for future monitoring 189
10 CARBON STOCKS AND WETLAND WATER REGIMES 190
Dams as sources of Greenhouse Gasses 190
Impact of dams on wetlands 191
Objectives 193
10.1 Results and discussions 193
Carbon stocks 193
Wetland water regimes 195
Wetland water regimes based on satellite imagery 199
10.2 Conclusions and recommendations for future monitoring 203
11 CULTIVATION IN HOME GARDENS 204
11.1 Introduction 204
Defining smallholder farmers 204
An overview of smallholder farmers in South Africa 204
Eastern Cape smallholder farmer context 206
An overview of smallholder irrigation in South Africa 206
Crop yield prediction a tools to identify problems 207
Objectives 209
11.2 Results and discussion 209
Actual yields 210
Yield gaps 211
11.3 Conclusions and recommendations for future studies 211
12 SOCIOLOGICAL SURVEYS 212
12.1 Introduction 212
12.2 Respondent demographics 213
12.3 Livelihoods and socio-economic activities 214
12.4 Social networks and social capital 214
12.5 Formal and informal safety nets 214
12.6 Social amenities 215
12.7 Ecological indicators, risk and vulnerability 215
12.8 Conclusion 215
13 BIG DAM, COMMUNITY DYNAMICS AND THE PURSUIT OF RURAL RENEWAL: INTERACTIONS AND INTERSECTIONS 216

13.1 Introduction 216
13.2 Access to clean water 217
Background physical information 217
Water and the community 218
13.3 Useful plants 221
Useful plant species 221
Potential impact of dam construction on utilisation of plant resources 226
13.4 Soil quality, yields and perceptions on cultivation in home gardens 227
General cultivation practices 227
Challenges associated with cultivation 228
13.5 Livestock farming and land quality 231
13.6 ‘Stopping the river’: The ethno-mystical dimension 233
13.7 “We don’t want that dam here”: People, space and place 234
13.8 A universe of intersections – discussion and conclusion 236
14 GENERAL CONCLUSIONS AND RECOMMENDATIONS FOR FUTURE RESEARCH 240
LIST OF REFERENCES 242
APPENDIX 1 – WATER QUALITY DATA 262
APPENDIX 2 – SOCIOLOGICAL QUESTIONNAIRE 269
APPENDIX 3 - SOCIOLOGICAL SURVEY DATA 288
15 RESPONDENT DEMOGRAPHICS 288
15.1 Gender 288
15.2 Marital Status 289
15.3 Age of respondents 289
15.4 Housing type 289
15.5 Number of people in residence 290
15.6 Kinship and sharing of financial burden 290
15.7 Location of schools 291
15.8 Reasons for children not attending school 291
15.9 Respondents’ levels of education 292
15.10 House ownership 293
16 LIVELIHOODS AND SOCIO-ECONOMIC ACTIVITIES 293
16.1 Employment status 293
16.2 Respondents’ occupations 294
16.3 Employment/Unemployment experience 295
16.4 Entrepreneurship 296
17 SOCIAL NETWORKS AND SOCIAL CAPITAL 299
17.1 Grassroots associations and membership 299
17.2 Youth activities and recreation 300
17.3 Recreational spaces and activities for older people 301
17.4 Social problems 303
17.5 Combating crime 305
18 FORMAL AND INFORMAL SAFETY NETS 306

18.1 Formal welfare grants ... 306
19 SOCIAL AMENITIES: AVAILABILITY, ACCESS AND COMMUNITY SATISFACTION ... 308
19.1 Drinking water ... 308
19.2 Water for general household use ... 309
19.3 Sanitation ... 310
19.4 Cellular phone ... 310
19.5 Healthcare ... 311
19.6 Educational amenities ... 311
19.7 Modes of public transport ... 312
19.8 Electricity ... 313
19.9 Available social amenities ... 313
20 ECOLOGICAL INDICATORS, RISK AND VULNERABILITY ... 314
20.1 Disasters ... 314
20.2 Diseases ... 315
20.3 Fire incidence ... 315
20.4 Ecological and agricultural assets ... 316
20.5 Fertiliser use ... 318
20.6 Crop yield ... 318
20.7 Agricultural labour input ... 319
20.8 Farming spaces ... 320
20.9 Livestock and grazing spaces ... 321
20.10 Irrigation ... 323

LIST OF FIGURES

Figure 1-1: Intersections – Possible cross-cutting issues for transdisciplinary monitoring (Van Tol et al., 2014b). 3
Figure 2-1: Location of the Mzimvubu catchment. 5
Figure 2-2: Predicted inundation footprint of Ntabelanga and Laleni dam with proposed irrigation areas. 6
Figure 2-3: The study area for description of physical environment, socio-economic and agricultural *status quo* with predicted footprint of the Ntabelanga dam. 7
Figure 2-4: Elevation expressed as meters above mean sea level (m.a.m.s.l) of the study area. 8
Figure 2-5: Location of proposed Ntabelanga dam wall (red arrow) and downstream view of the Tsitsa River (Located at Photo 9 in Figure 2-3). 9
Figure 2-6: Alluvial plains along the Tsitsa River below the proposed dam wall (located at Photo 5 in Figure 2-3). 9
Figure 2-7: Community 1 (Ntzebe) in the background on the banks of the Tsitsa River downstream of the proposed dam wall (located at Photo 2 in Figure 2-3). 10
Figure 2-8: View of the Ntabelanga (located at Photo 3 in Figure 2-3). Part of community 2 (Lower Sinxaku) is encircled in red. Note the extent of gully erosion in the foreground. ... 10
Figure 2-9: Average seasonal rainfall (mm) of SAWS sites Elliot and Mthata. 11
Figure 2-10: Seasonal trends in rainfall for the past five rain seasons (South African Weather Service). 12
Figure 2-11: Predicted change in precipitation (mm month^{-1}) for July and December 2050 (Midgley et al., 2007). 14
Figure 2-12: Projected change in median surface temperatures (˚C) for difference seasons in 2050. 14
Figure 2-13: DWA gauging weir T3H006 approximately 20 km downstream of the proposed dam wall (Photo 1 in Figure 2-3). 15
Figure 2-14: Daily average streamflow (m^3.s^{-1}) measured from 1951 to 2017 at T3H006 in the Tsitsa River. 16
Figure 2-15: Daily average streamflow (m^3.s^{-1}) from 2014 to 2017 measured at T3H006 in the Tsitsa River. 16
Figure 2-16: Broad land types of the study area. 18
Figure 2-17: Average soil depth derived from land types in the study area. 20
Figure 2-18: Average clay content (top and subsoils combined) of soils in the study area. . 21
Figure 2-19: Severely eroded land and broad land types of the study area. 22

Figure 2-20: Example of gully erosion commencing on old cultivated lands in land type Ab. 23
Figure 2-21: Spatial distribution of classified surface erodibility (K-factor) of the Ntabelanga area. 24
Figure 2-22: Spatial distribution of structural stability index in the Ntabelanga area. 25
Figure 2-23: Spatial distribution of classified soil erosion risk zones according to soil dispersion ratios........ 26
Figure 2-24: Spatial distribution of classified soil erosion risk zones prior to incubation....... 27
Figure 2-25: Severe gully erosion on an Estcourt soil form (located at Photo 4 in Figure 2-3)........ 28
Figure 2-26: Gully erosion located at Photo 6 in Figure 2-3. Full-grown *Acacia* trees highlight the extent of the erosion........ 28
Figure 2-27: Inside one of the gullies in Figure 2-26........ 29
Figure 2-28: Efforts to stop erosion along the road (Located at Photo 7 in Figure 2-3)....... 29
Figure 2-29: Degraded natural grassland in the study area........ 30
Figure 2-30: Dominant vegetation sites in the study area (adapted from Mucina and Rutherford, 2006)........ 31
Figure 2-31: Location of wetlands and indigenous forests in the study area. 31
Figure 2-32: A typical wetland occurring widely in the study area (located at Photo 8 in Figure 2-3)........ 32
Figure 3-1: Water quality sampling locations (A-T)........ 35
Figure 3-2: Monitoring locations for water samples (A-J correspond to letters in Figure 3-1)........ 35
Figure 3-3: Monitoring locations for water samples (K-T correspond to letters in Figure 3-1)........ 36
Figure 3-4: Map of the study area and selected sites. 38
Figure 3-5: Photographs of surveyed sites (white arrow – pit latrine; blue arrow – tributary stream)........ 38
Figure 3-6: The location of cross-sectional surveys for Site 5, below the confluence with the Inxu, to monitor increased embeddedness of coarse substrate and channel narrowing and or reduction in depth. 42
Figure 3-7: Sorting classes for substrate (Gordon et al*.,* 2004)........ 43
Figure 3-8: Average difference between mini SASS and SASS scores for the Tsitsa River. 50
Figure 3-9: Locality map of the study area including sites of vegetation characterization. ... 57
Figure 3-10: Assessing floral diversity and composition in a 5 m X 5 m quadrat (Photo: A. Maroyi)........ 58
Figure 3-11: Map of the 10 representative gardens at Lower Sinxaku 63
Figure 3-12: Location of soil profile observations and OC carbon samples......................... 65

Figure 3-13: Location of piezometers and sampling sites of the first instrumented wetland. 67
Figure 4-1: Typical example of compressed experimental flow diagram for Paracetamol identified using the non-targeted screen approach. 77
Figure 4-2: Typical example of Pharmaceuticals and Personal care Products identified using the non-targeted screen approach. 78
Figure 4-3: The correlation matrix (r values at significance levels = 0.05) of dissolved oxygen at various sampling points vs. monthly stream flow of the Tsitsa River. 84
Figure 4-4: The correlation matrix (r values at significance levels = 0.05) of temperature at various sampling points vs. monthly stream flow of the Tsitsa River. 85
Figure 4-5: The correlation matrix (r values at significance levels = 0.05) of turbidity at various sampling points vs. monthly stream flow of the Tsitsa River. 85
Figure 5-1: Hydropedological conceptual model for MT1. 92
Figure 5-2: Hydropedological conceptual model of MT2. 93
Figure 5-3: Site 3-Hydropedological conceptual model based on soil morphology. 94
Figure 5-4: Hydropedological conceptual model of MT4. 95
Figure 6-1: Hierarchical nature of rivers, from a large catchment scale to successively smaller scales of river segments, channel reaches, individual channel units (such as pools and riffles) and microhabitats (Adapted from Allan, 2004). 100
Figure 6-2: Locality map of monitoring sites in the Tsitsa River, Eastern Cape. 102
Figure 6-3: Longitudinal Profile of the Tsitsa River from its headwaters in the Drakensberg Mountains to below the confluence with the Inxu River. 103
Figure 6-4: Longitudinal Profile of the selected sites along the Tsitsa River reach ranging from the gorge to below the confluence with the Inxu River. A: End of dam inundation, B: Dam Wall, C: Confluence with Inxu River. 103
Figure 6-5: a) Upstream and b) downstream view of Site 1. 104
Figure 6-6: Downstream view of Site 2. 104
Figure 6-7: Downstream view of Site 3. 105
Figure 6-8: Confluence of the Inxu River with the Tsitsa River. 105
Figure 6-9: a) Upstream and b) downstream view of Site 4. 106
Figure 6-10: Upstream view of Site 5. 106
Figure 6-11: Example of cross-sectional transects with corresponding substrates and geo-habitats, surveyed in July 2015. 107
Figure 6-12: Example of cross-sectional transects with little or no seasonal change to channel topography. 108
Figure 6-13: Example of cross-sectional transects that have undergone a seasonal change in topography. In this case changes have occurred due to sand mining at low flows. 109

Figure 6-14: Channel features at a large scale for Site 1. 110
Figure 6-15: Channel features at a large scale for Site 2. 111
Figure 6-16: Channel features at a large scale for Site 3. 112
Figure 6-17: Channel features at a large scale for Site 4. 114
Figure 6-18: Channel features at a large scale for Site 5. 115
Figure 6-19: Seasonal variations in measured discharge. a = Rising stage of a flood, b = Receding stage of a flood. 116
Figure 6-20: Seasonal variation of average embeddedness values across each site. 116
Figure 6-21: Variation in surface fine sediment accumulation. 117
Figure 6-22: Turbid flood pulse during low flow, October 2015. 117
Figure 6-23: Variation in subsurface fine sediment accumulation 118
Figure 6-24: Variation in turbidity. a = Rising stage of a flood, b = Receding stage of a flood. 118
Figure 6-25: Variation in suspended sediment concentration. a = Rising stage of a flood, b = Receding stage of a flood. 119
Figure 6-26: Variation in water clarity. a = Receding stage of a flood, b = Lowering stage of a flood. 119
Figure 6-27: Flood Frequency curves for three rivers in the Mzimvubu catchment. 120
Figure 6-28: Regional Flood Frequency Curve of the Tsitsa River. 121
Figure 6-29: Seasonally measured discharge. a = Rising stage, b = Receding stage. 121
Figure 6-30: Example of a rating curve for Site 1. 122
Figure 6-31: Example of fluctuations in flow properties over time for Site 1. 122
Figure 6-32: Example of a change in energy slope, with changes in discharge, at sites with different bed gradients. 123
Figure 7-1: Box and whisker plots of substrate diversity for different habitats in each reach. 135
Figure 7-2: Box and whisker plots of sampled surface sediment concentration for different habitats in each reach. 136
Figure 7-3: Box and whisker plots of sampled subsurface sediment concentration for different habitats in each reach. 136
Figure 7-4: Box and whisker plots of sampled suspended sediment concentration for different habitats in each reach. 137
Figure 7-5: Box and whisker plots of sampled depths for different habitats in each reach. 138
Figure 7-6: Box and whisker plots of sampled flows for different habitats in each reach.... 138
Figure 7-7: Box and whisker plots macroinvertebrate diversity for different habitats in each reach. 139

Figure 7-8: Box and whisker plots of the ASPT for sediment sensitive species for different habitats in each reach. 140
Figure 7-9: Percentage distribution of different macroinvertebrate classes occurring in different concentration of surface sediment drape in the Tsitsa River. 151
Figure 7-10: Percentage distribution of different macroinvertebrate families occurring in different concentration of surface sediment drape in the Tsitsa River. 152
Figure 7-11: Factors to be monitored influencing aquatic biodiversity. 154
Figure 8-1: Hierarchical Cluster Analysis dendogram classification of vegetation plots based on weighted species presence. 158
Figure 8-2: Detrended Correspondence Analysis (DCA) ordination diagram showing the grouping of sample plots of the Ntabelanga area into six groups (A-F). 159
Figure 8-3: Canonical Correspondence Analysis (CCA) ordination scatter plot indicating the influence of environmental variables on species composition in the Ntabelanga area. 159
Figure 8-4: Riparian vegetation of Tsitsa river dominated by *Acacia baileyana, A. dealbata and A. mearnsii* (Photo: A. Maroyi). 164
Figure 8-5: Whilst low-lying areas will be flooded after the dam wall has been constructed, little immediate vegetation transformation is expected on rocky and sloppy ridges (Photo: A. Maroyi). 164
Figure 8-6: The use categories of useful plants recorded in the Ntabelanga area. 165
Figure 8-7: Large tracts of land along the Tsitsa River are devoted to grazing (Photo: A. Maroyi). 172
Figure 9-1: Conceptual framework for the soil management assessment tool (Andrews, 1998). 174
Figure 9-2: Grouping of indicators, interpretation indicators and calculation of Soil Quality Index (Andrews et al., 2001). 175
Figure 10-1: Soil association map of the entire attribute space. 194
Figure 10-2: Soil association map of the Ntabelanga dam footprint. 194
Figure 10-3: Wetlands directly downstream of Ntabelanga dam. 196
Figure 10-4: Distributions of red, brown and grey mottles within the soil profile. Colours of arrows indicate mottle colours. 199
Figure 10-5: Satellite imagery for wetland b in Figure 5 for a) 26/5/2002; b) 21/3/2011; c) 1/5/2014; d) 5/5/2015 and e) 1/3/2016. 200
Figure 10-6: Cumulative rainfall over different periods vs. surface water area. 201
Figure 10-7: Streamflow characteristics for different periods vs. surface water area. 201
Figure 13-1: Perceptions of drinking water quality. 218
Figure 13-2: Regularity of water flow for drinking water. 219
Figure 13-3: Regularity of water supply/flow for general household use 220

Figure 13-4: Type of sanitation in household. ... 221
Figure 13-5: Maize (*Zea mays*) agricultural field surrounded by *Aloe ferox* live fence (Photo: A. Maroyi). ... 222
Figure 13-6: *Catharanthus roseus* cultivated as ornamental and medicinal plant (Photo: P. Ngcaba). ... 222
Figure 13-7: *Phoenix reclinata* cultivated as ornamental and leaves used to make baskets, mats and other crafts (Photo: M. Mamera). ... 223
Figure 13-8: *Agave americana* and *Aloe ferox* used as live fence or hedge or enclosures around home gardens, agricultural fields or animal enclosures (Photo: A. Maroyi). ... 224
Figure 13-9: *Leonotis leonurus* commonly known as “wild dagga” is widely used as herbal medicine (Photo: P. Ngcaba). ... 225
Figure 13-10: Several plant species are used as herbal medicines in the Ntabelanga area (Photo: P. Ngcaba). ... 225
Figure 13-11: Different plant parts used as herbal medicines in the Ntabelanga area (Photo: P. Ngcaba). ... 226
Figure 13-12: Plant resources product flow diagram for the Ntabelanga area based on results derived from PRA exercises. ... 227
Figure 13-13: Production of seed-maize. ... 228
Figure 13-14: Practical plans to overcome water limitations in vegetable production employed by the farmer at MNS1 a) construct a well for water harvesting from the mountain, b&c) home-made irrigation scheme to d) produce vegetables throughout the year. ... 229
Figure 13-15: An old farmers’ land; only half of the field cultivated due to lack of labour. ... 230
Figure 13-16: Cattle, goat and sheep manure is an important source of nutrients for farming operations in the Ntabelanga area (Photo: A. Maroyi). ... 232
Figure 13-17: Employment status of survey respondents. ... 235

LIST OF TABLES

Table 2-1: Summary of average monthly rainfall (mm) data for the SAWS sites Elliot and Mthata 12
Table 2-2: Selected climatic parameters for the Ntabelanga area (Schulze et al., 2007) 13
Table 2-3: Summary of monthly streamflow, presented as daily average ($m^3.s^{-1}$) measured at T3H006 in the Tsitsa River between August 1998 and February 2017 17
Table 2-4: Study communities 32
Table 3-1: Substrate description categories (Gordon et al., 2004) 43
Table 3-2: Ecological categories and sensitivity scores used to interpret SASS data for this study. Adapted from Graham et al. (2004) and Dallas (2007). 51
Table 3-3: Interpretation of HMID values (Adapted from: (Gostner, 2012)) 51
Table 3-4: Macroinvertebrate Orders 52
Table 3-5: Sensitivity score of macroinvertebrates to surface sediment drape concentration 55
Table 3-6: Braun-Blanquet cover-abundance codes, values and median values (after Mueller-Dombois and Ellenberg, 1974; Werger, 1974; Whittaker, 1978; Van der Maarel, 2005) 58
Table 3-7: Demographic and socio-economic characteristics of ethnobotanical interviewees in the Ntabelanga area, n = 21 60
Table 3-8: Qualitative Data Collection Techniques 71
Table 4-1: Colour codes assigned to fitness for use ranges 74
Table 4-2: User specific guidelines 75
Table 4-3: Combined fitness for use categories 76
Table 4-4: Descriptive statistics of selected water quality for Tsitsa River (10 data collections; 3 sampling sites – Upstream of proposed dam wall) 79
Table 4-5: Descriptive statistics of selected water quality for Tsitsa River (10 data collections; 2 sampling sites – Downstream of proposed dam wall) 80
Table 4-6: Descriptive statistics of selected water quality for Tsitsa River Tributaries Upstream proposed dam wall (10 data collections; 3 sampling sites data 80
Table 4-7: Descriptive statistics of selected water quality for Tsitsa River Tributaries downstream proposed dam wall (10 data collections; 3 sampling sites data) 81
Table 4-8: Descriptive statistics of selected water quality for Drinking Water sources upstream proposed dam wall (10 data collections; 5 sampling sites) 81
Table 4-9: Descriptive statistics of selected water quality for Drinking Water sources downstream proposed dam wall (10 data collections; 2 sampling sites) 82

Table 4-10: Seasonal variation in water quality parameters of the Tsitsa River, S1-S4 83
Table 5-1: Soil morphological properties 89
Table 5-2: Selected soil physical properties of the different sites 91
Table 5-3: Microbial biomass levels for different sites below selected pit latrines 97
Table 6-1: Bed gradients for sites on the Tsitsa River 104
Table 6-2: Bed conditions along each transect in Site 1 109
Table 6-3: Percentage distribution of clasts in Site 1 110
Table 6-4: Bed conditions along each transect in Site 2 111
Table 6-5: Percentage distribution of clasts in Site 2 111
Table 6-6: Bed conditions along each transect in Site 3 112
Table 6-7: Percentage distribution of clasts in Site 3 112
Table 6-8: Bed conditions along each transect in Site 4 113
Table 6-9: Percentage distribution of clasts in Site 4 113
Table 6-10: Bed conditions along each transect in Site 5 114
Table 6-11: Percentage distribution of clasts in Site 5 115
Table 6-12: Roughness values for the monitoring sites 123
Table 6-13: Potential bed movement in Site 1 124
Table 6-14: Potential bed movement in Site 2 124
Table 6-15: Potential bed movement in Site 3 124
Table 6-16: Potential bed movement in Site 3 124
Table 6-17: Potential bed movement in Site 3 124
Table 6-18: Relative Bed Stability for selected sites (a = Rising stage, b = receding stage) 125
Table 7-1: Measured water quality variables for July 2015 129
Table 7-2: Measured water quality variables for October 2015 130
Table 7-3: Measured water quality variables for February 2016. 130
Table 7-4: Measured water quality variables for April 2016 131
Table 7-5: Measured water quality variables for August 2016 131
Table 7-6: Measured ASPT scores 131
Table 7-7: July 2015. Correlation between ASPT of macroinvertebrates, derived using SASS methodology, and measured water quality and habitat variables 132
Table 7-8: October 2015. Correlation between ASPT of macroinvertebrates, derived using SASS methodology, and measured water quality and habitat variables 132
Table 7-9: February 2016. Correlation between ASPT of macroinvertebrates, derived using SASS methodology, and measured water quality and habitat variables 133
Table 7-10: April 2016. Correlation between ASPT of macroinvertebrates, derived using SASS methodology, and measured water quality and habitat variables 133

Table 7-11: August 2016. Correlation between ASPT of macroinvertebrates, derived using SASS methodology, and measured water quality and habitat variables 133
Table 7-12: Reach 1, Rocky habitat. Correlation between variables affecting habitat quality, at a quadrat scale. Red shows correlation between independent factors on the ASPT for sediment sensitive biota 140
Table 7-13: Reach 1, Fine substrate habitat. Correlation between variables affecting habitat quality, at a quadrat scale. Red shows correlation between independent factors on the ASPT for sediment sensitive biota 141
Table 7-14: Reach 1, Marginal vegetation habitat. Correlation between variables affecting habitat quality, at a quadrat scale. Red shows correlation between independent factors on the ASPT for sediment sensitive biota 142
Table 7-15: Reach 2, Rocky habitat. Correlation between variables affecting habitat quality, at a quadrat scale. Red shows correlation between independent factors on the ASPT for sediment sensitive biota 142
Table 7-16: Reach 2, Fine substrate habitat. Correlation between variables affecting habitat quality, at a quadrat scale. Red shows correlation between independent factors on the ASPT for sediment sensitive biota 143
Table 7-17: Reach 2, Marginal vegetation habitat. Correlation between variables affecting habitat quality, at a quadrat scale. Red shows correlation between independent factors on the ASPT for sediment sensitive biota 144
Table 7-18: Reach 3, Rocky habitat. Correlation between variables affecting habitat quality, at a quadrat scale. Red shows correlation between independent factors on the ASPT for sediment sensitive biota 144
Table 7-19: Reach 3, Fine substrate habitat. Correlation between variables affecting habitat quality, at a quadrat scale. Red shows correlation between independent factors on the ASPT for sediment sensitive biota 145
Table 7-20: Reach 3, Marginal vegetation habitat. Correlation between variables affecting habitat quality, at a quadrat scale. Red shows correlation between independent factors on the ASPT for sediment sensitive biota 145
Table 7-21: Sediment sensitivity score sheet created for macroinvertebrate families found in the Tsitsa River 153
Table 8-1: List of plant species recorded from eight sites in the Ntabelanga area. Species marked with an asterisk (*) are exotic to South Africa 156
Table 8-2: Summary of floristic associations with environmental variables assessed in eight sites within the Ntabelanga area 162
Table 8-3: List of useful plant species recorded in the Ntabelanga area, arranged in descending order of importance 166

Table 8-4: Palatability, ecological value, distribution and frequency of grass species in Tsitsa river catchment area ... 170
Table 8-5: Variation in dry matter yield (kg/ha) in relation to the landscape gradient in the Ntabelanga area ... 171
Table 9-1: *Classification of the soils and link to International Classification Systems* ... 176
Table 9-2: Selected soil chemical analysis ... 178
Table 9-3: Selected soil physical analysis ... 179
Table 9-4: SMAF Factor Classes ... 180
Table 9-5: Soil Quality Index (SQI) for SOC ... 181
Table 9-6: Calculation of Soil Quality Index (SQI) for MBC ... 182
Table 9-7: Relationship between slope and maximum P contents to avoid environmental degradation ... 183
Table 9-8: Calculation of Soil Quality Index (SQI) in relation to P contents ... 184
Table 9-9: Calculated Soil Quality Index (SQI) for exchangeable K ... 185
Table 9-10: Calculated Soil Quality Index (SQI) for soil pH ... 186
Table 9-11: Calculated Soil Quality Index (SQI) for aggregate stability ... 187
Table 9-12: Calculated Soil Quality Index (SQI) for bulk density ... 188
Table 9-13: Combined Soil Quality Index (SQI) expressed as a percentage for the different soils ... 189
Table 10-1: Soil forms and soil associations of the Ntabelanga inundation footprint ... 193
Table 10-2: General properties of the soil associations and the total soil carbon stocks of the Ntabelanga dam footprint ... 195
Table 10-3: Organic carbon soil contents and soil morphological properties for the different piezometers ... 197
Table 10-4: Area of surface water of wetland b in Figure 5; cumulative streamflow over different periods and streamflow characteristics ... 199
Table 11-1: Current types of smallholder farmers in South Africa (SAF and PLAAS, 2013) ... 205
Table 11-2: Operational status of smallholder irrigation schemes by province in South Africa in 2010 (Van Averbeke et al., 2011; Sinyolo, 2013). ... 207
Table 11-3: Estimated yields for Lower Sinxaku (Schulze and Walker, 2007) ... 209
Table 11-4: Yield estimations based on soil properties and annual rainfall (FSSA, 2007) . 210
Table 11-5: Farmers' estimation of yields ... 210
Table 11-6: Measured yield from gardens in Lower Sinxaku ... 210
Table 11-7: Yield gaps in Lower Sinxaku ... 211
Table 13-1: Current sources of drinking water ... 218
Table 13-2: Current sources of water for general household use ... 219

Table 13-3: Experience of disease outbreaks 220
Table 13-4: Experience of disease outbreaks (by community) 220
Table 13-5: Impact of dam construction on availability of plant resources in the Ntabelanga area 231
Table 13-6: Proportion of households keeping livestock in the Ntabelanga area 232
Table 13-7: Constraints faced by households in managing available grazing lands in the Ntabelanga area 233
Table 13-8: Socio-cultural networks in the study communities 235
Table 13-9: Housing types in the study communities 235
Table 13-10: How do respondents cope with unemployment? 236

LIST OF ABBREVIATIONS

AGS	-	Aggregate Stability
BOD	-	Biochemical Oxygen Demand
CCA	-	Canonical Correspondence Analysis
cLHS	-	conditioned Latin Hypercube Sampling
COD	-	Chemical Oxygen Demand
DCA	-	Detrended Correspondence Analysis
DEM	-	Digital Elevation Model
DGPS	-	Differential Geographical Positioning System
DO	-	Dissolved Oxygen
DWA	-	Department of Water Affairs (now Department of Water and Sanitation – DWS)
EC	-	Electrical conductivity
EIA	-	Environmental Impact Assessment
FGD	-	Focus Group Discussion
GHG	-	Green House Gas
HCA	-	Hierarchical Cluster Analysis
HMID	-	Hydro-morphological Index of Diversity
LOI	-	Loss on Ignition
MBC	-	Microbial Biomass Carbon
MNS (1-10)	-	Home gardens in Lower Sinxaku for yield and SMAF
MT (1-4)	-	Pit latrine sample sites
MWP	-	Mzimvubu Water Project
NFEPA	-	National Freshwater Ecosystem Priority Areas
NWRS	-	National Water Resource Strategy
OC	-	Organic Carbon
OM	-	Organic Matter
PPCPs	-	Pharmaceuticals and personal care products
S (1-5)	-	Site (stream geomorphology study)
SAWS	-	South African Weather Service
SMAF	-	Soil Management Assessment Framework
SOC	-	Soil Organic Carbon
SQI	-	Soil Quality Index
TDS	-	Total Dissolved Solids
TS	-	Total Solutes

TSS	-	Total Suspended Solids
T (1-6)	-	Transect (stream geomorphology study)
UFH	-	University of Fort Hare
WRC	-	Water Research Commission

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1 INTRODUCTION

The Mzimvubu River is the largest undeveloped river in South Africa. This is despite the facts that the river has high annual runoff, high environmental status (NFEPA Report, 2011), high tourism potential, and is suitable for afforestation and moderately suitable for dryland/rainfed and irrigation agriculture (NWRS2, 2012). For these reasons, the Department of Water Affairs (DWA) investigated the potential of building a multipurpose dam in the Mzimvubu basin to serve as a catalyst for economic and social development. After studying 19 potential sites, the Ntabelanga site in the Tsitsa River was chosen as the most appropriate site for the multipurpose dam. A smaller dam, Laleni, will also be built for generation of hydroelectricity approximately 20 km downstream of Ntabelanga. The building of the dam/s as part of the Mzimvubu Water Project (MWP) was said to commence early in 2016 (during our last site visit in June 2017 it appears that building has not yet started).

Globally, large dams are vital development infrastructure. They help society to meet various needs. These needs can include water for domestic and industrial use, agricultural irrigation, and hydro-electric power. In the case of the proposed MWP, benefits such as job creation and agricultural rejuvenation have been highlighted by the Department of Water Affairs (DWA, 2012:1). A total of 2 686 ha have been identified for irrigated agriculture following the completion of MWP. Therefore, the development of the dam is being conceptualised in a way that will ensure that it is in tandem with the Eastern Cape Government's vision for the Mzimvubu River Basin. This vision includes afforestation, irrigation, hydropower, water transfer and tourism.

Despite the widely acknowledged benefits of large dams, dam development continues to come up against important questions of social and environmental sustainability (Altinbilek, 2002). In other words, the success of a dam project is no longer just a matter of whether it is 'technologically feasible' or whether it will drive 'economic development': it is equally an important sociological matter. Success is increasingly being measured by the extent to which the project coheres with specific social and environmental dynamics in the local area – in the short-, medium- and long-term (Raina, 2000; Biswas, 2004). While protests against dams – or, for that matter, pro-dam advocacy – are sometimes ideologically and politically motivated and have little to do with observed impacts, studies have shown that a failure to pay close attention to specific socio-cultural dynamics in the local area could expose the project to invidious local resistance, if not immediately, then certainly in the long run (Uphoff, 1996; Bisht, 2009). Already potential conflict around the Ntabelanga dam in terms of land-use has been highlighted by Van Tol et al. (2014a). Indeed, difficulties could arise even though local residents appeared to have initially welcomed the project.

There is also the crucial question of environmental impact, and, as indicated earlier, long-term monitoring of this is important for determining the long-term sustainability of a dam project. A large body of literature exists on the environmental impacts (both positive and negative) of dam construction (see for instance, Beck, Claassen & Hundt, 2012; Dumas et al., 2010). Nevertheless, because every river is unique in terms of its morphology, the landscapes it flows through and the species its supports, the impacts of dam construction on ecosystems will also be unique. According to McCully (2001:31), a ‘’*dam [dam construction] can be regarded as a huge, long-term and largely irreversible environmental experiment without a control*”.

Obviously, dam constructions have a direct impact on the environment through permanent inundation of previously dry areas, alteration of stream flow regimes (reduction in natural flooding), and fragmentation of river ecosystems, thereby reducing species diversity in almost all cases. Indirectly, land-use change associated with dam constructions – and this is both an environmental and a sociological issue – can significantly alter the equilibrium of ecosystems. These changes, generally, can lead to more intensive land utilisation. The irrigated land, previously used for rainfed cropping or grazing, for example, can result in more strain on the environment. Needless to say, these impacts add to the controversies around large dam projects (Biswas, 2004). Frequently, scientific studies associated with dam construction focus more on finding out the most technically feasible place to build it, than on the long-term socio-environmental issues that come in its train.

1.1 Aim and objectives

This project follows on a short term project where key monitoring aspects and interactions between these aspects were identified in the Ntabelanga area (Van Tol et al., 2014b). Figure 1-1 presents the potential interaction/intersections associated with dam construction in a rural area. The overall aim of this interdisciplinary project is to construct a baseline of environmental, agricultural and socio-economic intersections associated with the MWP.

More specifically the objectives were to monitor, measure and investigate to indicators of these intersections such as:

1. Water quality at selected monitoring locations in the Ntabelanga valley.
2. Potential pollution from on-site dry sanitation systems
3. Stream geomorphology of the Tsitsa River at selected locations in above and below the proposed Ntabelanga dam.

4. The aquatic bio-diversity at selected monitoring locations.
5. Natural vegetation in selected landscapes.
6. Soil quality of representative soils and cultivated fields
7. Carbon stocks and wetland water regimes at selected representative locations.
8. Dominant agricultural activities and the profitability and sustainability thereof.
9. Entrepreneurial spinoffs, local skills and income and socio-cultural resources in selected communities.
10. Perceptions hopes and fears of selected communities in relation to the planned project.

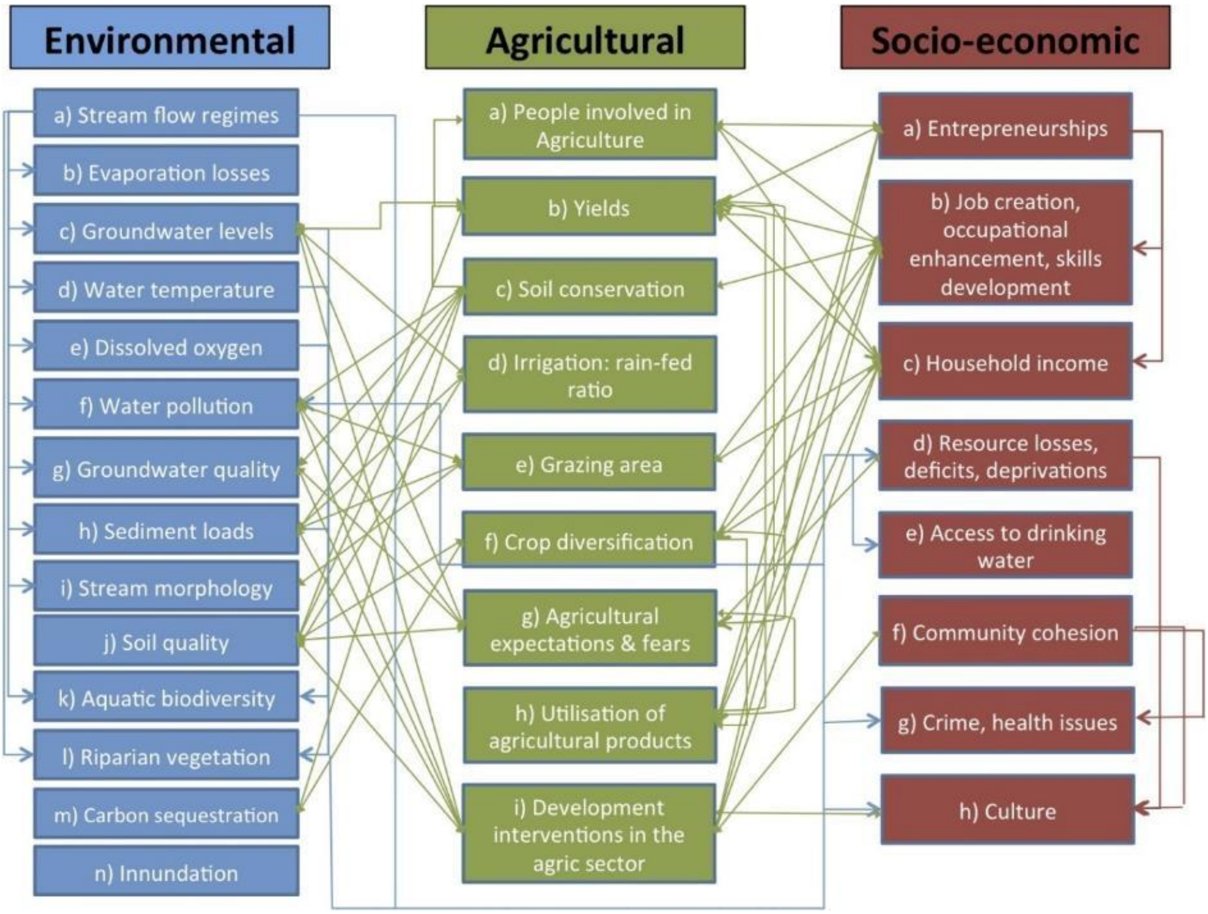

Figure 1-1: Intersections – Possible cross-cutting issues for transdisciplinary monitoring (Van Tol et al., 2014b).

Importantly, the focus was on the intersections/interactions between different monitoring aspects and not necessarily on measurements of all the aspects. Where possible, relevant literature, e.g. the Environmental Impact Assessment (EIA) of the MWP, was consulted to establish these intersections. Some aspects (e.g. soil erosion) were quantified as part of the preluding consultancy project (Van Tol et al., 2014). These were presented as results in the relevant sections.

In this report, a general description of the study area is provided in Section 2. This is followed by specific methodologies, results and discussions of different aspects or disciplines in Section 3-11 (following more or less the same sequence as that of the specific objectives above). The core of this project is then the multidisciplinary Section 13, which focus on interactions and intersections between the different aspects monitored. General conclusions and recommendations for future research is presented in Section 13.

2 ENVIRONMENTAL DESCRIPTION OF THE STUDY AREA

The Mzimvubu River falls within the Mzimvubu to Keiskamma Water Management Area 12 and lies mostly in the Eastern Cape Province (Figure 2-1). The catchment covers an area of 19 853 km^2 stretching from the Drakensberg Mountains on the Lesotho border to the Indian Ocean at Port St Johns. The Mzimvubu River is the largest undeveloped water resource in the country and benefits derived from the development of this river could be of national importance.

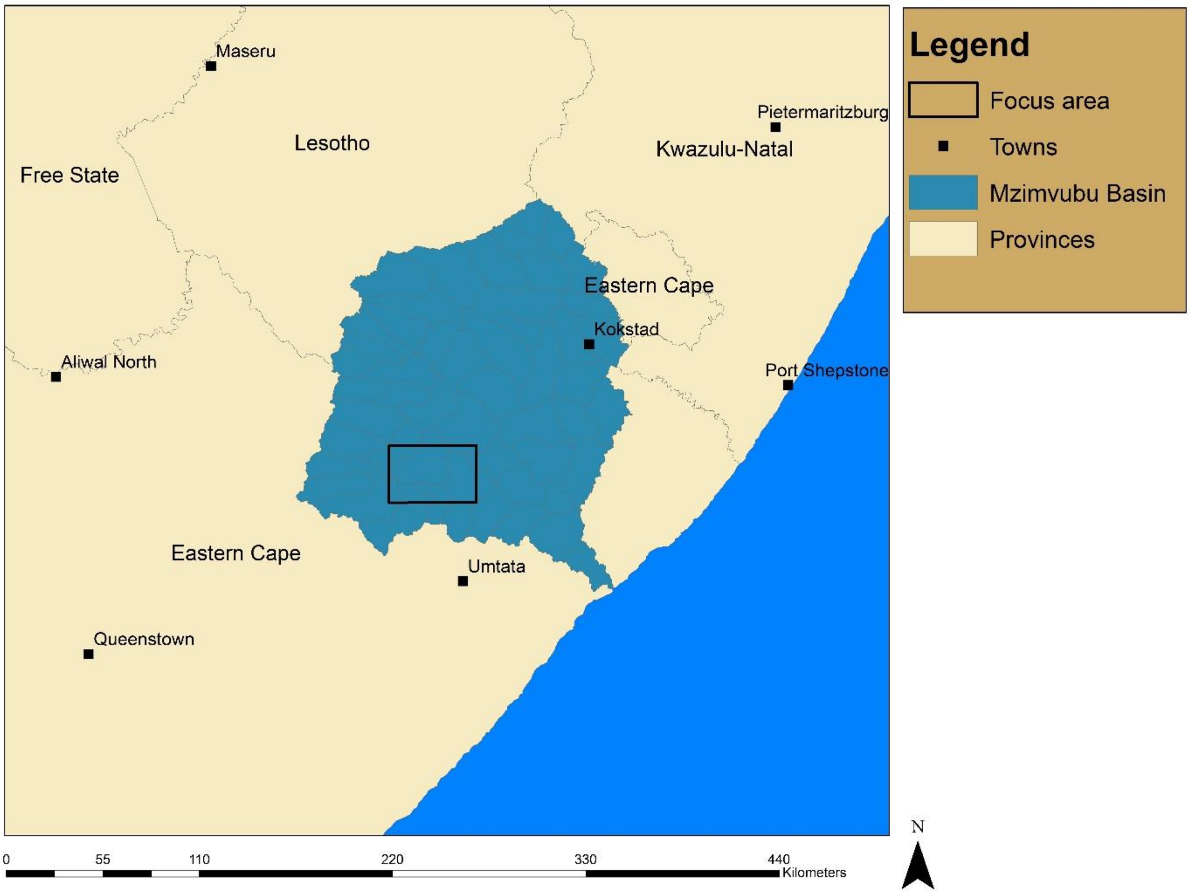

Figure 2-1: Location of the Mzimvubu catchment.

The Tsitsa River is one of the main tributaries of the Mzimvubu River and falls within tertiary catchments T35A-E. The planned Mzimvubu water project will consist of two dams, Ntabelanga and Laleni, which will be used for irrigation and hydroelectricity generation respectively (Figure 2-2). This study focus primarily on the Ntabelanga dam, and its impact on the environment, agriculture and the people. The area around the Ntabelanga dam is more densely populated and is also likely to be completed first.

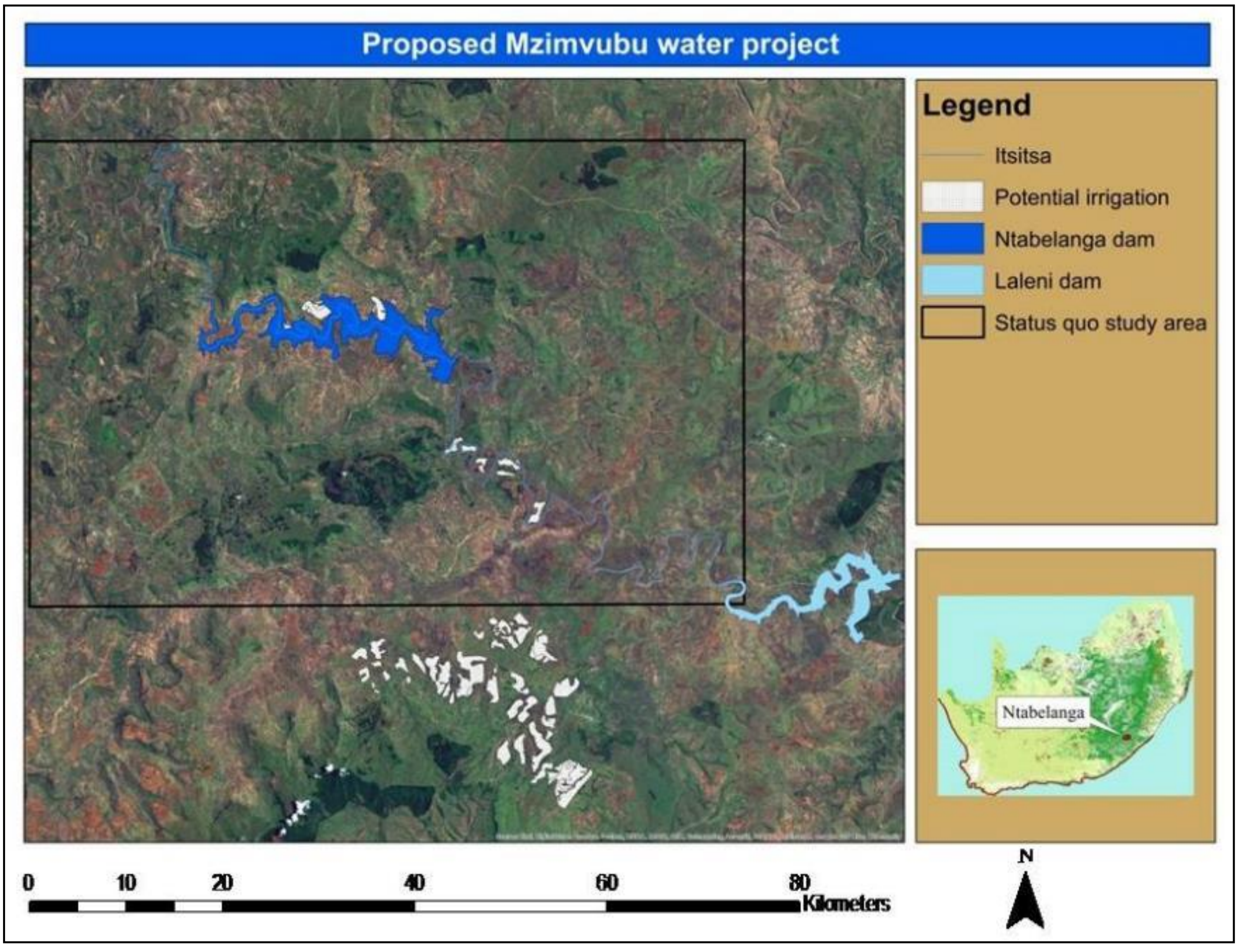

Figure 2-2: Predicted inundation footprint of Ntabelanga and Laleni dam with proposed irrigation areas.

2.1 The Ntabelanga Study Area

An area of approximately 1 500 km^2 surrounding the dam was selected for general descriptions of the soils, agricultural practices and environmentally sensitive areas (Figure 2-3). Although the greater part of this area will not be influenced directly by the planned development, it was included to discuss the nature of the environment in the vicinity of the dam. It should be noted that when this short term study commenced information regarding the Laleni dam and potential irrigation areas was not available and was consequently not included in the description of the physical environment. These areas do however form an integral part of the design of the long term monitoring project.

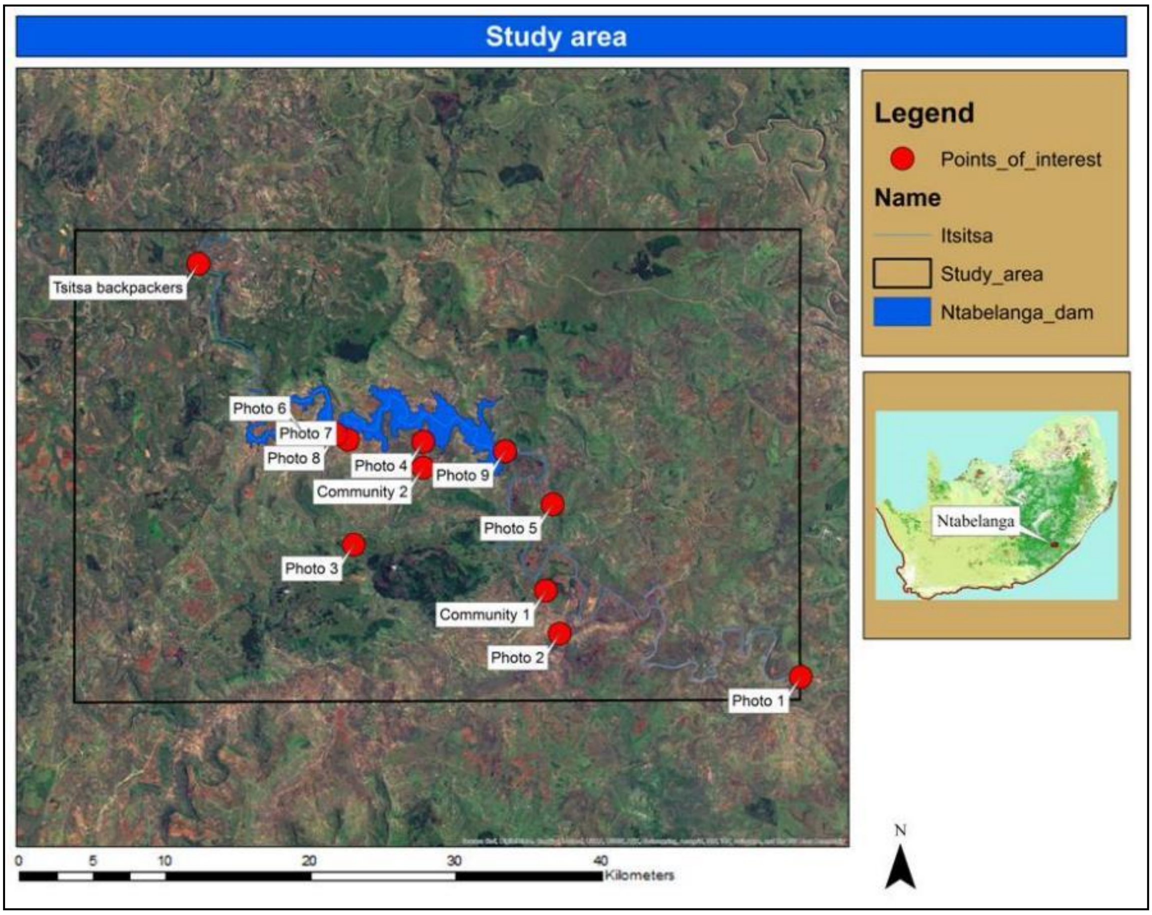

Figure 2-3: The study area for description of physical environment, socio-economic and agricultural *status quo* with predicted footprint of the Ntabelanga dam.

The proposed Ntabelanga dam is nestled between mountains, the foothills of the Drakensberg escarpment (Figure 2-4). The relief suggests that agricultural (irrigation) development will be limited to areas directly next to the proposed dam. The steep slopes hinder easy access to the dam and the communities around the dam. The proposed Ntabelanga dam wall is located in a scenic gorge, approximately 200 m wide (Figure 2-5). Below the proposed dam wall, the Tsitsa River meanders through relatively large, flat alluvial plains (Figure 2-6).

The proposed development will influence different communities on different levels for example: those below the dam will generally enjoy positive impacts of the dam such as constant water flow, less flooding, etc., whereas the population directly next to the dam will generally suffer from a loss of grazing land, limited access to free flowing water, etc. For these reasons two communities were identified to conduct sociological and agricultural research.

Community 1 (Ntzebe Village) lies on the banks of the Tsitsa River approximately 3 km downstream of the proposed dam wall (Figure 2-3 & Figure 2-7). Sociological insights obtained from this community are assumed to be indicative of perspectives of the population downstream of the dam.

Community 2 (Lower Sinxaku) is located on the edge of the anticipated footprint of the Ntabelanga dam (Figure 2-3 & Figure 2-8). Insights from this community are assumed to reflect those of communities around the actual Ntabelanga dam footprint.

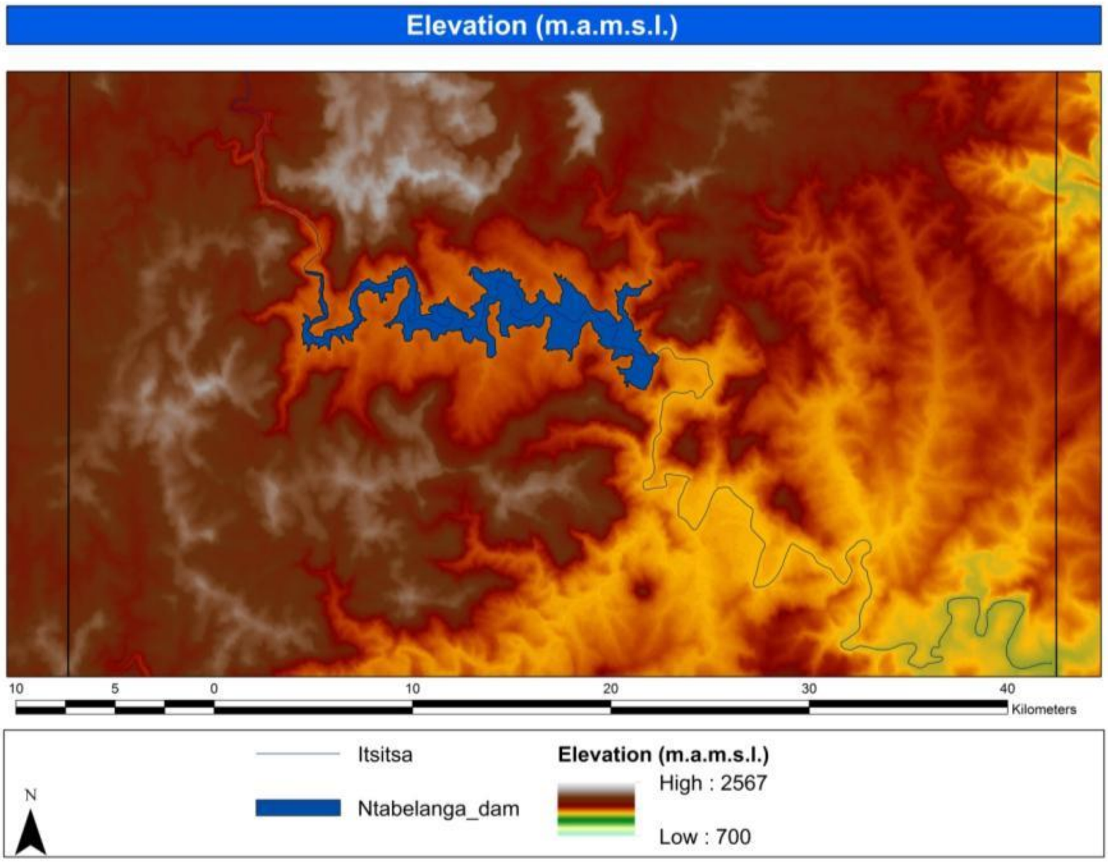

Figure 2-4: Elevation expressed as meters above mean sea level (m.a.m.s.l) of the study area.

Figure 2-5: Location of proposed Ntabelanga dam wall (red arrow) and downstream view of the Tsitsa River (Located at Photo 9 in Figure 2-3).

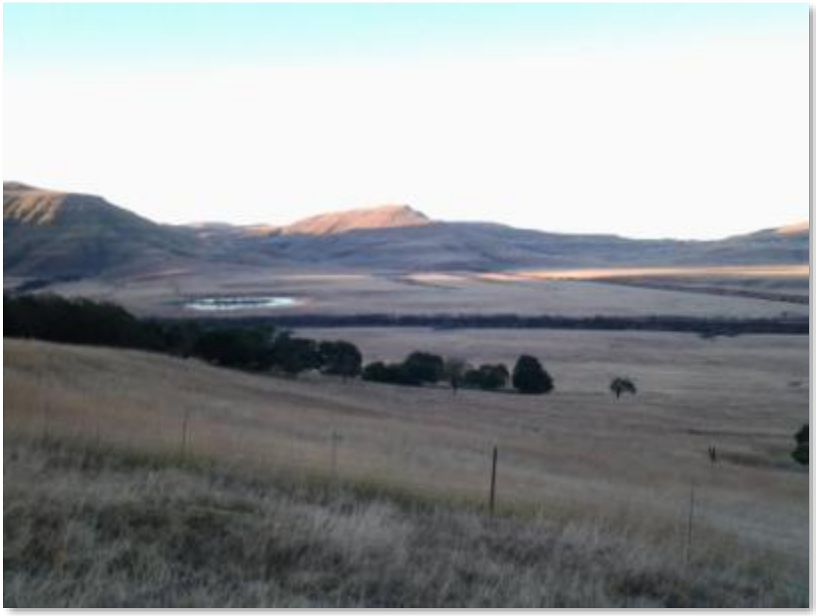

Figure 2-6: Alluvial plains along the Tsitsa River below the proposed dam wall (located at Photo 5 in Figure 2-3).

Figure 2-7: Community 1 (Ntzebe) in the background on the banks of the Tsitsa River downstream of the proposed dam wall (located at Photo 2 in Figure 2-3).

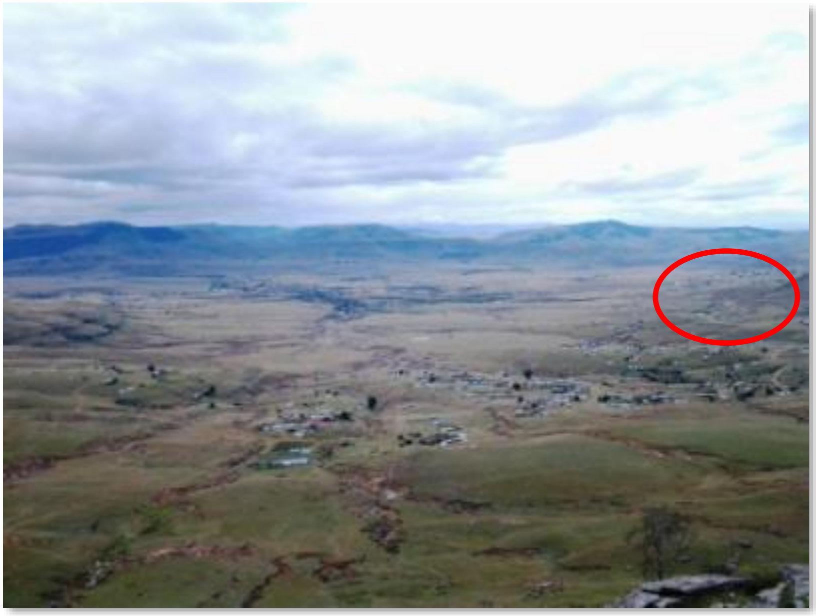

Figure 2-8: View of the Ntabelanga (located at Photo 3 in Figure 2-3). Part of community 2 (Lower Sinxaku) is encircled in red. Note the extent of gully erosion in the foreground.

2.2 Description of Environmental Situation

Climatic Information

Rainfall

The limited climatic information in the study area makes it difficult to infer relationships between rainfall and runoff (streamflow). The attempt to generate seasonal rainfall trends were based on the available data from two SAWS sites namely Mthata and Elliot (this is discussed in detail in Van Tol et al., 2014b). The selected study area is geomorphologically in the middle of these two sites and it was decided to average the rainfall of the sites in order to gain an idea of the long term seasonal rainfall patterns as well as average monthly rainfall for the selected study area. A summary of this data is presented in Figure 2-9 and Table 2-1 respectively.

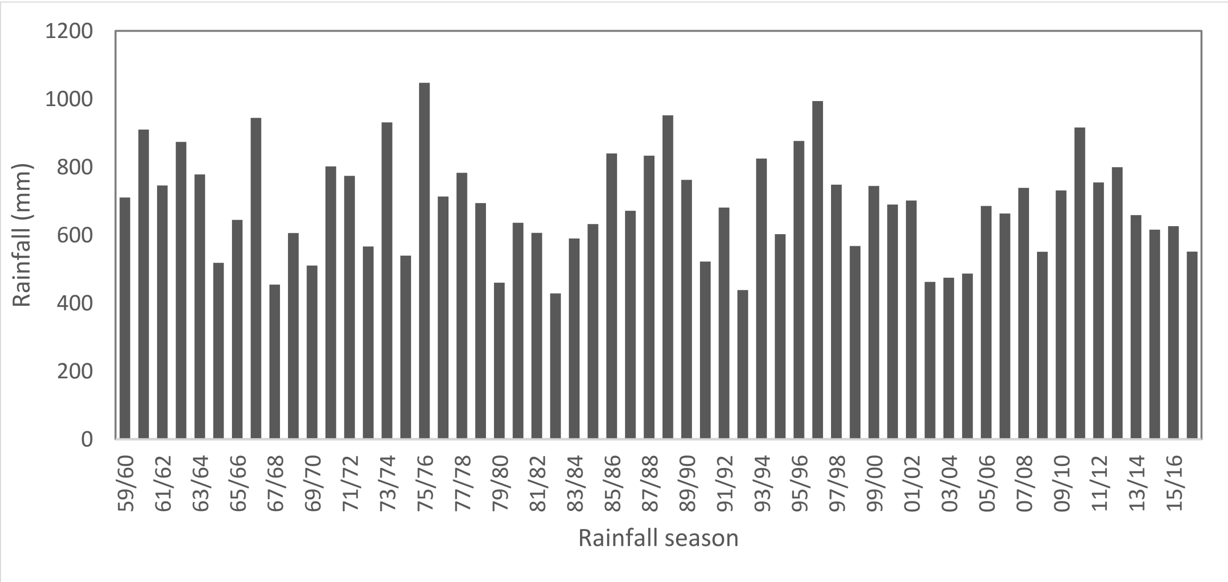

Figure 2-9: Average seasonal rainfall (mm) of SAWS sites Elliot and Mthata.

The average seasonal rainfall presented in Figure 2-9 suggests that there are definite dry and wet seasons typically associated with semi-arid areas (Note that there are seasons missing on the x-axis; it is therefore not a continuous chronological dataset). The minimum rainfall per season is approximately 400 mm whereas the highest rainfall recorded per season is well over 1 000 mm. This variation in rainfall highlights the challenges associated with dry-land crop production in semi-arid areas, i.e. in some years precipitation is insufficient to produce cash crops, for example maize.

The monthly rainfall volumes presented in Table 2-1 shows distinct summer rainfall characteristics with the majority of the rain recorded between November and March. These months, the growing season for most summer crops, are also marked by the largest deviation and variation in the rainfall. The minimum rainfall recorded indicates that during some months the risk for dry-land crop production can be immense.

Table 2-1: Summary of average monthly rainfall (mm) data for the SAWS sites Elliot and Mthata

	Minimum	Maximum	Average	Std. Dev
January	33.7	205.5	100.3	41.5
February	9.0	203.6	98.3	42.6
March	17.4	243.4	95.3	49.9
April	10.3	173.9	52.0	35.0
May	0.5	96.4	21.1	21.2
June	0.0	129.6	15.3	22.4
July	0.0	68.0	16.7	18.0
August	0.0	101.7	21.3	19.8
September	0.2	161.2	32.7	28.2
October	11.1	214.0	64.7	39.2
November	2.1	212.2	84.0	42.9
December	24.4	229.7	93.4	47.8

Figure 2-10 represents seasonal trends in rainfall for the entire Eastern Cape Province. Although the total cumulative rainfall was generally above 'normal' for the Province during the past five years, the past seasons (2015/16 and 2016/17) was marked by below normal rainfall during the growing season (October to April). This should be taken into consideration when interpreting agricultural produce in this study.

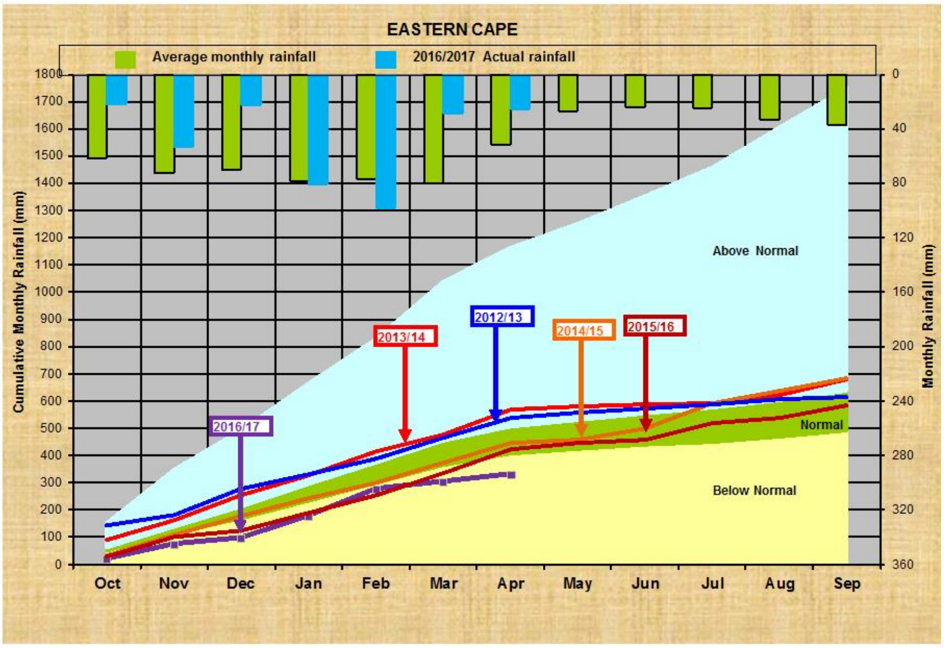

Figure 2-10: Seasonal trends in rainfall for the past five rain seasons (South African Weather Service).

Other climatic variables

The potential evaporation, daily average temperatures and heat units are presented in Table 2-2. Other relevant climatic parameters are discussed under the calculation of yield potentials.

Table 2-2: Selected climatic parameters for the Ntabelanga area (Schulze et al., 2007)

	ET0 (mm)	Mean daily temperature (˚C)	Heat Units (˚ days)
January	193	20.9	338
February	159	20.8	311
March	153	19.8	305
April	117	17.2	217
May	100	14.3	131
June	92	11.5	50
July	94	11.7	61
August	123	13.4	108
September	143	15.6	170
October	163	1637	205
November	175	18.4	250
December	202	20.1	306

The area falls within the semi-arid zone with an annual Aridity Index of 0.41. Highest potential evaporation rates are experienced during December (6.5 mm day^{-1}). Summers are mild with average daily temperatures above 20˚C, but winters are cool with frequent frost and daily average temperatures of approximately 12˚C (Table 2-2). The total heat unit during the growing season (October to April) is 1 930˚days.

Climate forecasts for the region

The Eastern Cape Province is expected to receive more rainfall due to climate change (Figure 2-11). The rainfall intensity is however also likely to increase resulting in an increase one-in-ten-year high river flows. Although the increase in precipitation will result in more available water (especially in the dry season), rural communities are likely to be exposed to more flooding (Schulze, R.E., 2010; Johnston et al., 2011). The annual temperatures are expected to increase throughout the province (Figure 2-12).

According Turpie & Visser (2012) the increase in precipitation might increase revenue of farmers in the Eastern Cape. Their predictions are that commercial horticultural farmers can expect a 16.6% increase in revenue, crop farmers an increase of 13.6% whereas livestock farmers can increase revenue by 34.9% due to changes in the precipitation and temperature.

By 2080 the subsistence farmers in the Eastern Cape is expected to obtain an increase of 7.5% due to increase in temperature and precipitation.

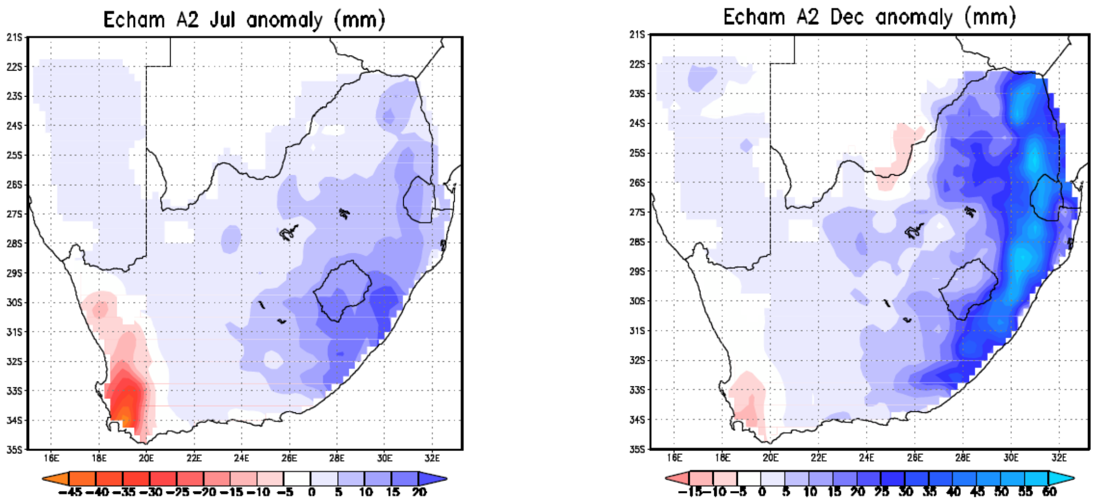

Figure 2-11: Predicted change in precipitation (mm month^{-1}) for July and December 2050 (Midgley et al., 2007).

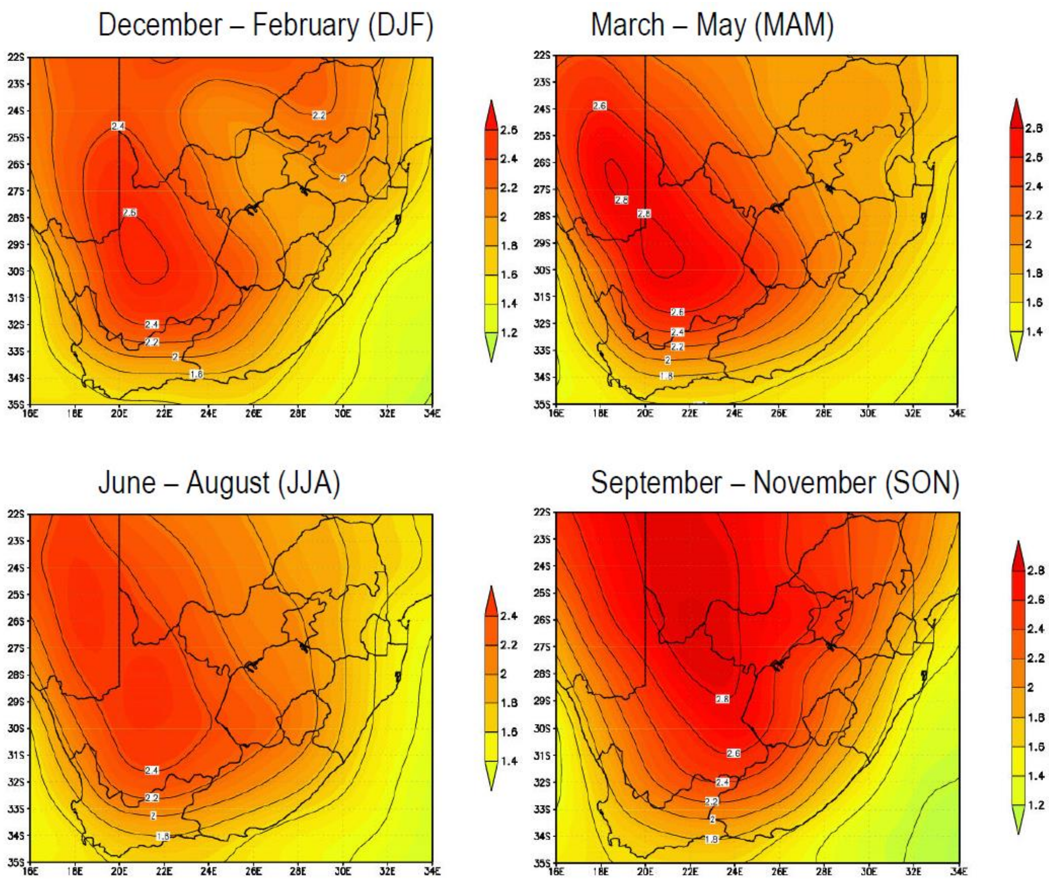

Figure 2-12: Projected change in median surface temperatures (˚C) for difference seasons in 2050.

Streamflow in the Tsitsa River

Streamflow was measured at weir T3H006 approximately 20 km downstream of the proposed dam wall (Figure 2-13). This weir is in a good condition and well maintained. A number of DWA weirs are present in the Tsitsa River and its tributaries above the proposed dam. None of these are, however, generating data at present. T3H003 at Halcyon drift approximately 20 km upstream of the proposed dam can be vital for future monitoring of in- and outflows to and from the Ntabelanga dam.

Figure 2-13: DWA gauging weir T3H006 approximately 20 km downstream of the proposed dam wall (Photo 1 in Figure 2-3).

Daily average flow ($m^3.s^{-1}$) at T3H006 for the period November 1951 to November 2011 is presented in Figure 2-14. Periods with missing data (e.g. 1984) is also included in Figure 2-14. The cumulative flow from November 1951 to January 2013 was calculated and is presented in Figure 2-15.

Figure 2-14 shows that the Tsitsa River at T3H006 is subject to extremely high flows on a regular basis. The maximum daily average flow recorded in the time period was on the 21st of March 1976 when 927 $m^3.s^{-1}$ or 80 million $m^3.day^{-1}$ flowed over weir T3H006. The regular flooding of the Tsitsa River can be expected to have significant positive and/or negative effects on the river ecosystem.

Since the start of the previous project in the beginning of 2014 (Van Tol, 2014b), the highest flow recorded was approximately 200 $m^3.s^{-1}$ (Figure 2-15). This should be taken into consideration when any extrapolation of the data pertaining to stream geomorphology and water quality is made.

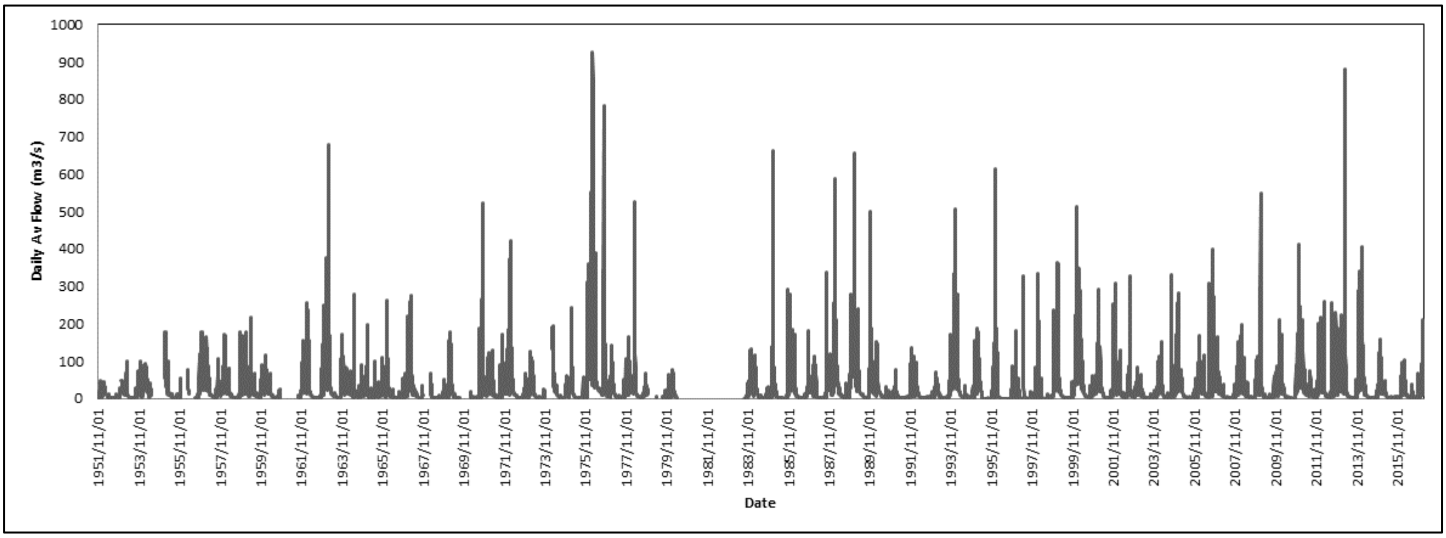

Figure 2-14: Daily average streamflow ($m^3.s^{-1}$) measured from 1951 to 2017 at T3H006 in the Tsitsa River.

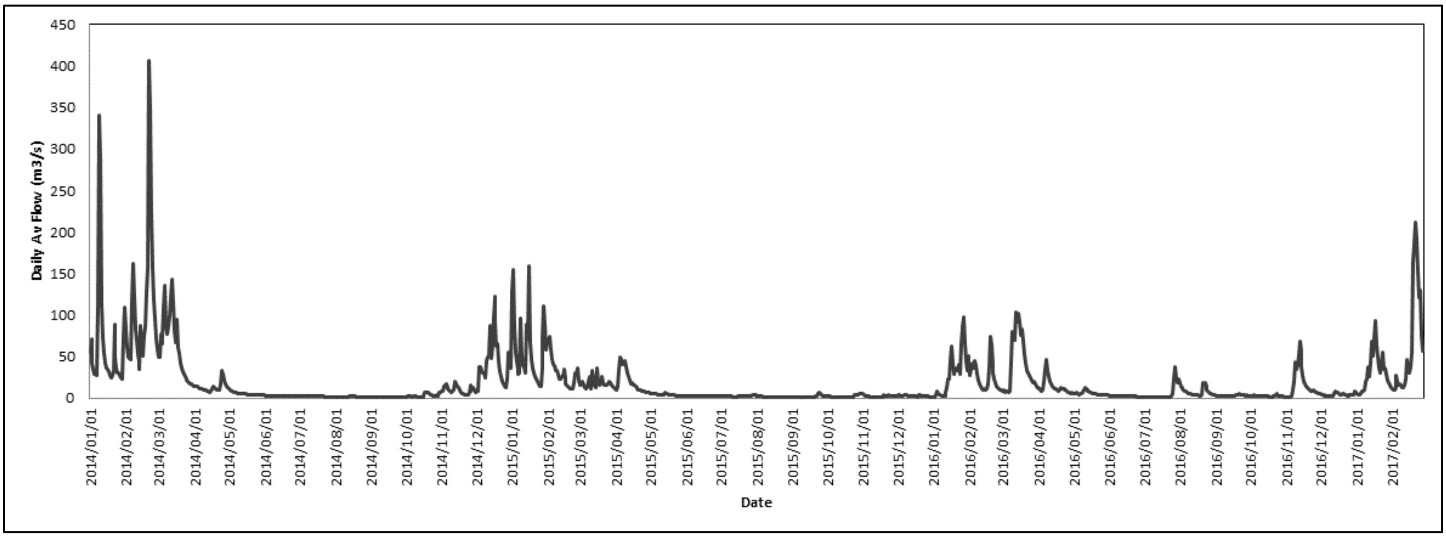

Figure 2-15: Daily average streamflow ($m^3.s^{-1}$) from 2014 to 2017 measured at T3H006 in the Tsitsa River.

Figure 2-14 indicates that the total seasonal streamflow trends were fairly constant during the past 60 years. Except for certain periods (e.g. 1979 to 1984) with missing data, there was no considerable deviation in the cumulative flow line, despite major land-use change (afforestation) in the headwaters of the Tsitsa River.

The monthly streamflow variations calculated from the good continuous dataset (August 1998-February 2017) is presented in Table 2-3. During the selected 18-year period, streamflow in the Tsitsa River never ceased. The lowest daily average flow (0.2 $m^3.s^{-1}$) was recorded in October 2010 and the highest flow was measured in February 2009 with a daily average of 547.3 m^3; it translates to approximately 47 million m^3 per day.

The months with the lowest flow were August-December. These months mark the start of the growing season for summer crops, which typically require adequate water for establishment to reduce the risk of low yields or crop failure.

Table 2-3: Summary of monthly streamflow, presented as daily average ($m^3.s^{-1}$) measured at T3H006 in the Tsitsa River between August 1998 and February 2017

	Minimum	Maximum	Average	Std. Dev
January	1.0	512.9	53.5	61.7
February	8.3	547.3	61.0	62.2
March	4.9	345.8	44.3	45.0
April	3.6	879.5	26.4	52.6
May	2.3	116.1	9.6	11.2
June	1.6	45.4	5.1	5.1
July	1.1	74.4	4.4	7.2
August	0.8	309.0	8.1	20.6
September	0.3	398.1	8.6	30.4
October	0.2	271.8	11.9	27.2
November	0.7	251.4	18.9	30.0
December	0.9	308.4	40.8	44.6

Soils

The broad land types in the study area are presented in Figure 2-16. They are briefly explained using the description of the Land Type Survey Staff (1972-2006) with some inference to their agricultural and ecological significance.

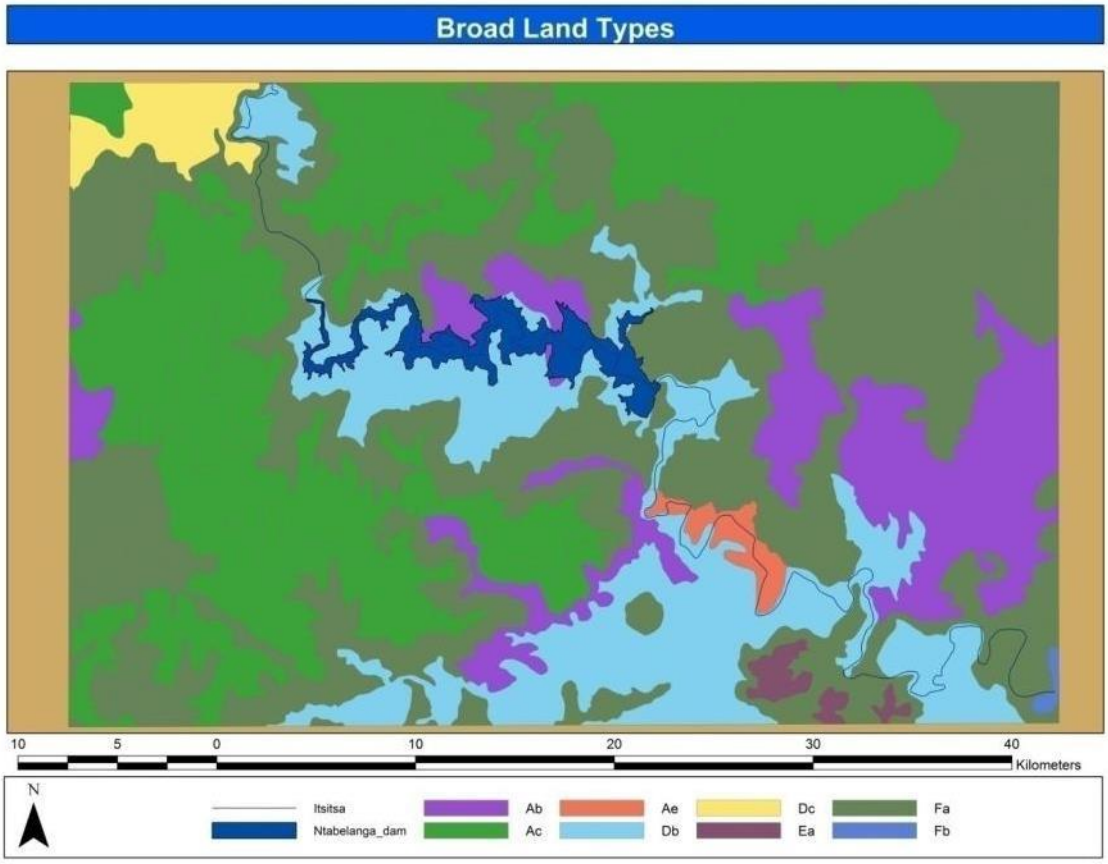

Figure 2-16: Broad land types of the study area.

A-land types in Figure 2-16 (i.e. Ab, Ac and Ae) refer to regions where freely drained yellow and red soils occupy more than 40% of the land area. The soils of *A*-land types are generally considered to be good for crop production and suitable for irrigation. Since these soils are freely drained saturation seldom occurs thereby reducing the chances of erosion. If brief description of the sub-classes follows:

- ***Ab***: red dystrophic and/or mesotrophic soils where yellow soils occupy less than 10% of the area whereas dystrophic and/or mesotrophic soils occupy a larger area than the high base status red-yellow apedal soils.
- ***Ac***: red and yellow soils occupy more than 10% of the area each. Distrophic and/or mesotrophic soils cover an area greater than high base status red and yellow apedal soils.
- ***Ae*:** refers to an area where more than 40% of the soils are red, high base status soils deeper than 300 mm.

D-land types in Figure 2-16 (i.e. Db and Dc) refer to regions where duplex soils are dominant. When exposed surfaces (bare rock, boulders, etc.) are omitted, 50% of the land area should be occupied by duplex in order for the land type to classify as a *D*-land type. The dominant soils in these land types are, therefore, marked by soils with textural differences between A and B horizons. Finer textured B horizons limit the suitability for agricultural production on these soils. The increase in texture is generally associated with a decrease in hydraulic conductivity and the formation of perched water tables on the A/B horizon can result. These soils are, therefore, generally susceptible erosion, especially in the *Db* land types. A short description of the subclasses follows:

- ***Db***: refers to an area where duplex soils with a non-red B horizon cover more than 50% of the land area.
- ***Dc***: in this land type duplex soils cover more than 50% of the land area and more than 10% of the remaining land area is occupied by soils with one or more of the following diagnostic horizons: vertic A, melanic A or red structured B.

E-land types (i.e. Ea in Figure 2-16) consist of soil with high base status dark or red soils (normally with a high clay content). These soils are weathered from basic parent materials (e.g. dolerite). Half of Ea land types are covered by soils with vertic A, melanic A and red structured B horizons. The soils of these land types are generally stable and resistant to erosion. Depending on the effective soil depth these soils can be suitable for crop production.

F-land types (i.e. Fa and Fb in Figure 2-16) are generally young landscapes where the dominant pedological processes have been weathering, clay illuviation and formation of orthic A horizons. Although the dominant soil forms are normally shallow Glenrosa and Mispah forms, any other soil forms can be accommodated in *F*-land types provided that they do not qualify the area for inclusion in other land types. The dominant soils in these land types are often shallow, thereby limiting the suitability for crop production. These land types are often found on relatively steep slopes, thereby increasing the risk of erosion of the soils. A brief description of the sub-classes follows:

- ***Fa***: refers to areas where lime does not occur frequently in the soils.
- ***Fb***: lime occurs frequently in one or more of the valley bottom soils.

The average soil depths and clay contents were derived from the broad land types, explaining the close associations between Figure 2-16, Figure 2-17 and Figure 2-18.

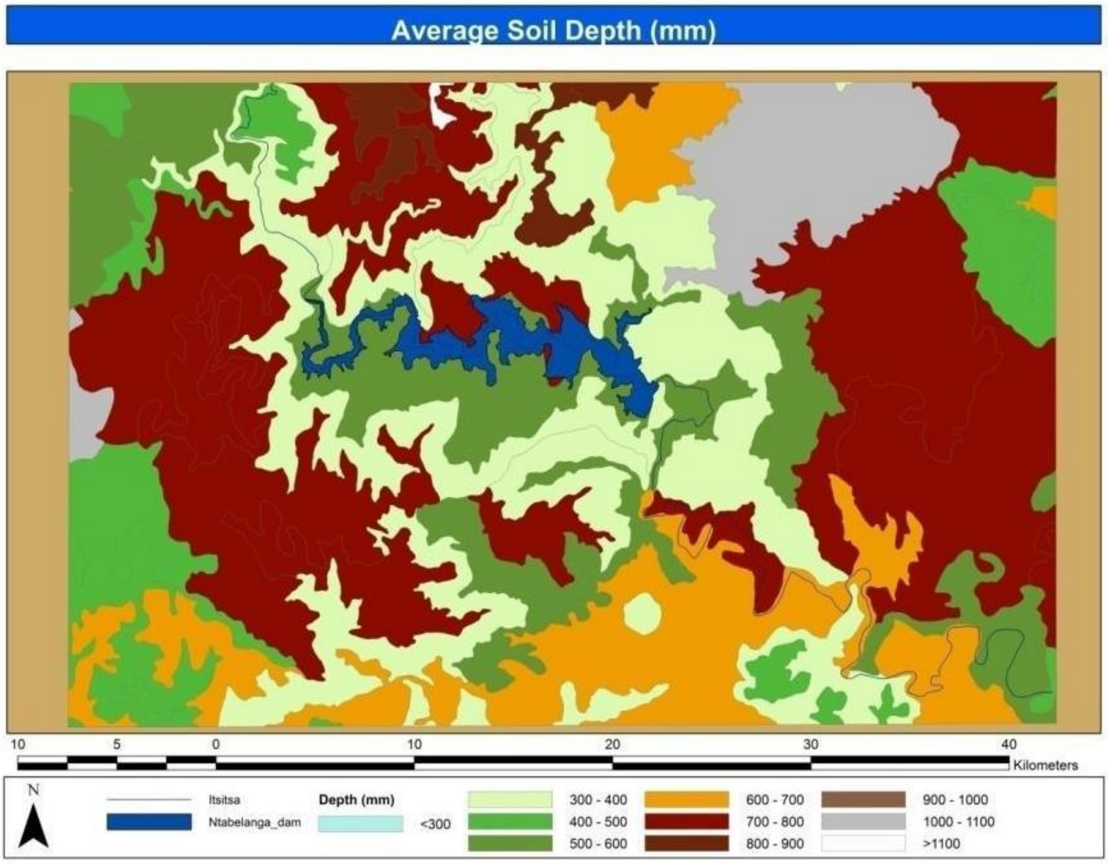

Figure 2-17: **Average soil depth derived from land types in the study area.**

Steep slopes (Figure 2-4) of relatively young landscapes (*F*-land types) are marked by shallow soils of the mountains surrounding the dam. Deeper soils occur on the *A*-land types (see discussion above). Directly north of the dam, deep freely drained soils of land type *Ab249* is found (Figure 2-16 and Figure 2-17). These soils are sandy (Figure 2-18), with an average clay content of between 15-20%. Land type *Ab249* covers an area of approximately 1 800 ha, although some of it will be submerged by the dam. Initial evaluations suggest that irrigation directly from the dam will be limited to these soils as the rest of the land bordering the dam are marked by relatively shallow duplex soils with average clay contents of 25-30%. The duplex nature of these soils makes them susceptible to erosion (see evidence in the following section).

Below the dam wall in the vicinity of community 2, land type *Ae382* marks deep well drained sandy soils, suitable for agricultural production and irrigation. This land type covers an area of approximately 930 ha with deep Hutton soil forms dominating 45% of the land area.

Although the aim of this report is not to evaluate the agricultural potential of the area, it is worth noting that even when the broad land types are deemed unsuitable for crop production and/or irrigation, there might still be suitable soils within the land type. For example, in land type *Db333,* which covers 20 000 ha, approximately 5% (1 000 ha) is covered by deep Oakleaf soils occurring in valley bottom positions (TMU 5). Detailed investigations must, therefore, be conducted to determine the developmental suitability of the soils bordering the dam and the river downstream.

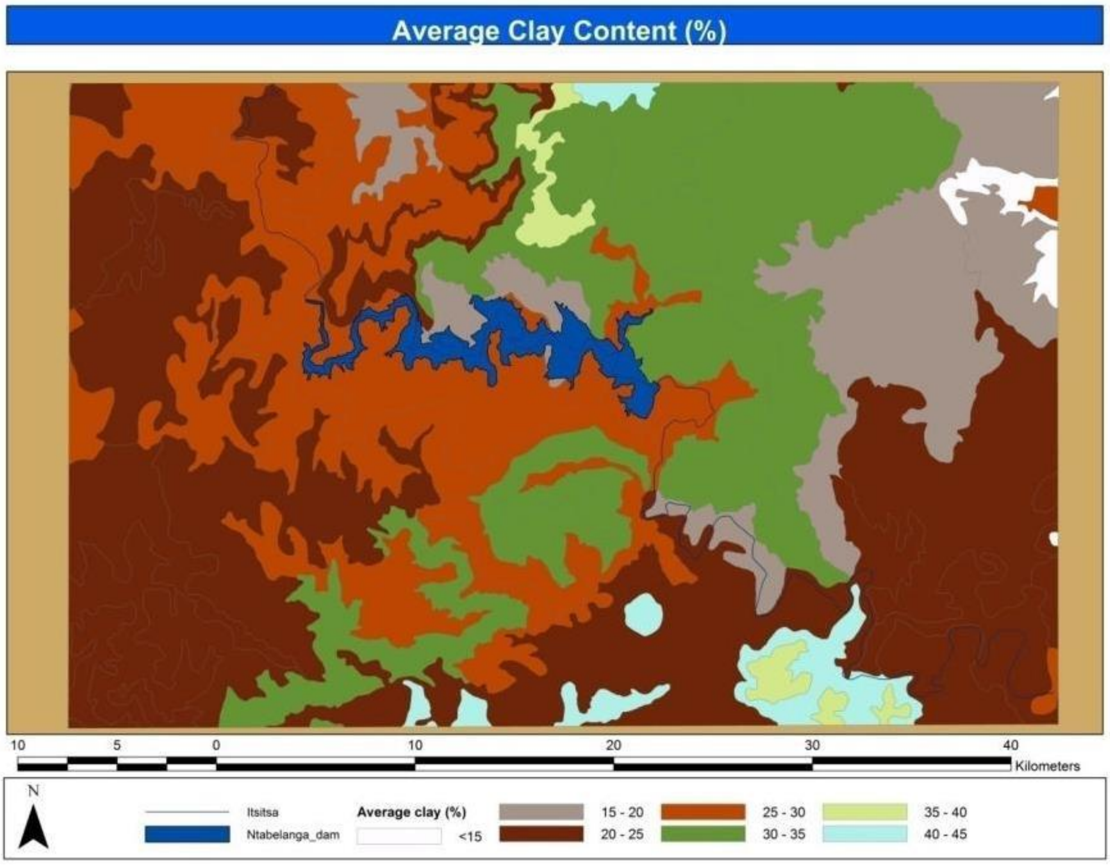

Figure 2-18: **Average clay content (top and subsoils combined) of soils in the study area.**

<u>Soil Erosion</u>

The extent of eroded land overlain on different broad land types in the study area is presented in Figure 2-19. Approximately 3 820 ha have been severely eroded. Erosion is prominent on Db, Fa and Ab land types with approximately 30, 18 and 15% of the land affected by gully erosion respectively.

Fa land types are young landscapes and with shallow soils on relatively steep slopes. The shallow depth and steep slopes limit the suitability of Fa land types for crop production and increase the likelihood of erosion occurring.

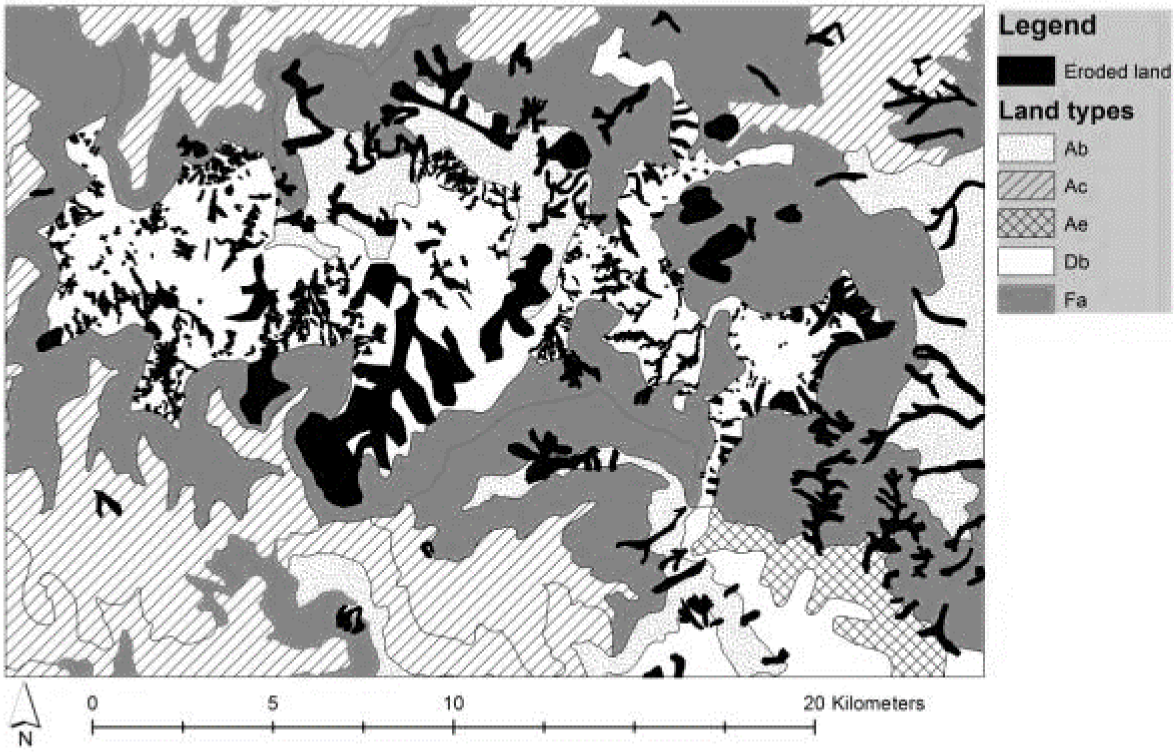

Figure 2-19: Severely eroded land and broad land types of the study area.

Ab land types refer to regions where freely drained yellow and red dystrophic and mesotrophic soils occupy more than 40% of the land area. The soils of Ab land types are generally considered to be good for crop production and suitable for irrigation with low sensitivity to erosion. It was therefore rather surprising to observe the degree of erosion on these land types. Aerial photographs suggest that gully erosion originate on old cultivated lands (Figure 2-20). Even with contouring the removal of natural vegetation and disruption of the soil structure by cultivation resulted in significant erosion on these land types.

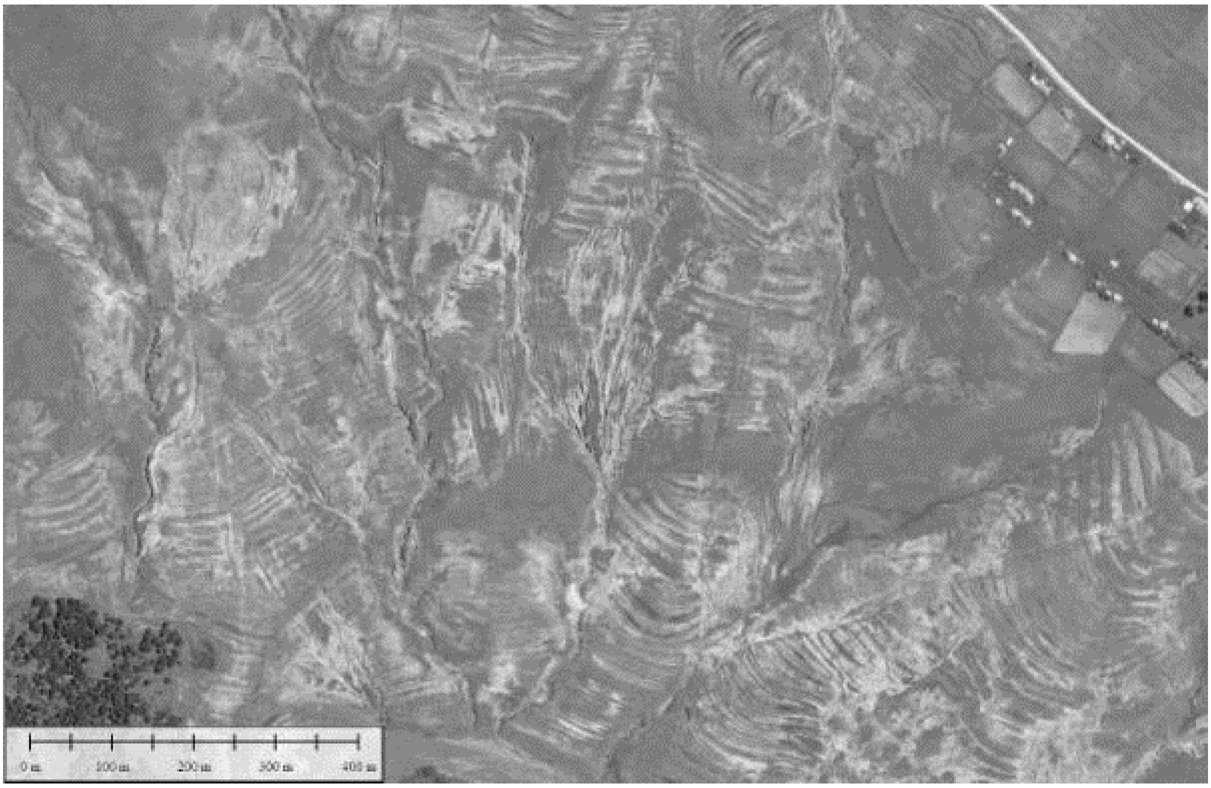

Figure 2-20: Example of gully erosion commencing on old cultivated lands in land type Ab.

In Db land types, duplex soils with non-red B horizons cover more than 50% of the land area (Land Type Survey Staff, 1972-2006). These soils are prone to erosion; the textural discontinuity often results in the generation of lateral flow and the B horizons are often marked by high Na contents making the soils highly dispersive, especially for duplex soils formed on Beaufort sediments.

The coverage of different erosion sensitivity indices of soils in land type Db344 is presented in Figure 2-24 to Figure 2-24. For more details on how these indices were developed see Pawarda, 2017.

The K-factor

The K-factors of the surface horizons ranged from 0.0471 to 0.0982 t.ha.h ha^{-1}MJ^{-1}.mm^{-1} in the area. Most (40%) parts of the area had a K-factor range value of 0.0693 - 0.0778 t.ha.h.ha^{-1}MJ^{-1} mm^{-1} and smallest portions (8%) with erodibility factor range value of 0.0596 - 0.0693 t.ha.h.ha^{-1} MJ^{-1} mm^{-1} (Figure 2-21). Only, 5% of the total area had a K-factor range value of 0.0876 - 0.0962 t.ha.h.ha^{-1}MJ^{-1}mm^{-1} contributed highest (35.2%) to the estimated soil loss in Ntabelanga. Soil associations with the highest K-factor range value (0.0982 - 0.10) t.ha.h.ha^{-1}MJ^{-1}mm^{-1}) contributed the least (5%) to estimated total soil loss. It is worth noting that the K-factor values derived in this study were based mainly on particle size distribution, soil organic carbon, and soil permeability rates. In reality, values for K-factor can be significantly altered by management (governed by the degree of soil disturbance, aggregation, organic matter content (Loch and Rosewell, 1992). Therefore, the deviations from the norm due to a variation in land management were not considered in this study and can only be dealt with at a much finer scale where more detailed information is available.

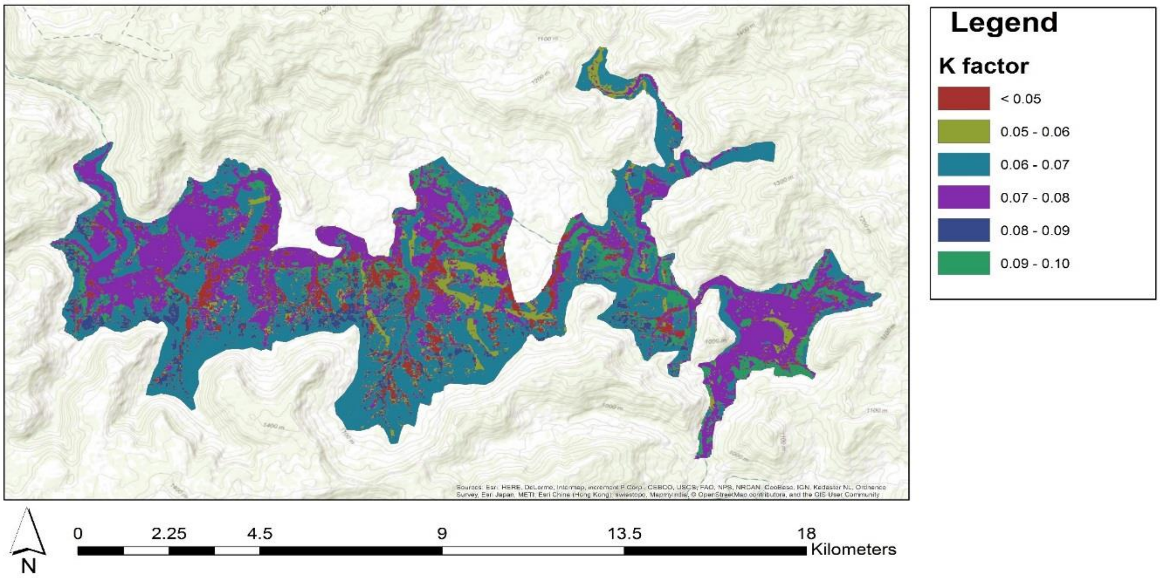

Figure 2-21: Spatial distribution of classified surface erodibility (K-factor) of the Ntabelanga area.

Structural Stability index (SI)

Reynolds et al. (2007) defined SI as the organic matter fraction divided by the silt and clay content and. SI ≤ 5% indicates structural degraded soils due to extensive loss of organic carbon; 5 < SI ≤ 7% indicates high risk of structural degradation due to insufficient organic carbon; 7 < SI ≤ 9% indicates low risk of structural degradation and >9% indicates sufficient SOC to maintain structural stability. All the soil associations in the Ntabelanga area had a SI value of less than 7% (Figure 2-22), indicating high risk of structural degradation, therefore addition of organic matter is important to avoid further degradation. Most (60.2%) soil associations had structural stability index (SI) of <0.8 which contributed 48% of the estimated total soil loss (Figure 2-24). An increase in SI resulted to a reduction in total soil loss, the highest range (1.9 - 3.3) SI value of the area covered 10.6% of total area and contributed least (13.6%) to total soil loss.

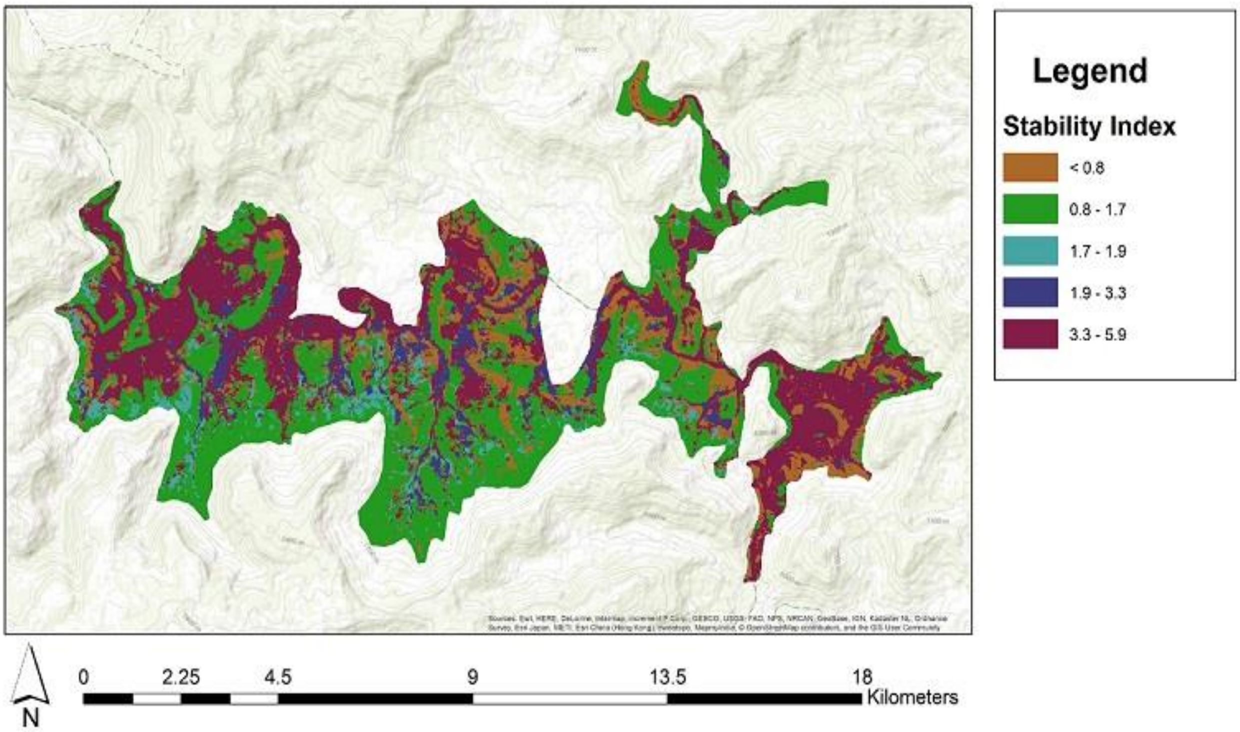

Figure 2-22: Spatial distribution of structural stability index in the Ntabelanga area.

Dispersion ratio (DR)

This index has been shown to reflect accurately soil erodibility in soils high in silt and clay and hence is not accurate in soils with high sand content (Ezeabasili et al., 2014). The dispersion ratios (DR) of the soil associations ranged from 0.05 to 0.97, most (42.7%) soil associations with DR range value of 0.07 - 0.08, accounted for the highest (36.6%) of estimated total soil loss in Ntabelanga (Figure 2-24). According to Hazelton and Murphy (2007), the minimum dispersion ratio falls above the 'slight' category (6 - 30%), the average and maximum dispersion in the 'very high' (>65%) category. It therefore indicates that the all the soil associations are susceptable to erosion. A small region (9.4% of the total area) had a DR range values of 0.09 - 0.10, with a highest (59.2%) contribution to the estimated soil loss (Figure 2-23). The estimated soil loss was proportional to the area covered by the soil with a specific DR range values. Van Zijl et al. (2014) noted that soil dispersion is a dependent soil variable that distinguishes the duplex soils from the other soils and can therefore be used to identify areas with a high gully erosion potential. The conditions needed for piping to occur are: soil with a dispersive nature, free water accumulating within the subsoil and an outlet for this free water (Hardie et al., 2012). This could suggest that the Ntabelanga area has great potential of piping as the largest area is covered by slight and maximum dispersion category (Figure 2-23). Possible conservation practices must aim to increase aggregate stability at the soil surface, prevent clay dispersion and increase the infiltration rate of the subsurface horizons.

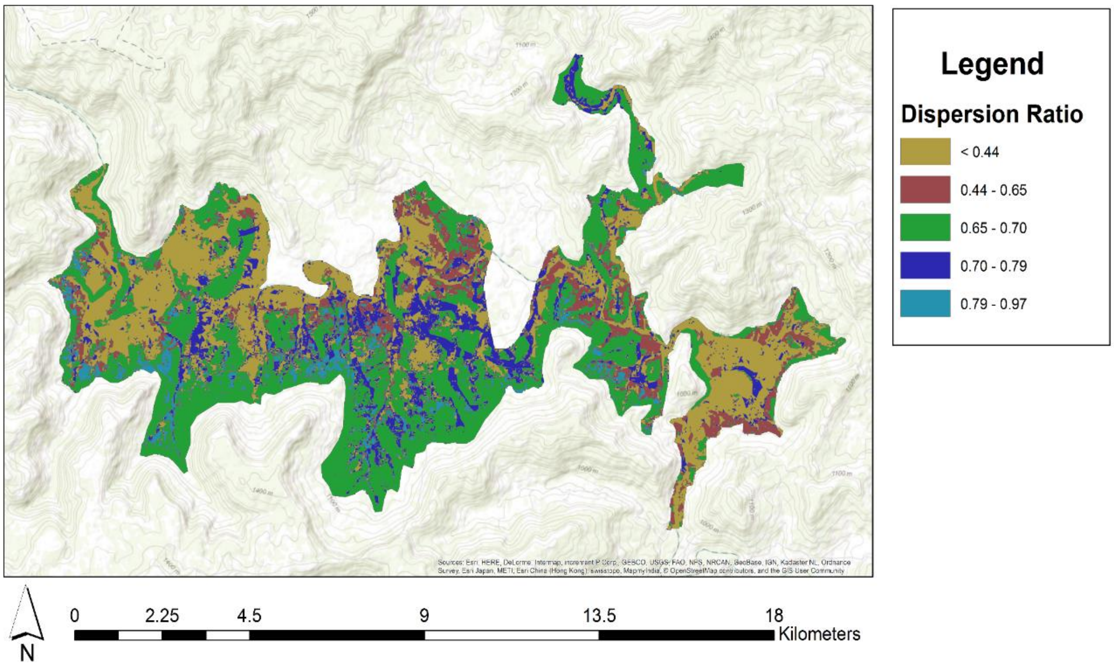

Figure 2-23: Spatial distribution of classified soil erosion risk zones according to soil dispersion ratios

Initial rainfall erosivity prior incubation

Largest portions (70%) of the area experienced predicted soil loss rate of <5 t ha yr^{-1} and smallest portions (1.5%) experienced very high predicted erosion rates (>20 t ha yr^{-1}) (Figure 2-24). However, about 93% of the estimated total soil loss (t ha yr^{-1}) was from areas with erosion rates of above 5 t ha yr^{-1} (Figure 2-24).

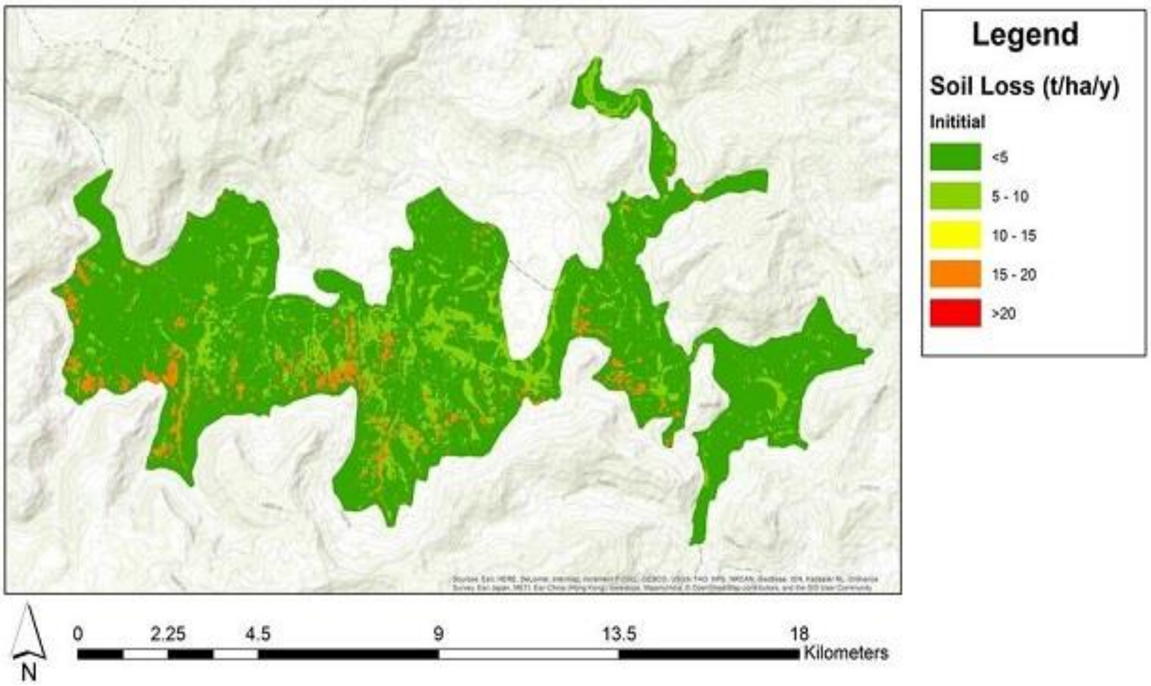

Figure 2-24: Spatial distribution of classified soil erosion risk zones prior to incubation.

Current crop production practices are closely associated with the soils having low sensitivity to erosion. Based on the extent of eroded land (Figure 2-19) and the dominance of soils with high sensitivity to erosion (Figure 2-25) any large-scale expansion of crop production practices seems unlikely on Db344.

Figure 2-25 to Figure 2-27 accentuates the extent of erosion in the study area. Efforts to stop erosion are presented in Figure 2-28. From the interviews it became clear that people and government tried to reduce erosion along roads through a process called 'IZIKREKELA', whereby both men and women carry big stones and deposit them in gullies to stop the furthering of erosion. Apparently, this process was stopped a few years ago.

The extent of land degradation is further highlighted by Figure 2-29 showing natural degraded grasslands in the study area (NLC, 2000). The majority of natural grasslands bordering the dam have been subject to degradation.

Figure 2-25: Severe gully erosion on an Estcourt soil form (located at Photo 4 in Figure 2-3).

Figure 2-26: Gully erosion located at Photo 6 in Figure 2-3. Full-grown *Acacia* trees highlight the extent of the erosion.

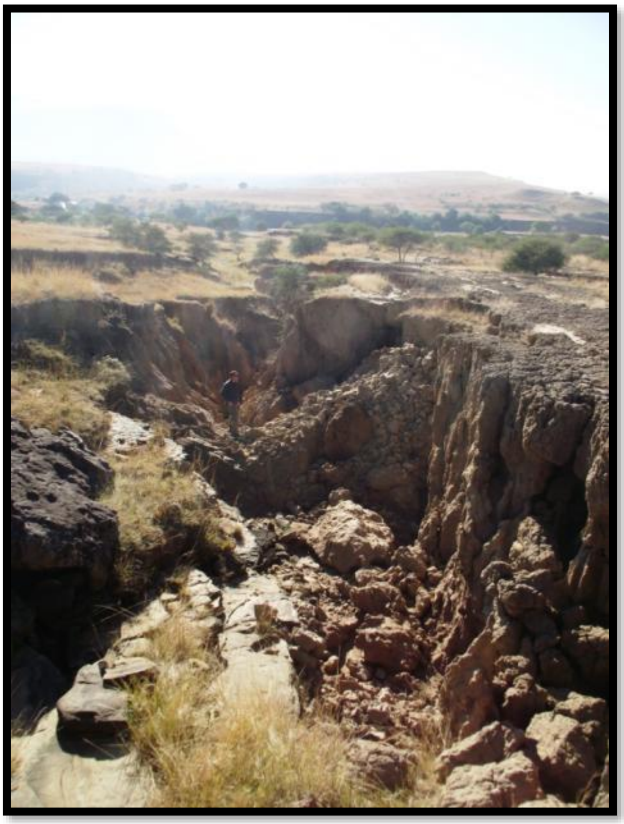

Figure 2-27: Inside one of the gullies in Figure 2-26.

Figure 2-28: Efforts to stop erosion along the road (Located at Photo 7 in Figure 2-3).

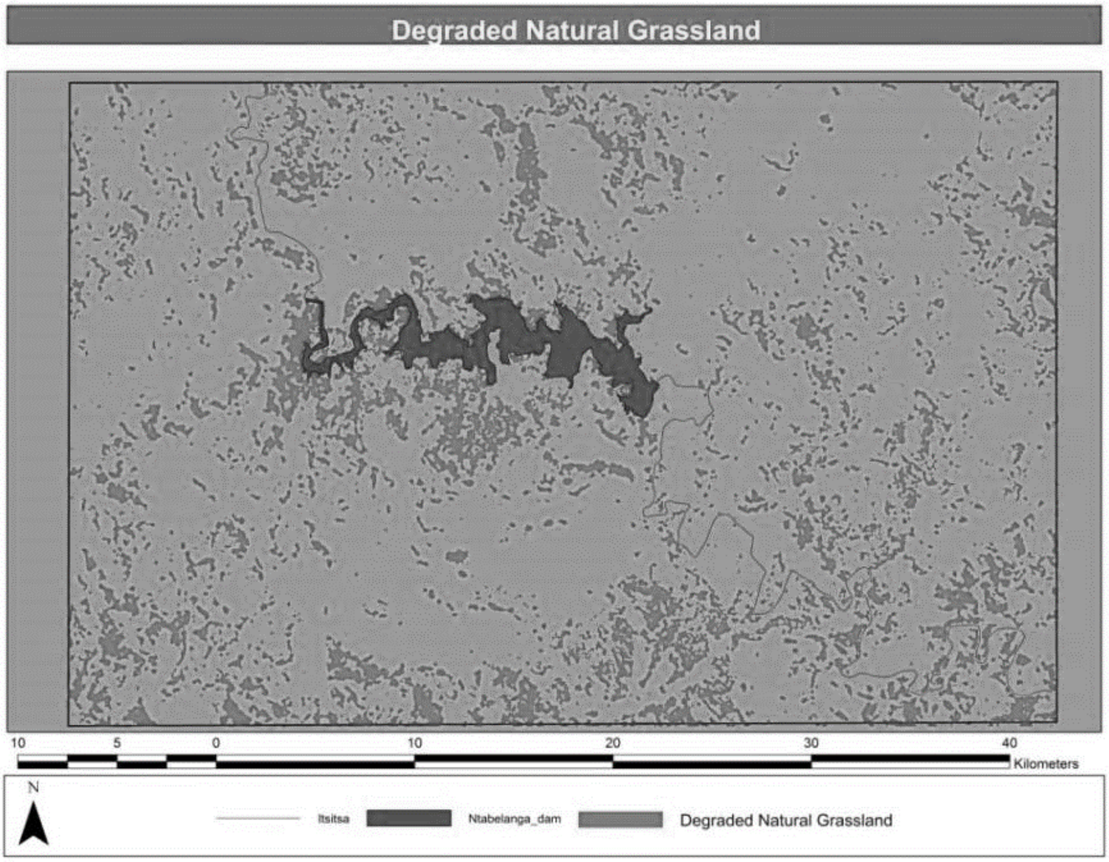

Figure 2-29: **Degraded natural grassland in the study area.**

Vegetation, Wetlands and Natural Forests

The dominant veld types forms part of the Drakensberg Foothill Moist Grasslands and the East Griqualand Grasslands (Figure 2-30) with some areas below the proposed dam wall forming part of the Eastern Valley bushveld (Mucina and Rutherford, 2006). Isolated patches of Southern Mistbelt Forests and Mthata Moist Grassland also occur (Figure 2-30).

Major wetlands and the location of natural forests were obtained from the Land Cover Database, 2000. The occurrence of wetlands and natural forests are presented in Figure 2-31. The natural forests are generally found on steep slopes and higher elevations (Figure 2-4) where orthographic rain creates a micro-climate suitable for their occurrence.

Figure 2-31 only shows the location of relatively large wetlands in the study area. A number of smaller wetlands were identified in the study area during the two field visits (e.g. Figure 2-32). The degradation of these wetlands can have significant influences on the water delivery to streams, both in terms of water quantity and quality.

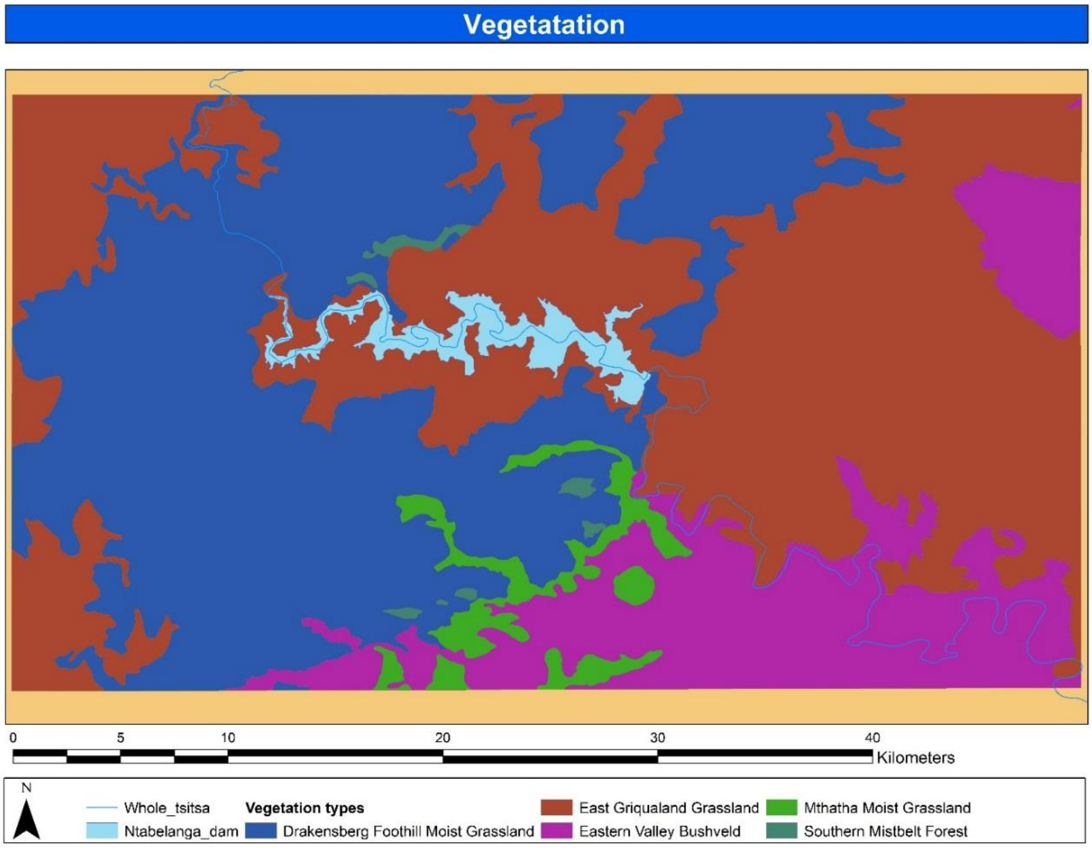

Figure 2-30: Dominant vegetation sites in the study area (adapted from Mucina and Rutherford, 2006).

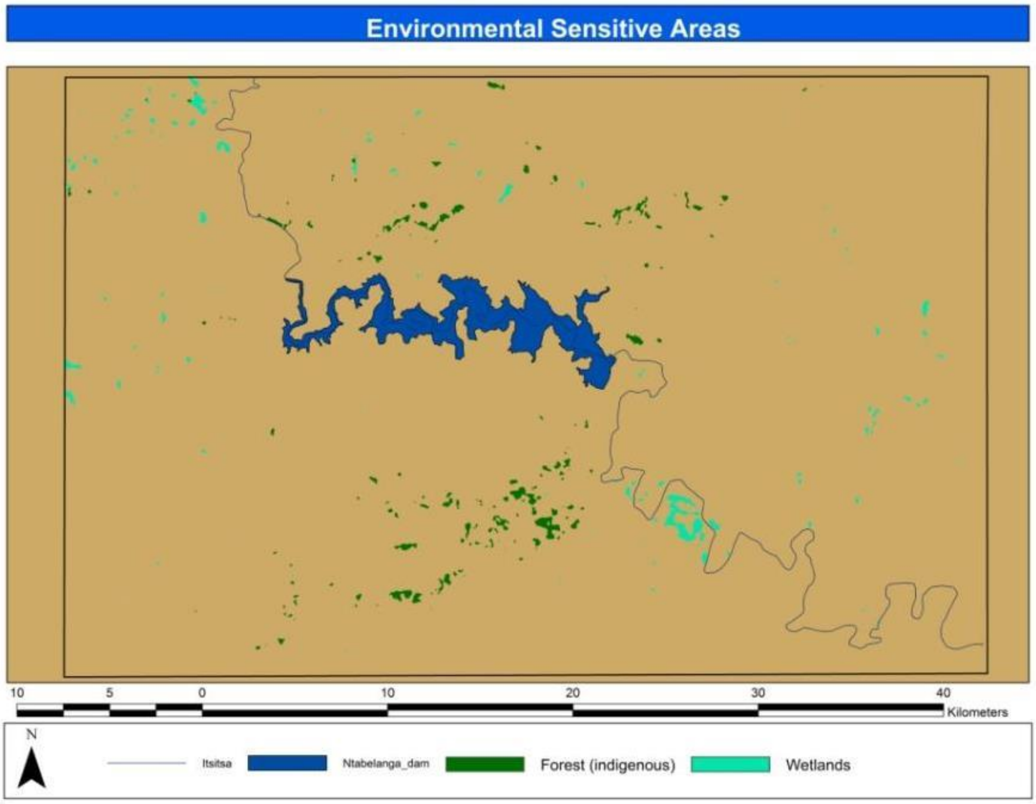

Figure 2-31: **Location of wetlands and indigenous forests in the study area.**

Figure 2-32: A typical wetland occurring widely in the study area (located at Photo 8 in Figure 2-3).

2.3 Studied communities

Five communities formed the empirical core of the natural scientific and sociological data collection. These were: Emqokolweni (with a special focus on the dam inlet section of Ngxoto), Lower Sinxaku, Ngqongweni, Ndzebe and Ndibanisweni Administrative Area (AA) – see Table 2-4.

Table 2-4: Study communities

Community	Local Municipality	District
Ngxoto (Emqokolweni)	Elundini	Joe Gqabi
Lower Sinxaku	Elundini	Joe Gqabi
Ngqongweni	Nyandeni	OR Tambo
Ndzebe	Mhlontlo	OR Tambo
Ndibanisweni AA*	Mhlontlo	OR Tambo

*This community was earlier misidentified in Akpan et al. (2014) as KuGubengxa

The reasons for choosing these communities were the same as those outlined previously (Van Tol et al., 2014). The intention was to capture, in a more standardised way, the ecological and socio-economic status quo in the different communities, as they potentially had varying levels of exposure to dam impacts. For instance, some of the more direct socio-ecological impacts – such as dam inundation and attendant social dislocation and displacement – are likely to be more directly felt in three of the five communities: Emqokolweni (especially sections of the town, like Ngxoto, that fall directly within the dam footprint), Lower Sinxaku and Ngqongweni.

Ndzebe is expected to be impacted more or less indirectly, and mostly positively, although the possibility of dam-induced floods cannot be ruled out. Ndibanisweni Administrative Area (AA), near Tsolo, is perhaps the only "all-benefits-no-cost" community of the five. Relatively far removed from the dam footprint, it is included in the official irrigation plan for the dam and stands to benefit from irrigated agriculture.

As shown in the relevant chapters of this report, all five communities had broadly similar physical features and socio-economic and cultural attributes. For instance, the communities were grossly susceptible to gully erosion, a reality that made the likelihood of large-scale commercial agriculture – even with irrigation possibilities offered by the proposed dam – quite slim (see Van Tol et al., 2014). Falling within the Maize Mixed Farming System (No. 9) – according to Dixon et al. (2001): the area operates a Tribal Land authority system where state land is held in trust by traditional leaders. Within this system, average land holding per family is approximately 1 ha, of which a portion is devoted to subsistence agriculture. This takes place relatively close to the homestead (see Van Tol et al., 2014: 4). According to Van Tol et al. (2014:4), "large areas of communal land – the higher-lying mountains surrounding the communities – are typically used for grazing of livestock, especially cattle."

Despite the deep cultural vibrancy of the area, there was widespread poverty, with 72% of sampled residents describing themselves as unemployed, and a significant proportion (48%) reporting dependence on social grants. Many younger men could be said to be actively involved in the rural livestock economy, especially in their roles as "herd boys". Interestingly, the general feeling among the older generation was that rather than take interest in rural agriculture, the local youth had their heads filled with urban dreams. Modern commercial activities were few and far between in the communities, with each community having just a handful of *spaza* (convenience) shops. The hub of buying and selling for local residents were towns such as Maclear, Tsolo and Qumbu.

Further justifications are provided in the sections below with regard to why specific sites were included in the different aspects of the study.

3 METHODOLOGICAL NOTES

3.1 Introduction

As stated earlier, the study was conceptualised with one main goal in mind: to lay a robust empirical foundation for monitoring the short-, medium- and long-term impacts of the Ntabelanga dam. For the purposes of the study, three main, but interrelated dimensions were delineated, namely: ecological, agricultural and sociological. For a thorough apprehension of these dimensions – and indeed the dam-environment-community nexus – the study adopted an interdisciplinary and collaborative mode of inquiry. It sought to integrate "information, data, techniques, tools, perspectives, concepts, and/or theories from two or more disciplines or bodies of specialized knowledge" – in particular, physical geography, agricultural science and sociology – with a view to advancing understanding or tackling problems "whose solutions are beyond the scope of a single discipline or field of research practice" (see National Academy of Science et al., 2004:26). The researchers believed this approach would enable them to interrogate cross-cutting issues associated with the dam from both natural scientific and sociological perspectives. Even so, an interdisciplinary inquiry enabled the team to contemplate the possibility that the Ntabelanga dam would more than simply herald rural renewal; it could engender profound ecological, agricultural and socio-cultural disruptions in the same communities that the dam developers believed would only derive benefits.

This chapter provides important notes on how baseline data were obtained pertaining to the different facets around which long-term monitoring was deemed pertinent. These include water quality, pollution and hydropedological issues, stream channel geomorphology, aquatic biodiversity, vegetative analysis, soil quality yields and yield gaps, as well as sociological and economic dynamics.

3.2 Water quality monitoring

Sampling sites

Monitoring sites were selected to represent different water resources, e.g. main river, tributaries, taps, etc. (Figure 3-1). The accessibility of the sites was a key consideration in the selection processes. Twenty fixed sites were identified for water quality monitoring (of which eight sites were from the Tsitsa River, seven were from the Tsitsa River tributaries and five were from the taps/ground water from villages most likely to be affected by the dam development. Figure 3-2 and Figure 3-3) present photographs of some of the sampling sites used for water quality study.

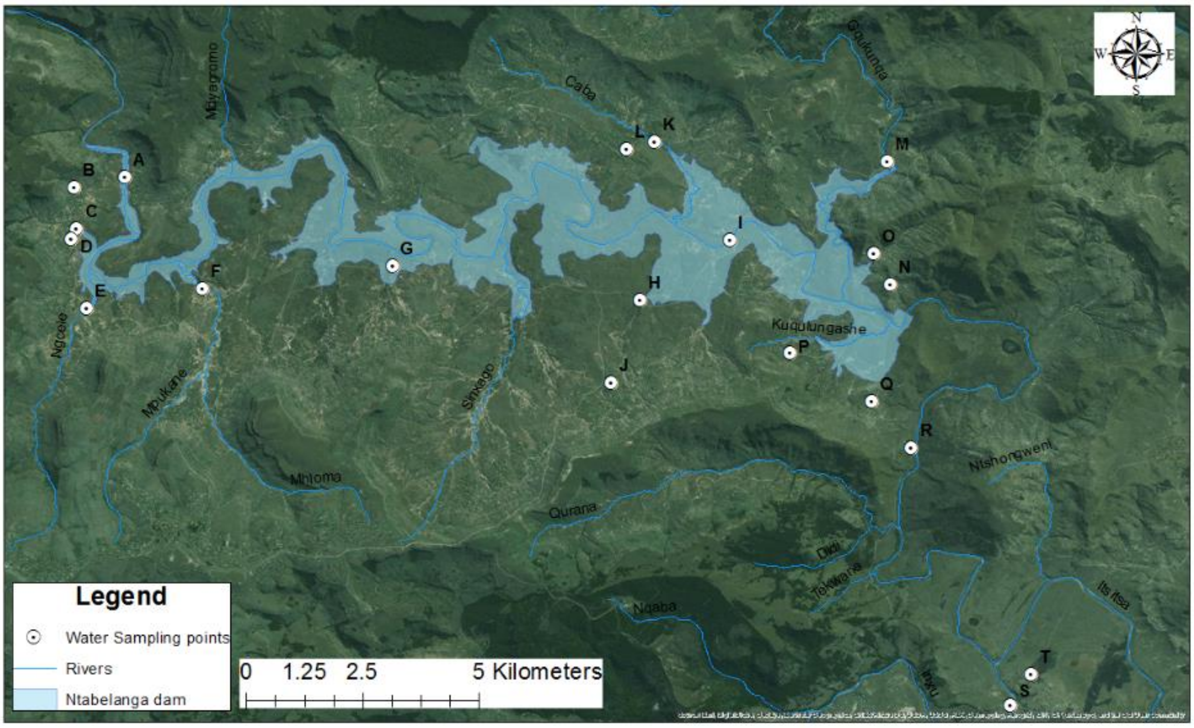

Figure 3-1: Water quality sampling locations (A-T).

Figure 3-2: Monitoring locations for water samples (A-J correspond to letters in Figure 3-1).

Figure 3-3: Monitoring locations for water samples (K-T correspond to letters in Figure 3-1).

Materials

Methanol, water and acetonitrile of LC-MS quality was purchased from Sigma Aldrich (USA), while the formic acid (analytical grade) was purchased from Agilent, USA. The LC-MS column was purchased from Agilent (USA). (USA). All reagents and standard were freshly prepared in LC-MS grade water or solvent before use. YSI PRO DSS multi-parameter portable water quality instrument was purchased from Monitoring and Control Laboratories (PTY) LTD, (South Africa).

A portable digital JENWAY model pH meter 3505 with glass electrode was used to determine the pH of the water samples in the laboratory. A general purpose JENWAY digital portable model conductivity meter/TDS 470 was used to determine the water surface temperature, total dissolved solids (TDS) and electrical conductivity (EC) on the field. Analysis of dissolved oxygen (DO), bio-chemical oxygen demand (BOD), chemical oxygen demand (COD), total solutes (TS), total suspended solids (TSS), alkalinity, chloride ion and phosphate ion were analysed using the AL 450 Aqua lytic photometer according to the manufacturer instructions. Total hardness was determined by using EDTA titrimetric method. Statistical analyses were performed using SYSTAT 16.0 (SPSS, USA). Results from the water analysis are expressed as mean values of replicate determinations with their standard errors.

Analytical procedure

Pharmaceuticals and personal care products (PPCPs)
Surface water and drinking water samples were collected in 250 ml amber glass bottles (to avoid plastic contamination) from 16 sampling points. The samples were transported to the laboratory for analysis. Before the analysis, both surface and drinking water was vacuum filtered through glass fibre filters.

Data processing and analysis

All the targeted PPCPs were analysed using 5600 AB SCIEX Triple TOF hybrid mass spectrometer (Applied Bio systems Sciex, USA) equipped liquid chromatography apparatus (LC, Shimadzu, LC 20 AD, and binary pump) operated in both the positive and negative turbo ion spray (ESI) mode. The LC chromatography was fitted with a reverse phase column.

3.3 Pollution from latrines

Site selection

Five pit latrines were selected, all located close to tributaries draining directly into the Tsitsa River. Two were in Ngxoto, one in Upper Sinxaku and the remaining two sites were located in the Ngqongweni, near the proposed dam wall (Figure 3-4).The pit latrines were selected because of easy accessibility: they were located not far from the available local roads, which made it easier to transport sampling instruments to the five study sites. The sites are also located close to the Tsitsa River tributaries.

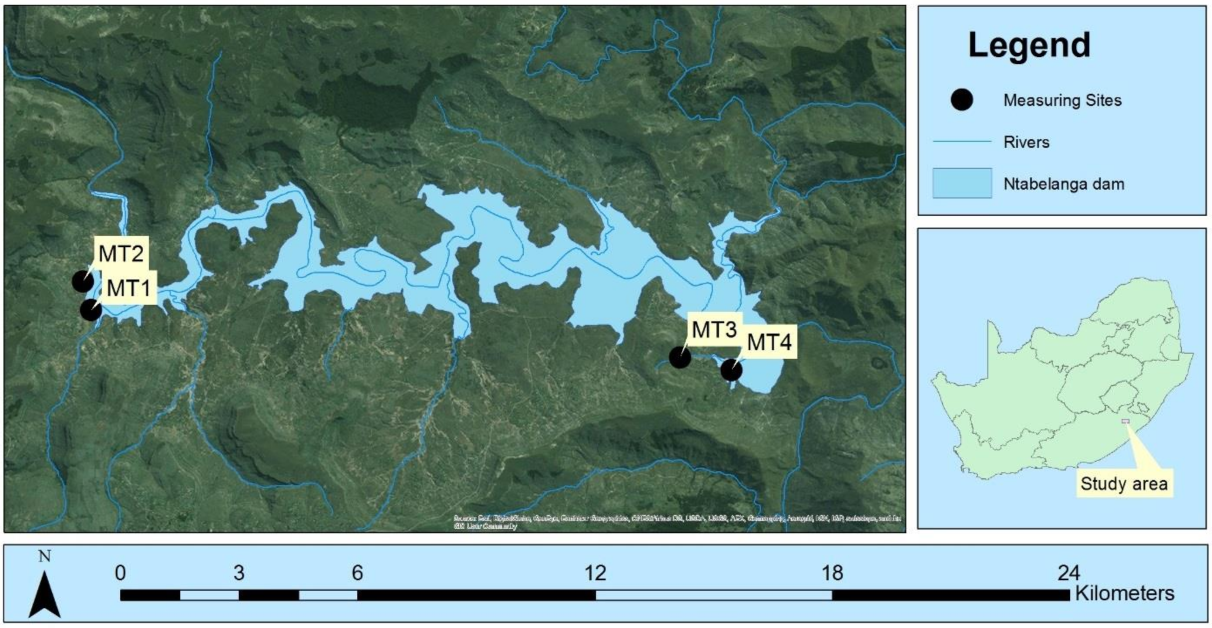

Figure 3-4: Map of the study area and selected sites.

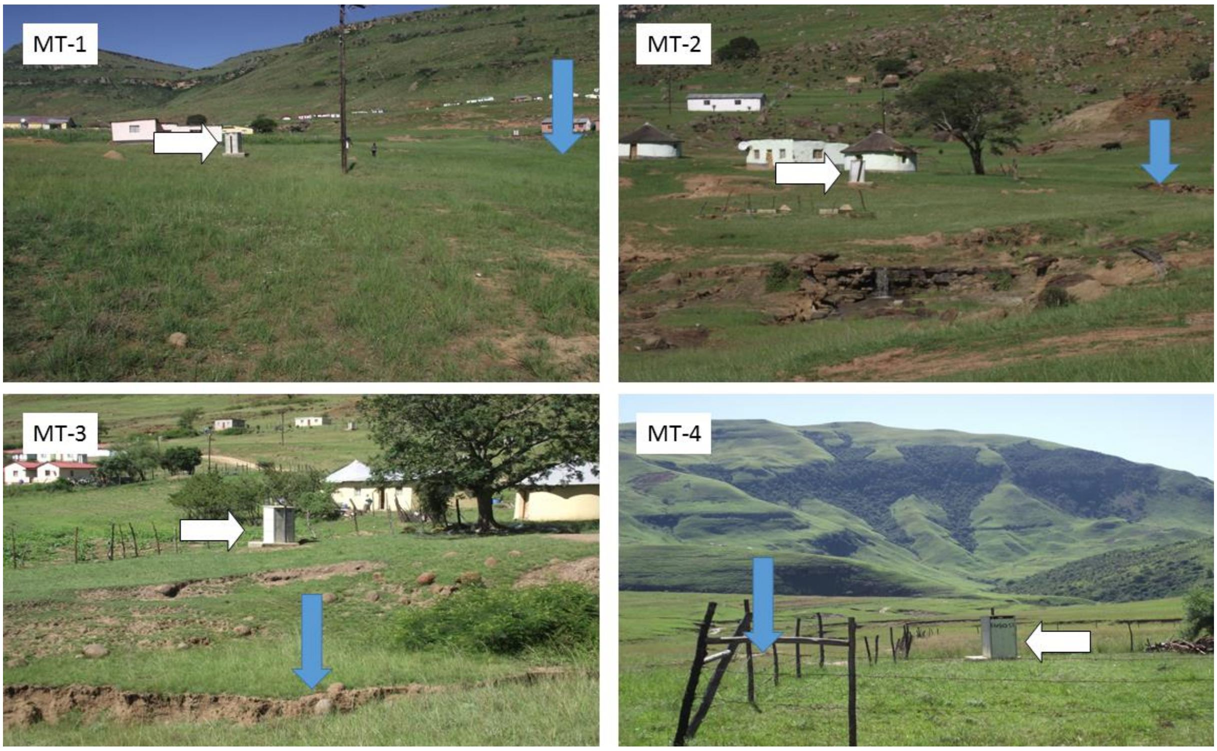

Figure 3-5: Photographs of surveyed sites (white arrow – pit latrine; blue arrow – tributary stream).

The selected hillslope transects with the pit latrines were sampled at 2.5 m; 8 m and 15 m respectively towards the tributary streams. A hand auger was used to sample three points along transects in the direction of the streams at each site to the depth of the bedrock. The soils were classified in accordance to the South African Soil Taxonomy (Soil Classification

Working Group, 1991). Sociological aspects surrounding each pit latrine, such as number of household inhabitants were also recorded.

Hydropedological conceptualisation and microbial sampling

The hydropedological interpretation of the soils followed the classification of soils on hillslopes following the technique by Van Tol et al. (2011) and Van Tol et al. (2013). In this technique, any soil features, including the classification is related to the hydrological response of the soils. The spatial distributions of the soils are then related to the hydrological behaviour of the landscape.

Microbiological analyses in soil samples were conducted for two main bacteria indicators; faecal coliforms and *E. coli* bacteria as well as the natural coliforms bacteria. The total bacteria and total coliforms counts were also determined from agars with growing colonies observed. To accommodate the seasonal changes, samples were collected towards winter (May 2016) and summer (November 2016). A total of 90 soil samples were therefore collected from the different pit latrines.

<u>Bacteria indicators (Faecal coliforms and E. coli)</u>

The analysis for the faecal coliforms and *E. coli*, bacteria was conducted at Bemlab. The soil samples were extracted with Ringers solution. The decanted soil extracts were analysed using the membrane filtration method (USEPA, 2002) and the Polymerase Chain Reaction (PCR) method (Mullis**,** 1980) to identify the presence of and verify the bacterium. For each soil sample, 100 ml of the extract was be placed into a sterile honey jar. Thereafter, a single sachet of Colilert medium was added to the sample. The jar was then shaken gently until the media was dissolved. The sample was poured into a sub-divided Quanti-Tray, consisting of small and large wells and sealed in an IDEXX Quanti-Tray sealer. Each tray was incubated at 35˚C ± 1˚C for 18 hours. Results were enumerated by placing each tray under a 6 Watt 365 nm UV light and counting the total number of small and large wells that fluoresced. *E. coli* densities were taken as the number of positive wells which were then converted to most probable number (MPN) using the IDEXX MPN tables.

<u>Chemical properties</u>

The 90 soil samples collected for microbial analysis were also used to determine the soil pH and the total organic carbon (%). The soil pH was measured in 1 M KCl and an equivalent soil-water pH measurement to ensure convenience. Initially the soil samples were measured and placed in a beaker; then a particular volume of water or 1 M KCl was dispensed to the soil. The soil solution was shaken vigorously in 15-minute intervals up to one hour. The pH meter and electrode were calibrated using pH 4 and 7 buffers. Finally, the electrode was placed in the solution to respectively record the two different pH values reported.

Soil samples analysed for organic percentages, followed the soil organic matter loss by the ignition method (Ball, 1964). The obtained organic matter contents were used to calculate the soil organic carbon through a conversion factor using the formula:

$$OC\% = \boldsymbol{OM}\% / \mathbf{1.72}. \qquad \textbf{(eq. 1)}$$

Where, OM – organic matter (%) and 1.72 is a constant factor to convert to total organic carbon (%). The OC contents recorded from each sampling site were determined for both top and sub horizons in the study sites.

Hydraulic property measurements

Undistributed core soil samples from each horizon were collected to determine the hydrological input factors for the flow model. The cores were used to determine the soil bulk density (g/cm^3) following the formulae: -

$$\frac{\boldsymbol{mass\ of\ dry\ soil\ sampled}(\boldsymbol{g})}{\boldsymbol{soil\ volume}\ (\boldsymbol{cm3})}. \qquad \textbf{(eq. 2)}$$

Soil porosity (micro pores/cm), was determined using the inverse from the obtained bulk densities and porosity:

$$F = \frac{\mathbf{1}-\boldsymbol{Bd}}{\boldsymbol{Pd}}; \qquad \textbf{(eq. 3)}$$

Where, F – porosity, Bd – Bulk density and Pd – particle density

The hydraulic conductivity functions were determined in the laboratory using a permeameter that uses the steady-state method. The utilised method measures hydraulic conductivity by maintaining a constant hydraulic head gradient across the soil samples, which attains a steady-state water flow through the samples. Steady-state conditions are achieved when the influent flow rate is equal to the effluent flow rate. The hydraulic conductivities, k_W, which corresponded to the applied matric suction, were recorded. The saturated hydraulic conductivity (K_s) was measured using the constant-head conductivity test from two undistributed core samples. Each core in the laboratory was measured at three respective suction tensions (Kh), 5 mm; 30 mm and 150 mm from the different depths. The unsaturated hydraulic conductivity of the soil was initially recorded using the double ring method on the core samples. Transition between the sub-horizons and the underlying bedrock was determined through auguring a hole to the solid rock. Then pipe down a Guelph permeameter to measure the saturated hydraulic conductivity where it was possible.

The final input factor was the water retention capacity of the soils. To determine this, the hanging water column method was used for the parameter. This technique determines a water retention curve in a Buchner funnel, also known as the Haines apparatus (Haines, 1930). Initially the volumetric water content (θ), was calculated from the wetted soil samples using the formula-

$$\boldsymbol{\theta} = \frac{(\boldsymbol{Mws} - \boldsymbol{Mods})}{\boldsymbol{\rho WvS}}; \qquad \textbf{(eq. 4)}$$

Where Mws – mass of wet soil, Mods-mass of oven dry soil, ρW– density of water and Vs – volume of the soils. A water retention curve was then plotted of the volumetric water content (θ) against the matric head gradient (h_m) obtained.

3.4 Stream channel geomorphology

Monitoring Sites

Monitoring sites for the investigation of characteristics of channel morphology were identified at a reach scale using 2009 and 2013 digital aerial photographs. Aerial photographs were provided by the Rhodes University Geography Department who sourced the images from National Geo-Spatial Information, Cape Town. These photographs have a suitable resolution (1:10 000 orthophotos, with 50 cm resolution) in the area of interest. Long profiles of the river channel in the area of interest were used to identify distinct changes in gradient which point to different process sets. The desktop study based on aerial photography was supported by a field survey in May 2015, in which sites were verified.

Physical Variables

Physical variables define the geomorphology of a stream. Rivers vary spatially allowing for a variety of habitats, each supporting a range of biota. Physical variables were monitored seasonally (every 3-4 months) to note changes in habitat quality.

<u>Cross-sectional surveys</u>

Cross-sectional surveys of channel topography were conducted at the sub-reach scale, using a Differential Geo Positioning System (DGPS). Four to six cross-sectional surveys were conducted per site. The number of cross-sectional surveys varied according to the number of channel morphology features present in each site so as to obtain accurate channel dimensions (Figure 3-6). Repeat monitoring of cross-sectional transects were conducted to see if there were any seasonal changes in channel topography due to sedimentation or lack thereof.

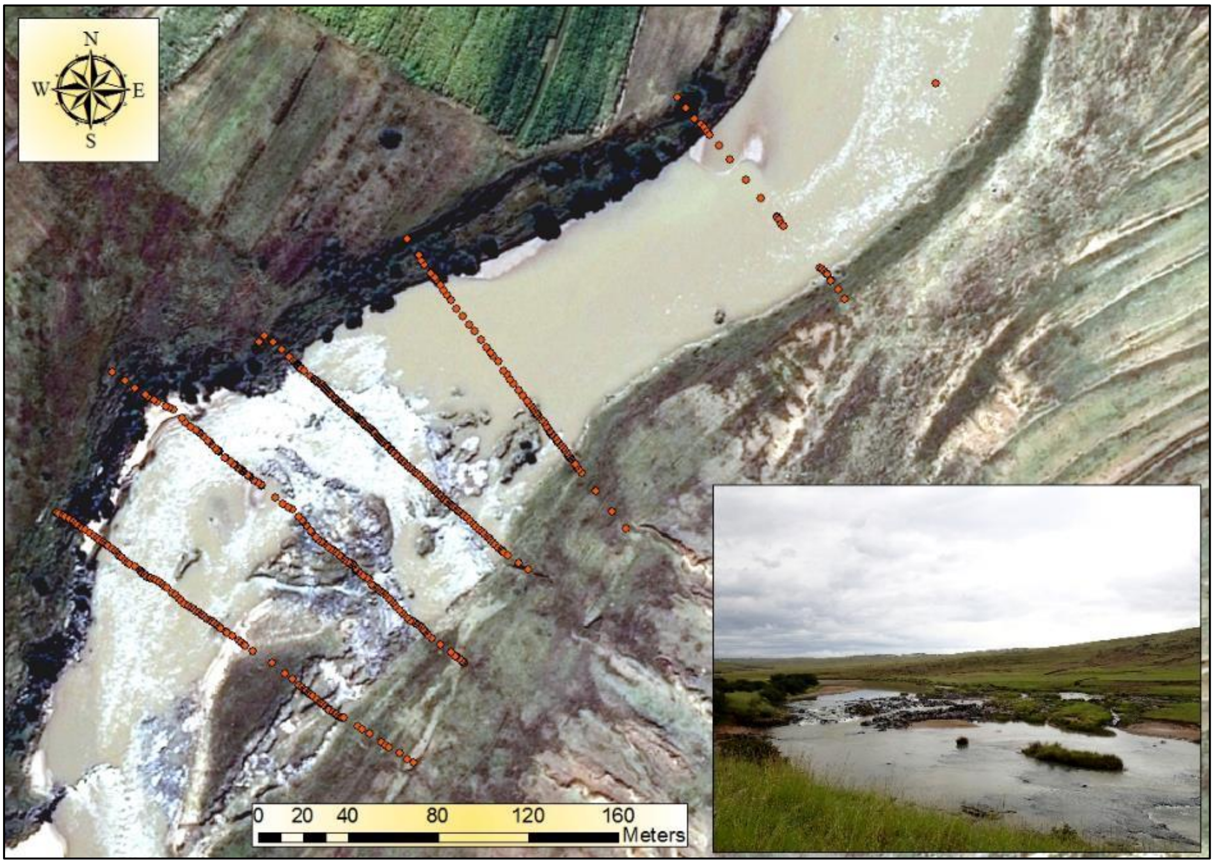

Figure 3-6: The location of cross-sectional surveys for Site 5, below the confluence with the Inxu, to monitor increased embeddedness of coarse substrate and channel narrowing and or reduction in depth.

<u>Substrate</u>

The magnitude of sedimentation of substrates can be measured in numerous ways including the area of streambed covered, the types of clasts being embedded, the depth of coverage, the amount of sediments covering the substrate and the percentage of interstitial spaces filled (see Waters, 1995). Substrate, an important driver of habitat type, was measured using both visual assessments and quantitative assessments.

A visual assessment was conducted according to methods taken from Gordon et al*.* (2004). Three to five quadrats (measuring on average one square metre) were placed along the known transects, covering all the morphologies, in each site. Clast sizes of the **coarse substrates (>4 mm and excluding bedrock outcrops)** found within each quadrat were used to establish the dominant particle size distribution along each transect. By randomly measuring particle diameter of a minimum of 100 clasts a pebble count, ranging across each site was conducted to get an overall picture of the distribution of the coarse bed material across each site. The median particle size (D_{50}) values were extracted and the percentage distribution by clast type for each site was estimated.

Particle size data can be used to access sorting and embeddedness values (Figure 3-7 and Table 3-1). Following Gordon et al. (2004), the size class of the largest and second largest clast type was recorded and the percentage cover of fine sediments was estimated. A level of embeddedness was determined along with a sorting category of the sediment, which was selected based on the diversity of clast sizes within each quadrat area. Embeddedness was monitored seasonally under different flow conditions to monitor patches of fines collecting on the bed sediment.

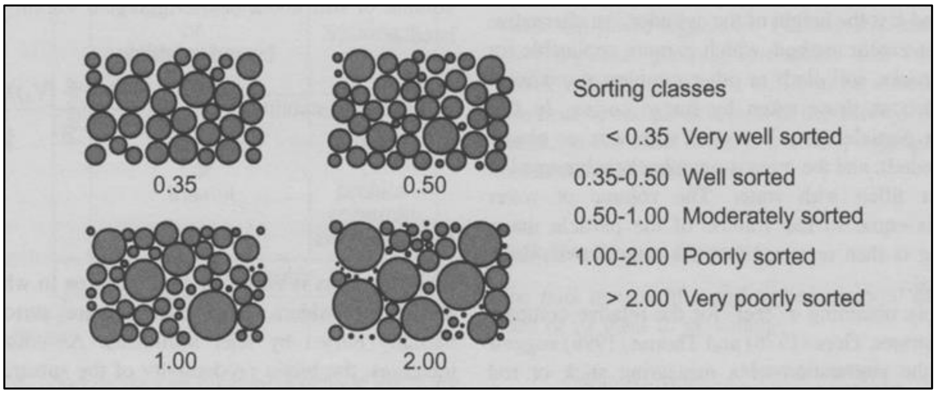

Figure 3-7: Sorting classes for substrate (Gordon et al., 2004).

Table 3-1: Substrate description categories (Gordon et al., 2004)

Code	Substrate Description
1	Fines (sand and smaller)
2	Small gravel (4-25 mm)
3	Medium gravel (25-50 mm)
4	Large gravel (50-75 mm)
5	Small cobble (75-150 mm)
6	Medium cobble (150-225 mm)
7	Large cobble (225-300 mm)
8	Small boulder (300-600 mm)
9	Large boulder (>600 mm)

A quantitative assessment was conducted by following the methods taken from Lambert & Walling (1988) and Duerdoth et al. (2015). By taking disturbance samples of fine sediment stored on the stream bed (surface and subsurface) an assessment of the variation in fine sediment accumulation over time was conducted. A large spherical bucket, with the bottom removed, was placed over the substrate on the channel bed. The depth of the water level in the bucket was recorded. The fine bed sediments were disturbed by vigorously stirring the water with a stick, without touching the river bed, for 30 - 60 seconds or until the bed had been sufficiently disturbed. A water sample was taken. Subsequently a further 30 seconds of disturbance was conducted by stirring up and digging in the top 10 cm of the bed substrate to raise any subsurface fine sediment into suspension. Samples of both the surface and subsurface deposited fine sediments were collected for each disturbance to quantify the combined surface drape and subsurface fine sediment deposits. Deposited fine sediment is unlikely to be evenly distributed across a river bed (Duerdoth et al., 2015). Measurements were taken, in different biotopes (flow, depth, substrates), along each known transect in each site, in the middle of a quadrat in which a visual assessment was conducted. In several cases the disturbance technique was limited to fine gravels and sands as the bucket could not be firmly fixed into coarse gravels or cobble beds. However, where the bucket could be firmly fixed, (without flow of water into or out of the bucket) to the substrates, including coarse gravels, cobbles and bedrock, disturbance samples were taken. In the case of bedrock only a surface sample could be taken. Coarse gravels and cobble beds found in fast flowing rapids were not suitable for disturbance samples and are expected to not be conducive to the deposition of fine materials (Tharme & King, 1998). During high flow disturbance samples could only be taken in quadrates where water depth did not exceed the depth of the bucket.

Suspended sediment samples were taken at each site. A sample was taken that accurately represented the rivers current sediment load. Samples were taken during every field visit in order to correlate the sediment data to seasonal hydraulic processes.

A laboratory analysis of the water samples of surface drape, subsurface fine sediment deposits and suspended sediments collected were conducted after each field visit. The concentration of sediment was measured by using the filtration method from Gordon et al. (2004). In the filtration method a water sample, with a known volume, is filtered and the amount of sediment trapped on the filter is weighed after drying. Sediment concentrations were determined by passing an entire water sample through a vacuum filtration setup. Weighed 90 mm diameter Macherey-Nagel glass fibre filter paper disks, with an average pore size of 0.6 µm were used (Gurnell et al., 1992). The filter paper and sediment were dried in the oven at a temperature of 50˚C for a minimum of 24 hours or until it was dry. The sediment was not dried overnight at 105˚C due to the availability of ovens and this may lead to marginal overestimations in sediment weight (Van der Waal, 2014). However, this will vary according to sediment type. After drying, the filter paper and extracted sediment were cooled to room temperature and weighed again. The sediment concentration was calculated using the following formula:

$$c_s = \frac{(Mass\ of\ filter + Sediment) - (Mass\ of\ Filter)}{Volume\ of\ water\ sample} \times 10^3$$

Where:

c_s *= Sediment Concentration (mg l-1)*

Mass in grams

Volume (in litres) of water sample (weight of water, calculated by subtracting the empty bottle from the weight of the full water sample bottle, was converted to volume assuming 1 kilogram = 1 litre).

The sediment concentrations were determined by, first, calculating the volume of water in the bottle (weight of water, calculated by subtracting the empty bottle from the weight of the full water sample bottle, was converted to volume assuming 1 kilogram = 1 litre), the weight of the extracted sediment and then dividing the sediment weight by the volume of water.

Turbidity

Turbidity is caused by particles and dissolved substances in water including organic, inorganic and suspended particulates (Henley et al., 2000). Abiotic matter is commonly sourced from eroded materials or sediments that have been previously deposited in the river bed but have become entrained due to high flows. Increased turbidity results in a change in water clarity. An increase in turbidity affects light penetration into the water which in turn directly affects aquatic biota. A combination of qualitative data and quantitative data was used to measure turbidity. Quantitative data is most commonly measured using a nephelometric turbidimeter that measures the weakening of a beam of light through a water sample in other words, the instrument measures the absorption and scatter properties of light when it passes through water (Henley et al., 2000). Qualitative data is collected by using a water clarity tube (GroundTruth, 2013). GroundTruth (2013) state that the clarity tube is one of the few inexpensive methods for testing turbidity and has fewer limitations than its counterparts. Turbidity was measured seasonally in order to observe how turbidity changes over time with the flow hydraulics of a river.

Flow Hydraulics

Measurement of discharge in relation to current water levels, water surface slope (shear stress) and suspended sediment were monitored over time to investigate the processes forming the current river condition. These measurements are a necessary input to assessing substrate and sediment mobility.

<u>Discharge</u>

Discharge is an important variable determining channel response over time (Rowntree & Wadeson, 1999). Flood runoff is important in determining geomorphological processes as high discharges are required for significant sediment entrainment and transport. Measurements of discharge in relation to current water levels were monitored over time to investigate the current stream condition. Discharge measurements were taken along one known cross-sectional transect at each site, with the most uniform flow and stable bed, using a Flow Mate 2000 portable flow meter. The total width of the channel along each transect was measured and the width of the channel was divided into 20 equal units. At the mid-point in each unit the depth and velocity was measured. Discharge was calculated using the Velocity-Area method (Gordon et al., 2004).

Discharge for each unit was calculated using the following formula:

$$D = (d \times l) \times v$$

Where:

D = *discharge (m^3/s)*

d = *depth (m)*

l = *length of unit (m)*

v = *flow velocity (m/s)*

The total discharge (m^3/s) for the site was measured by calculating the sum of all the unit discharges along the transect.

During high discharges, when flow was too high to safely access the river, an adaption of the Velocity-Area Method (Gordon et al., 2004) was used to calculate discharge. This was done across a known cross-sectional transect with the most uniform flow and stable bed. By using the known area of the river cross-section and the average surface velocity, measured by observing the rate of travel of a float across a known distance, discharge was calculated using the following formula:

$$Q = VA$$

Where:

Q = *discharge (m^3/s)*

V = average velocity (m/s)

A = cross-sectional area of the water (m^2)

Level loggers were used to collect continuous flow data, including floods and baseflows, to calculate hydrodynamic properties of the river channel. Level loggers were installed at each site to collect continuous data on variations in depth (water pressure above the logger) and temperature. Readings of discharge versus water level were used to create rating curves. Fluctuations in flow properties for each site were picked up by plotting line graphs of the level logger data over time.

Water slope

Channel long profiles and water slope can be used to work out what processes might come into effect at different water levels. Measurements of the water slope were conducted using a DGPS. Water level readings on the edge of the bank were taken during each transect covering each morphological channel unit (i.e. pool and riffle), starting at the upstream point of each site and ending at the downstream point.

Mannings roughness

From measured water surface slope and discharge readings the roughness (Manning's n) for each site was calculated (Rowntree & Wadeson, 1999; Gordon et al., 2004) using the following formula:

$$Q = \frac{1}{n} A R^{2/3} S^{1/5}$$

Where:

Q = discharge (m^3/s)

n = Manning's roughness coefficient

A = cross-sectional area of the flow (m^2)

R = hydraulic radius (m)

S = slope

Sediment mobility

Sediment entrainment, transport and deposition are a fundamental response of a channel to an altered flow regime. The potential movement of sediment at varying flows was calculated by working out Relative Bed Stability (RBS) and Shear Stress using variables such as water slope, water depth, median particle diameters and velocities (Gordon et al., 2004).

Relative bed stability (RBS) can be calculated using the following formula:

$$RBS = Vc/Vb$$

Where:

Vc = *Critical velocity needed to move a particle (*$Vc = 0.155\sqrt{d}$ *where* d *is the median particle diameter)*

Vb = *Near bed velocity at a given discharge (*$Vb = 0.7V$ *where* V *is the velocity for the cross-section in m/s)*

If values for RBS are greater than 1.0, the value at which particles would be expected to move (Gordon et al., 2004), the bed would be considered stable. If the value is less than 1.0 the bed is considered unstable and movement is possible.

Shear stress (τ) is the stress that water exerts on the bed. Shear stress increases with discharge but is unevenly distributed within a channel. Shear stress can be calculated from the following formula:

$$\tau = pgdS$$

Where:

p = *specific weight of water*

g = *gravitational acceleration (= 9.807 9 m/s*^{2}*)*

d = *water depth*

S = *energy slope*

3.5 Aquatic biodiversity

Aquatic biodiversity was monitored at the same sites as those used for characterisation of stream channel geomorphology.

Materials and methods

<u>Habitat quality</u>

Water quality variables are an important driver of the health of aquatic habitats. Local climate and geology commonly dictate the dissolved solutes that make up a large proportion of the total transported load of a stream. Five variables (Pennack, 1971; Mellado Diaz et al., 2008) were identified for a short term habitat assessment, namely water temperature, pH, electrical conductivity (EC), dissolved oxygen content and dissolved nitrogen and phosphate concentration. In rivers that are well mixed a rapid assessment of the average water quality for a river reach can be measured by tacking a single representative sample (Gordon et al., 2004). Samples were taken in the middle of each site, prior to any other field measurement activities to avoid disturbance or contamination of the sample site. Measurements were taken in the field to avoid contamination of the samples. A rapid assessment of water quality was conducted by looking at the macroinvertebrates present as well as the diversity of habitats conducive to macroinvertebrate health.

Temperature

The thermal characteristics of a river system vary due to natural and anthropogenic hydrological, climatic and structural changes within a river channel and catchment area (Dallas & Day, 2004). In turn this directly affects the life cycle patterns (reproductive periods, rates of development and emergence times) and metabolic processes in aquatic organisms. Water should not be allowed to vary from the background daily average water temperature, considered to be normal for a site, at the specific time of day or season, by >2˚C (DWAF, 1996). An AZ8403 Dissolved Oxygen probe meter was used to measure water temperature (˚C) at each site.

Electrical Conductivity (EC) and pH

Conductivity is the measure of the ability of a sample of water to conduct a current. Reduced growth rates and fecundity in aquatic organisms is commonly linked to small or sudden changes in EC and pH due to increased energy requirements. pH should fall between 6 and 8 to indicate a balanced system. EC and pH were measured using a handheld Hanna Combo pH, EC and TDS meter.

Dissolved Oxygen (DO)

The survival of aquatic organisms critically relies on the maintenance of sufficient dissolved oxygen concentrations (>80%). An AZ8403 Dissolved Oxygen probe meter was used to measure dissolved oxygen. However, for the last monitoring survey, in August 2015 the Dissolved Oxygen probe was malfunctioning and it was decided to not to use the data.

Phosphate Concentrations

High levels of dissolved phosphate concentrations can be toxic to aquatic organisms. Phosphate concentration was measured using a Visicolor ECO colorimetric test kit. Dissolved nitrogen concentration was also measured; however, the available Visocolor alpha colorimetric Nitrate test kit was inadequate to produce accurate results.

Macroinvertebrates

River health, in terms of water quality, can be rapidly assessed by looking at the taxa richness of macroinvertebrate species sensitive to water quality (Dickens & Graham, 2002). A SASS score was calculated for each site by sampling period to look at a rapid assessment of water quality, giving a measure of river health at the site scale.

The ASPT is the total sensitivity score for all the classes/families found, divided by the number of classes/ taxa found. The ASPT for the first two monitoring surveys (July and October 2015) were calculated using Mini SASS methods going down to order level were as the remainder of the monitoring surveys (February, April and August 2016) were done following an adaption of SASS methods going down to family level. Because the SASS method goes down to family level there will be a higher number of taxa found at each site and therefore a higher corresponding SASS score. However, when the SASS score is divided by the number of taxa found, the ASPT varies only slightly from the ASPT calculated using Mini SASS protocol (Figure 3-8). This trend differs from that of the Mini SASS/ SASS score which is not comparable. Therefore, for this study it was seen fit to compare the ASPT derived by Mini SASS methods in the first two monitoring surveys to the ASPT derived by SASS methods in the remaining monitoring surveys. However, this may not be the case for other river systems. SASS and mini-SASS data were interpreted using Table 3-2.

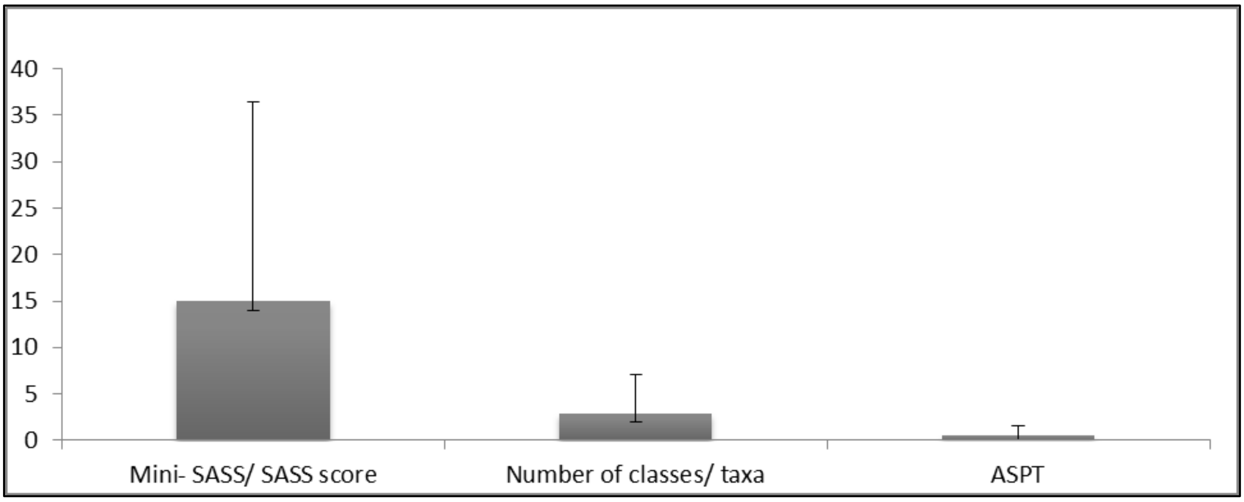

Figure 3-8: Average difference between mini SASS and SASS scores for the Tsitsa River.

Table 3-2: Ecological categories and sensitivity scores used to interpret SASS data for this study. Adapted from Graham et al. (2004) and Dallas (2007).

Ecological Category	Ecological condition	Description	Sensitivity score (ASPT)	
			Sandy Habitat	Rocky Habitat
A	Natural	Unmodified, natural	>6.9	>7.9
B	Good	Largely natural with few modifications	5.8-6.9	6.8-7.9
C	Fair	Moderately modified	4.9-5.8	6.1-6.8
D	Poor	Largely modified	4.3-4.9	5.1-6.1
E	Very Poor	Seriously modified	<4.3	<5.1

Hydro-morphological Index of Diversity (HMID)

Habitat diversity, affecting macroinvertebrate communities, based on different flows and depths was assessed using the Hydro-morphological Index of Diversity (HMID) (Gostner, 2012). The HMID was obtained by calculating the coefficient of variation (CV) of flow velocities and water depth readings for each quadrat (see Biological Variables) by using the following formula:

$$HMID_{quadrat} = \left(1 + \frac{\sigma_v}{\mu_v}\right)^2 \times \left(1 + \frac{\sigma_h}{\mu_h}\right)^2$$

Where:

$HMID_{quadrat}$ = *Hydro-morphological Index of Diversity per quadrat*

σ = *standard deviation*

μ = *mean*

v = *velocity (m.s^{-1})*

h = *depth (m)*

Higher HMID values correspond to higher hydromorphological heterogeneity (Table 3-3).

Table 3-3: Interpretation of HMID values (Adapted from: (Gostner, 2012))

HMID value	Description
<5	Very little variability in hydraulic variables
5 9	Moderate variability in hydraulic variables
>9	High variability in hydraulic variables

Time-based Statistical analyses

A time based analyses of measured variables affecting water quality was conducted to find out which independent variables correlate most (positively or negatively) with the site based water quality ASPT of sensitive macroinvertebrates during each monitoring survey. Independent variables include the HMID, Dissolved Oxygen (%), Temperature (˚C), pH, EC (µs), Clarity (cm), Turbidity (FTU), Suspended Sediment concentration (mg l^{-1}) and Discharge ($m^3.s^{-1}$).

Biological Variables

Biological variables are a benchmark of wildness. Macroinvertebrates provide barometers of river health as they are the first to register ill effects of negative impacts on a river system. Changes in habitat result in changes in types of organisms and give a clear indication of the current condition of a river channel.

The macroinvertebrate community structure was established at a family level using a variation of the Mini SASS technique (Graham et al., 2004) combined with adaptions from the South African Scoring System (SASS) (Dickens & Graham, 2002). The overall relationship between macroinvertebrates and habitat conditions were identified based on a ranking and scoring system by identifying macroinvertebrate families in different habitat types (substrate, flow, depth, embeddedness, etc.). Thirteen key macroinvertebrate orders were identified in the Tsitsa River (Table 3-4)(Graham et al*.,* 2004).

Table 3-4: Macroinvertebrate Orders

Code	Macroinvertebrate Order
1	**Annelidae- *Hirudinea*** (Leeches)
2	**Turbellaria** (Flat worms)
3	**Crustacea** (Crabs or shrimps)
4	**Mollusca** (Snails or Limpets)
5	**Odonata- *Zygoptera*** (Damselflies)
6	**Plecoptera** (Stoneflies)
7	**Trichoptera** (Cased and uncased caddisfly)
8	**Ephemeroptera** (Mayflies excluding *Baetidae*)
9	**Hemiptera or Coleoptera** (Bugs or beetles)
10	**Annelidae- *Oligochaeta*** (Worms)
11	**Odonata- *Anisoptera*** (Dragonflies)
12	**Ephemeroptera- *Baetidae*** (Minnow mayflies)
13	**Diptera** (Flies)

Sample collection was conducted following an adaption of the SASS protocol laid out by Dickens & Graham (2002). Samples were taken across known transects in each site. A specified net with fine mesh, held downstream of the sample point catching macroinvertebrates dislodged from the substrate or marginal vegetation, was used for sample collection. In addition fine sediments were sieved through the net and hand picking and visual observations of substrates and vegetation was conducted in order to record all the habitat niches. Each family of macroinvertebrate found was listed and abundance was noted. The corresponding physical habitat was noted. The number of samples per transect depended on the channel width as well as the number of biotopes present. Across a site samples were taken on all biotopes present in the site including, stones in and out of current, bedrock, marginal vegetation in and out of current, aquatic vegetation and gravel, sand and mud. Sample sites corresponded to the same location as for the quantitative and qualitative substrate measurements. The Average Score per Taxa (ASPT) for water quality and sensitivity to sediment drape was calculated for the macroinvertebrates in each sample location.

A quantitative assessment was conducted by following methods taken from Lambert & Walling (1988) and Duerdoth et al*.* (2015). By taking disturbance samples of fine sediment stored on the stream bed, an assessment of the variation in fine sediment accumulation over time was conducted. A spherical bucket, 31 cm high, with the bottom removed, was placed over the substrate on the channel bed. The diameter of the bucket was 33 cm permitting for a known area of 0.03 m^2 to be sampled for each disturbance. The depth of the water level in the bucket was recorded. The fine bed sediments were disturbed by vigorously stirring the water with a stick, without touching the river bed, for 30-60 seconds or until the bed had been sufficiently disturbed. A water sample was taken. Deposited fine sediment is unlikely to be evenly distributed across a river bed (Duerdoth et al*.*, 2015). Measurements were taken, in different biotopes (flow, depth, substrates), along each known transect in each site, in the middle of a quadrat in which a biological assessment was conducted. In several cases the disturbance technique was limited to fine gravels and sands as the bucket could not be firmly fixed into coarse gravels or cobble beds. However, where the bucket could be firmly fixed, (without flow of water into or out of the bucket) to the substrates, including coarse gravels, cobbles and bedrock, disturbance samples were taken. In the case of bedrock only a surface sample could be taken. Coarse gravels and cobble beds found in fast flowing rapids were not suitable for disturbance samples and are expected to not be conducive to the deposition of fine materials (Tharme & King, 1998). During high flow disturbance samples could only be taken in quadrats where water depth did not exceed the depth of the bucket.

A laboratory analysis of the water samples of surface drape, subsurface fine sediment deposits and suspended sediments collected were conducted after each field visit. The concentration of sediment was measured by using the filtration method from Gordon et al. (2004). In the filtration method a water sample, with a known volume, is filtered and the amount of sediment trapped on the filter is weighed after drying. Sediment concentrations were determined by passing an entire water sample through a vacuum filtration setup. Weighed 90 mm diameter Macherey-Nagel glass fibre filter paper disks, with an average pore size of 0.6 µm were used (Gurnell et al., 1992). The filter paper and sediment were dried in the oven at a temperature of 50˚C for a minimum of 24 hours or until it was dry. The sediment was not dried overnight at 105˚C due to the availability of ovens and this may lead to marginal overestimations in sediment weight (Van der Waal, 2014).

However, this will vary according to sediment type. After drying, the filter paper and extracted sediment were cooled to room temperature and weighed again. The sediment concentration was calculated using the following formula:

$$c_s = \frac{(Mass\ of\ filter + Sediment) - (Mass\ of\ Filter)}{Volume\ of\ water\ sample} \times 10^3$$

Where:

c_s = *Sediment Concentration (mg l-1)*

Mass in grams

Volume (in litres) of water sample (weight of water, calculated by subtracting the empty bottle from the weight of the full water sample bottle, was converted to volume assuming 1 kilogram = 1 litre).

The sediment concentrations were determined by first calculating the volume of water in the bottle (weight of water, calculated by subtracting the empty bottle from the weight of the full water sample bottle, was converted to volume assuming 1 kilogram = 1 litre), the weight of the extracted sediment and then dividing the sediment weight by the volume of water.

The percentage distribution of macroinvertebrate classes and families found in different concentrations of surface drape sediments was calculated. Surface drape conditions were divided into three categories namely; Low (<1 mg l^{-1}), Medium (1-10 mg l^{-1}) and High (>10 mg l^{-1}) and the percentage distribution of macroinvertebrate classes and families were calculated for each according to the number of observations of each macroinvertebrate class and family present.

SASS scores are based on the sensitivity of macroinvertebrates to changes in water quality. Therefore, it was essential to create a score based on the sensitivity/ tolerance of macroinvertebrates to fine sediment accumulation in the Tsitsa River under current conditions. Fine sediment accumulation in terms of sediment drape was seen as representative of current habitat condition. Coarse gravels and cobble beds found in fast flowing rapids are expected to not be conducive to the deposition of fine materials (Tharme & King, 1998), therefore hosting a different range of macroinvertebrate families to areas of lower flow with higher concentrations of sediment drape. A fine sediment habitat score was calculated by ranking the sensitivity of different families of macroinvertebrates by the maximum concentration of suspended sediment and surface drape of fine silt (mg l^{-1}) in which they were observed (n = 540). The macroinvertebrate families were then ranked from most sensitive to least sensitive to surface sediment drape and assigned a sensitivity score (Table 3-5). The higher the sensitivity score the more sensitive the macroinvertebrate family is to surface sediment drape for example, macroinvertebrate families only found in quadrats where the maximum concentration of surface sediment drape falls between 0.1 - 0.2 mg l^{-1} are assigned a score of 13 whereas macroinvertebrate families found in quadrats where the maximum concentration of surface sediment drape falls between 60.1-80.1 mg l^{-1} are assigned a score of 2.

Table 3-5: Sensitivity score of macroinvertebrates to surface sediment drape concentration

Sensitivity Score	Surface Sediment Drape (mg l^{-1})
1	>80.1
2	60.1-80.0
3	40.1-60.0
4	20.1-40.0
5	10.1-20.0
6	8.1-10.0
7	6.1-8.0
8	4.1-6.0
9	2.1-4.0
10	1.1-2.0
11	0.6-1.1
12	0.2-0.6
13	0.1-0.2
14	<0.1

Statistical Analyses

Statistical methods offer a visual interpretation of relationships between drivers of sediment processes and the impact of sediment on habitat (Piégay & Vaudor, 2016).

The Shannon Diversity Index was used to assess the both the heterogeneity of substrate (substrate diversity) and macroinvertebrate types (macroinvertebrate diversity) found in each quadrat. The Shannon Diversity Index is based on the number of types present as well as the proportion of each type present in a specified site (Boyero, 2003). The diversity score (H’) for substrate was calculated using the 9 substrate description categories with the addition of two substrate categories namely, bedrock as the 10th substrate category and vegetation (both aquatic and marginal vegetation) making up the 11th category. The maximum possible score for substrate diversity is 2.4 H'. The diversity score for macroinvertebrates was calculated using 13 macroinvertebrate classes (Table3-6). The proportion of each macroinvertebrate class was estimated by observed abundances in the field. The maximum possible score for macroinvertebrate diversity is 2.6 H'.

The maximum possible score is obtained when each type is equally presented within a quadrat. The following formula is used to calculate the Shannon Diversity Index:

$$H' = \sum -(P_i \ln P_i)$$

Where:

H' = Shannon Diversity Index (Heterogeneity score)

P_i = Proportion of the i^{th} substrate/macroinvertebrate type

Patch Scale Analyses

A patch scale analyses was conducted to tease out relationships between macroinvertebrate taxa and physical habitat conditions. The analysis was divided into three reaches namely; Reach 1 (Site 1 above the proposed dam), Reach 2 (Site 2 and 3 between the dam and the Inxu River confluence) and Reach 3 (Site 4 and 5 below the confluence). A further division to single out habitats was done and separate analyses were conducted for habitats dominated by coarse substrates (rocky), fine substrates (fines) and marginal and aquatic vegetation (vegetation).

Substrate Diversity (H'), Suspended Sediment concentrations (mg l^{-1}) (for marginal vegetation), Surface Sediment drape concentration (mg l-1) mg l^{-1} and Subsurface Sediment concentration (mg l^{-1}) (for other habitats), Depth (m), Flow (m.s^{-1}) and Macroinvertebrate Diversity (H') were correlated to the sediment sensitivity score of macroinvertebrates (Table 3-5) to see which independent variable has the largest effect on macroinvertebrates in different habitats and seasons. Box and whisker plots of the above variables were drawn to show the variability of sampled data, as well as outliers, for each habitat in each reach. Box and whisker plots show the minimum, first quartile, median, third quartile and maximum of the set of data. The larger the distance between the first quartile and the third quartile indicates the variability of the data, with a larger distance being more variable. The maximum and minimum values show possible outliers in the data.

3.6 Vegetative analysis

Research approach

Assessment of plant species diversity

Fieldwork was conducted in March and November 2016 in the study area. Nineteen plots (red squares in Figure 3-9) measuring 5 m X 5 m (Figure 3-10), based on the results of a species-area curve (Mueller-Dombois and Ellenberg, 1974) that was determined prior to the sampling process were used to assess plant species diversity and composition via the Braun-Blanquet survey technique. The exact locality of each plot was recorded using Global Positioning System (GPS). Within each sample plot, the habitat information and species present were recorded. A cover-abundance value was assigned to each species present in a sample plot according to the Braun-Blanquet cover-abundance scale (Mueller-Dombois and Ellenberg, 1974; Werger, 1974; Whittaker, 1978; Van der Maarel, 2005) as presented in Table 3-6. Plant species were identified in the field and the taxon names conform to those of Germishuizen et al. (2006). Unknown plant species were collected, pressed, oven-dried and were identified by Mr Tony Dold, curator of the Schonland Herbarium, Rhodes University, Grahamstown.

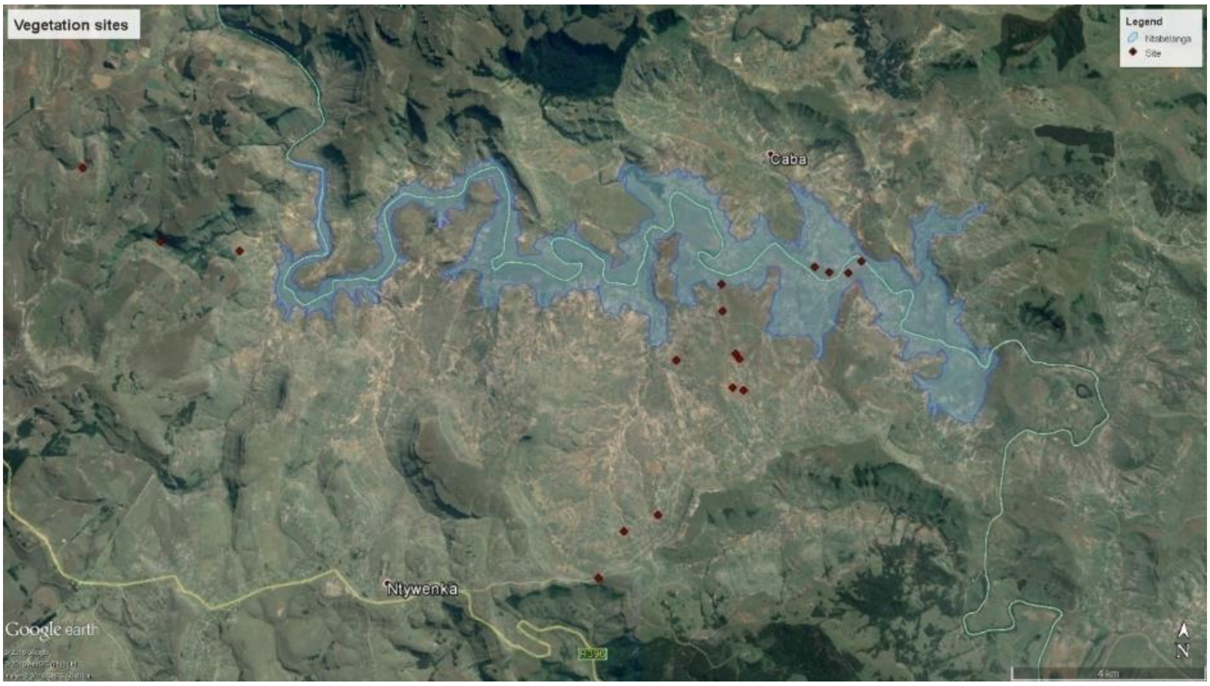

Figure 3-9: Locality map of the study area including sites of vegetation characterization.

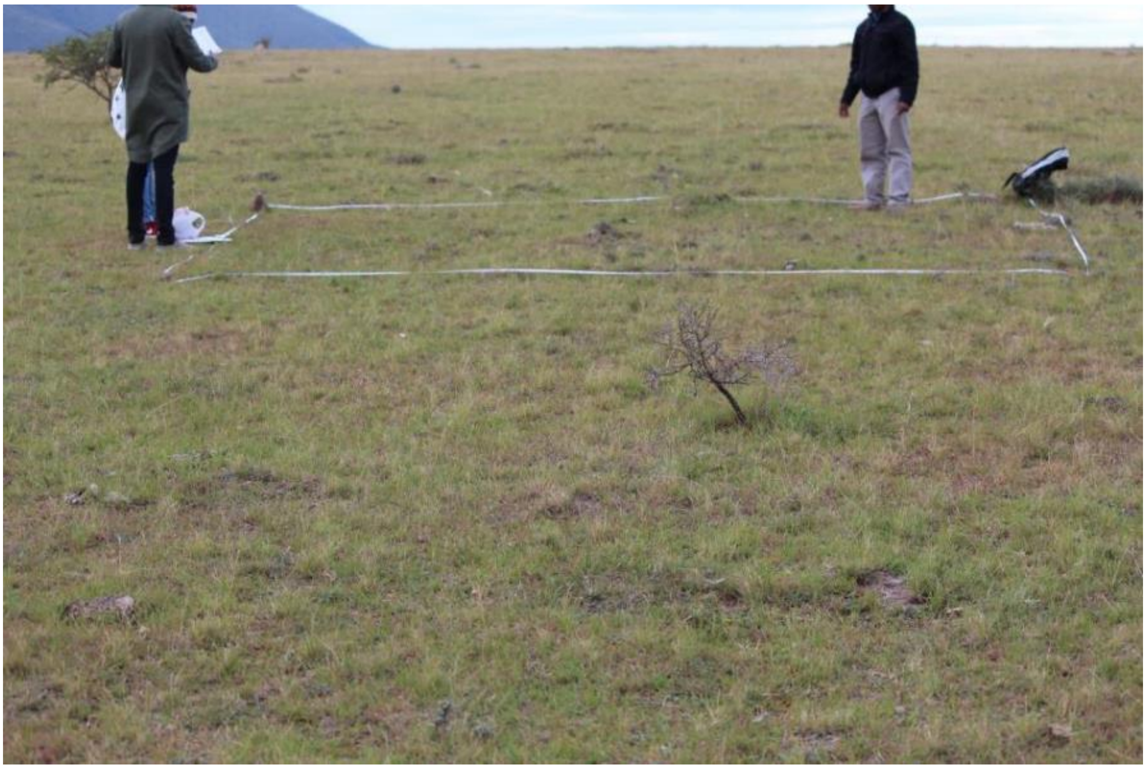

Figure 3-10: Assessing floral diversity and composition in a 5 m X 5 m quadrat (Photo: A. Maroyi).

Table 3-6: Braun-Blanquet cover-abundance codes, values and median values (after Mueller-Dombois and Ellenberg, 1974; Werger, 1974; Whittaker, 1978; Van der Maarel, 2005)

Braun-Blanquet code	Cover (%)	Median cover (%)
R	<5	1
+	<5	2
1	<5	3
2m	<5	4
2a	5-12.5	8
2b	12.5-25	18
3	25-50	38
4	50-75	68
5	75-100	88

The following environmental data were collected: C (%), Ca (cmol kg^{-1}), clay (%), erosion (%), herb height (cm), K (cmol kg^{-1}), litter cover (%), Mg (cmol kg^{-1}), Na (cmol kg^{-1}), NH_4-N (mg L^{-1}), NO_3-N (mg L^{-1}), pH, rock cover (%), sand (%), silt (%), slope (%), total vegetation cover (%) and tree height (cm). These measurements were recorded in every plot. Multivariate data analysis were performed on the vegetation data to explore the floristic variation, to detect and visualise similarities in the plots. The agglomerative method of Hierarchical Cluster Analysis (HCA) in MINITAB was performed to define the group of plots with similar species composition. Canonical Correspondence Analysis (CCA) was performed using Palaeontological Statistics (Hammer et al., 2001), version 3.06. Patterns of plant species composition in relation to the measured environmental factors were analysed using CCA. Detrended Correspondence

Analysis (DCA) was performed on the same data set using Palaeontological Statistics (Hammer et al., 2001). According to Legendre and Legendre (1998), CCA and DCA are direct gradient analysis techniques that relate species composition and abundance to environmental variation enabling the significant relationship between plant species and environmental variables to be determined. Factors hypothesised to influence vegetation composition and abundance in this study were captured in a spreadsheet as environmental variables.

Assessment of useful plant species – Ethnobotanical interviews

Twenty-one randomly selected individuals were interviewed in March and November 2016 for purposes of identifying and assessing plants deemed useful in the study communities. This method is referred to in this report as “ethnobotanical interview”, to distinguish it from the sociological interview method referred to later in this chapter, and in other sections of this report. Table 3-7 summarises the demographic and socio-economic characteristics of the interviewees. More than half (71.4%) of participants were females and 52.4% were above 50 years, while 23.8% were below 40 years of age. More than half of the participants (52.4%) were married, 23.8% were divorced; 19.0% and 14.3% were widowed and single respectively (Table 3-7). More than three quarters of the households (86.2%) comprised between four and nine family members, while the number of children and adults per household ranged between 0 to 13 and 1 to 6 respectively (Table 3-7). Two-thirds of the participants (66.7%) were educated up to primary level, 21.7% were educated up to secondary level and 19.0% had attained tertiary education.

Table 3-7: Demographic and socio-economic characteristics of ethnobotanical interviewees in the Ntabelanga area, n = 21

Socio-economic variable		Number	%
Gender	Female	15	71.4
	Male	6	28.6
Age (years)	<20	1	4.8
	20-29	2	9.5
	30-39	3	14.3
	40-49	4	19.0
	50-59	6	28.6
	60-69	3	14.3
	>70	2	9.5
Marital status	Single	3	14.3
	Married	9	52.4
	Divorced	5	23.8
	Widowed	4	19.0
Household size	1-3	2	9.5
	4-6	9	52.9
	7-9	7	33.3
	>10	3	14.3
Adults in a household			4[a] (1-6)
Children in a household			6[a] (0-13)
Highest level of education	No formal education	6	28.6
	Primary (grade 1-7)	8	38.1
	Secondary (grade 8-12)	4	21.7
	Tertiary	3	19.0
Occupation	Unemployed	13	61.9
	Employed	2	9.5
	Self-employed	3	14.3
	Other	3	14.3
Combined monthly income	Less than R1000 (74.1 US$)	12	57.1
	R1001-2000 (74.1-148.1 US$)	6	28.6
	>R2001 (148.2 US$)	1	4.8
	Not disclosed	2	9.5

[a]Values are medians unless otherwise indicated, figures in brackets are ranges

The majority of the participants (61.9%) were unemployed, correlating with 57.1% surviving on less than R1000.00 (US$74.1) per month (Table 3-7). Interviews with participants revealed different sources of income including the following (in descending order of importance): child support grant from government (33.3%), remittances by family members who live and work elsewhere (28.6%), old age pension grant from government (14.3%), salary and wages (9.5%), retirement pension (4.8%), income from farming and off-farming activities (4.8% each). Demographic and socio-economic characteristics of the people who participated in the current study correlate with findings obtained by Paumgarten et al. (2005) that show that the profile of the rural population in many of the former homeland areas in South Africa are characterised by a poor skills base, low levels of education, low economic activity and a strong reliance on state pensions and migrant remittances.

This ethnobotanical investigation utilised participatory rural appraisal (PRA) methods (Chambers, 1994), emphasising in-depth discussions with participants using open-ended questions in data gathering. Cunningham (2001) argued that structured and semi-structured interviews with local communities enables the researcher to understand much about the local peoples' culture, traditional knowledge and use of plant resources from the surrounding ecosystems. Documenting such contextual details can be essential to understanding and meeting the local community's expectations from an ethnobotanical research and also as part of establishing a broader, contextual framework necessary to understand the complex relationships between people and the plant resources around them. Such research strategies of acquiring and sharing ethnobotanical knowledge is important in understanding the values and uses of wild plant species as well as plant species managed in home gardens.

Structured and semi-structured interviews were carried out in isiXhosa, a language spoken by all participants. In order to ensure that participant's right to voluntarily decide to participate in this research on home gardens, all participants were requested to sign the University of Fort Hare (MAR011) consent form, after the researcher or research assistants had fully explained the nature of research work, acknowledged indigenous prior rights, responsibilities of participants and agreed on active community participation in all stages of the research. The researcher also agreed to a working relationship with the community, including knowledge of and willingness to comply with local governance systems, cultural laws and protocols, social customs and etiquette as stipulated by the International Society of Ethnobiology. The questionnaire was administered to one family member, female or male head of the household or in the absence of both, any member of the family who was above 18 years. During the interviews we documented information on:

1. the names of useful plant species, including species grown and managed in home gardens,
2. uses and preparation of useful plant species,
3. perceptions of households on the importance of plant resources within the Ntabelanga area, and
4. possible positive and negative impacts of the proposed dam on availability and utilisation of useful plant species.

Results obtained through the use of the questionnaires were complemented by personal observation, informal discussions and guided field walks or surveys with the participants.

3.7 Assessment of grazing potential

This study also sought to determine the identity, state and dry matter yield of palatable grass species in the rangelands within the Ntabelanga area. This is important as damming will flood some of the grazing land, leaving residents with a fraction of the current grazing land. Twenty one randomly selected individuals were interviewed in March and November 2016 (Table 3-7). Through PRA exercises (Chambers, 1994) we documented livestock species in the Ntabelanga area, nature and availability of grazing land, existence of management system on communal grazing land and the impacts the planned dam is likely to have on communal grazing areas.

Rangeland condition was estimated based on the dry matter yield and composition of palatable species (Barnes et al., 1984). Palatable grass species were grouped into three palatability classes: highly palatable, moderately palatable and poorly palatable. We used forage production and biomass to estimate the annual output of the palatable grass biomass. This parameter is commonly used to measure the harvest of above ground standing crop. For dry matter determination, grass shoots were harvested to stubble height from 0.5 X 0.5 m quadrats. The harvested materials were dried to a constant weight at 72°C and weighed to determine total dry matter (DM) yield.

3.8 Assessment of soil quality, yields and yield gaps

Soil quality

Soil samples were collected from 16 different sites in the Ntabelanga area, ten of these were located in the Lower Sinxaku villages (Figure 3-11). The soils were sampled from each plot at a depth of 0-30 cm. Samples were then weighed for bulk density determinations. Samples were analysed by Nvirotek Laboratories in Hartbeespoortdam, South Africa. Microbial biomass carbon determination was done by Colorimetric method with Potassium Permangenate. Macro-aggregate stability was determined using the wet sieving method. Soil texture determination was done by. Electrical conductivity (EC) and pH were determined with an electrode on a saturated paste extract. Extraction of cations Na, K, Ca, and Mg and concentrations of N, K, Cu, Fe, Mn, and Zn were done using the Mehlic method. Phosphorous was measured by Bray 2 method.

Soil Management Assessment Framework

Aggregate stability (AGS), pH, electric conductivity (EC), extractable P and K, bulk density (Bd), soil organic carbon (SOC) and microbial biomass carbon (MBC) were used to calculate a soil quality index (SQI) for the selected sites using the SMAF (see more details in section 9). These indicators are sensitive to soil management and they contribute significantly to soil functionality regarding crop productivity. The data will be scored with previously published algorithms (Andrews et al., 2004; Wienhold et al., 2009; Stott et al., 2010) and used to compute the indices in each site.

To score the various indicators, knowledge of the soil taxonomic classification, texture, and general climate is required to select appropriate factors used for the scoring algorithms. The selected organic matter factor class, based on soil classification and used for scoring AGS, MBC and SOC varies with variation in soil type. The climate factor, impacting the scoring for the biological indicators MBC and SOC is also determined by the climate of the area. The soil P, EC, and pH scoring are partially dependent on previous soil management with respect to the crops that were grown. Besides obtaining individual indicator scores, a combined SQI for each area will be calculated by summing the scores, multiplying by 100, and dividing by the number of measurements (7). The overall SQI for each area will be computed by finding the average of the soil samples in each area.

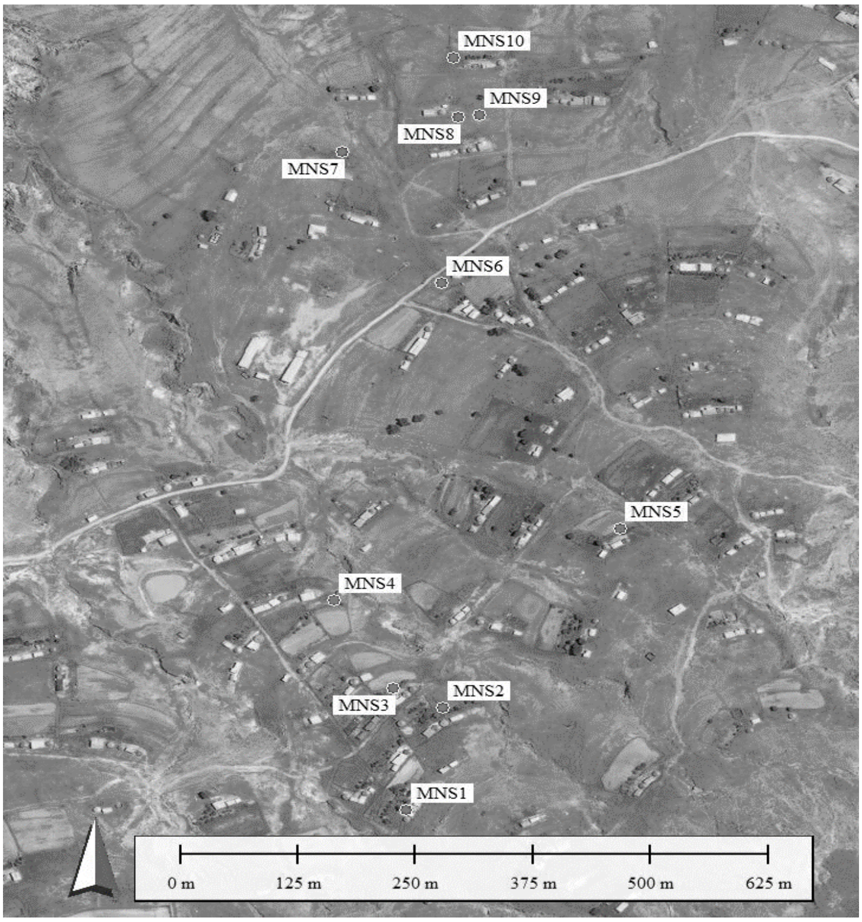

Figure 3-11: Map of the 10 representative gardens at Lower Sinxaku

Yield measurements

There were initially 10 gardens (season of 2014/2015) from which the maize yields were to be directly measured from. For the second maize season in 2015/2016 the yields were measured from only five gardens because some of the gardens were not planted and some farmers had already consumed all the produce. During the third season 2016/2017, maize yields were measured from only four gardens due to the same reasons stated above.

Maize yield measurement procedure

For each of the gardens a planted area was measured, for already harvested fields storage areas were measured too. For cob calibration, a bread crate of with 0.52 m by 0.59 m dimensions was used to mark an area of harvested cobs, then the cobs within that area were all measured for their length and diameter.

In case of unharvested gardens an area of 25 m^2 was measured in the garden and all the cobs within that area were harvested and the same procedure of measuring cob length and diameter was followed. Then 15 cobs were selected randomly (all sizes) to represent the whole field, the cobs were measured for length and diameter, shelled and their weight was also taken. Regression analysis were used to determine the relation between length and diameter and the weight of the seed. Lastly, three cobs were requested from farmers for oven drying to determine the moisture content.

SMAF indicator selection

Aggregate stability (AGS), pH, electric conductivity (EC), extractable P and K, bulk density (Bd), soil organic carbon (SOC) and microbial biomass carbon (MBC) were used to calculate a soil quality index (SQI) for the selected sites using the SMAF. These indicators are sensitive to soil management and they contribute significantly to soil functionality with regard to crop productivity. The data was scored with previously published algorithms (Andrews et al., 2004; Wienhold et al., 2009; Stott et al., 2010) and used to compute the indices for each site. To score the various indicators, knowledge of the soil taxonomic classification, texture, and general climate is required to select appropriate factors used for the scoring algorithms. The selected organic matter factor class, based on soil classification and used for scoring AGS, MBC and SOC varies with variation in soil type. The climate factor, impacting the scoring for the biological indicators MBC and SOC was also determined by the climate of the area. The soil P, EC, and pH scoring are partially dependent on previous soil management with respect to the crops that were grown. Besides obtaining individual indicator scores, a combined SQI for each site was determined and expressed as a percentage. Details on how each SQI was calculated are presented in the results section.

3.9 Carbon stocks and wetland water regimes

Estimation of carbon stocks

Carbon stocks under the Ntabelanga dam footprint were quantified by first creating a soil map following a digital soil mapping approach. A total of 129 observation points, representing the entire attribute space were identified (Figure 3-12), using the conditioned Latin Hypercube Sampling (cLHS). cLHS uses co-variates noted to influence the distribution of the soil (altitude, aspect, profile curvature, planform curvature, topographical wetness index, slope and multi resolution valley bottom floor (MRVBF)) (cLHS; Minasny and McBratney, 2006). The soils at these 129 observation points were classified in accordance with the South African Soil Taxonomy (Soil Classification Working Group, 1991). The identified soil forms were interpreted and divided into soil associations in order to simplify the mapping.

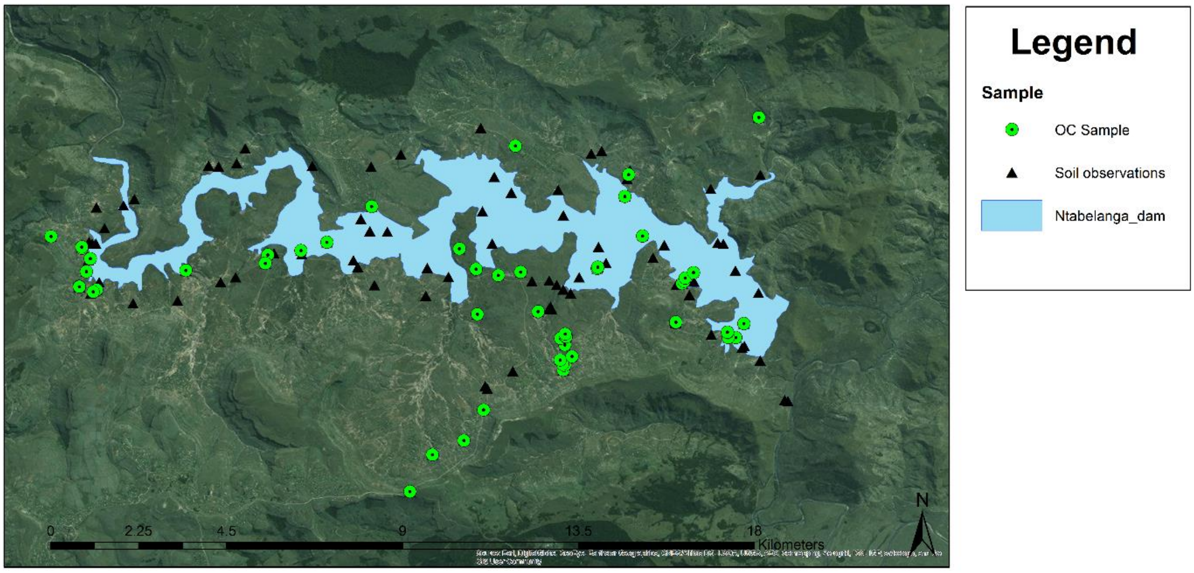

Figure 3-12: Location of soil profile observations and OC carbon samples.

Soil samples were collected using a soil auger and spade from depths of 0-10, 10-20, 20-30 and 60 cm (Figure 3-12). Some of these samples were collected for other projects (Honors and M.Sc. projects) therefore the discrepancy in the location of the *Soil Observations* and *OC Measurements* points in Figure 3-12. The OC samples do however represent the dominant profiles and horizons of the study area and was therefore used to describe the OC content of the soil associations. OC contents from 57 observation points were utilised to quantify carbon stocks.

The soil samples were air-dried and sieved on a 2 mm sieve. The organic carbon content was analysed using the Loss on Ignition (LOI) method. Soil samples were dried in crucibles of known weight in an oven for 24 hours and then weighed. Thereafter the samples were burnt in a muffle furnace for 3-5 hours and weighed. Soil Organic Matter (SOM) was calculated with the following equation:

$$SOM(\%) = \frac{\Delta m}{m} \times 100$$

Where Δm is the loss of mass of the soil after ignition at 550˚C (g) and ms mass of the soil dried at 105˚C (g).

The Bulk Density (ρb) was measured on undisturbed samples using core sampler and calculated using the following equation:

$$pb(g.cm^{-3}) = \frac{m}{V}$$

Where m is the dry mass of the soil (g) and V is volume of the core sample holder (cm^3)

The samples collected are representatives of an area with a specific soils type and the bulk density was used to determine the amount of soil organic carbon of a soil profile. Based on the soil map and carbon contents of map units, the carbon stocks under the inundation footprint was calculated.

Wetland water regimes

Mapping and delineation of wetlands associated with the dam infrastructure (inundation, pipelines and roads) were conducted during the environmental impact assessment. This study will therefore not try to duplicate this. Wetlands below the Ntabelanga dam footprint were identified visually using by Global mapper v16.0 (+OTF). Open Topography Lidar Portal sources were used to differentiate terrain features from the cultivated lands and together SRTM Worldwide Elevation Data (3-arc-second-Resolution) wetlands adjacent to the Tsitsa River were identified.

The original objective was to describe the hydromorphological features of representative wetlands and instrument them with piezometers in order to quantify long term water regimes. A total of 9 piezometers were installed in the first representative wetland. These piezometers are 55 mm in diameter PVC pipes partially slotted at the bottom, following the methodology of Sprecher (2000). The last piezometer (P9), furthest away from the wetland was installed approximately 3 meters from the Tsitsa River and the others at different locations to record any variation in water levels influenced by stream flow changes (Figure 3-13).

Figure 3-13: Location of piezometers and sampling sites of the first instrumented wetland.

Soil samples (22) were taken at 10 cm depth intervals with an Auger and analyzed for organic matter (OM) following the soil organic matter loss on ignition method (Ball, 1964). The organic matter content was used to calculate the soil organic carbon through conversion a factor by the formula: OC$\boldsymbol{\%}$=$\boldsymbol{OM}\%/_{\boldsymbol{1.72}}$. The OC content obtained from each sampling point was determined for the top and sub-soils within the wetland since it's directly influenced with the redox potential conditions existing.

Shortly after installing 9 piezometers in the first wetland (Figure 3-13), the instruments were stolen. Here we reported on the description of the hydromorphology and classification of the soils (Soil Classification Working Group, 1991), but opted for a different (more secure approach), to understand wetland functioning below the proposed Ntabelanga dam.

A wetland with surface water present was identified directly below the dam. Using available Google Earth satellite images, we delineated the area with surface water. Five images from 2002 until 2016 with acceptable quality were available for this particular wetland. We then established relationships between the area with visible surface water, rainfall and streamflow. Current rainfall data was only available for the Mthata rainfall station and this was used as surrogate for the lack of climatic data in the study area. We used five different periods prior to the image data (1 month, 3 months, 6 months, 12 months and 24 months), and compare the cumulative rainfall with the surface water area. It was assumed that there will be very good correlations between cumulative rainfall and streamflow, and cumulative streamflow was therefore not compared to surface water area. The average daily streamflow on the image date as well as the maximum average daily streamflow 1 month, 3 months and 6 months *prior* to the image date was however used to establish relationship between surface water area and streamflow.

3.10 Methods of sociological data collections

A brief sketch of the study communities has already been provided in chapter 2. This section explains the research methods utilised in the collection of sociological data. The methods were: community survey, focus group discussion, in-depth interview and field observation. The sampling procedures utilised are also explained. The section ends with some notes on social research ethics.

Community survey – Instrument and themes

The survey instrument consisted of 78 structured items, subdivided into six (6) sections. It was adapted from a questionnaire developed by the Wilson Akpan and Philani Moyo (see BCCM 2014) and utilised in a survey of Greater Newlands, conducted for the Buffalo City Metropolitan Municipality in the Eastern Cape (BCCM 2014). Below is an outline of the six sections of the survey instrument:

Respondent demographics

Respondent demographics serve two important purposes in this report. Firstly, they are variables against which some of the responses in the main survey are cross-tabulated, thus giving much needed nuance and intuitiveness to specific responses. Secondly, for long-term monitoring of the dam-community-environment nexus, it is important that one is able to gauge impacts with reference to specific demographics, such as gender, age group, educational background. This section of the instrument contains 13 close-ended items.

Livelihoods and socio-economic activities

Large dams are typically portrayed by their developers – in this case, the South African government – as mechanisms for socio-economic renewal. The Ntabelanga dam is described as a multi-purpose dam designed around an ambitious vision: industrial and domestic water supply, ecotourism, electricity generation and irrigation in the area (Molewa, 2013). Its completion, the government believes, will bring a new lease of life not only to the communities selected for this survey but to a much wider expanse of the rural Eastern Cape, especially those in the OR Tambo and Joe Gqabi axis. The research team has previously documented community members' hopes and fears with regard to the proposed dam (Van Tol et al., 2014, Akpan et al., 2015, Akpan et al., 2017). A total of 18 items were included in the survey instrument to generate baseline data on current livelihoods and major socio-economic activities. Several of the instrument questions were sensitive to established parameters for measuring the socio-economic impact of, in particular, projects located in socio-economically marginalised communities. Monitors must, for example, be able to gauge how such projects help to improve incomes, lead to the acquisition of new skills, and curb welfare dependency in the affected communities at the very least (see Gedze, 2012:4).

Social networks and social capital

In order to understand the potential economic dynamism of a community, it is often important to look beyond indicators such as educational attainment, age distribution, employment and entrepreneurial opportunities, and actual economic activities within a given community. A useful way to gauge how socio-economically 'healthy' a community is, or could be, is to understand the informal trust networks by which a community constructs its everyday existence. It is within these networks that everyday problems affecting a community are articulated and tackled, economic challenges are addressed (in sometimes none-economic ways), visions of the future and concerns about the present are shared, and new opportunities for collective well-being arise. Above all:

> An understanding of social capital in a community makes it possible…to gauge the sustainability possibilities of specific development interventions. Usually, development agencies hope that there is a 'high' rather than 'low' social capital in a community. This is often indicative of a healthy 'civil society' at the local level (BCMM 2014:9-10).

The third section of the survey instrument contained eight (8) items whose objective was to provide a baseline of the nature of social networks and extent of social capital currently existing in the study communities.

Formal and informal safety nets

South Africa's extensive formal social welfare system – the biggest in Africa – is well known. In 2015 the number of households on one form of social grant or another in the country stood at 45.5%, while government's total spend on these grants was about R121 billion during the 2014/2015 financial year (StatsSA, 2016). As at February 2017, the South African Social Security Agency (SASSA) paid out over 17 million grants (SASSA, 2017), of which Eastern Cape's share was the second highest (2 753 941), after KwaZulu-Natal (3 889 110).

In the terrain of social and community development, studies have shown that one way of knowing whether a development intervention – specifically, an anti-poverty programme – has made a meaningful impact in certain communities is to gauge the extent to which it has brought about a reduction in the number of able-bodied people who currently depend on social welfare grants (see Gedze, 2012:4). The five survey items devoted to the issue of safety nets focused not only on formal social welfare but also informal. Long-term monitoring of the socio-economic impact of the dam must necessarily take account of not only how existing safety nets contribute to the quality of social existence in the area but also how it has impacted on the nature, operation and coverage of such safety nets.

Social amenities: availability, access and community satisfaction

Because large dams are "pivotal infrastructure" (Van Tol et al., 2014:1), their construction often has huge impacts on the existing canvass of social amenities in a given area. In the case of the Ntabelanga dam, the government has already pronounced on its putative benefits – it will boost eco-tourism, enable the generation of hydroelectric power, improve domestic and industrial water supply and support irrigation for the possible modernisation of local agricultural activities. If the intention is to make the community see the dam in this light and embrace it, then a profile of the infrastructural status quo in the communities becomes imperative. The 14 items in the survey instrument were meant to generate baseline data on these, but also on how community members feel about the state of social amenities they have access to at the moment – amenities such as electricity, water supply, telephony, local transport, etc. The idea is to lay the foundation for understanding whether, as a result of a large dam being constructed in the area, there have been additions to, or improvements (or perhaps even declines) in these amenities over time.

Ecological risk and vulnerability

The final section of the survey instrument, with 22 items, focused on ecological issues, including aspects currently perceived by community members as posing a risk – over which there is a feeling of collective vulnerability. Capturing a baseline of ecological indicators is important because, as previously reported (Akpan et al., 2015:16), the dam itself has been imagined by some focus group participants as a socio-ecologically disruptive project that could lead to people being "killed" or "thrown away", and homes being "torn down".

Besides risk and vulnerability, this section of the instrument also helped to gauge the prevailing sense of what constitutes ecological "assets" in the area – and how this intersects with local notions of livelihood and socio-economic and cultural wholeness. The section thus captures, among other variables, types of livestock kept (including the socio-economic and cultural importance attached to livestock), grazing regimes, types of crop planted, methods of crop production, etc.

Survey sampling procedure

The total sample size for the survey was 300 randomly selected respondents/households. Each of the five communities was allocated 60 questionnaires. The survey was based on a margin of sampling error of $\pm$5.7% (based on an infinite universe) and confidence level of 95%.

Focus group discussion (FGD), in-depth interview and field observation

Both conventional and town-hall focus group methods were utilised in the study, in addition to in-depth interviews and field observation. Conventional FGDs adhered to the small-size model (involving 6-10 participants per focus group), while town-hall FGDs were necessitated by community dynamics – making it imperative to involve a larger number of participants per focus group (in some cases as many as 50 – Akpan et al., 2017). Table 3-8 provides important information about the utilisation of these three qualitative data collection techniques.

Table 3-8: **Qualitative Data Collection Techniques**

Community	Conventional FGD		Town hall FGD		In-depth interview	Field observation
	No.	Group Size	No.	Group Size		
Emqokolweni	-	-	1	55	1	✓
Lower Sinxaku	1	10	1	15	-	✓
Ngqongweni	1	6	-	-	4	✓
Ndzebe	-	-	-	-	8	✓
Ndibaniswení AA	-	-	1	55	1	✓

A note on research ethics

The study adhered to all relevant ethical protocols, among them voluntary participation, informed consent, and respondent anonymity. Although the importance of completing the survey was explained to respondents, they were free to withdraw from it at any stage should they feel it was taking too long or felt any discomfort whatsoever. Several data collectors were hired per community and trained for the survey. There was a fixed remuneration rate per questionnaire and each data collector was assigned a specific number of questionnaires, to be completed within a two-week period. That way, data collectors did not have to attempt to complete too many questionnaires in a single day, thereby subjecting respondents to physical and psychological strain. The data collection was concluded within a fortnight. A field coordinator was appointed in each community to oversee the completion of the questionnaire and also ensure that the task was carried out in the most ethical manner.

4 WATER QUALITY

River basin has been a major source of water supply for many purposes and provides fertile lands, which support the development of highly populated residential areas due to its favorable conditions (Mouri et al., 2011). Human settlements and industries have long been concentrated along rivers, estuaries, and coastal zones owing to the predominance of water-borne trade. A river's water quality is the composite of several interrelated compounds, which are subjected to local and temporal variations and also affected by the volume of water flow (Mandal et al., 2010). Rivers constitute the main inland water body for domestic, industrial, and agricultural activities and often carry large municipal sewage, industrial wastewater discharges, and seasonal runoff from an agricultural field (Singh et al., 2004; Pradhan et al., 2009; Hu et al., 2011). The river waters have been contaminated as a result of the discharges of wastewater containing degradable organics, nutrients, domestic effluent, and agricultural waste (Dimitrovska et al., 2012). River water pollution can be linked to the type of wastewater produced by urban, industrial, and agricultural activities that flows into surface and subsurface waters.

The increase in human population and economic activities has grown in scale; the demands for large-scale suppliers of fresh water from various competing end users have increased tremendously. The decline in the quality and quantity of surface water resources can be attributed to water pollution and the improper management of the resource (Mustapha and Nabegu, 2011). Many regions around the world are simultaneously impacted by urbanization processes and industrial and agricultural activities, and many cities in developing countries have been developed without adequate and proper planning. This has led to indiscriminate actions, including dumping of wastes into the water and washing and bathing in open surface water bodies (Cukrov et al., 2012). The deteriorating water quality affects man, animal, and plant life with far-reaching consequences. From the environmental, economical, and/or social point of view, it is important to identify these sources and their contribution to the total contamination of an area (Tobiszewski et al., 2010).

This section represents assessed water quality at selected monitoring locations in the Tsitsa River and its tributaries and levels of selected boreholes at selected locations. The data set will comprise of 14 parameters of water quality, and Pharmaceutical and personal care levels (PPCPs). The results of this study will help inform ongoing adaptive management efforts aimed at water quality remediation by documenting trends in water quality across various land use zones within the study area before any disturbances to the Tsitsa River due construction and also provide a baseline for future water quality risk assessment.

4.1 Water Quality Guidelines

Water quality guidelines can be used to describe fitness-for-use. The fitness-for-use range can be divided into four categories, ranging from “ideal” to “unacceptable”. These categories are described as:

Ideal : the user of the water is not affected in any way;

Acceptable : slight to moderate problems are encountered;

Tolerable : moderate to severe problems are encountered; and

Unacceptable: the water cannot be used under normal circumstances.

The fitness-for-use range is also colour coded for ease of interpretation of information in Table 4-1

Table 4-1: Colour codes assigned to fitness for use ranges

Fitness for use range	Colour code
Ideal	Blue
Acceptable	Green
Tolerable	Yellow
Unacceptable	Red

Fitness for use category

For each user group a particular set of guidelines for water quality is relevant (developed by DWS). The guidelines provide a description of the effect that changes in water quality will have on the user, and not an interpretation of whether this is acceptable or not. From these guidelines the cut-off values for the different fitness-for-use categories have been set. A breakdown of these values is given in Table 4-1.

Table 4-2: User specific guidelines

Variable	Units	Colour Ranges			
		Blue	Green	Yellow	Red
DOMESTIC					
Total Ammonia	mg l^{-1} N				
EC	µS/cm	<700	700 to 1500	1500 to 3700	>3700
pH	pH units at 25˚C	5.0 to 9.5	4.5 to 5.0 9.5 to 10	4.0 to 4.5 10.0 to 10.5	<4.5 >10.5
Nitrate/Nitrite	mg l^{-1} N	<6.00	6 to 10	10 to 20	>20
Phosphate	mg l^{-1} P	N/A	N/A	N/A	N/A
Sulphate	mg l^{-1} SO_4	0 to 200	200 to 300	300 to 400	>400
Chloride	mg l^{-1} Cl	<100	100 to 200	200 to 600	<600
AGRICULTURE					
Total Ammonia	mg l^{-1} N				
EC	µS/cm	<400	400 to 900	900 to 2700	>2700
pH	pH units at 25˚ C	6.5 to 8.5	<6.5 >8.5		
Nitrate/Nitrite	mg l^{-1} N				
Phosphate	mg l^{-1} P				
Sulphate	mg l^{-1} SO_4	<1000	1000 to 1500	1500 to 2000	>2000
Chloride	mg l^{-1} Cl	<100	100 to 175	175 to 350	>350
AQUATIC ECOLOGY					
Total Ammonia	mg l^{-1} N	<0.140	0.140 to 0.300	0.300 to 2.00	>2.00
EC	µS cm^{-1}				
pH	pH units at 25˚ C	6.5 to 8.5	5.5 to 6.5 8.5 to 9.0	5.0 to 5.5 9.0 to 9.5	<5.00 >9.5
Nitrate/Nitrite	mg l^{-1} N				
Phosphate	mg l^{-1} P	<0.005	0.005 to 0.025	0.025 to 0.250	>0.250
Sulphate	mg l^{-1} SO_4				
Chloride	mg l^{-1} Cl				

Combined fitness for use

In order to determine the fitness for use of the Mzimvubu study area as a whole, the different fitness for use categories for different users affected by the same variable have been reconciled. This was done by selecting the most stringent value for each cut-off value in order to arrive at the management levels. However not all cut off values for the analysed parameters are shown on the summarized table below. A summary of these values are given in Table 4-3.

Table 4-3: Combined fitness for use categories

Variable	Units	Colour Ranges			
		Blue	Green	Yellow	Red
Total Ammonia	mg l^{-1} N	<0.140	0.140 to 0.300	0.300 to 2.00	>2.00
EC	µS cm^{-1}	<400	400 to 900	900 to 2700	>2700
pH	pH units at 25˚C	6.5 to 8.5	5.5 to 6.5 8.5 to 9.0	5.0 to 5.5 9.0 to 9.5	<5.0 >9.5
Nitrate/Nitrite	mg l^{-1} N	<6.00	6.00 to 10	10 to 20	>20
Phosphate	mg l^{-1} P	<0.005	0.005 to 0.025	0.025 to 0.250	>0.250
Sulphate	mg l^{-1} SO_4	0 to 200	200 to 300	300 to 400	>400
Chloride	mg l^{-1} Cl	<100	100 to 200	200 to 600	>600

4.2 Results and discussion

Identification of pharmaceuticals and personal care products (PPCPs)

The screening of PPCPs was achieved using the ABSciex 5600 Triple TOF LCMS with the aid of the PeakView^{Tm} and the MasterView^{Tm} software's. A typical identification experimental flow diagram is as shown in Figure 4.1 showing the identification of paracetamol from one of the sample collected downstream lined pit latrines. Figure 4-2 shows some of the identified PPCPs from various sampling points. Noteworthy are the intensities of the identified PPSPs which increase downstream which depicts the increasing concentration of these PPCPs going downstream. The identification of some of these contaminants in some of the drinking water samples can be as a result of the underground water table being level to the depth of the pit latrines. This is also raise questions as to the quality of the drinking water once the dam wall is closed. The water table is going to be raised affecting the most of the drinking water sources. The identification of the pharmaceuticals and personal care products residues is of major given some of the families depend of the river water for drinking purposes (Figure 3-3). Although these concentrations of these PPCPs are below the recommended limits for household use, the long term accumulative effects is of concern.

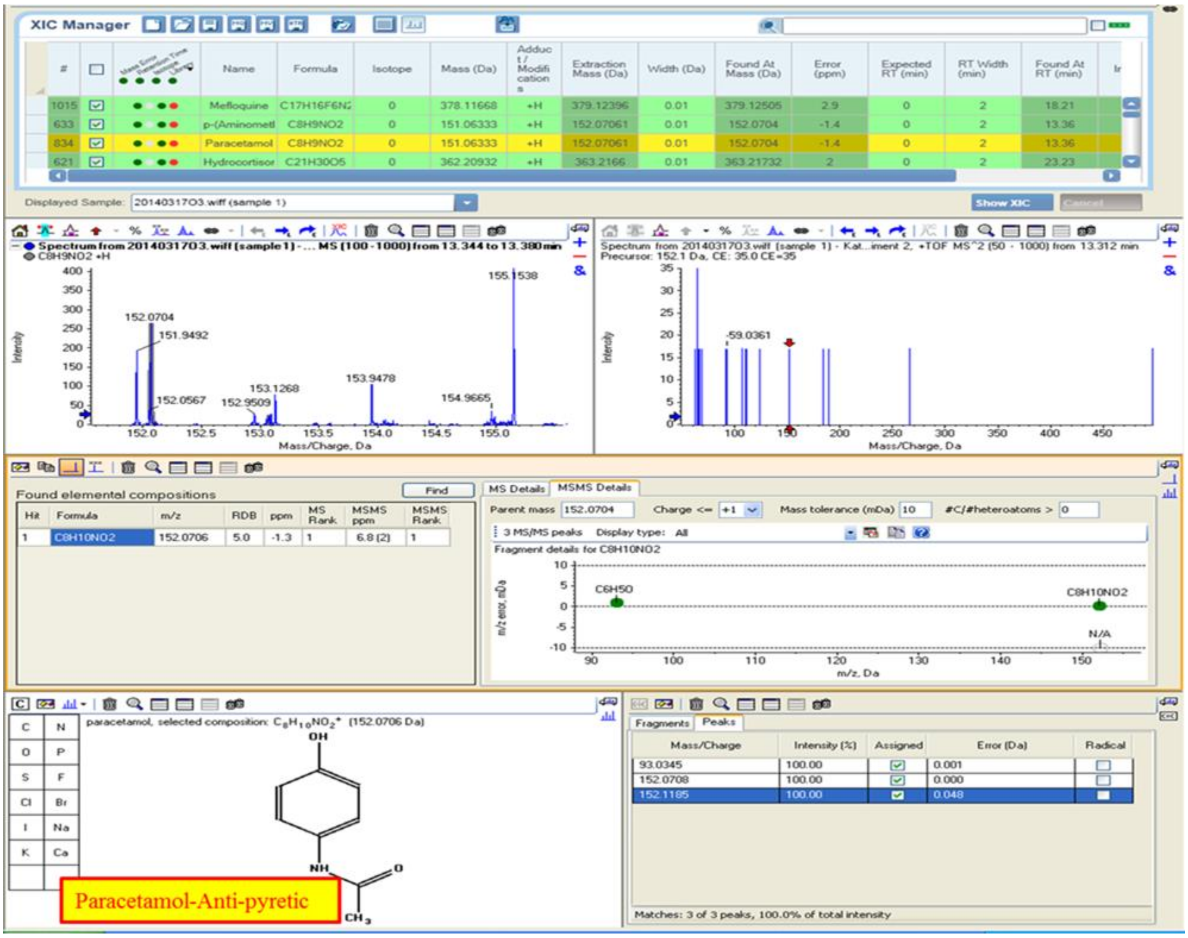

Figure 4-1: Typical example of compressed experimental flow diagram for Paracetamol identified using the non-targeted screen approach.

Index	CompoundName	Formula	BaseMass	MassError	FoundAtRT	concentration	Intensity
SAMPLE A							
	Paracetamol	C8H9NO2	151.0633286	0.0100045	13.9874494	0.8887645	10987.09876
	Irbesartan	C25H28N6O	428.2324598	-0.687919801	16.04240045	0.683854593	2880.307565
	Timolol	C13H24N4O3S	316.1569127	-3.348135085	13.90910948	0.552692832	5625.099091
	Biotin	C10H16N2O3S	244.0881644	245.0998074	17.81575188	0.143228114	52672.89054
	Pindolol	C14H20N2O2	248.1524781	-3.506577709	9.208119368	0.604766698	9086.999102
SAMPLE B							
	NEGATIVE						
SAMPLE C							
	Dihydralazine	C8H10N6	190.0966944	15.17530969	15.09546709	0.130177928	6360.422298
	Paracetamol	C8H9NO2	151.0633286	0.0100045	13.9874494	0.8887645	3934.125474
SAMPLE H							
	Pindolol	C14H20N2O2	248.1524781	-3.506577709	9.208119368	0.604766698	2786.495857
	Carbimazole	C7H10N2O2S	186.0462995	25.43315919	8.032960396	0.170333275	1231.764847
SAMPLE I							
	3,4-Methylenedioxymethamphetamine	C11H15NO2	193.1102789	4.191347237	7.890232458	0.455789071	17785.50013
	Primidone	C12H14N2O2	218.1055279	-9.568949062	8.380806586	0.20956766	6141.887037
	Paracetamol	C8H9NO2	151.0633286	0.0100045	13.9874494	0.8887645	11875.09848
SAMPLE K							
	Pindolol	C14H20N2O2	248.1524781	-3.506577709	9.208119368	0.604766698	8689.340496
SAMPLE L							
	Paracetamol	C8H9NO2	151.0633286	0.0100045	13.9874494	0.8887645	5768.098756
	Biotin	C10H16N2O3S	244.0881644	245.0998074	17.81575188	0.122281143	201765.5605
	Pindolol	C14H20N2O2	248.1524781	-3.506577709	9.208119368	0.604766698	4542.999102
SAMPLE P							
	Pindolol	C14H20N2O2	248.1524781	-3.506577709	9.208119368	0.604766698	2786.495857
	Biotin	C10H16N2O3S	244.0881644	245.0998074	17.815643	0.0876542	67554.74876
SAMPLE Q							
	Paracetamol	C8H9NO2	151.0633286	0.0100045	13.9874494	0.8887645	9758.655434
	Biotin	C10H16N2O3S	244.0881644	245.0998074	17.815643	0.0476542	48976.23454
	Metamfepramone	C11H15NO	177.1153642	3.777819394	8.21249553	0.152304522	8478.806627
	Pindolol	C14H20N2O2	248.1524781	-3.506577709	9.208119368	0.604766698	1034.09857
SAMPLE T							
	Paracetamol	C8H9NO2	151.0633286	0.0100045	13.9874494	0.8887645	2345.098766

Figure 4-2: Typical example of Pharmaceuticals and Personal care Products identified using the non-targeted screen approach.

Water Quality indicators (parameters)

The summary of descriptive statistics of the results of the analysis is presented in Table 4-4, indicating the maximum, minimum, mean values of the parameters and standard error. TS recorded the highest value of 950 mg l^{-1} and 947 mg l^{-1} (Table 4-5 and Table 4-6) for Tsitsa River samples collected upstream and downstream the proposed Ntabelanga dam wall respectively, 957 mg l^{-1} and 879 mg l^{-1} (see Table 4-6 and Table 4-7) for Tsitsa River tributaries samples collected upstream and downstream the proposed Ntabelanga dam wall site respectively and 785 mg l^{-1} and 765 mg l^{-1} (Table 4-8 and Table 4-9) for samples collected from underground drinking water sources upstream and downstream the proposed Ntabelanga dam site respectively. The chloride ion concentration exhibited the least values of 0.5 mg l^{-1} and 0.4 mg l^{-1}; 0.4 mg l^{-1} and 0.35 mg l^{-1} and 0.38 mg l^{-1} and 0.4 mg l^{-1} for the above described samples collections respectively. The standard error around the means is substantially high and random. This could be as result of spatial seasonal changes and also the different anthropogenic activities surrounding the study area.

Table 4-4: Descriptive statistics of selected water quality for Tsitsa River (10 data collections; 3 sampling sites – Upstream of proposed dam wall)

Parameter	Min.	Max.	Mean	Std. Error.
Turbidity (NTU)	3.53	5.80	4.88	0.07
Temperature (˚C)	24.6	32.4	28.2	0.09
Conductivity (µS cm^{-1})	30.4	118	86.9	2.03
pH	6.60	8.97	7.1	0.05
TS (mg l^{-1})	36.0	950	293	13.9
TSS (mg l^{-1})	22.0	875	183	13.9
TDS (mg l^{-1})	24.6	58.2	45.1	1.09
Hardness (mg l^{-1})	5.05	44.8	30.1	1.3
Alkalinity (mg l^{-1})	0.40	3.02	2.33	0.12
Chloride (mg l^{-1})	0.5	1.81	1.02	0.06
Phosphate (mg l^{-1})	1.60	21.0	5.34	0.29
BOD (mg l^{-1})	2.50	18.9	11.2	0.38
COD (mg l^{-1})	90	294	174	3.05
DO (mg l^{-1})	0.77	3.58	1.93	0.09

Table 4-5: Descriptive statistics of selected water quality for Tsitsa River (10 data collections; 2 sampling sites – Downstream of proposed dam wall)

Parameter	Min.	Max.	Mean	Std. Error.
Turbidity (NTU)	3.50	6.00	5.08	0.06
Temperature (˚C)	26.3	30.9	27.2	0.06
Conductivity (µS cm^{-1})	26.4	127	90.6	2.43
pH	6.40	7.79	7.01	0.03
TS (mg l^{-1})	47.0	947	227	14.7
TSS (mg l^{-1})	20.0	892	183	14
TDS (mg l^{-1})	17.1	70.0	45.1	1.13
Hardness (mg l^{-1})	6.00	56.0	26.1	1.1
Alkalinity (mg l^{-1})	0.40	4.00	2.03	0.08
Chloride (mg l^{-1})	0.4	2.41	1.26	0.05
Phosphate (mg l^{-1})	1.20	19.0	5.34	0.32
BOD (mg l^{-1})	1.50	20.0	8.23	0.40
COD (mg l^{-1})	120	286	178	2.85
DO (mg l^{-1})	0.63	3.63	1.80	0.06

Table 4-6: Descriptive statistics of selected water quality for Tsitsa River Tributaries Upstream proposed dam wall (10 data collections; 3 sampling sites data

Parameter	Min.	Max.	Mean	Std. Error.
Turbidity (NTU)	3.50	6.00	4.88	0.06
Temperature (˚C)	26.3	30.9	28.2	0.07
Conductivity (µS cm^{-1})	26.4	127	86.9	2.98
pH	6.40	7.79	7.01	0.11
TS (mg l^{-1})	47.0	957	227	12.2
TSS (mg l^{-1})	20.0	892	183	16
TDS (mg l^{-1})	17.1	70.0	45.1	1.15
Hardness (mg l^{-1})	6.00	56.0	26.1	1.2
Alkalinity (mg l^{-1})	0.40	4.00	2.03	0.08
Chloride (mg l^{-1})	0.4	2.41	1.26	0.07
Phosphate (mg l^{-1})	1.20	19.0	5.34	0.42
BOD (mg l^{-1})	1.50	20.0	8.23	0.40
COD (mg l^{-1})	120	286	178	3.32
DO (mg l^{-1})	0.63	3.63	1.80	0.08

Table 4-7: Descriptive statistics of selected water quality for Tsitsa River Tributaries downstream proposed dam wall (10 data collections; 3 sampling sites data)

Parameter	Min.	Max.	Mean	Std. Error.
Turbidity (NTU)	2.80	5.20	3.21	0.04
Temperature (˚C)	22.4	29.9	26.3	0.35
Conductivity (µS cm^{-1})	23.5	123	78.4	1.78
pH	5.80	7.6	7.01	0.04
TS (mg l^{-1})	42.0	879	238	15.3
TSS (mg l^{-1})	18.0	846	175	16
TDS (mg l^{-1})	16.2	67.2	45.1	1.16
Hardness (mg l^{-1})	5.67	53.0	26.1	1.21
Alkalinity (mg l^{-1})	0.30	5.00	2.70	0.07
Chloride (mg l^{-1})	0.35	2.72	2.1	0.06
Phosphate (mg l^{-1})	1.30	16.0	6.5	0.29
BOD (mg l^{-1})	1.70	16.0	8.23	0.38
COD (mg l^{-1})	112	279	178	2.76
DO (mg l^{-1})	0.56	2,98	1.65	0.07

Table 4-8: Descriptive statistics of selected water quality for Drinking Water sources upstream proposed dam wall (10 data collections; 5 sampling sites)

Parameter	Min.	Max.	Mean	Std. Error.
Turbidity (NTU)	1.50	2.80	1.82	0.04
Temperature (˚C)	22.6	32.3	26.1	0.04
Conductivity (µS cm^{-1})	15.4	139	78.2	2.01
pH	6.10	8.1	6.9	0.03
TS (mg l^{-1})	45.0	785	222	13.4
TSS (mg l^{-1})	15.0	657	171	10
TDS (mg l^{-1})	15.1	49.0	38.1	1.05
Hardness (mg l^{-1})	4.00	48.0	22.1	1.08
Alkalinity (mg l^{-1})	0.20	3.00	1.05	0.06
Chloride (mg l^{-1})	0.38	3.32	1.26	0.03
Phosphate (mg l^{-1})	1.80	16.0	5.10	0.21
BOD (mg l^{-1})	1.60	18.0	7.86	0.35
COD (mg l^{-1})	98	265	166	1.97
DO (mg l^{-1})	0.43	3.62	1.50	0.07

Table 4-9: Descriptive statistics of selected water quality for Drinking Water sources downstream proposed dam wall (10 data collections; 2 sampling sites)

Parameter	Min.	Max.	Mean	Std. Error.
Turbidity (NTU)	1.30	3.00	1.34	0.05
Temperature (˚C)	20.1	30.9	24.4	0.05
Conductivity (µS cm^{-1})	14.4	132	72.5	1.93
pH	5.90	7.9	5.07	0.04
TS (mg l^{-1})	42.0	756	212	13.0
TSS (mg l^{-1})	14.0	645	167	9.0
TDS (mg l^{-1})	13.9	43.0	34.1	1.0
Hardness (mg l^{-1})	3.50	46.0	21.5	1.1
Alkalinity (mg l^{-1})	0.20	2.90	1.03	0.06
Chloride (mg l^{-1})	0.4	2.68	1.2	0.04
Phosphate (mg l^{-1})	1.60	15.0	4.44	0.19
BOD (mg l^{-1})	1.50	17.0	6.93	0.33
COD (mg l^{-1})	90	256	157	1.87
DO (mg l^{-1})	0.41	2.65	1.50	0.07

The Mzimvubu catchment experiences two main seasonal patterns which are the Dry season usually in t period June-November and rainy season in the period December-April. The data obtained were grouped into three seasons as first Dry (S1), dry (S3) and second rainy (S2), rainy (S4) as shown in Table 4.10.

The COD exhibited the highest values across the seasons 160 mg l^{-1}, 178 mg l^{-1}, 181 mg $l^{-1}$and 193 mg l^{-1} for S1, S2, S3 and S4 respectively. Similarly, chloride ion recorded the least values of 1.43 mg l^{-1}, 1.34 mg l^{-1}, 106 mg $l^{-1}$and 1.19 mg $l^{-1}$for S1, S2, S3 and S4, respectively. The high TS value of 493 mg l^{-1} 393 mg l^{-1} for the S2 and S4 could be due to high rainfall in the month of January, February and March.

All variables for which fitness for use criteria were established, indicate ideal concentrations/conditions. Negligible spatial variation in water quality was observed. It is noteworthy that the seasonal BOD levels are quite high, with a minimum of 6.18 mg l^{-1} (S3 in (Table 4-10) and maximum 8.3 mg l^{-1} (S2 in Table 4-10). However, the mean of dissolved oxygen content of the water is relatively less with a minimum of 1.5 mg l^{-1} (Table 4-9 and Table 4-10). Waters are generally low in dissolved oxygen (means, 1.50-1.80 mg l^{-1}), reflecting organic loads, as indicated by BOD and COD levels. The mean values of these parameters appear to be co-related. Elevated nutrient measurements in the surface are limited to inorganic forms of nitrogen. Clearly, there are abundant non-point and point sources of nitrogen (and phosphorus) nutrients in a mixed rural and agricultural environment. The other source for high levels of nutrient sources could be fertilizers and cow dung used for sustenance farming by villagers within the Mzimvubu catchment. Electrical Conductivity (EC) (mS/m) provide an indication of salinization of water resources. Orthophosphate (PO4-P) (mg l^{-1}) levels are an indicator of the nutrient levels in water resources Chloride (Cl) (mg l^{-1}) levels are indicator of agricultural impacts, sewage effluent discharges in this pit latrines, and industrial impacts (upstream). Ammonia (NH3-N) (mg l^{-1}) levels are an indicator of toxicity of the water sources.

Table 4-10: Seasonal variation in water quality parameters of the Tsitsa River, S1-S4

Parameters	Dry Season (S1)	Rainy Season (S2)	Dry Season (S3)	Rainy Season (S4)
Turbidity (NTU)	4.10 ± 0.13	5.80 ± 0.05	4.58 ± 0.12	5.26 ± 0.10
Temperature (˚C)	26.3 ± 0.2	30.7 ± 0.4	28.4 ± 0.2	29.7 ± 0.4
TSS (mg l^{-1})	108 ± 10.0	345 ± 18	98.1 ± 7.5	340 ± 26
TDS (mg l^{-1})	38.0 ± 2.0	65.0 ± 3.0	40.1 ± 1.6	58.5 ± 0.3
TS (mg l^{-1})	145 ± 10	405 ± 10	142 ± 8	393 ± 26
pH	6.01 ± 0.03	7.56 ± 0.03	6.22 ± 0.02	7.13 ± 0.02
Conductivity	58.2 ± 1.3	64.2 ± 1.3	85.3 ± 2.7	117 ± 1
DO (mg l^{-1})	1.80 ± 0.04	1.89 ± 0.10	1.93 ± 0.16	1.55 ± 0.05
BOD (mg l^{-1})	9.4 ± 0.75	8.3 ± 0.83	6.18 ± 0.47	7.28 ± 0.45
COD (mg l^{-1})	160 ± 24	178 ± 25	181 ± 6	193 ± 5
Total Hardness (mg l^{-1})	15.8 ± 1.4	12.8 ± 1.2	36.4 ± 1.4	26.1 ± 0.92
Alkalinity (mg l^{-1})	2.51 ± 0.10	2.60 ± 0.13	1.83 ± 0.17	1.66 ± 0.07
Chloride (mg l^{-1})	1.43 ± 0.20	1.34 ± 0.10	1.06 ± 0.05	1.19 ± 0.04
Phosphate (mg l^{-1})	5.65 ± 0.67	4.15 ± 0.35	3.73 ± 0.25	6.63 ± 0.57

S1 (June 2015-November 2015); S2 (November 2015-April 2016); S3 (June 2016-November 2016); S4 (November 2016-April 2017).

Stream flow vs. Water Quality

Flow is the volume of water passing a particular point in a stream at any given time. Flow rates affect water temperature, dissolved oxygen, turbidity, salinity and the concentrations of pollution level. The best water quality usually occurs under conditions where there is sufficient flow to ensure good oxygenation of the water, to enhance dilution and flushing of pollutants and to limit the build-up of algae.

To address the linkage between stream flow and water quality, daily average measurements of stream flow at a selected weir below the proposed dam wall (DWA weir T3H006 approximately 20 km downstream of the proposed dam wall) were used. The Pearson correlation matrix was used to statistically compare the stream flow of the Tsitsa River Vs. Water quality. The results in Figure 4-3 show a strong uphill relationship between stream flow and Tsitsa River sample points A,G,I,R and T particularly in the months of high rainfall resulting in good oxygenation of the Tsitsa River. There was however a moderate positive relationship between flow rate and temperature (Figure 4-4) and turbidity (Figure 4-5) in the months of low rainfall. However in the months of high rainfall, the Tsitsa River is likely to experience high stream flow rates leading to increased turbidity and with however less temperature variations, placing less stress on aquatic life.

Overall, low flow in the Tsitsa River can lead to low oxygen levels, reduced flushing of pollutants that build up over time, increased salinity and larger temperature variations ,placing stress on aquatic life. High flows in the Tsitsa River can lead to increased sediment load, increased turbidity, and increased salts and nutrients loads (see Annexures for additional information).

Variables	age Stream	hly flow (r	A	G	I	R	T	D	E	F	K	M	O	B	J	L	N
Average S	**1**	0.605	**0.659**	**0.804**	**0.678**	0.593	**0.682**	**0.649**	**0.646**	**0.637**	**0.716**	0.576	0.567	**0.734**	**0.793**	**0.683**	**0.818**
Monthly f	0.605	**1**	**0.829**	**0.798**	**0.745**	0.599	**0.729**	**0.660**	**0.731**	**0.649**	0.416	0.536	0.428	0.625	**0.738**	**0.826**	**0.852**
A	**0.659**	**0.829**	**1**	**0.794**	**0.722**	**0.915**	**0.909**	**0.878**	**0.751**	**0.698**	**0.654**	**0.790**	**0.748**	**0.876**	**0.930**	**0.870**	**0.885**
G	**0.804**	**0.798**	**0.794**	**1**	**0.901**	**0.689**	**0.783**	**0.694**	**0.930**	**0.896**	**0.792**	0.564	0.529	**0.820**	**0.893**	**0.915**	**0.936**
I	**0.678**	**0.745**	**0.722**	**0.901**	**1**	**0.697**	**0.834**	**0.799**	**0.767**	**0.769**	0.613	0.464	0.473	**0.748**	**0.797**	**0.820**	**0.787**
R	0.593	0.599	**0.915**	**0.689**	**0.697**	**1**	**0.943**	**0.927**	0.621	0.617	**0.680**	**0.822**	**0.841**	**0.886**	**0.871**	**0.787**	**0.753**
T	**0.682**	**0.729**	**0.909**	**0.783**	**0.834**	**0.943**	**1**	**0.959**	**0.675**	**0.653**	**0.643**	**0.791**	**0.785**	**0.824**	**0.879**	**0.837**	**0.833**
D	**0.649**	**0.660**	**0.878**	**0.694**	**0.799**	**0.927**	**0.959**	**1**	0.584	0.598	0.593	**0.741**	**0.766**	**0.843**	**0.863**	**0.760**	**0.740**
E	**0.646**	**0.731**	**0.751**	**0.930**	**0.767**	0.621	**0.675**	0.584	**1**	**0.975**	**0.858**	0.615	0.559	**0.790**	**0.870**	**0.938**	**0.915**
F	**0.637**	**0.649**	**0.698**	**0.896**	**0.769**	0.617	**0.653**	0.598	**0.975**	**1**	**0.903**	0.631	0.607	**0.829**	**0.863**	**0.928**	**0.869**
K	**0.716**	0.416	**0.654**	**0.792**	0.613	**0.680**	**0.643**	0.593	**0.858**	**0.903**	**1**	**0.740**	**0.755**	**0.860**	**0.857**	**0.824**	**0.808**
M	0.576	0.536	**0.790**	0.564	0.464	**0.822**	**0.791**	**0.741**	0.615	0.631	**0.740**	**1**	**0.978**	**0.766**	**0.792**	**0.778**	**0.774**
O	0.567	0.428	**0.748**	0.529	0.473	**0.841**	**0.785**	**0.766**	0.559	0.607	**0.755**	**0.978**	**1**	**0.795**	**0.782**	**0.725**	**0.707**
B	**0.734**	0.625	**0.876**	**0.820**	**0.748**	**0.886**	**0.824**	**0.843**	**0.790**	**0.829**	**0.860**	**0.766**	**0.795**	**1**	**0.957**	**0.868**	**0.835**
J	**0.793**	**0.738**	**0.930**	**0.893**	**0.797**	**0.871**	**0.879**	**0.863**	**0.870**	**0.863**	**0.857**	**0.792**	**0.782**	**0.957**	**1**	**0.919**	**0.935**
L	**0.683**	**0.826**	**0.870**	**0.915**	**0.820**	**0.787**	**0.837**	**0.760**	**0.938**	**0.928**	**0.824**	**0.778**	**0.725**	**0.868**	**0.919**	**1**	**0.955**
N	**0.818**	**0.852**	**0.885**	**0.936**	**0.787**	**0.753**	**0.833**	**0.740**	**0.915**	**0.869**	**0.808**	**0.774**	**0.707**	**0.835**	**0.935**	**0.955**	**1**
S	**0.697**	**0.690**	**0.695**	**0.761**	**0.716**	**0.636**	**0.719**	**0.645**	**0.706**	**0.730**	**0.687**	**0.760**	**0.758**	**0.735**	**0.764**	**0.806**	**0.824**

Values in bold are different from 0 with a significance level alpha=0.05

Figure 4-3: The correlation matrix (r values at significance levels = 0.05) of dissolved oxygen at various sampling points vs. monthly stream flow of the Tsitsa River.

Variables	age Stream	hly flow (r	A	G	I	R	T	D	E	F	K	M	O	B	J	L	N	S
Average S	**1**	0.605	-0.324	0.373	0.152	0.073	-0.124	-0.249	**0.728**	**0.676**	0.485	0.087	0.138	**0.806**	0.470	0.341	0.536	0.327
Monthly f	0.605	**1**	0.451	0.474	-0.024	0.117	-0.274	**-0.674**	**0.732**	**0.709**	0.299	0.302	0.169	0.620	0.399	0.200	0.584	0.350
A	-0.324	0.451	**1**	0.205	-0.436	0.063	-0.243	-0.259	-0.010	0.022	0.005	0.275	-0.349	-0.219	-0.177	-0.432	0.186	-0.050
G	0.373	0.474	0.205	**1**	0.275	**0.654**	-0.037	0.127	**0.812**	**0.843**	**0.655**	-0.123	0.169	**0.660**	**0.746**	0.378	**0.929**	**0.687**
I	0.152	-0.024	-0.436	0.275	**1**	**0.744**	-0.037	-0.077	0.361	0.368	-0.230	**-0.665**	0.558	0.555	0.450	**0.860**	0.264	**0.724**
R	0.073	0.117	0.063	**0.654**	**0.744**	**1**	-0.104	0.211	0.454	0.497	0.077	**-0.648**	0.151	0.525	0.415	0.545	0.611	**0.773**
T	-0.124	-0.274	-0.243	-0.037	-0.037	-0.104	**1**	0.346	0.060	0.086	0.466	0.487	0.473	0.061	0.035	0.002	-0.354	-0.477
D	-0.249	**-0.674**	-0.259	0.127	-0.077	0.211	0.346	**1**	-0.256	-0.207	0.317	-0.267	-0.358	-0.249	-0.173	-0.268	0.001	-0.158
E	**0.728**	**0.732**	-0.010	**0.812**	0.361	0.454	0.060	-0.256	**1**	**0.995**	**0.645**	0.072	0.444	**0.924**	**0.785**	0.534	**0.797**	0.613
F	**0.676**	**0.709**	0.022	**0.843**	0.368	0.497	0.086	-0.207	**0.995**	**1**	**0.660**	0.047	0.433	**0.906**	**0.766**	0.517	**0.809**	0.626
K	0.485	0.299	0.005	**0.655**	-0.230	0.077	0.466	0.317	**0.645**	**0.660**	**1**	0.424	0.071	0.492	0.460	-0.070	0.513	0.017
M	0.087	0.302	0.275	-0.123	**-0.665**	**-0.648**	0.487	-0.267	0.072	0.047	0.424	**1**	0.188	-0.068	0.014	-0.330	-0.261	**-0.665**
O	0.138	0.169	-0.349	0.169	0.558	0.151	0.473	-0.358	0.444	0.433	0.071	0.188	**1**	0.488	0.589	**0.775**	-0.010	0.206
B	**0.806**	0.620	-0.219	**0.660**	0.555	0.525	0.061	-0.249	**0.924**	**0.906**	0.492	-0.068	0.488	**1**	**0.717**	**0.684**	**0.678**	0.626
J	0.470	0.399	-0.177	**0.746**	0.450	0.415	0.035	-0.173	**0.785**	**0.766**	0.460	0.014	0.589	**0.717**	**1**	**0.695**	**0.675**	0.610
L	0.341	0.200	-0.432	0.378	**0.860**	0.545	0.002	-0.268	0.534	0.517	-0.070	-0.330	**0.775**	**0.684**	**0.695**	**1**	0.354	**0.663**
N	0.536	0.584	0.186	**0.929**	0.264	0.611	-0.354	0.001	**0.797**	**0.809**	0.513	-0.261	-0.010	**0.678**	**0.675**	0.354	**1**	**0.781**
S	0.327	0.350	-0.050	**0.687**	**0.724**	**0.773**	-0.477	-0.158	0.613	0.626	0.017	**-0.665**	0.206	0.626	0.610	**0.663**	**0.781**	**1**

Values in bold are different from 0 with a significance level alpha=0.05

Figure 4-4: The correlation matrix (r values at significance levels = 0.05) of temperature at various sampling points vs. monthly stream flow of the Tsitsa River.

Variables	age Stream	hly flow (r	A	G	I	R	T	D	E	F	K	M	O	B	J	L	N	S
Average S	**1**	0.605	0.208	0.247	**0.647**	0.265	-0.382	-0.014	-0.167	0.407	-0.189	0.042	0.141	-0.197	-0.424	0.620	-0.054	-0.180
Monthly f	0.605	**1**	0.031	-0.152	0.588	0.315	-0.286	0.193	0.462	0.540	0.186	0.004	0.411	-0.384	-0.261	0.623	0.557	0.151
A	0.208	0.031	**1**	0.376	-0.129	-0.150	0.106	0.102	-0.554	0.251	-0.316	-0.277	0.313	0.460	-0.054	0.120	-0.207	**0.751**
G	0.247	-0.152	0.376	**1**	-0.340	**-0.757**	0.458	-0.566	-0.601	-0.006	-0.150	0.241	0.216	0.468	-0.055	-0.305	-0.104	-0.109
I	**0.647**	0.588	-0.129	-0.340	**1**	**0.724**	**-0.827**	0.415	0.284	0.269	-0.095	-0.243	-0.249	-0.418	-0.463	**0.748**	0.356	-0.210
R	0.265	0.315	-0.150	**-0.757**	**0.724**	**1**	**-0.834**	**0.715**	0.187	0.303	-0.357	-0.483	-0.315	-0.551	-0.266	0.477	-0.046	0.013
T	-0.382	-0.286	0.106	0.458	**-0.827**	**-0.834**	**1**	**-0.777**	-0.037	-0.080	0.438	0.498	0.520	0.519	0.547	-0.354	-0.113	0.041
D	-0.014	0.193	0.102	-0.566	0.415	**0.715**	**-0.777**	**1**	0.006	0.150	-0.488	-0.561	-0.366	-0.319	-0.529	0.062	0.066	0.430
E	-0.167	0.462	-0.554	-0.601	0.284	0.187	-0.037	0.006	**1**	-0.076	**0.780**	0.241	0.109	-0.314	0.150	0.408	**0.696**	-0.111
F	0.407	0.540	0.251	-0.006	0.269	0.303	-0.080	0.150	-0.076	**1**	-0.348	-0.307	0.187	0.110	-0.358	0.346	0.054	0.170
K	-0.189	0.186	-0.316	-0.150	-0.095	-0.357	0.438	-0.488	**0.780**	-0.348	**1**	0.571	0.321	0.062	0.392	0.289	0.512	-0.110
M	0.042	0.004	-0.277	0.241	-0.243	-0.483	0.498	-0.561	0.241	-0.307	0.571	**1**	0.543	0.255	0.198	0.121	0.005	-0.423
O	0.141	0.411	0.313	0.216	-0.249	-0.315	0.520	-0.366	0.109	0.187	0.321	0.543	**1**	0.110	0.443	0.236	0.065	0.247
B	-0.197	-0.384	0.460	0.468	-0.418	-0.551	0.519	-0.319	-0.314	0.110	0.062	0.255	0.110	**1**	-0.147	-0.054	-0.102	0.175
J	-0.424	-0.261	-0.054	-0.055	-0.463	-0.266	0.547	-0.529	0.150	-0.358	0.392	0.198	0.443	-0.147	**1**	-0.162	-0.127	0.009
L	0.620	0.623	0.120	-0.305	**0.748**	0.477	-0.354	0.062	0.408	0.346	0.289	0.121	0.236	-0.054	-0.162	**1**	0.275	-0.025
N	-0.054	0.557	-0.207	-0.104	0.356	-0.046	-0.113	0.066	**0.696**	0.054	0.512	0.005	0.065	-0.102	-0.127	0.275	**1**	0.064
S	-0.180	0.151	**0.751**	-0.109	-0.210	0.013	0.041	0.430	-0.111	0.170	-0.110	-0.423	0.247	0.175	0.009	-0.025	0.064	**1**

Values in bold are different from 0 with a significance level alpha=0.05

Figure 4-5: The correlation matrix (r values at significance levels = 0.05) of turbidity at various sampling points vs. monthly stream flow of the Tsitsa River.

4.3 Conclusion and continuous monitoring actions

The water quality in the Tsitsa system, both with reference to the Tsitsa River, its tributaries and drinking water sources is considered to be good. The majority of water quality parameters and element concentrations comply with guidelines for use categories. In terms of "fitness for use" classification, the selected water quality parameters are classified as "ideal" for use. The results hereby presented in this report are a clear status of the quality of the Tsitsa River and its tributaries before any disturbances to the river. Given the good water quality any disturbances pertaining to the proposed development, especially during the construction phase, are like to negatively affect water quality status. Mitigation measures should thus be implemented to restrict negative impact on the system supplemented with continuous monitoring of the water quality.

5 POTENTIAL POLLUTION FROM DRY-SANITATION SYTEMS

5.1 Introduction

Water is the limiting factor to growth and therefore the cornerstone of prosperity in semi-arid areas. The rapid increase in the world population, the growing sophistication of its needs and activities for the maintenance of present day life style and the process of industrialization have not only resulted in vastly increased pressure and depletion of water resources but also caused generation of enormous quantities of waste (Cole, 2014). According to Ashton et al. (2008), the deterioration of water resources is due to increased pollution caused by anthropogenic activities. DWAF (1998) stated that environmental pollution problems in South Africa started during the first half of the 19th century, with the development of towns and industries and associated accumulation of wastes in urban areas. Thus studies by Soko, (2014) argued that, the socio-economic conditions; environmental awareness; attitude and everything that happens in a catchment area are reflected in the quality of the water that flows through it.

In developing countries, many households use pit latrines because of their low cost and easy availability (Cairncross et al., 2010; Jain, 2011). Pit latrines generally lack a physical barrier, such as concrete, between stored excreta and soil and/or groundwater (Van Ryneveld and Fourie, 1997*).* *Improved* pit latrines are the most basic and inexpensive form of improved sanitation (Graham and Polizzotto, 2013). Examples of improved sanitation systems includes; water-based toilets that flush into sewers, septic systems, or pit latrines; and ventilated improved pit latrines (Albonico et al., 2008; Cairncross et al., 2010). The South African government set a target for delivering basic access to water by 2008 (25 litres per capita per day) and basic on-site dry latrines sanitation throughout the country (DWAF, 1994). South Africa has already halved the basic water backlog by 2005, and there has been a 40 percentage increase in the sanitation services, since 1994 which was well within the time frame of the MDGs (DWAF, 2010). However the targets were not achieved in full, as 8.2 million people lacked the basic services, where 2 million households were without water and 3.9 million households lacked basic sanitation services (DWAF, 2010).

In the context of developing countries, water from protected supplies is frequently derived from ground-water via protected springs, protected dug wells, tube wells, and boreholes (UN, 2008). According to the study by Rosa and Clasen (2010), the use of groundwater, which typically receives no subsequent treatment to improve quality for drinking water supplies, is increasing dramatically. Many people in developing countries rely upon untreated groundwater supplies for their drinking water (ARGOSS, 2001).

Due to the increase uses of both pit latrines and groundwater resources in developing countries, there is concern that pit latrines may cause human and ecological health impacts associated with microbiological and chemical contamination of groundwater (Graham and Polizzotto, 2013). Ground water can become contaminated and there is special concern that the introduction of on-site sanitation systems may in certain circumstances contribute to contamination of drinking water supplies was also raised by ARGOSS, (2001). Hence it is important that the improvement of water and sanitation should be integrated and properly planned. Thus, one of the outcomes of poorly planned water and sanitation systems' may be the contamination of drinking water by faecal matter derived from on-site sanitation (ARGOSS, 2001).

The Mzimvubu River catchment in the Eastern Cape of South Africa is within one of the poorest and least developed regions of the country (DWS, 2014). In the Ntabelanga area 56% of the households still rely on pit-latrines (MDG Capacity Assessment, 2009) and 32.4% use groundwater in particular river sources as well as 4.4% which depend on dam or stagnant sources (Statistics South Africa, 2011). The census data, further categories on sanitation access that; 27.2% have pit latrines with ventilation while 42.4% use pit latrines without ventilation (Statistics South Africa, 2011). The acceleration for development in the catchment has being identified through harnessing the water resources of the Mzimvubu River, with the planned Ntabelanga dam construction proposed (DWS, 2014).

Rosenberg et al. (2000) states however that; the extent of both negative and positive environmental effects from dam construction on a single catchment can be massive. Along with synthetic industrial chemical wastes and global warming, dams produce global effects that may continue well into the future (Rosenberg et al., 1997). Large-scale hydrological alteration leads to a suite of interrelated environmental impacts (Rosenberg et al., 2000).The environmental chain-of-effects is set in motion by impeding natural flows of water and sediments, and by altering natural seasonal patterns of river discharge (Vorosmarty and Sahagian, 2000). During flooding, recharge to ground water is continuous; given sufficient time, the water table may rise to the land surface and completely saturate the shallow aquifer (Winter et al., 1998). Dam reservoirs can cause a permanent rise in the water table that may extend a considerable distance from the reservoir, because the base level of the stream, to which the ground-water gradients had adjusted, is raised to the higher reservoir levels (Wildi, 2010).

Accordingly reviews by Winter et al. (1998) groundwater levels decrease in areas with diverted rivers and increase in the areas close to, and downstream of, reservoirs. The effects of dam reservoirs on the interaction of ground water and surface water are greatest near the reservoir and directly downstream from it (Winter et al., 1998).

In areas where pit latrines must be used the risks of aquifer contamination are high. Furthermore Howard et al. (2003) strongly emphasized that, these high-risk areas will include those areas where the water table is high or where there are very rapid groundwater flow rates.

This study aimed to investigate the potential of stream and groundwater pollution from pit latrines in the proximity to the proposed Ntabelanga dam. More specifically the objectives in this section were:

- To describe the soil morphology and measure physical properties of soils directly below the selected pit latrines,
- To characterise the hillslope hydropedological behaviour downslope of the selected pit latrines and
- To determine the contents of faecal coliforms and *E coli* pollution of soils and water in selected positions downslope the pit latrines.

These objectives will facilitate discussions of the potential of latrines to pollute surface and groundwater aquifers and the results could be used to simulate the fate of organic contaminants in future work.

5.2 Results

Soil morphology

Apedal soils of the Clovelly form are present at the upslope positions of MT1, i.e. MT1-1 and MT1-2, as well as mid- and lower slope positions of MT2, i.e. MT2-2 and MT2-3. These horizons are characterized with weak structures and fast vertical flow rates, presumable recharging groundwater (Table 5-1). Saturation at the soil/bedrock interface is visible at MT1-3 in the Tukulu soil.

High clay contents and strong structure are some of the dominant properties of the Sepane and Katspruit soils observed at MT3. Redox morphology indicate saturation at the soil bedrock interface in the Sepane soil whereas the Katspruit soil is saturated for long periods of time (Table 5-1).

Table 5-1: Soil morphological properties

Sites	Depth (cm)	Colour		Structure		Mottles					DH	Soil forms	Soil groups
		Dry	Wet	Strength	Shape	(%)	Frequency	Size	Colour	Root channels		(SAST)	(WRB)
MT1-1	0-30	10YR5/3	10YR4/6	weak	single grained	/	none	/	/	/	*[1]*ot*		
	30-60	10YR5/6	7.5YR5/6	weak	apedal	/	none	/	/	/	*[2]*ye*		
	60-90	10YR7/6	7.5YR4/6	weak	crumb	/	none	/	/	/	*[3]*un*		
	90-120	10YR4/2	10YR 4/2	Medium	crumb	/	none	/	/	/	*[4]*un*	Clovelly	Alisols
MT1-2	0-30	10YR5/6	10YR 4/4	Medium	angular blocky	/	none	/	/	/	*ot*		
	30-60	10YR4/4	10YR 3/4	weak	apedal	/	none	/	/	/	*ye*		
	60-90	10YR5/6	10YR 4/4	weak	blocky	/	none	/	/	/	*un*		
	90-120	10YR4/6	10YR 5/3	Medium	blocky	/	none	/	/	/	*un*	Clovelly	Alisols
MT1-3	0-30	10YR4/3	10YR 3/2	Medium	SANBL	/	none	/	/	/	*ot*		
	30-60	10YR6/3	10YR 3/3	Medium	angular blocky	5	few	small	yellow , black	/	*[2]*ne*		
	60-90	10YR6/4	10YR 4/2	Medium	crumb	10	Many	Medium	grey	bleached	*[3]*uw*		Stagno-
	90-110	10YR8/2	7.5YR4/6	strong	crumb	10	Many	Medium	grey, yellow	bleached	*[4]*uw*	Tukulu	sols
MT2-1	0-15	10YR5/4	10YR4/3	Medium	single grained	/	none	/	/	/	*ot*		
	15+	10YR5/3	10YR4/2	/	/	/	none	/	/	/	*[2]*lc*	Glenrosa	Leptosols
MT2-2	0-30	10YR4/6	10YR3/4	weak	apedal	/	none	/	/	/	*ot*		
	30-50	10YR5/6	7.5YR4/4	weak	apedal	/	none	/	/	/	*ye*	Clovelly	Alisols
MT2-3	0-30	10YR4/4	10YR 3/3	weak	granular	/	none	/	/	/	*ot*		
	30-60	10YR5/6	10YR 4/6	Medium	blocky	/	none	/	/	/	*ye*		
	60-90	10YR4/6	10YR 4/4	weak	blocky	/	none	/	/	/	*un*		
	90-110	10YR5/6	10YR 3/2	weak	crumb	/	none	/	/	/	*un*	Clovelly	Alisols
MT3-1	0-17	10YR5/3	10YR3/2	weak	SANBL	/	none	/	/	/	*Ot*		
	17-60	10YR3/3	10YR2/2	strong	SANBL	/	none	/	/	/	*[2]*vp*		
	60-79	7.5YR3/2	7.5YR3/1	strong	SANBL	2	few	small	brown grey	bleached	*uw*	Sepane	Planosols
MT3-2	0-19	10YR5/3	10YR3/2	Medium	granular	/	none	/	/	/	*[1]*ot*		
	19-61	10YR4/2	10YR3/2	strong	SANBL	/	none	/	/	/	*[2]*vp*		
	61-70	10YR4/3	10YR 3/3	strong	SANBL	3	Few	small	brown grey	/	*uw*	Sepane	Planosols
MT3-3	0-20	10YR4/3	10YR 3/4	strong	crumb	/	none	/	/	/	*ot*		
	20-80	10YR5/6	10YR 4/2	strong	crumb	7	Many	Medium	grey	bleached	*[2]*gh*		
	80+	10YR6/1	7.5YR4/1	Medium	crumb	10	Many	Large	grey, yellow	/	*un*	Katspruit	Gleysols
MT4-1	0-20	10YR5/3	7.5YR3/2	Medium	granular	/	none	/	/	/	*ot*		
	20-60	10YR5/4	7.5YR3/2	weak	SANBL	5	Many	Medium	yellow red	Rusty	*ne*		
	60-85	10YR5/3	10YR5/4	Medium	crumb	12	Many	Medium	grey, yellow	bleached	*uw*	Tukulu	Stagnosol

MT4-2	0-30	10YR5/4	7.5YR3/3	Medium	granular	/	none	/		/	*ot*		
	30-60	10YR5/4	7.5YR3/2	weak	SANBL	5	Many	Medium	yellow, red	Rusty	*ne*		
	60-85	10YR5/3	10YR5/4	Medium	crumb	15	Many	Medium	grey, yellow	bleached	*uw*	Tukulu	Stagnosol
MT4-3	0-30	10YR4/3	10YR3/3	Medium	SANBL	3	few	small	red, grey	/	*ot*		
	30-60	10YR4/4	10YR3/4	Medium	SANBL	5	Many	Medium	orange, brown	bleached	*[2]ne		
	60+	10YR4/4	10YR3/4	/	/	/	/	/	/	/	*uw	Tukulu	Stagnosol

**[1]ot – Orthic A horizon; *[2]ye – Yellow-brown apedal B horizon; *[2]ne – Neocutanic B horizon; *[2]lc – Lithocutanic B horizon; *[2]vp – Pedocutanic B horizon; *[2]gh – G-horizon; *[3/4]un – unspecified; *[3]uw – Unspecified material with signs of wetness;*

MT4 is dominated by Tukulu soils, which have a moderate structure and indications of saturation at the soil bedrock interface. In the valley bottom (MT4-3), Swartland soils are prominent.

Soil physical properties

The physical properties of the soils at selected locations below the pit latrine study sites are presented in Table 5-2. In general the soils of MT1 and MT2 are relatively sandy with slightly higher hydraulic conductivities compared to MT3 and MT4.

Table 5-2: Selected soil physical properties of the different sites

			Particle size distribution (%)				
Sites	**Depth (cm)**	**Horizon**	**Clay**	**Silt**	**Sand**	**Bulk density ($g.cm^{-3}$)**	**Ks ($mm.h^{-1}$)**
MT1-1	0-30	*ot*	13.3	7.9	78.2	1.47	23.1
	30-60	*ye*	18.1	7.8	73.9	1.65	17.7
	60-90	*un*	23.1	19.2	57.3	1.55	4.5
	90-120	*un*	23.1	19.2	57.3	1.55	4.5
MT1-2	0-30	*ot*	7.9	16.2	75.0	1.40	25.5
	30-60	*ye*	18.1	7.8	73.9	1.65	17.7
	60-90	*un*	23.1	19.2	57.3	1.55	4.5
	90-120	*un*	23.1	19.2	57.3	1.55	4.5
MT1-3	0-30	*ot*	16.9	20.7	63.0	1.44	12.8
	30-60	*ne*	23.4	19.5	56.6	1.53	1.2
	60-90	*uw*	22.9	19.0	58.0	1.58	3.04
	90-110	*uw*	23.1	19.2	57.3	1.58	3.04
MT2-1	0-15	*ot*	13.4	8.8	77.2	1.57	24.77
	15+	*li*	13.9	7.6	79.0	1.55	25.5
MT2-2	0-30	*ot*	13.3	8.2	78.0	1.53	28.8
	30-50	*ye*	13.8	8.4	77.1	1.54	29.33
MT2-3	0-30	*ot*	13.1	7.6	78.8	1.55	13.28
	30-60	*yb*	13.8	8.4	77.1	1.54	22.1
	60-90	*un*	12.0	8.3	79.3	1.59	2.01
	90-110	*un*	12.0	8.3	79.3	1.59	2.01
MT3-1	0-17	*ot*	23.3	14.6	62.4	1.57	14.29
	17-60	*vp*	23.3	17.8	58.8	1.54	1.8
	60-79	*uw*	22.5	18.5	59.0	1.45	5.3
MT3-2	0-19	*ot*	23.3	14.6	62.4	1.57	11.73
	19-61	*vp*	23.3	17.8	58.8	1.54	1.8
	61-70	*uw*	22.5	18.5	59.0	1.45	5.3
MT3-3	0-20	*ot*	23.3	14.6	62.4	1.57	16.29
	20-80	*gh*	28.6	14.3	56.0	1.45	5.4
	80+	*un*	22.5	18.5	59.0	1.45	5.4
MT4-1	0-30	*ot*	21.3	18.5	59.7	1.37	44.2
	30-60	*ne*	17.9	20.6	61.5	1.58	10.48
	60-90	*uw*	21.3	6.8	71.2	1.58	7.46
	90-110	*uw*	21.3	6.8	71.2	1.58	7.46
MT4-2	0-30	*ot*	21.3	18.5	59.7	1.37	16.4
	30-60	*ne*	17.9	20.6	61.5	1.58	10.48
	60-85	*uw*	21.3	6.8	71.2	1.58	7.46
MT4-3	0-30	*ot*	21.3	18.5	59.7	1.37	16.4
	30-60	*ne*	26.8	3.2	69.2	1.58	1.8

Hydropedological behaviour

<u>Study site MT1</u>

A Clovelly soil form can hydropedologically be referred to as a recharge soil. Mostly these soils enhance the recharge of the groundwater, including lower positions through fractured bedrocks. The soil form is characterized with a weak to medium apedal structure with brown to yellow soil colours morphologically. These soils are considered freely drained profiles; this is supported by bright yellow-brown colours. Vertical flow of water is dominant in these profiles. Figure 5-1 presents the typical flow through this slope; the thickness of the arrow indicates the flow rates, whereas thicker arrows presents faster flowrates than thinner arrows.

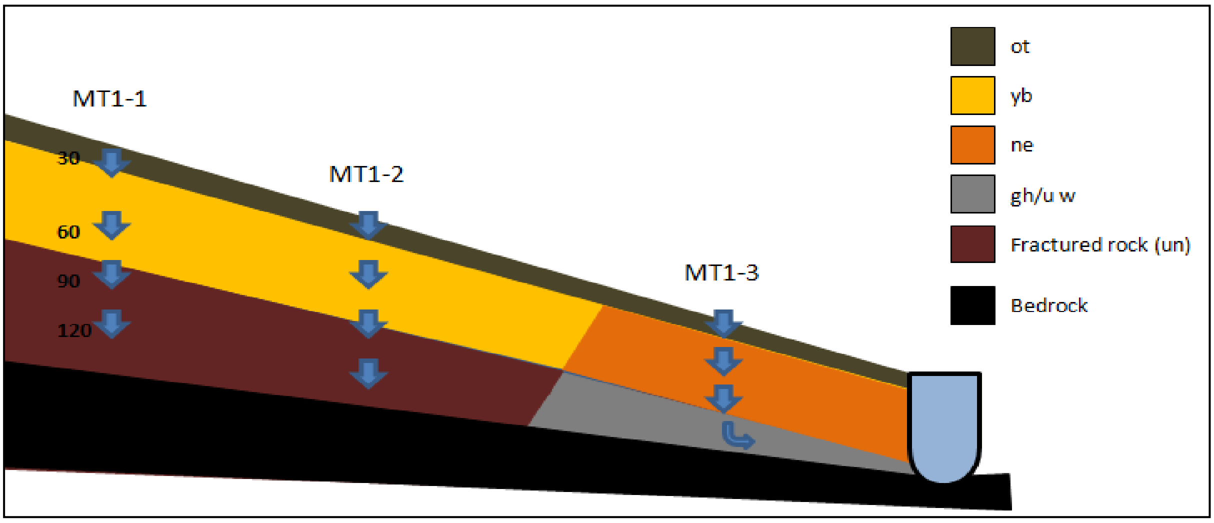

Figure 5-1: Hydropedological conceptual model for MT1.

On sample point MT1-3 with a Tukulu soil form, evidently indicates the presence of an impermeable bedrock underneath the fractured rock. The soil form shows restricted drainage at the soil-rock interface, this soil is called a deep interflow soil. A neocutanic B horizon can have reduced water flow transmission, despite of such soil properties; vertical flow of water was dominant. The stronger and crumb structures observed, when saturated for long periods can immensely retarded water conduction through the soils. These fairly young soils, sometimes can be formed through deposition of finer materials from the upper hillslope positions. When the upper parts textural classes are finer clay particles, the ability for water moment can be minimal despite of increments in the retention capacity. Evidence of saturation was observed on the underline horizon on MT1-3 as shown above in Figure 5-1. But the occurrence of mottles was also observed in the soil matrix of the Neocutanic horizon, as the frequency and sizes were increasing into the underline horizon. Yellow and grey mottles apart from the bleaching which was observed indicated periods of reduction due to periodical or longer periods of water saturation. This can occur due to the fluctuation of the water table.

Since the upper profiles were more freely drained, lateral flow usually teamed interflow could also have contributed, to the saturation conditions observed below in the event that beneath the fracture rock, the profile had slowly permeable bedrock. Besides recharging the groundwater aquifer this can also be a potential source for water in the lower terrain parts soil horizons.

<u>Study site MT2</u>

The upper parts of MT2 is dominated by fairly shallow soils near the pit latrine with an increase in soil depth towards the lowest point near the stream. A Glenrosa soil form was observed at MT2-1, similar to a Leptosols (WRB, 2014). The shallow soils in MT2-1, was underline with fragmented partially weathered rock emerging into permeable fractured bedrocks. This sample point had a limited profile development. The course lithocutanic horizon indicated the prevalence of rock disintegration activities over a considerable period of time. This diagnostic horizon has a higher potential for vertical flow of water through the soil. A fractured substratum existing in line with the course or fragmented rock facilitate easy water movement through the available grabs. As MT2-2 and MT2-3, were classified as a Clovelly soil form (Acrisols-WRB group), characterized with apedal soil layers which are freely drained soils without hydromorphic properties occurring. Mostly with weak medium to moderate structures. Figure 5-2 below shows the main direction of flow through the soil profiles on the hillslope which also indicates the positions of these well drained apedal horizons.

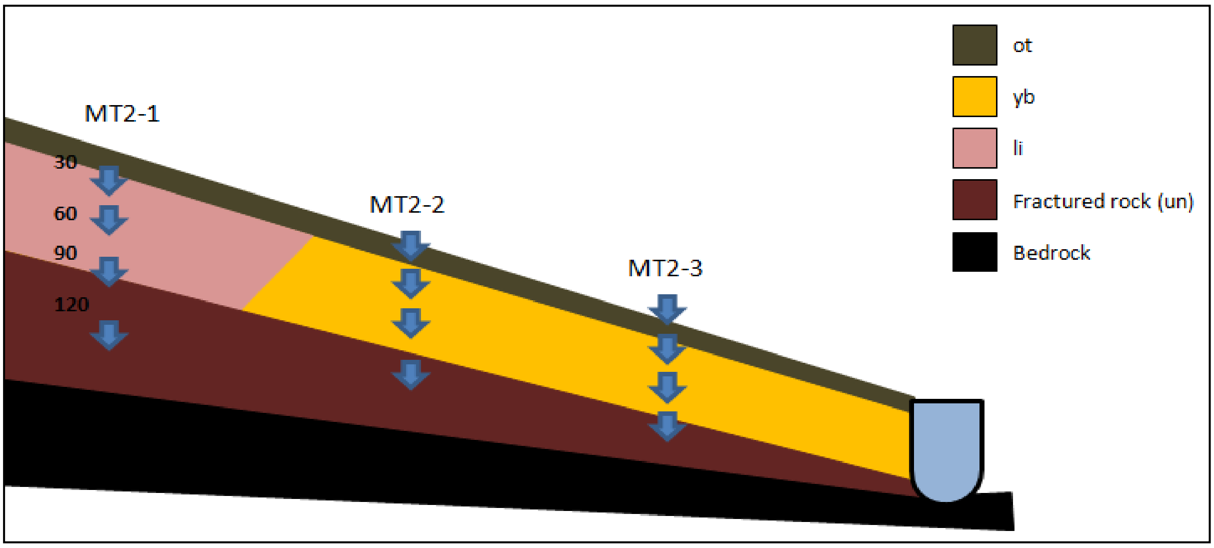

Figure 5-2: Hydropedological conceptual model of MT2.

Hydrological movement of infiltrating and percolating water through the profiles was more vertical flow recharging the groundwater as seen in Figure 5-2 above. Transmission through lateral flow is limited in this site, as throughout the profiles signs of saturation were minimal despite of the shallow soil depths perceived.

Study site MT3

MT3-1 to MT3-2 was classified under a Sepane soil form (Gleyic Luvisols-WRB group). This soil form is characterized with strong sub-angular blocky to angular blocky structures. The diagnostic horizons have limited water movement caused by the strongly developed structures. These profiles tend to have higher clay contents in the subsoil B horizon than the overlying A horizon due to clay migrations. The clay eluviation is the main factor to the limited permeability of these profiles. Generally vertical flow of water is minimal promoting more interflow towards the lower parts of the profile. Despite of this well acknowledged emphasis MT3-1 to MT3-2 was predominated more with vertical flow through the profile. Below Figure 5-3 gives a clear representation of the main flow paths which are dominant within the identified soil profiles.

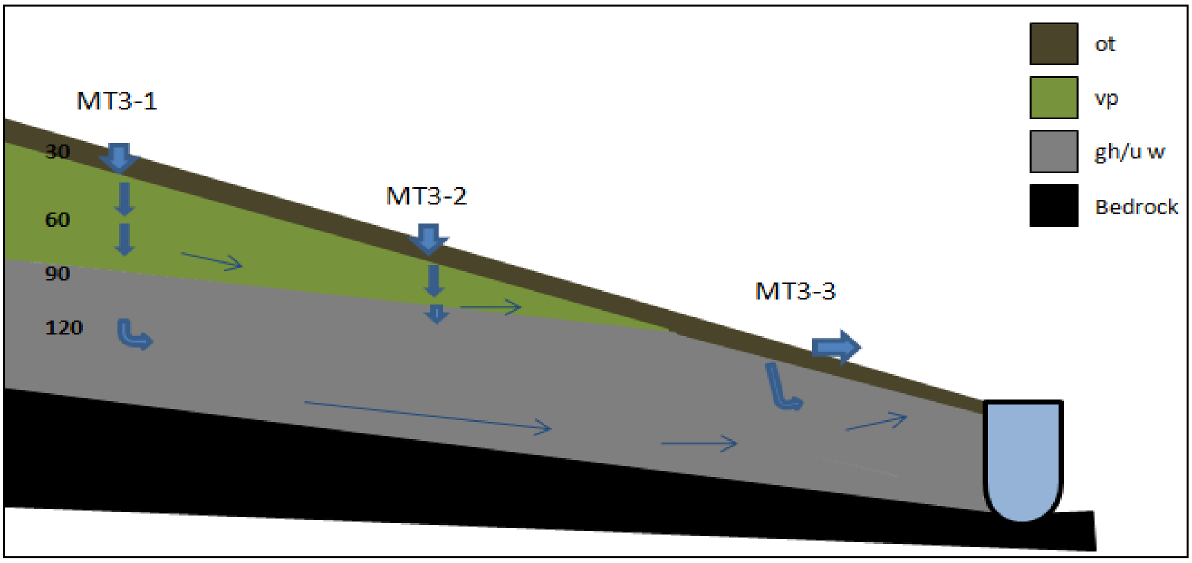

Figure 5-3: Site 3-Hydropedological conceptual model based on soil morphology.

These observations showed that the available bedrock was impermeable, thus slow water flow percolations which subjected the B horizon to longer periods of saturation. Interflow towards the lower parts of the section become dominant, resulting in the saturated diagnostic (gh) horizon obtained in site MT3-3 with a Katspruit soil form (Gleysols-WRB groups) shown above in Figure 5-3. Such horizons are referred to as responsive soils. The soils are saturated throughout the year or periodically. Many, medium mottles can be observed dominated with grey and yellow colours. These profiles are also bleached in the soil matrix. The hydromorphic properties indicated oxidation and reduction (redox) processes due to stagnation of water in the soil. Lateral flow of water was more predominate in the soil profile. This can be observed mostly as return flow on the soil surface which ends up as runoff into streams illustrated above in Figure 5-3 with thicker arrows at the surface, as the soils are saturated mostly throughout a longer period of time.

Study site 4

Tukulu soil forms was observed from MT4-1 to MT4-3. This is typically relatively young developed profiles. The colours ranged between brown to dark yellowish brown for the profiles. The soils had a weakly to moderately developed sub-angular blocky and crumb structures in the A and B1 horizons. These properties reflect relatively high hydrological conductivity. Water movement through the A and B1 horizon is predominantly vertical. Figure 5-4 below also indicating the direction of flow through the soil profile.

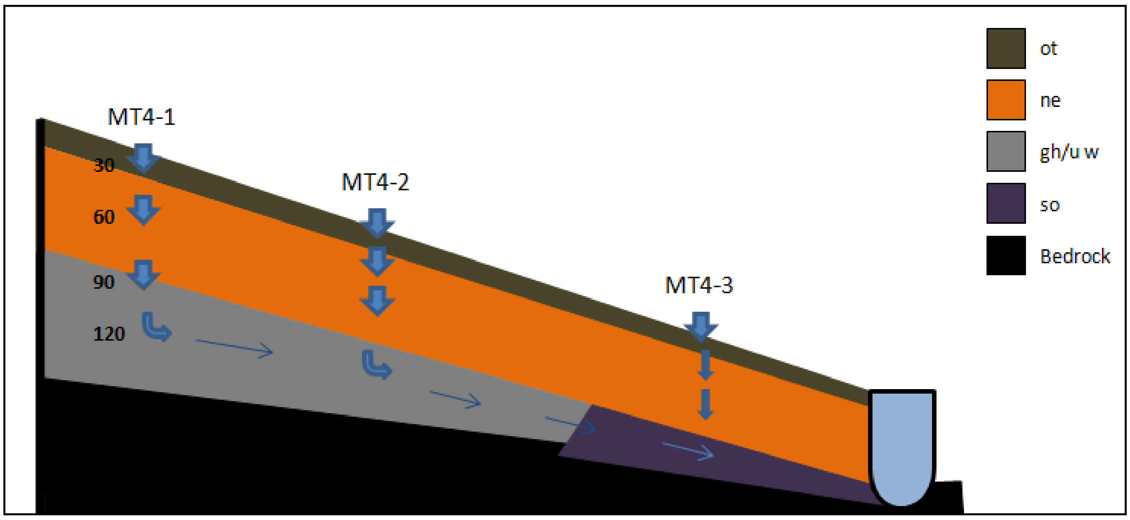

Figure 5-4: Hydropedological conceptual model of MT4.

This B2 horizon (unspecified material with signs of wetness) was dominated by medium; red, yellow and grey mottles. The percentages recorded were more than 10% which can also be categorized under a soft plinthic. The soils were also bleached which shows evidence of material movement within the profile and the root channels were rusty because of redox processes occurring. Usually the channels provide an aeration route which oxidizes the reduced soils hence changing the ferric state (Fe^{2+}) back to the reddish ferrous state (Fe^{3+}). The saturated horizon indicated the availability of a restrictive impermeable bedrock below the fractured bedrock with a low infiltration rates.

Microbial biomass

This section presents the recorded microbial pollutants (CFU g/soil). The levels and concentration of Total coliforms, faecal coliforms and *Escherichia* coli (*E.*coli) biomass is affected by a variety of factors. Chemical compositions of a soil such as the p H and the total organic carbon are among the factors that influence the measured quantities available. The type of soil available as well as the various depths to the bedrock, including the fluctuating water table can promote and enhance the potential for pollution to groundwater resources. The different sections of the hillslope transect towards the lower parts of the terrain can indicate a risk of pollution. When the biomass measured persist consistently above the acceptable levels from the source of the faecal material; groundwater becomes harmful for human utilization.

After a laboratory test of soils and water the presence of *E*. coli showed that some horizons were contaminated with faecal matter. Acceptable levels for total coliforms, faecal coliforms and *E.*coli according to guidelines for safe ground and drinking water should be; <1 CFU/100 mL or <1 CFU g/soil (WHO, 2008; USEPA, 2009; SANS, 2011; Nova Scotia, 2016). Findings from Ogden et al. (2001) proposed that concentrations in the range <100 CFU g/soil possess a low risk to groundwater contamination. Observed microbial biomass levels are presented in Table 5-3.

<u>Total bacteria</u>

The total bacterium for all the sites was analysed to determine the likelihood occurrence and growth of natural coliform bacterium. Apart from the selected indicator bacteria, population growths for coliforms was counted from the soil samples. These natural colony forming units can also be used as a reference base, hence predict the most potential sites with necessarily favourable bacteria survival conditions. The highest concentrations in the study, generally was observed in winter as compared to summer seasons as shown in Table 5-3. A count above 9×10^6 CFU g/ soil was obtained from site 3 (MT3-1) closest to the pit latrine. Most of the sites in the study recorded values below a minimum range of 1×10^6 CFU g/soil during the summer season.

The concentrations declined in the rainy summer season, as the highest value above 2×10^6 CFU/g soil analysed was observed also from site 3 (MT3-1). During this rainy season in summer the concentrations increased in the deeper B horizons as compared to the upper A horizons which had higher values under the winter season. A minimum average of 3 x 10^5 CFU/g soil was detected during winter in all the study sites.

Table 5-3: Microbial biomass levels for different sites below selected pit latrines

Sites	Depth (cm)	Total Bacteria (CFU/g)		Faecal Coliforms (CFU/g)		*E.coli* (CFU/g)	
		Summer	Winter	Summer	Winter	Summer	Winter
MT1-1	0-30	220000	1200000	3700	<1	10	<1
	30-60	90000	220000	21000	<1	70	<1
	60-90	68000	350000	<1	80	<1	<1
	90-120	58000	56000	70	<1	<1	<1
MT1-2	0-30	193000	1010000	<1	<1	<1	<1
	30-60	73000	280000	<1	<1	<1	<1
	60-90	60000	8000	10	10	<1	<1
	90-120	32000	160000	<1	40	<1	<1
MT1-3	0-30	144000	1100000	100	110	<1	<1
	30-60	66000	169000	<1	<1	<1	<1
	60-90	85000	48000	60	<1	20	<1
	90-110		198000		160		<1
MT2-1	0-30	490000	2400000	220	<1	<1	<1
	30-60	141000		70		<1	
	60-90	127000		<1		<1	
	90-120	590000		<1		<1	
MT2-2	0-30	280000	5200000	<1	30	<1	<1
	30-60	310000	71000	150	<1	<1	<1
	60-90	124000		710		<1	
	90-120	82000		160		<1	
MT2-3	0-30	1100000	310000	70	<1	40	<1
	30-60	350000	120000	<1	<1	<1	<1
	60-120	240000	63000	<1	<1	<1	<1
MT3-1	0-30	640000	1500000	<1	100	<1	10
	30-60	1600000	9100000	60	1700	20	120
	60-90	700000		110		30	
	90-120	2110000	2400000	100	700	30	10
MT3-2	0-30	740000	1200000	1000	190	<1	10
	30-60	560000	6400000	<1	400	<1	<1
	60-90	660000	690000	<1	10000	<1	<1
	90-120	460000		<1		<1	
MT3-3	0-30	900000	430000	30	120	<1	<1
	30-60	460000	102000	<1	<1	<1	<1
	60-90	580000	1700000	200	42000	<1	180
	90-120	296000		<1		<1	
MT4-1	0-30	72000	1800000	160	<1	<1	<1
	30-60	380000	580000	210	<1	20	<1
	60-90	500000	390000	170	<1	<1	<1
	90-120	300000	64000	170	<1	<1	<1
MT4-2	0-30	620000	2400000	180	9000	30	<1
	30-60	400000	360000	40	40	10	<1
	60-90	620000	350000	230	40	<1	<1
	90-120	540000		<1		<1	
MT4-3	0-30	220000		290		<1	
	30-60	360000		<1		<1	

Faecal coliforms

The analysed samples for pollutes on faecal coliforms showed that most of the sites for both winter and summer seasons had counts which were <1 CFU/g as presented in Table 5-3.

The highest pollution risk to the water resources was recorded in site 3 (MT3-3) with a count above 4 x 10^4 CFU g/ soil in winter and above 2.2 X 10^4 CFU g/ soil in summer in site (MT1-1). Contents exceeding 8 x 10^3 CFU/g were observed on sites MT1, MT3 and MT4 as well. These levels pose risks to water resource contamination as they are way above the minimum recommended guideline ranges. In most of the sites elevated levels were observed during the rainy summer season.

E.coli bacteria

Soil samples analysed for the indicator *E*. coli bacteria showed that most of the sites had <1 CFU/g. The obtained data under the different seasons in Table 5-3, demonstrate the prevalence during the rainy season. This is evident on the conditions favourable for the bacteria to migrate from the source, i.e. the pit latrines.

The highest value of 1.8 x 10^2 CFU/g was observed in site MT3 (MT3-3). The same site also had the second highest count of 1.2 x10^2 CFU/g in the topsoil sample point close to the pit latrine (MT3-1) during the winter season. MT3-1 to MT3-3 were the only horizons which showed elevated concentrations of the *E*.coli in the winter season. A large proportion of the study sites had, during the rainy summer season, an average CFU/g content of more than 2 x 10^1. This is especially true for MT1, MT2 and MT4, which had *E*.coli population of less than <1 CFU/g during the winter season. The obtained data demonstrates that, *E*.coli bacteria migration from the source pit latrine is influenced by water movement. As the soil water flow rate increase the bacteria mobility directly rises. The threats on water resource pollutions can imamate due to a constant supply of the bacteria from the source pit latrine.

5.3 Conclusions and recommendations for future monitoring

The results show that the selected pit latrines may pose threats to the quality of surface and groundwater resources. This is especially true for MT3 and landscapes with similar hydropedological behaviour. During the last field survey, water for household consumption was collected directly below site MT3. The health risk from pit latrine pollution is therefore a real issue in the study area.

Future monitoring on the pollution potential of pit latrines should aim to quantify the direct contribution of these facilities to surface and groundwater resources. Simulations of the migration of microbial pollutants from pit latrines through the landscape will also aid to predict the impact of the dam construction (and associated changes in groundwater/surface water interactions) might have on water quality in the study area.

6 STREAM CHANNEL GEOMORPHOLOGY

6.1 Introduction

The natural and land use processes within a river catchment play a pivotal role in the current condition of the river channel and have a major influence on river habitats and associated biological diversity. Rivers are complex systems and need to be studied at a range of scales (Allan, 2004). Church (2002) notes that changes in a riverine system occur systematically along a drainage system as the flow, gradient and sediment characteristics vary. This variation in the landscape results in a characteristics sequence of morphological and habitat types (Church, 2002).

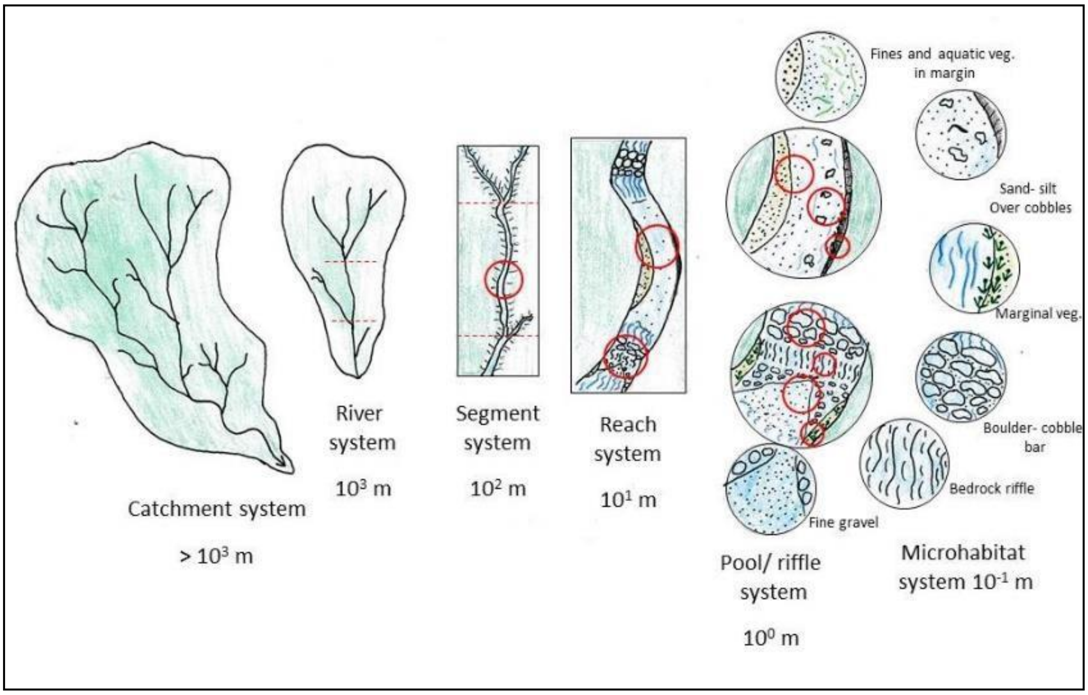

Figure 6-1: Hierarchical nature of rivers, from a large catchment scale to successively smaller scales of river segments, channel reaches, individual channel units (such as pools and riffles) and microhabitats (Adapted from Allan, 2004).

River conditions at a local scale are influenced by the river reach as well as processes occurring in the surrounding landscape (Allan, 2004). Figure 6-1 shows that the small-scale (pool/riffle and microhabitat system) creation and maintenance of habitats for aquatic organisms is shaped from channel processes at intermediate scales (segment and reach system).This in turn stems from large-scale factors (catchment system), such as geology, climate and topography, which shape channel processes by controlling the geomorphic processes within a stream system. Allan (2004) identified that the reach scale morphology is influenced by the catchment slope, input of water and sediment from upstream, valley confinement and bed and bank materials.

It has been recognised by many authors that increased sedimentation and turbidity have a direct impact on ecological health in fluvial systems, and is commonly seen as a detrimental aquatic pollutant (Ritchie, 1972; Lemly, 1982; Henley et al., 2000; Allan, 2004). Natural erosional processes have always contributed to a certain amount of sedimentation in streams. However, anthropogenic impacts on the landscape have augmented the amount of sediment entering fluvial systems. Silt from erosional processes has become a recurring problem (Ellis, 1936). Ellis (1936) states that excessive loads of erosion silt have significantly increased the turbidity of streams as well as the amount of sediment and silt being deposited on river substrates, resulting in a marked change in both aquatic habitats and associated biota.

Sedimentation results from particulates of silt, sand and/or fine gravels, sourced from eroded materials which enter a stream system from the surrounding landscape, which are deposited on the stream bed during periods of reduced water velocity (Henley et al., 2000). Sedimentation occurs at various scales depending on the amount of sediment entering a system. The preconditions for deposition are determined by the current condition of the channel which is shaped by the flow hydraulics within the channel.

It is hypothesised that the likely effects of the proposed Ntabelanga Dam will take place on two scales. Between the dam and the confluence with the Inxu there will be a severe loss of sediment and a reduction in flood magnitude causing one or more of the following: channel widening due to bank erosion, channel deepening due to bed incision, armouring of the bed through the loss of fines and loss of gravel bars. The main impact on habitats will be the loss of fine substrate and reduced flow in an extended channel. Below the confluence, reduction in flood magnitude combined with a continued sediment input from the Inxu River will have one or more of the following effects: sediment deposition in a tributary bar immediately downstream of the confluence and an increased formation of channel bars downstream, channel narrowing and/or reduction in depth and increased embeddedness of coarse substrate. Furthermore, rehabilitation in the upper Tsitsa Catchment may result in a loss of sediment. Changes can be monitored in the gorge site above the proposed Ntabelanga Dam. A reduced sediment supply without a reduction in flood magnitude will result in less sediment deposition and decreased embeddedness of coarse substrate. Through studying the relationship between the above variables, a baseline for future monitoring was created.

6.2 Results and Discussion

Desktop Analysis

Monitoring sites

Five fixed sites were established in variable reaches of the Tsitsa River. Four sites were established in the downstream reach and one in the upstream reach proximal to the proposed Ntabelanga Dam (Figure 6-2). Sites chosen are long enough to include a characteristics range of channel morphology such as pools, riffles and rapids and range from 150-300 meters in length (Rowntree & Wadeson, 1999). A further site was chosen on the Inxu River to help quantify the amount of suspended sediment flowing into the Tsitsa River.

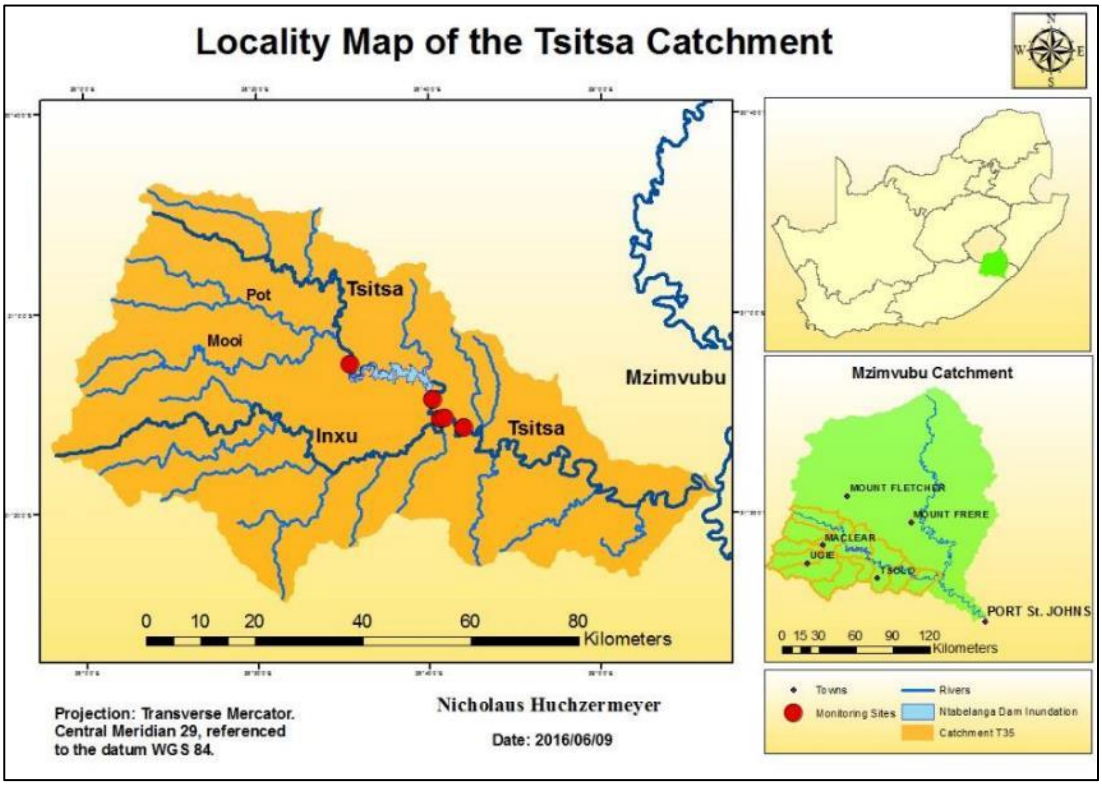

Figure 6-2: Locality map of monitoring sites in the Tsitsa River, Eastern Cape.

Morphology of the Tsitsa River

The Tsitsa River is a main tributary in the Mzimvubu Catchment and has its headwaters in the Drakensberg Mountains. The Tsitsa River flows into the Mzimvubu River which discharges into the Indian Ocean at Port St. Johns (Figure 6-2). The baseline study conducted in this research will focuses on sites in the Tsitsa River above the proposed Ntabalanga Dam site and below the dam wall up to below the confluence with the Inxu River, a major sediment source for the Tsitsa River (Figure 6-3).

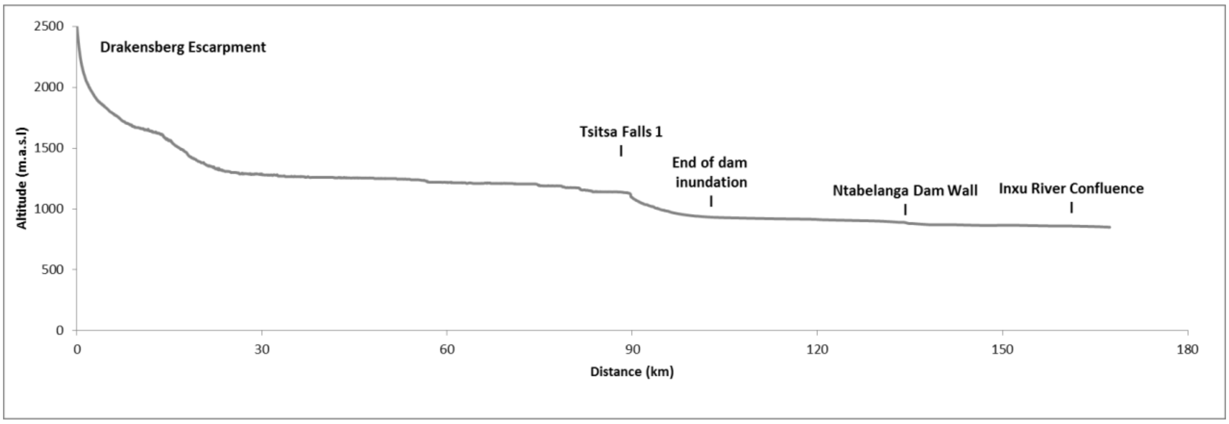

Figure 6-3: Longitudinal Profile of the Tsitsa River from its headwaters in the Drakensberg Mountains to below the confluence with the Inxu River.

Each site represents the channel reach in which it is located (Figure 6-4). In the Tsitsa River three main reaches, proximal to the proposed Ntabelanga Dam, have been identified each including a range of features that can be monitored for their response to the dam.

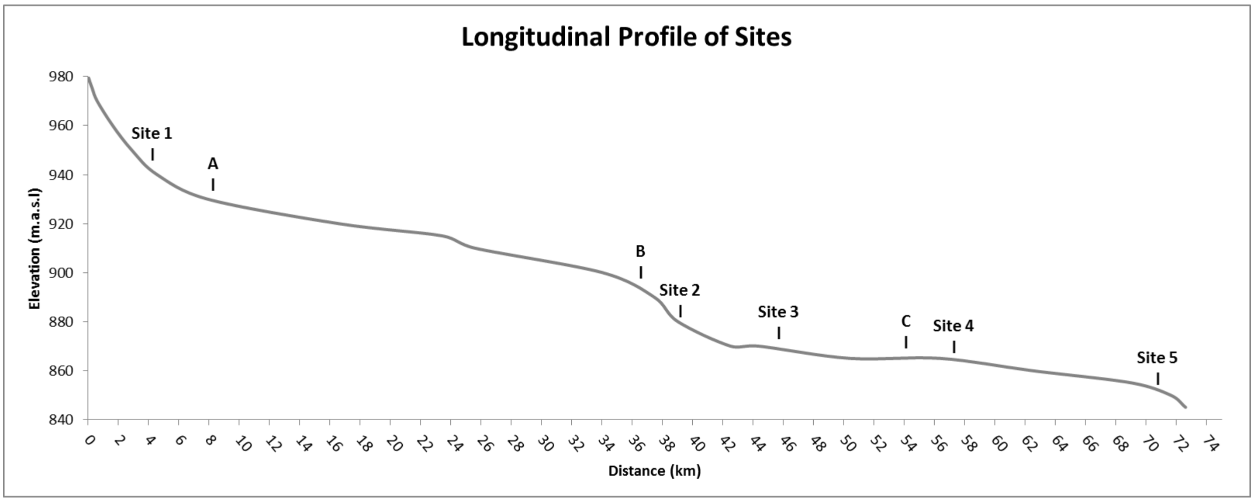

Figure 6-4: Longitudinal Profile of the selected sites along the Tsitsa River reach ranging from the gorge to below the confluence with the Inxu River. A: End of dam inundation, B: Dam Wall, C: Confluence with Inxu River.

A significant factor affecting channel morphology is the gradient of the river bed. Sites chosen on the Tsitsa river have varying bed gradients (Table 6-1) each pointing to different process sets in the river channel. The gradient of the river bed determines the energy slope of the site at different discharges and affects sediment deposition or entrainment and channel shape.

Table 6-1: Bed gradients for sites on the Tsitsa River

Site	**Bed gradient**
1	**0.006**
2	**0.007**
3	**0.008**
4	**0.002**
5	**0.003**

The gorge reach, represented by Site 1 (Figure 6-5), above the proposed dam, is characterised by a confined channel, with a dominating bedrock substrate and input of coarse material from the side walls. The gorge reach has a low potential for the deposition of fine sediments.

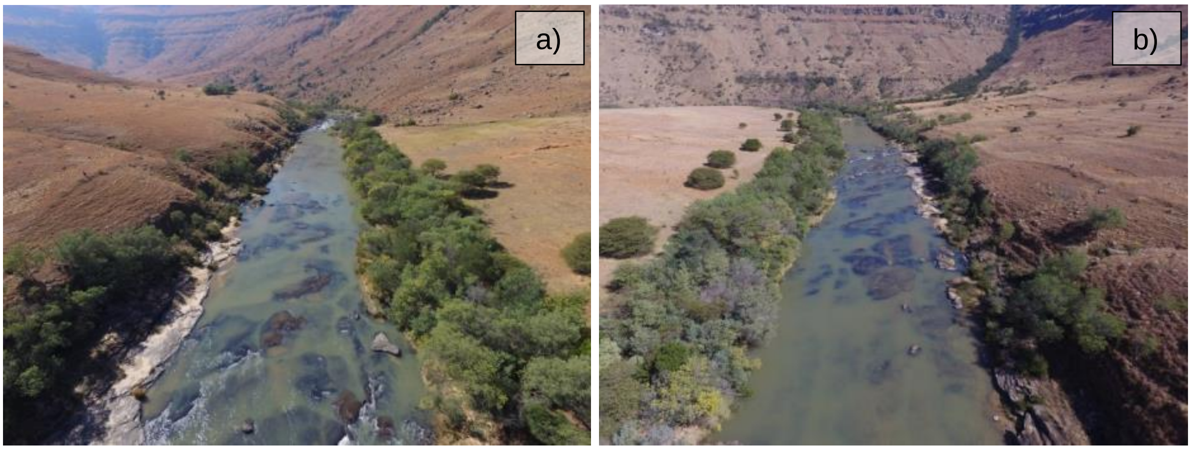

Figure 6-5: a) Upstream and b) downstream view of Site 1.

The channel downstream of the dam is characterised by varying gradients. Two sites were chosen in this reach, the first immediately downstream of the dam (Figure 6-6) and the second (Figure 6-7) upstream of the confluence of the Tsitsa River with the Inxu River.

Figure 6-6: Downstream view of Site 2.

Figure 6-7: Downstream view of Site 3.

The Inxu River is a tributary flowing into the Tsitsa River (Figure 6-8), below the proposed Ntabelanga Dam, that acts as an important sediment source and will provide continued sediment input into the Tsitsa after the dam has been constructed.

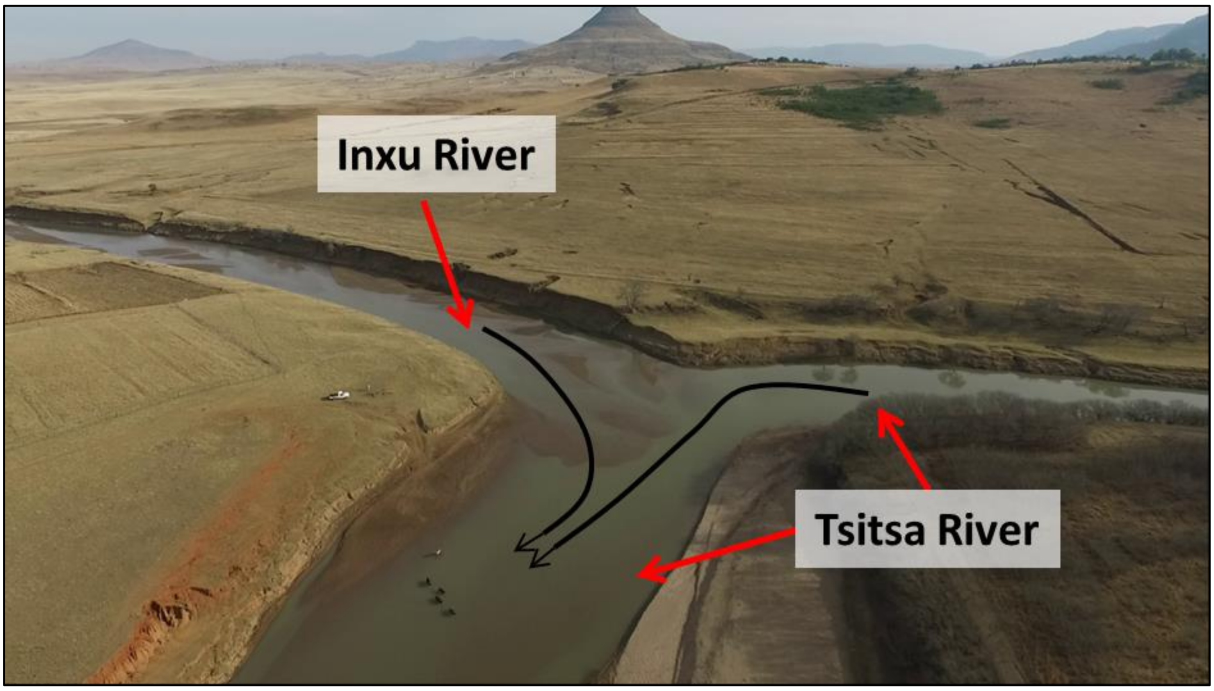

Figure 6-8: Confluence of the Inxu River with the Tsitsa River.

The channel downstream of the Inxu River is characterised by an additional sediment input. Two sites were chosen below the confluence. The first site (Figure 6-9) is a lower gradient site where increased sediment deposition may develop pronounced in-channel bars.

Figure 6-9: a) Upstream and b) downstream view of Site 4.

The last site (Figure 6-10), below the Inxu confluence, is a complex site containing coarse substrate that can be monitored to see the effect of sediment deposition on embeddedness.

Figure 6-10: Upstream view of Site 5.

Physical Variables

Through the monitoring of physical variables in the Tsitsa River a baseline of the current river condition has been set up. This baseline survey will allow the long term impacts of the Ntabelanga Dam to be assessed.

Cross-sectional surveys

Cross-sectional transects were surveyed for each site during July 2015. These transects (Figure 6-11) can be used as a reference for the current condition of the Tsitsa river before the construction of the Ntabelanga Dam. Cross-sectional transects for all the sites, including distribution of substrates, geo-habitats and July 2015 inundation levels can be found in Appendix 3.

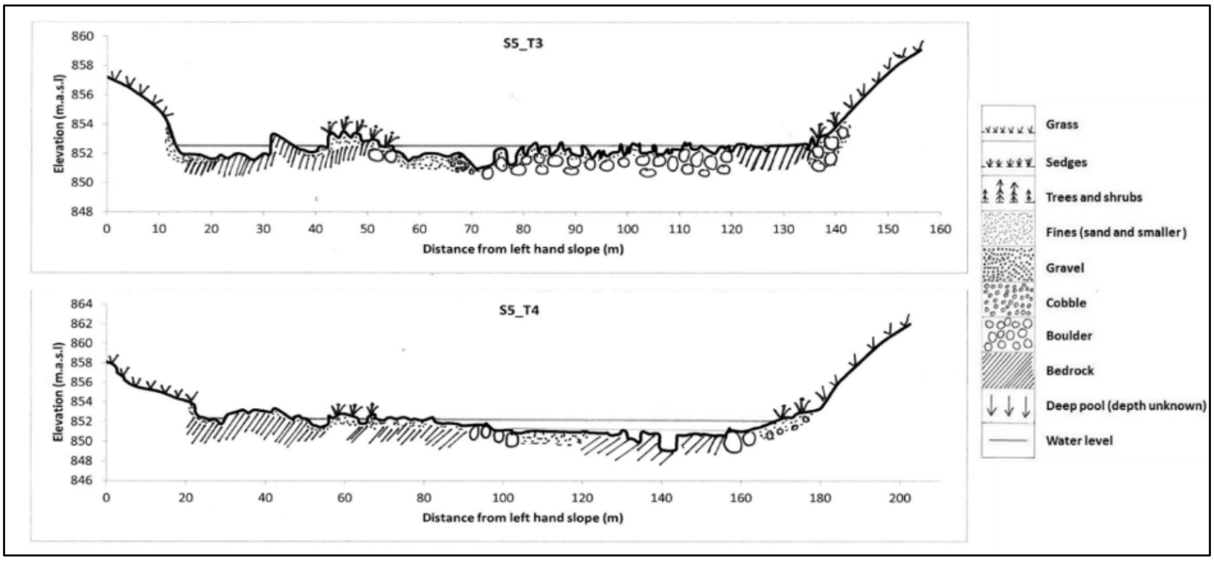

Figure 6-11: Example of cross-sectional transects with corresponding substrates and geo-habitats, surveyed in July 2015.

In August 2016, approximately a year after the first cross-sectional transects were surveyed, all the transects were resurveyed to pick up any significant changes in channel morphology after a single wet and dry season. The majority of sites did not undergo any major changes in channel morphology (Figure 6-12). Small changes can be picked up on silt and sand banks that are easily entrained during high flows or deposited in low flows. Some of the changes can be accounted for by surveyor bias. This commonly occurs on boulder morphologies where the position of surveying points varies. However these changes are trivial. A full record of the July 2015 and August 2016 cross-sectional transects can be found in Appendix 4.

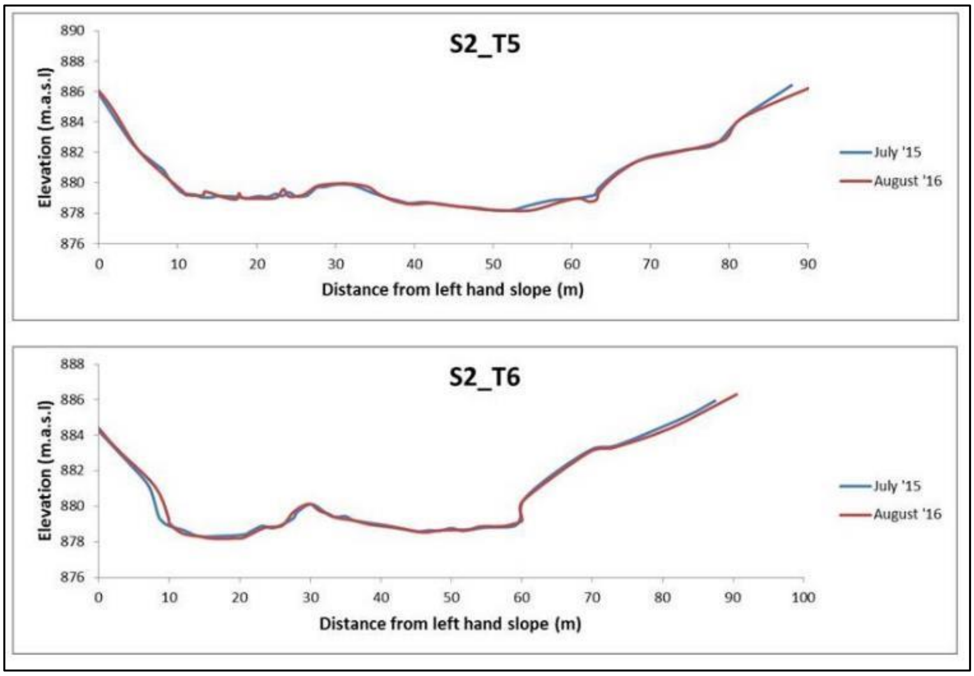

Figure 6-12: Example of cross-sectional transects with little or no seasonal change to channel topography.

The only site that underwent a significant change in channel morphology was Site 4 (Figure 6-12). It is important to note that these changes occurred primarily due to anthropogenic impacts, in the form of sand mining operations, on the river sand bars and channel banks. These activities are likely to continue after the construction of the Ntabelanga Dam and may continue to change the morphology in sites that have easily accessible sand banks, such as Site 4. All of the sites contain sand banks and Site 4 is dominated by fine sediments. These sand bars and banks can be entrained and transported at high discharges and deposited at low discharges. These sections of the river are susceptible to major pattern changes irrespective of the construction of the Ntabelanga Dam. However the dam will affect the frequency of major floods and cut off sediment above the Inxu confluence, thus affecting the natural flow and sediment regime of the river.

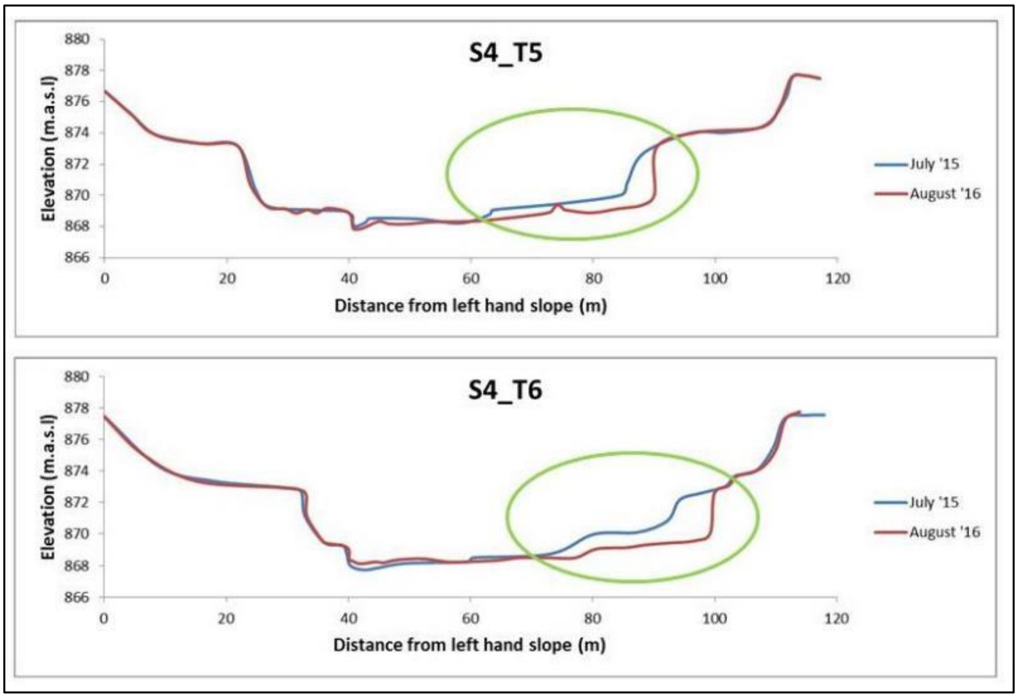

Figure 6-13: Example of cross-sectional transects that have undergone a seasonal change in topography. In this case changes have occurred due to sand mining at low flows.

<u>Substrate</u>

Coarse Substrate

Site 1 is dominated by bedrock riffles which make up the majority of the site (Table 6-15). Site 1 is situated in the gorge reach of the Tsitsa River with a relatively high gradient and confined channel. Therefore there is very little deposition of fines. Measured coarse substrates that can be entrained (>4 mm and excluding bedrock) are predominantly cobbles and boulders (Table 6-2 and Table 6-3) situated in the lee of bedrock slabs and in slower flow along the river banks.

Table 6-2: Bed conditions along each transect in Site 1

Transect	D_{50} (mm)	Dominant Substrate
1	380	Small boulder
2	295	Large cobble
3	550	Small boulder
4	600	Large boulder

Table 6-3: Percentage distribution of clasts in Site 1

Clast Category	Diameter Range (mm)	Percentage Distribution (D_{50})
Small gravel	**4-25**	**2**
Medium gravel	**25-50**	**8**
Large gravel	**50-75**	**13**
Small cobble	75-150	24
Medium cobble	**150-225**	**10**
Large cobble	**225-300**	**10**
Small boulder	300-600	25
Large boulder	**>600**	**8**

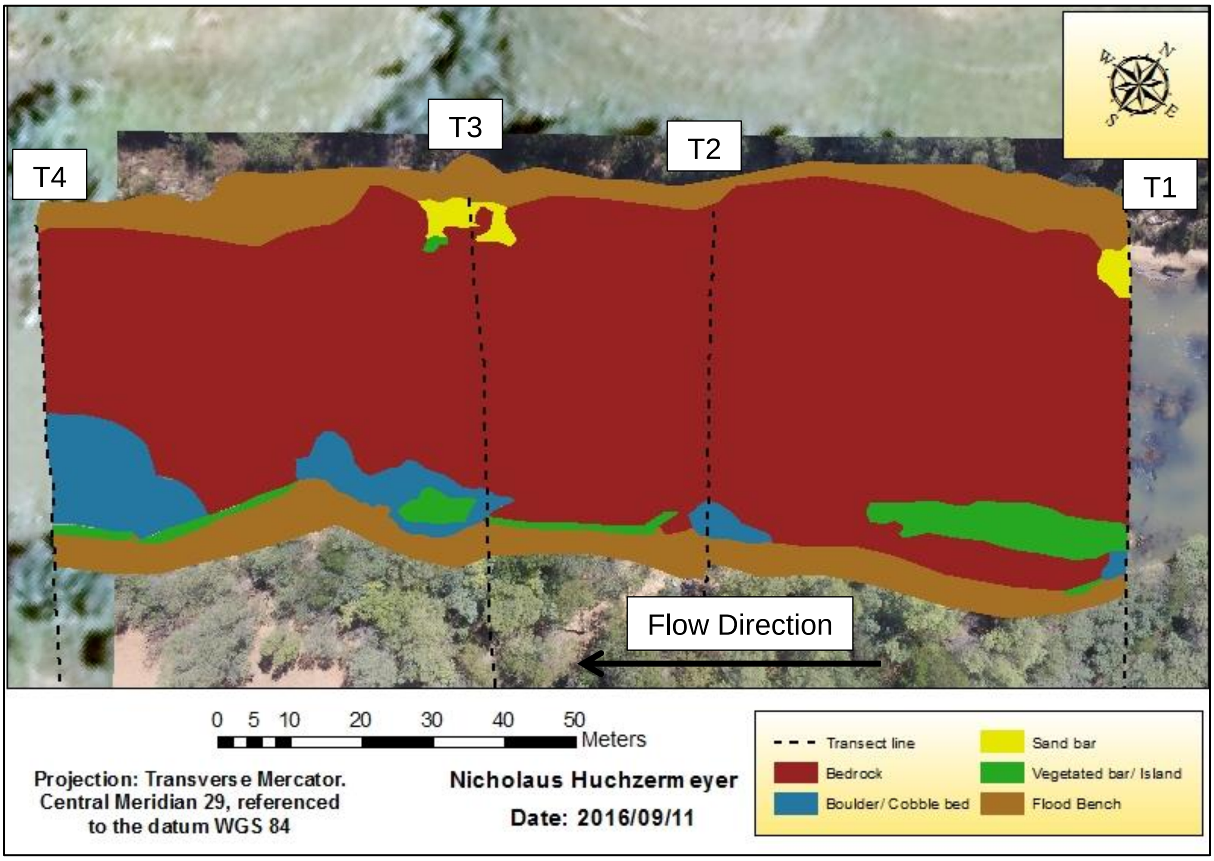

Figure 6-14: Channel features at a large scale for Site 1.

Site 2 has a variety of morphologies starting in a pool, with sand and bedrock substrates, ranging through a boulder, cobble and bedrock rapid into a low gradient pool and back into boulder and cobble rapids (Figure 6-15). The dominant substrates vary along the transects ranging from gravel to boulders (Table 6-4). The dominant coarse substrates distributed across the site are small cobbles and small boulders (Table 6-5).

Table 6-4: Bed conditions along each transect in Site 2

Transect	D_{50} (mm)	Dominant Substrate
1	580	Small boulder
2	380	Small boulder
3	260	Large cobble
4	33	Medium gravel
5	295	Large cobble
6	315	Small boulder

Table 6-5: Percentage distribution of clasts in Site 2

Clast Category	Diameter Range (mm)	Percentage Distribution (D_{50})
Small gravel	4-25	6
Medium gravel	25-50	13
Large gravel	5-75	6
Small cobble	**75-150**	**18**
Medium cobble	150-225	8
Large cobble	225-300	13
Small boulder	**300-600**	**25**
Large boulder	>600	11

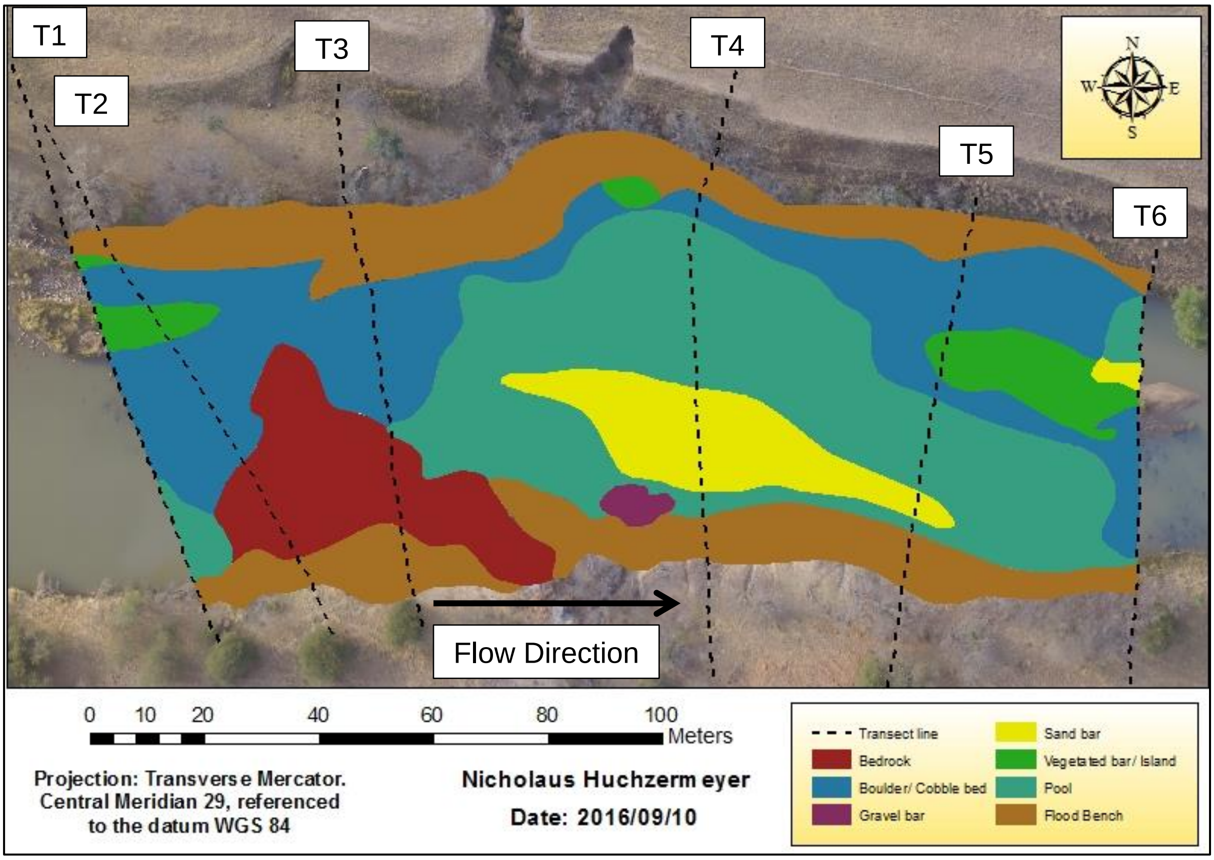

Figure 6-15: Channel features at a large scale for Site 2.

Site 3 has the highest bed gradient of all the sites and is confined to a narrow channel. It varies from bedrock at the top through a boulder and cobble rapid into a low gradient pool with deposits of fine sediments (Figure 6-16). The bed conditions are highly variable and range from fines to small boulders (Table 6-7). The dominant coarse substrates across the site are large gravels, commonly from surrounding alluvial fans, as well as small cobbles.

Table 6-6: Bed conditions along each transect in Site 3

Transect	D_{50} (mm)	Dominant Substrate
1	± 4	Fines
2	240	Small boulder
3	280	Large cobble
4	620	Medium gravel
5	295	Large cobble

Table 6-7: Percentage distribution of clasts in Site 3

Clast Category	Diameter Range (mm)	Percentage Distribution (D_{50})
Small gravel	**4-25**	**1**
Medium gravel	**2-50**	**5**
Large gravel	5-75	17
Small cobble	75-150	30
Medium cobble	**150-225**	**8**
Large cobble	**225-300**	**10**
Small boulder	**300-600**	**14**
Large boulder	**>600**	**15**

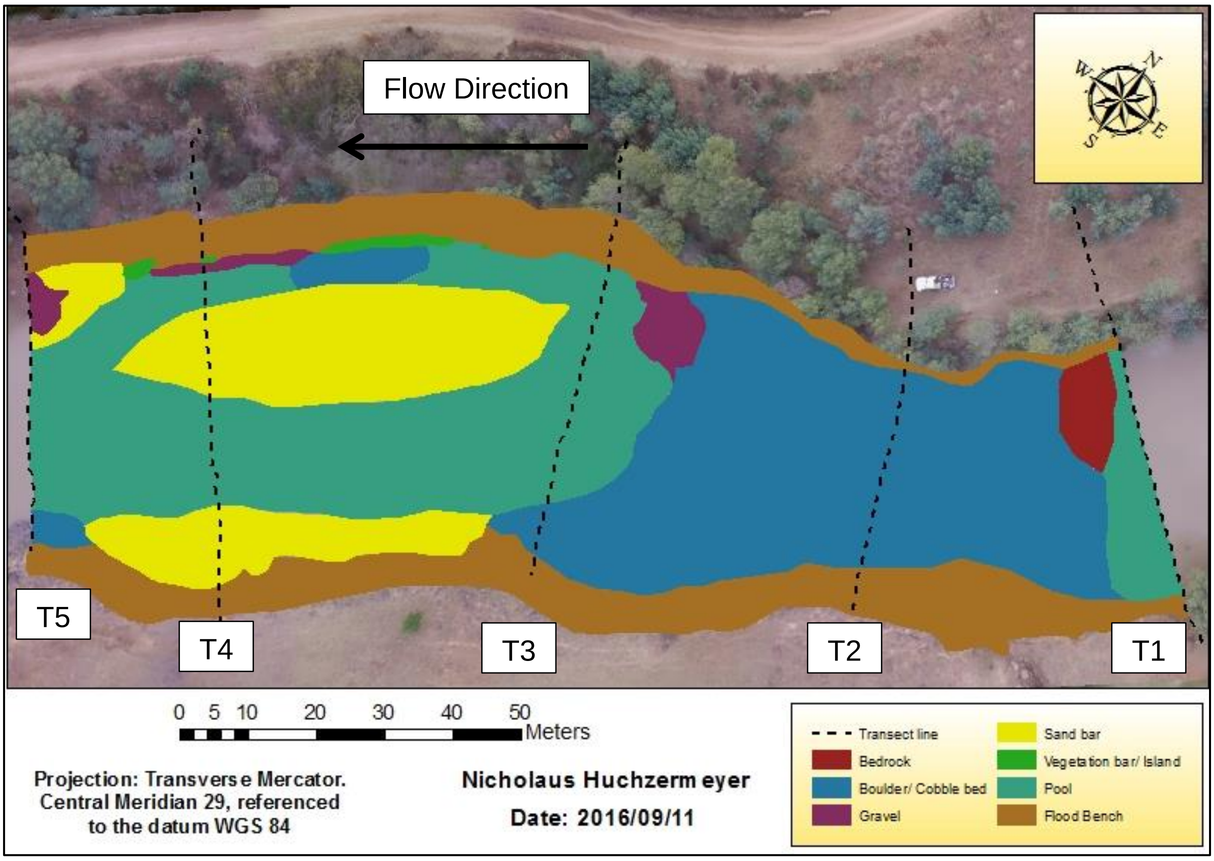

Figure 6-16: Channel features at a large scale for Site 3.

Site 4 has a low gradient with a wide but incised channel. Sand bars make up the greatest proportion of the substrate (Table 6-8), with a small section of bedrock (Table 6-8) on the outside edge of the channel where conditions are less susceptible to deposition of fines (Figure 6-17).

Table 6-8: Bed conditions along each transect in Site 4

Transect	D_{50} (mm)	Dominant Substrate
1	5.5	Small gravel
2	± 4	Fines
3	± 4	Fines
4	± 4	Fines
5	± 4	Fines
6	± 4	Fines

Table 6-9: Percentage distribution of clasts in Site 4

Clast Category	Diameter Range (mm)	Percentage Distribution (D_{50})
Small gravel	4-25	80
Medium gravel	**25-50**	**0**
Large gravel	**50-75**	**0**
Small cobble	**75-150**	**0**
Medium cobble	**150-225**	**0**
Large cobble	**225-300**	**0**
Small boulder	**300-600**	**0**
Large boulder	>600	20

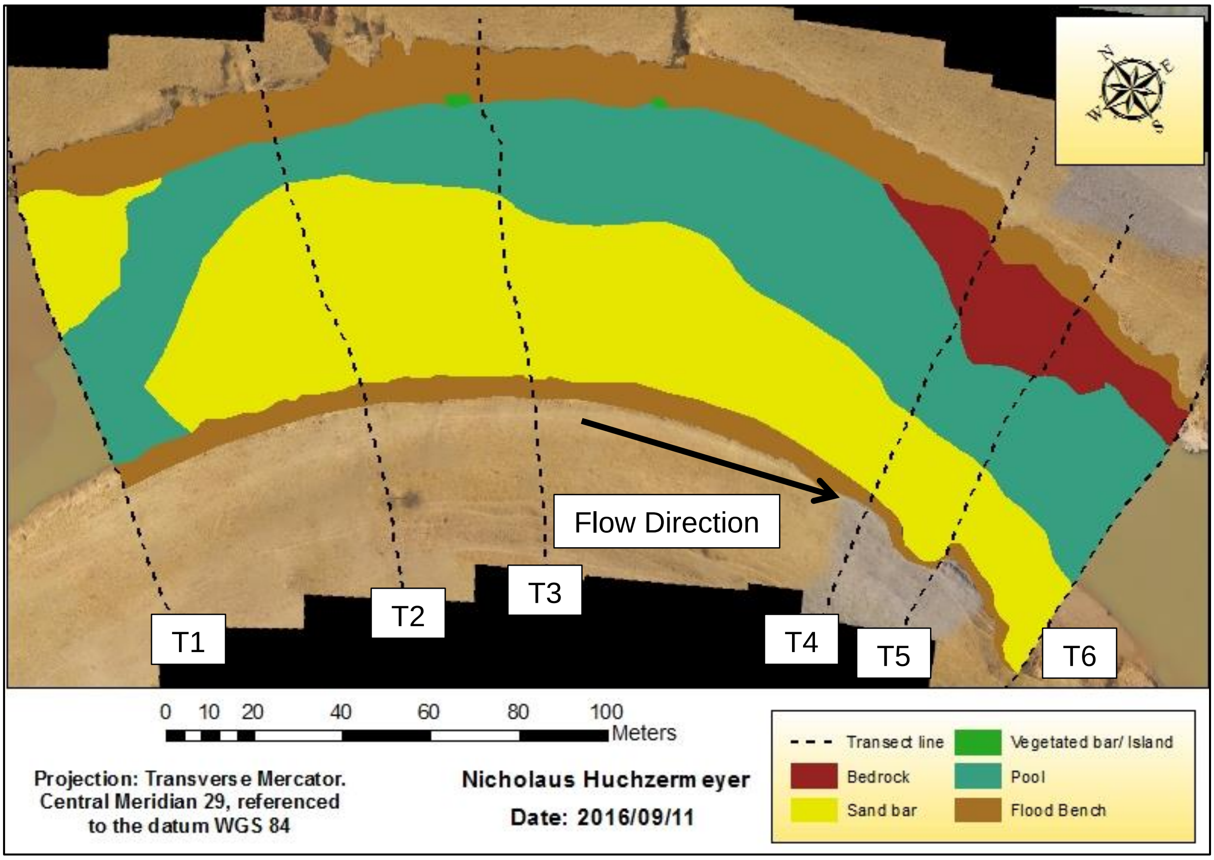

Figure 6-17: Channel features at a large scale for Site 4.

Site 5 is a highly complex site with a wide meandering channel ranging over a variety of substrates (Figure 6-18). The site ranges from a low gradient pool dominated by fines into a boulder and cobble rapid, with gravels deposited at the foot of the rapids. The rapids extend into a lower bed gradient with a cobble and bedrock substrate (Table 6-10). The coarse substrate most dominantly distributed across the site is boulders (Table 6-11).

Table 6-10: Bed conditions along each transect in Site 5

Transect	D_{50} (mm)	Dominant Substrate
1	± 4	Fines
2	± 4	Fines
3	805	Large boulder
4	28	Medium gravel
5	300	Large cobble

Table 6-11: Percentage distribution of clasts in Site 5

Clast Category	Diameter Range (mm)	Percentage Distribution (D_{50})
Small gravel	4-25	3
Medium gravel	25-50	7
Large gravel	50-75	6
Small cobble	75-150	14
Medium cobble	150-225	16
Large cobble	225-300	13
Small boulder	**300-600**	**22**
Large boulder	**>600**	**19**

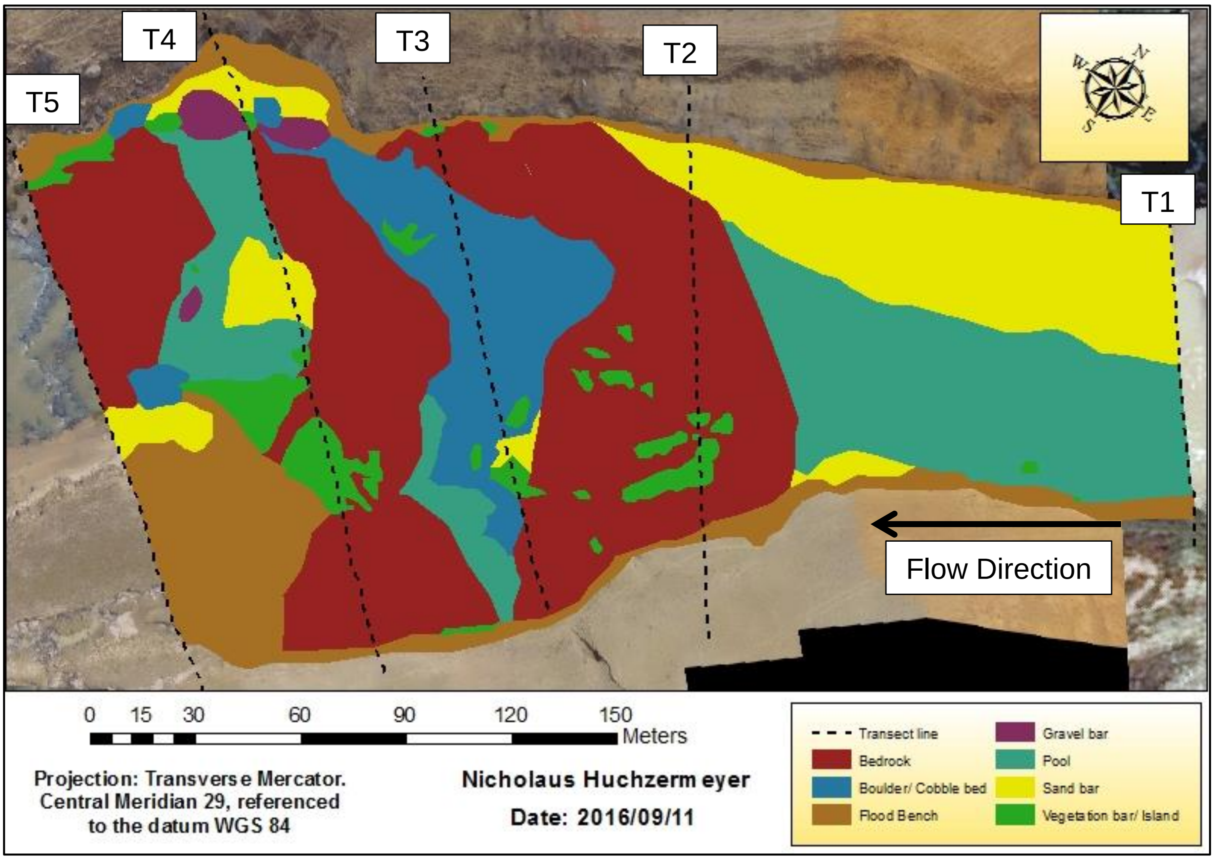

Figure 6-18: Channel features at a large scale for Site 5.

Fine Substrate

Discharge and flow velocities play an important role in sediment mobility and the stability of beds. Figure 6-19 shows the seasonal variation of measured discharges. Winter months with little or no rainfall have low discharge values (July 2015). The lowest discharges were measured in October 2015. The highest discharges were measured in February and April 2016 due to heavy rains in the catchment. August 2016 also experienced a relatively high discharge for winter months due to snow melt in the catchment.

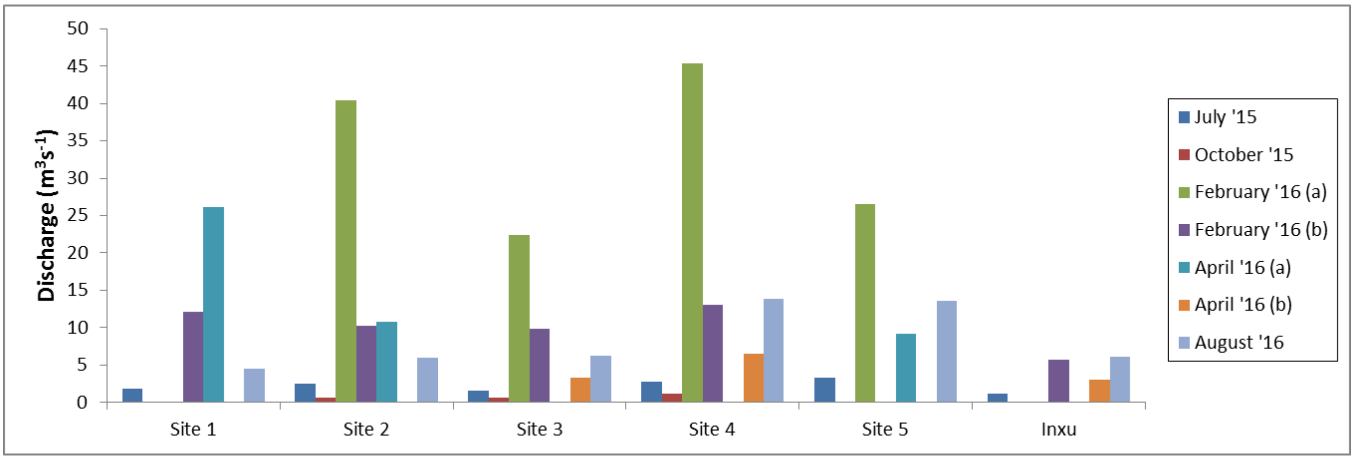

Figure 6-19: Seasonal variations in measured discharge. a = Rising stage of a flood, b = Receding stage of a flood.

Embeddedness values give an indication of fine sediment (<4 mm) accumulation across sites. Figure 6-20 gives an indication of the average embeddedness values across dominant substrate types in each site. The general trend from the figure is that embeddedness values increase during lower discharges, implying deposition of fine materials. During very high flows (February 2016) embeddedness values decrease implying entrainment of fines. A more in-depth analysis of embeddedness values in each site is still being conducted.

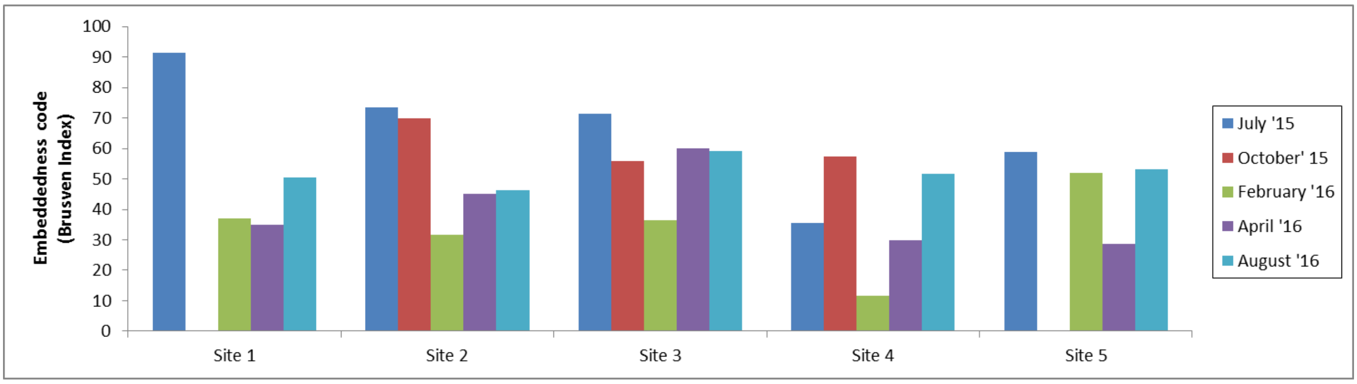

Figure 6-20: Seasonal variation of average embeddedness values across each site.

Disturbance samples of fine sediment stored on the stream bed (surface and subsurface) vary over time. From Figure 6-21 we can see that fine sediment accumulation differs between sites and does not necessarily follow discharge trends alone. Generally fine sediment accumulation increases the more turbid the flows are. Very high flows as well as summer baseflows are likely to entrain sediment (February 2016) whereas medium, turbid flows (April 2016, August 2016) are more likely to deposit sediment on the bed, increasing surface disturbance values. During periods of low flow the energy slope is not sufficient to entrain fine sediments resulting in higher disturbance values (July 2015 and October 2016). Small local rainfall events increase the turbidity of the river but not the flow, which in turn increases the amount of sediment deposited on the bed (Figure 6-22). Surface drape is more easily deposited or entrained than subsurface deposits.

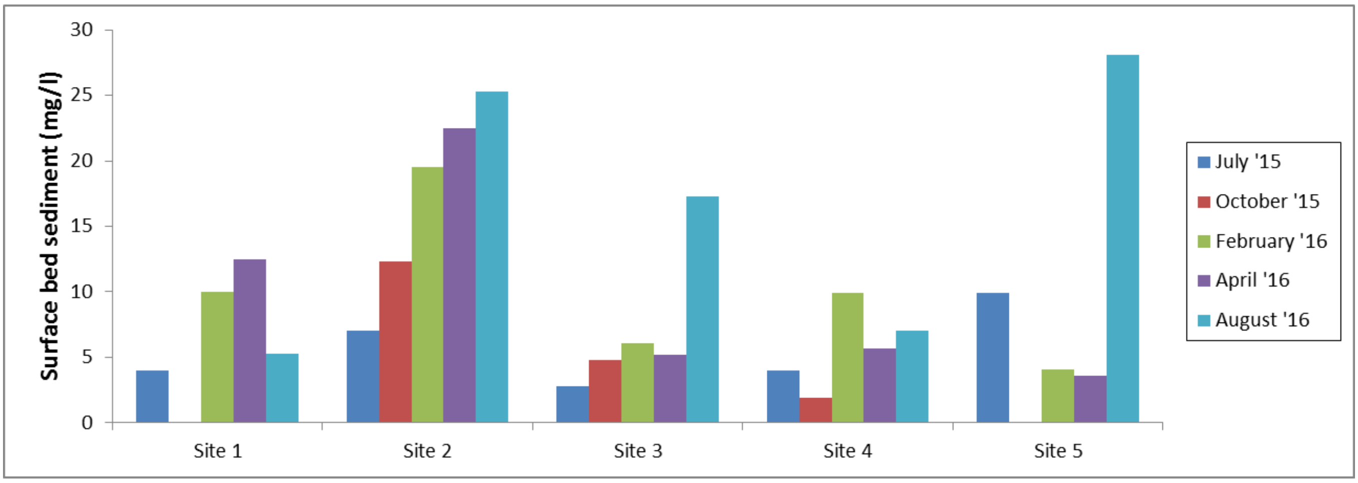

Figure 6-21: Variation in surface fine sediment accumulation.

Figure 6-22: Turbid flood pulse during low flow, October 2015.

Samples of both the surface and subsurface deposited fine sediments were collected for each disturbance to quantify the combined surface drape and subsurface fine sediment deposits. Subsurface fine sediment deposits (Figure 6-23) are affected by the gradient of specific sites as well as the dominant substrate. A bedrock dominated site with a relatively high gradient (Site 1) has a low potential for the deposition of subsurface deposits. Sites with diverse substrates (Site 2) are more likely to have higher subsurface deposits.

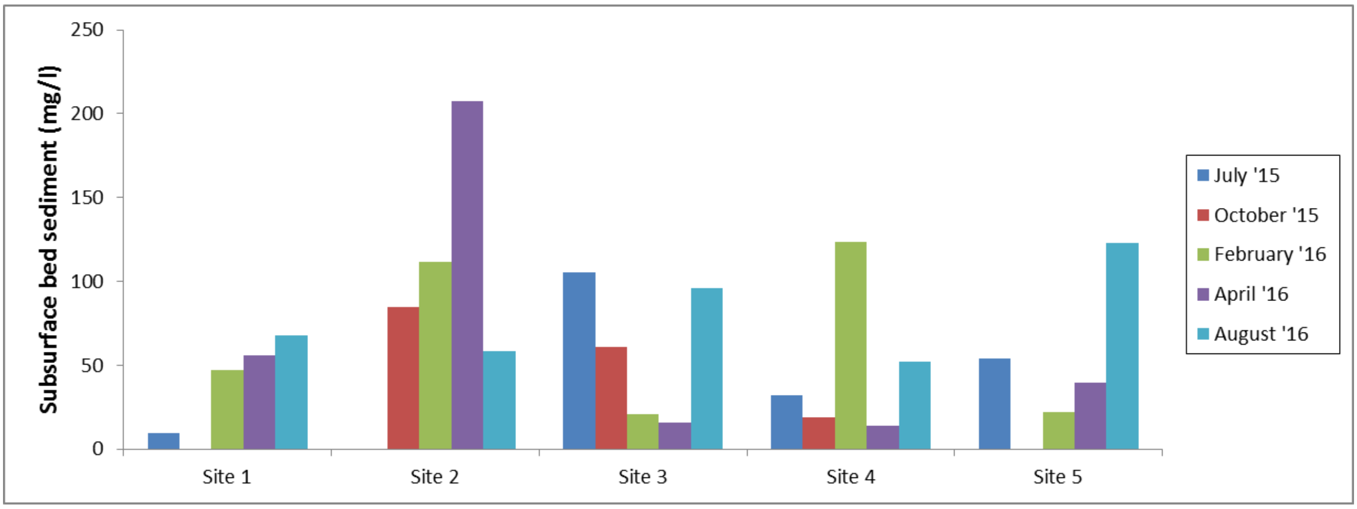

Figure 6-23: Variation in subsurface fine sediment accumulation

Turbidity

Turbidity, clarity and suspended sediment concentration give an indication of how much sediment is being carried by the river. In the Tsitsa catchment high rainfall events cause erosion of the highly dispersive soils which increase the turbidity (Figure 6-24) and suspended sediment concentrations (Figure 6-25) of the river and reduce its clarity (Figure 6-26). The rising stages of floods carry a higher concentration of suspended sediment than the receding stages of floods. This implies that the flood has a higher energy slope for sediment entrainment as it approaches its peak. As the flood recedes sediment is deposited back onto the bed as surface drape.

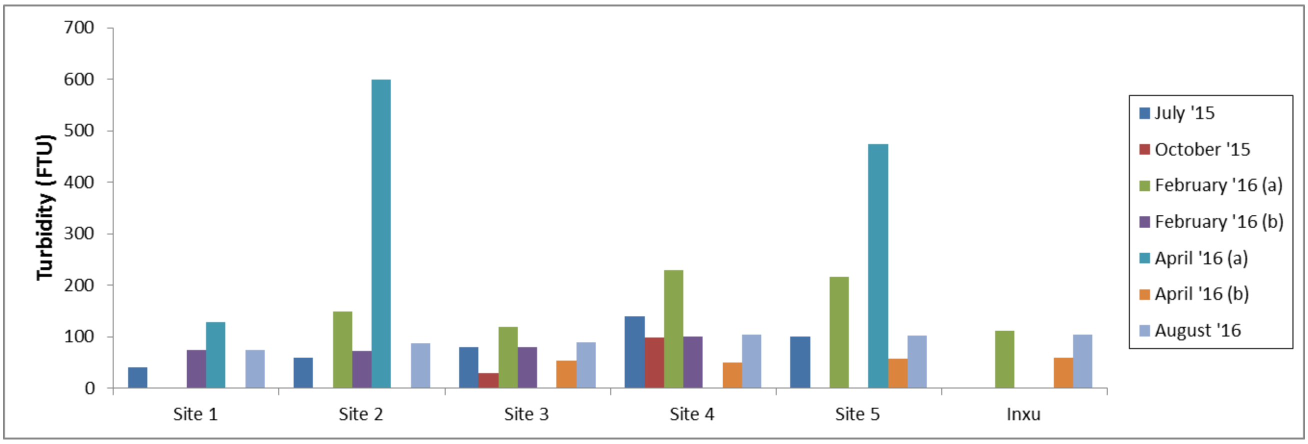

Figure 6-24: Variation in turbidity. a = Rising stage of a flood, b = Receding stage of a flood.

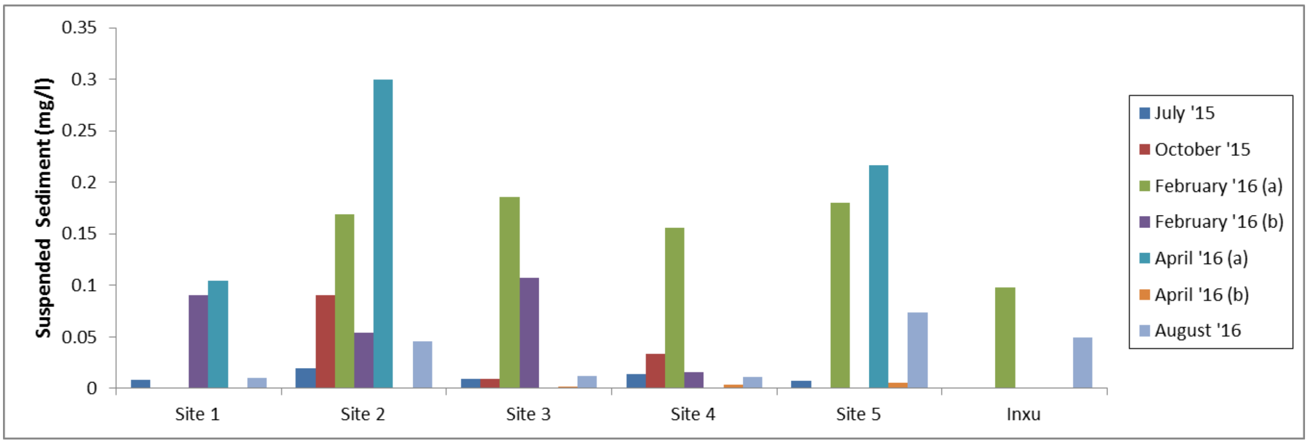

Figure 6-25: Variation in suspended sediment concentration. a = Rising stage of a flood, b = Receding stage of a flood.

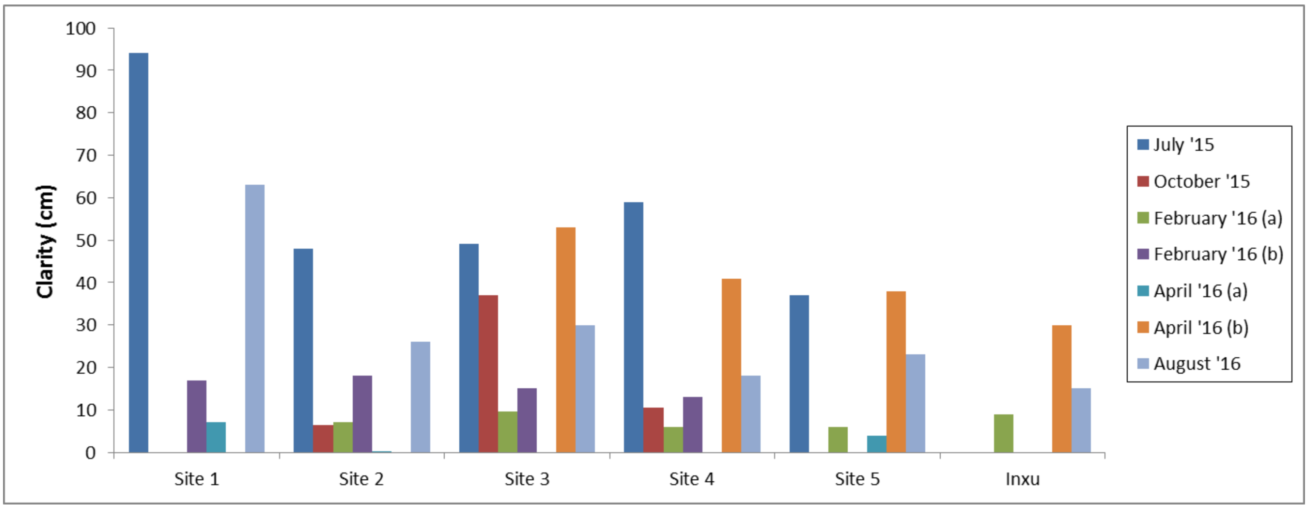

Figure 6-26: Variation in water clarity. a = Receding stage of a flood, b = Lowering stage of a flood.

Flow Hydraulics

Discharge

Flood frequency

Flood data is available from three gauging stations for three rivers in the Mzimvubu catchment (Water and Sanitation, 2015). The Tsitsa River has a catchment area of 4 285 km^2 above the gauging station and the other two rivers, the Tina River a tributary of the Mzimvubu River and the Mooi River a tributary of the Tsitsa River, have significantly smaller catchment areas above the gauging stations (2957 km^2 and 307 km^2 respectively). Figure 6-27 shows the relationship between flood magnitude (peak discharge) and the recurrence intervals of floods in the three sub-catchments within the Mzimvubu catchment. Floods in the Mzimvubu catchment are capable of mobilizing a large amount of sediment including bedloads, in turn altering the form of the bed of the river. The Tsitsa River has the highest peak discharge at the 10 year flood recurrence interval and the 10 year flood will occur when peak discharges are equal to or exceed 935 m^3/s. The mean annual flood will occur with a peak discharge of approximately 449 m^3/s. From figure 31 we can see that a larger catchment area (such as that of the Tsitsa River) will result in a bigger mean annual flood and therefore peak discharges (in the 10 year flood interval) compared to the two rivers with smaller catchment areas (the Tina River appears to have larger floods at larger recurrence intervals because each gauging station has a limit above which large floods are estimated).

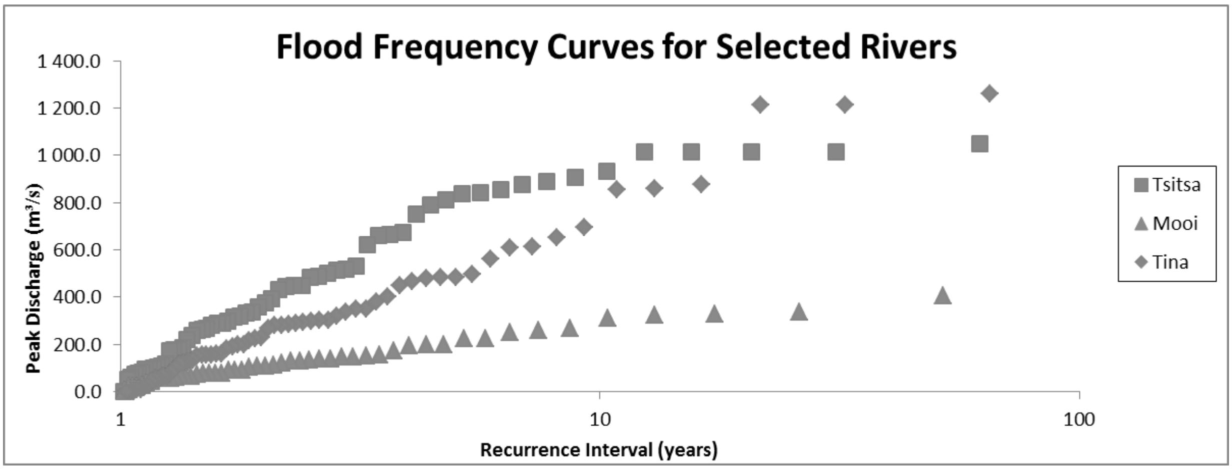

Figure 6-27: Flood Frequency curves for three rivers in the Mzimvubu catchment.

The geomorphic structure of a river is commonly associated with large flow events that have significant energy to move the bed substrate and change channel bank morphology, in turn reshaping river channels (Church, 1995; Chessman et al*.,* 2006). The frequency of large floods are commonly affected downstream of a dam, having a major effect on the downstream geomorphological and ecological processes (Petts, 1980; Ligon et al., 1995; Power et al., 1996; Chessman et al*,.* 2006; Petts & Gurnell, 2013). The construction of the Ntabelanga Dam will have severe impacts on downstream flood magnitudes and downstream sediment supply. From Figure 6-28 we can see that the higher the magnitude of the flood the less frequently it occurs. High magnitude floods can mobilise and transport bigger particle sizes. However, more frequent, lower magnitude floods play an important role in moving smaller particles. The frequency of these smaller floods results in a cumulative effect of sediment transport down the river system. However, with the construction of a dam both low and high magnitude floods will become more infrequent downstream as they get captured behind the dam wall.

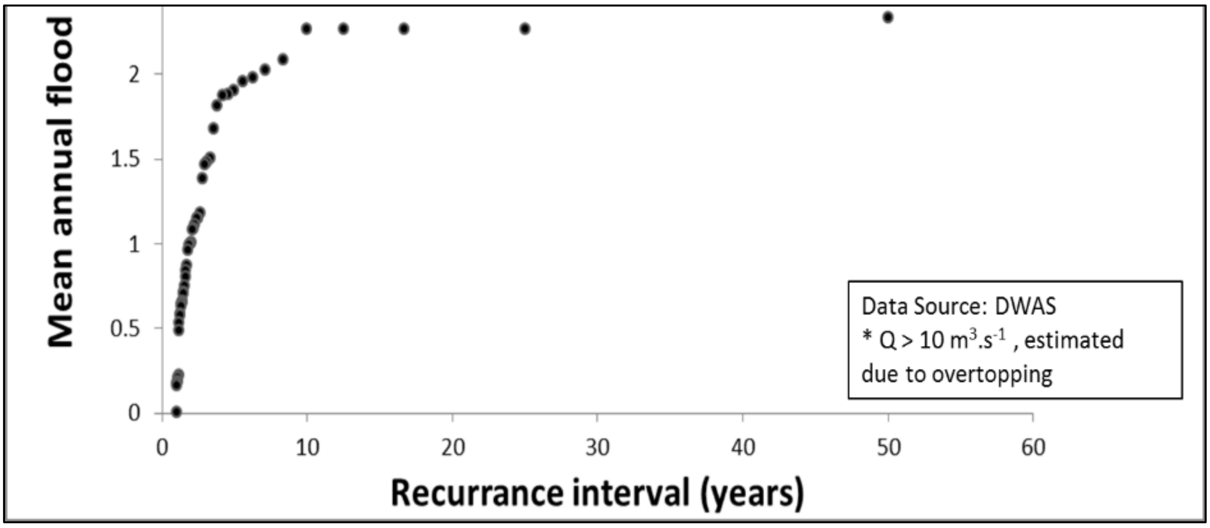

Figure 6-28: Regional Flood Frequency Curve of the Tsitsa River.

Seasonally measured discharges (Figure 6-29) and known depths to the river bed, at the level loggers, are used to create rating curves (Figure 6-30). The rating curves are then used to extrapolate level logger readings to instantaneous discharges (Figure 6-31) which can be plotted to show seasonal fluctuations in flow properties as well as peak discharge. Analyses of the level logger data for each site are still being conducted.

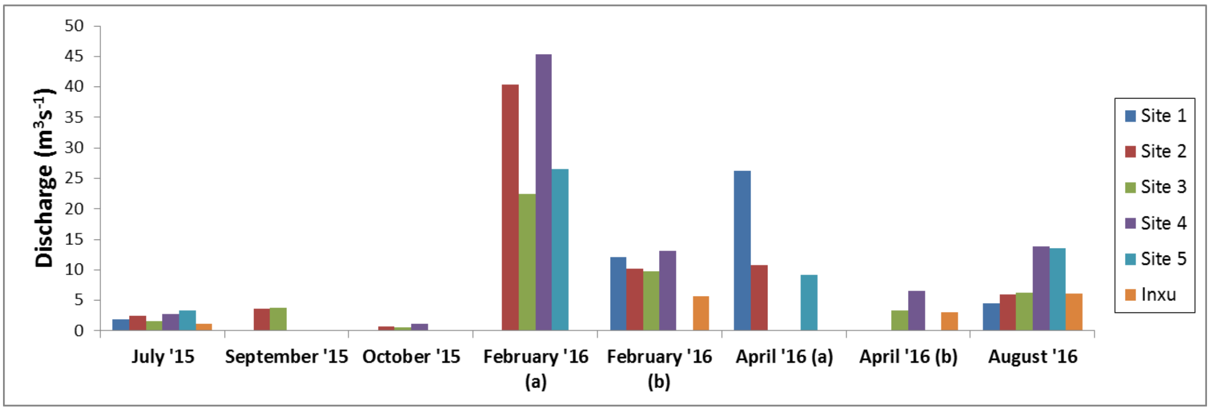

Figure 6-29: Seasonally measured discharge. a = Rising stage, b = Receding stage.

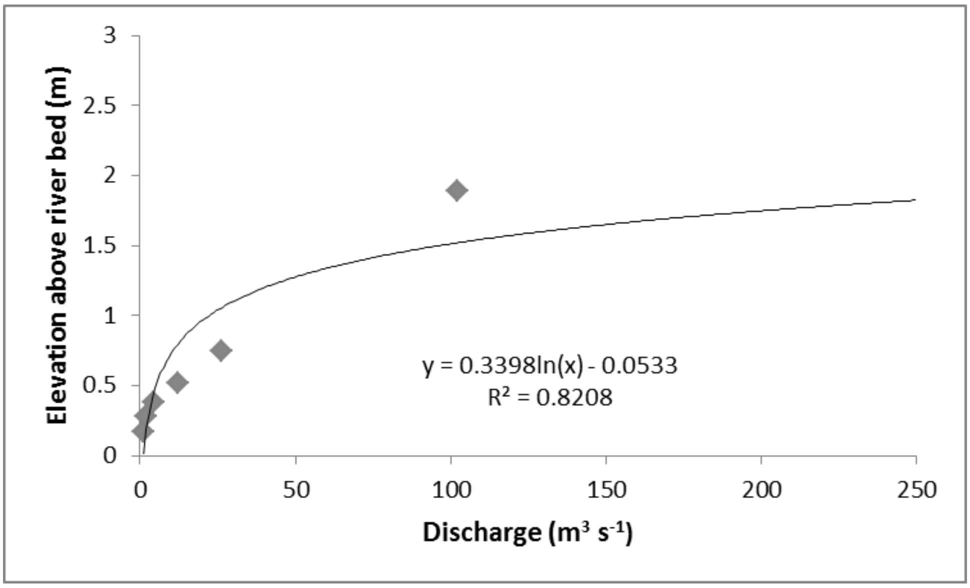

Figure 6-30: Example of a rating curve for Site 1.

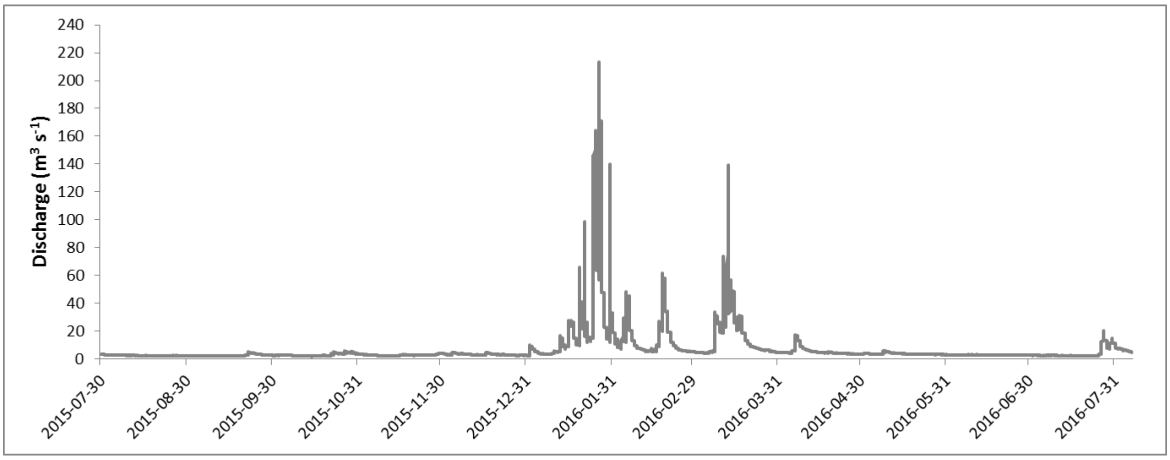

Figure 6-31: Example of fluctuations in flow properties over time for Site 1.

<u>Water slope</u>

Channel long profiles and water slope give an indication of the energy exerted on the bed of the river at different water levels. Sites with a high bed gradient have more significant increases in energy exerted on the bed at differing water levels than sites with gentler gradients (Figure 6-32). Longitudinal profiles and their corresponding energy slopes at different discharges can be found in Appendix 5.

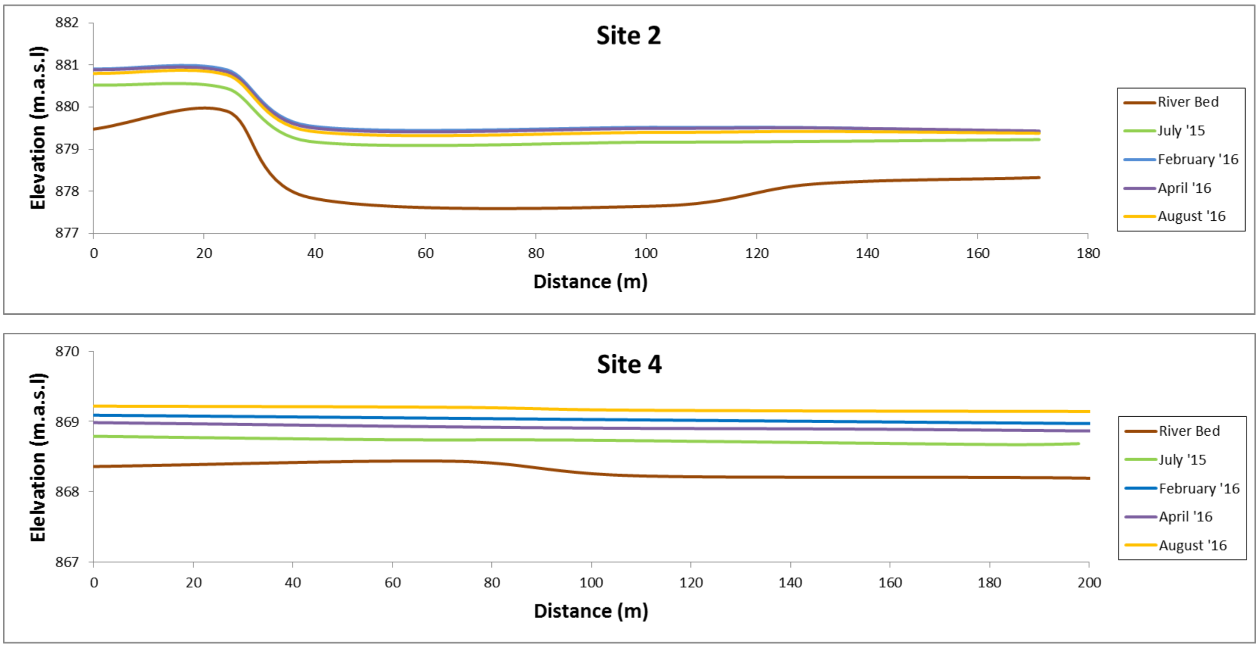

Figure 6-32: Example of a change in energy slope, with changes in discharge, at sites with different bed gradients.

Mannings roughness

Roughness generally decreases with significant increases in discharge. Site 1, 2 and 3 have relatively high gradients and are narrower channels which result in higher roughness values especially at low flows (Table 6-12). Site 4, below the confluence has a very low gradient and a correspondingly low roughness factor. Site 5 is the widest and least confined site resulting in varying roughness factors.

Table 6-12: Roughness values for the monitoring sites

	July '15	February '16	April '16	August '16
Site 1	0.17	0.11	0.04	0.15
Site 2	0.2	0.14	0.2	0.33
Site 3	0.19	0.15	0.12	0.19
Site 4	0.03	0.04	0.03	0.03
Site 5	0.05	0.07	0.2	0.12

Sediment mobility of coarse substrates

Table 6-13 to

Table 6-17 show the potential bed movement of coarse substrates in each site. The closer to 1 the Entrainment Ratio is the less stable the bed and if the value is greater than 1 bed movement is possible. Site 1 and 5 show an extremely stable bed due to their dominant substrates and morphological characteristics. Site 2 and 3 also show stable beds. Site 4 has the least stable bed and sediment movement will occur during high summer flows such as those found in February 2016.

Table 6-13: Potential bed movement in Site 1

	July '15	February '16	April '16	August '16
Shear Stress	13.94	31.76	27.74	20.75
Critical Shear Stress	491.44	491.44	491.44	491.44
Entrainment Ratio	0.03	0.06	0.06	0.04
Bed Movement	None	None	None	None

Table 6-14: Potential bed movement in Site 2

	July '15	February '16	April '16	August '16
Shear Stress	36.69	104.62	54.81	54.61
Critical Shear Stress	330.01	330.01	330.01	330.01
Entrainment Ratio	0.11	0.32	0.17	0.17
Bed Movement	None	None	None	None

Table 6-15: Potential bed movement in Site 3

	July '15	February '16	April '16	August '16
Shear Stress	35.57	62.14	43.51	54.02
Critical Shear Stress	266.02	266.02	266.02	266.02
Entrainment Ratio	0.13	0.23	0.16	0.2
Bed Movement	None	None	None	None

Table 6-16: Potential bed movement in Site 3

	July '15	February '16	April '16	August '16
Shear Stress	1.88	**6.6**	1.81	2.06
Critical Shear Stress	6.29	**6.29**	6.29	6.29
Entrainment Ratio	0.33	**1.05**	0.29	0.33
Bed Movement	None	**Movement**	None	None

Table 6-17: Potential bed movement in Site 3

	July '15	February '16	April '16	August '16
Shear Stress	22.57	29.77	40.78	32.95
Critical Shear Stress	471.14	471.14	471.14	471.14
Entrainment Ratio	0.05	0.06	0.09	0.07
Bed Movement	None	None	None	None

The Relative Bed Stability (Table 6-18) shows the potential movement of coarse substrates (>4 mm and excluding bedrock outcrops). The larger the number the more stable the bed. The river bed becomes less stable at higher flows with very low bed stability and particle movement in Site 4 during high summer flows.

Table 6-18: Relative Bed Stability for selected sites (a = Rising stage, b = receding stage)

	July '15	September '15	October '15	February (a) '16	February (b) '16	April '16	August '16
Site 1	14.15	n/a	n/a	n/a	6.83	3.34	11.43
Site 2	13.14	12.63	14.28	13.46	5.47	12.16	18.25
Site 3	12.48	13.1	13.79	6.39	5.46	7.49	9.03
Site 4	1.48	1.68	1.37	0.78	1.37	1.53	1.27
Site 5	5.58	n/a	n/a	n/a	5.6	17.08	9.15

6.3 Concluding remarks and recommendations for future monitoring

This baseline study provides a set of data about the current geomorphic condition of selected sites in the Tsitsa River as well as seasonal variations in flow hydraulics against which post-impoundment impacts can be assessed.

7 MONITORING AQUATIC BIODIVERSITY AND HABITAT CONDITIONS

7.1 Introduction

The natural and land use processes within a river catchment play a pivotal role in ecosystem health and have a dominant influence on habitats within a river as well as its biological diversity. It has been recognised by many authors that increased sedimentation and turbidity have a direct impact on ecological health in fluvial systems, and is commonly seen as a detrimental aquatic pollutant (Ritchie, 1972; Lemly, 1982; Henley et al., 2000; Allan, 2004). Henley et al*.* (2000) state that the sedimentation and resulting turbidity in a river system impact various aquatic trophic levels through mortality, reduced physiological functioning and drifting of organisms to seek new niches. Natural erosional processes have always contributed to a certain amount of sedimentation in streams. However, anthropogenic impacts on the landscape have augmented the amount of sediment entering fluvial systems. Silt from erosional processes has become a recurring problem (Ellis, 1936). Ellis (1936) states that excessive loads of erosion silt have significantly increased the turbidity of streams as well as the amount of sediment and silt being deposited on river substrates, resulting in a marked change in both aquatic habitats and associated biota.

During turbid flows sedimentation specifically affects river habitats and associated biota by a combination of the following factors: increasing turbidity, the decrease of light penetration, varying rates of temperature change, scouring and abrasion of substrate, infilling and draping of interstitial spaces between diverse substrates reducing available habitat niches, coating of gills and respiratory surfaces, trapping organic material and other substances on the stream bed which are unfavourable to aquatic biota, reducing stream depth heterogeneity and reducing marginal vegetation and erosional banks due to deposition (Ellis, 1936; Steinman & McIntire, 1990; Allan, 2004). This can result in a decrease in pool species (reduction in depth and marginal habitats), rocky substrate species (reduced habitat niches) and sensitive species. In addition the extensive alteration of local scale food webs of aquatic organisms, starting at the primary trophic level , results in reduced rates of growth and reproduction (Henley et al*.,* 2000). However, Henley et al*.* (2000) indicate that the effects of sedimentation and turbidity can be directly linked to the amount of sediment entering a system as well as the time period over which a system is exposed to high sediment loads.

Rivers are complex systems and need to be studied at a range of scales (Allan, 2004). Church (2002) notes that changes in a riverine system occur systematically along a drainage system as the flow, gradient and sediment characteristics vary. This variation in the landscape results in a characteristics sequence of morphological and habitat types (Church, 2002).

River conditions at a local scale are influenced by the river reach as well as processes occurring in the surrounding landscape (Allan, 2004). Small-scale (pool/riffle and microhabitat system) creation and maintenance of habitats for aquatic organisms is shaped from channel processes at intermediate scales (segment and reach system).This in turn stems from large-scale factors (catchment system), such as geology, climate and topography, which shape channel processes by controlling the geomorphic processes within a stream system. Allan (2004) identified that the reach scale morphology is influenced by the catchment slope, input of water and sediment from upstream, valley confinement and bed and bank materials.

Macroinvertebrates are the most preferential group of aquatic organisms to use in the biomonitoring of streams (Dickens & Graham, 2002; Türkmen & Kazanci, 2010), due to their ability to occupy various specific family related microhabitats. If these microhabitats are exposed to a change due to organic or inorganic pollutants macroinvertebrates respond by a change in community composition rather than adapting to the change in habitat (Türkmen & Kazanci, 2010).

7.2 Results and Discussion

Habitat quality

Table 6-8 show measured values of water quality variables and the ASPT derived using SASS for each site, during each monitoring survey. Water quality at different sites is affected by external factors such as the underlying geology, point sources of pollutants and sediment inputs into the channel. Discharge also plays an important role on the water quality of a site. It is important to note that discharges varied significantly between monitoring surveys and during monitoring surveys not all the sites were measured under the same discharge or at the same time. There is a general trend between water quality measured in seasons with low discharges (Table 7-1, Table 7-2, Table 7-3 and Table 7-5) and water quality variables measured in seasons with higher discharges (Table 7-4 and Table 7-5). This will be discussed in more depth below.

The HMID measured during low discharges was very high showing a high variability in hydraulic variables. Months which were sampled under high discharges had lower HMID scores falling between moderate to high variability in hydraulic variables. However, it is expected that during higher discharges there should be a larger range of hydraulic variables (flows and depths), but due to practical reasons the middle of the channel is not accessible during high discharges making it impossible to sample the hydraulic variability in the middle of the channel. Therefore, at low discharges a larger proportion of the channel can be sampled for hydraulic variability. Site 1-3 and 5 show variable HMID scores over different discharges with a general trend of high HMID scores. Site 4, characterised by a very homogenous bed with a low gradient, had the lowest HMID scores, which may affect the number of macroinvertebrate families present in this site.

At low discharges in winter months phosphate levels were very low ranging from 0-0.3 mg l^{-1} in July 2015 and August 2016. October 2015 experienced higher levels of phosphates at low discharge, ranging from 0-1.3 mg l^{-1}. The highest measured phosphate level was found in Site 3 after a small rainfall event bringing a small but turbid flood pulse through the site. Summer months, February and April 2016, with high discharges and turbid waters had phosphate levels ranging from 0.3-1 mg l^{-1}. There is a trend with an increase in phosphate levels after rainfall events' implying that runoff in the catchment is bringing phosphates into the river system, which is then carried down the system by floods. An increase in phosphate concentrations is likely to occur due to leaching of sewage from pit latrines or runoff from cultivated lands (Dallas & Day, 2004). Rivers with healthy amounts of marginal and aquatic vegetation take up phosphates, regulating spikes in phosphate levels experienced during floods (DWAF, 1996). Concentrations of phosphates need to be considerably higher than those found to have a significant impact on biotic health (Dallas & Day, 2004).

Dissolved Oxygen (DO) concentrations show a general trend of being greater than 80% saturation with no significant difference between varying discharges. The lowest measured DO was 72% measured in Site 1 at low discharges in July 2015. None of the DO concentrations fall below 50% which is defined as sub-lethal to aquatic organisms (DWAF, 1996). Therefore concentrations of DO are not seen to have any significant impacts on biotic health in the Tsitsa River over the monitoring period.

Water temperatures in winter months range from 9.5 - 13.5˚C in July 2015 and 6.9 - 9.5˚C in August 2016. August 2016 has lower temperatures due to snow melt in the catchment. During summer months water temperatures range from 14.7-25.7. These were measured at different times of day. The highest temperatures were found in Site 4 which is the shallowest site with the slowest moving water, allowing for higher but more variable water temperatures. It is difficult to establish whether the water temperatures impacted aquatic biota negatively, due to the spatial differences in temperatures and the differences in temperature tolerances of biota. Therefore, the measured temperature data can be used as a baseline, before dam construction, for the current site-specific temperatures found for the Tsitsa River over the monitoring period.

A well buffered South African river will be expected to have a pH ranging between 6 and 8, but fluctuations occur due to a changes in temperature, photosynthetic activity or biotic respiration and decomposition of organic matter (DWAF, 1996; Dallas & Day, 2004). In Site 1 pH varied from 7.7 - 8.2, Site 2 pH varied from 7.5 - 8.2, Site 3 pH varied from 7.5 - 8.3, Site 4 pH varied from 7.4 - 8.1 and Site 5 pH varied from 7.5 - 8.1. This indicates a balanced system with seasonal fluctuations in pH.

According to Dallas & Day (2004) very little information is available on the tolerance of aquatic organisms to increased conductivity. The rate of change rather than the absolute change is important in accessing the effects on organisms. Electric Conductivity (EC) levels seasonally ranged from 16.9 - 127 µs cm^{-1} with a general trend of a decrease in EC with an increase in turbidity and flow. This could possible occur due to the influx of rain water into the stream network.

The clarity of the water can be linked to rainfall events in the catchment resulting in an increased runoff and turbidity within the river. Site 1 generally had the lowest clarity, as it is situated highest up in the catchment and clarity slowly decreased as you moved down the river system, implying a cumulative decrease in clarity. A similar trend can be found when looking at Turbidity. Turbidity increases as you move down the river system. Turbidity peaked during high discharges when runoff from rainfall in the catchment increases the turbidity.

Table 7-1: Measured water quality variables for July 2015

Site	1	2	3	4	5
HMID	12.3	9.8	10.5	7.6	10.8
Phosphates (mg l^{-1})	0	0.3	0	0	0
Dissolved Oxygen (%)	72	83	75	91	97
Temperature (˚C)	9.6	13.4	10.3	11	9.5
pH	8.2	8.1	8.1	7.9	8.1
Electric Conductivity (µS cm^{-1})	60	59	67	95	85
Clarity (cm)	94	48	49	33	37
Turbidity (FTU)	40	60	80	100	100
ASPT	5.4	6.3	5.9	4.3	5.9

Table 7-2: Measured water quality variables for October 2015

Site	2	3	4
HMID	22.1	8.0	4.0
Phosphates (mg l^{-1})	1.3	0.2	0
Dissolved Oxygen (%)	81.2	84.4	81.7
Temperature (˚C)	19	20.9	15.6
pH	8.0	8.2	8.1
Electric Conductivity (µS cm^{-1})	85	87	127
Clarity (cm)	6.5	37	10.5
Turbidity (FTU)	130	30	98
ASPT	6	6.1	5.6

The ASPT gave a rapid idea of the ecological state of the river. The ASPT in Site 1 ranged from 5.4 to 7.4 implying a fair to natural ecological state. Site 2 ranged from 5.8 to 6.3 implying a good ecological state. Site 3 ranged from 5.9 to 6.8 implying a good ecological state. Site 4, dominated by a sandy habitat, ranged from 4.3 to 6.2 implying a poor to good ecological state. Site 5 ranged from 5.4 to 6.7 implying a moderate to good ecological state. A rapid assessment of the Tsitsa River implies that the state of the Tsitsa River changes depending on the season and the reach. The Gorge reach ranges from moderately modified to unmodified (ecological category A-C), the reach between the dam wall and the Inxu River confluence is largely natural with few modifications (ecological category B) and the Tsitsa River below the confluence of the Inxu River ranges from largely modified (Site 4) to largely natural with few modifications (Site 5) (ecological category A-D).

Table 7-3: Measured water quality variables for February 2016.

Site	1	2	3	4	5
HMID	5.9	6.1	5.9	3.6	11.5
Phosphates (mg l^{-1})	0.5	0.3	0.7	1	0.5
Dissolved Oxygen (%)	89.5	85.8	89.6	87.3	86.3
Temperature (˚C)	21.3	20.8	25.4	25.7	22.7
pH	8.1	8.2	8.0	7.9	8.1
Electric Conductivity (µS cm^{-1})	31	23	28	31	28
Clarity (cm)	17	7	9.5	6	6
Turbidity (FTU)	74	150	120	230	216
ASPT	7.4	5.8	6.8	5.0	6.7

Table 7-4: Measured water quality variables for April 2016

Site	1	2	3	4	5
HMID	8.4	8.6	9.5	3.4	6.7
Phosphates (mg l^{-1})	0.3	No data	0.4	1	0.5
Dissolved Oxygen (%)	81.9	82.4	89	77.8	85.5
Temperature (˚C)	14.7	16.9	19.5	25.5	19.9
pH	7.6	7.5	8.3	7.4	7.5
Electric Conductivity (µS cm^{-1})	43	16.9	58	62	65
Clarity (cm)	7	0.2	53	41	38
Turbidity (FTU)	128	>2000	54	50	58
ASPT	6.4	6.0	6.8	6.2	6.4

Table 7-5: Measured water quality variables for August 2016

Site	1	2	3	4	5
HMID	15.5	9.2	11.5	6.9	9.3
Phosphates (mg l^{-1})	0.3	0	0.2	0.3	0.2
Dissolved Oxygen (%)	No data	No data	No data	No data	No data
Temperature (˚C)	6.9	7.5	7.4	8.2	9.5
pH	7.7	7.5	7.5	7.8	7.8
Electric Conductivity (µS cm^{-1})	41	35	38	47	43
Clarity (cm)	63	26	30	18	23
Turbidity (FTU)	74	88	90	104	102
ASPT	6.3	6.2	6.2	4.9	6.4

Table 7-6: Measured ASPT scores

Site	1	2	3	4	5
July 2015	5.4	6.3	5.9	4.3	5.9
October 2015	No Data	6	6.1	5.6	No Data
February 2016	7.4	5.8	6.8	5.0	6.7
April 2016	6.4	6.0	6.8	6.2	6.4
August 2016	6.3	6.2	6.2	4.9	6.4

In order to understand which of the above mentioned variables might be affecting the ASPT, we need to look at which of the variables show a good (positive or negative) correlation to the ASPT (to Table 7-11).

In July 2015 (see Table 7-7) HMID and pH positively correlate with the ASPT implying that an increase in habitat diversity and pH increased the ASPT. EC negatively correlates to ASPT implying that an increased EC decreased the ASPT.

Table 7-7: July 2015. Correlation between ASPT of macroinvertebrates, derived using SASS methodology, and measured water quality and habitat variables

Independent Variables	Correlation Coefficient to ASPT
HMID	**0.738**
Phosphate (mg l^{-1})	0.384
Dissolved Oxygen (%)	-0.312
Temperature (˚C)	0.066
pH	**0.768**
Electric Conductivity (µS cm^{-1})	**-0.743**
Clarity (cm)	0.301
Turbidity (FTU)	-0.444
Discharge (m^3 s^{-1})	-0.191

October 2015 (Table 7-8) experienced the lowest discharge during monitoring surveys. Discharge correlates negatively to discharge implying that at very low discharges the ASPT is increased. A reduction in the ASPT can also be correlated with an increase in EC. An increase in ASPT can be correlated to an increase in habitat diversity (HMID), DO, Temperature and water clarity.

Table 7-8: October 2015. Correlation between ASPT of macroinvertebrates, derived using SASS methodology, and measured water quality and habitat variables

Independent Variables	Correlation Coefficient to ASPT
HMID	**0.520**
Phosphate (mg l^{-1})	0.459
Dissolved Oxygen (%)	**0.538**
Temperature (˚C)	**0.985**
pH	0.027
Electric Conductivity (µS cm^{-1})	**-0.973**
Clarity (cm)	**0.559**
Turbidity (FTU)	-0.385
Discharge (m^3 s^{-1})	**-0.994**

February 2016 (Table 7-9) experienced high and turbid flows with both flow and turbidity reducing over the monitoring survey. An increased discharge, turbidity and phosphate concentration results in a decrease in the ASPT. An increase in water clarity and habitat diversity increased the ASPT.

Table 7-9: February 2016. Correlation between ASPT of macroinvertebrates, derived using SASS methodology, and measured water quality and habitat variables

Independent Variables	Correlation Coefficient to ASPT
HMID	**0.560**
Phosphate (mg l^{-1})	**-0.504**
Dissolved Oxygen (%)	0.497
Temperature (˚C)	-0.326
pH	0.356
Electric Conductivity (µS cm^{-1})	0.022
Clarity (cm)	**0.578**
Turbidity (FTU)	**-0.643**
Discharge (m^3 s^{-1})	**-0.927**

April 2016 (Table 7-10) experienced low flows and turbidity at the beginning of the monitoring survey which then increased over time. The ASPT was increased with higher habitat diversity, DO, and pH APST decreased by an increase in temperature and phosphate concentrations.

Table 7-10: April 2016. Correlation between ASPT of macroinvertebrates, derived using SASS methodology, and measured water quality and habitat variables

Independent Variables	Correlation Coefficient to ASPT
HMID	**0.862**
Phosphate (mg l^{-1})	**-0.993**
Dissolved Oxygen (%)	**0.759**
Temperature (˚C)	**-0.808**
pH	**0.507**
Electric Conductivity (**µS cm^{-1}**)	-0.098
Clarity (cm)	-0.135
Turbidity (FTU)	-0.095
Discharge (m^3 s^{-1})	0.368

In August 2016 (Table 7-11) the ASPT increases with an increase in habitat diversity and clarity. The ASPT is reduced by an increase in both discharge and turbidity.

Table 7-11: August 2016. Correlation between ASPT of macroinvertebrates, derived using SASS methodology, and measured water quality and habitat variables

Independent Variables	Correlation Coefficient to ASPT
HMID	**0.913**
Phosphate (mg l^{-1})	0.220
Dissolved Oxygen (%)	n/a
Temperature (˚C)	-0.264
pH	-0.044
Electric Conductivity (**µS cm^{-1}**)	-0.269
Clarity (cm)	**0.810**
Turbidity (FTU)	**-0.700**
Discharge (m^3 s^{-1})	**-0.547**

Biological Variables

It has been recognised by many authors that increased sedimentation and turbidity have a direct impact on ecological health in fluvial systems, and is commonly seen as the most detrimental aquatic pollutant (Ritchie, 1972; Lemly, 1982; Henley et al., 2000; Allan, 2004; Jones et al., 2011).

The community structure of macroinvertebrates is dependant on substrate type and conditions. Several variables affect the suitability of habitats to different macroinvertebrate families. In areas where flow is sufficient to wash away fines (eg. cobble riffles) macroinvertebrate abundance and diversity increases (higher ASPT) and the river maintains a more natural condition. Macroinvertebrates seek refuge in aquatic vegetation during high turbid flows. Presence of vegetation in sites containg fines sediment deposits increases the ASPT. Lack of vegetation, low flows and depths and high concentrations of fine sediment with a low substrate diversity decreased the ASPT.

The more diverse substrate is on the river bed the more habitat types are available for colonisation by macroinvertebrates. Figure 7-1 shows that for Reach 1 substrate diversity is highly variable in the Rocky habitat, ranging from a low diversity in bedrock dominated habitats to more diverse substrates in cobble beds. Reach 2 has the highest overall substrate diversity. The fines in Reach 1 and 2 have less variability with the majority of the data exhibiting no substrate diversity. Vegetation shows the least variation in substrate diversity, commonly occurring along the banks as marginal vegetation alongside fine sediments. The variability can be accounted for by the proportions of each habitat presented within a quadrat. The more equally presented each substrate type, the higher the ‘H score.

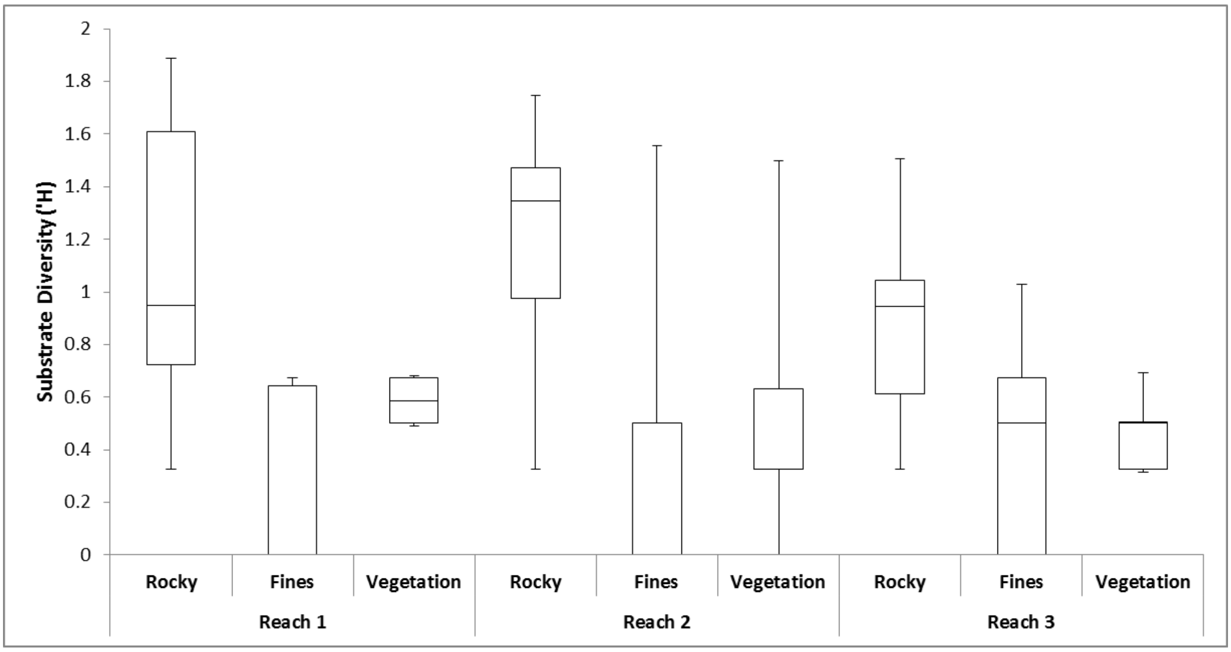

Figure 7-1: Box and whisker plots of substrate diversity for different habitats in each reach.

Surface sediment drape results from the deposition of suspended sediment during reduced water velocity and covers the stream bed substrate. Figure 7-2 shows that the concentrations of fine sediment drape have less variability and are generally lower than the concentrations of fine sediment found in habitats dominated by fines. Rocky habitats are generally found in faster flowing water which is less suitable for the deposition of sediment whereas habitats dominated by fines are found in areas of the river where deposition takes place due to reduced flow conditions. Reach 1 has the lowest concentration of fine sediment drape, implying less deposition both rocky and fine habitats. Reach 2 and 3 have similar variability in fine sediment deposition. The median concentration of fine sediment drape is low in rocky habitats. Reach 2, which includes Site 4, has the highest median for fine sediment drape concentrations in habitats dominated by fines. Outliers in habitats dominated by fines in Reach 2 and 3 were sampled on silt banks which are very fine and exhibit a high concentration of fine sediment drape.

Subsurface sediment fills interstitial spaces of bed substrate or in severe cases covers an entire bed of substrate. It is deposited during prolonged periods of reduced water velocity and is not as easily entrained as surface sediment drape. Figure 7-2 shows trends similar to those of surface sediment drape concentrations, however subsurface sediment concentrations are significantly higher (Figure 7-3). The subsurface sediment concentration in rocky habitats in Reach 1 has very little subsurface fine sediment deposits, implying very little deposition of fines in this habitat. Reach 1 is dominated by bedrock substrate which occurs in fast flowing parts of the river. There is a higher variability of concentrations of subsurface sediment concentrations in habitats dominated by fines possibly due to the variability in the depths of fine sediment deposits as well as the grain size of the sediment.

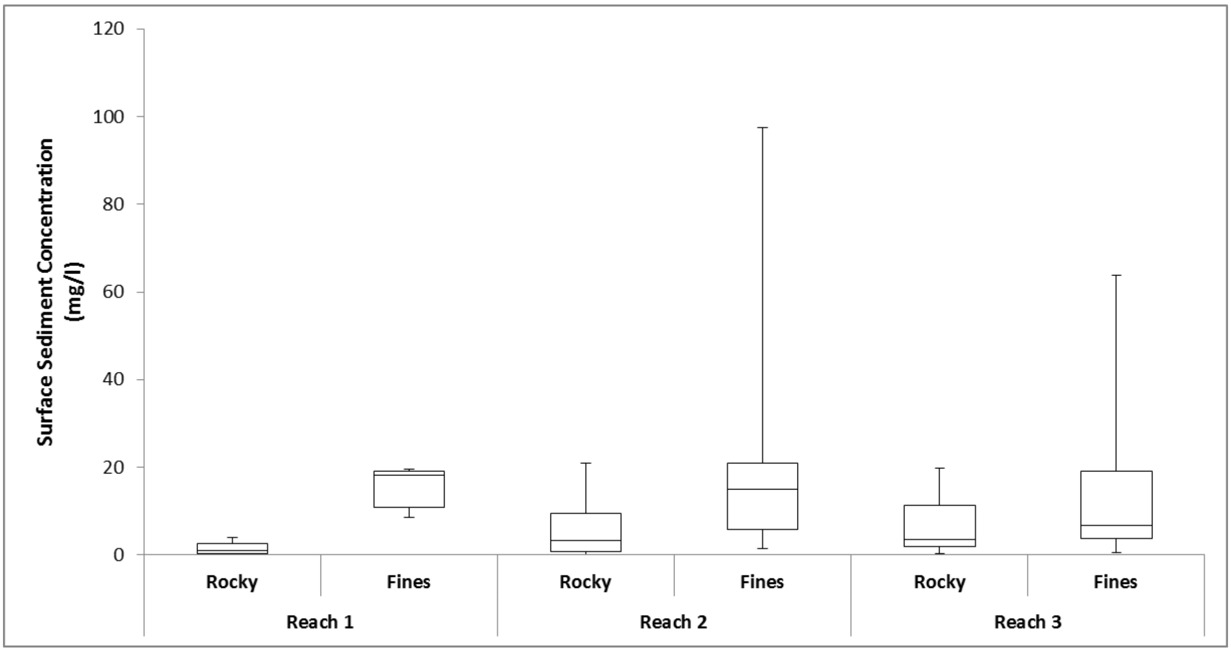

Figure 7-2: Box and whisker plots of sampled surface sediment concentration for different habitats in each reach.

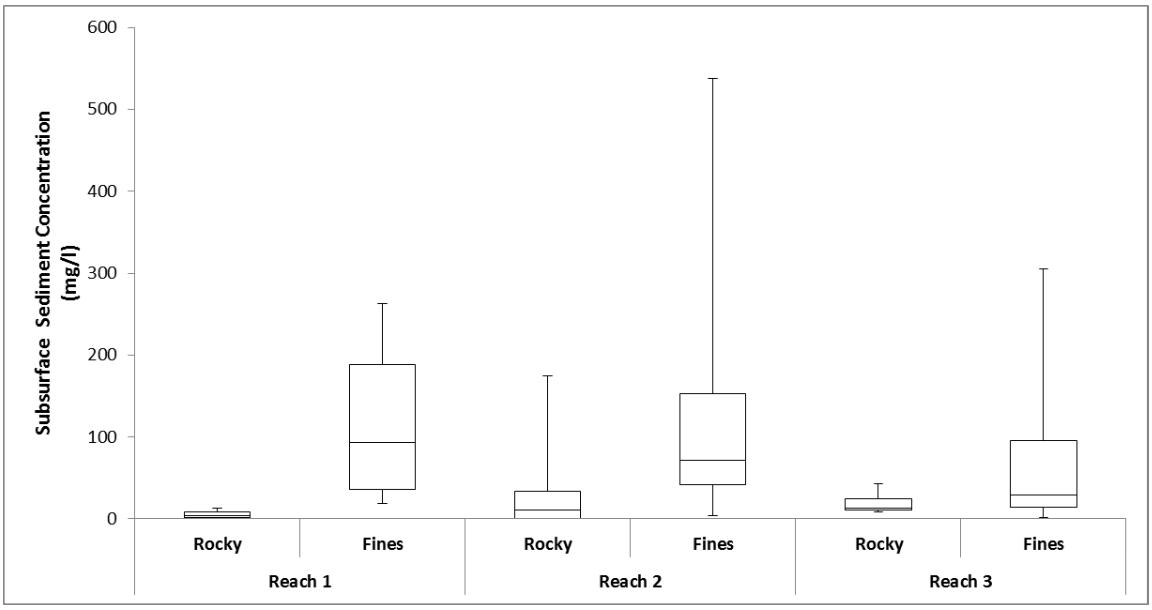

Figure 7-3: Box and whisker plots of sampled subsurface sediment concentration for different habitats in each reach.

More turbid flows generally occur due to an increase in suspended sediment concentrations sourced from eroded materials which enter the river system. Excessive suspended sediment concentrations affect both river habitats and associated biota. Figure 7-4 shows suspended sediment concentrations for each reach. Reach 1 and 2 have similar trends with lower concentrations in Reach 1. Reach 3 below the Inxu River confluence shows higher concentrations of suspended sediment with the median being equal to the third quartile of the data. The outlier in Reach 2 was sampled during the peak stage of a very turbid flood.

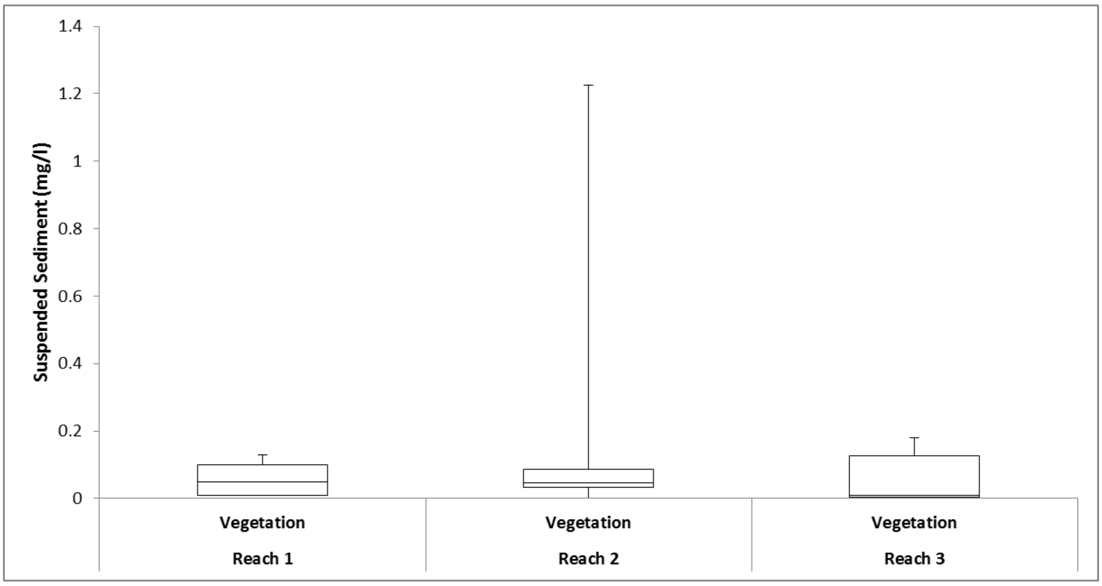

Figure 7-4: Box and whisker plots of sampled suspended sediment concentration for different habitats in each reach.

Different water depths allow for different habitat conditions. A more variable water depth results in more diverse habitats. Figure 7-5 shows that Reach 1 has more variable depths in the rocky and vegetation habitats, with the highest variability found in the vegetation habitat. Reach 2 shows similar trends however overall the depths are less. Reach 2 is less confined than Reach 1. Reach 3 shows the least variability and shallowest depths. Reach 3 is characterised by a lower gradient and wider channel resulting in a more homogenous channel bed.

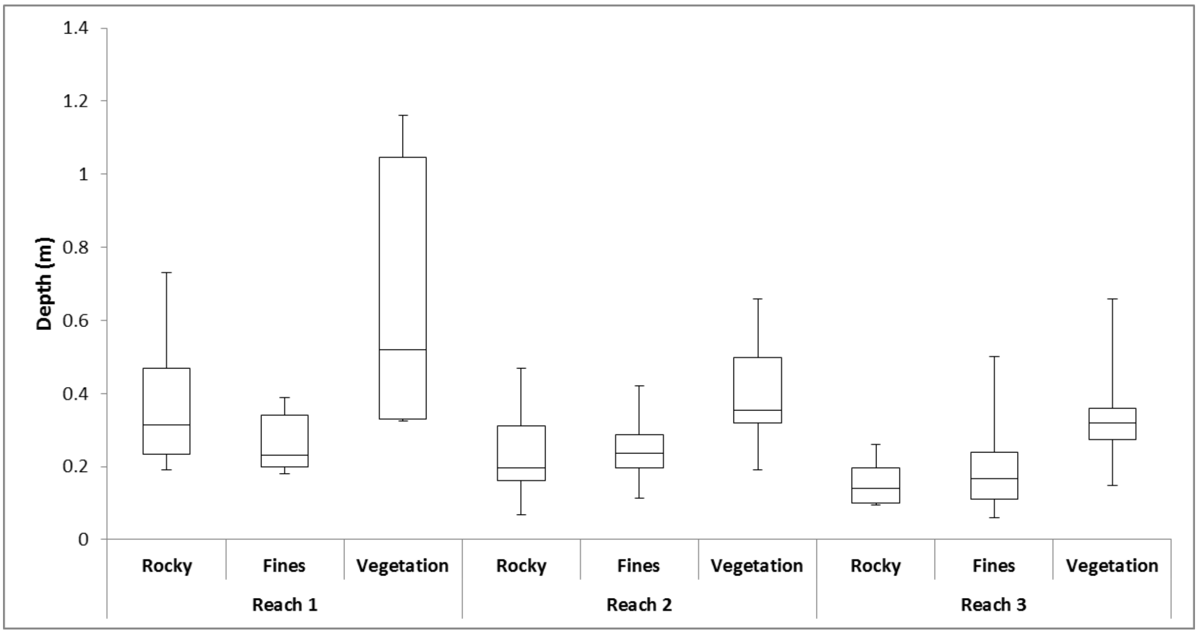

Figure 7-5: Box and whisker plots of sampled depths for different habitats in each reach.

Different flow conditions affect aquatic biota differently. Flow can be closely linked to sediment regimes. Different flows allow for different habitat conditions. Figure 7-6 shows a general trend of higher variability and higher flows in both rocky and vegetation habitats. The fines habitat has less variability and lower flows implying that fines are deposited under reduced flow conditions.

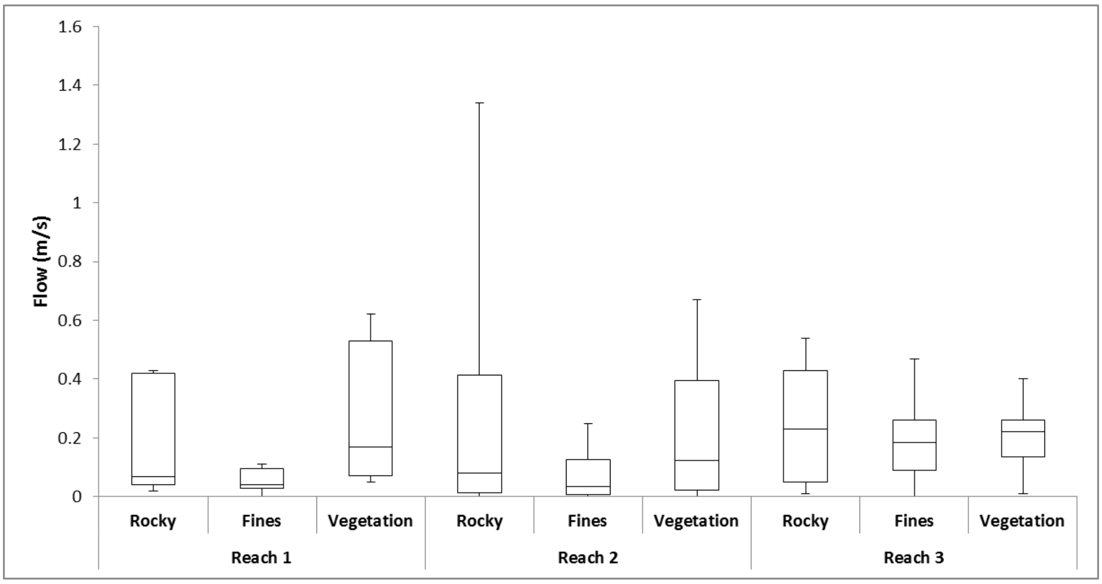

Figure 7-6: Box and whisker plots of sampled flows for different habitats in each reach.

Macroinvertebrate diversity shows the abundance and proportion of different types of macroinvertebrates present in each habitat. Figure 7-7 shows that rocky habitats, in particular

Reach 1, have the highest variability of macroinvertebrate diversity. Bedrock dominated habitats will have a lower diversity of macroinvertebrates whereas cobble beds will have a higher diversity of macroinvertebrates due to a higher diversity of available habitat. There are no significant differences in the medians of different habitat types implying that different macroinvertebrate communities inhabit different habitat types, with none of the habitats being significantly more suitable for macroinvertebrate diversity.

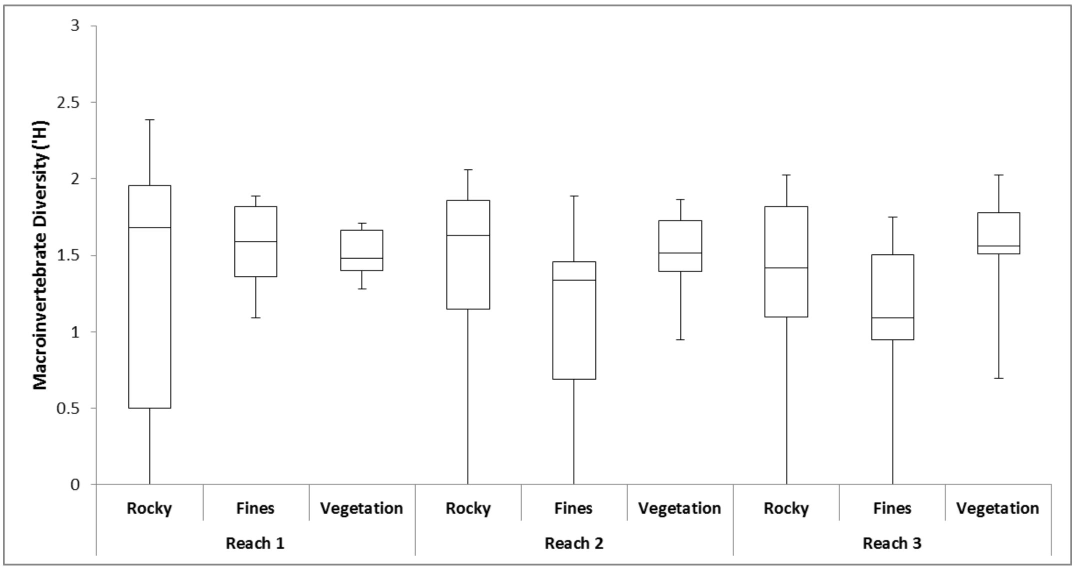

Figure 7-7: Box and whisker plots macroinvertebrate diversity for different habitats in each reach.

Different macroinvertebrate families have differing tolerances to fine sediment accumulation. A higher ASPT implies a larger occurrence of macroinvertebrates that are sensitive to fine sediment accumulation. Figure 7-8 shows that Rocky habitats, particularly in Reach 1, are inhabited by sediment sensitive macroinvertebrate families. Macroinvertebrate families occurring in marginal vegetation are also not tolerant to high sediment concentrations. As expected habitats dominated by fines are also inhabited by macroinvertebrates that are less sensitive to sediment accumulation.

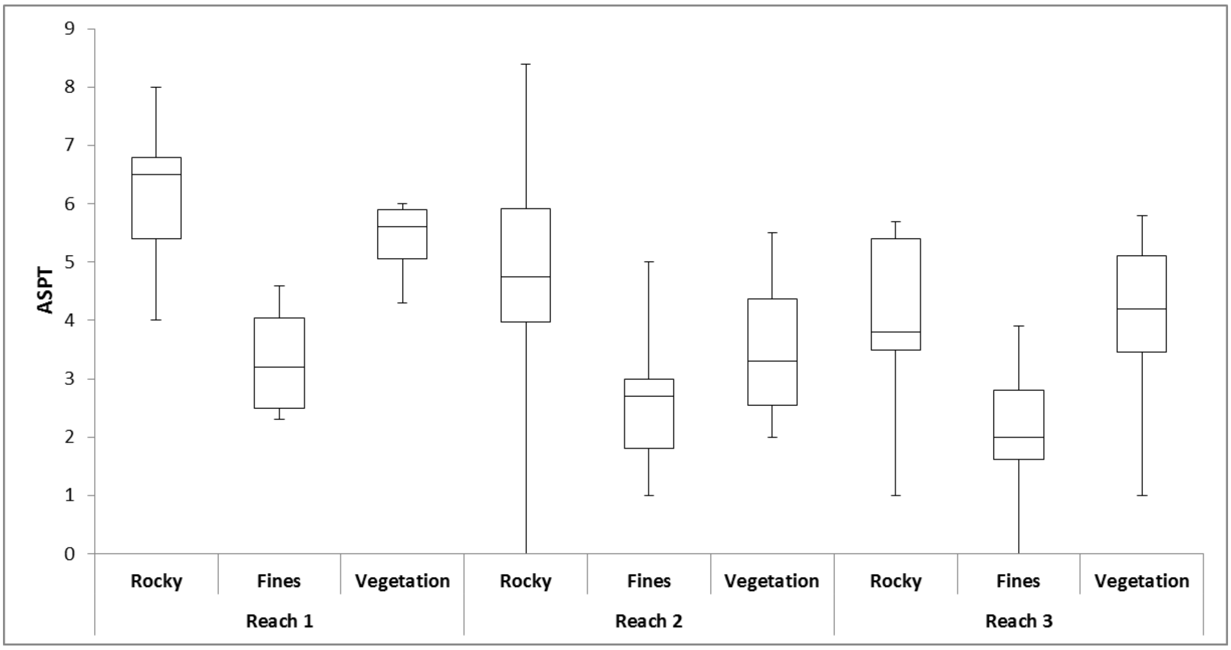

Figure 7-8: Box and whisker plots of the ASPT for sediment sensitive species for different habitats in each reach.

The influence of the above variables on each other differs in each habitat type in each reach depending on the characteristics of the reach. Different reaches were monitored over the same time period. However flow in the Tsitsa River is highly variable. Not all the sites could be monitored at the exact same time during each field visit. Therefore, variations in depth, flow and sediment concentrations occur due to changes in the hydrology over the sampling period. The correlation between variables varies between each Reach. The reader must note that these changes are chiefly due to differences in morphology but partially also due to sampling periods.

Table 7-12 shows that rocky habitats in Reach 1 show very little deposition of fines to clog up interstitial spaces, allowing for a variety of habitats to be colonised by a diversity of macroinvertebrates. Therefore there is a strong correlation between substrate diversity, macroinvertebrate diversity and the ASPT. There is a negative correlation between the concentration of surface and subsurface sediment and flow implying that rocky habitats occur in fast flowing water which entrains rather than deposits sediment. This in turn correlates with the macroinvertebrate diversity implying that taxa in the rocky habitat prefer higher flows, possibly due to the lack of fine sediment.

Table 7-12: Reach 1, Rocky habitat. Correlation between variables affecting habitat quality, at a quadrat scale. Red shows correlation between independent factors on the ASPT for sediment sensitive biota

	Substrate Diversity (H')	Surface (mg l-1)	Sub-surface (mg l-1)	Depth (m)	Flow (m.s^{-1})	Macroinvertebrate Diversity (H')	ASPT: Surface sediment sensitivity
Substrate Diversity (H')	1						
Surface (mg l^{-1})	-0.34	1					
Subsurface (mg l^{-1})	-0.07	**0.98**	1				
Depth (m)	0	**0.81**	0.14	1			
Flow (m.s^{-1})	0.35	**-0.60**	**-0.63**	0	1		
Macroinvertebrate Diversity (H')	**0.72**	**-0.63**	-0.19	0.15	**0.75**	1	
ASPT: Surface sediment sensitivity	**0.89**	-0.31	-0.23	0.26	0.41	**0.79**	1

Table 7-13 shows that substrate diversity can be negatively correlated with macroinvertebrate diversity meaning that a reduction in substrate diversity (only fines present) results in a reduction in the abundance and types of taxa present. There is a strong negative correlation between substrate diversity and surface sediment implying that habitats dominated by fines have very little substrate diversity. There is a strong correlation between the concentration of subsurface sediments and the ASPT in Reach 1 as subsurface disturbance samples were low due to the reach morphological characteristics not being prone to the deposition of fines. Flow has a negative correlation to ASPT implying that the higher the flow the lower the ASPT. Fine sediments in Reach 1 were limited and found near rocky and marginal vegetation habitats.

Table 7-14 shows that there is a strong negative correlation between substrate diversity and suspended sediment, implying that the higher the suspended sediment the higher the substrate diversity. This can be linked to the correlation between substrate diversity and flow. Generally the higher the flow, the more marginal vegetation is covered including those with a range of substrates for example, marginal vegetation at a low flow might only have a part sticking into the water whereas at high flow marginal vegetation and part of the river bank make up a more diverse substrate. Depth correlates with the macroinvertebrate diversity and ASPT implying that an increase in depth results in larger numbers of sensitive macroinvertebrates in the marginal vegetation habitat.

Table 7-13: Reach 1, Fine substrate habitat. Correlation between variables affecting habitat quality, at a quadrat scale. Red shows correlation between independent factors on the ASPT for sediment sensitive biota

	Substrate Diversity (H')	Surface (mg l-1)	Sub-surface (mg l-1)	Depth (m)	Flow (m.s^{-1})	Macroinvertebrate Diversity (H')	ASPT: Surface sediment sensitivity
Substrate Diversity (H')	1						
Surface (mg l^{-1})	**-0.99**	1					

Subsurface (mg l^{-1})	-0.34	0.32	1				
Depth (m)	0.45	**-0.53**	0.43	1			
Flow ($m.s^{-1}$)	0.42	-0.44	-0.32	0.37	1		
Macroinvertebrate Diversity (H')	**-0.87**	**0.87**	**0.51**	-0.18	-0.04	1	
ASPT: Surface sediment sensitivity	0.12	-0.12	**0.72**	0.38	**-0.61**	-0.16	1

Table 7-14: Reach 1, Marginal vegetation habitat. Correlation between variables affecting habitat quality, at a quadrat scale. Red shows correlation between independent factors on the ASPT for sediment sensitive biota

	Substrate Diversity (H')	Suspended Sediment (mg l-1)	Depth (m)	Flow ($m.s^{-1}$)	Macro-invertebrate Diversity (H')	ASPT: Surface sediment sensitivity
Substrate Diversity (H')	1					
Suspended Sediment (mg l^{-1})	**-0.99**	1				
Depth (m)	0.33	-0.28	1			
Flow ($m.s^{-1}$)	**-0.83**	**0.88**	0	1		
Macroinvertebrate Diversity (H')	0.04	-0.02	**0.75**	0.01	1	
ASPT: Surface sediment sensitivity	**0.38**	-0.29	**0.74**	0.18	-0.15	1

Table 7-15 shows a positive correlation between substrate diversity and macroinvertebrate diversity implying that in Reach 2, the higher the diversity of substrates the higher the abundance and types of taxa found. Because of the varying morphologies in which rocky habitats are found in Reach 2 most of the correlations are randomly distributed showing little or no correlation to each other, with macroinvertebrate diversity having the strongest correlation to the ASPT.

Table 7-15: Reach 2, Rocky habitat. Correlation between variables affecting habitat quality, at a quadrat scale. Red shows correlation between independent factors on the ASPT for sediment sensitive biota

	Substrate Diversity (H')	Surface (mg l-1)	Sub-surface (mg l-1)	Depth (m)	Flow ($m.s^{-1}$)	Macroinvertebrate Diversity (H')	ASPT: Surface sediment sensitivity
Substrate Diversity (H')	1						
Surface (mg l^{-1})	-0.40	1					
Subsurface (mg l^{-1})	0.01	**0.58**	1				
Depth (m)	0.14	0.18	-0.10	1			
Flow ($m.s^{-1}$)	0.47	**-0.53**	-0.39	-0.06	1		
Macroinvertebrate Diversity (H')	**0.59**	-0.28	0.18	0.26	0.37	1	
ASPT: Surface sediment sensitivity	0.14	-0.01	-0.31	0.14	0.15	0.47	1

Table 7-16 shows a strong correlation between surface and subsurface concentrations. The corresponding increase in subsurface concentration with surface concentration implies that the surface sediment is less variable (i.e. not entrained and deposited as easily as in Reach 1). An increase in depth also correlates to an increase in macroinvertebrate diversity, possibly with an increase in depth macroinvertebrates are less affected by surface drape and an increase in depth allows for more diverse habitat conditions. An increase in surface sediment concentrations decreases the ASPT as expected.

Table 7-16: Reach 2, Fine substrate habitat. Correlation between variables affecting habitat quality, at a quadrat scale. Red shows correlation between independent factors on the ASPT for sediment sensitive biota

	Substrate Diversity (H')	Surface (mg l-1)	Sub-surface (mg l-1)	Depth (m)	Flow ($m.s^{-1}$)	Macroinvertebrate Diversity (H')	ASPT: Surface sediment sensitivity
Substrate Diversity (H')	1						
Surface (mg l^{-1})	-0.19	1					
Subsurface (mg l^{-1})	-0.36	**0.75**	1				
Depth (m)	-0.1	0.42	0.42	1			
Flow ($m.s^{-1}$)	0.32	-0.19	-0.19	0.05	1		
Macroinvertebrate Diversity (H')	0.21	0.28	0.28	**0.52**	0.20	1	
ASPT: Surface sediment sensitivity	0.46	**-0.51**	-0.16	-0.33	-0.08	**0.55**	1

Table 7-17 shows that an increase in flow can be correlated with an increase in depth. An increase in depth and flow can be correlated to an increase in macroinvertebrate diversity and an increase in suspended sediment concentration can be linked to a higher ASPT. Floods in the Tsitsa River increase the depth, flow and suspended sediment concentration of the water. In Reach 2 where marginal vegetation is prolific on the banks of the river macroinvertebrates tend to cling to the vegetation during these floods. Therefore a higher diversity of macroinvertebrates was found.

Table 7-18 shows a strong correlation between surface drape and sub-surface sediment concentrations implying that rocky substrates are quite highly embedded and voids between larger particles are likely filled with fines. An increase in depth correlates to a reduction in surface drape and sub-surface concentrations implying that fine sediment is being deposited in shallower water. Subsurface sediment drape decreases with an increase in flow implying that faster moving water is entraining rather than depositing fine sediment. Scouring of the bed and entrainment of bed sediment occurs during high flows.

Table 7-17: Reach 2, Marginal vegetation habitat. Correlation between variables affecting habitat quality, at a quadrat scale. Red shows correlation between independent factors on the ASPT for sediment sensitive biota

	Substrate Diversity (H')	Suspended Sediment (mg l-1)	Depth (m)	Flow ($m.s^{-1}$)	Macro-invertebrate Diversity (H')	ASPT: Surface sediment sensitivity
Substrate Diversity (H')	1					
Suspended Sediment (mg l^{-1})	-0.05	1				
Depth (m)	-0.44	-0.44	1			
Flow ($m.s^{-1}$)	-0.42	-0.18	**0.70**	1		
Macroinvertebrate Diversity (H')	-0.26	-0.17	**0.60**	**0.51**	1	
ASPT: Surface sediment sensitivity	0.04	**0.74**	-0.41	-0.35	-0.17	1

Table 7-18: Reach 3, Rocky habitat. Correlation between variables affecting habitat quality, at a quadrat scale. Red shows correlation between independent factors on the ASPT for sediment sensitive biota

	Substrate Diversity (H')	Surface (mg l-1)	Sub-surface (mg l-1)	Depth (m)	Flow ($m.s^{-1}$)	Macroinvertebrate Diversity (H')	ASPT: Surface sediment sensitivity
Substrate Diversity (H')	1						
Surface (mg l^{-1})	-0.03	1					
Subsurface (mg l^{-1})	0.15	**0.94**	1				
Depth (m)	-0.31	**-0.57**	**-0.79**	1			
Flow ($m.s^{-1}$)	0.01	-0.24	**-0.58**	0.37	1		
Macroinvertebrate Diversity (H')	0.48	-0.22	-0.22	-0.26	-0.04	1	
ASPT: Surface sediment sensitivity	0.01	0.16	-0.13	-0.35	-0.22	**0.78**	1

Surface sediment does not show a similar trend but this may be explained by seasonal flow patterns. When flow is low (low baseflow) surface sediment is deposited when flow is high (high baseflow/ floods) surface sediment is entrained. Macroinvertebrate diversity correlates with a high ASPT implying that the taxa present are diverse and there are sensitive species present. This can be linked to the low surface sediment concentrations in the Rocky Reach.

Table 7-19 shows that surface sediment concentrations correlate to subsurface concentrations implying that Reach 3 has thick deposits of fines including silt banks. There is a slight positive correlation between ASPT and macroinvertebrate diversity.

Table 7-19: Reach 3, Fine substrate habitat. Correlation between variables affecting habitat quality, at a quadrat scale. Red shows correlation between independent factors on the ASPT for sediment sensitive biota

	Substrate Diversity (H')	Surface (mg l-1)	Sub-surface (mg l-1)	Depth (m)	Flow ($m.s^{-1}$)	Macroinvertebrate Diversity (H')	ASPT: Surface sediment sensitivity
Substrate Diversity (H')	1						
Surface (mg l^{-1})	-0.18	1					
Subsurface (mg l^{-1})	-0.36	**0.89**	1				
Depth (m)	-0.31	0.07	0.18	1			
Flow ($m.s^{-1}$)	-0.07	-0.24	0	0.32	1		
Macroinvertebrate Diversity (H')	-0.34	0.20	0.43	0.07	-0.29	1	
ASPT: Surface sediment sensitivity	-0.15	-0.31	-0.18	0.32	-0.17	**0.52**	1

Table 7-20 shows that higher suspended sediment concentrations can be correlated with an increase in substrate diversity. An increase in depth and macroinvertebrate diversity correlates to an increase in ASPT. This can be explained by an increase in submerged marginal vegetation during higher, more turbid flows in which a multitude of macroinvertebrates find refuge.

Table 7-20: Reach 3, Marginal vegetation habitat. Correlation between variables affecting habitat quality, at a quadrat scale. Red shows correlation between independent factors on the ASPT for sediment sensitive biota

	Substrate Diversity (H')	Suspended Sediment (mg l-1)	Depth (m)	Flow ($m.s^{-1}$)	Macro-invertebrate Diversity (H')	ASPT: Surface sediment sensitivity
Substrate Diversity (H')	1					
Suspended Sediment (mg l^{-1})	**0.84**	1				
Depth (m)	-0.16	-0.49	1			
Flow ($m.s^{-1}$)	0.10	-0.05	-0.30	1		
Macroinvertebrate Diversity (H')	-0.22	-0.41	0.37	0.32	1	
ASPT: Surface sediment sensitivity	-0.23	-0.36	**0.63**	-0.18	**0.65**	1

When exposed to a change in habitat, for example due to an increase in sediment deposition on the river bed or suspended sediment concentration, macroinvertebrates respond to a change in community structure rather than adapt to the change (Türkmen & Kazanci, 2010; Jones et al., 2011). Figure 7-9 shows the community structure of different macroinvertebrate classes' occurring in habitats with varying fine sediment drape concentrations (Low = <1 mg l^{-1}; Medium = 1-10 mg l^{-1}; High = >10 mg l^{-1}). Different families in each class have a varying tolerance to fine sediment concentrations (Figure 7-10). Each class of macroinvertebrates and the families in each class, found in the Tsitsa River are discussed below. A statement of the optimal habitat in which each macroinvertebrate class occurs is given followed by the conditions, with regard to fine sediment concentration, in which each family found in the Tsitsa River was observed. Macroinvertebrates found in the least abundance will be discussed first followed by macroinvertebrate classes more tolerant to fine sediment concentrations.

Hirudinae (Leeches) are found in found in shallow pools or areas of the river with reduced flow (Gerber & Gabriel, 2002). Hirudinae commonly latch onto substrate and are found under stones. In the Tsitsa River, shallow pool areas and areas of reduced flow were highly embedded with high concentrations of sediment drape and are therefore not suitable for Hirudinae. A low abundance of Hirudinae was found in habitats with a low concentration of surface sediment drape (Figure 7-9).

Turbellaria (Flatworms), such as Planaria, are sensitive to strong light, and are found under stones or other solid objects (Gerber & Gabriel, 2002). In the Tsitsa River a low abundance of Turbellaria were found in less embedded coarse substrates with low to medium concentrations of sediment drape, as well as clinging onto marginal vegetation.

Crustacea, such as Potamonautidae, are found under or among rocks (Gerber & Gabriel, 2002). In the Tsitsa River a low abundance of Crustacea were found in rocky habitats with low to medium concentrations of surface sediment drape.

Mollusca, such as Ancylidae, occur on rocks or any other submerged object whereas families such as Sphaeriidae occur in coarse sands and fine gravels (Gerber & Gabriel, 2002). In the Tsitsa River Ancylidae were found in rocky habitats with low to medium concentrations of fine sediment drape, with a higher abundance in low concentrations. Sphaeriidae occurred in medium concentrations of fine sediment drape. However, Mollusca were not found in habitats with high concentrations of fine sediment drape.

Zygoptera (Damselflies) are found in marginal vegetation in slower moving water (Gerber & Gabriel, 2002). In the Tsitsa River only the Coenagrionidae family was found in a low, medium and high concentrations of fine sediment with abundance being lower at a higher concentration.

Plecoptera (Stoneflies), such as Perlidae, occur under stones in rocky habitats (Gerber & Gabriel, 2002). Plecoptera are very sensitive to pollutants and make useful indicators of water quality. In the Tsitsa River Perlidae were found in low, medium and high concentrations of surface sediment. Perlidae were not found in high abundance.

Trichoptera (Caddisflies) are found in rocky habitats, under stones, or in marginal vegetation (Gerber & Gabriel, 2002). In the Tsitsa River Ecnomidae were found under stones in habitats with low to medium concentrations of fine sediment drape. There are several types of Hydropsychidae species in the Hydropsychidae family. In the Tsitsa River more species were found in habitats with low fine sediment drape concentrations, with only one species occurring in medium concentrations of fine sediment drape. The highest abundance was found in rocky habitats with low fine sediment drape concentrations. Leptoceridae construct cases from plant material and occur in marginal vegetation. In the Tsitsa River were found under varying fine sediment concentrations with an increase in abundance, the lower the sediment concentration.

Ephemeroptera (Mayflies) vary greatly in shape and size, with each family being well adapted to suit the variety of habitats in which they occur (Gerber & Gabriel, 2002). Ephemeroptera generally prefer habitats with lower fine sediment concentrations, however different families have different tolerances to sediment concentrations. Caenidae occur in stones or muddy habitats in slow water (Gerber & Gabriel, 2002). In the Tsitsa River they were found to be relatively tolerant to high sediment concentrations and occurred relatively abundantly. Heptageniidae occur in fast flowing habitats with stone substrates or amongst submerged coarse organic matter (Gerber & Gabriel, 2002). In the Tsitsa River Heptageniidae were found in habitats with a high sediment concentration, however their abundance was higher the lower the concentration of fine sediment drape. Leptophlebiidae occur in gentle flow in rocky substrates (Gerber & Gabriel, 2002). In the Tsitsa River Leptophlebiidae were found in relatively high abundance in low to high concentrations of sediment drape; however, abundance decreased with an increase in the concentration of fine sediment drape. Oligoneuridae occur in fast flowing streams in patches of coarse sand or gravels (Gerber & Gabriel, 2002). In the Tsitsa River Oligoneuridae were found in summer in patches of gravel in fast flowing areas of the river. Oligoneuridae were not found in habitats with a high concentration of fine sediment drape. Prosopistomatidae occur under stones in fast flow (Gerber & Gabriel, 2002). In the Tsitsa River Prosopistomatidae were found in habitats with a low to medium concentration of fine sediment drape. Tricorythidae occur in fast flow under or around rocky substrates (Gerber & Gabriel, 2002). In the Tsitsa River Tricorythidae were found in habitats with a low to high concentration of fine sediment drape, with abundance decreasing with an increase in sediment concentration (Figure 7-9 and Figure 7-10).

Hemiptera (Bugs) are only partly adapted to aquatic habitats. Some types occur on the surface of the water and have respiratory characteristics of terrestrial insects while others live below the surface but are air breathers and need to go to the surface at intervals for oxygen (Gerber & Gabriel, 2002). Belostomatidae occur in shallow pools and slow moving areas of the river (Gerber & Gabriel, 2002). In the Tsitsa River Belostomatidae were found in low abundance in low to medium concentrations of fine sediment. Corixidae occur in shallow pools and muddy areas of the river(Gerber & Gabriel, 2002). Corixidae were found in low to high concentrations of fine sediment with the highest abundance in habitats with a high sediment concentration. Gerridae occur on the surface of pools in shaded areas (Gerber & Gabriel, 2002). Gerridae were found in low abundance in habitats with low concentrations of fine sediment. Naucoridae occur in dense marginal vegetation in shallow water (Gerber & Gabriel, 2002). Naucoridae were found in low to high concentrations of fine sediment with an increase in abundance with an increase in sediment concentration. Nepidae occur in marginal vegetation in pools or shallow water (Gerber & Gabriel, 2002). Nepidae were found in low abundance in habitats with low to medium concentrations of fine sediment. Notonectidae occur in pools and backwaters (Gerber & Gabriel, 2002). Notonectidae were found in habitats with low to high concentrations of fine sediment with little variation in abundance between the different habitats. Veliidae occur in pools alongside marginal vegetation and commonly run along the surface of the water (Gerber & Gabriel, 2002). Veliidae were found in habitats with low to high concentrations of fine sediment and their abundance was not affected by an increase in sediment concentration.

Coleoptera (Beetles) occupy a variety of habitats, from fast flowing streams to backwater ponds (Gerber & Gabriel, 2002). Several Coleoptera are aquatic in both their larval and adult stages. Several Coleoptera are air breathers. Dytiscidae occur on the edges of streams in marginal vegetation as well as in pools with reduced flow (Gerber & Gabriel, 2002). In the Tsitsa River Dytiscidae were found in marginal vegetation habitats with low to medium concentrations with an increase in abundance with an increase in the concentration of surface sediment drape. Elmidae occur in rocky substrates in fast flows (Gerber & Gabriel, 2002). In the Tsitsa River Elmidae were not found in habitats with a high sediment concentration. Gyrinidae occur on the surface of the water in slow moving water and pools (Gerber & Gabriel, 2002). In the Tsitsa River Gyrinidae were found in habitats with low to high concentrations of sediment with a low abundance in habitats with a high sediment concentration. Hydrophilidae occur in marginal vegetation and muddy patches along river banks in slow moving water or pools (Gerber & Gabriel, 2002). Hydrophilidae were found in similar abundance in low and high concentrations of fine sediment. Psephenidae occur on rocks in shallow fast flowing water

(Gerber & Gabriel, 2002). Psephenidae were found in low to medium concentrations of fine sediment drape.

Due to the ability of some families of Hemiptera and Coleoptera to breath air as well as live on the surface of the water they show a general trend of being tolerant to or not affect by different levels of sediment concentrations and occur abundantly.

Oligochaeta (Worms) occur in fine substrates in pools and areas of little flow in a river (Gerber & Gabriel, 2002). In the Tsitsa River Oligochaeta were found in sandy habitats with low to high concentrations of fine sediment concentration with an increase in abundance with an increase in sediment concentration.

Anisoptera (Dragonflies) occur both under stones and in sandy habitats (Gerber & Gabriel, 2002). In the Tsitsa River Anisoptera show a general trend of being more abundant in habitats with medium to high concentrations of fine sediment concentrations. Aeshnidae occur under stones in varying flows (Gerber & Gabriel, 2002). Aeshnidae were found in low to medium concentrations of fine sediment. Corduliidae occur in sand and stones in areas of reduced flow (Gerber & Gabriel, 2002). A low abundance of Corduliidae were found in low to high concentrations of fine sediment. Gomphidae occur on sand banks on the edge of the river (Gerber & Gabriel, 2002). Gomphidae were found in very high abundance in sandy habitats with low to high concentrations of fine sediment. Libellulidae occur amongst stones and coarse sand in areas of reduced flow (Gerber & Gabriel, 2002). Libellulidae were found in low to high concentrations of fine sediment with an increase in abundance with a decrease in fine sediment concentrations.

Species of Baetidae (Minnow Mayflies) occur in a variety of habitats including rocks, sand and vegetation (Gerber & Gabriel, 2002). Baetidae were found in low to high concentrations of fine sediment concentration. However, only 1-2 species were found in abundance in habitats with high concentrations of fine sediment. The presence of more than 2 species indicated a habitat with lower fine sediment concentrations.

Diptera (Flies) occur in a wide variety of habitats from stagnant pools to areas of high flow (Gerber & Gabriel, 2002). In the Tsitsa River Diptera occur in abundance in low to high concentrations of fine sediment. Athericidae occurs in vegetation and organic matter (Gerber & Gabriel, 2002). In the Tsitsa River a low abundance of Athericidae were found in medium concentrations of fine sediment. Ceratopogonidae occur in sand and mud at the edges of a river (Gerber & Gabriel, 2002). Ceratopogonidae were found in low to high concentrations of fine sediment with an increase in abundance with an increase in fine sediment concentration. Chironomidae are commonly found in any water body and in rivers are generally found in pools (Gerber & Gabriel, 2002). A high abundance of Chironomidae were found with an increase in abundance with an increase in fine sediment concertation. Culicidae floats under the surface a water body and commonly occurs in pools or temporary puddles (Gerber & Gabriel, 2002). A low abundance of Culicidae were found in low and high concentrations of fine sediment. Dixidae occurs in slow streams and backwater areas of fast flowing rivers (Gerber & Gabriel, 2002). A low abundance of Dixidae were found in medium concentrations of fine sediment. Muscidae occur in shallow water commonly with the presence of organic matter or algae (Gerber & Gabriel, 2002). A low abundance of Muscidae was found in low and high concentrations of fine sediment. Psychodidae occur in various habitats in streams (Gerber & Gabriel, 2002). A low abundance of Psychodidae were found in medium concentrations of fine sediment. Simuliidae attach themselves to substrates in shallow areas with increased flow (Gerber & Gabriel, 2002). Simuliidae were found in areas of low to high concentrations of fine sediment, with an increase in abundance with a reduction in the concentration of fine sediment. Tabanidae occur in muddy areas of pools (Gerber & Gabriel, 2002). A low abundance of Tabanidae were found in low to medium concentrations of fine sediment concentration. Tipulidae species are habitat specific and occur at the bottom of streams, muddy edges of streams or in aquatic vegetation (Gerber & Gabriel, 2002). Tipulidae were found in medium to high concentrations of fine sediment (Figure 7-9 and Figure 7-10).

There is a general trend between macroinvertebrates that occur in rocky habitats decreasing in abundance with an increase in fine sediment concentrations. Macroinvertebrates that naturally occur in sandy habitats are less affected and are possibly benefited by an increase in fine sediment accumulation. However, field observations showed a decrease in abundance of macroinvertebrate families under excessively high fine sediment concentrations such as those found in thick silt deposits.

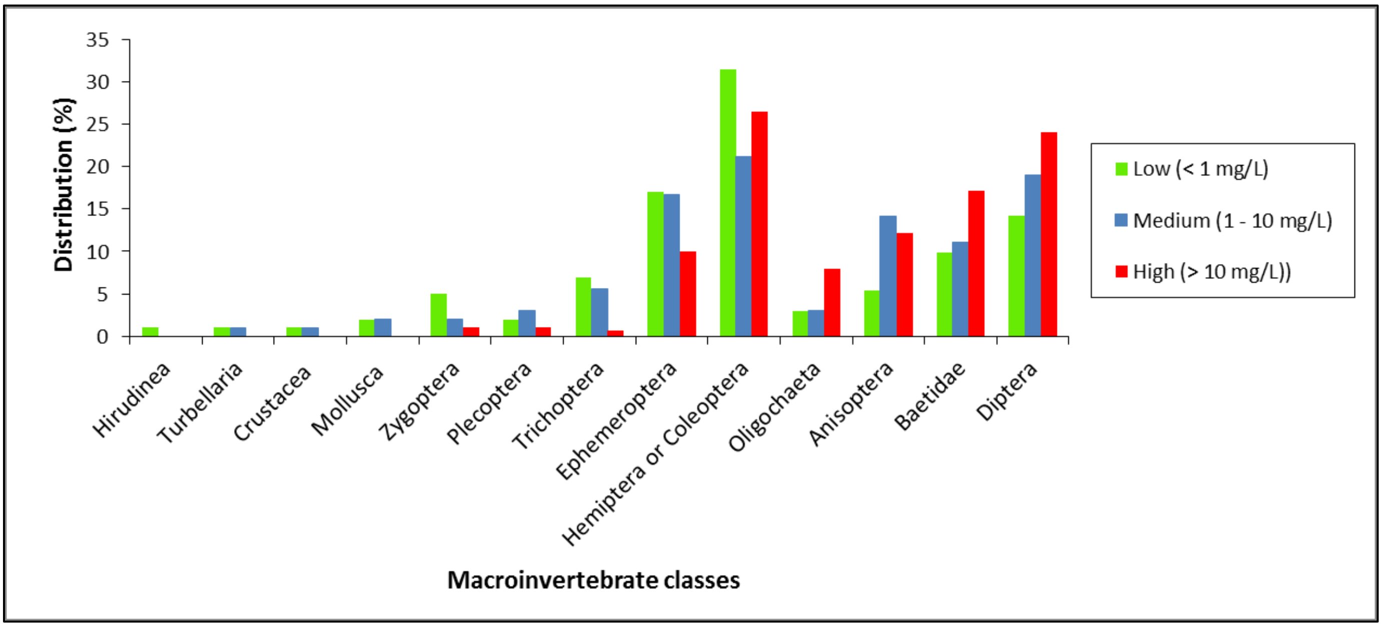

Figure 7-9: Percentage distribution of different macroinvertebrate classes occurring in different concentration of surface sediment drape in the Tsitsa River.

From (Table 7-21) a rapid assessment, under the current conditions (water quality and flow variability) in the Tsitsa River, can be carried out to look at the impacts on fine sediment drape on macroinvertebrate families. An ASPT or total score can be calculated. Macroinvertebrate families with higher sensitivity scores are less tolerant to fine sediment drape which causes less favourable habitat conditions for them. An increase in occurrences and abundance of these macroinvertebrates implies less fine sediment drape.

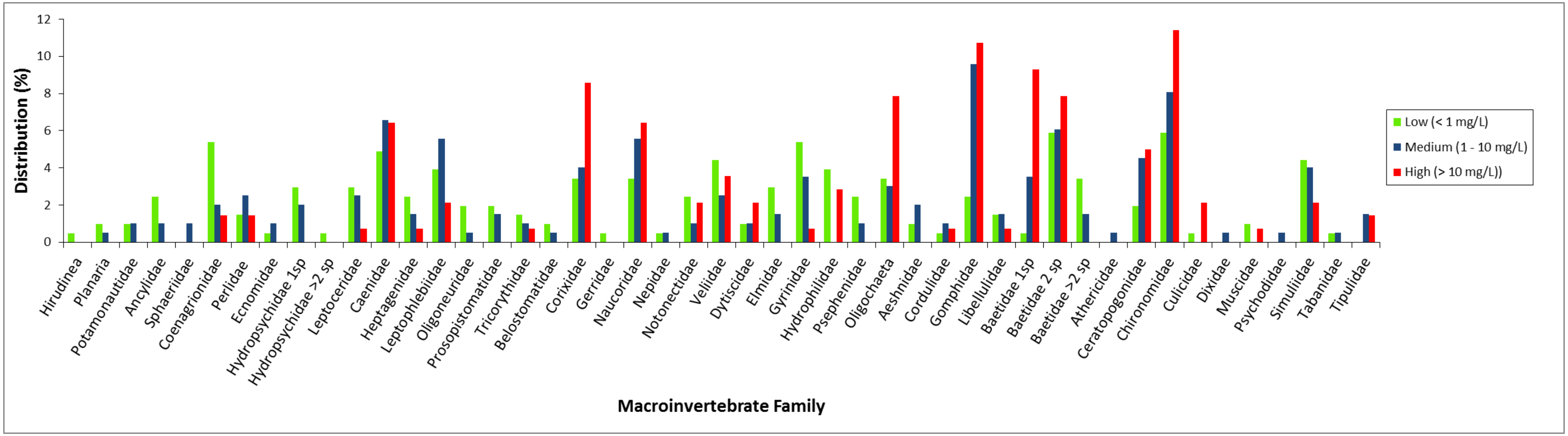

Figure 7-10: Percentage distribution of different macroinvertebrate families occurring in different concentration of surface sediment drape in the Tsitsa River.

Table 7-21: Sediment sensitivity score sheet created for macroinvertebrate families found in the Tsitsa River

Macroinvertebrate Class	Macroinvertebrate Family	Sensitivity Score
Annelidae (Leeches)	*Hirudinea*	13
Turbellaria (Flat worms)	*Planaria*	10
Crustacea (Crabs or shrimps)	*Potomonautidae*	10
Mollusca (Snails or Limpets)	*Ancylidae*	8
	Sphaeriidae	10
Odonata- *Zygoptera* (Damselflies)	*Coenagrionidae*	5
Plecoptera (Stoneflies)	*Perlidae*	5
Trichoptera (Cased and uncased caddisfly)	*Hydropsychidae 1 sp*	8
	Hydropsychidae 2 sp	10
	Hydropsychidae >2 sp	13
	Ecnomidae	7
	Leptoceridae	5
Annelidae (Worms)	*Oligochaeta*	1
Ephemeroptera- (Minnow Mayflies)	*Baetidae 1 sp*	1
	Baetidae 2 sp	2
	Baetidae >2 sp	5
Ephemeroptera (Mayflies excluding Minnow Mayflies)	*Caenidae*	1
	Heptageniidae	5
	Leptophlebiidae	5
	Oligoneuridae	10
	Prosopistomatidae	9
	Tricorythidae	5
Diptera (Flies)	*Athericidae*	7
	Ceratopogonidae	1
	Chironomidae	1
	Culicidae	1
	Dixidae	10
	Muscidae	5
	Psychodidae	10
	Simuliidae	1
	Tabanidae	8
	Tipulidae	4
Hemiptera and Coleoptera (Bugs and beetles)	*Belostomatidae*	10
	Corixidae	3
	Dytiscidae	1
	Elmidae	7
	Gerridae	14
	Gyrinidae	5
	Hydraenidae	8
	Hydrophilidae	2
	Naucoridae	3
	Nepidae	10
	Notonectidae	5
	Psephenidae	8
	Veliidae	5

7.3 Concluding Remarks and recommendations for future monitoring

By looking at the processes creating habitat in the Tsitsa River under current conditions, a physical habitat score for the Tsitsa River, that is taxa related, was created in which one can score taxa in terms of their sensitivity to bed conditions with an emphasis on fine sediment accumulation. Documenting seasonal changes in the Tsitsa River will hopefully aid further research in the area as well as create a better understanding of the current processes at work between sediment characteristics and river habitats. Post dam impacts can be monitored at all the Sites. Although not the intention of this study, these monitoring sites can be used to monitor the impact of catchment wide rehabilitation on river health prior to the dam being built. After dam construction the top site, above the dam inundation, can still be used as a monitoring point for rehabilitation (Figure 7-11).

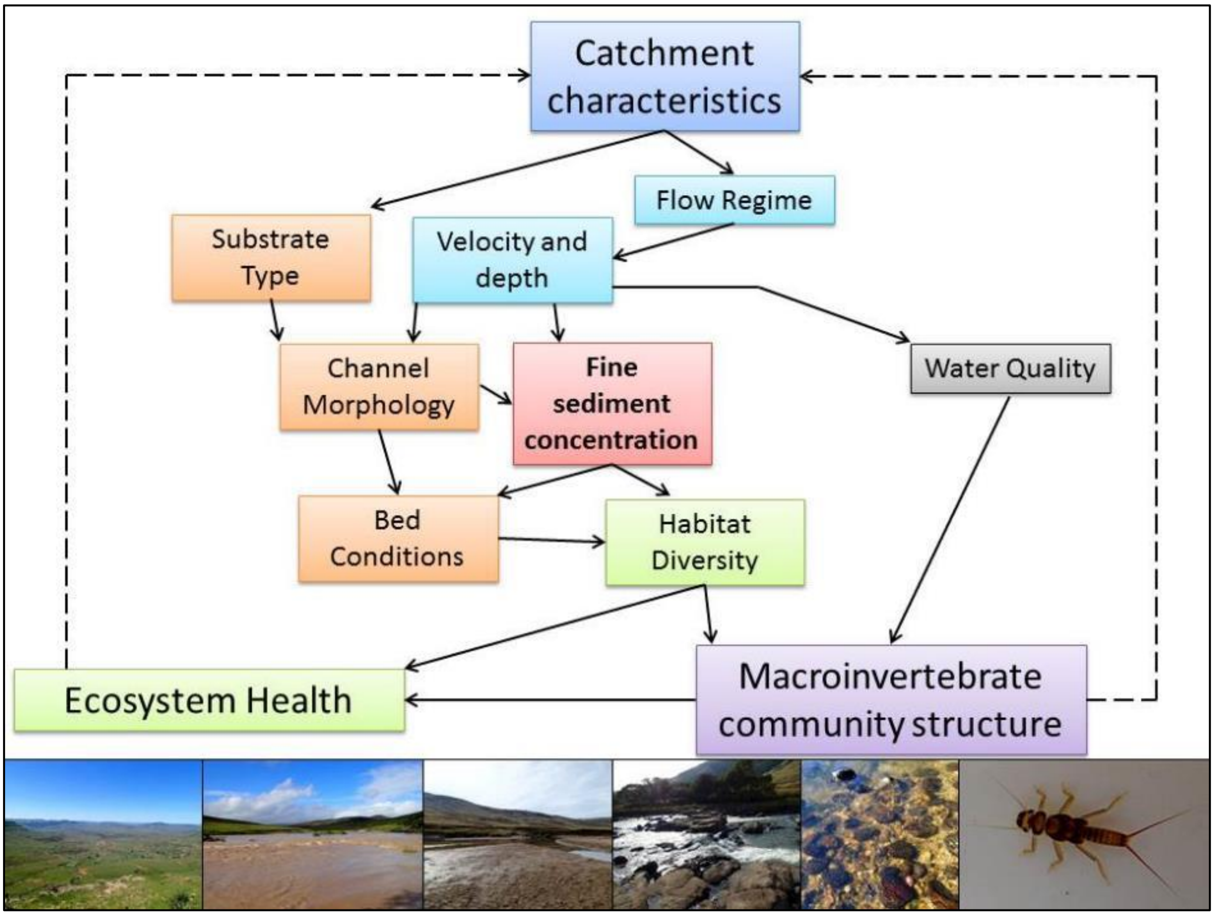

Figure 7-11: Factors to be monitored influencing aquatic biodiversity.

8 VEGETATION DIVERSITY, COMPOSITION AND UTILISATION

8.1 Introduction

Plant species are a component of biodiversity, a multi-dimensional term which includes genes, species, functional forms, adaptations, habitats, ecosystems, as well as the variability within and between them (Laurila-Pant et al., 2015). The Tsitsa River catchment falls within the Maputaland-Pondoland-Albany Hotspot, a geographical region characterised by high biodiversity, endemism, cultural and socio-economic diversity (Mittermeier et al., 2004). According to the Millenium Ecosystem Assessment (MEA, 2003), there are four benefits associated with biodiversity, namely provisioning, regulating, cultural and support services. Plant biodiversity is particularly important for the resource poor people in rural areas as they have a long-established tradition of using plants for food, medicinal purposes and as a source of fodder for livestock. This study investigated floral diversity, composition and plant utilisation within the Ntabelanga area in the Eastern Cape province, South Africa. The Department of Water and Sanitation (DWS) proposed construction of two dams along the Tsitsa river (Figures 1 and 2), Ntabelanga dam located 25 km east of Maclear town and north of the R396 and Laleni dam located 17 km north east of Tsolo town. Therefore, this study was aimed at:

1. documenting plant diversity within the Ntabelanga area before the construction of the dam wall and the first filling phase,
2. assessing how plant resources in the catchment area are utilised by the local people, and
3. assessing the grazing potential of the grazing land within the catchment area as livestock was perceived to be important to local livelihoods.

8.2 Results and discussion

Plant diversity and composition

A total of 75 species belonging to 24 families and 57 genera were recorded from six sites within the Ntabelanga area (Table 8-1). Of the documented taxa, 11.4% are exotic to South Africa. Plant families with the highest number of species were: Asteraceae with 15 species, followed by Poaceae with 14 species, Cyperaceae (10 species), Fabaceae and Rubiaceae (5 species each), Lobeliaceae (3 species) and Acanthaceae, Aspodelaceae, Lamiaceae, Oxalidaceae, Polygalaceae, Scrophulariaceae, Verbenaceae and Vitaceae with 2 species each. All these families are among the largest families in South Africa characterised by at least 50 species each (Germishuizen et al., 2006). The rest of the plant families were represented by a single species each (Table 8-1). The most common genera in order of frequency were *Cyperus* with four species followed by *Bulbostylis, Helichrysum, Lobelia* and *Senecio* with three species each and *Berkheya, Eragrostis, Finicia, Hypparrhenia, Oxalis, Richardia* and *Sporobolus* with two species each.

Table 8-1: List of plant species recorded from eight sites in the Ntabelanga area. Species marked with an asterisk (*) are exotic to South Africa

Scientific name	Family	Plots in which species were recorded
Acacia karroo Hayne	Fabaceae	18
Aloe arborescens Mill.	Asphodelaceae	12
Aloe ferox Mill.	Asphodelaceae	6
Andropogon eucomus Nees	Poaceae	5, 17
Anthospermum galioides Rchb. f. ssp. galioides	Rubiaceae	6, 7, 8, 18, 19
Aristida congesta Roem. & Schult. ssp. *barbicollis* (Trin. & Rupr.) De Winter	Poaceae	4, 5, 6, 7, 8, 10, 15, 16, 19
Asparagus laricinus Burch.	Asparagaceae	6
Berkheya discolor (DC.) O. Hoffm. & Muschl.	Asteraceae	6
Berkheya bipinnatifida (Harv.) Roessler ssp. *bipinnatifida*	Asteraceae	12
Bulbine abyssinica A. Rich.	Asphodelaceae	1, 2, 3
Bulbostylis contexta (Nees) M. Bodard	Cyperaceae	2, 17
Bulbostylis densa (Wall.) Hand.-Mazz. ssp. *afromontana* (Lye) R.W. Haines	Cyperaceae	6
Bulbostylis hispidula (Vahl) R.W. Haines ssp. *pyriformis* (Lye) R.W. Haines	Cyperaceae	4, 5, 10
Cineraria spp.	Asteraceae	14
Chamaecrista capensis (Thunb.) E. Mey. var. *capensis*	Fabaceae	16
Commelina africana L. var. *africana*	Commelinaceae	18
Conostomium spp.	Rubiaceae	5
**Conyza bonariensis* (L.) Cronquist	Asteraceae	2
Crabbea hirsuta Harv.	Acanthaceae	1, 2, 19
Crassula setulosa Harv. var. setulosa	Crassulaceae	12
Cussonia paniculata Eckl. & Zeyh. spp. *paniculata*	Araliaceae	6
Cynodon dactylon (L.) Pers.	Poaceae	2, 3, 4, 6, 9, 10, 16
Cyperus brevis Boeck.	Cyperaceae	7, 8, 15, 18
Cyperus congestus Vahl	Cyperaceae	6
Cyperus esculentus L. var. *esculentus*	Cyperaceae	6
Cyperus spp.	Cyperaceae	17
Cyphostemma spp.	Vitaceae	6
Digitaria ternata (A. Rich.) Stapf	Poaceae	14
Eragrostis chloromelas Steud.	Poaceae	1, 4, 5, 6, 7, 11, 14
Eragrostis gummiflua Nees	Poaceae	4, 5, 17
Erigeron spp.	Asteraceae	1
Euphorbia inaqualatera Sond. var. *inaqualatera*	Euphorbiaceae	16
Ficinia brevifolia Kunth.	Cyperaceae	1
Ficinia deusta (P.J. Bergius) Levyns	Cyperaceae	7, 8, 14, 15, 18, 19
Helichrysum cerastioides DC. var. *cerastioides*	Asteraceae	6

Scientific name	Family	Plots in which species were recorded
Helichrysum glomeratum Klatt	Asteraceae	1, 3, 4, 6, 7, 8, 13, 15, 16, 17, 18, 19
Helichrysum odoratissimum (L.) Sweet	Asteraceae	2, 10, 11, 14
Hermannia parviflora Eckl. & Zeyh.	Malvaceae	6
Hyparrhenia hirta (L.) Stapf	Poaceae	5, 7, 9, 11, 12, 14, 16, 17, 18, 19
Hyparrhenia spp.	Poaceae	13
Hypoestes forskaolii (Vahl) R. Br.	Acanthaceae	2, 12
Hypoxis argentea Harv. ex Baker var. *sericea* Baker	Hypoxidaceae	1, 7, 15, 18
Indigofera spp.	Fabaceae	6, 8, 19
Kalanchoe rotundifolia (Haw.) Haw.	Crassulaceae	6
Kyllinga alata Nees	Cyperaceae	2, 4, 10, 14
Lantana rugosa Thunb.	Verbenaceae	6
Lobelia flaccida (C. Presl) A. DC. ssp. *flaccida*	Lobeliaceae	17
Lobelia spp.	Lobeliaceae	10
Lobelia thermalis Thunb.	Lobeliaceae	13
Melinis repens (Willd.) Zizka ssp. *repens*	Poaceae	5
Microchloa caffra Nees	Poaceae	4, 6, 7, 8, 11
Nidorella pinnata (L.f.) J.C. Manning & Goldblatt	Asteraceae	12, 13, 14, 19
**Oenothera rosea* L’Hér. ex Aiton	Onagraceae	16
Oxalis smithiana Eckl. & Zeyh.	Oxalidaceae	13
Oxalis spp.	Oxalidaceae	2, 4, 6, 16
**Paspalum distichum* L.	Poaceae	13
Polygala amatymbica Eckl. & Zeyh.	Polygalaceae	1, 8
**Richardia brasiliensis* Gomes	Rubiaceae	18
**Richardia humistrata* (Cham. & Schltdl.) Steud.	Rubiaceae	4, 6, 7, 8, 9, 10, 11, 13, 14, 16, 17, 19
Rubia spp.	Rubiaceae	2
Rumex spp.	Polygonaceae	2
**Schkuhria pinnata* (Lam.) Kuntze ex Thell.	Asteraceae	16
Selago spp.	Scrophulariaceae	16
Senecio decurrens DC.	Asteraceae	1
Senecio inaequidens DC.	Asteraceae	6
Senecio retrorsus DC.	Asteraceae	11, 12, 15, 19
Setaria sphacelata (Schumach.) Moss var. *sericea* (Stapf) Clayton	Poaceae	2
Sporobolus africanus (Poir.) Robyns & Tournay	Poaceae	6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19
Sporobolus fimbriatus (Trin.) Nees	Poaceae	9, 10, 12, 13, 16, 17
Stachys aethiopica L.	Lamiaceae	12
Sutera cooperi Hiern	Scrophulariaceae	6
**Taraxacum officinale* Weber	Asteraceae	2, 3, 4, 5, 8, 9, 13, 14, 17, 18
Tephrosia capensis (Jacq.) Pers. var. *acutifolia* E. Mey.	Fabaceae	12, 13
Teucrium trifidum Retz.	Lamiaceae	6, 19
Tulbaghia acutiloba Harv.	Alliaceae	1, 18
**Verbena* spp.	Verbenaceae	17
**Zinnia peruviana* (L.) L.	Asteraceae	6
Zornia capensis Pers. ssp. *capensis*	Fabaceae	7, 8, 9, 13, 18

Hierarchical Cluster Analysis (HCA) classified the 19 sample plots into six main vegetation clusters which are approximately 52% similar (Figure 8-1). Each one of the six clusters reflects the homogeneity of the communities in terms of plant species composition, dominance and the environmental factors influencing such a structure and composition. Similar results were obtained by DCA analysis which separated 19 plots into six clusters (Figure 8-2) along slope (axis 1) and potassium content (axis 2). The differences in species composition among the six floristic clusters is a result of different environmental factors. It is evident that species diversity and composition were mainly influenced by calcium, carbon, erosion, magnesium, potassium and slope (Figure 8-3). Natural vegetation is known to respond to several environmental gradients and the identification of the principle environmental factors is regarded as a major challenge in the assessment of floristic composition (Jayakumar and Nair, 2012). Janssens et al. (1998) investigated the relationship between plant diversity and different soil chemical factors and found a positive relationship between species richness and diversity and the concentration of extractable phosphorus and potassium in soil. In a different study, Kumar et al. (2010) found a strong positive correlation between tree species richness and the concentration of nitrogen, phosphorus and carbon. Therefore, species diversity and composition may serve as a good indicator of soil fertility.

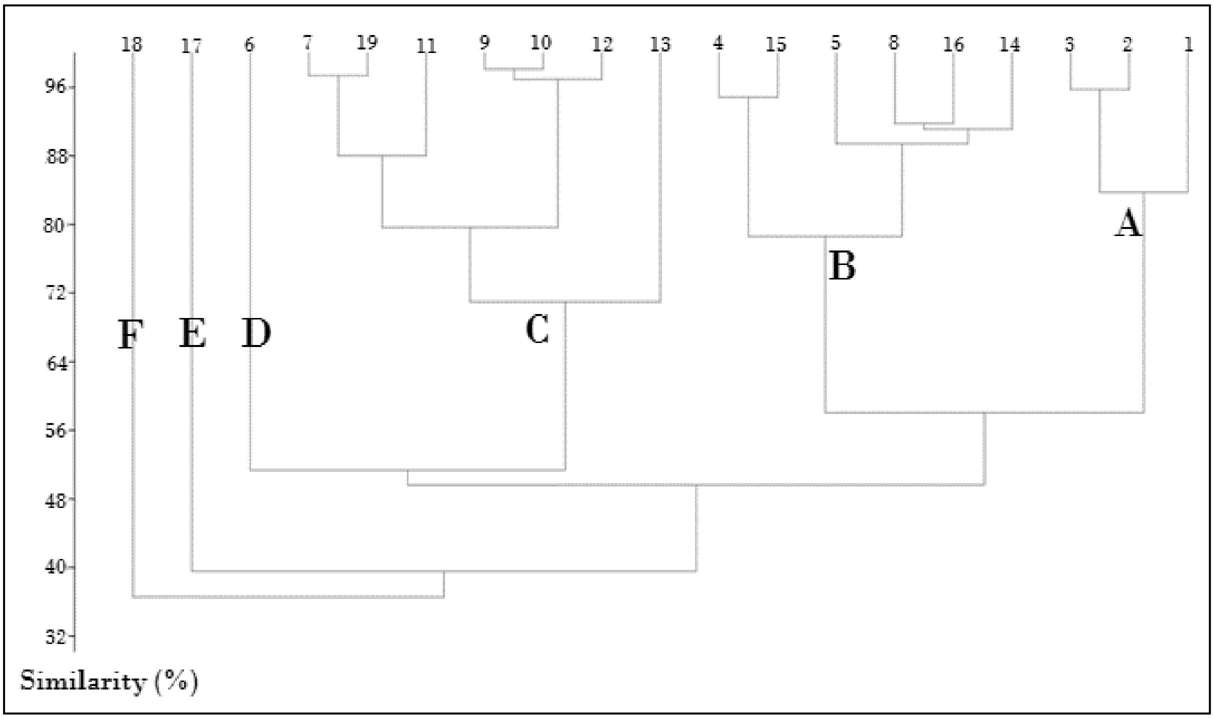

Figure 8-1: Hierarchical Cluster Analysis dendogram classification of vegetation plots based on weighted species presence.

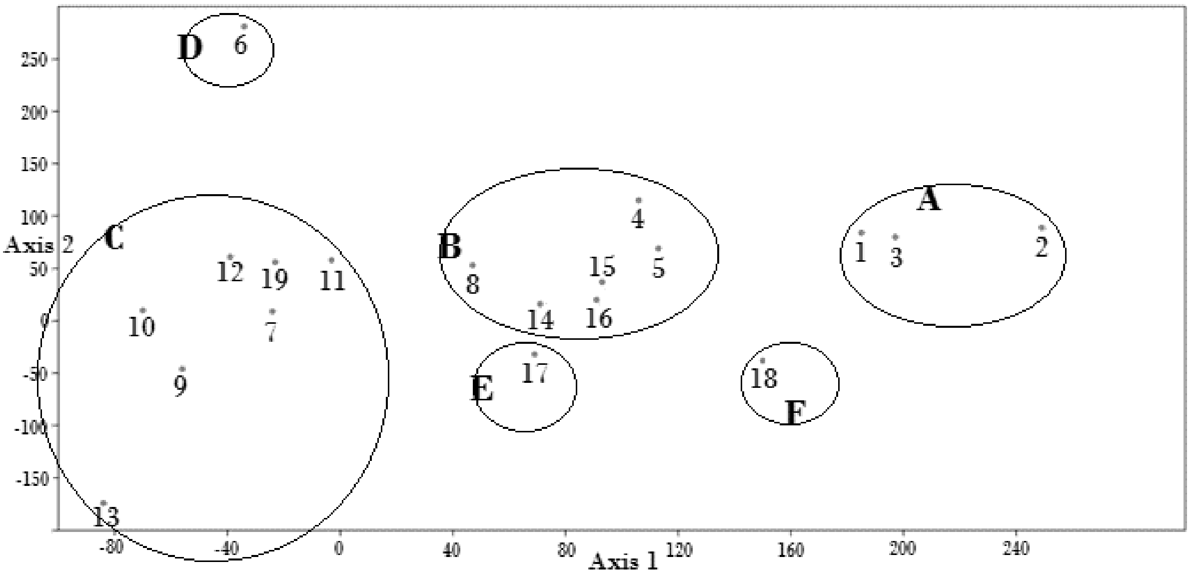

Figure 8-2: Detrended Correspondence Analysis (DCA) ordination diagram showing the grouping of sample plots of the Ntabelanga area into six groups (A-F).

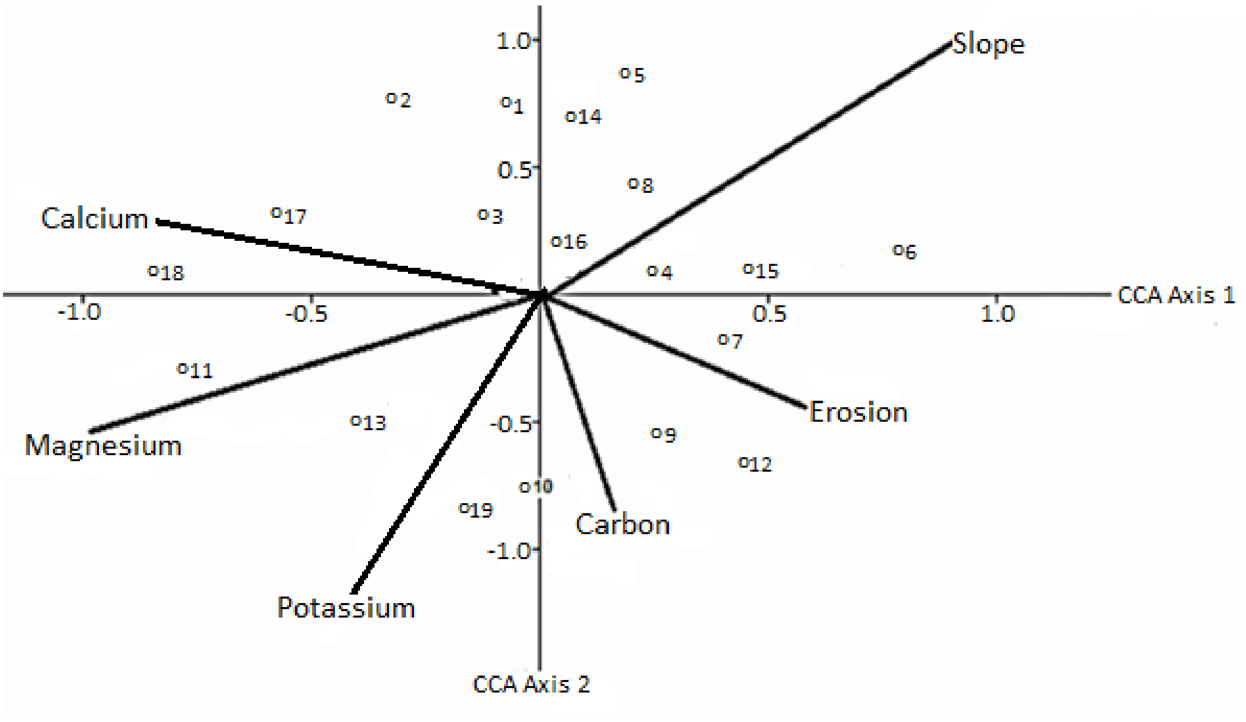

Figure 8-3: Canonical Correspondence Analysis (CCA) ordination scatter plot indicating the influence of environmental variables on species composition in the Ntabelanga area.

The floristic and environmental characteristics of the six clusters are summarised below:

Cluster A: This cluster was dominated by perennial herbs and grasses namely *Bulbine abyssinica, Crabbea hirsuta, Cynodon dactylon, Helichrysum glomeratum* and *Taraxanum officinale* (Table 4). A total of 19 species were recorded in this cluster with *Bulbine abyssinica* recorded in this cluster only and in no other cluster (Table 8-2). Some of the plots were rocky, with an overage rock cover of about 8.5%. This cluster had the least carbon and sodium content of 0.29% and 23.43 cmolkg^{-1} respectively in comparison with other clusters (Table 8-2).

Cluster B: This cluster was dominated by annual and perennial herbs, shrubs and grasses namely *Aristida congesta* spp. *barbicollis, Ficinia deusta, Helichrysum glomeratum, Hypparrhenia hirta, Richardia humistrata, Sporobolus africanus* and *Taraxanum officinale* (Table 4). A total of 33 species were recorded in this cluster with *Chamaecrista capensis, Euphorbia inaqualatera* var. *inaqualatera, Cineraria* spp., *Conostomium* spp., *Digitaria ternata, Schkuhria pinnata* and *Selago* spp. recorded in this cluster only and in no other cluster (Table 8-2). This cluster had the highest average vegetation cover (82.5%) and carbon content (5.06%) in comparison with other clusters (Table 8-2). Most of the plots forming this cluster were generally flat, with an average slope of 5.83% (Table 8-2).

Cluster C: This cluster was dominated by perennial herbs and grasses namely *Helichrysum glomeratum, Hyparrhenia hirta, Richardia humistrata, Sporobolus africanus, Sporobolus fimbriatus* and *Zornia capensis* (Table 4). A total of 33 plant species were recorded in this cluster (Table 8-2). This cluster had the lowest sand content (59.1%) and highest silt and ammonium nitrogen contents of 19.9% and mgL^{-1} respectively (Table 8-2).

Cluster D: This cluster consisted of a single plot characterised by a total of 24 plant species. Thirteen plant species were recorded in this cluster only including annual plants such as *Bulbostylis densa* ssp. *afromontana* and *Zinnia peruviana*. The majority of the common plants in this cluster were either perennial herbs, shrubs or trees which included *Aloe ferox, Asparagus laricinus, Berkheya discolor, Cussonia paniculata* ssp. *paniculata, Cyphostemma* spp., *Helichrysum cerastioides* var. *cerastioides, Kalanchoe rotundifolia, Lantana rugosa, Senecio inaequidens, Sutera cooperi* and *Teucrium trifidum* (Table 8-2). This cluster had the lowest litter cover (2%) and highest slope (70%), tree height (500 cm), pH (5.58), calcium (1186.77 cmolkg^{-1}), nitrate nitrogen (0.78 mgL^{-1}) and clay content of 23% in comparison with other clusters (Table 8-2).

Cluster E: This cluster consisted of a single plot characterised by a total of 12 plant species. Plant species common in this cluster and recorded in this cluster only included annual or perennial herbs such as *Cyperus* spp., *Lobelia flaccida* ssp. *flaccida* and *Verbena* spp. (Table 8-2). This cluster had the highest sand content (77%) and the lowest pH (5), potassium (34.75 $cmolkg^{-1}$), calcium (303.56 $cmolkg^{-1}$), magnesium (102 $cmolkg^{-1}$), nitrate nitrogen (0.2 mgL^{-1}), clay (13%) and silt (10%) contents in comparison with other clusters (Table 8-2).

Cluster F: This cluster consisted of a single plot characterised by a total of 13 plant species. Plant species common in this cluster and recorded in this cluster only included *Acacia karroo*, perennial herbs such as *Commelina africana* var. *africana* and *Richardia brasiliensis* (Table 8-2). This cluster had the lowest vegetation cover (60%) and the highest litter cover (10%), potassium (127.75 $cmolkg^{-1}$), sodium (79.33 $cmolkg^{-1}$), magnesium (493 $cmolkg^{-1}$) and ammonium nitrogen (0.35 mgL^{-1}) contents in comparison with other clusters (Table 8-2).

Impact of dam construction on plant diversity and composition

The construction of the dam entails the clearance of vegetation, several infrastructural developments and construction of the dam wall. All these activities will lead to loss of some plant species, destruction of species habitats, transformation of clusters A to F (Figure 8-2), creation of new habitats, increase in the number of alien species and modify the conditions to which the documented plants have adapted. All these activities will lead to significant changes in species diversity and composition. The riparian vegetation of Tsitsa River is currently dominated by exotic species, *Acacia dealbata* Link, *A. decurrens* Willd. and *A. mearnsii* De Wild. (Figure 8-4 and Figure 8-5) and other related riparian vegetation. All these three species are aggressive invaders and declared weeds classified in the category 2 of the Conservation of Agricultural Resources Act 1983 (Act no. 43 of 1983) (South Africa, 1983). After damming, a new “riparian vegetation” will be created which will be different from the original riparian vegetation shown in Figure 8-5 in terms of species diversity and composition. Once the dam wall is constructed, all low-lying areas will be flooded but little immediate transformation will occur on rocky ridges (see Figure 8-5), with some species expected to adapt to new environmental conditions. Previous research by Nilsson et al. (1997) showed that dam construction results in changing the magnitude and extent of floodplain inundation and land-water interaction, leading to disruption of plant reproduction, allowing the encroachment of upland plants previously prevented by frequent flooding.

Table 8-2: Summary of floristic associations with environmental variables assessed in eight sites within the Ntabelanga area

	Floristic clusters					
	A	**B**	**C**	**D**	**E**	**F**
No. of plots	3	6	7	1	1	1
No. of species	19	33	31	24	12	13
No. of genera	18	31	29	22	11	13
No. of families	10	11	12	13	6	8
Common species	*Bulbine abyssinica, Crabbea hirsuta, Cynodon dactylon, Helichrysum glomeratum, Taraxanum officinale*	*Aristida congesta* spp. *barbicollis, Ficinia deusta, Helichrysum glomeratum, Hypparrhenia hirta, Richardia humistrata, Sporobolus africanus, Taraxanum officinale*	*Helichrysum glomeratum, Hypparrhenia hirta, Richardia humistrata, Sporobolus africanus, Sporobolus fimbriatus, Zornia capensis*	*Aloe ferox, Asparagus laricinus, Berkheya discolor, Bulbostylis densa* ssp. *afromontana, Cussonia paniculata* ssp. *paniculata, Cyphostemma* spp., *Helichrysum cerastioides var. cerastioides, Kalanchoe rotundifolia, Lantana rugosa, Senecio inaequidens, Sutera cooperi, Teucrium trifidum, Zinnia peruviana*	*Cyperus* spp., *Lobelia flaccida* ssp. *flaccida, Verbena* spp.	*Acacia karroo, Commelina africana* var. *africana, Richardia brasiliensis*
Unique species	*Bulbine abyssinica*	*Chamaecrista capensis, Euphorbia inaqualatera* var. *inaqualatera, Cineraria* spp., *Conostomium* spp., *Digitaria ternata, Schkuhria pinnata, Selago* spp.	0	*Aloe ferox, Asparagus laricinus, Berkheya discolor, Bulbostylis densa* ssp. *afromontana, Cussonia paniculata* ssp. *paniculata, Cyphostemma* spp., *Helichrysum cerastioides* var. *cerastioides, Kalanchoe rotundifolia, Lantana rugosa, Senecio inaequidens, Sutera cooperi, Teucrium trifidum, Zinnia peruviana*	*Cyperus* spp., *Lobelia flaccida* ssp. *flaccida, Verbena* spp.	*Acacia karroo, Commelina africana* var. *africana, Richardia brasiliensis*
Mean values of environmental variables						
Total vegetation cover (%)	71.7	82.5	80.3	65	75	60

Litter cover (%)	5	5	4.4	2	5	10
Rock cover (%)	8.3	0	0	0	0	0
Slope (%)	20	5.83	14.3	70	10	10
Erosion (%)	5	0	0	5	5	0
Tree height (cm)	120	40	150	500	0	0
Herb height (cm)	28.3	25.83	22.5	25	15	40
pH	5.04	5.36	5.05	5.68	5	5.17
K (cmolkg^{-1})	39.72	81.31	90.2	101.43	34.75	127.75
Na (cmolkg^{-1})	23.43	32.97	54.7	28.98	40.86	79.33
Ca (cmolkg^{-1})	479.08	808.32	843.5	1186.77	303.56	1035.02
Mg (cmolkg^{-1})	170	298	382	407	102	493
NO_3-N (mgL^{-1})	0.4	0.62	0.64	0.78	0.2	0.48
NH_4-N (mgL^{-1})	1.18	1.14	1.3	0.93	0.65	0.35
C (%)	O.29	5.06	1.11	0.99	0.66	1.52
Clay (%)	21	21.7	21	23	13	21
Silt (%)	16	17.3	19.9	13	10	16
Sand (%)	63	61	59.1	64	77	63

Figure 8-4: Riparian vegetation of Tsitsa river dominated by *Acacia baileyana, A. dealbata and A. mearnsii* (Photo: A. Maroyi).

Figure 8-5: Whilst low-lying areas will be flooded after the dam wall has been constructed, little immediate vegetation transformation is expected on rocky and sloppy ridges (Photo: A. Maroyi).

Useful plant species

A total of 56 useful plant species were recorded in the Ntabelanga area (Figure 8-6 and Table 8-3). Plant species mentioned by at least 50 percent of the participants included (arranged in descending order of importance) *Brassica oleracea* L. (cabbage), *Spinacia oleracea* L. (spinach), *Zea mays* L. (maize), *Solanum tuberosum* L. (potato), *Allium cepa* L. (onion), *Cucurbita moschata* Duchesne ex Poir. (butternut), *Daucas carota* L. (carrot), *Capsicum annuum* L. (pepper), *Prunus persica* (L.) Batsch (peach), *Artemisia afra* Jacq. ex Willd. (wormwood), *Helichrysum gymnocomum* DC., *Lycopersicon esculentum* Mill. (tomato), *Cucurbita maxima* Duchesne (pumpkin) and *Beta vulgaris* L. (beetroot). With the exception of *Artemisia afra* and *Helichrysum gymnocomum* which were collected from the wild as herbal medicines, all these important plant species were cultivated in home gardens as cereal crop, edible tubers, fruit trees, leafy vegetables and spices (Table 8-3). Nine different uses of plants recorded in Ntabelanga area were identified (Figure 8-6): beverage, cereal and crafts (one species each), ornamental, live fence or hedge (three species each), edible tuber or root (six species), vegetables (nine species), fruits (16 species) and herbal medicine (28 species).

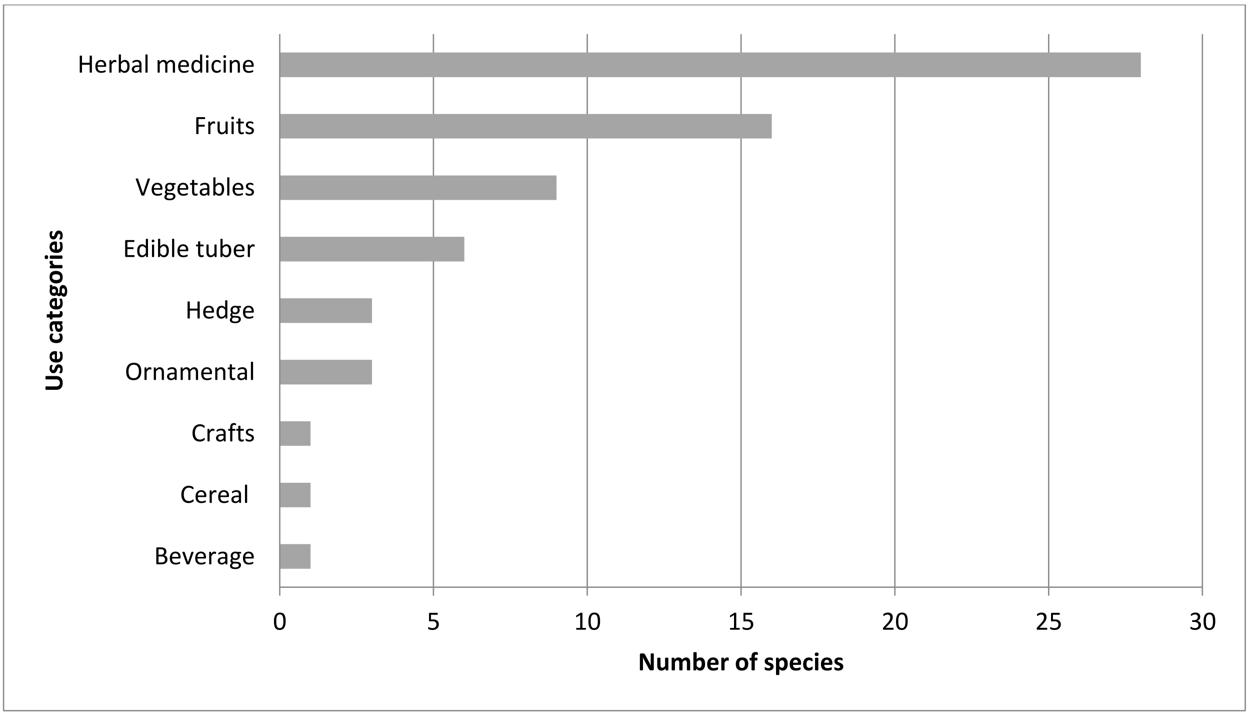

Figure 8-6: The use categories of useful plants recorded in the Ntabelanga area.

Table 8-3: List of useful plant species recorded in the Ntabelanga area, arranged in descending order of importance

Scientific name	English (E) and Xhosa (X) names	Plant use category	Frequency (%)
Brassica oleracea L.	Cabbage (E), ikhaphetshu (X)	Leaves cooked as vegetables or made into salad. Cabbage head preserved for later use	90.5
Spinacia oleracea L.	Imifuno (X), spinach (E)	Leaves cooked as vegetables or made into salad	85.7
Zea mays L.	Maize (E), umbone (X)	Cereal and beverage: dry seed pounded into samp or green mealies roasted or cooked. Shelled seeds and unshelled fruits preserved for later use.	85.7
Solanum tuberosum L.	Amazambane (X), potato (E)	Tubers cooked, baked, fried, mashed and made into salad. Tubers preserved for later use	81.0
Allium cepa L.	Itswele (X), onion (E)	Tubers added to vegetables, meat and salad. Tubers preserved for later use	76.2
Cucurbita moschata Duchesne ex Poir.	Butternut (E), ithanga (X)	Fruit is roasted or mashed; young shoots, flowers and fruits cooked as vegetables. Fruits preserved for later use	76.2
Daucas carota L.	Carrots (E), umnqathi (X)	Root eaten raw, cooked, mixed with other vegetables or meat. Root preserved for later use	71.4
Capsicum annuum L.	Itshilisi (X), pepper (E)	Fruit is cooked, mixed with other vegetables or meat. Fruits preserved for later use	71.4
Prunus persica (L.) Batsch	Ipesika (X), peach (E)	Fruits edible, preserved for later use	66.7
Artemisia afra Jacq. ex Willd.	Wormwood (E), umhlonyana (X)	Leaves used as herbal medicine	61.9
Helichrysum gymnocomum DC.	Impepho (X)	Whole plant used as herbal medicine	61.9
Lycopersicon esculentum Mill.	Tomato (E), tumata (X)	Fruit eaten raw in salad or cooked, mixed with other vegetables or meat. Fruits preserved for later use	57.1
Cucurbita maxima Duchesne	Ithanga (X), pumpkin (E)	Fruit is roasted or mashed; young shoots, flowers and fruits cooked as vegetables. Fruits preserved for later use	57.1
Beta vulgaris L.	Beetroot (E)	Root cooked and eaten on their own or made into salad. Root preserved for later use	52.4
Phaseolus vulgaris L.	Bean (E), mbotyi (X)	Green pods and dry seeds boiled as vegetables and can be mixed with other vegetables or meat. Dry seeds preserved for later use	47.6
Citrus sinensis (L.) Osbeck	Iorenji (X), orange (E)	Fruits edible, preserved for later use	47.6

Malus domestica Borkh.	Apile (X), apple (E)	Fruits edible, preserved for later use	38.1
Musa X *paradisiaca* L.	Banana (E)	Fruits edible, preserved for later use	38.1
Ipomoea batatas (L.) Lam.	Bhatata (X), sweet potato (E)	Tubers cooked and eaten on their own. Tubers preserved for later use	38.1
Psidium guajava L.	Guava (E), ugwava (X)	Fruits edible, preserved for later use. Also used as herbal medicine.	33.3
Lactuca sativa L.	Ilethasi (X), lettuce (E)	Leaves eaten raw or made into salad. Vegetable head preserved for later use	33.3
Citrus limon (L.) Burm. f.	Lamuni (X), lemon (E)	Fruits edible, preserved for later use	28.6
Alepidea amatymbica Eckl. & Zeyh.	Giant alepidea, iqwili (X)	Roots used as herbal medicine	28.6
Aloe ferox Mill.	Ikhala (X), Aloe	Leaves used as herbal medicine and whole plant as live fence	28.6
Tulbaghia acutiloba Harv.	Isivumbampunzi (X)	Bulb used as herbal medicine	28.6
Prunus armeniaca L.	Apricot (E)	Fruits edible, preserved for later use	28.6
Pisum sativum L.	Erityisi (X), pea (E)	Young seeds boiled as vegetables and can be mixed with other vegetables or meat.	23.8
Agave americana L.	Agave (E), ikhamanga (X)	Whole plant used as live fence and leaf sap as herbal medicine	19.0
Elephantorrhiza elephantina (Burch.) Skeels	Intololwane (X)	Rhizome used as herbal medicine	19.0
Catharanthus roseus (L.) G. Don	Periwinkle (E)	Ornamental, roots used as herbal medicine	19.0
Alepidea serrata Eckl. & Zeyh.	Ubulawu (X)	Roots used as herbal medicine	14.3
Allium sativum L.	Garlic (E)	Tubers added to vegetables and meat. Tubers preserved for later use	14.3
Aloe ciliaris Haw.	Aloe (E), intelezi (X)	Leaves used as herbal medicine	14.3
Amaranthus hybridus L.	Nomdlomboyi (X), pigweed (E)	Leaves cooked as leafy vegetables	14.3
Bidens pilosa L.	Black jack (E), umhlabangulo (X)	Leaves cooked as leafy vegetables	14.3
Centella coriacea Nannfd.	Unongotyozana (X)	Roots used as herbal medicine and leaves cooked as leafy vegetables	14.3
Cheilanthes hirta Sw.	Buhlungubenyoka (X), Parsley fern (E)	Leaves and roots used as herbal medicine	14.3
Chenopodium spp.	Mbilikicane (X)	Leaves and roots used as herbal medicine	14.3
Vitis vinifera L.	Grape (E), umdiliya (X)	Fruits edible	14.3
Opuntia ficus-indica (L.) Mill.	Itolofiya (X), prickly pear (E)	Fruits edible, preserved for later use. Also used as hedge, ornamental and herbal medicine	14.3

Persea americana Mill.	Avocado (E)	Fruits edible, preserved for later use	14.3
Brassica rapa L.	Turnip (E)	Leaves and roots cooked as vegetables. Leaves and roots preserved for later use	14.3
Leonotis leonurus (L.) R. Br.	Imvovo (X), wild dagga (E)	Leaves and roots used as herbal medicine	14.3
Bulbine abyssinica A. Rich	Bushy bulbine (E), tswelana (X)	Bulb used as herbal medicine	9.5
Asparagus asparagoides (L.) Druce	Inyongo (X), smilax (E)	Roots used as herbal medicine	9.5
Sida rhombifolia L.	Common sida (E)	Roots used as herbal medicine	9.5
Bowiea volubilis Harv. ex Hook. f.	Climbing onion (E), tsivelana (X)	Bulb used as herbal medicine	9.5
Phoenix reclinata Jacq.	Cycad (E), isundu (X)	Ornamental, leaves used to make baskets, mats and other crafts	9.5
Acokanthera oblongifola (Hochst.) Codd	Dune poison bush, ubuhlungubenyoka (X),	Bark and roots used as herbal medicine	9.5
Carpobrotus edulis (L.) L. Bolus	Sour fig (E), unomatyumtyum (X)	Bark and roots used as herbal medicine	9.5
Ficus spp.	Fig (E), umngxam (X)	Bark and roots used as herbal medicine	9.5
Hermannia spp.	Inceba (X)	Roots used as herbal medicine	9.5
Pittosporum viridiflorum Sims.	Umkhwenkwe (X), white cape beech (E)	Bark, leaves and roots used as herbal medicine	9.5
Scilla spp.	Umasixabane (X)	Bulb used as herbal medicine	9.5
Sonchus asper (L.) Hill	Irwabe (X), sowthistle (E)	Roots used as herbal medicine and leaves cooked as leafy vegetables	9.5
Ficus carica L.	Fig (E), ikwiwane (X)	Fruits edible, preserved for later use. Also used as herbal medicine	4.8

State of grazing land in Ntabelanga area

A total of 14 grass species were identified in this study (Table 8-1). Three grass species generally regarded as highly palatable were recorded in the Ntabelanga area: *Cynodon dactylon*, *Setaria sphacelata* var. *sericea* and *Sporobolus fimbriatus.* The following eight species regarded as moderately to poorly palatable were also recorded in study area: *Andropogon eucomis*, *Aristida congesta* ssp. *barbicollis*, *Digitaria ternata*, *Eragrostis chloromelas*, *Eragrostis gummiflua*, *Melinis repens* ssp. *repens*, *Microchloa caffra* and *Sporobolus africanus* (Table 8-4). The majority of these grass species (71.4%) are increaser grass species, that is, they increase in abundance when the veld is under or over-utilised (Trollope et al., 1989).

The highly palatable *Setaria sphacelata* var. *sericea* and *Sporobolus fimbriatus* are the only decreaser species documented in this study, these species tend to decrease in abundance when the veld is under or over-utilised (Trollope et al., 1989). *Aristida congesta* ssp. *barbicollis*, *Cynodon dactylon, Hypparrhenia hirta* and *Sporobolus africanus* dominated riparian zone, disturbed habitats and the bottom areas (Table 8-4). The sloppy zone was dominated by *Eragrostis chloromelas*, *Melinis repens* ssp. *repens* and *Microchloa caffra*. The dominant grass species such as *Aristida congesta* ssp. *barbicollis*, *Cynodon dactylon, Eragrostis chloromelas*, *Hypparrhenia hirta, Sporobolus africanus* and *Sporobolus fimbriatus* (Table 8-4) were most abundant in well-drained soil in the grassland, disturbed places such as old cultivated lands, roadsides and on the periphery of Tsitsa River. Table 8-5 presents variation in dry matter yield (kg/ha) of selected grass species growing in two landscape gradients in the Ntabelanga area. Dry matter yield ranged from 94.4±8.0 to 341.5±26.8 kg/ha from the sloppy areas to the bottom, that is flat zones and grazing areas on the periphery of the Tsitsa River (Table 8-5). The average yield of the bottom zone is significantly higher ($P<0.05$) than the dry matter yield of sloppy areas.

Table 8-4: Palatability, ecological value, distribution and frequency of grass species in Tsitsa river catchment area

Grass species	Palatability	Ecological value	Distribution		Frequency (%)
			Bottom	Sloppy	
Andropogon eucomis	Poorly palatable	Increaser ii	Dominant*	-	2.0
Aristida congesta ssp. *barbicollis*	Moderately palatable	Increaser ii	Dominant	Present	14.4
Cynodon dactylon	Highly palatable	Increaser ii	Dominant	Present	11.8
Digitaria ternata	Poorly palatable	Increaser ii	Dominant	-	1.2
Eragrostis chloromelas	Moderately palatable	Increaser ii	Present	Dominant	12.6
Eragrostis gummiflua	Poorly palatable	Increaser ii	Dominant	-	3.8
Hypparrhenia hirta	Poorly palatable	Increaser i	Dominant	Present	29.2
Hypparrhenia spp.	-	-	Dominant	-	1.1
Melinis repens ssp. *repens*	Moderately palatable	Increaser ii	-	Dominant	1.2
Microchloa caffra	Poorly palatable	Increaser ii	Present	Dominant	2.5
Paspalum distichum	-	-	Dominant	-	1.0
Setaria sphacelata var. *sericea*	Highly palatable	Decreaser	Bottom	-	2.0
Sporobolus africanus	Poorly palatable	Increaser ii	Bottom	Present	41.3
Sporobolus fimbriatus	Highly palatable	Decreaser	Bottom	Rare	16.4

*Dominant = >10%; present = 1-10%; rare = <1%

Impact of dam construction on grazing potential

The proposed dam will reduce the grazing land, leading to overstocking, which is known to cause overgrazing as a result of the following:

1. the loss of palatable plant species,
2. loss of plant cover,
3. soil erosion,
4. loss of soil fertility, and
5. reduced capacity by the land to support palatable plant species.

Reduction of grazing land through damming will cause carrying capacity to diminish over time and therefore, the quality and productivity of livestock will deteriorate through lower calving rates and lower annual growth of individual species. Another consequence of damming is that total biomass will be reduced, leading to overgrazing of the available grazing lands. This means that more pressure will be placed on remaining grasslands and the process will accelerate over time, leading to run-away erosion and further loss of palatable grass species. Damming will force residents to graze their livestock in residential areas, cropping land, abandoned or old cropping lands due to reduced grazing land. Our assessment revealed that abandoned old cropping lands usually have annual weedy species and other related species which are of limited grazing value.

The periphery of Tsitsa River and flat grassland currently used as grazing land (see Figure 8-7) are most likely to be flooded due to damming. This zone has higher dry matter yield and higher numbers of moderately and highly palatable grass species than the sloppy zone (see Table 8-4 and Table 8-5). Flooding will negatively affect abundance of moderately and highly palatable species such as *Aristida congesta* ssp. *barbicollis*, *Cynodon dactylon, Setaria sphacelata* var. *sericea*, *Sporobolus africanus* and *Sporobolus fimbriatus*. Therefore, there is no doubt that flooding will destroy the most palatable or preferred species and this will grant an opportunity to less palatable or less desirable species to take over the rangeland. Damming will cause significant changes in vegetation structure, composition, grassland productivity, and the expected heavy grazing pressure will result in disappearance of decreaser species and replaced by increaser or invader species.

Table 8-5: Variation in dry matter yield (kg/ha) in relation to the landscape gradient in the Ntabelanga area

Grass species	Bottom	Sloppy
Aristida congesta ssp. *barbicollis*	298.3±32.8	237.5±24.2
Cynodon dactylon	141.1±19.4	115.7±6.4
Eragrostis chloromelas	163.1±17.4	204.4±20.8
Hypparrhenia hirta	333.1±31.6	284.7±23.1
Microchloa caffra	103.5±7.9	136.2±11.3
Sporobolus africanus	341.5±26.8	275.8±22.6
Sporobolus fimbriatus	183.6±17.1	94.4±8.0

Figure 8-7: Large tracts of land along the Tsitsa River are devoted to grazing (Photo: A. Maroyi).

8.3 Conclusion and recommendations for future monitoring

Several ecological and ethnobotanical techniques have been used to evaluate plant diversity and composition within the Ntabelanga area, how these plant resources are currently utilised by the local people, including the grazing potential of the grazing land in the study area. This study revealed that plant resources provide a wide range of goods and provisioning services to the residents of the Ntabelanga area. The impacts of the proposed dam were evaluated in the context of how such a project will affect plant biodiversity, livestock production and human livelihoods.

9 SOIL QUALITY

9.1 Soil Management Assessment Framework (SMAF) to evaluate soil quality

The increase of soil erosion rates, losses in organic matter, depreciation in soil fertility and productivity, chemical and heavy metal contamination, and dilapidation of air and water quality are reasons for the interest in the concept of soil quality (SQ) and its evaluation (Andrews et al., 2004). There are many definitions for SQ which in many instances contradict, however Karlen et al. (1997) defined it as “the capacity of the soil to function”. Soil functions comprise of: water flow and retention, solute transport and retention, physical stability and support; retention and cycling of nutrients; buffering and filtering of potentially toxic materials; and maintenance of biodiversity and habitat (Andrews et al., 1997; Daily et al., 1997). Dynamic SQ refers to the anthropological impact and management on soil functions (Andrews et al., 2004; Seybold et al., 1998). Since mismanagement of soil can be hazardous to soil functions, there is a need for tools and methods to assess and monitor SQ (Doran and Jones, 1996). Measuring soil functions directly is a challenge and may need longer periods to acquire quantifiable changes (Wienhold et al., 2009). In this context Andrews et al. (2004) developed soil management assessment framework (SMAF) as non-linear indexing tool to assess soil function. The SMAF was created for farmers and their advisors in evaluating the ongoing management activities (Wienhold et al., 2009).

SMAF Assessment procedure

The SMAF consists of three steps: indicator selection, indicator interpretation, and integration into a soil quality index (Andrews et al., 2004) (Figure 9-1). The indicator selection step uses an expert system of decision rules to recommend indicators for inclusion in the assessment based on the user’s stated management goals, location and current practice. For instance, if the user is adding manure, soil test P is suggested as one indicator to include in the assessment. In the indicator interpretation step, observed indicator data is transformed into a unit less score based on clearly defined, site-specific relationships to soil function (Andrews et al., 2004). The soil functions of interest include crop productivity, nutrient cycling, physical stability, water and solute flow, contaminant filtering and buffering, and biodiversity.

The indicator interpretation step use various factors (i.e. organic matter, texture, climate, slope, region, mineralogy, weathering class, crop, sampling time, and analytical method) to adjust threshold values in the scoring curves that are then used to assign a relative value of 0 to 1 for each type of data being collected (Andrews et al., 2004). The integration steps allows for the individual indicator scores to be combined into a single index value. This can be done with equal or differential weighting for the various indicators depending upon the relative importance of the soil functions for which they are being measured. The SMAF is still under development, but it currently has about 13 indicators with scoring curves consisting of interpretation algorithms which includes macro-aggregate stability (AGS), plant-available water holding capacity, water filled pore space (WFPS), bulky density, electrical conductivity, soil pH, sodium adsorption ratio (SAR), extractable P and K, soil organic carbon (SOC), microbial biomass carbon (MBC), potentially mineralizable nitrogen (N_{min}), and β-glucosidase (BG) activity (Stott et al., 2011).

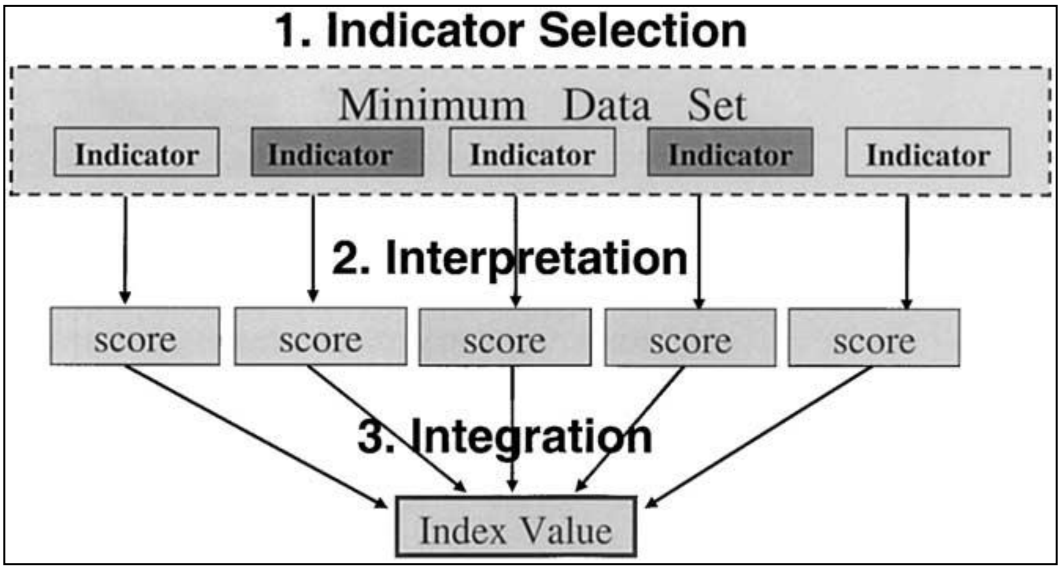

Figure 9-1: Conceptual framework for the soil management assessment tool (Andrews, 1998).

<u>Indicator Selection</u>

The SMAF uses a series of decision rules (Andrews et al., 2004) in a database format, to generate a list of suggested indicators from the more than 80 integrative measurements related to ecosystem processes and function currently residing in the database. The decision rules use the management goals for the site, associated soil functions, as well as other site-specific factors, like region or crop sensitivity, as selection criteria. These rules tables serve as an expert system to select appropriate soil quality indicators (Andrews et al., 2002a).

To generate a list of suggested indicators, a user of the tool replies to a number of questions, one of which pertains to the user's primary management goal for the site. A table in the database identifies the critical functions associated with each management goal: maximize productivity, waste recycling, or environmental protection. For example, if the user chooses waste recycling as the primary management goal, the program identifies the functions nutrient cycling, water relations, filtering and buffering, and resistance and resilience as important to that goal. In a second database table, a list of indicators is associated with each identified soil function. The list is further narrowed using several additional criteria: climate, crop or rotation, tillage practice(s), assessment purpose, and inherent soil properties (such as organic matter class, texture, slope, degree of weathering, or pH). Each indicator has a unique combination of goals, functions, and additional criteria that must be satisfied for it to be suggested as a minimum data set (MDS) indicator. The database structure of the decision rules program for Step 1 allows for easy updates and refinements: goals, functions, indicators, selection rules, and their associations can all be altered, added or deleted via changes to the database, updating selection rules without altering the program itself (Figure 9-2).

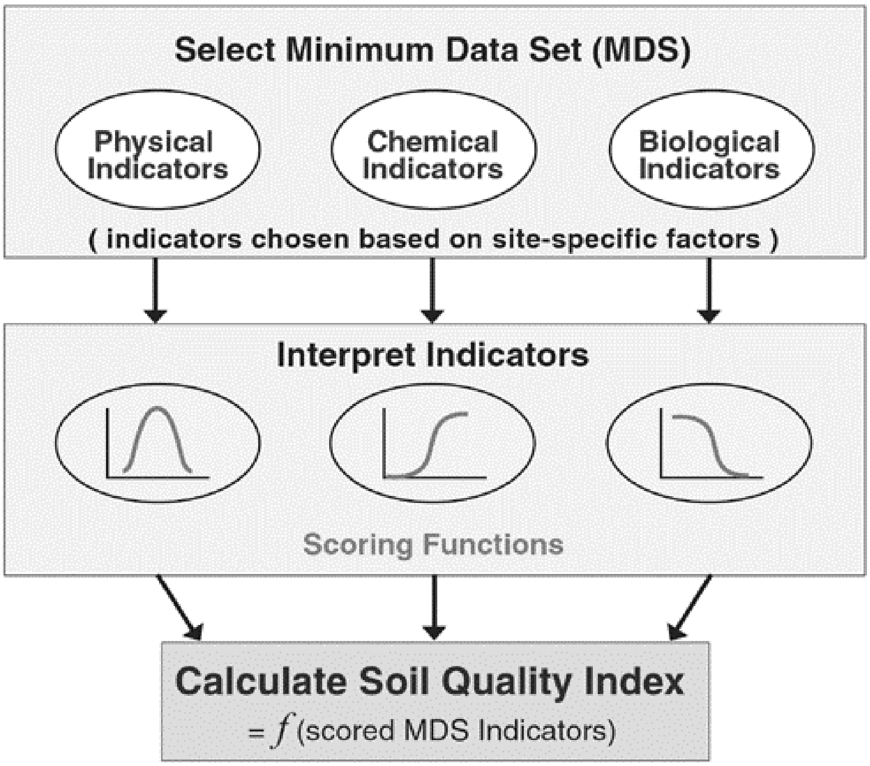

Figure 9-2: Grouping of indicators, interpretation indicators and calculation of Soil Quality Index (Andrews et al. (2001).

The resulting suggested indicator list is grouped according to critical soil function. The user is asked to select four to eight indicators with at least one indicator from each function. To maximize flexibility and accessibility, the user has final say as to which indicators are selected for the MDS and can elect to ignore the suggested list or use a different number of indicators. Currently there are 80+ indicators that can be offered for the suggested list, but only 13 are available for use in the next step (because scoring algorithms are yet to be fully developed).

The objective in this section was to quantify the soil health using SMAF of selected croplands and natural veld

9.2 Results and discussion

Soil classification

The soils of the home gardens in Lower Sinxaku were classified as Clovelly, Glenrosa, Valsriver or Hutton soil forms (Table 9-1). Clovelly and Hutton soils typically have high agricultural potential whereas the potential of Glenrosa and Valsriver soils are limited by depth and strong structure respectively.

The soils of the vegetation survey sites were classified as Swartland, Clovelly, Glenrosa, Hutton, Oakleaf and Milkwood forms (Table 9-1). Of these forms, Swartland and Glenrosa are the most sensitive to degradation due to water erosion.

Table 9-1: ***Classification of the soils and link to International Classification Systems***

	Site	Soil Form	WRB[1]	USDA[2]	Texture Class
Lower Sinxako	MNS1	Clovelly	Ferrasol	Ustox	SaClLm
	MNS2	Clovelly	Ferrasol	Ustox	SaLm
	MNS3	Glenrosa	Leptosol	Ustepts	SaClLm
	MNS4	Valsrivier	Luvisol	Ustalf	SaClLm
	MNS5	Valsrivier	Luvisol	Ustalf	SaClLm
	MNS6	Hutton	Ferrasol	Ustox	SaLm
	MNS7	Glenrosa	Leptosol	Ustepts	SaLm
	MNS8	Hutton	Luvisol	Ustalf	SaClLm
	MNS9	Glenrosa	Leptosol	Ustepts	SaClLm
	MNS10	Clovelly	Ferrasol	Ustox	SaClLm
Vegetation sites	Site 1	Swartland	Luvisol	Ustalf	SaClLm
	Site 2	Swartland	Luvisol	Ustalf	SaClLm
	Site 3	Swartland	Luvisol	Ustalf	SaLm
	Site 4	Clovelly	Ferrasol	Ustox	SaClLm
	Site 6	Glenrosa	Leptosol	Ustepts	SaLm
	Site 6	Hutton	Ferrasol	Ustox	SaClLm
	Site 7	Oakleaf	Cambisol	Ustepts	SaClLm
	Site 8	Milkwood	Phaeozem	Ustolls	SaLm
	KuGubengxa	Hutton	Ferrasol	Ustox	SaClLm

[1]WRB – Reference Groups of the FAO'; [2]USDA – Suborder of United States Department of Agriculture.

Soil chemical and physical properties

Approximately 60% of soils in South Africa have low organic matter content and are subject to degradation. The soil organic matter (SOM) levels are reported to further decline in arable lands where monoculture cereal production, intensive tillage, with short to no fallow is practiced. In the Eastern Cape (EC) soil degradation has also been identified to be among the major causes of low crop productivity and it is generally accepted that the soil degradation is caused by organic matter depletion due to conventional tillage practices that involve the tilling of land. Therefore, the solution to the problem of soil degradation will involve adoption of management practices that will arrest the loss of SOM and increase it (Mandiringana et al., 2005). This chapter aims at describing soil properties of the sampled areas and indicate their soil health status of the soil using SMAF.

Ntabelanga is marked by a semi-arid climate with large variability in rainfall. Despite the restricted and unreliable rainfall, smallholder farmers in the area depend on the rain fed cropping systems. Rainfall inconsistence is a main challenge to the farmers in the five villages. Famers complain about unreliable or completely no yields as a result of variation of the rainfall patterns.

Soils in the Ntabelanga area are characterized by steep slopes, highly eroded with shallow depths. The old abandoned cultivated fields are full of gullies and the widening of dongas near the grave sites is threatening. The dongas are wide and deep along the river banks and the phenomenon is more common at lower Sinxaku area. Gully erosion is a serious problem in the study area. It affects the land in three ways. The first is the expansion of the gully side-ways is that it damages farm lands and reduces the size of farm plots. Secondly the gully increases in length in the field. The third is the increase in the depth of the gully, which almost blocks communication between villages and households within the same village. The other impact is increase in the depth of gully that drains moisture from the adjacent farm plots. This affects availability of moisture for the crops to be grown. During unexpected intense storms, huge quantities of water from the gully damage crop lands down-stream, causing loss in income.

Table 9-2: Selected soil chemical analysis

	Site	pH (H_2O)	CEC	N	P (BrayII)	Melich III K	Melich III Na	Melich III Ca	Melich III Mg	Base Saturation Ca	Base Saturation Mg	Base Saturation K	Base Saturation Na	Base Saturation H
			$cmol_c/kg^{-1}$	mg/kg						%				
Lower Sinxako	MNS1	6.45	15.53	108.59	95.50	905.08	30.85	1388.69	518.53	43.98	27.16	14.79	0.87	8.25
	MNS2	5.14	10.62	77.23	66.00	303.36	21.07	743.26	169.31	35.55	13.18	7.36	0.87	35.92
	MNS3	6.19	7.44	72.13	26.00	396.32	28.76	637.97	224.58	42.34	24.84	13.68	1.72	12.21
	MNS4	5.90	6.65	70.90	12.50	170.69	23.23	619.67	173.92	46.89	21.61	6.42	1.56	17.93
	MNS5	6.27	8.48	56.45	13.00	96.69	26.88	830.53	306.56	49.28	29.84	2.98	1.38	11.36
	MNS6	6.05	5.93	69.67	13.50	255.48	21.01	583.44	133.92	49.27	18.61	10.73	1.55	14.48
	MNS7	6.14	20.88	68.77	93.50	269.32	22.60	2141.38	683.48	51.40	26.61	3.42	0.47	12.84
	MNS8	6.18	9.58	85.63	8.00	318.02	23.23	908.95	297.41	47.41	25.43	8.51	1.06	12.37
	MNS9	6.20	13.21	85.79	32.00	619.80	27.72	1176.91	410.42	44.53	25.44	11.99	0.91	11.93
	MNS10	6.88	8.24	60.37	12.50	228.27	21.41	1007.42	235.58	61.39	23.42	7.08	1.13	2.45
Vegetation sites	Site 1	6.41	9.89	0.83	2.00	127.75	79.33	1035.02	493	52.34	40.86	3.30	3.49	0.00
	Site 2	6.88	9.66	1.70	1.00	101.43	28.98	1186.77	407	61.44	34.57	2.69	1.30	0.00
	Site 3	6.25	2.62	0.85	1.00	34.75	40.86	303.56	102	57.97	31.85	3.39	6.79	0.00
	Site 4	6.72	4.80	1.05	2.00	136.27	27.86	559.88	187	58.31	31.91	7.26	2.52	0.00
	Site 6	6.44	8.91	2.93	1.00	69.30	65.12	958.36	447	53.76	41.08	1.99	3.18	0.00
	Site 6	6.28	3.99	1.58	1.00	39.72	23.43	479.08	170	60.06	34.84	2.55	2.55	0.00
	Site 7	6.31	9.49	1.11	1.00	69.87	61.39	1026.53	477	54.08	41.23	1.88	2.81	0.00
	Site 8	5.31	4.34	1.78	1.00	89.46	19.17	408.09	179	47.01	33.78	5.27	1.92	12.03
	KuGubengxa	6.27	5.05	18.15	2.00	102.01	31.84	624.77	186	61.90	30.19	5.17	2.74	0.00

The high soil erosion rate with rapid gully formation is ascribed to instability of soils with high susceptibility of soils to erosion, steep slopes and bare soils. Management practices such as conventional tillage, which include ploughing, results in fast decomposition of organic matter, reduce microbial activity and reduced aggregate stability. In addition the removal of crop residues leaves bare soils which are vulnerable to splash and wind erosion resulting to decreased soil fertility. In a study that was conducted in Ntabelanga by Van Tol et al. (2014) the results showed that soils in the area were highly eroded with gullies originating from old cultivated lands. The study also indicated that removal of vegetation and disturbance of soil structure resulted in severe erosion in the area.

Table 9-3: Selected soil physical analysis

	Site	BD[1]	Clay	Silt	Sand	Aggregate Stability	SOC[2]	Active C
		g/cm^3	%	%	%	Stabile %	%	mg/kg
Lower Sinxako	MNS1	1.14	22	27	51	28.19	2.85	714.7
	MNS2	1.21	19	20	61	0.87	1.45	277.2
	MNS3	1.24	27	24	49	2.74	1.36	277.2
	MNS4	1.28	25	11	64	5.07	1.26	312.5
	MNS5	1.29	21	18	61	10.33	0.88	312.5
	MNS6	1.30	17	15	68	14.05	1.23	347.8
	MNS7	1.34	15	14	71	7.87	1.20	418.3
	MNS8	1.21	33	17	50	10.36	1.69	418.3
	MNS9	1.24	31	20	49	12.50	1.76	383.0
	MNS10	1.25	27	24	49	10.53	0.98	383.0
Vegetation sites	Site 1	0.93	21	16	63	39.30	1.52	464.18
	Site 2	1.06	23	13	64	42.70	0.99	266.62
	Site 3	1.02	13	10	77	36.93	0.66	164.30
	Site 4	1.15	23	27	50	44.69	1.75	520.63
	Site 6	1.03	19	19	62	30.12	0.75	189.00
	Site 6	1.21	21	16	63	21.66	0.29	220.75
	Site 7	1.09	27	26	47	16.67	0.89	379.51
	Site 8	1.21	19	13	68	69.41	1.39	372.46
	KuGubengxa	1.12	25	26	49	9.62	0.53	217.22

[1]BD – bulk density; [2]SOC – Soil Organic Carbon (Organic Matter ÷ 1.72)

Erosion in the area is also accredited to less vegetation which exposes soils to water (raindrop splashing) and wind erosion. The area is partially covered with different species of grasses, shrubs and *acacia karroo* (sweet thorn). The *acacia karroo* grows in semi-arid areas and has suppressive effect on other vegetation growing around it; as a result, areas that had high distribution of it had little or no grasses and therefore subjecting soils to high rates of erosion.

The degree of erosion varies with soil form as shown in the above table where the soil factor is rated from 0.4 to 1, 1 being optimum. Clovelly and Hutton soils are good with soil depth that goes from 30 cm to 110 cm. Glenrosa soils are highly erodible with shallow depth and a soil factor of 0.4. These soils have a depth ranging from 0 to 30 cm. which is not sufficient for maize the major crop produced in the area which requires a soil depth of 200 cm soil depth. The limited soil depth results in limited growth in maize crop and therefore poor yields. To attest to that one farmer said:

Globally the soil fraction contents for organic matter is around 5%, but in semi-arid and arid climate a maximum of 2% is usually recorded. The average organic content of the garden soils was 2.5% which is optimum for crop production under correct management systems.

SMAF assessments

General factor classes

SMAF makes use of several factor classes to divide the soils into typical ranges. These divisions are based on *inter alia* the pedological classification (USDA – sub-orders), climate (seasonal temperatures and annual rainfall), texture classes and the crop which will be cultivated. Typical classes are presented in Table 9-4.

Table 9-4: SMAF Factor Classes

		SMAF Factor Classes				
		OM[1]	**Texture**	**Climate**	**Crop**	**Slope**
Lower Sinxako	MNS1	4	2	1	32	3
	MNS2	4	2	1	32	3
	MNS3	4	2	1	32	2
	MNS4	3	2	1	32	2
	MNS5	3	2	1	32	2
	MNS6	4	2	1	32	2
	MNS7	4	2	1	32	2
	MNS8	3	2	1	32	2
	MNS9	4	2	1	32	1
	MNS10	4	2	1	32	2
Vegetation sites	Site 1	3	2	1	11	1
	Site 2	3	2	1	11	3
	Site 3	3	2	1	11	2
	Site 4	4	2	1	11	2
	Site 6	4	2	1	11	2
	Site 6	4	2	1	11	2
	Site 7	4	2	1	11	3
	Site 8	2	2	1	11	2
	KuGubengxa	4	2	1	32	2

[1]OM – Organic Matter class associated with USDA suborder classification

Soil Organic Carbon (SOC)

The algorithm for calculation of the SOC is an exponential function in the form of:

$$y = \frac{a}{1 + b^{-c \times OC}}$$

Where *y* is the SMAF indicator score *a* and *b* is fixed parameters (*a* = 1; b = 50.1) and *c* is related to the inherent OM class (associated with the classification (*c1*), soil texture (*c2*) and climate (*c3*) such that:

$$c = (c1 \times c2) + (c1 \times c2 \times c3)$$

OC is the total Organic Carbon (%) present in the soil. Specific SMAF factor class values for SOC determination is presented in Table 9-5 together with the calculated Soil Quality Index for SOC.

Table 9-5: Soil Quality Index (SQI) for SOC

			SMAF Factor Class							
	Site	**SOC (%)**	**OM**	**Texture**	**Climate**	**c1**	**c2**	**c3**	**c**	**SQI**
Lower Sinxako	MNS1	2.85	4	2	1	3.81	1.25	0.15	5.48	1.00
	MNS2	1.45	4	2	1	3.81	1.25	0.15	5.48	0.98
	MNS3	1.36	4	2	1	3.81	1.25	0.15	5.48	0.97
	MNS4	1.26	3	2	1	2.17	1.25	0.15	3.12	0.50
	MNS5	0.88	3	2	1	2.17	1.25	0.15	3.12	0.24
	MNS6	1.23	4	2	1	3.81	1.25	0.15	5.48	0.94
	MNS7	1.20	4	2	1	3.81	1.25	0.15	5.48	0.94
	MNS8	1.69	3	2	1	2.17	1.25	0.15	3.12	0.80
	MNS9	1.76	4	2	1	3.81	1.25	0.15	5.48	1.00
	MNS10	0.98	4	2	1	3.81	1.25	0.15	5.48	0.81
Vegetation sites	Site 1	1.52	3	2	1	2.17	1.25	0.15	3.12	0.70
	Site 2	0.99	3	2	1	2.17	1.25	0.15	3.12	0.31
	Site 3	0.66	3	2	1	2.17	1.25	0.15	3.12	0.14
	Site 4	1.75	4	2	1	3.81	1.25	0.15	5.48	1.00
	Site 6	0.75	4	2	1	3.81	1.25	0.15	5.48	0.55
	Site 6	0.29	4	2	1	3.81	1.25	0.15	5.48	0.09
	Site 7	0.89	4	2	1	3.81	1.25	0.15	5.48	0.72
	Site 8	1.39	2	2	1	1.55	1.25	0.15	2.23	0.30
	KuGubengxa	0.53	4	2	1	3.81	1.25	0.15	5.48	0.27

Microbial Biomass Carbon (MBC)

An exponential algorithm is used to interpret Microbial Biomass Carbon (MBC); also termed active carbon. MBC is influenced by OM class, soil texture as well as the growing season and climate. The algorithm is:

$$y = \frac{a}{1 + b^{-c \times MBC}}$$

Where *y* is the SQI in terms of MBC, *a* and *b* are again constants (*a* = 1 and *b* = 40.748) and see captures the impact of inherent OM (*c1*), texture (*c2*) and climate and growing season (*c3*) in the form of:

$$c = c1 \times c2 \times c3$$

MBC represents the active carbon (mg.kg^{-1}) present in the soil. Specific SMAF factor class values for MBC determination is presented Table 9-6 in together with the calculated Soil Quality Index for MBC.

Table 9-6: Calculation of Soil Quality Index (SQI) for MBC

			SMAF Factor Class							
	Site	**Active C (mg/kg)**	**OM**	**Texture**	**Season xClimate**	**c1**	**c2**	**c3**	**c**	**SQI**
Lower Sinxako	MNS1	714.7	4	2	2.1	0.021	1.025	0.920	0.020	1.000
	MNS2	277.2	4	2	2.1	0.021	1.025	0.920	0.020	0.865
	MNS3	277.2	4	2	2.1	0.021	1.025	0.920	0.020	0.865
	MNS4	312.5	3	2	2.1	0.019	1.025	0.920	0.018	0.865
	MNS5	312.5	3	2	2.1	0.019	1.025	0.920	0.018	0.865
	MNS6	347.8	4	2	2.1	0.021	1.025	0.920	0.020	0.964
	MNS7	418.3	4	2	2.1	0.021	1.025	0.920	0.020	0.991
	MNS8	418.3	3	2	2.1	0.019	1.025	0.920	0.018	0.974
	MNS9	383.0	4	2	2.1	0.021	1.025	0.920	0.020	0.982
	MNS10	383.0	4	2	2.1	0.021	1.025	0.920	0.020	0.982
Vegetation sites	Site 1	464.18	3	2	2.1	0.019	1.025	0.920	0.018	0.988
	Site 2	266.62	3	2	2.1	0.019	1.025	0.920	0.018	0.726
	Site 3	164.30	3	2	2.1	0.019	1.025	0.920	0.018	0.306
	Site 4	520.63	4	2	2.1	0.021	1.025	0.920	0.020	1.000
	Site 6	189.00	4	2	2.1	0.021	1.025	0.920	0.020	0.522
	Site 6	220.75	4	2	2.1	0.021	1.025	0.920	0.020	0.674
	Site 7	379.51	4	2	2.1	0.021	1.025	0.920	0.020	0.980
	Site 8	372.46	2	2	2.1	0.012	1.025	0.920	0.012	0.658
	KuGubengxa	217.22	4	2	2.1	0.021	1.025	0.920	0.020	0.658

Soil Phosphorus (P)

For interpretation of the P content it is first necessary to determine whether the P contents was available at optimum levels for the different crops before selecting an algorithm. Available P contents significantly higher than that required by the plants might result in environmental degradation. In order to evaluate the P levels it is also necessary to include the method of determination. In this study the Bray method was used (Table 9-2). Lastly a 'weathering class' was also included, where distinctions were made between highly weathered and slightly weathered soils.

The first algorithm is used when the soil P contents (mg.kg^{-1}), with method and weathering factored in (termed 'methodfactor'), is smaller than the P_max (i.e. optimum P for specific crop + 6 mg.kg^{-1}):

$$y = \frac{\left(a \times b + c \times (P \times methodfactor)^{d}\right)}{\left(b + (P \times methodfactor)^{d}\right)}$$

Where *y* is the interpretation score and *a*, *c* and *d* are fixed parameters with values of 9.25 x 10^{-6}, 1 and 3.06 respectively. The *b* value is calculated using the crop value, SOC content (%) and the texture class.

If the P content is higher than P_max, it might lead to environmental degradation such as eutrophication of streams due to overlandflow. The latter is greatly influenced by the slope of the land as expressed in Table 9-7.

Table 9-7: Relationship between slope and maximum P contents to avoid environmental degradation

Slope (%)	Slope class	Environmental tolerable P (mg/kg)
0-2	1	160
2 to 5	2	140
5 to 9	3	115
9 to 15	4	85
15+	5	60

Soils with P contents which are greater than the optimum levels but are not threating the environment is assigned a value of 1 (Table 9-8).

Table 9-8: Calculation of Soil Quality Index (SQI) in relation to P contents

		P (mg/kg)	SMAF Factor Class: Method	Weather-ring	Slope	Method factor	Re-calculated P[1] (mg/kg)	P_opt[2] (mg/kg)	Environmental P3 (mg/kg)	b1	b2	b3	b	SQI
Lower Sinxako	MNS1	95.50	3	2	3	0.66	63.03	19	115	293.00	0.01	0.99	295.9	1.000
	MNS2	66.00	3	2	3	0.66	43.56	19	115	293.00	0.01	0.99	295.9	1.000
	MNS3	26.00	3	3	2	1.00	26.00	19	140	293.00	0.01	0.99	295.9	1.000
	MNS4	12.50	3	3	2	1.00	12.50	19	140	293.00	0.02	0.99	298.1	0.884
	MNS5	13.00	3	3	2	1.00	13.00	19	140	293.00	0.02	0.99	298.1	0.896
	MNS6	13.50	3	2	2	0.66	8.91	19	140	293.00	0.01	0.99	295.9	0.732
	MNS7	93.50	3	3	2	1.00	93.50	19	140	293.00	0.01	0.99	295.9	1.000
	MNS8	8.00	3	3	2	1.00	8.00	19	140	293.00	0.02	0.99	298.1	0.661
	MNS9	32.00	3	3	1	1.00	32.00	19	160	293.00	0.01	0.99	295.9	1.000
	MNS10	12.50	3	2	2	0.66	8.25	19	140	293.00	0.01	0.99	295.9	0.683
Vegetation sites	Site 1	2.00	3	3	1	1.00	2.00	19	160	293.00	0.02	0.99	298.1	0.027
	Site 2	1.00	3	3	3	1.00	1.00	19	115	293.00	0.02	0.99	298.1	0.003
	Site 3	1.00	3	3	2	1.00	1.00	19	140	293.00	0.02	0.99	298.1	0.003
	Site 4	2.00	3	2	2	0.66	1.32	19	140	293.00	0.01	0.99	295.9	0.008
	Site 6	1.00	3	3	2	1.00	1.00	19	140	293.00	0.01	0.99	295.9	0.003
	Site 6	1.00	3	2	2	0.66	0.66	19	140	293.00	0.01	0.99	295.9	0.001
	Site 7	1.00	3	2	3	0.66	0.66	19	115	293.00	0.01	0.99	295.9	0.001
	Site 8	1.00	3	3	2	1.00	1.00	19	140	293.00	0.03	0.99	300.3	0.003
	KuGubengxa	2.00	3	2	2	0.66	1.32	19	140	293.00	0.01	0.99	295.9	0.008

[1]P contents for interpretation, method factored in; [2]Optimum P levels for plant growth; [3]Maximum tolerable P contents associated with different slopes.

Exchangeable Potassium (K)

For interpretation of the exchangeable K the following exponential algorithm is used:

$$y = a\left(1^{-bK}\right)$$

Where *y* is the interpretation score, *K* is Melich-III extractable K and *a and b* are defined differently for different texture classes, for coarse texture soils *a* and *b* is 1.054133 and -0.00981 respectively. Calculated SQI in terms of exchangeable K is presented in Table 9-9.

Table 9-9: Calculated Soil Quality Index (SQI) for exchangeable K

	Site	K (mg/kg)	SQI
Lower Sinxako	MNS1	905.08	1.00
	MNS2	303.36	1.00
	MNS3	396.32	1.00
	MNS4	170.69	0.86
	MNS5	96.69	0.65
	MNS6	255.48	0.97
	MNS7	269.32	0.98
	MNS8	318.02	1.00
	MNS9	619.80	1.00
	MNS10	228.27	0.94
Vegetation sites	Site 1	127.75	0.75
	Site 2	101.43	0.66
	Site 3	34.75	0.30
	Site 4	136.27	0.78
	Site 6	69.30	0.52
	Site 6	39.72	0.34
	Site 7	69.87	0.52
	Site 8	89.46	0.62
	KuGubengxa	102.01	0.67

Soil pH

Since different crops perform better at different pH levels, it is important to include crop factors for the interpretation of soil pH. The soil quality score is determined using the following equation:

$$y = a^{\frac{-(pH-b)^2}{2c^2}}$$

Where *y* is again the Soil Quality Index (SQI) score, *a* is a fixed parameter (= 1), *pH* is the soil $pH_{(H2O)}$, and *b* and *c* are site specific parameters. The optimum pH for a specific crop is *b* and *c* reflects a 'range' (also crop specific) of expectable pH values and calculated using:

$$c = \left(1.2627176 \times \left(\frac{range}{2}\right)\right) + \left(0.29161387 \times \left(\frac{range}{2}\right)^2\right)$$

Calculated SQI for soil pH are presented in Table 9-10.

Table 9-10: Calculated Soil Quality Index (SQI) for soil pH

	Site	pH (H2O)	Crop Code	b	c	SQI
Lower Sinxako	MNS1	6.45	32	6.30	1.55	1.00
	MNS2	5.14	32	6.30	1.55	0.76
	MNS3	6.19	32	6.30	1.55	1.00
	MNS4	5.90	32	6.30	1.55	0.97
	MNS5	6.27	32	6.30	1.55	1.00
	MNS6	6.05	32	6.30	1.55	0.99
	MNS7	6.14	32	6.30	1.55	0.99
	MNS8	6.18	32	6.30	1.55	1.00
	MNS9	6.20	32	6.30	1.55	1.00
	MNS10	6.88	32	6.30	1.55	0.93
Vegetation sites	Site 1	6.41	11	6.70	0.99	0.96
	Site 2	6.88	11	6.70	0.99	0.98
	Site 3	6.25	11	6.70	0.99	0.90
	Site 4	6.72	11	6.70	0.99	1.00
	Site 6	6.44	11	6.70	0.99	0.97
	Site 6	6.28	11	6.70	0.99	0.91
	Site 7	6.31	11	6.70	0.99	0.93
	Site 8	5.31	11	6.70	0.99	0.37
	KuGubengxa	6.27	32	6.30	0.99	1.00

Macro-aggregate stability

The interpretation and scoring (*y*) of aggregate stability rely on a sinusoidal limit function:

$$y = a + b\cos(cx - d)$$

Where *a, b* and *c* are fixed parameters with values of -0.8, 1.7993 and 0.0196 respectively. The stabile aggregates (%) are presented by *x*. The site specific parameter (*d*) is determined by the OM class (*d1*), soil texture class (*d2*) and the Fe_2O_3 class (*d3*). For the latter *Ultisols* are treated differently than the rest of the USDA orders. None of the soils in this study were *Ultisols* and all were assigned into Fe_2O_3 class 2 with a value of 1 which represents *d3* in the following equation:

$$d = d1 \times d2 \times d3$$

Calculated Soil Quality Index scores in relation to aggregate stability are presented in Table 9-11.

Table 9-11: Calculated Soil Quality Index (SQI) for aggregate stability

	Site	AGS[1] %	SMAF Factor Class OM	SMAF Factor Class Texture	d1	d2	d	SQI
Lower Sinxako	MNS1	28.19	4	2	0.90	1.06	0.95	0.86
	MNS2	0.87	4	2	0.90	1.06	0.95	0.27
	MNS3	2.74	4	2	0.90	1.06	0.95	0.32
	MNS4	5.07	3	2	1.02	1.06	1.08	0.20
	MNS5	10.33	3	2	1.02	1.06	1.08	0.35
	MNS6	14.05	4	2	0.90	1.06	0.95	0.60
	MNS7	7.87	4	2	0.90	1.06	0.95	0.45
	MNS8	10.36	3	2	1.02	1.06	1.08	0.35
	MNS9	12.50	4	2	0.90	1.06	0.95	0.57
	MNS10	10.53	4	2	0.90	1.06	0.95	0.52
Vegetation sites	Site 1	39.30	3	2	1.02	1.06	1.08	0.91
	Site 2	42.70	3	2	1.02	1.06	1.08	0.95
	Site 3	36.93	3	2	1.02	1.06	1.08	0.89
	Site 4	44.69	4	2	0.90	1.06	0.95	0.99
	Site 6	30.12	4	2	0.90	1.06	0.95	0.88
	Site 6	21.66	4	2	0.90	1.06	0.95	0.75
	Site 7	16.67	4	2	0.90	1.06	0.95	0.66
	Site 8	69.41	2	2	1.07	1.06	1.14	0.95
	KuGubengxa	9.62	4	2	0.90	1.06	0.95	0.50

[1]AGS – aggregate stability; % of stabile aggregates.

Bulk density

For interpretation of bulk density the following function is used (Grossman et al., 2001):

$$y = a - b^{(-cBD^{d})}$$

For fine textured soils the clay mineralogy is taken into consideration, but for coarse textured soils (like the soils in this study) only the parameters *b, c* and d were derived simply from the texture factor class. *BD* is the measured bulk density (g.cm^{-3}), *a* is a fixed parameter (0.994) and *y* is the interpretation score. Results are presented in Table 9-12.

Table 9-12: Calculated Soil Quality Index (SQI) for bulk density

	Site	BD[1] g/cm^3	Texture class	b	c	d	SQI
Lower Sinxako	MNS1	1.14	2	0.79	88.03	-12.06	0.99
	MNS2	1.21	2	0.79	88.03	-12.06	0.99
	MNS3	1.24	2	0.79	88.03	-12.06	0.99
	MNS4	1.28	2	0.79	88.03	-12.06	0.99
	MNS5	1.29	2	0.79	88.03	-12.06	0.98
	MNS6	1.30	2	0.79	88.03	-12.06	0.97
	MNS7	1.34	2	0.79	88.03	-12.06	0.93
	MNS8	1.21	2	0.79	88.03	-12.06	0.99
	MNS9	1.24	2	0.79	88.03	-12.06	0.99
	MNS10	1.25	2	0.79	88.03	-12.06	0.99
Vegetation sites	Site 1	0.93	2	0.79	88.03	-12.06	0.99
	Site 2	1.06	2	0.79	88.03	-12.06	0.99
	Site 3	1.02	2	0.79	88.03	-12.06	0.99
	Site 4	1.15	2	0.79	88.03	-12.06	0.99
	Site 6	1.03	2	0.79	88.03	-12.06	0.99
	Site 6	1.21	2	0.79	88.03	-12.06	0.99
	Site 7	1.09	2	0.79	88.03	-12.06	0.99
	Site 8	1.21	2	0.79	88.03	-12.06	0.99
	KuGubengxa	1.12	2	0.79	88.03	-12.06	0.99

[1]BD – Bulk density

Table 9-13 presents a summary of the soil health status of the sites categorized according to the Soil management assessment framework (SMAF). The optimum value for each of the parameters is 100% and the lower the values the more the need to improve soils in that specific parameter. As observed the garden's soil quality indexes (SQI) go as high as 97.8% in MNS1 and as low as 58.4% for KuGubengxa. This can be related to the farmers' management ability (see section 11).

The overall SQI of uncultivated soils of the vegetation survey sites ranged between 50.4% and 82.4% (Table 9-13). Degradation of the uncultivated fields due to water erosion and overgrazing can be attributed to the low SQI levels.

Table 9-13: Combined Soil Quality Index (SQI) expressed as a percentage for the different soils

		SOC	MBC	P	K	pH	AGS	BD	Total SQI (%)
Lower Sinxako	MNS1	1.000	1.000	1.000	1.000	0.995	0.856	0.994	97.8
	MNS2	0.983	0.865	1.000	1.000	0.757	0.266	0.994	83.8
	MNS3	0.972	0.865	1.000	1.000	0.998	0.318	0.993	87.8
	MNS4	0.502	0.856	0.884	0.860	0.968	0.200	0.985	75.1
	MNS5	0.239	0.856	0.896	0.646	1.000	0.348	0.979	70.9
	MNS6	0.943	0.964	0.732	0.968	0.987	0.601	0.975	88.1
	MNS7	0.936	0.991	1.000	0.979	0.995	0.454	0.932	89.8
	MNS8	0.796	0.974	0.661	1.000	0.997	0.349	0.994	82.4
	MNS9	0.997	0.982	1.000	1.000	0.998	0.566	0.993	93.4
	MNS10	0.813	0.982	0.683	0.942	0.934	0.519	0.992	83.8
Vegetation sites	Site 1	0.698	0.988	0.027	0.753	0.956	0.913	0.994	76.1
	Site 2	0.306	0.726	0.003	0.665	0.983	0.946	0.994	66.0
	Site 3	0.136	0.306	0.003	0.305	0.900	0.886	0.994	50.4
	Site 4	0.997	0.999	0.008	0.777	1.000	0.994	0.994	82.4
	Site 6	0.549	0.522	0.003	0.520	0.966	0.882	0.994	63.4
	Site 6	0.088	0.674	0.001	0.340	0.915	0.753	0.994	53.8
	Site 7	0.720	0.980	0.001	0.523	0.925	0.657	0.994	68.6
	Site 8	0.305	0.658	0.003	0.616	0.370	0.954	0.994	55.7
	KuGubengxa	0.265	0.658	0.008	0.667	1.000	0.497	0.994	58.4

9.3 Conclusions and recommendations for future monitoring

This section presented methodology and results to quantify the soil health status of 19 sites in the study area. The soil health status, presented as the Soil Quality Index (SQI) ranged between 50.4% and 97.8%. Low organic carbon, P and K contents were the main reason for the low SQI levels, especially in uncultivated sites.

The results should be used as a baseline against which any soil rehabilitation action can be compared. It is also a useful indicator to evaluate the impact of land-use change on the soil health status. In the context of this study, the land-use change can be the conversion to irrigated agriculture or changes in grazing regimes associated with the inundation footprint.

10 CARBON STOCKS AND WETLAND WATER REGIMES

Dams as sources of Greenhouse Gasses

In the past the assumption was that the generation of hydroelectricity from dams is a green source of energy; this notion has been disputed and it is now accepted that large dams can contribute significantly to GHG emissions and therefore climate change (Fearnside, 1995; Mukheibir, 2007; Fearnside, 2011; Sikder and Elahi, 2013). Approximately 23% of the atmospheric methane (CH_4) globally are released by large dams (Bastviken et al., 2011).

GHG's emissions associated with large dams are emitted either during the construction phase (e.g. disturbance of the soil, emissions from construction equipment and transport roads) or indirectly throughout the dams' life cycle. Flooding a terrestrial ecosystem results in creation of an aquatic ecosystem which causes anaerobic decomposition of resident organic carbon (OC) hence the release of GHG's particularly CH_4 (St. Louis et al., 2000; Tremblay et al., 2005; Kemenes et al., 2011; Desmukh, 2013). The amount of GHG's emitted from the dam is directly related to the area flooded (Rudd et al., 1993). Because of the resident OC decomposition the land changes from a carbon sink to a source (Kaplan et al., 2011). The amount of OC stored in the soils does determine the amount of GHG's to be emitted.

It is possible to estimate the GHG (methane and carbon dioxide) that can potentially be released in a large area judging by the organic material that was there prior to impoundment (Levy et al., 2012). Although natural dams do produce and emit carbon to the atmosphere (Cole et al., 2007) characteristics of a hydroelectric reservoir can release more GHG's than natural systems, especially in the first twenty years after inundation (Barros et al., 2011). In such reservoirs gases are released in four different pathways viz; the diffusive flux from dam surface, bubbling flux restricted to the most shallow area in the reservoir, degassing downstream of the dam and diffusive flux downstream of the dam (Abril et al., 2005). When CH_4 is produced in the water, it forms bubbles at the bottom and reach the surface through diffusion (DelSontro et al., 2010). Methane is directly transported to the air through bubbling and/or off-gassing of the waters. Carbon dioxide is the more abundant gas in the atmosphere, however CH_4 is known to have a global warming potential 21 times greater than that of CO_2 (Kemenes et al., 2011).

An understanding of the regional contributions and trends of anthropogenic carbon emissions is critical to design mitigation strategies like carbon sequestration, carbon foot printing and carbon credits aimed at stabilizing atmospheric GHG's (Mozejko, 2009). Typically, the 'spinoffs' from a large storage dam can result in a positive carbon balance. For example; one of the anticipated outcomes from the Mzimvubu Water Project is new areas under afforestation. Forestation is considered a form of sequestration because carbon is absorbed from the atmosphere by the plants during the process of photosynthesis (Lal, 2008a). The Ntabelanga dam is also a catalyst for environmental restoration through large scale erosion rehabilitation activities, this will no-doubt result in sequestering of carbon through reducing erosion of SOC rich top soils and creating artificial wetlands. These positives should be taken into account when carbon balances of the entire project are conducted.

Impact of dams on wetlands

Cowardin et al. (1979) provides the official federal definition of wetlands: "*Wetlands are lands transitional between terrestrial and aquatic systems where the water table is usually at or near the surface or the land is covered by shallow water*". Other definitions include places where plants and animals live amid standing water or saturated soils, also called swamps, sloughs, marshes, bogs, fens, seeps, oxbows, shallow ponds, or wet meadows (IDALS, 1998). According to the World Commission on large Dams (WCD, 2000) the effectiveness of existing environmental mitigation measures on large dams should be assessed and unanticipated impacts identified, opportunities for enhancement and restoration should be identified and acted upon. Dams fundamentally alter rivers and the use of a natural resource (WCD, 2000). Damage from dams may require assessment on a watershed basis extending upstream and downstream (McCully, 2001).

The water regime may change as a result of destruction of nature, unexpected floods may occur and consequently vegetation and natural structures in the riverbanks can be damaged (Tahmiscioglu et al., 2007). As a result of dam construction and holding of sediments in reservoirs, sediment feeding of downstream channel or shore beaches is prevented (Stott and Smith, 2001). The main hydraulic effect is the discharge of the collection basin to a stationary reservoir instead of a stream bed. Therefore, an instant change will start downstream; downstream of a stream dries partially or totally whenever the reservoir begins to accumulate water (Tahmiscioglu et al., 2007). During this temporary or periodically repeating time interval, the hydrological balance can collapse and structural obstructions are observed in the water dependent ecosystem (Stott and Smith, 2001).

In 2000, the first global survey of dams showed that their overall impact was negatively leading to the loss of forests and wetland ecosystem services (WCD, 2000). These services include lodging of a large and diverse number of animals and plant species (Gislason and Russell, 1997), water purification by trapping sediments and excessive nutrients and heavy metals (Mitsch and Gosselink, 1993), water storage; thereby enhancing groundwater recharge and prolonging base flow as well as reducing peak flows (Kotze et al., 2005) and carbon sequestration (Badiou et al., 2010).In fact, a group of scientist and economists as suggested by Costanza et al. (1997), has estimated that on average, one hectare of wetlands provides non market services worth about 15 times more than those provided by one hectare of forestland. Globally, wetlands annually perform needed services that would cost some $10 trillion US-dollars to replace which was reviewed in 2007 (Brady and Weil, 2008).

Since uses and management of wetlands are regulated by governments in many other countries, billions of US-dollars are at stake in determining what is and what is not protected as a wetland. There is widespread agreement that the wetter end of a wetland occurs where the water is too deep for rooted, emergent vegetation to take hold. According to Brady and Weil, (2008), the difficulty is in precisely defining the so-called drier end of the wetland, the boundary which exist non-wetland, upland systems in which the plant-soil-animal community is no longer predominantly influenced by the presence of anaerobic soils. Although Hydromorphic properties indicate that anaerobic conditions existed, they do not indicate the duration of saturation and reduction (Verpraskas and Lindbo, 2012). The distribution of Hydromorphic properties depends on the distribution of oxygen in the soil and it is controlled by depth and duration of the water table and aeration of the soil through interpedal and biopores (Veneman et al., 1976).

Despite the numerous proven advantages, wetland conversion to other land uses has been a problem historically and continues to the present day. Over time, wetlands have been drained, dredged, filled, levelled, and flooded to the extent that less than half of the original acreage remains (Dahl, 1990; Whittecar and Daniels, 1999). The conservation of the remaining wetlands is now a priority with management authorities; however, management is hindered by a lack of knowledge of the biota and wetland processes (Balla and Davis, 1994).

Objectives

Specific objectives in this section were:

i) To quantify the carbon stocks under the Ntabelanga dam inundation footprint based on pedometrical extrapolation of representative soil profiles, which can be used to quantify potential GHG emissions in future and

ii) To characterise water regimes of representative wetlands to understand the hydrological behaviour

10.1 Results and discussions

Carbon stocks

Fourteen different soil forms were identified under the proposed Ntabelanga footprint (Table 10-1). These soils were divided into 5 different soil associations (Table 10-1, Figure 10-1). Based on the areas occupied by the various soil associations (Figure 10-1, Figure 10-2), the total carbon stock of the soils under the footprint could be calculated (Table 10-2).

Table 10-1: Soil forms and soil associations of the Ntabelanga inundation footprint

Soil forms (Soil Classification Working Group, 1991)	Soil Association
Estcourt and Sterkspruit	Duplex
Swartland and Sepane	Semi-duplex
Kroonstad, Katspruit and Longlands	Wet
Bonheim	Melanic
Bloemdal, Hutton, Tukulu and Oakleaf	Apedal
Mispah and Glenrosa	Shallow

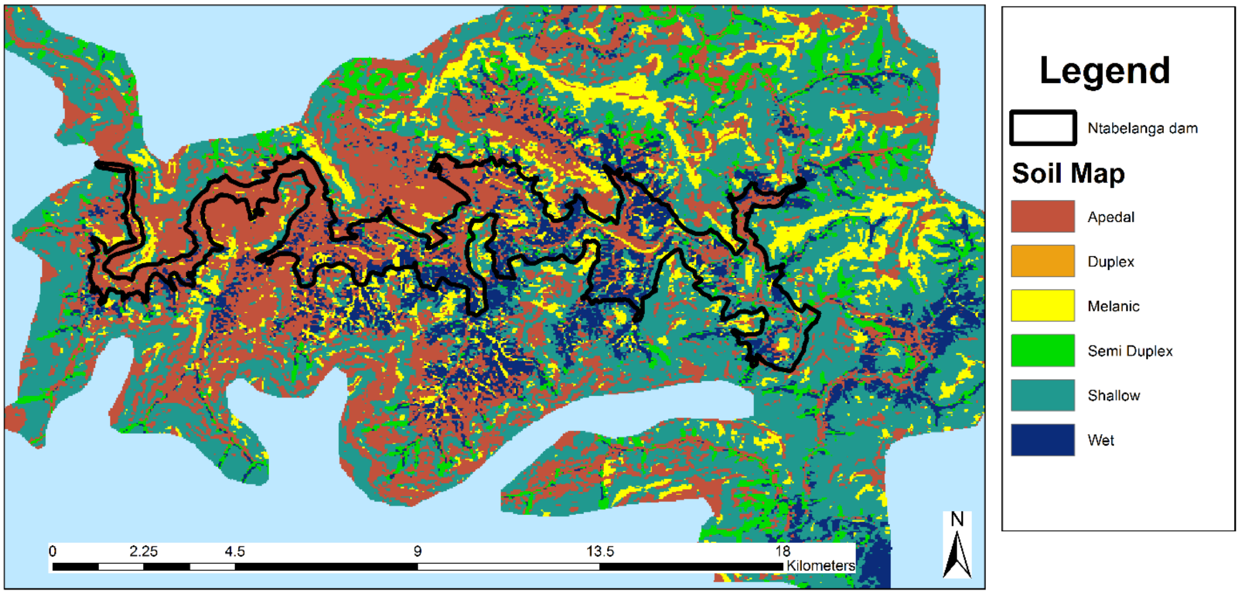

Figure 10-1: Soil association map of the entire attribute space.

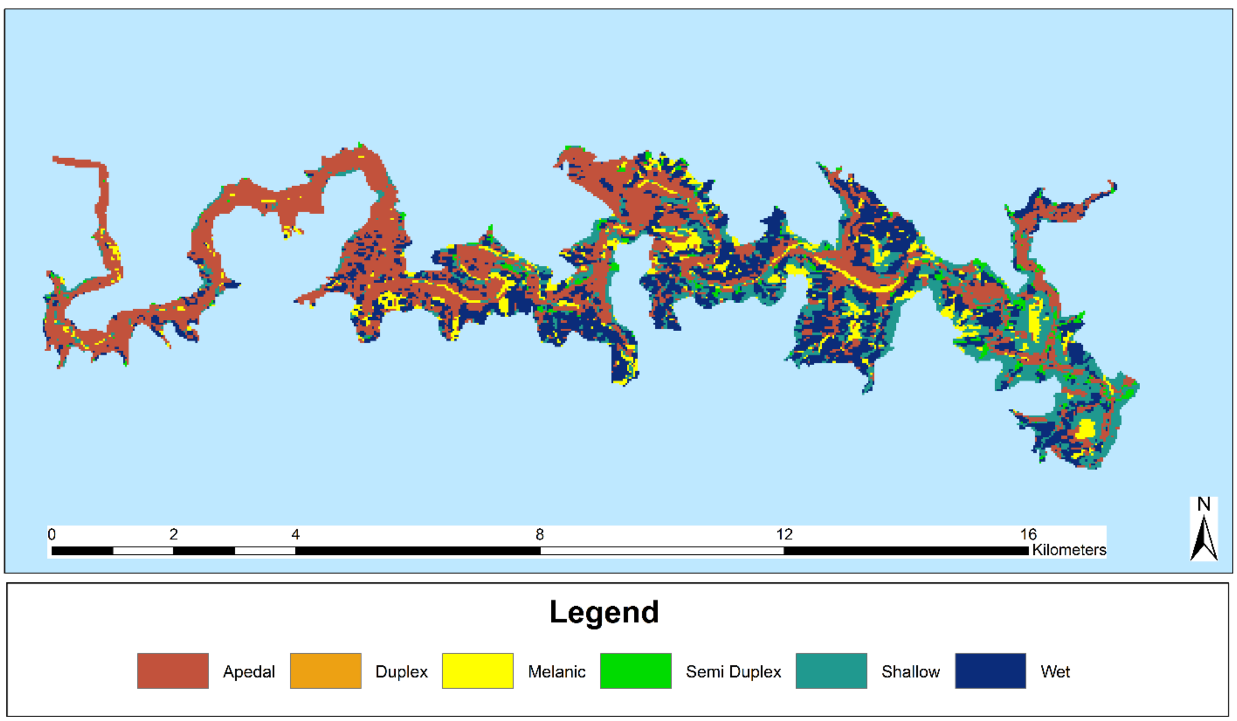

Figure 10-2: Soil association map of the Ntabelanga dam footprint.

Table 10-2: General properties of the soil associations and the total soil carbon stocks of the Ntabelanga dam footprint

Soil Association	Horizon	Depth (mm)	OC%	Db	Area (ha)	Carbon (t C ha-1)	Carbon Stocks (t)
Duplex	A	200	0.47	1.41	85.31	13.25	1130.68
	B	700	0.32	1.31		29.34	2503.30
Semi-duplex	A	300	0.90	1.45	190.15	39.15	7444.32
	B	1000	0.93	1.35		125.55	23873.16
Wet	A	300	1.15	1.52	517.32	52.44	27128.01
	G	1000	0.71	1.34		95.14	49217.37
Melanic	A	300	1.23	1.37	98.93	50.55	5001.01
	B	900	0.59	1.41		74.87	7406.70
Apedal	A	300	0.47	1.67	879.36	23.55	20706.35
	B	1200	0.59	1.62		114.70	100859.37
Shallow	A	350	1.59	1.32	237.74	73.46	17463.70
Total					3779.86		262733.97

Based on Table 10-2 it is clear that the OC contents of all the soils in under the Ntabelanga footprint are relatively low, typical of semi-arid environments. The highest OC contents were measured in the A horizons of the shallow soil association. These soils occur on steep slopes, with limited access to grazers. The largest areas of the inundation footprint are occupied by apedal soils (approximately 880 ha). These soils are derived from alluvial deposits and have relative low OC contents. Soils with indications of saturation (i.e. ‘Wet’ association) occupies approximately 520 ha. The total OC carbon stored under the proposed 3780 ha Ntabelanga dam footprint is 262 734 tonnes, i.e. approximately 70 t ha^{-1}. This is less than the 93 t ha^{-1} (Dabasso, Tadesse and Hoag, 2014) and 79 t ha^{-1} (Albaladejo et al., 2012) of similar semi-arid environments. Physical and chemical soil degradation is noticeable in the area, resulting in a decline in the soil health. The soils under the dam footprint are currently serving as a sink for atmospheric carbon; once the dam is inundated it will become a source for Greenhouse Gasses. Because decomposition of the soil organic carbon will occur under anaerobic conditions, the release of large quantities of methane is a real possibility. This will be measured with the methodology described and be reported on in the near future.

Wetland water regimes

The wetlands located directly downstream of the Ntabelanga dam along the Tsitsa river are presented in Figure 10-3. In this area, 12 small wetlands were identified foothills of mountainous belts. Since wetlands under the inundation footprint were identified during the Environmental Impact Assessment it was not repeated here.

The wetland marked (a) in Figure 10-3 was installed for a short period and some results are presented below. The water regime from satellite imagery was determined for the wetland marked (b) in Figure 10-3.

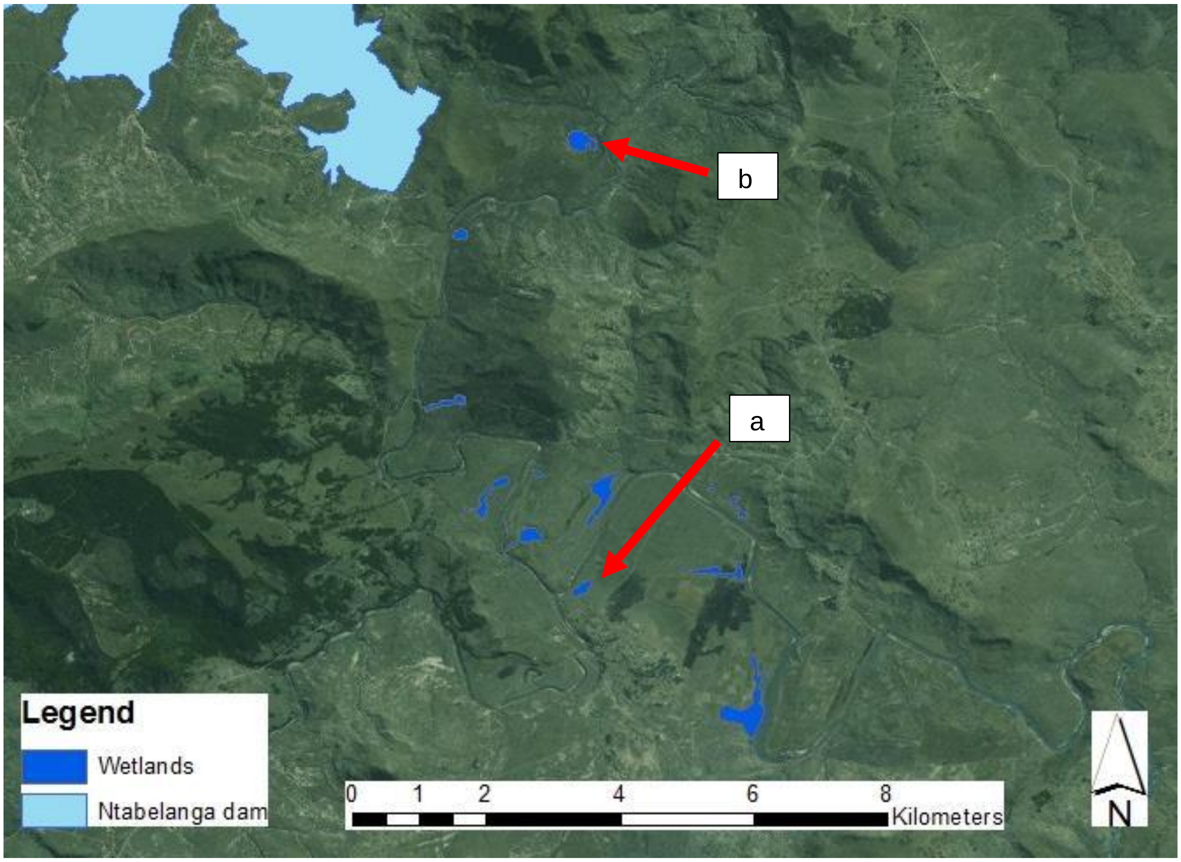

Figure 10-3: Wetlands directly downstream of Ntabelanga dam.

The installed groups of piezometers, terrain sites, organic matter (OM) and organic carbon (OC) contents, selected soil morphology properties observed in different diagnostic horizons and soil forms for each installed piezometer site are shown below in Table 10-3.

Table 10-3: Organic carbon soil contents and soil morphological properties for the different piezometers

Piezometer	Depth (cm)	OM (%)	OC (%)	Munsell colour Moist	Dry	Mottles (%); frequency; size; colour		Root channels	Diagnostic horizon	Soil form (SAST)	Soil group (WRB)
T1	0-25	3	1.74	7.5YR2.5/2	10YR5/3	-	None	-	ot*[1]		
	25-90	2.7	1.57	5YR3/1	10YR4/3	1	Few; small; red	-	yb*[2]	Clovelly	Alisols
T2	0-40	3.4	1.98	10YR3/2	10YR4/2	-	None	-	ot		
	40-110	1.5	0.87	7.5YR4/2	10YR3/6	5	Many; medium; red	-	yb	Clovelly	Alisols
	0-40	3.6	2.09	10YR3/1	10YR6/1	3	Few; small; red	Rusty	ot*[1]		
P1	40-110	3.7	2.15	7.5YR5/6	10YR5/6	10	Many; medium; grey	-	gh*[2]	Katspruit	Gleysol
	0-40	4.8	2.79	10YR4/1	10YR6/3	7	Many; medium; red	-	ot		
P2	40-105	2.9	1.69	10YR3/2	10YR5/2	3	Few; small; brown	-	gh	Katspruit	Gleysol
	0-60	3.2	1.86	7.5YR3/2	10YR5/2	5	Many; medium; grey	Bleached	ot		
P3	60-120	3.1	1.74	10YR4/1	10YR5/2	10	Many; medium; red	-	gh	Katspruit	Gleysol
	0-20	3.1	1.74	10YR3/2	10YR5/2	3	Few; small; grey	Bleached	ot		
P4	20-100	2.4	1.4	10YR3/2	10YR6/2	10	Many; medium; red	-	gh	Katspruit	Gleysol
	0-20	3.1	1.8	10YR2/2	7.5YR3/2	1	Few; small; brown	Bleached	ot		
P5	20-80	2.1	1.22	7.5YR3/2	10YR4/2	2	Few; medium; brown	Bleached & Rusty	gh	Katspruit	Gleysol
	0-30	4.2	2.44	7.5YR3/1	10YR5/1	2	Few; small; brown	Bleached & Rusty	ot		
P6	30-100	2.1	1.22	7.5YR4/1	7.5YR5/1	10	Many; medium; brown	Rusty	gh	Katspruit	Gleysol
	0-30	3.6	2.09	7.5YR3/1	5YR2.5/1	-	None	-	ot		
P7	30-50	3.2	1.86	5YR3/1	2.5YR3/4	1	Few; medium; brown	-	gh	Katspruit	Gleysol
	0-40	3.2	1.86	5YR3/2	10YR4/2	-	None	-	ot		
P8	40-105	2.7	1.57	5YR3/4	2.5YR4/6	-	None	-	nc*[2]	Oakleaf	Fluvisol
	0-30	3.4	1.98	7.5YR3/3	5YR4/4	-	None	-	ot		
P9	30-100	2.2	1.28	5YR3/4	2.5YR4/6	-	None	-	nc	Oakleaf	Fluvisol

*[1]ot – orthic A horizon; *[2]gh – G horizon; *[2]nc – Neocutanic B horizon; *[2]yb –yellow brown apedal B horizon

The soils were classified as either Katspruit (Ks) or Kroonstad (Kd) soil forms (Soil Classification Working Group, 1991). In the Ks an Orthic A horizon (*ot*), prominently rich in OC, overlies a G horizon (*gh*), although the Kd is dominantly common in these areas, with an E horizon (*gs*) between the *ot* and the *gh*. These soil forms are similar to a Gleysol (WRB). The water level was more than 1.2 m deep when the piezometers were installed (with exception of P6, where it was present at 1.06 m). Water in P6 had an average redox (Eh) of 174 mv S^{-1} whilst the surface flooded water recorded 150 mv S^{-1} when measured with an ORP meter. On the second field visit early October 2015, a reading of 0.80 mv S^{-1} was recorded in the ponded wetland water. The low Eh value during the second visit is most likely due to long periods without rainfall, limited oxidized water was therefore added to system. Most of the piezometers were unfortunately removed from the study site; thus no further ORP readings could be taken.

The moist states of the soils from piezometer 1 to 7 were mostly grey in colour as determined from the Munsell colour chart (Table 10-3). The grey colours in the piezometers were also associated to a higher OC content which was recorded within the top soils when analysed. A correlation between the water levels against the OC was restricted due to limitations of the recorded deeper water table levels in the selected wetland study site.

The highest OM and OC content for the top soil were respectively recorded in piezometer 2 with 4.8% (OM) as related to the calculated 2.79% (OC). While the lowest OC content was recorded in piezometer 4, 5, and 8 with an average approximately around 1.8%. The OC (%) content are relatively high from a depth of 0-40 cm which emphasizes a high content with relatively small decreases in OC with depth.

Brown, red and grey mottles were identified in the Katspruit soils of the wetland study site (Figure 10-3). The grey mottles across the sampling site were common in the reduced soil profile morphology (*gh* horizon) subsoil as contrasted to the brown and red mottles which predominated within the top soils (*ot* horizon). The brown mottles were also randomly distributed especially in the top soil horizon.

Most of the root channels from P3, 4, 5 and 6 were bleached. Fe oxidation was evident from piezometer P1, 5 and 6 as the root channels were rusty (Table 10-3) due to variations in oxidation-reduction potentials, typically associated with saturated wetland areas. The wetland ponded surface water illustrated an absent of reduction and depletion indicators which is mostly reflected by oxidized Fe (orange water) usually attributed to continuous saturation of the surface especially in the *ot* horizons.

Figure 10-4: Distributions of red, brown and grey mottles within the soil profile. Colours of arrows indicate mottle colours.

Wetland water regimes based on satellite imagery

Table 10-4: Area of surface water of wetland b in Figure 5; cumulative streamflow over different periods and streamflow characteristics

Time step (Figure 7)		a	b	c	d	e
	Date	5/26/2002	3/21/2011	5/1/2014	5/5/2015	1/3/2016
	Area (ha)	8.1576	7.6251	7.3901	7.5124	6.7883
Rainfall (mm)	1 month	20	96	70.3	83.2	120
	3 months	126	350	282	232	226
	6 months	508	629	552	539	344
	12 months	833	768	669	660	552
	24 months	1810	1405	1625	1329	1207
Streamflow ($m3\ s^{-1}$)	Specific day	3	127	12	5	10
	Max (1 month)	5	209	33	48	97
	Max (3 months)	130	413	406	56	97
	Max (6 months)	308	413	406	158	97

Seasonal changes in the free surface water in an identified wetland are presented in Figure 10-5. The area covered by surface water during times a-e are presented in Table 10-4. The area covered by surface water ranges from 8.16 in 2002 to 6.79 ha in 2016. It appears that the recent national drought is therefore impacting these wetland resources as well.

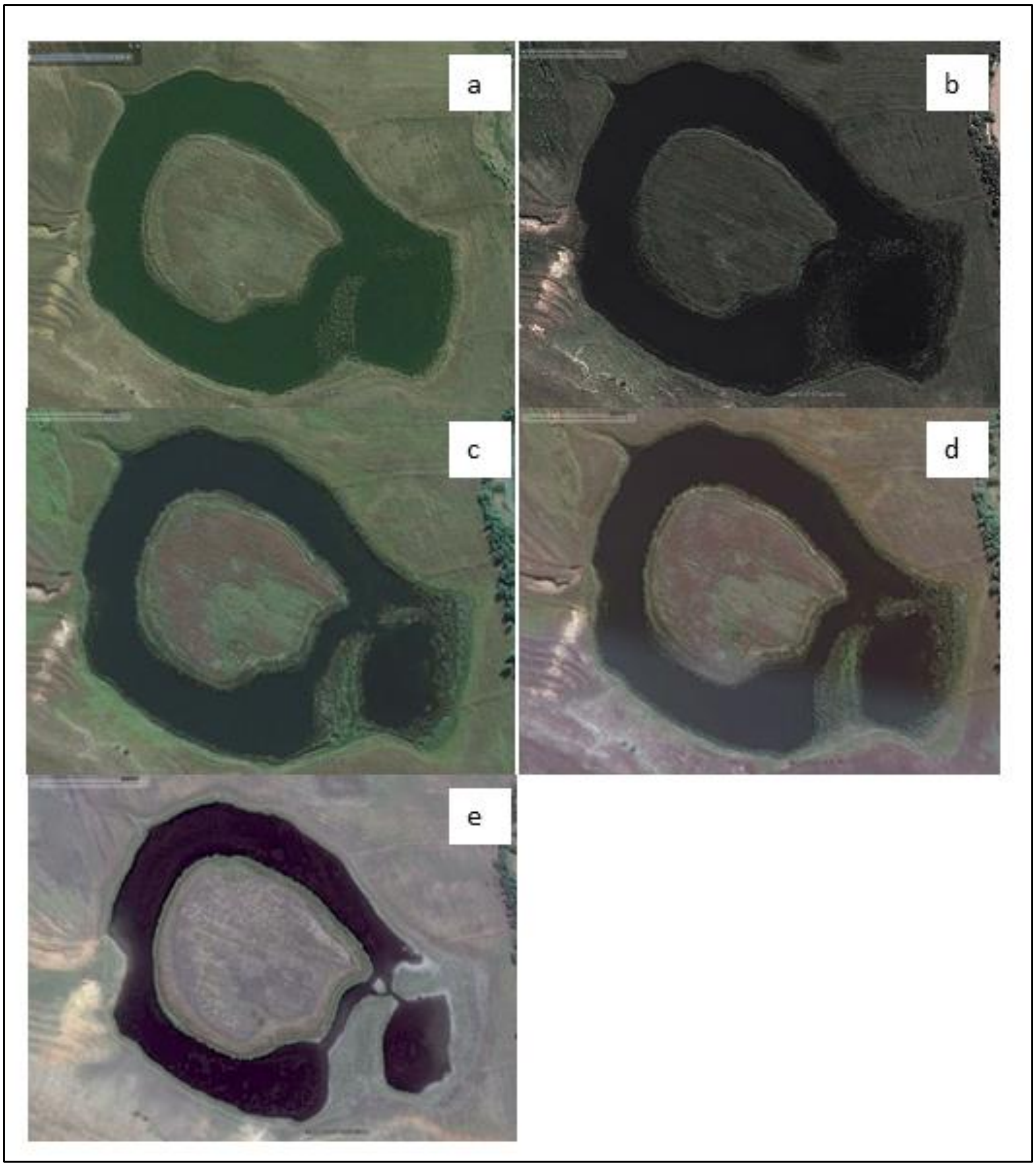

Figure 10-5: Satellite imagery for wetland b in Figure 5 for a) 26/5/2002; b) 21/3/2011; c) 1/5/2014; d) 5/5/2015 and e) 1/3/2016.

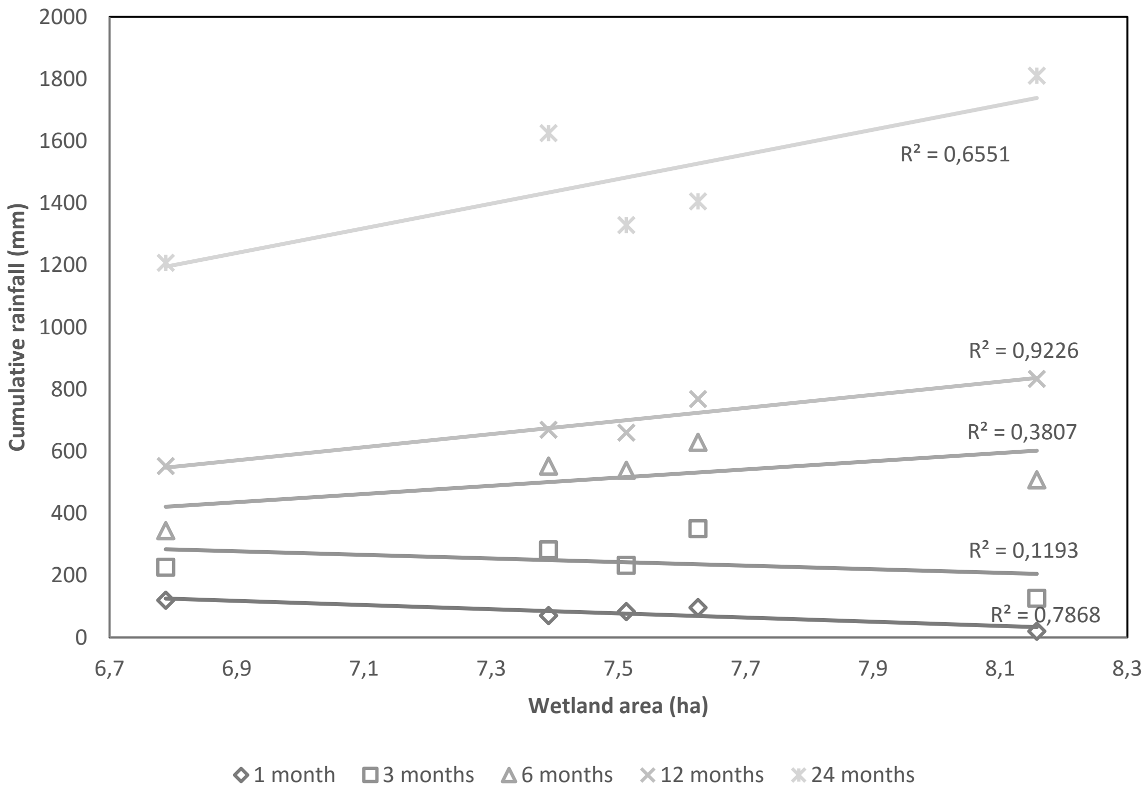

Figure 10-6: Cumulative rainfall over different periods vs. surface water area.

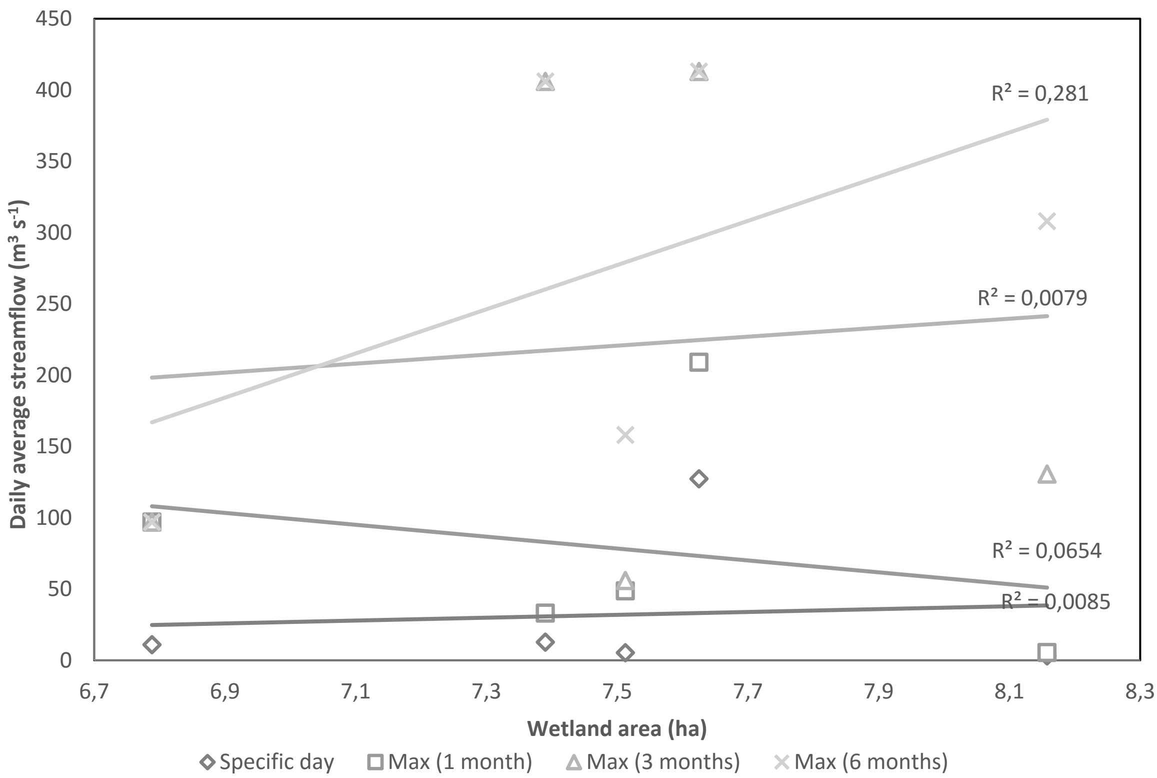

Figure 10-7: Streamflow characteristics for different periods vs. surface water area.

Figure 10-6 shows that there are negative correlations between the cumulative monthly and 3-month rainfall and the surface area covered by water, i.e. the more rain, the smaller the saturated area. This obviously does not make sense and it is clear that the short-term weather (<3 months) does not influence the wetland hydrology. The six months cumulative rainfall shows a positive correlation with the surface water area, albeit a weak one. An excellent correlation between 12-month rainfall and surface area is evident in Figure 10-6 (R^2 = 0.92). Although still positive the correlation tends to become less accurate when 24 months cumulative rainfall is considered. Our interpretation therefore is that the water contents of wetlands below the Ntabelanga dam is a function of seasonal rainfall.

Since the recorded rainfall values have a greater effect on the seasonality of the wetland, the water regime of the wetlands can be influenced and controlled directly the contribution of surface runoff to – and flooding of the wetland. Lateral and preferential flow in the soil profile can result in an intersection of the water table usually were restrictive impermeable layers exist, hence groundwater can also be a water source for the wetland. Although profile percolation of water is slower, but the Tsitsa River daily stream flow discharge has a long-term effect on supplying water throughout the year as contrasted to rainfall storms received sometimes not even on a regular reliable basis. The wetland hydrological interaction between the Tsitsa River and the study area are dependent on the terrain gradients which exist as it determines the direction of the lateral flow within the profile. Thus, when the discharge increases a blocking and filling effect will be observed in the wetland as it becomes flooded. But when the channel discharge is lowered during the dry seasons or when artificial discharge is controlled an emptying effect can mostly be experienced as the wetland drains into the adjacent Tsitsa River. These results are similar to wetland studies according to Wang et al. (2011), on the Poyang lake area in China. Thus, the wetland in the study site will not be saturated throughout the year, which is also suggested from the average stream flow and rainfall results (table 1 and 2). Since the climate has a high evaporative demand, during the dry summer seasons, capillary movement can also be experienced which can increase the surface saturation of the wetland area. The evaporative climatic potentials can also be a challenge on the flooded water within the wetland especially during these harsh dry season conditions.

Very weak correlations between streamflow characteristics in the form of actual flow on the imagery date as well has historic maximum daily flows are observed in Figure 9. The weak correlations suggest that the water contents of the wetlands are not impacted by the streamflow. The wetlands are therefore not fed by the stream but are most likely feeding the stream. The relative elevation of the wetlands above the streambed supports this; the wetlands are approximately 3 m higher. Reduction in flood events associated with the dam is therefore unlikely to impact wetland water regimes.

The impact of the Ntabelanga dam on wetland water regimes will only have significant impacts on wetlands directly below the dam. Sediment ‘hungry’ water exiting the dam, has high erosive capacity and resulting in further incision of the streambed (McCully, 2001). In losing wetlands (i.e. wetlands feeding the streams), streambed incision can significantly lower water tables and thereby alter wetland water regimes (Omar, Le Roux & Van Tol, 2013).

10.2 Conclusions and recommendations for future monitoring

The proposed Ntabelanga dam will convert 3 780 ha from a sink of atmospheric carbon to a source of Greenhouse gasses. Currently the soils under the proposed footprint stores approximately 262 733 tonnes of organic carbon. When the area is inundated, organic carbon will be decomposed under anaerobic conditions. This will result in the release of Greenhouse gasses and especially methane, which global warming potential 21 times greater than carbon dioxide. The potential greenhouse gas emissions should be quantified in future studies.

A desktop study to identify and delineate representative wetlands downstream of the proposed dam was conducted. One of these wetlands were instrumented, but the instruments were removed without permission shortly thereafter. Using satellite imaginary, the surface water area of a representative hillslope was measured during five time-steps. By comparing environmental conditions, such as cumulative rainfall and streamflow it was possible to conclude that the wetlands water is not impacted by the streamflow. The wetlands are in fact losing water to the stream. The proposed dam is therefore only going to impact the wetlands indirectly by lowering of the streambed. This impact is restricted to the wetlands directly below the proposed dam wall.

11 CULTIVATION IN HOME GARDENS

11.1 Introduction

There are approximately 14 million hectares of arable land in South Africa with only 4% of the total landmass having high agricultural potential for crop production (Shange, 2014; DoA, 2009). South African agricultural production contributes more than 5% to the gross domestic product (GDP), and the Eastern Cape contributes about 1.9% to the national GDP. The major agricultural practices are the production of maize, wheat, deciduous and subtropical fruits, sugar cane, vegetables, poultry, sheep, goats and cattle (Nel and Davis, 1999). Smallholder farmers mostly produce for home consumption with less intention to market; as a result, they tend to cultivate small-plots. Nevertheless, their contribution to food security initiatives and job creation in the rural areas can be remarkable (Aliber et al., 2009).

Defining smallholder farmers

Several definitions for 'smallholder farmers' exist which depend on the context, country and ecological zone. Mostly the term "smallholder" is used exchangeable with 'small-scale' or 'resource poor' farmers. This definition can be summarized as those farmers who have limited resources in comparison to commercial farmers. They are also defined as farmers who own small plots of land where they basically grow subsistence crops for household consumption (DAFF, 2012).

The main production characteristics of smallholder farmers are outdated technologies, low returns and high labour fluctuations with women playing a prominent role in the production process. Smallholders differ in terms of farm size, distribution of resources between food and cash crops, use of external inputs and hired labour, produce sold and household consumption (Kirsten and Van Zyl, 1998).

Smallholders can play a significant role in the creation of livelihood and food security in the poor rural areas. However, this sub-sector generally has low productivity mark be poor yields resulting in the loss of interest in agricultural production amongst the urban and rural households. Thus, there is a need to increase productivity of smallholder farmers to guarantee long term food security (DAFF, 2012).

An overview of smallholder farmers in South Africa

South African agriculture consists of two main categories of farmers, subsistence farmers mostly found in the former homelands and large-scale commercial farmers (Thamanga-Chitja and Morojele, 2014). The South African agricultural sector is regarded as a dualistic nature with highly capitalized commercial sector and undercapitalized smallholder farming sector. National Department of Agriculture reported that commercial farmers use about 86% of farmland whereas 14% is communal land occupied by smallholder farmers (Shange, 2014).

In the South African context smallholder farmers are mostly associated with low production and are considered to be non-commercial (Kirsten and Van Zyl, 1998). The majority of South African smallholder farmers are poor, mostly illiterate and are based in the rural areas with little or no infrastructure, access to external inputs (such as fertilizers) or markets (Thamanga-Chitja and Morojele, 2014; Jacobs, 2008). The communities that smallholder farmers live in are mainly ruled by the traditional male chiefs, with the majority of the producers being females (FAO, 2002). Approximately 2.6 million people derive their livelihood from agriculture.

The Eastern Cape and Limpopo Provinces are inhabited by the poorest households (Thamanga-Chitja and Morojele, 2014; Statistics South Africa, 2012). Many of the households in rural South Africa depends on ‘mixed livelihood incomes’; meaning that salaries, social grants and household produce all contribute to the income (Statistics South Africa, 2012). Examples of different levels of mixed livelihood incomes are presented in Table 11-1.

Table 11-1: Current types of smallholder farmers in South Africa (SAF and PLAAS, 2013)

	Subsistence-oriented smallholders	**Market-oriented smallholders in loose value chains**	**Market-oriented smallholders in tight value chains**	**Small-scale capitalist farmers**
Objective of production	Household consumption	Household consumption+ cash income	Cash income +some home consumption	Profit
Proportion of marketed output	None or insignificant	50% or >	75% or >	100%
Contribution to household income	Reduces expenditure on food	Variable – from small to significant	Significant	Very significant
Labour	Family	Family+ Some hired	Family+ significant members hired	Hired
Mechanization	Very low	Low	Medium to High	High
Capital intensity	Very low	Low	Medium to high	High
Access to finance	Absent	Some	Significant	Very significant
Numbers in South Africa	2-2.5 million	200-250 000	-	-

Eastern Cape smallholder farmer context

The Eastern Cape covers about 1.7 million hectares of land and it has variety of soils and climatic conditions allow diversity of agricultural activities. Approximately 6.5 million of South Africans originate from the Eastern Cape, which is 13.5% of the South Africa's population (Statistics South Africa, 2008). In 2002 UNDP (2004) reported the Eastern Cape is one of the poorest provinces with a large portion of population (63%) surviving below the country's poverty line. Smallholder farmers occupy 30% of the area which they utilize for subsistence farming of mixed agricultural practices. These include grazing of cattle, goats and sheep: production of maize, beans, and pumpkins on personally owned land ranging from 1 to 5 hectares. Grains and vegetables such as maize, potatoes, cabbage, Swiss chard, onions, peas and carrots are grown in gardens which are between 0.1 to 0.5 hectares (Mandiringana et al., 2005).

An overview of smallholder irrigation in South Africa

Irrigation defines a structured, controlled and synthetic water supply to a cropped area to supplement rainfall and to minimize drought with an objective of maximizing crop production (Tlou et al., 2006). Irrigation water makes sure that there is enough water in the soil to provide for the crop and hence the reduction of water deficit which is a limiting factor in plant growth (Van Averbeke et al., 2011). In South Africa irrigated agriculture grants a smart investment, because water deficiencies caused by low unpredictable rainfall restricts crop production that is dependable on the rainfall. In support of the above DWAF (2004) stated that scarcity of water is a most important constraint to socio-economic development in South Africa. As a result the South African government has and is investing reasonably in the improvement of irrigation, with rural smallholder irrigation being the first priority to decrease poverty and improving food security.

The highest amount (62%) of water in South Africa is used in the agricultural sector (Kanyoka et al., 2008; Sinyolo, 2013). South Africa has approximately 1.3 million ha of land under irrigation yet only about 0.1 million ha of land is accessed by the smallholder farmers (Fanadzo et al., 2010). Small-holder irrigation is defined as subsistence or traditional irrigation systems that are used for production by approximately 200 000-250 000 farmers, mainly for domestic consumption (Backeberg, 2006). The sustainability of these irrigation schemes are however low (Table 11-2).

Table 11-2: Operational status of smallholder irrigation schemes by province in South Africa in 2010 (Van Averbeke et al., 2011; Sinyolo, 2013).

Province	Number of operational schemes	Number of non-operational schemes	Number with unknown operation status	Total
Limpopo	101	69	0	170
Eastern Cape	51	16	5	72
KwaZulu-Natal	35	0	1	36
Mpumalanga	7	2	0	9
Western Cape	7	1	0	8
Northern Cape	2	1	0	3
Free State	1	1	0	2
North West	2	0	0	2
Total	206	90	6	302

Majority of irrigation schemes are found in the Limpopo province (56%) followed by Eastern Cape (23%) and KwaZulu-Natal (12%) (Van Averbeke et al., 2011; Sinyolo, 2013). Table 11-2 show that about 80% of smallholder irrigation schemes in South Africa are situated three provinces (Limpopo, Eastern Cape and KwaZulu-Natal). The sustainability of irrigation schemes in South Africa is the main problem. Of the 296 smallholder irrigation schemes with known operational status in 2011, above 30% were non-operational functioning (Van Averbeke et al., 2011).

Crop yield prediction as a tool to identify problems

Crop yield prediction facilitate improved management through management of irrigation, fertilisation and other inputs. Crop yield predictions can also be used to identify yield gaps, i.e. difference between potential yield given specific crop, climatic and soil conditions and actual yields. Several techniques exist to predict yields.

<u>Process-based crop models</u>

Process-based models are commonly used to predict the effect of environmental factors (i.e. temperature, light, carbon dioxide, water and nutrients) on crop growth and yields (de Reffije, 2009). These models are made such that they simulate crop responses at a plot and field level (Zinyengere et al., 2013). Process-based models possess a general aim of crop yield estimation by simulating the input of soil water, nutrient, and plant growth and developmental processes to the harvestable plant products (Thorp, 2014).

Empirical crop modelling

Empirical models are less complex and are used for expression of observed data used for final estimation of yields. The yields are conveyed as regression equations with one or more factors. These models are highly suitable for homogeneous systems such as the greenhouse production system (Chimonyo et al., 2015). They can be characterized into the following groups:

Statistical

Statistical models need historical data on the crop yields and climate to build up statistical relationships (Lobell and Burke, 2010; Zinyengere et al., 2013). They are created in such a way that they function at a multi-seasonal and regional scale hence suitable for the analysis of inter-annual variability of regional production. In addition, they can be alternated with process-based methods for testing climate impacts at a coarse, spatial scale (Hertel and Rosch, 2010; Lobell et al., 2008; Burke et al., 2009). The main benefits of statistical models are their less dependence on field calibration and clear evaluation of model uncertainties by using the coefficients of determination and confidence intervals (Zinyengere et al., 2013; Hertel and Rosch, 2010). Conversely statistical models have disadvantage, their validity is not guaranteed for future under the varying climatic conditions (Malebojoa et al., 2010). Moreover, these models require past relationships to determine future, however these relationships are not easy to validate especially in the Southern African region since the historical data may be unavailable (White et al., 2011). In addition, the other limitation in the statistical models for future crop response prediction is the lack of adaptation responses (Zinyengere et al., 2013). These limitations can be conquered by bringing forth economic models which analyse adaptation at the farm-level revenues (Lobell and Burke, 2010; Zinyengere et al., 2013).

Ricardian

Ricardian approach concentrates on assessing the climate change effect on the agriculture (Mendelsohn et al., 1994). The model does not only depend on complex crop yield models, but it is a cross-sectional technique used for estimation of empirical relationship between land values and climate. Land values are reverted on climate, soil, geographic characters, and socio-economic control variables (Van Passel et al., 2012). This method focuses on making farmers economical alert so as to choose farming activities with highest returns on a given area of land (Gbetibeuo and Hassan, 2005). The advantage of ricardian model is that it entails all the agricultural farm practices; it does not take grains only into consideration. Moreover, the model records efficient adaptations made by farmers within their local climate (Van Passel et al., 2012). However, this technique has limitations such as not accounting for the varying factors for farm productivity (Deschenes and Greenstone, 2007).

Objectives

The objectives of this section were:

i) to estimate the potential yield of maize crops in the study area using a bio-physical approach,

ii) to quantify the actual yield of maize crops through physical measurements, interviews with local farmers and Focus Group Discussions (FDG's),

iii) to quantify the yield gap between the estimated and the potential yields and

11.2 Results and discussion

Potential yields

Potential yields, estimated from climate data for the Lower Sinxaku, range between 3.85 and 6.69 $t.ha^{-1}$ depending on the hybrid and plant date Table 11-3.

Table 11-3: Estimated yields for Lower Sinxaku (Schulze and Walker, 2007)

Hybrid	Plant date		
Ultra-Short Hybrid	15-Oct	Yield ($t\ ha^{-1}$)	4.36
		CV (%)	27
	15-Nov	Yield ($t\ ha^{-1}$)	4.49
		CV (%)	26
	15-Dec	Yield ($t\ ha^{-1}$)	3.85
		CV (%)	33
Short Hybrid	15-Oct	Yield ($t\ ha^{-1}$)	6.10
		CV (%)	29
	15-Nov	Yield ($t\ ha^{-1}$)	6.00
		CV (%)	25
	15-Dec	Yield ($t\ ha^{-1}$)	5.66
		CV (%)	30
Medium Hybrid	15-Oct	Yield ($t\ ha^{-1}$)	6.69
		CV (%)	28
	15-Nov	Yield ($t\ ha^{-1}$)	6.39
		CV (%)	27
	15-Dec	Yield ($t\ ha^{-1}$)	5.96
		CV (%)	32
Long Hybrid	15-Oct	Yield ($t\ ha^{-1}$)	6.10
		CV (%)	28
	15-Nov	Yield ($t\ ha^{-1}$)	5.83
		CV (%)	26
	15-Dec	Yield ($t\ ha^{-1}$)	5.72
		CV (%)	30

Estimated yields based on the soil properties such as depth and nature of 'restricting layer' and mean annual rainfall (695 mm) are presented in Table 11-4. Shallow Glenrosa soils has the lowest potential yield (2.5 $t.ha^{-1}$) while deep Clovelly and Hutton soils tend to have the highest potential for maize production in the Lower Sinxaku area (5.4 $t.ha^{-1}$).

Table 11-4: Yield estimations based on soil properties and annual rainfall (FSSA, 2007)

Site	Soil form	Restricting layer	Depth (m)	Potential yield (t.ha-1)
MNS1	Clovelly	Broken rock	>0.9	5.4
MNS2	Clovelly	Broken rock	>0.9	5.4
MNS3	Glenrosa	Broken rock	0.3	2.5
MNS4	Valsrivier	Clay	0.6	4.6
MNS5	Valsrivier	Clay	0.6	4.6
MNS6	Hutton	Broken rock	>0.9	5.4
MNS7	Glenrosa	Broken rock	0.3	2.5
MNS8	Hutton	Broken rock	>0.9	5.4
MNS9	Glenrosa	Broken rock	0.3	2.5
MNS10	Clovelly	Broken rock	>0.9	5.4

Actual yields

Estimated yields based on interviews with the farmers are presented in Table 11-5. These estimations were determined by requesting the farmers to estimate how many 20 kg bags can be filled following a typical growing season. A very crude estimation which was then followed by actual measurements of their harvest (Table 11-6).

Table 11-5: Farmers' estimation of yields

Site	Area cultivated (ha)	Number of 20 kg bags	Total harvest (t)	Farmers estimated yield ($t.ha^{-1}$)
MNS1	0.058	4	0.08	1.37
MNS2	0.017	1	0.02	1.18
MNS3	0.027	1	0.02	0.75
MNS4	0.015	1	0.02	1.33
MNS8	0.055	6	0.12	2.18
MNS9	0.011	0.5	0.01	0.89
MNS10	0.047	0.5	0.01	0.21

Table 11-6: Measured yield from gardens in Lower Sinxaku

Site	Year	Calibration equation	R^2	Moisture content (%)	Total yield (t)	Area cultivated (ha)	Yield ($t.ha^{-1}$)
MNS1	1	y = -157.07 + 8.59 x L + 10.90 x C	0.67	20.38	0.195	0.058	2.67
MNS2	1	y = -393.61 + 8.29 x L + 19.67 x C	0.80	31.92	0.046	0.017	1.84
MNS3	1	y = -317.71 + 2.72 x L + 27.41 x C	0.89	13.40	0.054	0.027	1.77
MNS4	1	y = -396.73 + 6.33 x L + 24.95 x C	0.82	40.30	0.037	0.015	1.46
MNS8	1	y = -180.38 + 8.34 x L + 11.76 x C	0.91	14.47	0.066	0.055	1.02
MNS1	2	y = -220.65 + 11.90 x L + 10.32 x C	0.92	9.87	0.239	0.136	1.58
MNS3	2	y = -184.53 + 10.08 x L + 7.36 x C	0.85	9.84	0.062	0.068	0.83
MNS4	2	y = -256.11 + 6.48 x L + 19.16 x C	0.89	34.31	0.222	0.101	1.44
MNS8	2	y = -267.98 + 8.16 x L + 16.99 x C	0.69	10.26	0.093	0.073	1.13

Measured yields ranged between 0.83 $t.ha^{-1}$ in MNS3 during the second growing season and 2.67 $t.ha^{-1}$ in MNS1 during the first growing season. Important to note is that nothing was cultivated on the other gardens during this time. The average yield for those farmers who did cultivate during the two years of the study was approximately 1.53 $t.ha^{-1}$.

Yield gaps

Using only measured yields and soil specific yield estimations (Table 11-4) it is clear that significant yield gaps exists between potential and actual yields (Table 11-7). In most cases the yield gaps are larger than the actual yields.

Table 11-7: Yield gaps in Lower Sinxaku

Site	FSSA yield estimation	Actual yield	Yield gap
		($t.ha^{-1}$)	
MNS1	5.4	2.67	2.73
MNS2	5.4	1.84	3.56
MNS3	2.5	1.77	0.73
MNS4	4.6	1.46	3.14
MNS8	5.4	1.02	4.38
MNS1	5.4	1.58	3.82
MNS3	2.5	0.83	1.67
MNS4	4.6	1.44	3.16
MNS8	5.4	1.13	4.27

11.3 Conclusions and recommendations for future studies

This section quantified yields in 10 home gardens in Lower Sinxaku. Although this is a fairly small sample size representing only one community, the interviews with more than 300 residents as well as visual observations during field visits, indicate that the large yield gaps presented in this chapter is applicable in the larger Ntabelanga area. The farmers provided reasons for the poor yields (discussed in section 13); listing unreliable rainfall, lack of labour and lack of external inputs as the dominant factors. Even though these are certainly valid reasons for the poor yields, a farmer who had all of the previous still only produced 49% of the potential yield. Poor quality seeds might therefore be another significant factor which limits the productivity of home gardens in the study area.

Future work should expand this yield gap approach to identify constraints to agricultural production to other villages in the study area and include other crops and vegetables. Such a study should be conducted over multiple seasons to capture the impact of different climatic trends on yields.

12 SOCIOLOGICAL SURVEYS

12.1 Introduction

Since the formal announcement by the South African government of a plan to build a major multi-purpose dam – to be known as Ntabelanga Dam – in the OR Tambo/Joe Gqabi axis of the Eastern Cape Province (Molewa, 2013), attempts have been made by the present research team and other scholars to understand and communicate specific ecological and socio-economic dynamics of the area as a whole, but in particular the communities likely to be directly or indirectly impacted by the dam, ahead of the commencement of construction. One such attempt is an article entitled "Soil erosion and dam dividends: science facts and rural 'fiction' around the Ntabelanga dam, Eastern Cape, South Africa" (Van Tol, Akpan, Kanuka, Ngesi and Lange, 2014). The main sociological argument in the work was that fulfilling the technological and financial requirements for the construction of a major dam was just one condition for a project of this nature to fulfil its purpose. The sustainability of a dam project rested also on how specific sociological dynamics in the affected communities were dealt with. For instance, should local expectations about the dam and idiographic narratives about the dam-culture-environment nexus be ignored, that could constitute a major sustainability breach. The article then provided a detailed ecological picture of the soil erosion situation in the dam communities as well as preliminary ethnographic accounts of how community members appraised the putative dividends of the proposed dam.

In another report (Akpan, Van Tol, Rowntree, Okeyo, Maroyi, Bradley, Mutingwende and Huchzermeyer, 2015), in which the authors juxtapose a more in-depth "ethnoecology" of the proposed dam with a qualitative account of the socio-economic realities in the dam communities, the argument was made that the socio-economic adversities in the dam communities should not serve to justify the "imposition" of development on people. The report pointed out that:

> *The relatively benign narratives about anticipated benefits should offer some hope to developers (in this case the state) that the Ntabelanga Dam will eventually be embraced by the communities, but this cannot be overstated or taken for granted. The focus of monitoring has to be on how the expressed hopes and fears as well as conceptions and misconceptions [about the dam] eventually become reconciled – or, more practically, how these change in the coming years.*

As the sociological aspects of these two studies were based on interview, focus group and observational data, they only provided "insider perspectives", not a standardised, overall, picture. There was always going to be a need to generate measurable socio-economic baseline data, as this would be crucial for monitoring, in a more quantifiable way, how the dam impacts the communities in the near, medium and long term. This is the primary focus of this chapter of the report. It brings together the results of a survey conducted in the five dam communities that have been the sites of the previous studies. The survey was conducted between mid-November and early December 2016.

Detailed statistical tables and figures have been provided in Appendix 3, conforming to the different survey themes, namely:

- Respondent demographics
- Livelihoods and socio-economic activities
- Social networks and social capital
- Formal and informal safety nets
- Social amenities
- Ecological indicators, risk and vulnerability

In the subsections below, only concise summaries of relevant survey findings are presented. Aspects of these findings have also been invoked in the analysis of 'intersections' presented in the next chapter.

12.2 Respondent demographics

About 62% of the survey respondents were female, while 38% were male. Most respondents (52%) were married. While most of the respondents (37%) were between the ages of 15-24%, the single most populous age cohort in the sample of 600 respondents were men and women aged 65 and above (16.4%).

A majority of respondents (36%) lived in mud dwellings (36%) – mostly owned by them – with 39% reporting an average household size of 3-4 people. Households were composed as follows: respondent and spouse (49%), respondent and children (69%), respondent and parents (44%) respondent and parents (44%), and respondent and friends (14%). Besides the respondent, financial support in the household was provided by spouse (28%), children (21%), parent/other relative (35%), and friends (4%).

More than 70% of respondents had children of school-going age, 49% of whom attended primary school, 15% (pre-primary), 18% (secondary), and 6% (tertiary). For respondents whose children of school-going age were not currently attending school, two main explanations were provided: lack of money for fees and other school needs (56%), and lack of money for school transport (30%). Respondents themselves reported 'primary' as their highest level of education (49%), high school (46%), diploma (4%), and bachelor's (less than 1%).

12.3 Livelihoods and socio-economic activities

Only 22% of respondents reported being employed. An additional 6% reported being self-employed. The rest were unemployed. Most respondents (48%) relied on social grants, 22 subsisted on piece jobs while 11% depended on relatives for daily sustenance. Although there was a convenience store (*spaza*) in each of the study communities, 79% of respondents stated that the stores were mostly owned by (non-South African) immigrants. Besides these stores and liquor stores – of which there was one in each community (or within easy reach of community members) – there was almost no other 'modern' business activity in the study communities.

12.4 Social networks and social capital

The most important grassroots association in the area was the burial society (76%). This was followed by *stokvels* (49%), youth clubs/associations (39%) and women's clubs (29%). The definitive recreational activity for local youth was sport, the local sport fields being the main recreational spaces. For older persons, tending the farm was described as a 'recreational' activity. With farming as a 'recreational' activity, the farm stood out as the main 'recreational' space for older people.

More than 80% of community member reported that alcohol abuse was a major social issue in the area. Compared to alcohol abuse, drug abuse was not a prominent social issue: only 49% of respondents reported that there was a drug abuse problem; the majority (51%) said it was not a major social issue. The existence of domestic violence as a social problem was reported by 46% of respondents. According to 56% of respondents, crime and disputes in the area were dealt with by involving the entire community, instead of it being simply a problem for the 'police'.

12.5 Formal and informal safety nets

As indicated earlier, South Africa's extensive official safety net (social welfare grants) extended to the study area. Approximately 39% of respondents reported receiving child support grants. Old age grants were received by 25% of respondents while 6% and 5% of respondents received disability and foster care grants respectively. Most respondents who received one type of grants or the other had been on such grants for five years or longer, on average. There was little or no awareness of the existence of informal safety nets in the study area: only 13% of respondents believed there were any organisations within the community that catered for the less privileged.

12.6 Social amenities

The reach of modern social amenities in the area was limited. Drinking water was mostly sourced from communal water taps and through rain water harvesting, with only 64% of respondents reporting that the quality of drinking was of good quality. Even so, 52% of respondents were unsatisfied with the regularity of water flow. Similarly, water for general household use was sourced from communal taps and through rain water harvesting. User satisfaction was equally low with regard to the regularity of water flow.

There were no in-house sanitation facilities for a majority of respondents (44%), while 29%, 19% and 8% of respondents relied on pit, ventilated pit, and bucket latrines respectively. The use of cellular phones was widespread (90%), while the reverse was the case with access to modern healthcare facilities (77% of respondents had no access to health clinics). There was relatively good access to schools (as confirmed by 78% of respondents). Public transport (buses and taxis) was available but unreliable. Similar perceptions existed with regard to electricity (59% of respondents said the electricity supply in the area was unreliable).

12.7 Ecological indicators, risk and vulnerability

In the view of most respondents, the area was prone to lightening (70%), strong wind (70%), wild fires (59%) and drought (47%). Flooding was also reported as a relatively significant ecological problem 39%). Indeed, at least 59% of respondents had once suffered a major loss through a fire incident. Relatively common public health issues in the area were: chicken pox (53%), cholera (32%) and diarrhoea (30%).

12.8 Conclusion

As stated from the outset, dams are typically portrayed by their developers as cornucopia. The South African government intends for the Ntabelanga dam to bring about rural renewal in aspects such hydroelectric power generation, irrigation, and ecotourism. Employment generation, household income enhancement, the weaning of masses of local residents off social grants, infrastructure provisioning, and drastic improvements in the overall quality of life in the dam communities (at the very least) are logical concomitants of the dam project. The community profiles provided in this chapter offers a crucial baseline for monitoring how the dam has brought about (positive and/or negative) changes in crucial aspects of community existence in the short, medium and long them.

13 BIG DAM, COMMUNITY DYNAMICS AND THE PURSUIT OF RURAL RENEWAL: INTERACTIONS AND INTERSECTIONS

13.1 Introduction

Since the formal announcement by the South African government to launch the Mzimvubu Water Project (MWP) in the OR Tambo/Joe Gqabi axis of the Eastern Cape Province (Molewa, 2013), attempts have been made by the present research team and other scholars to understand and communicate specific ecological and socio-economic dynamics of the area as a whole, but in particular the communities likely to be directly or indirectly impacted by the dam, ahead of the commencement of construction. One such attempt is an article entitled "Soil erosion and dam dividends: science facts and rural 'fiction' around the Ntabelanga dam, Eastern Cape, South Africa" (Van Tol et al., 2014a). The main sociological argument in the work was that fulfilling the technological and financial requirements for the construction of a major dam was just one condition for a project of this nature to fulfil its purpose. The sustainability of a dam project rested also on how specific sociological dynamics in the affected communities were dealt with. For instance, should local expectations about the dam and idiographic narratives about the dam-culture-environment nexus be ignored, that could constitute a major sustainability breach.

In the report by Van Tol et al. (2014b), a matrix of hypothesised "intersections" among different aspects of the dam was presented, and a model of environmental, agricultural and socio-economic monitoring activities proposed (Figure 1-1). It was based on that model that the study utilised a robust interdisciplinary and collaborative mode of inquiry. Interdisciplinary research "integrates information, data, techniques, tools, perspectives, concepts, and/or theories from two or more disciplines or bodies of specialized knowledge to advance fundamental understanding or to solve problems whose solutions are beyond the scope of a single discipline or field of research practice" (see National Academy of Science et al., 2004:26). It opens up the possibility of understanding the dam-environment-community nexus in a holistic way and helps to highlight cross-cutting issues that the different disciplines can tackle. The matrix in Figure 1-1, for example, offers a preliminary idea of the possible areas of intersection among different aspects of the dam project.

This section provides a baseline analysis of how the various aspects (environmental, agricultural and socio-economic) intersect, thus giving an indication of what issues might become crucial in the short-, medium- and long-term. It must be pointed out that although the construction of the dam provides the background for these cross-cutting discussions, many of the interactions occur in similar areas without any planned infrastructure development.

13.2 Access to clean water

Background physical information

Based on water quality data (Table 4-4 - Table 4-9), the only parameter which is higher than the norm is the turbidity. Turbidity is a measure of the light-scattering ability of water and is indicative of the concentration of suspended matter in water. The turbidity of water is also related to clarity, a measure of the transparency of water and **settleable material (**suspended matter which settles after a defined time period as opposed to that which remains in suspension). Micro-organisms are often associated with turbidity; hence, low turbidity minimises the potential for transmission of infectious diseases. The probability of the presence of carcinogenic asbestos fibres is also reduced under conditions of low turbidity. Turbidity also affects the aesthetic quality of water.

Consumption of turbid water *per se* does not have any direct health effects, but associated effects due to microbial contamination or the ingestion of substances bound to particulate matter, do. Turbidity can have a significant effect on the microbiological quality of water. Microbial growth in water is most extensive on the surface of particulates and inside loose, naturally-occurring flocs. River silt also readily adsorbs viruses and bacteria. During treatment, micro-organisms become entrapped in the floc formed during coagulation and breakthrough of the floc may represent significant microbial contamination.

Consumption of highly turbid, chlorinated water may therefore pose a health risk. Particulate matter can also protect bacteria and viruses against disinfection. The adsorptive properties of some suspended particles can lead to the entrapment of undesirable inorganic and organic compounds in water, including metal-humate complexes and herbicides (e.g. 2,4-D, Paraquat, Diquat). This may interfere with the detection of such compounds, and could be an indirect health risk. Turbidity may also be associated with the presence of inorganic ions such as manganese(II). For example, when water containing manganese(II) ions is treated with chlorine and left to stand, slow reaction kinetics indicate that colloidal manganese(IV) oxide is formed, leading eventually to the formation of a fine precipitate.

The analysis of the potential pollution from pit latrines show that 3 of the 4 study sites have high likelihood of polluting streams with faecal coliforms and result in infection and spreading of diseases (Table 5-3).

Water and the community

Data obtained through a sociological survey of the study communities revealed important sociological issues pertaining to water in the area. These include current sources of water for various uses, perceptions about water quality and regularity of water flow, among others. For instance, the data showed that the two most important sources of drinking water in the community were communal taps (43% of respondents) and rainwater harvesting (26% of respondents) (Table 13-1). A small proportion (11%) of households had water taps located inside residence. Respondents generally held a positive view about the quality of these water sources (64%) (Figure 13-1).

Table 13-1: Current sources of drinking water

Water source	Percent	Frequency
Water tap located inside residence	32	11.0
Water tap located outside residence within the same yard	4	1.4
Communal water tap	126	43.3
Stand pipe	1	0.3
Rain water harvesting	76	26.1
Rain and municipal water	13	4.5
River	17	5.8
Own tank	1	0.3
Stand pipe and rain	1	0.3
Communal and rain	3	1.0
Communal and stand pipe	1	0.3
Water in the residence and rain harvesting	1	0.3
Wetlands	13	4.5
Communal and wetland	2	0.7

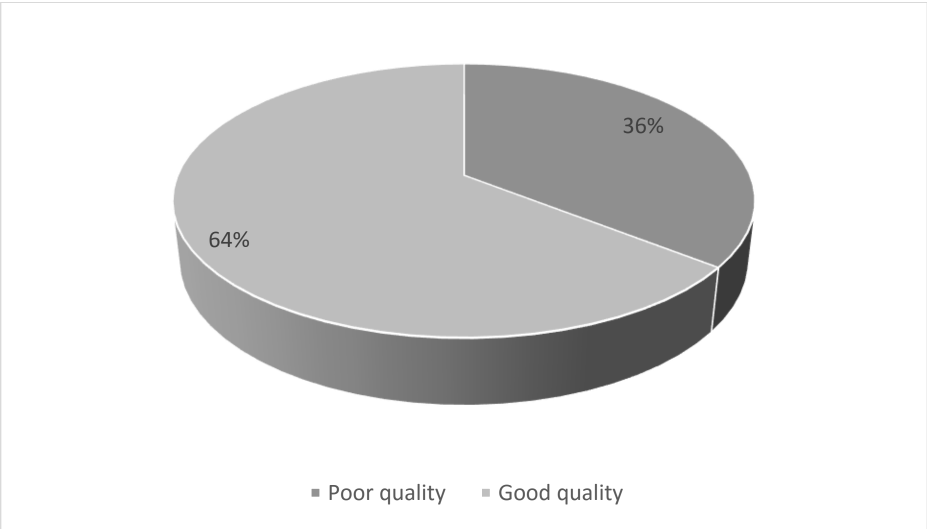

Figure 13-1: Perceptions of drinking water quality.

The regularity of water flow was a problem for many households (Figure 13-2). Only 52% of respondents reported that water flow was regular; 48% described the water flow as either irregular or unreliable.

Water for general household use was mostly sourced from the same sources as drinking water (communal taps and rainwater harvesting) (Table 13-2). As with drinking water, most respondents (58%) reported that there was “irregular” or “unreliable” supply of water for general domestic use.

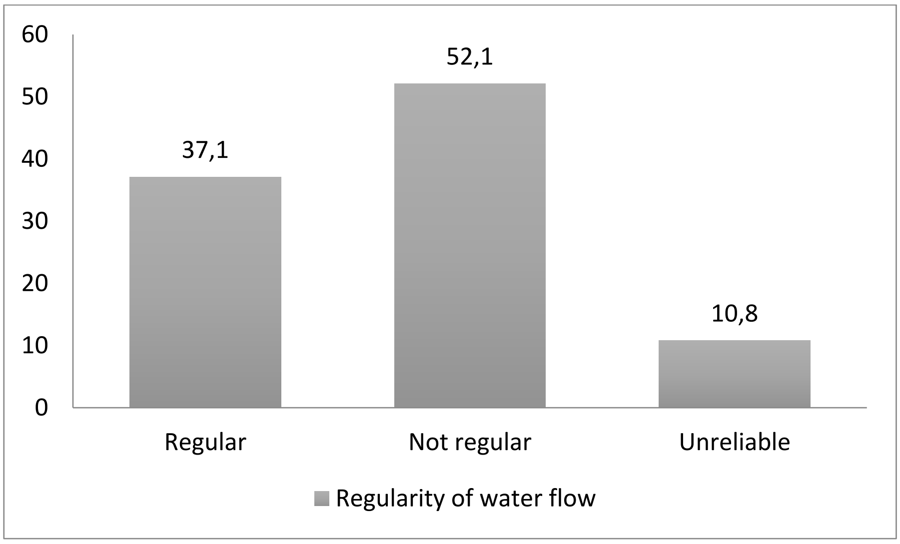

Figure 13-2: Regularity of water flow for drinking water.

Table 13-2: Current sources of water for general household use

Water source	Percent	Frequency
Water tap located inside residence	27	9.4
Water tap located outside residence within the same yard	2	0.7
Communal water tap	133	46.5
Stand pipe	2	0.7
Rain water harvesting	72	25.2
Rain and municipal water	13	4.5
River	19	6.6
Communal and rain	2	0.7
Wetlands	13	4.5
Communal and wetland	3	1.0

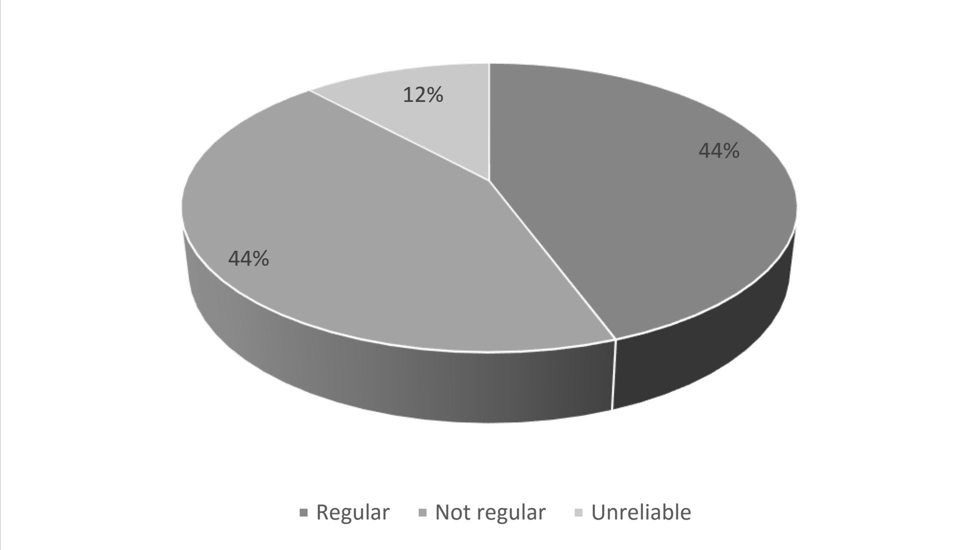

Figure 13-3: Regularity of water supply/flow for general household use

Local residents were relatively familiar with outbreaks of water-borne diseases, with cholera and diarrhoea being the most reported (especially in Lower Sinxaku) (Table 13-3 and Table 13-4). Household sanitation situation in the area directly mirrored the sources of general household water reported above: 44% of households reported not having sanitation facilities installed in residence (Figure 13-4). The main types of household sanitation were bucket latrine (8%), pit latrine (29%) and ventilated latrine (19%).

Table 13-3: Experience of disease outbreaks

Disease outbreak	Frequency	Percent
Cholera	97	32.4
Dysentery	40	13.4
Diarrhoea	90	30.1
Scabies	42	14.0
Chicken pox	159	53.2
Malaria	46	15.4
No disease outbreak	80	26.8

Table 13-4: Experience of disease outbreaks (by community)

Disease outbreak	Ngqongweni	Ndzebe	Emqokolweni	Ndibanisweni AA	Lower Sinxaku
Cholera	0 (0.0)	43 (72.9)	10 (16.7)	4 (6.7)	40 (66.7)
Dysentery	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	40 (66.7)
Diarrhoea	2 (3.3)	26 (44.1)	13 (21.7)	9 (15.0)	40 (66.7)
Scabies	0 (0.0)	0 (0.0)	1 (1.7)	1 (1.7)	40 (66.7)
Chicken pox	32 (53.3)	50 (84.7)	23 (38.3)	29 (48.3)	25 (41.7)
Malaria	1 (1.7)	0 (0.0)	3 (5.0)	1 (1.7)	41 (68.3)
No disease outbreak	27 (45.0)	2 (3.4)	14 (23.3)	23 (38.3)	14 (23.3)

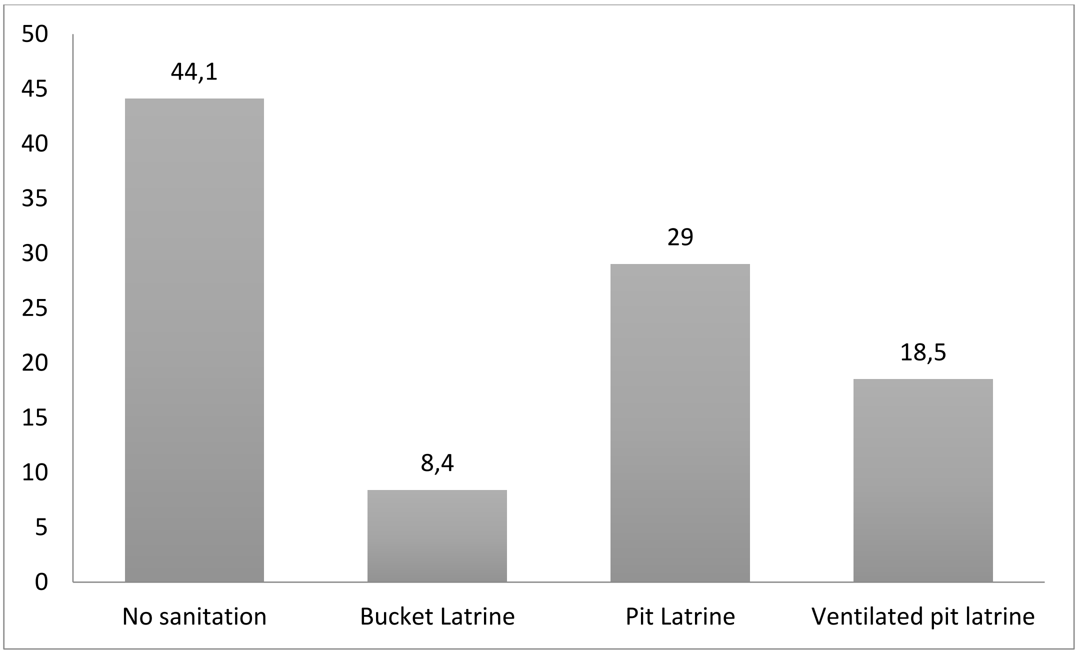

Figure 13-4: Type of sanitation in household.

13.3 Useful plants

Useful plant species

A total of 56 useful plant species were recorded in the Ntabelanga area (Figure 8-6 and Table 8-3). The documented useful plants seem to suggest that plant resources in the Ntabelanga area are mainly used as sources of food, either collected from the wild, managed or tolerated in home gardens or agricultural fields. Some of the food crops were grown as monocultures. Some examples of these were: *Allium cepa, Allium sativum, Beta vulgaris, Brassica oleracea, Brassica rapa, Capsicum annuum, Cucurbita moschata, Daucas carota, Ipomoea batatas, Lactuca sativa, Lycopersicon esculentum, Phaseolus vulgaris, Pisum sativum, Solanum tuberosum, Spinacia oleracea* and *Zea mays*. Intercropping was also practised, especially intercropping *Zea mays* with *Cucurbita maxima* or *Ipomoea batatas;* and *Brassica oleracea* was also intercropped with *Allium cepa* and/or *Allium sativum* and/or *Brassica rapa* and/or *Capsicum annuum* and/or *Lactuca sativa* and/or *Spinacia oleracea. Zea mays* (Figure 13-5) was the only cereal crop recorded in this study, cultivated by 85.7% of the participants. Among the edible plants recorded in the Ntabelanga area included traditional leafy vegetables which were gathered from the wild, these included *Amaranthus hybridus, Bidens pilosa, Centella coriacea* and *Sonchus asper.* Cultivated fruit trees which were grown in orchards included *Citrus limon, Citrus sinensis, Ficus carica, Malus domestica, Musa* X *paradisiaca, Opuntia ficus-indica, Persea americana, Prunus armeniaca, Prunus persica, Psidium guajava* and *Vitis vinifera.* Ornamental plants recorded in this study included *Catharanthus roseus* (Figure 13-6), *Opuntia ficus-indica* and *Phoenix reclinata* (Figure 13-7). *Agave americana* (Figure 13-8) and

Aloe ferox (Figure 13-5 and Figure 13-8) were used as live fence or hedge plant around home gardens, crop fields and animal enclosures.

Figure 13-5: Maize (*Zea mays*) agricultural field surrounded by *Aloe ferox* live fence (Photo: A. Maroyi).

Figure 13-6: *Catharanthus roseus* cultivated as ornamental and medicinal plant (Photo: P. Ngcaba).

Half of the useful plant species (28 species, see Table 8-3) recorded in the Ntabelanga area were used as herbal medicines. Although the average frequency (less than 20%, see

Figure 8-6) of this use category was low, the high amount of medicinal use reports indicates that plants still play an important role in rural healthcare systems. Some of the medicinal plants recorded in this study are widely used as herbal medicines in South Africa and other countries. Such species include *Catharanthus roseus* (Figure 13-6) and *Leonotis leonurus* (Figure 13-9). According to Semenya and Potgieter (2013) *Catharanthus roseus* is actively cultivated by traditional healers in the Limpopo province in their home gardens as the species is widely used as herbal medicine for treating gonorrhoea and other related diseases and ailments. Similarly, *Leonotis leonurus* commonly known as “wild dagga” is traditionally used as a decoction, both topically and orally, in the treatment of a wide variety of conditions such as haemorrhoids, eczema, skin rashes, boils, itching, muscular cramps, headache, epilepsy, chest infections, constipation, spider and snake bites (Nsuala et al., 2015).

Figure 13-7: *Phoenix reclinata* cultivated as ornamental and leaves used to make baskets, mats and other crafts (Photo: M. Mamera).

Figure 13-8: *Agave americana* and *Aloe ferox* used as live fence or hedge or enclosures around home gardens, agricultural fields or animal enclosures (Photo: A. Maroyi).

The ethnobotanical interviews revealed that medicinal plants are an important aspect of the daily lives of many people within the Ntabelanga area as an important part of the Xhosa cultural heritage. Local people harvested whole plants in some cases (Figure 13-10) or harvested only bark, bulbs, leaves and roots (Figure 13-11). While some whole plants or plant parts can be used in a fresh state, many plants or plant parts are dried and stored (Figure 13-11) for future use. Interviews with participants and observations made in the study area revealed that the indigenous knowledge systems of the Xhosa people are dynamic and adaptive.

This can be seen in the incorporation of introduced medicinal plant species such as *Agave americana*, *Catharanthus roseus, Ficus carica, Opuntia ficus-indica, Psidium guajava* and *Sonchus asper* into indigenous knowledge systems involving herbal medicines. Some of the medicinal plant species which include *Alepidea amatymbica, Artemisia afra, Bowiea volubilis, Catharanthus roseus* and *Tulbaghia acutiloba* are cultivated in home gardens mainly due to high demand for herbal medicines resulting in over-exploitation of wild plant populations. Previous research by Wiersum et al. (2006) also found *Alepidea amatymbica* and *Bowiea volubilis* to be some of the preferred medicinal plants that are cultivated in home gardens in the Eastern Cape Province as herbal medicines. According to these authors, households in the Eastern Cape Province selectively manage plant species that are important to them so as to ensure that such species are readily available in the home gardens. Wiersum et al. (2006) argued that cultivation of medicinal plants can serve as a tool for combined biodiversity conservation and poverty alleviation; resulting in increased social capital and human dignity.

Figure 13-9: ***Leonotis leonurus*** **commonly known as "wild dagga" is widely used as herbal medicine (Photo: P. Ngcaba).**

Figure 13-10: Several plant species are used as herbal medicines in the Ntabelanga area (Photo: P. Ngcaba).

Figure 13-11: Different plant parts used as herbal medicines in the Ntabelanga area (Photo: P. Ngcaba).

Potential impact of dam construction on utilisation of plant resources

The value of plant resources as a source of household livelihoods needs was ubiquitously perceived (Figure 13-12), with all participants reporting that the planned dam will negatively affect the availability of plant resources in the Ntabelanga area. More than half of the participants (52.4%) are convinced that edible, medicinal and other useful plants collected from the wild will be affected by damming. About a quarter of the ethnobotanical interviewees (9.5%) mentioned the possibility of increased number of alien plant species, weeds, pests and diseases as a result of the flooding. It is noteworthy to mention that some participants (9.5%) argued that plant diversity in home gardens will increase as water will be available throughout the year and home gardening activities will also be enhanced due to increased water supply. According to some participants (9.5%), availability of water in home gardens is one of the essential resources required to ensure food production in the Ntabelanga area.

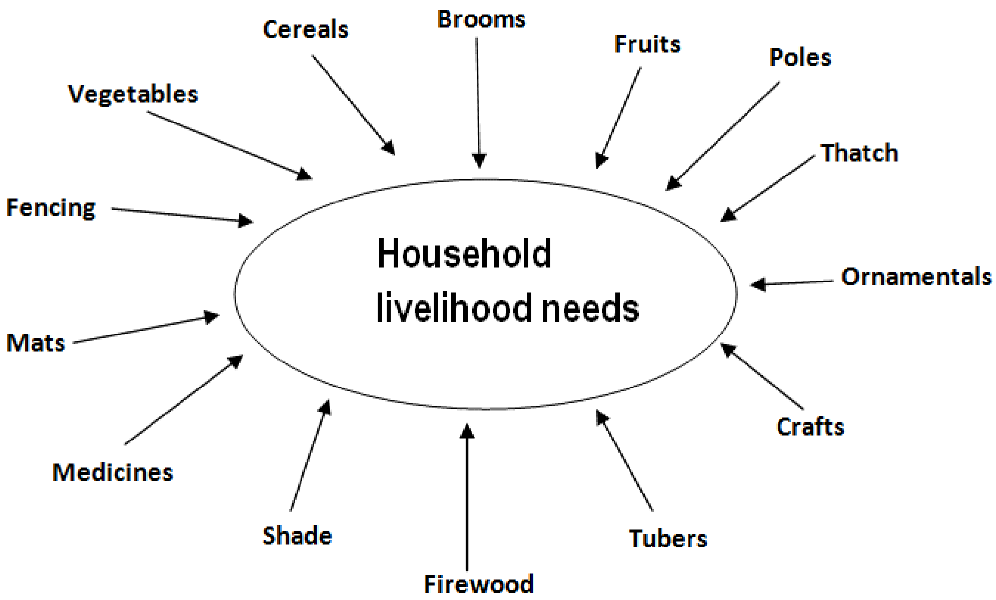

Figure 13-12: Plant resources product flow diagram for the Ntabelanga area based on results derived from PRA exercises.

13.4 Soil quality, yields and perceptions on cultivation in home gardens

General cultivation practices

In the Lower Sinxaku area, cultivation of primary crops are restricted to home gardens (<1 ha). Larger fields of between 1 to 5 ha which were previously cultivated are now abandoned due to factors such as lack of labour, absence of cultivation equipment and soil erosion. Maize is the major crop which are planted mainly for human consumption (white maize) but also for livestock feed (yellow maize). Farmers produce their own seed-maize. The seed (for both white and yellow maize) is selected from the best performing cobs which is determined in terms of the length, diameter and grain size. According to farmers' interviews this seed is kept suspended downwards with the dry husk to prevent weevil infestation (Figure 13-13).

Figure 13-13: Production of seed-maize.

Vegetables such as spinach, cabbage, potatoes, carrots and tomatoes are planted in rotation with maize by some of the farmers (though it depends on the rainfall of the year). Farmers are fully operating under rain-fed conditions except for few that irrigate with river water on a small scale. The area is dry, as a result most of the gardens have been left untouched for years.

Challenges associated with cultivation

All the farmers listed the lack of rainfall (water scarcity) and the inconsistency as the number one challenge to their crop production.

"These days' heavy rains come in the wrong season".

Ngxotho Interviewee.

There are however other water sources in the area, such as the springs and mountain water. A channel of rocky dongas, transporting water from the surrounding mountains down the valley, were used by the farmer at MNS1 as a water harvesting technical resources. He further constructed a well and developed an irrigation scheme to cultivate vegetables throughout the year (Figure 13-14).

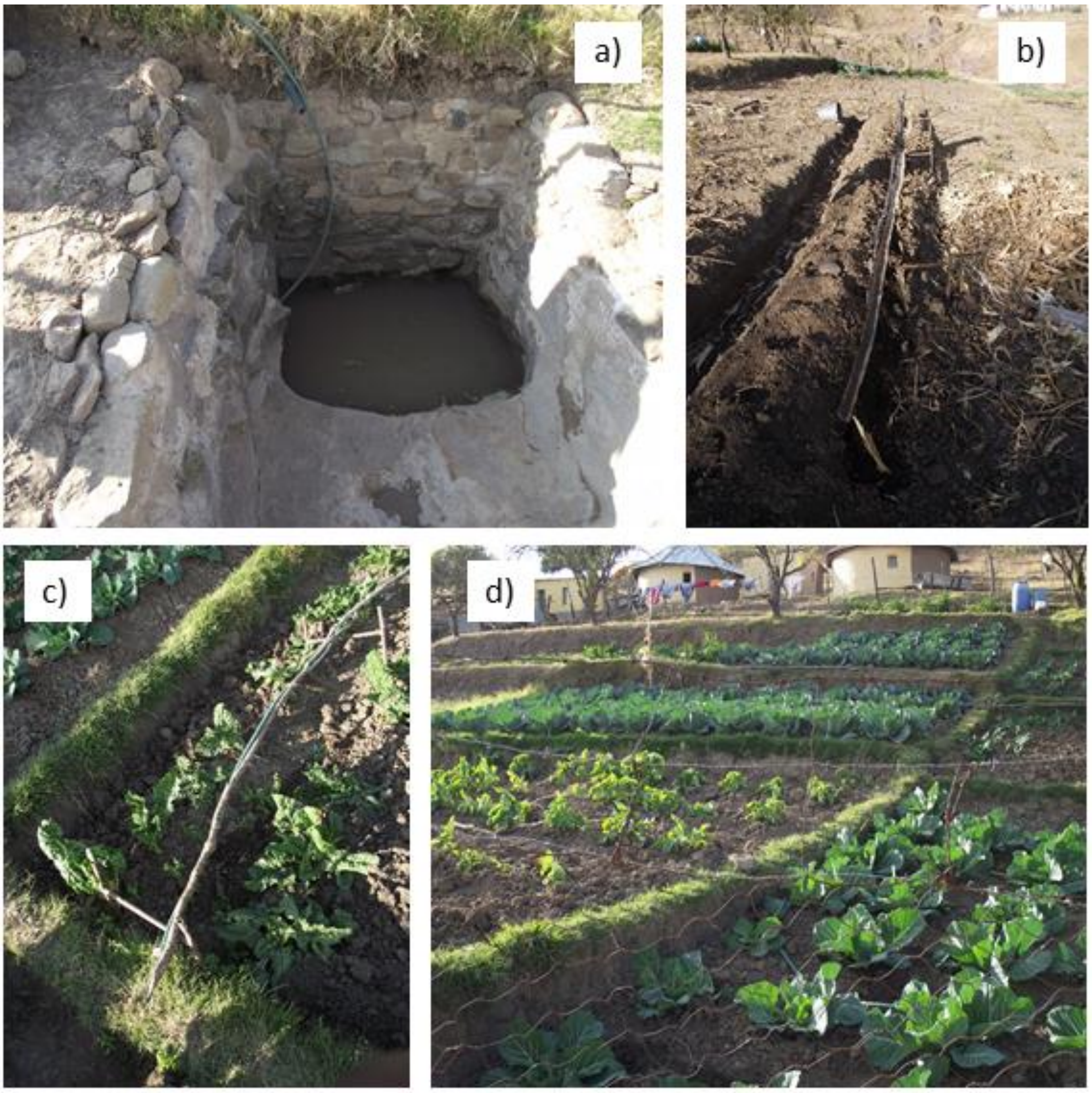

Figure 13-14: Practical plans to overcome water limitations in vegetable production employed by the farmer at MNS1 a) construct a well for water harvesting from the mountain, b&c) home-made irrigation scheme to d) produce vegetables throughout the year.

Another major problem is unavailability of labour, as much as the farmers own small plots some of them are not used to full capacity since there is scarcity of labour. The available labour is quite old people with ages ranging from 50 to 75, while the youth is out in the cities in search of jobs (Figure 13-15). Only 0.7% of 'younger' respondents considers agriculture/cultivation as a recreational activity compared to 10.7% of the 'older' respondents.

> *"I can only cultivate a small portion of my garden because I do not have the energy to weed the whole of it"*
>
> *Lower Sinxaku* Interviewee.

Figure 13-15: An old farmers' land; only half of the field cultivated due to lack of labour.

Some farmers have shallow soils which are not suitable for maize production though it is a major crop.

> *"There are years I do not harvest anything from my garden because its soil is too shallow and rocky. I try to add manure to improve it and when I'm lucky I get to eat green mealies"*
>
> *Lower Sinxaku Interviewee*

Another challenge is that farmers in the area mostly rely on organic manure to fertilize and maintain their soil.

> *"We access synthetic fertilizers when the government officers supply, which rarely occurs"*
>
> *Lower Sinxaku Interviewee*.

Worth noting, but not eluded to by the interviewees is the lack of access to good quality seed. Taking the farmer at MNS1 as an example who recorded yield gaps of 2.73 and 3.82 t.ha^{-1} during the first and second growing season respectively (Table 11-7). This farmer's fields are well fertilised and irrigated, and he clearly illustrated an ability to manage his land optimally (Figure 13-14), but still do his fields do not yield close to their potential (although by far the best of the studied sites. Poor quality seeds or wrong cultivars together with unreliable water precipitation might be the reason for this.

This farmer is already irrigating good quality soils for vegetable production and demonstrated the ability to improve the soil quality through incorporation of organic material. Higher maize yields might be obtained if he practice in-field rainwater harvesting to ensure improved soil water regimes for production.

The contribution of irrigation towards rejuvenation of agriculture in the area will depend on timely advice and access to fertilisers and especially good quality seeds. If the latter is not done, it appears this planned development might be another statistic of a failed intervention as reported in Table 11-2.

13.5 Livestock farming and land quality

Interviews with the Ntabelanga area residents revealed that livestock keeping is an important economic activity as it contributes to household food supply and it is also regarded as an important source of cash income. In the Ntabelanga area, households keep six types of livestock species (Table 13-5). All households keep goats, cattle are kept by 90.5% of the households, while sheep are kept by 85.7% of the households (Table 13-6). These figures are higher than the national proportion in South Africa which is 57% for goats, 35% for cattle and 10% for sheep (Mmbengwa et al., 2015). Goats provide meat, cattle are mainly used for milk, beef and draught power and sheep provide meat and wool. The main purpose of donkeys and horses are as mode of transportation. Other uses of livestock species include production of milk, particularly from cattle, skins and manure (Figure 13-16). Livestock are considered as important status symbol of rural people and also provide ready cash to the household through sales when the need arises. Cattle are used in paying bride prizes while goats and sheep are mainly used for traditional and religious sacrifices. Cousins (2008) and Mmbengwa et al. (2015) argue that livestock, particularly cattle form a fundamental part of the lives of rural people's lifestyle in South Africa, as cattle are often used in paying lobola (bride-worth) and other social activities.

Table 13-5: Impact of dam construction on availability of plant resources in the Ntabelanga area

Variable	Proportion (%)
Edible plants and herbal medicines collected from the wild will be negatively affected	52.4
Number of alien plant species, weeds, pests and diseases will increase	23.8
Availability of water will result in revival of home gardening activities	9.5
Availability of water will result in increased plant diversity in home gardens	9.5
Possible to have home garden produce throughout the year	9.5

Table 13-6: Proportion of households keeping livestock in the Ntabelanga area

Livestock	Frequency	%
Goats	21	100
Cattle	19	90.5
Sheep	18	85.7
Horses	6	28.6
Donkeys	4	19.0
Pigs	4	19.0

Figure 13-16: Cattle, goat and sheep manure is an important source of nutrients for farming operations in the Ntabelanga area (Photo: A. Maroyi).

Interviews with participants revealed that the best grazing land is in the mountains, but unfortunately residents' no-longer use these due to high labour costs in managing livestock and increased livestock theft. Similar results were obtained by Lesoli (2008) who argued that rangelands in the Eastern Cape Province consist of a mixture of uplands, gently sloping areas and bottom lands, the bottom and gently sloping lands are generally grazed approximately three times more intensely, than associated uplands because of easy access by the livestock. Interviews with participants and personal observation also revealed that the grazing lands in Tsitsa river catchment area are communally grazed with insufficient or no management system in place. When participants were asked about constraints and challenges being faced in managing livestock, 62.0% of the participants mentioned inappropriate burning regimes with no control or management, followed by limited or no rotational grazing system in place (35.2%), little or no fencing to control where and when livestock should graze (24.1%) and uncontrolled or unmanaged livestock (19.0%) (Table 13-7). Research by Vetter (2013) revealed that insufficient grazing, weak institutional capacity to manage common grazing resources, livestock diseases, drought and stock theft are major constraints on livestock production in South Africa.

Table 13-7: Constraints faced by households in managing available grazing lands in the Ntabelanga area

Variable	Proportion (%)
Inappropriate burning regimes with no control or management	62.0
Limited or no rotational grazing system in place	35.2
Little or no fencing to control where and when livestock should graze	24.1
Uncontrolled or unmanaged livestock	19.0

13.6 ‘Stopping the river’: The ethno-mystical dimension

The ethnobotanical interview data pertaining to, especially, the medicinal and spiritual uses of local plants in the study area (discussed above) were corroborated by data obtained during a focus group session with 15 sangomas (both male and female) in Lower Sinxaku. The sangomas expressed strong sentiments about the importance of the Tsitsa river, and what its ‘stoppage’ could mean for the area. Water is central to the spiritual vocation of sangomas and, by extension, to the spiritual health of the community. For sangomas – at least those that participated in the FGD – (flowing) water from a river is not the same thing as “stagnant” water from a dam. A river symbolises life and nourishes the world of the living. Its “life-giving” quality lies in the fact that it flows. This is what is relished by the ancestors, who use river water to bring healing and spiritual release to the afflicted. “Stagnant” water (from a dam) cannot serve this purpose, the research participants maintained. During the FGD, the sangomas shared critical insights about the “river-community nexus, from a socio-cultural and mystical point of view, and how a major dam project could interfere with that relationship” (Akpan et al., 2017:8). In their words:

- *This is not good. We don’t use dam water. We use river water or the ocean [for healing purposes].*
- *Our work will fail*
- *With a dam, that means there is no more Tsitsa [River]. Tsitsa will be no more!*
- *We don’t go to the healing places on our own accord; we are shown where to go. Now what happens when you are directed [by the ancestors] to go to a place that now has still [stagnant] water? That is the big problem*

- *When the elders left [When those who are now "ancestors" were still alive on earth], the water was moving. Now it will be a person purposefully stopping the flow. The government is robbing and deceiving us.*

Dam inundation, therefore, has more than just an environmental and agricultural impact. While it will power the generation of hydro-electricity, and make water readily available for irrigated agriculture (with all its benefits), as well as solve the domestic water and sanitation problems in the study area, it is bound to truncate local ecological sovereignty and devastate the local botanical system through, for example, the proliferation of "unwanted" alien vegetation. The effect is also likely to be calamitous for the spiritual healthcare system – at least from the point of view of *sangomas,* spiritual health practitioners regarded by many in the study area as custodians of local knowledge.

13.7 "We don't want that dam here": People, space and place

Most research participants acknowledged that because of the acute water shortage in the area, the dam would bring great relief. Animals would easily find water to drink, the fields would be irrigated, crop harvests would become abundant, commercial agriculture would become imaginable for many people, employment opportunities would be created (see Figure 13-17), and life as they knew it would be positively different. However, the empirical data showed that despite the present deplorable socio-economic conditions in the various communities, and the near-desperate need for socio-economic rejuvenation, people had strong sentimental attachments to the homes, fields, animals, the river, and the socio-cultural networks (Table 13-10) that defined their existence. Especially in the communities nearest to the proposed dam, such as Ngqongweni, Emqokolweni and Lower Sinxaku, the strong people-environment bond was such that even when no oppositional stance was openly expressed with regard to the proposed dam project, one could still feel a sense of how residents might react to any plans to relocate them.

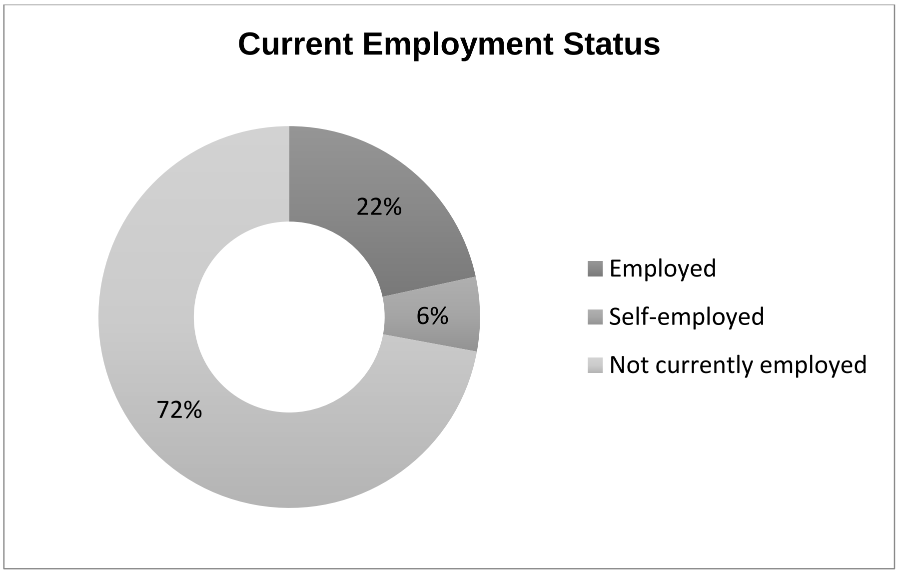

Figure 13-17: Employment status of survey respondents.

Table 13-8: Socio-cultural networks in the study communities

Available organisation	Frequency	Percent
Burial society	228	76.3
Women's club/association	87	29.1
Neighbourhood club/association	81	27.1
Hometown Association	61	20.4
Men's club/association	31	10.4
Youth club/association	101	33.8
Cooperatives	40	13.4
Stokvel	134	44.8
Church/church club/association	69	23.1

In several of the FGD and in-depth interview sessions, the fear of displacement was expressed using very strong metaphors: displacement was likened to being "killed", being "torn down", and being "thrown away":

> *Government will build this dam, right? And then they will move us and throw us far away where we will gain nothing. They want to tear our houses down [*Table 13-9*]. With it, the children will work and we will all get jobs. But we don't want that work. You see that house over there? They are going to tear those ones down* (Female interviewee, Ngqongweni)

Table 13-9: Housing types in the study communities

Housing type	Frequency	Percent
Mud	98	35.5
Rondavel	19	6.9
Flat	98	35.5
Gable	7	2.5
Corner house	4	1.4
Rondavel and flat	12	4.3
Corner house and flat	3	1.1
A Room	4	1.4
Brick	27	9.8
RDP	4	1.4

It was as if the prospect of a “better” life was at once the certainty of doom (Table 13-10). The perspectives of local spiritual healers (sangomas), summarised in the previous subsection, are best captured in the following words:

> *From what I can see, we can get employment from the dam. Beyond that there is nothing to be gained. They will kill our fields. They are moving us, to put us where? They will look for a place for us? They will cut for us a place among the agricultural fields? The fact is that we don’t want to be moved, we don’t want to go to strange villages. We want to remain here* (Male sangoma, Lower Sinxaku).

Table 13-10: How do respondents cope with unemployment?

Means of meeting day-to-day needs	Frequency	Percent
Rely on social grants	143	47.8
Do piece job	65	21.7
Depend on relatives	32	10.7

In Ngxoto, the dam inlet section of Emqokolweni community, one town hall FGD participant voiced the following as one of the many reasons the dam project could complicate their lives:

> *Movement of graves and homes will be a problem because the ancestors won’t be happy. Elaborate rituals will have to be done and that is expensive.* [Town hall FGD participant, Emqokolweni]

One female interviewee in Ngqongweni expressed her sentiments bluntly, indicating that while there would be jobs, the dam spelt trouble for the community:

> *We don’t want that dam here. They may make promises of building people new houses. I have five houses in my homestead: will they replace all five? If the dam must come here, they must not move us or disturb our houses. They must find a way of working around our community.*

Besides concerns that touched on space-place sensitivities, respondents also feared that the proposed Ntabelanga Dam might have a negative impact on the communities’ social fabric. There would be an influx of “migrant workers” and “strangers”, which would exacerbate the problem of unwanted pregnancies and drug addiction. New ways would have to be found to keep children safe; otherwise, incidents of drowning would be a serious challenge. The communities would now be faced with new levels – and even new types – of crime.

13.8 A universe of intersections – discussion and conclusion

Taken together, the foregoing results reveal at least three things. One, the natural environment and the socio-cultural environment in the study communities are inextricably linked. Two, although the botanical universe serves the human universe in ways that are not robustly “economistic”, the keyword that defines the human-environmental interface is holism, as exemplified by the varied – sometimes mystical – ways in which nature (represented by plant resources and the Tsitsa River, for example) is valued. Three, environmental, agricultural and socio-economic realities in the study communities intersect in such demonstrable ways that the overall impacts of a major multipurpose dam in the area can only be imagined within the framework of such intersections.

As propagated by the state and its agencies, the dam can, from a socio-economic point of view, make possible easy access to potable water and water for general household use, and should be able to bolster job creation and occupational and skills enhancement. Indeed, it can become a galvanising basis for skills development and local entrepreneurship development. All this can translate to improved household income and a better quality of life for different segments of the community members in the long run. Members of the study communities recognise these potentials, and in some ways, may be willing to embrace the project.

However, what the study also highlights is that these putative benefits could come at a huge cost, if local concerns and certain community dynamics are not recognised and taken on board early in the dam development process. In the various communities – with the exception, perhaps, of Ndibanisweni AA, which is located too far away from the dam to be directly adversely affected – the dam has clear socio-economic, agricultural and environmental aspects that intersect in distinct, sometimes adverse, ways.

For instance, social displacement seems unavoidable. According to members of the ‘dam wall’ community (Ngqongweni), people have been made to contemplate the near-certainty of relocation. What this indicates is that a ‘redevelopment’ of the area is inevitable; but this is bound to entail interventions in the agricultural sector, including, perhaps, a tinkering with grazing areas, grazing regimes and even the number and demographics of people involved in agriculture. Such new realities could impact one way or another on household income, but will definitely impact on the quality of human dwelling and instigate a new sense of space and place. This explains why community members picture the future utilising grim phrases such as being “killed”, being “torn down”, and being “thrown away”. These are metaphors of future-shock which contradict their otherwise supportive narratives about possible dam-induced rural renewal (*“Our community used to be sustained through planting crops. We want to plant crops again”* – see Van Tol et al., 2014:10).

Besides, while the putative potable, agricultural and industrial water supply benefit of the proposed dam is acknowledged, a crucial segment of the community – *sangomas,* who are generally regarded as important custodians of local knowledge – have sounded a word of caution about the devastating implications of water inundation on both the mystical ecology and the spiritual and cultural well-being of the community. From their perspective, a dam might signify development and modernisation for the living, but the living cannot function without the guidance of ancestors and spirits – and water inundation is a bad omen for spiritual activities and ultimately for the reciprocal relationship between the world of the living and the abode of ancestors. Thus, cultural issues intersect directly with environmental aspects of a big dam.

Almost in the same vein, easy access to drinking water – a clear dam benefit – is counterpoised by the possibility of dam inundation. It could lead to resource losses, deficits and deprivations. In a socio-economically depressed area where families have very limited access to arable farm plots (1-3 ha on average), and where 49% of residents depend on welfare grants, 22% of the labour force subsist on piece jobs and 11% of the adult population are supported by family members, resource losses arising from dam inundation cannot be viewed as a challenge that has simple remedies: the intersection of environmental and socio-economic aspects of the project must be closely watched. Indeed, this is why, in the Ntabelanga area, a big dam project is a distinct source of hope and dread.

Social cohesion seems quite high in the study communities and is partly indicated by 'social capital, which in turn, is indicated by the preponderance of grassroots associations. These include burial societies, women's clubs, neighbourhood associations, hometown associations, men's clubs, youth clubs, cooperatives, *stokvels,* and churches – with burial societies identified by 68% of the survey respondents as being by far the most popular, and men's clubs and cooperatives the least popular (reported by approximately 1.7% and 0.3% of respondents respectively). The possibility exists that a 're-development' of the area (through new agricultural interventions) and access to new income sources could impact membership of, and people's commitment to, these grassroots associations in different ways. However, there is a sense that factors such as potential social displacement could adversely affect the functioning of such associations. Community cohesion is caught in these possibilities.

The matrix of intersections does not end there. There is the issue of social deviance. The community survey data reveal that community awareness of issues such as alcohol abuse, drug abuse and domestic violence currently stands at 82%, 51% and 54% respectively. While these mirror the communities' high unemployment statistic (72%) – also revealed by the community survey – it would be of interest to see how possible improvements in income (linked to the proposed dam's job-creation potential) as well as a possible new wave of inward rural-rural and urban-rural migration of workers and job seekers would affect these indices.

In the final analysis, the question to which researchers must constantly seek answers is: to what extent can a dam project change the quality of social existence in South Africa's rural communities?

14 GENERAL CONCLUSIONS AND RECOMMENDATIONS FOR FUTURE RESEARCH

Large storage dams, such as those planned under the Mzimvubu Water Project (MWP), impact social and environmental dynamics in the local area. The success of the MWP will not only depend on technical feasibility but also to the extent to which it coheres with socio-economic and environmental dynamics – in the short-, medium- and long-term. Since large infrastructure projects are essentially 'long-term, irreversible experiments without a control', it is paramount that robust baseline are established *prior* to such a project. This was done for the planned Ntabelanga dam in the Tsitsa River, which will form part of the MWP.

The baseline provided in the report included the quantification of physical attributes in the study area, such as:

i) Water quality indices at 20 sites in the Tsitsa River, its tributaries as well as several other sources of water for 10 sampling times spreading over two years
ii) The potential of pit-latrines to pollute surface and groundwater sources in the study area
iii) Stream geomorphology and associated indices at five sites above and below the planned dam
iv) Aquatic diversity, habitat and health status in the Tsitsa River at the same sites where stream geomorphology was described
v) Vegetation diversity, composition and condition of representative landscape positions
vi) The socio-economic value of natural vegetation for human and livestock consumption
vii) Carbon stocks under the dam footprint for quantification of GHG emissions
viii) Water regime of a representative wetland
ix) Soil health status of cultivated fields and natural veld and
x) Yields and yield gaps of maize as the dominant crop cultivated in home gardens.

A fundamental aim of this project was to interpret the physical attributes in relation to the socio-economic situation. Socio-economic baseline indicators were captured from more than 300 local residents residing in villages which will be impacted by the MWP on different levels. The socio-economic surveys not only serve as baseline for the current situation and perceptions, hopes and fears pertaining to the MWP, but also provide valuable insights to interactions and intersections between the environment, agriculture and socio-economic dynamics in this study area.

The present study was designed principally to establish a baseline of environmental, agricultural and socio-economic data that would aid the long-term impact monitoring of the Ntabelanga dam. Thus, by nature, future studies will rely on this baseline indicators to evaluate change. Such studies should be mindful of the boundaries/limitations in which this baseline was established, this include climatic conditions and space-time specific data collection.

Empirical data from the study communities have brought out in bold relief important dynamics that clearly are crucial for the long-term monitoring effort – and the sustainability of the dam. These include space-place dynamics, but especially the disaffection felt by many in the study communities about the “sidelining” of community members during the initial phases of the project. The fact that the dam construction has not begun as of the time of concluding the present study is perhaps something positive, as a crucial, more sociological, phase of the study can now be enacted. It should focus on possibilities of community-based impact monitoring of the Ntabelanga dam, with a key emphasis on uncovering a strategy for empowering affected communities to themselves “monitor” and “measure” how the dam affects them.

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Appendix 1 – Water Quality data

	Parameter: Biochemical Oxygen Demand(BOD)															
	TSITSA RIVER						TSITSA TRIBUTARIES (TST)					DRINKING WATER				
	Upstream			Downstream			Upstream	Downstream				Upstream		Downstream		
	TS 1	TS2	TS3	TS4	TS5	TS6	TST1	TST2	TST 3	TST 4	TST 5	DW 1	DW 2	DW 3	DW 4	DW 5
Jul 15	2.5	4.0	6.0	1.5	2.1	11.8	1.7	2.6	3.6	4.5	6.4	1.60	2.7	3.9	9.2	16
Sep 15	3.8	3.6	4.7	5.6	3.8	14.5	2.1	3.6	4.2	4.6	5.8	1.50	2.4	4.5	6.7	8.4
Nov 15	2.6	3.4	5.7	7.8	6.5	15.6	3.7	4.9	8.3	12.9	13.4	1.70	1.90	2.1	3.3	10.3
Jan 16	8.7	12.5	18.9	12.8	17.6	20.0	6.3	8.5	10.9	14.5	16.0	2.2	3.2	3.8	4.2	5.2
Mar 16	6.5	11.2	16.7	15.5	12.9	9.8	5.9	6.2	9.7	11.2	15.5	2.6	3.1	4.4	6.1	11.8
May 16	7.8	13.5	12.6	9.8	7.9	6.8	4.1	5.9	7.4	9.2	14.8	2.3	5.7	7.9	9.4	15
Jul 16	2.8	6.7	7.3	2.5	3.4	12.9	2.1	2.9	4.5	6.8	7.8	1.9	2.1	3.4	8.9	17
Sep 16	4.0	4.2	4.8	5.7	4.1	13.9	1.9	3.6	4.9	5.1	6.7	1.7	2.6	6.5	7.2	8.9
Nov 16	3.1	3.5	5.9	8.1	6.8	17.9	3.3	5.1	7.5	10.9	12.9	1.60	1.80	2.3	4.5	8.5
Jan 17	9.8	11.8	15.9	13.8	16.5	18.9	7.7	8.2	9.9	13.8	15.7	2.3	3.5	3.9	4.4	10.5

	Parameter: Turbidity (NTU)															
	TSITSA RIVER						TSITSA TRIBUTARIES (TST)					DRINKING WATER				
	Upstream			Downstream			Upstream		Downstream			Upstream			Downstream	
	TS1	TS2	TS3	TS4	TS5	TS6	TST1	TST2	TST3	TST4	TST5	DW1	DW2	DW3	DW4	DW5
Jul 15	4.5	5.5	4.3	3.5	5.8	3.5	3.5	5.4	3.5	4.7	4.9	2.1	1.8	2.1	1.9	2.0
Sep 15	3.5	4.6	5.3	6.0	4.2	4.3	3.8	4.9	2.8	2.6	2.1	1.30	1.6	1.9	1.8	1.4
Nov 15	3.6	4.6	4.8	5.8	4.8	4.1	3.7	4.7	2.9	5.2	5.0	1.4	2.2	2.1	1.2	1.3
Jan 16	4.3	5.2	5.8	5.6	4.4	3.8	3.5	5.3	3.1	4.6	4.8	1.4	1.6	3.0	1.4	1.5
Mar 16	3.6	4.4	5.5	5.5	4.7	4.2	4.8	5.1	4.7	4.9	5.2	1.3	1.8	2.8	3.0	1.9
May 16	3.8	4.5	4.9	5.2	5.5	3.2	4.3	4.6	4.7	4.7	4.9	1.5	2.9	2.8	1.7	1.5
Jul 16	3.9	5.4	4.1	3.4	5.7	3.3	3.7	3.7	3.9	4.8	5.2	1.3	2.7	1.5	1.8	1.7
Sep 16	4.4	4.7	5.4	5.6	4.2	4.4	3.8	3.6	3.5	3.7	4.0	1.5	2.1	2.5	2.1	2.2
Nov 16	4.7	4.5	4.6	5.9	4.9	4.5	3.6	5.6	2.8	2.8	5.1	1.4	2.2	2.2	1.3	2.9
Jan 17	4.2	5.0	5.6	5.8	4.6	3.9	3.8	6.0	2.9	3.1	5.2	1.3	2.3	2.6	2.4	1.8

	Parameter: Temperature (˚C)															
	TSITSA RIVER						TSITSA TRIBUTARIES (TST)					DRINKING WATER				
	Upstream			Downstream			Upstream		Downstream			Upstream			Downstream	
	TS1	TS2	TS3	TS4	TS5	TS6	TST1	TST2	TST3	TST4	TST5	DW1	DW2	DW3	DW4	DW5
Jul 15	26.2	24.0	32.4	26.9	26.3	30.9	30.9	26.3	22.4	26.6	29.3	22.6	22.5	20.1	21.0	22.0
Sep 15	26.3	27.0	26.5	26.7	27.2	29.2	30.0	27.1	23.0	26.0	28.9	20.7	21.0	22.2	21.9	21.9
Nov 15	24.5	23.8	23.7	23.6	25.0	25.6	25.3	26.7	27.5	24.5	27.8	22.7	22.3	21.8	20.2	20.1
Jan 16	32.2	30.3	29.0	30.2	31.5	32.0	27.8	26.6	25.9	25.4	25.7	22.0	22.2	22.1	20.6	21.7
Mar 16	30.8	30.6	31.8	30.9	29.6	28.6	28.9	27.8	27.6	24.3	25.6	23.0	22.9	20.8	21.8	22.0
May 16	29.0	30.2	32.9	26.5	29.7	28.0	28.6	26.8	24.8	24.4	27.6	21.0	21.9	22.0	21.8	20.0
Jul 16	26.5	24.5	31.9	25.0	26.0	29.9	28.9	26.5	21.9	27.0	28.9	21.9	21.8	20.2	21.0	22.6
Sep 16	27.0	27.3	26.9	26.4	27.9	30.2	29.2	27.1	22.7	25.9	28.6	22.0	22.2	22.3	22.0	20.5
Nov 16	23.9	27.0	24.5	25.0	26.0	25.9	24.9	25.9	27.6	24.0	27.2	21.8	22.1	22.3	22.1	20,8
Jan 17	30.7	31.2	28.9	29.7	31.6	29.4	27.6	26.7	25.0	25.0	25.8	22.0	22.3	21.6	20.8	22.0

	Parameter: Electrical Conductivity (µS/cm)															
	TSITSA RIVER						TSITSA TRIBUTARIES (TST)					DRINKING WATER				
	Upstream				Downstream		Upstream			Downstream		Upstream			Downstream	
	TS1	TS2	TS3	TS4	TS5	TS6	TST1	TST2	TST3	TST4	TST5	DW1	DW2	DW3	DW4	DW5
Jul 15	44	79	90	98	122	129	34	35	47	68	78	14.4	15.6	16.5	16.3	16.7
Sep 15	14.4	38	56.8	98	124	130	35	40	48	56	75	14.6	15.8	22.0	21.9	20.6
Nov 15	30.4	49	75	103	118	127	40	75	83	90	101	14.5	17.9	20.5	19.8	20.7
Jan 16	56	87	119	121	125	130	46	74	88	108	119	15.0	18.9	15.9	17.8	19.0
Mar 16	65	69	122	134	136	139	56	60	76	90	122	14.9	20.7	22.8	26.0	20.5
May 16	30	38	85	98	118	122	60	65	72	88	95	14.5	22.0	24.6	30.8	27.9
Jul 16	48	85	96	114	124	131	36	39	45	64	73	14.6	16.9	17.3	18.3	21.6
Sep 16	15.4	40	58	90	120	134	37	40	50	59	68	14.8	16.7	24.5	22.8	19.5
Nov 16	30	54	65	104	120	129	44	68	75	87	96	14.5	18.4	20.7	19.5	20.2
Jan 17	47	83	115	124	126	132	37	64	75	97	118	14.4	22.0	16.7	17.4	18.9

	Parameter: pH															
	TSITSA RIVER						TSITSA TRIBUTARIES (TST)					DRINKING WATER				
	Upstream			Downstream			Upstream		Downstream			Upstream			Downstream	
	TS1	TS2	TS3	TS4	TS5	TS6	TST1	TST2	TST3	TST4	TST5	DW1	DW2	DW3	DW4	DW5
Jul 15	6.7	6.7	6.6	6.4	7.7	7.8	5.8	6.0	7.2	7.3	7.1	6.1	6.4	6.6	5.9	6.0
Sep 15	6.6	6.7	8.5	6.6	7.2	7.5	5.9	6.1	6.3	6.7	7.6	6.3	6.6	8.1	6.1	7.5
Nov 15	6.7	7.5	8.1	6.8	7.4	7.8	6.7	7.0	7.4	6.9	7.5	6.4	7.7	7.9	7.2	7.9
Jan 16	6.6	7.3	8.0	6.7	7.2	7.6	7.4	7.6	7.6	7.0	7.3	6.8	7.4	8.0	7.4	7.7
Mar 16	6.9	7.1	7.3	6.6	6.9	7.1	6.7	6.9	6.7	7.3	7.4	6.4	7.1	7.6	6.9	7.4
May 16	6.8	7.0	7.1	6.7	6.5	7.8	5.6	5.8	6.6	6.5	6.3	6.1	6.3	6.7	7.0	7.6
Jul 16	6.8	6.8	6.6	6.5	7.6	7.7	5.7	5.9	7.2	7.4	7.0	6.2	6.3	6.8	6.0	6.2
Sep 16	6.7	6.8	8.9	6.9	7.3	7.6	6.0	6.2	6.4	6.6	7.3	6.4	6.7	7.8	6.2	7.5
Nov 16	6.8	7.5	8.2	7.0	7.5	7.9	6.8	7.2	7.3	6.8	7.3	6.5	6.9	7.8	7.3	7.7
Jan 17	6.8	7.4	7.9	6.8	7.3	7.5	7.3	7.7	7.5	6.9	7.2	6.6	6.9	7.3	7.3	8.0

	Parameter: TS (mg/L))															
	TSITSA RIVER						TSITSA TRIBUTARIES (TST)					DRINKING WATER				
	Upstream			Downstream			Upstream		Downstream			Upstream			Downstream	
	TS1	TS2	TS3	TS4	TS5	TS6	TST1	TST2	TST3	TST4	TST5	DW1	DW2	DW3	DW4	DW5
Jul 15	40	65	125	47	97	120	76	84	91	42	65	45	65	71	87	298
Sep 15	45	89	245	78	130	231	47	89	102	67	74	42	56	58	72	302
Nov 15	67	185	312	89	120	161	67	109	567	92	345	43	49	52	69	531
Jan 16	85	468	950	120	340	947	85	126	957	308	879	51	101	256	305	785
Mar 16	36	79	131	145	345	865	90	114	456	405	764	49	64	74	200	683
May 16	84	145	236	41	68	189	67	78	87	398	507	47	62	293	298	502
Jul 16	56	69	115	53	105	131	70	83	105	64	98	42	68	77	93	301
Sep 16	51	96	305	92	135	245	39	81	145	78	201	42	59	66	73	291
Nov 16	72	192	315	91	122	157	60	98	674	231	490	43	52	67	79	502
Jan 17	87	502	789	121	332	753	88	121	846	312	804	49	105	234	296	701

	Parameter: COD (mg/L)															
	TSITSA RIVER						TSITSA TRIBUTARIES (TST)					DRINKING WATER				
	Upstream			Downstream			Upstream		Downstream			Upstream			Downstream	
	TS1	**TS2**	**TS3**	**TS4**	**TS5**	**TS6**	**TST1**	**TST2**	**TST3**	**TST4**	**TST5**	**DW1**	**DW2**	**DW3**	**DW4**	**DW5**
Jul 15	90	134	165	120	137	203	112	119	197	201	256	98	112	135	145	149
Sep 15	134	142	180	123	154	198	118	127	199	222	261	101	115	145	131	128
Nov 15	145	176	290	135	241	280	127	135	206	231	271	99	122	165	179	240
Jan 16	165	201	295	145	253	286	134	167	207	265	279	102	132	176	189	265
Mar 16	155	187	287	129	231	275	131	155	189	241	244	103	116	127	145	178
May 16	137	155	189	127	167	189	122	127	156	178	191	99	112	131	129	146
Jul 16	97	143	172	125	156	209	115	121	187	198	244	99	113	134	147	148
Sep 16	131	155	178	137	161	201	121	131	201	211	243	98	118	143	133	136
Nov 16	154	185	286	137	228	276	129	137	210	254	267	101	128	171	178	234
Jan 17	170	198	291	146	247	284	139	165	202	266	278	102	135	165	201	256

APPENDIX 2 – SOCIOLOGICAL QUESTIONNAIRE

UNIVERSITY OF FORT HARE

SOCIO-ECONOMIC SURVEY – NTABELANGA DAM
(24 NOVEMBER – 8 DECEMBER, 2016)

Dear Sir/Ma'am:

This questionnaire is being administered to collect baseline socio-economic and environmental data from residents of some of the communities that will be directly or indirectly affected by the new (proposed) Ntabelanga Dam, Eastern Cape. We will greatly appreciate your time in responding the questions. Our field researchers will explain each of the questions to you in your own language, if this is different from English. Please note that this is part of a policy-oriented and academic study aimed at monitoring the short-, medium- to long-term impact of the dam and to assist policy makers in planning ways to make the dam project sustainable. The data will be used confidentially, and your participation in this study is entirely voluntary. Please remember to sign a Consent Form that will be issued to you by our field staff.

Thank you very much for your time and responses.

Professor Wilson Akpan &
Dr. Johan van Tol
RESEARCH COORDINATORS

SECTION 1: Demographics

1. Gender:	Male		Female									
2. Marital status:	Single		Married		Divorced		Cohabiting					
3. Please indicate your age range	15-19		20-24		25-29		30-34		35-39		40-44	
	45-49		50-54		55-59		60-64		65+			
4. What type of house do you live in?												
5. How many people live with you in your current residence?	I live alone		1 to 2		3 to 4		5 to 6		6+			
6. If other people live with you, how are they related to you? (Please tick all the applicable)	Spouse/ partner		Children		Parent/other relative		Friend(s)		Other (Please specify)			

7. If you provide partial support for those who live with you, who else contributes	Spouse/ partner	Children	Parent/other relative	Friend(s)	Other (Please specify)
Other (please specify)					
8. Do you have children of school-going age?	Yes	No			
9. If yes, what type of school are they currently attending?	Pre-primary	Primary	Secondary	Tertiary	
10. If they are currently attending school (besides Tertiary), is the school located in this community?	Yes	No			
11. If not attending any school (besides tertiary), why:	No money for fees and other school needs	No money for transport (school located too far)	Other (Please specify)		
12. What is your highest educational level?	Primary school	High school	Diploma	Bachelor's degree	Postgraduate
13. What is your status in relation to the house you currently live in? *(Please tick all the applicable)*	I own the structure/shelter/house/flat	I rent the structure/shelter/house/flat	Other (Please specify)		

SECTION 2: Livelihoods and socio-economic activities

14. What is your monthly income?	Below R500	R500 – R1000	R1001 – 1500	R1501 – R1200	R2001 – R2500	R2501 – R3000	R3001 – R3500	R3501 – R4000	R4001 – R4500
15. Please indicate your current employment status	Employed	Self-employed	Not currently employed						
16. If employed (or self-employed), is your place of work located in this community?	Yes	No							

17. How many members of your household (apart from yourself) have the following employment status(es)	Employed		Self-employed		Not currently employed															
18. If you are employed, in which area is your place of work?																				
19. What is your occupation?																				
20. If you are currently employed, please indicate in which sector	Agriculture		Retail		Education		Manufacturing		Hospitality/ Tourism		Transport		Other (please specify)							
21. If you are currently employed, do you have any additional means of generating income?	Yes		No																	
22. If you are currently unemployed, for how long have you been unemployed?	< 6 months		6 months - 1year		1 year – 18 months		18 months – 2 years		2-3 years		3-4 years		4-5 years		5+ years		Never been employed			
23. If you are currently unemployed, do you actively look for a job?	Yes		No																	
24. If you are currently unemployed, how do you make money to meet your day-to-day needs?	Rely on social grants		Do piece jobs		Depend on relatives		Depend on people's generosity		Other (Please specify)											
25. Do you know of someone who owns a (spaza) shop in this community?	Yes		No																	
26. In your opinion, does it look like that the shop attracts many customers?	Yes		No																	

27. What is the nationality of the spaza shop owner(s)?	South African		Other		Don't Know													
28. Are there sufficient spaza shops in this community?	Yes		No															
29. How many liquor outlets do you know of in this community?	None		1 to 3		4 to 6		7 to 10		>10									
30. What other kinds of small-scale business activities do you know about in this area?																		
31. How many people do you know in this community who own other businesses (apart from spaza shops)?	None		1 to 5		5 to 10		11 to 15		16 to 20		>20							

SECTION 3: Social network and social capital

32. Which of the following organisations exist(s) in this community? *(Please tick all the applicable)*	Burial society		Women's club/association		Neighbourhood club/association		Hometown association		Men's club/association		Youth club/association		Cooperatives		Stokvel		Church/ Church club/ association	
	Other religious organisation/club (Please specify)																	
	Other (Please specify)																	
33. Which of these associations do you belong to:	Burial society		Women's club/association		Neighbourhood club/association		Hometown association		Men's club/association		Youth club/association		Cooperatives		Stokvel		Church/ Church club/association	

	Other religious organisation/club (Please specify)						
	Other (Please specify)						
34. What activities do most <u>youth</u> in the community take part in for recreation or entertainment purposes							
35. Where do most <u>youth</u> in the community go for recreational or entertainment activities?							
36. What activities do most <u>adults</u> in the community take part in for recreational or entertainment purposes?							
37. Where do most <u>adults</u> in the community go for recreational or entertainment activities?							
38. Does this community experience any of the following? *(Please tick all the applicable)*	Alcohol abuse		Drug abuse		Domestic violence		
	Other:						
39. How are issues of crime or disputes resolved in this community?	By reporting to the police		By involving community members (e.g. community peace committee)		Other *(please specify)*		

SECTION 4: Formal and informal safety nets

40. Which of the following social grants do you currently receive?	Child support grant		Old age pension		Disability grant		Foster care grant		Unemployment benefit		Other (Please specify)		Not a recipient of any grant	
41. If a recipient, for how long have you been receiving this grant:	0-1 year		2-5 years		5+ years									
42. How many other members of your household receive social grants	No one else receives social grants in household		Child support grant		Old age pension		Disability grant		Foster care grant		Other grant			
43. Apart from support from kind-hearted community members, are there structures/organisations in the community that help the underprivileged?	Yes		No											
44. If Yes, what is the name of such structure/organisa-tion														

SECTION 5: Social amenities: availability, access & community satisfaction

45. Where do you source drinking water from?	Water tap(s) located inside residence		Water tap(s) located outside residence but within the same yard		Communal water tap(s)		Stand pipe(s)		Rainwater harvesting		From municipal tanker(s)		Other sources (please specify)	
46. How do you describe the quality of drinking water?	Poor quality		Good quality											
47. How do you describe the regularity of water flow	Regular		Not regular		Unreliable									

47. Where do you source water from for general household use?	Water tap(s) located inside residence		Water tap(s) located outside residence but within the same yard		Communal water tap(s)		Stand pipes		Rainwater harvesting		From municipal tanker(s)		Other sources (please specify)	
48. How would you describe the regularity of supply/flow of water for general household use?	Regular		Not regular		Unreliable									
49. What sanitation system does your household have access to?	Indoor flush toilet (linked to Municipal sewer)		Indoor flush toilet (linked to septic tank)		Ventilated pit latrine		Pit latrine		Bucket toilet		No sanitation			
50. Do you use a cellular phone?	Yes		No											
51. Do you have access to a health clinic in this community?	Yes		No											
51. Is there a school in this community?	Yes		No											
52. How do children in this neighbourhood go to school?	By public transport/school bus		On foot (long walk)		On foot (short walk)		Other (please specify)							
53. What is the most important mode of public transport available to people in this neighbourhood?	Buses		Mini bus taxis		Train		Other (Please specify)							
54. How would you describe the public transport service available to you? *(Please tick all the applicable)*	Reliable		Accessible		Affordable		Not affordable		Not reliable		Not accessible			
55. How is the electricity supply in this area?	Reliable		Not reliable											

56. *Please tick:* Which of the following amenities are available in this community	Buses		Mini bus taxis		Electricity supply		Refuse removal		Parks/open spaces		Police station		Post office		ATMs		Library	
	Government information office		Sport field/facilities		Cemeteries		Connectivity to the internet		Community hall		Street lighting		Shops		Clinics			

SECTION 6: Ecological indicators, risk and vulnerability

57. Which of the following disasters has this community ever experienced? (Please tick all the applicable)	Flooding		Mud slides		Fire		Strong winds		Lightning		Heat wave		Drought		Other	
58. What disease outbreak has this community ever experienced, to the best of your knowledge? *(Please tick all the applicable)*	Cholera		Dysentery		Diarrhoea		Scabies		Chicken pox		Malaria		No disease outbreak			
Other (please specify)																
Other (Please specify)																
59. Has the community experienced any of the following fire incidents?	Veld fire		Fires caused by faulty electrical connection		Fires caused by candle, paraffin stove		Uncontrolled cooking fire									
Other, specify																
60. Did people suffer any major losses (e.g. loss of life, loss of houses, farms, livestock) as a result of the fire?	Yes		No													
61. What are the MAJOR crop produced in this area?																
62. What other crops are grown?																

63. To the best of your knowledge, what kinds of crops did people produce in this area 10 – 20 years ago, or further back)?					
6.4 Where do people currently obtain their seed?					
65. Do people use fertilizer?	Yes		No		
66. What is the typical yield for each crop? (in bags)	Crop name:______________________________ Typical yield (in bags?) ______________________________ Crop name: ______________________________ Typical yield (in bags?) ______________________________ Crop name: ______________________________ Typical yield (in bags?) ______________________________ Crop name: ______________________________ Typical yield (in bags?) ______________________________					
67. How do people produce crops in the present? *(Please Tick all the applicable)*	a. Use of contractors? --- b. Only by hand? --- c. Other? (Please specify) ---				
68. Do people have vegetable gardens in this village?	Yes		No		
69. Do they produce vegetables?	Yes		No		
70. If Yes, which vegetables?					
71. How important is livestock in this community?					

72. Which animals (livestock) do people keep in this town?	
73. Where do the animals graze	
74. How big is the grazing area?	
75. To the best of your knowledge, is the grazing area bigger or smaller than it used to be?	a. Bigger than before -- b. Smaller than before -- c. Very much the same as before ------------------------------------ d. Can't say --
76. Are there more or fewer animals than before in this community?	a. More than before -- b. Fewer than before -- c. Very much the same as before ------------------------------------ d. Can't say -- e. Other responses --
77. Are there specific do's and don'ts about how the grazing area in this village is to be used? (e.g.: *specific areas for specific animals, specific areas for specific sections of the community, specific areas for specific seasons, etc.)?*	
78. If irrigation were introduced and new areas developed for crop production, how do you think this will impact on the erosion problem?	

Thank you. We greatly value your time and responses.

APPENDIX 3 - SOCIOLOGICAL SURVEY DATA

The data in this appendix are presented in line with the survey themes outlined in the previous section. The themes are:

- Respondent demographics
- Livelihoods and socio-economic activities
- Social network and social capital
- Formal and informal safety nets
- Social amenities: availability, access and community satisfaction
- Ecological indicators, risk and vulnerability

15 RESPONDENT DEMOGRAPHICS

15.1 Gender

Table 15-1: Gender distribution of participant by Community of residence

Community	All n = 299	Male n = 115	Female n = 184
Ngqongweni	60 (100)	15 (25)	45 (75.0)
Ndzebe	59 (100)	19 (32.2)	40 (67.8)
Mqokolweni	60 (100)	26 (43.3)	34 (56.7)
Ndibanisweni AA	60 (100)	25 (41.7)	35 (58.3)
Lower Sinxaku	60 (100)	30 (50.0)	30 (50.0)

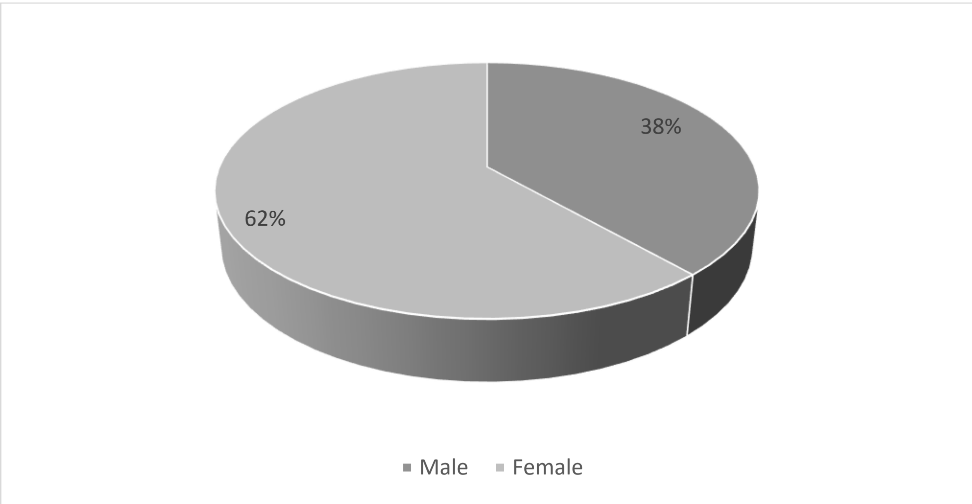

Figure 15-1: Overall gender distribution.

15.2 Marital Status

Table 15-2: Marital status by gender

Marital status	All	Male	Female
Single	113 (41.2)	57 (56.4)	56 (32.4)
Married	143 (52.2)	39 (38.6)	104 (60.1)
Divorced	13 (4.7)	5 (5.0)	8 (4.6)
Cohabiting	5 (1.8)	0 (0.0)	5 (2.9)

15.3 Age of respondents

Table 15-3: Age distribution

Age	All	Male	Female
15-19	12 (4.1)	5 (4.5)	7 (3.9)
20-24	30 (10.3)	15 (13.4)	15 (8.3)
25-29	32 (11.0)	20 (17.9)	12 (6.7)
30-34	34 (11.6)	18 (16.1)	16 (8.9)
35-39	12 (4.1)	7 (6.2)	5 (2.8)
40-44	17 (5.8)	3 (2.7)	14 (7.8)
45-49	20 (6.8)	9 (8.0)	11 (6.1)
50-54	21 (7.2)	6 (5.4)	15 (8.3)
55-59	31 (10.6)	4 (3.6)	27 (15.0)
60-64	35 (12.0)	12 (10.7)	23 (12.8)
≥65	48 (16.4)	13 (11.6)	35 (19.4)

15.4 Housing type

Table 15-4: Type of dwelling

Housing type	Frequency	Percent
Mud	98	35.5
Rondavel	19	6.9
Flat	98	35.5
Gable	7	2.5
Corner house	4	1.4
Rondavel and flat	12	4.3
Corner house and flat	3	1.1
A Room	4	1.4
Brick	27	9.8
RDP	4	1.4

15.5 Number of people in residence

Table 15-5: Number of people in residence

Number of people in residence	Frequency	Percent
Live alone	24	8.1
1-2	54	18.2
3-4	116	39.2
5-6	54	18.2
≥7	48	16.2

15.6 Kinship and sharing of financial burden

Table 15-6: Kinship within a residence

Relationship with other people in same residence	Frequency	Percent
Spouse	125	41.8
Children	207	69.2
Parent/other relative	131	43.8
Friends	41	13.7

Table 15-7: Economic support within a given residence

Who else supports, besides respondent?	Frequency	Percent
Spouse	85	28.4
Children	64	21.4
Parent/other relative	104	34.8
Friends	12	4.0

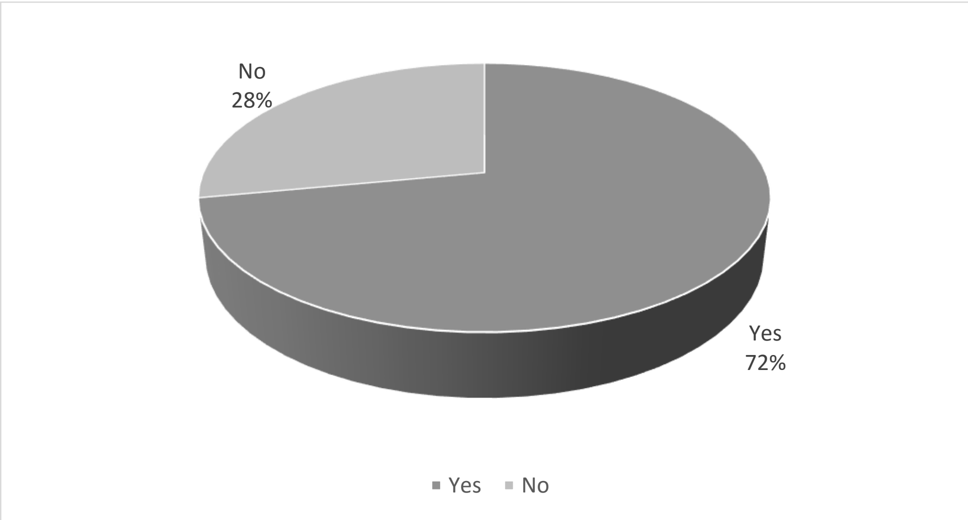

Figure 15-2: Respondents with children of school-going age.

Table 15-8: Levels of schooling – children of school-going age

Level of schooling	Frequency	Percent
Pre-primary	44	14.7
Primary	145	48.5
Secondary	51	17.1
Tertiary	17	5.7

15.7 Location of schools

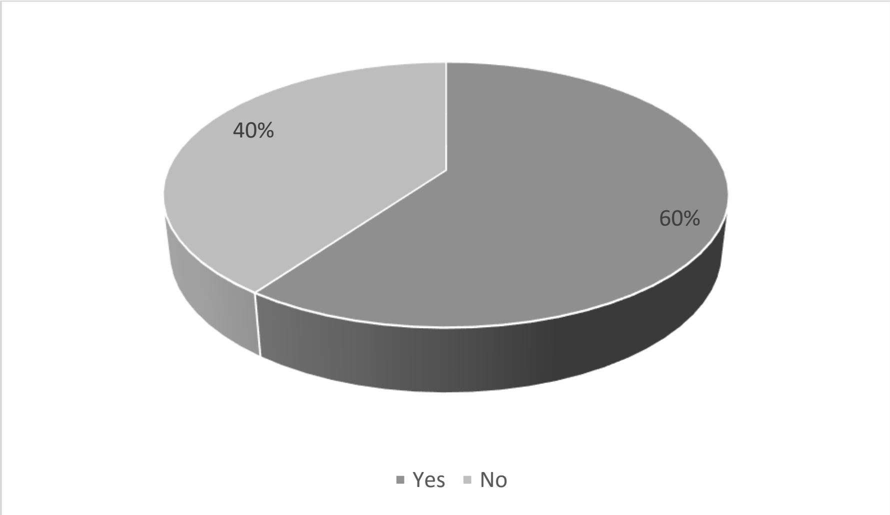

Figure 15-3: Location of schools; are they located in the community?

15.8 Reasons for children not attending school

Table 15-9: Reasons for children not attending school

Reason	Frequency	Percent
No money for fees and other needs	45	55.6
No money for transport/school too far	24	29.6
Children are under-age	4	4.9
Dropped out	2	2.5
No child	4	4.9
Children are over-age	2	2.5

15.9 Respondents' levels of education

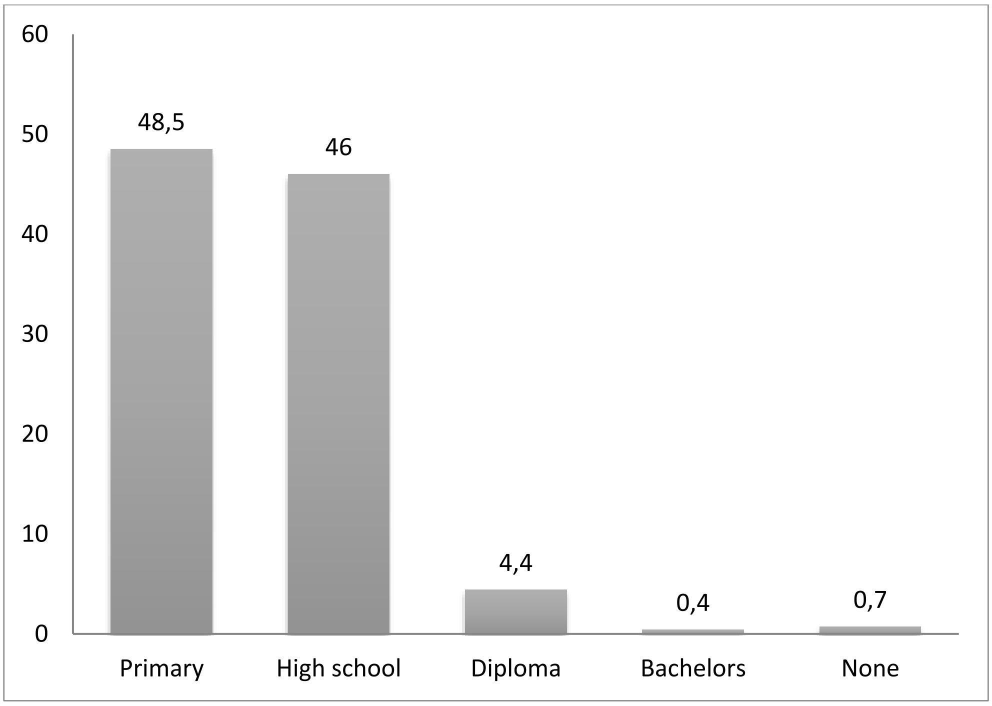

Figure 15-4: Highest educational levels

Table 15-10: Respondents' educational attainment (by community and gender)

	Primary	High school	Diploma	Bachelor's	None
Community					
Ngqongweni	42 (72.4)	14 (24.1)	0 (0.0)	0 (0.0)	2 (3.4)
Ndzebe	23 (46.9)	26 (53.1)	0 (0.0)	0 (0.0)	0 (0.0)
Ngqongweni	34 (56.7)	26 (43.3)	0 (0.0)	0 (0.0)	0 (0.0)
Ndibanisweni AA	3 (6.1)	35 (71.4)	10 (20.4)	1 (2.0)	0 (0.0)
Lower Sinxaku	30 (53.6)	24 (42.9)	2 (3.6)	0 (0.0)	0 (0.0)
Gender					
Male	41 (38.3)	59 (55.1)	6 (5.6)	1 (0.9)	0 (0)
Female	91 (55.2)	66 (40.0)	6 (3.6)	0 (0.0)	2 (1.2)

15.10 House ownership

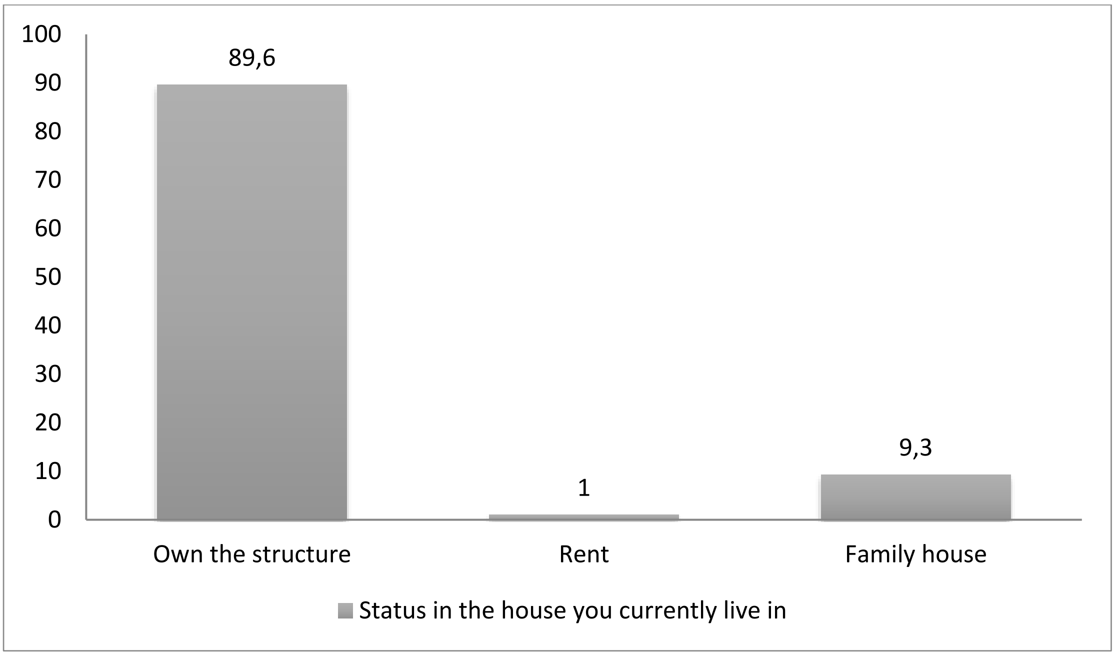

Figure 15-5: House ownership status.

16 LIVELIHOODS AND SOCIO-ECONOMIC ACTIVITIES

16.1 Employment status

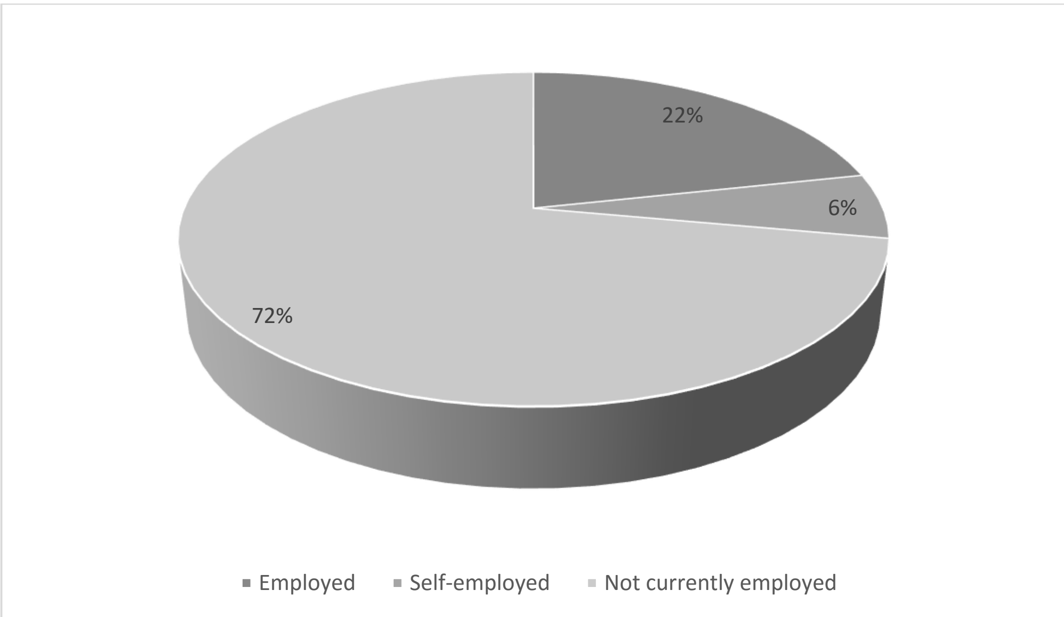

Figure 16-1: Respondents' employment status

Table 16-1: Employment status by community

Community	Employed	Self employed	Unemployed
Ngqongweni	6 (10.2)	1 (1.7)	52 (88.1)
Ndzebe	2 (3.5)	1 (1.8)	54 (94.7)
Ngqongweni	20 (33.9)	4 (6.8)	35 (59.3)
Ndibanisweni AA	8 (15.1)	10 (18.9)	35 (66.0)
Lower Sinxaku	26 (44.1)	2 (3.4)	31 (52.5)

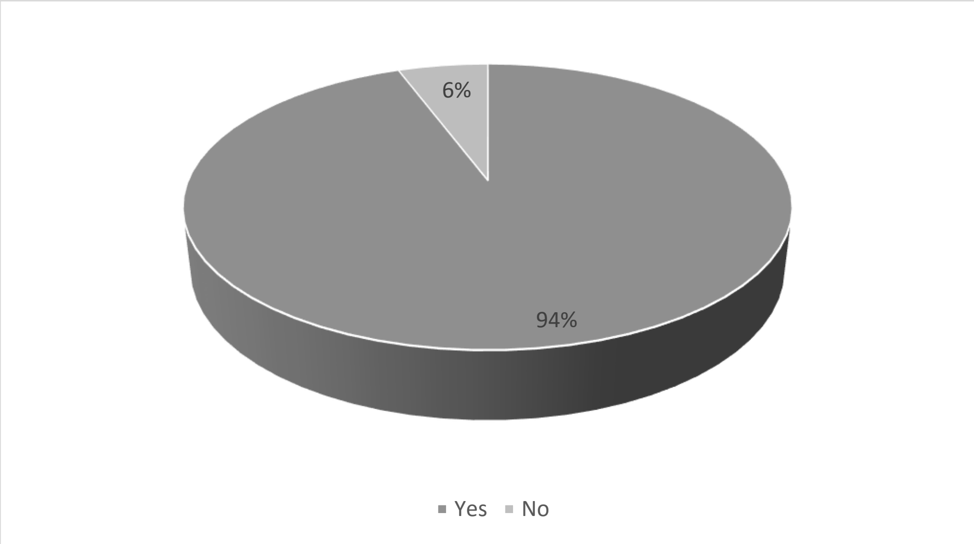

Figure 16-2: Location of place of employment; within the community or not?

Table 16-2: Employment status of family members

Questions	Frequency	Percent
Is any member of your family employed?	64	21.4
How many of them?		
One	55	18.4
Two	9	3.0
Is any member of your family self-employed?	12	4.0

16.2 Respondents' occupations

Table 16-3: Respondents' occupation

Employment	Frequency	Percent
Mining	2	2.7
Manufacturing	2	2.7
Agriculture	3	4.1
Educator	8	11.0
Clerk	2	2.7
Cleaning	8	11.0
Cook	1	1.4
Road construction	4	5.5
Gardening	7	9.6

Environmental (*Working for Water*)	3	4.1
Driving	2	2.7
Shepherd	1	1.4
Community Work Programme (CWP)	3	4.1
Expanded Public Works Programme (EPWP)	6	8.2
Security	4	5.5
Sewing	2	2.7
Selling	2	2.7
Nursing	1	1.4
Chief	1	1.4
Traffic officer	1	1.4
Casual workers	7	9.6
Plumbing	1	1.4
Supervision	2	2.7

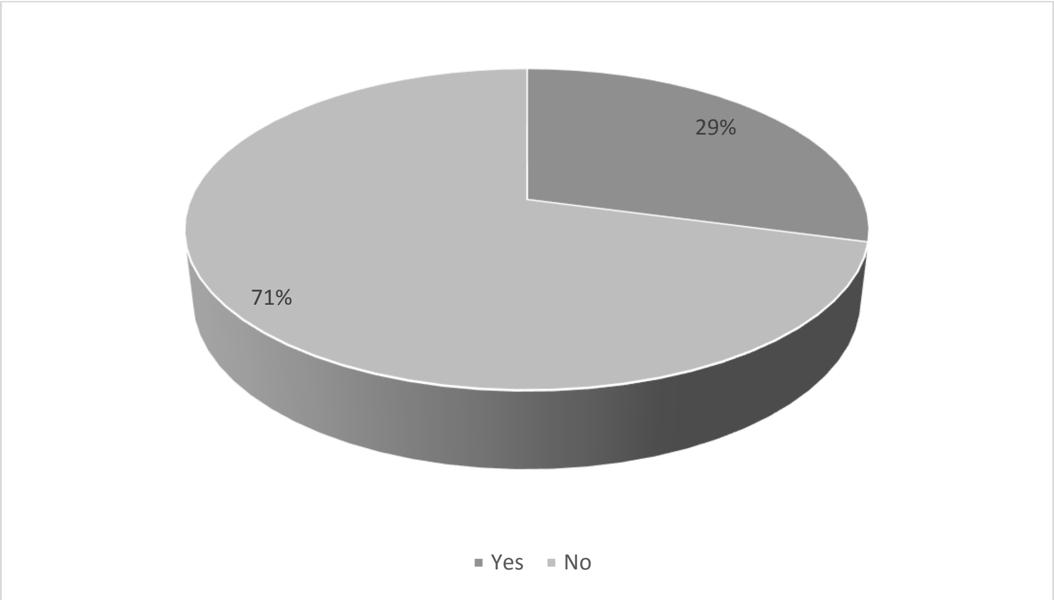

Figure 16-3: Do respondents have additional means of generating an income?

16.3 Employment/Unemployment experience

Table 16-4: Length of time as unemployed

Length of time as an unemployed person	Frequency	Percent
< 6 months	14	6.1
6 months to 12 months	22	9.6
One year to 18 months	12	5.3
18 months to 2 years	8	3.5
2 years to 3years	17	7.5
3 years to 4 years	8	3.5
4 years to five years	5	2.2
Above 5 years	37	16.2
Never been employed	105	46.1

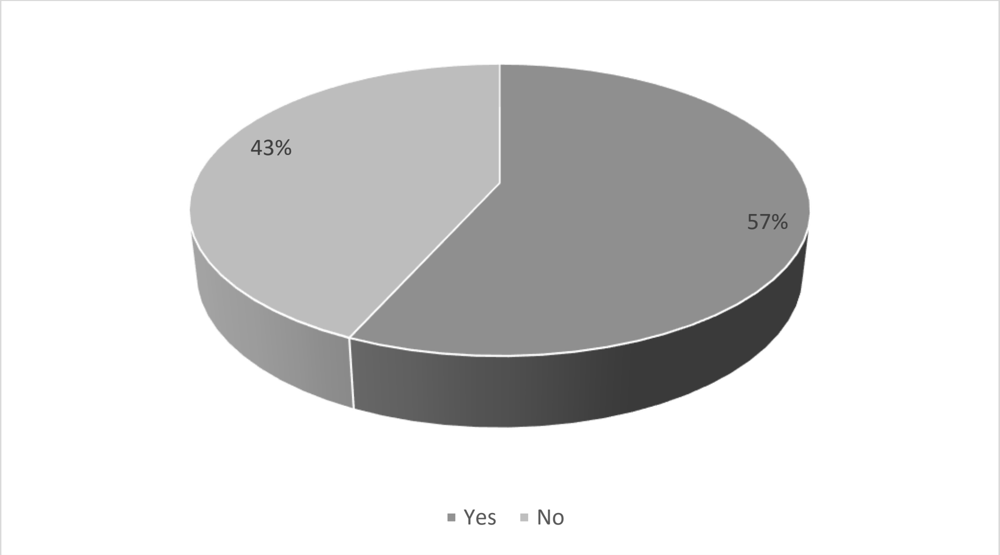

Figure 16-4: Job search; respondents who are currently looking for employment.

Table 16-5: Job search (by gender)

Currently looking for job	Male	Female
Yes	55 (67.1)	72 (50.7)
No	27 (32.9)	70 (49.3)

Table 16-6: Coping with unemployment

Means of meeting day-to-day needs	Frequency	Percent
Rely on social grants	143	47.8
Do piece job	65	21.7
Depend on relatives	32	10.7

16.4 Entrepreneurship

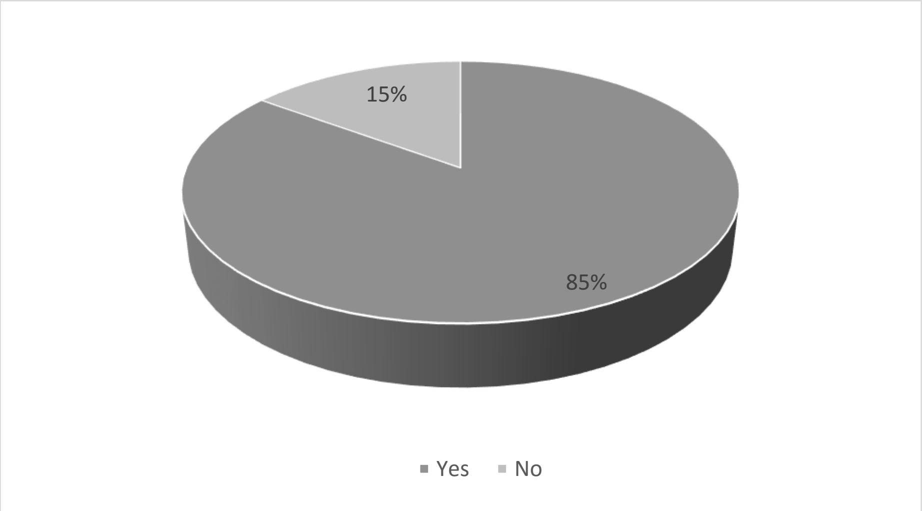

Figure 16-5: Awareness of availability of small, medium and micro business (know someone with spaza shop?)

Table 16-7: Awareness of existence of small (community-by-community breakdown)

Know anyone in this community who owns a *spaza* shop?	**Yes**	**No**
Ngqongweni	51 (85.0)	9 (15.0)
Ndzebe	57 (96.6)	2 (3.4)
Ngqongweni	59 (100.0)	0 (0.0)
Ndibanisweni AA	31 (53.4)	27 (46.6)
Lower Sinxaku	53 (89.8)	6 (10.2)

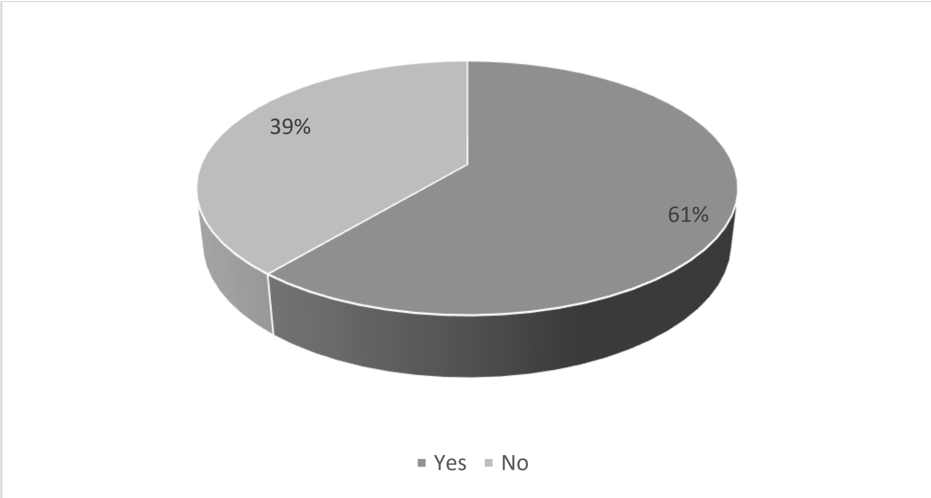

Figure 16-6: Awareness of health of small business (Does the spaza shop attract many customers?).

Table 16-8: Awareness of health of small business (community-by-community breakdown)

Does the *spaza* shop in your community attract many customers?	**Yes**	**No**
Ngqongweni	29 (51.8)	27 (48.2)
Ndzebe	21 (39.6)	32 (60.4)
Ngqongweni	41 (68.3)	19 (31.7)
Ndibanisweni AA	36 (63.2)	21 (36.8)
Lower Sinxaku	46 (80.7)	11 (19.3)

Table 16-9: Nationality of small business owner

Nationality of the *spaza* shop owner	**South Africa**	**Others**	**Don't know**	**p-value**
All	222 (79.0)	15 (5.3)	44 (15.7)	0.000
Ngqongweni	52 (94.5)	0 (0.0)	3 (5.5)	
Ndzebe	55 (98.2)	0 (0.0)	1 (1.8)	
Ngqongweni	60 (100.0)	0 (0.0)	0 (0.0)	
Ndibanisweni AA	15 (25.9)	10 (17.2)	33 (56.9)	
Lower Sinxaku	40 (76.9)	5 (9.6)	7 (13.5)	

Table 16-10: Perceptions of entrepreneurial self-sufficiency

Are there as many *spaza* shops as you would like to see in this community?	**Yes**	**No**
All	127 (46.2)	148 (53.8)
Ngqongweni	30 (51.7)	28 (48.3)
Ndzebe	5 (9.8)	46 (90.2)
Ngqongweni	14 (23.7)	45 (76.3)
Ndibanisweni AA	38 (65.5)	20 (34.5)
Lower Sinxaku	40 (81.6)	9 (18.4)

Table 16-11: Number of liquor stores

How many liquor stores do you know of in this community?	**None**	**1-3**	**4-6**
All	75 (26.3)	205 (71.9)	5 (1.8)
Ngqongweni	19 (32.8)	38 (65.5)	1 (1.7)
Ndzebe	21 (36.2)	34 (58.6)	3 (5.2)
Ngqongweni	6 (10.0)	54 (90.0)	0 (0.0)
Ndibanisweni AA	8 (13.6)	51 (86.4)	0 (0.0)
Lower Sinxaku	21 (42.0)	28 (56.0)	1 (2.0)

Table 16-12: Other business

Other business in the community	**Frequency**	**Percent**
Sewing	1	0.3
Selling vegetable	17	5.7
Selling cloths	14	4.7
Selling liquor	5	1.7
Operating a tavern	11	3.7
Operating a shebeen	20	6.7
Poultry	13	4.3
Maize selling	1	0.3
Bead making and knitting	1	0.3
CWP	4	1.3

Table 16-13: Number of entrepreneurs

Number of people who own other businesses	**Frequency**	**Percent**
None	187	64.0
1 to 5	102	34.9
5 to 10	3	1.0

17 SOCIAL NETWORKS AND SOCIAL CAPITAL

17.1 Grassroots associations and membership

Table 17-1: Available grassroots associations

Available organisation	Frequency	Percent
Burial society	228	76.3
Women's club/association	87	29.1
Neighbourhood club/association	81	27.1
Hometown Association	61	20.4
Men's club/association	31	10.4
Youth club/association	101	33.8
Cooperatives	40	13.4
Stokvel	134	44.8
Church/church club/association	69	23.1

Table 17-2: Available grassroots associations (by community)

Available organisation	Ngqongweni	Ndzebe	Ngqongweni	Ndibanisweni AA	Lower Sinxaku
Burial society	1 (1.7)	58 (98.3)	60 (100.0)	53 (88.3)	56 (93.3)
Women's club/association	19 (31.7)	23 (39.0)	1 (1.7)	3 (5.0)	41 (68.3)
Neighbourhood club/association	25 (41.7)	10 (16.9)	0 (0.0)	6 (10.0)	40 (66.7)
Hometown Association	21 (35.6)	0 (0.0)	0 (0.0)	0 (0.0)	40 (66.7)
Men's club/association	6 (10.0)	1 (1.7)	1 (1.7)	2 (3.3)	21 (35.0)
Youth club/association	35 (58.3)	1 (1.7)	19 (31.7)	5 (8.3)	41 (68.3)
Cooperatives	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	40 (66.7)
Stokvel	17 (28.3)	15 (25.4)	49 (81.7)	4 (6.7)	49 (81.7)
Church/church club/association	8 (13.3)	3 (5.1)	9 (15.0)	9 (15.0)	40 (66.7)

Table 17-3: Membership of grassroots associations

Type of organization	Frequency	Percent
Burial society	204	68.2
Women's club/association	34	11.4
Neighbourhood club/association	24	8.0
Hometown Association	16	5.4
Men's club/association	5	1.7
Youth club/association	16	5.4
Cooperatives	1	0.3
Stokvel	37	12.3
Church/church club/association	27	9.0

Table 17-4: Membership of grassroots associations (by community)

Type of organisation	Ngqongweni	Ndzebe	Ngqongweni	Ndibanisweni AA	Lower Sinxaku
Burial society	0 (0.0)	54 (91.5)	56 (93.3)	43 (71.7)	51 (85.0)
Women's club/association	11 (18.3)	13 (22.0)	1 (1.7)	5 (8.3)	4 (6.7)
Neighbourhood club/association	19 (31.7)	3 (5.1)	0 (0.0)	2 (3.3)	0 (0.0)
Hometown Association	16 (26.7)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)
Men's club/association	2 (3.3)	0 (0.0)	0 (0.0)	2 (3.3)	1 (1.7)
Youth club/association	8 (13.3)	0 (0.0)	4 (6.7)	3 (5.0)	1 (1.7)
Cooperatives	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	1 (1.7)
Stokvel	7 (11.7)	4 (6.8)	13 (21.7)	0 (0.0)	13 (21.7)
Church/church club/association	6 (10.0)	1 (1.7)	2 (3.3)	5 (8.3)	13 (21.7)

17.2 Youth activities and recreation

Table 17-5: Most common youth activities

Youth activities	Frequency	Percent
Sport	240	80 .3
Drinking alcohol	10	3.3
Playing cards	2	0.7
Music	4	1.3
Making community clean	1	0.3
Traditional dance	21	7.0
Cultivating crops	2	0.7

Table 17-6: Most common youth activities (by community)

Youth activities	Ngqongweni	Ndzebe	Ngqongweni	Ndibanisweni AA	Lower Sinxaku
Sport	60 (100.0)	53 (89.8)	47 (78.3)	45 (75.0)	35 (58.3)
Drinking alcohol	1 (1.7)	5 (8.5)	0 (0.0)	4 (6.7)	0 (0.0)
Playing cards	0 (0.0)	0 (0.0)	2 (2.3)	0 (0.0)	0 (0.0)
Music	0 (0.0)	0 (0.0)	0 (0.0)	4 (6.7)	0 (0.0)
Making community clean	0 (0.0)	0 (0.0)	0 (0.0)	1 (1.7)	0 (0.0)
Traditional dance	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	21 (35.0)
Cultivating crops	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	2 (3.3)

Table 17-7: Recreational and entertainment spaces for young people

Recreational spaces	Frequency	Percent
Sport field	189	63.2
Spaza shop	7	2.3
Tavern	5	1.7
Other communities	45	15.0
Own community	26	8.7
Community hall	4	1.3
Go the farm or school garden	1	0.3

Table 17-8: Recreational and entertainment spaces for young people (by community)

Recreational spaces	Ngqongweni	Ndzebe	Ngqongweni	Ndibanisweni AA	Lower Sinxaku
Sport field	60 (100.0)	37 (62.7)	21 (35.0)	38 (63.3)	33 (55.0)
Spaza shop	3 (5.0)	3 (5.1)	0 (0.0)	1 (1.7)	0 (0.0)
Tavern	0 (0.0)	2 (3.4)	0 (0.0)	3 (5.0)	0 (0.0)
Other communities	0 (0.0)	15 (25.4)	30 (50.0)	0 (0.0)	0 (0.0)
Own community	0 (0.0)	0 (0.0)	4 (6.7)	3 (5.0)	19 (31.7)
Community hall	0 (0.0)	0 (0.0)	0 (0.0)	2 (3.3)	4 (1.3)
Farm or school garden	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	1 (1.7)

17.3 Recreational spaces and activities for older people

Table 17-9: Recreational activities for older persons

Activities	Frequency	Percent
Going out with friends	4	1.3
Watching soccer	5	1.7
Going to *spaza* shop	2	0.7
Taking care of their farm	31	10.4
Going out to drink (alcohol)	20	6.7
Doing home chores	5	1.7
Playing netball	12	4.0
Going to church	6	2.0
Collect wood	5	1.7
Going to the gym	3	1.0
Traditional dance	2	0.7
Voting/holding meetings	3	1.0
Knitting	1	0.3
Music	2	0.7
Playing soccer	7	2.3

Table 17-10: Recreational activities for older persons (by community)

Activities	Ngqongweni	Ndzebe	Ngqongweni	Ndibanisweni AA	Lower Sinxaku
Going out with friends	1 (1.7)	0 (0.0)	1 (1.7)	1 (1.7)	1 (1.7)
Watching soccer	1 (1.7)	1 (1.7)	0 (0.0)	2 (3.3)	1 (1.7)
Going to *spaza* shop	1 (1.7)	0 (0.0)	0 (0.0)	0 (0.0)	1 (1.7)
Taking care of the farm	1 (1.7)	2 (3.4)	0 (0.0)	8 (13.3)	20 (33.3)
Going out to drink (alcohol)	0 (0.0)	7 (11.9)	0 (0.0)	13 (21.7)	0 (0.0)
Doing home chores	0 (0.0)	5 (8.5)	0 (0.0)	0 (0.0)	0 (0.0)
Playing netball	0 (0.0)	1 (1.7)	0 (0.0)	0 (0.0)	11 (18.3)
Going to church	0 (0.0)	1 (1.7)	0 (0.0)	5 (8.3)	0 (0.0)
Collect wood	0 (0.0)	0 (0.0)	5 (8.3)	0 (0.0)	0 (0.0)
Going to the gym	0 (0.0)	0 (0.0)	2 (3.3)	0 (0.0)	1 (1.7)
Traditional dance	0 (0.0)	0 (0.0)	0 (0.0)	2 (3.3)	0 (0.0)
Voting/holding meetings	0 (0.0)	0 (0.0)	0 (0.0)	2 (3.3)	1 (1.7)
Knitting	0 (0.0)	0 (0.0)	0 (0.0)	1 (1.7)	0 (0.0)
Music	0 (0.0)	0 (0.0)	0 (0.0)	2 (3.3)	0 (0.0)
Playing soccer	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	7 (11.7)

Table 17-11: Recreational and entertainment spaces for older persons

Recreational spaces	Frequency	Percent
Spaza shop	2	0.7
Farm/ school garden	25	8.4
Ceremonies	7	2.3
Tavern	18	6.0
Sport field	22	7.4
Home	7	2.3
Church	16	5.4
Stay in this community	11	3.7
Community hall	8	2.7

Table 17-12: Recreational and entertainment spaces for older persons (by community)

Recreational spaces	Ngqongweni	Ndzebe	Ngqongweni	Ndibanisweni AA	Lower Sinxaku
Spaza shop	2 (3.3)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)
Farm/ school garden	1 (1.7)	0 (0.0)	0 (0.0)	3 (5.0)	21 (35.0)
Ceremonies	0 (0.0)	5 (8.5)	0 (0.0)	0 (0.0)	2 (3.3)
Tavern	0 (0.0)	4 (6.8)	0 (0.0)	14 (23.3)	0 (0.0)
Sport field	0 (0.0)	2 (3.4)	0 (0.0)	2 (3.4)	18 (30.0)
Home	0 (0.0)	7 (11.9)	0 (0.0)	0 (0.0)	0 (0.0)
Church	0 (0.0)	1 (1.7)	0 (0.0)	14 (23.3)	1 (1.7)
Stay in the community	0 (0.0)	0 (0.0)	8 (13.3)	2 (3.3)	1 (1.7)
Community hall	0 (0.0)	0 (0.0)	0 (0.0)	7 (11.7)	1 (1.7)

17.4 Social problems

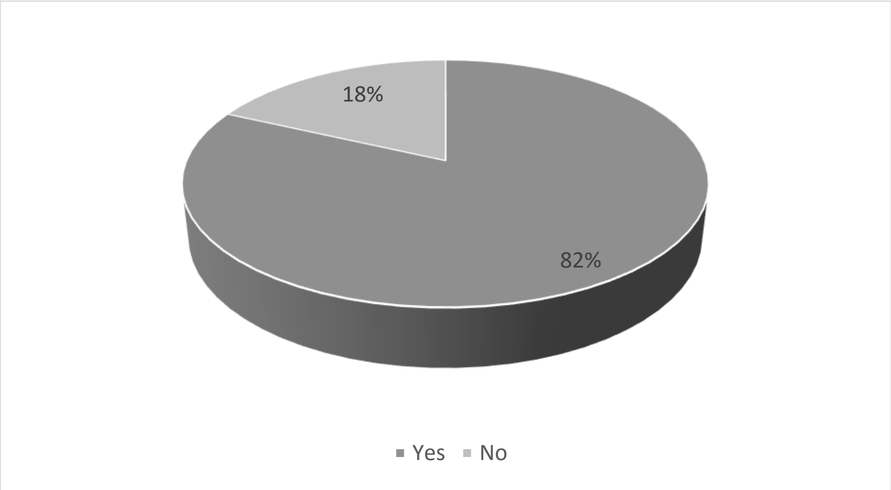

Figure 17-1: Respondent's awareness of the existence of alcohol abuse; is there alcohol abuse in this community?

Table 17-13: Respondent's awareness of the existence of alcohol abuse (by community)

Community	Yes	No
Ngqongweni	38 (63.3)	22 (36.7)
Ndzebe	54 (91.5)	5 (8.5)
Ngqongweni	39 (65.0)	21 (35.0)
Ndibanisweni AA	54 (91.5)	6 (10)
Lower Sinxaku	60 (100.0)	0 (0.0)

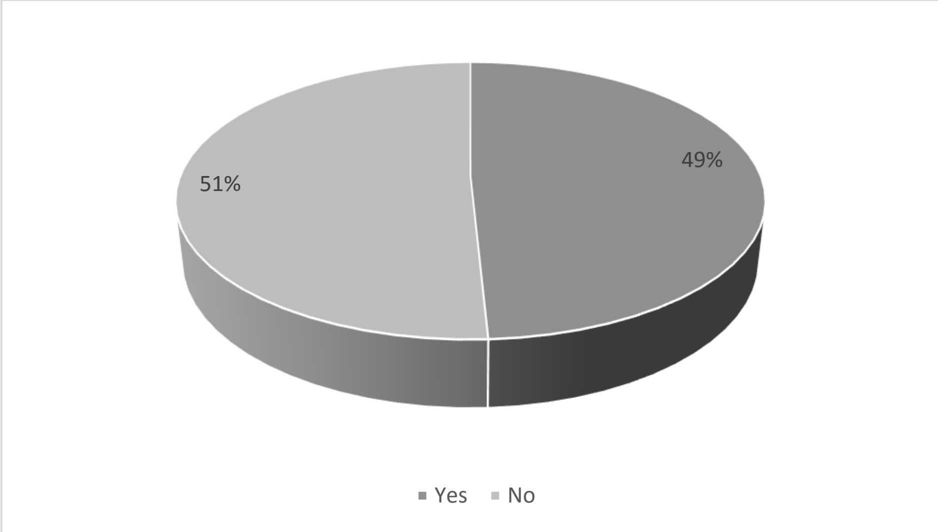

Figure 17-2: Respondents' awareness of the existence of drug abuse; is there a problem of drug abuse in this community?

Table 17-14: Respondents' awareness of the existence of drug abuse (by community)

Community	Yes	No
Ngqongweni	37 (61.7)	23 (38.3)
Ndzebe	30 (50.8)	29 (49.2)
Ngqongweni	7 (11.7)	53 (88.3)
Ndibanisweni AA	32 (53.3)	28 (46.7)
Lower Sinxaku	41 (68.3)	19 (31.7)

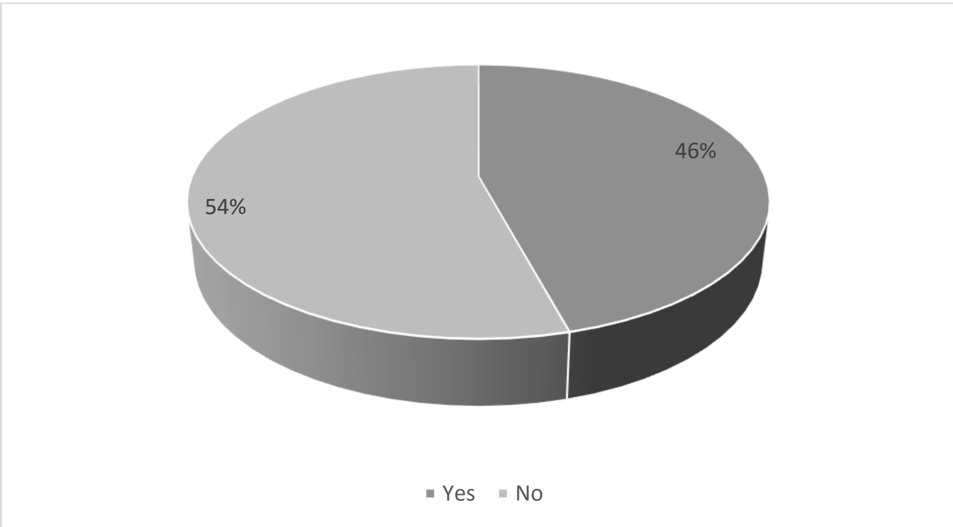

Figure 17-3: Community awareness of the existence of domestic violence; is there domestic violence in this community?

Table 17-15: Community awareness of the existence of domestic violence

Community	Yes	No
Ngqongweni	30 (50.0)	30 (50.0)
Ndzebe	43 (72.9)	16 (27.1)
Ngqongweni	22 (36.7)	38 (63.3)
Ndibanisweni AA	5 (8.3)	55 (91.7)
Lower Sinxaku	37 (61.7)	23 (38.3)

17.5 Combating crime

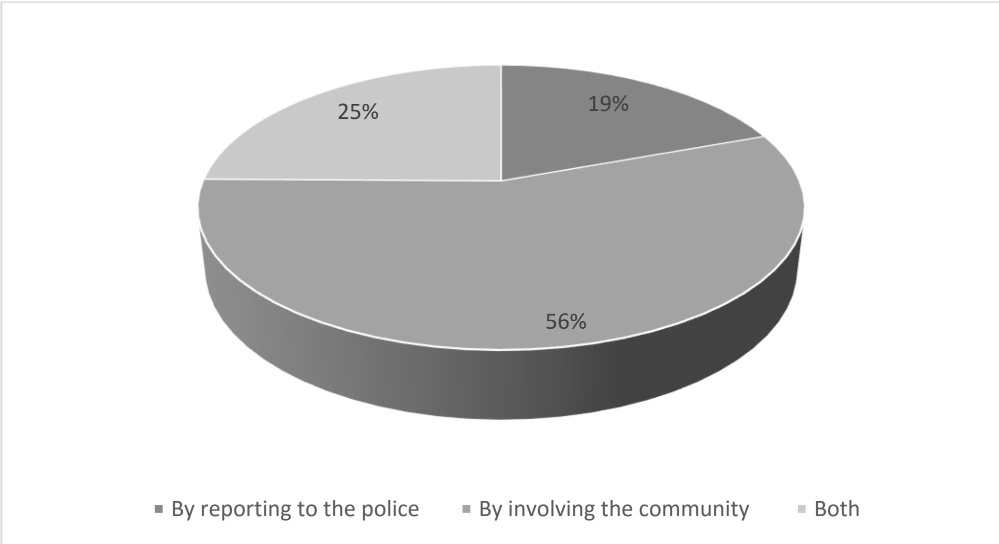

Figure 17-4: Ways of dealing with crime and disputes

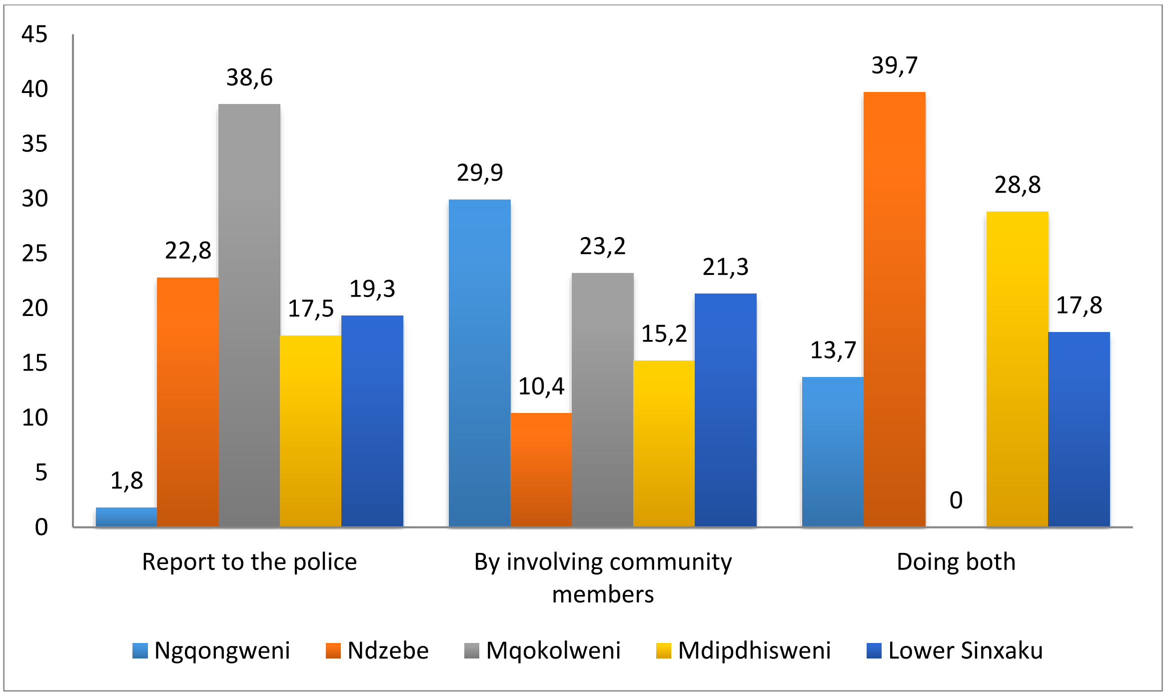

Figure 17-5: Ways of dealing with crime and disputes

18 FORMAL AND INFORMAL SAFETY NETS

18.1 Formal welfare grants

Table 18-1: Types of social grants received

Type of grant	Frequency	Percent
Child support grant	115	38.5
Old age pension	74	24.7
Disability grant	17	5.7
Foster care grant	13	4.3
Unemployment benefit	1	0.3
No grant	105	35.1

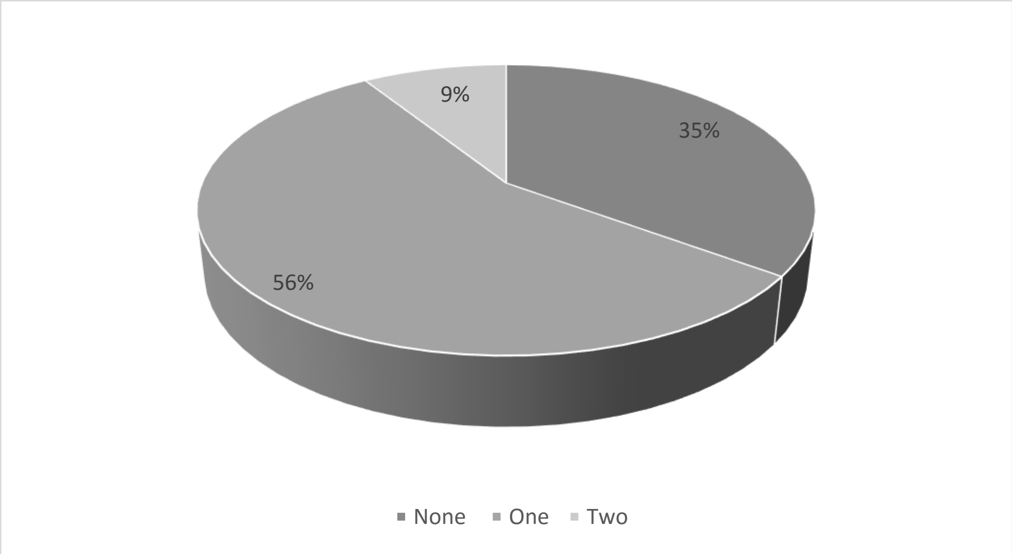

Figure 18-1: Number of grants received

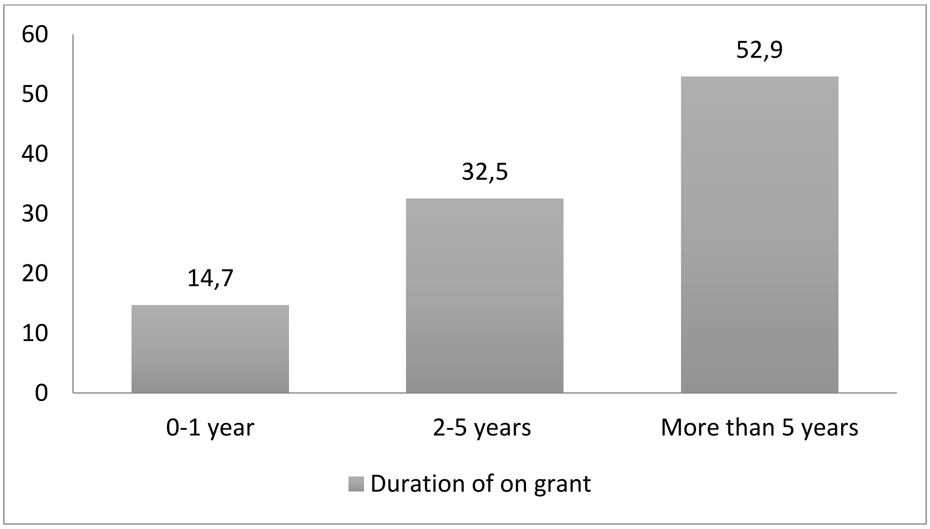

Figure 18-2: Length of time as a grant recipient

Table 18-2: Other household members on social grant

Number of other household members and grant type	Frequency	Percent
No one else	79	26.4
Child support:		
1	26	8.7
2	25	8.4
3	12	4.0
4	2	0.7
6	2	0.7
Old age pension:		
1	24	8.0
3	1	0.3
Disability grant	3	1.0
Foster care:		
1	5	1.7
2	1	0.3

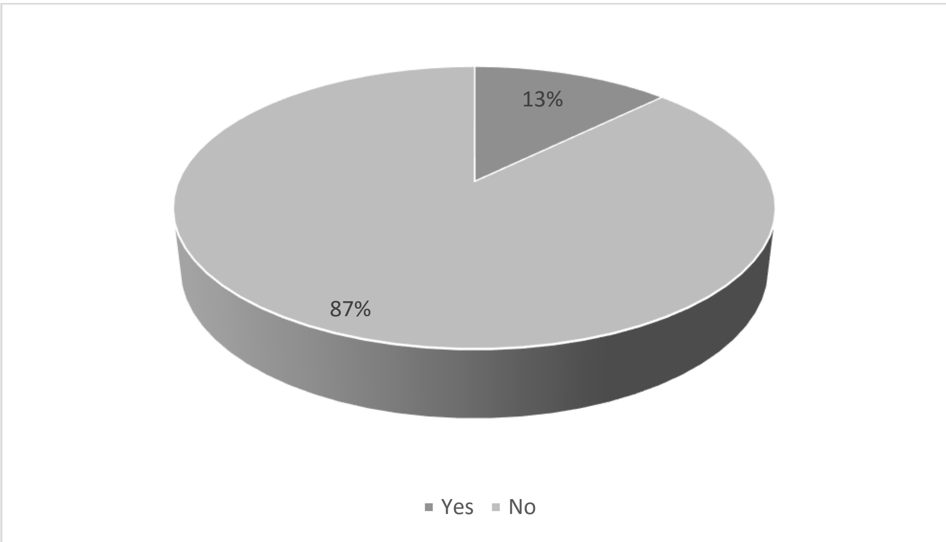

Figure 18-3: Respondents' awareness of community organisations supporting the underprivileged

19 SOCIAL AMENITIES: AVAILABILITY, ACCESS AND COMMUNITY SATISFACTION

19.1 Drinking water

Table 19-1: Sources of drinking water

Water source	Percent	Frequency
Water tap located inside residence	32	11.0
Water tap located outside residence within the same yard	4	1.4
Communal water tap	126	43.3
Stand pipe	1	0.3
Rain water harvesting	76	26.1
Rain and municipal water	13	4.5
River	17	5.8
Own tank	1	0.3
Stand pipe and rain	1	0.3
Communal and rain	3	1.0
Communal and stand pipe	1	0.3
Water in the residence and rain harvesting	1	0.3
Wetlands	13	4.5
Communal and wetland	2	0.7

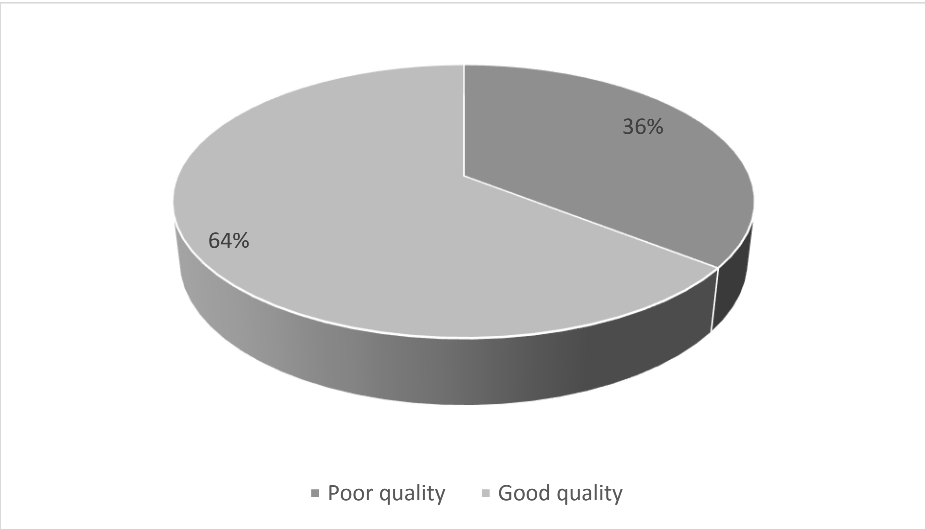

Figure 19-1: Perceptions of drinking water quality

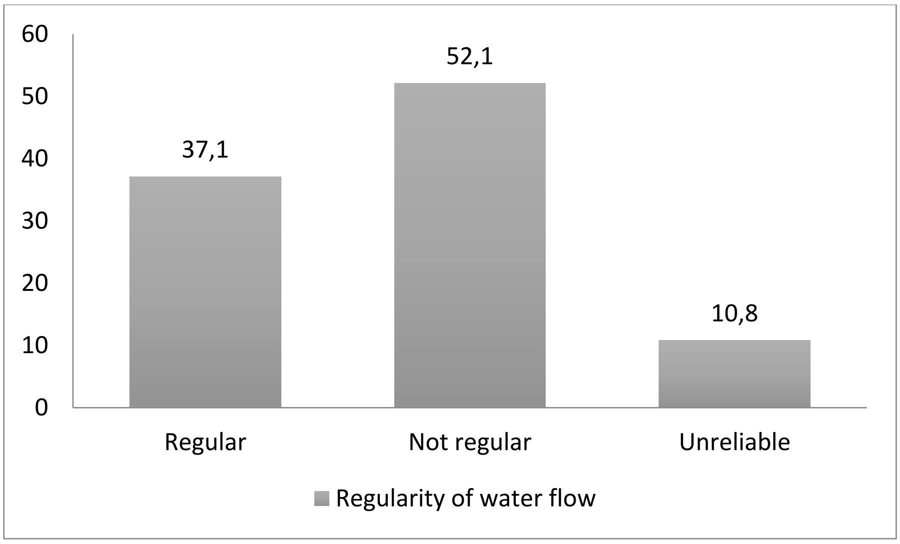

Figure 19-2: Regularity of water flow for drinking water.

19.2 Water for general household use

Table 19-2: Sources of water for general household use

Water source	Percent	Frequency
Water tap located inside residence	27	9.4
Water tap located outside residence within the same yard	2	0.7
Communal water tap	133	46.5
Stand pipe	2	0.7
Rain water harvesting	72	25.2
Rain and municipal water	13	4.5
River	19	6.6
Communal and rain	2	0.7
Wetlands	13	4.5
Communal and wetland	3	1.0

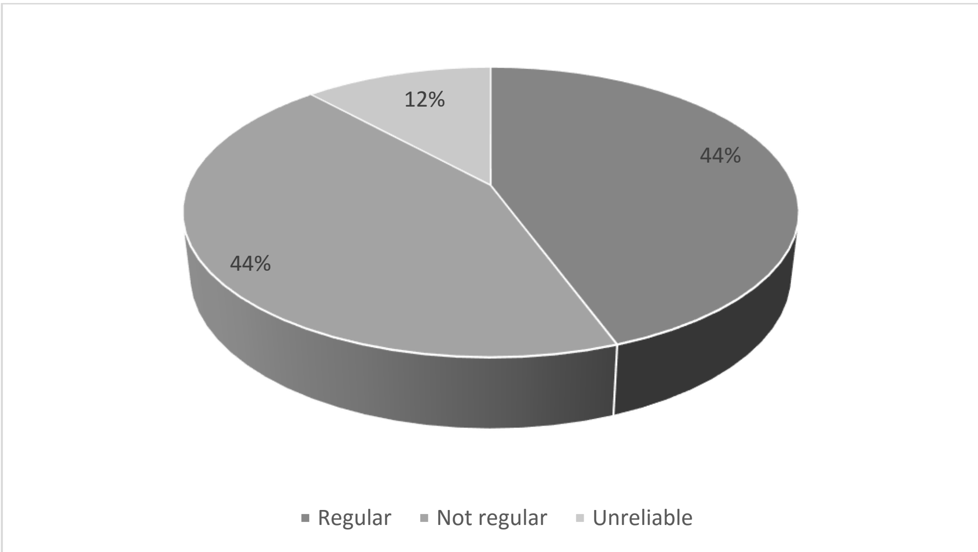

Figure 19-3: Regularity of water supply/flow for general household use

19.3 Sanitation

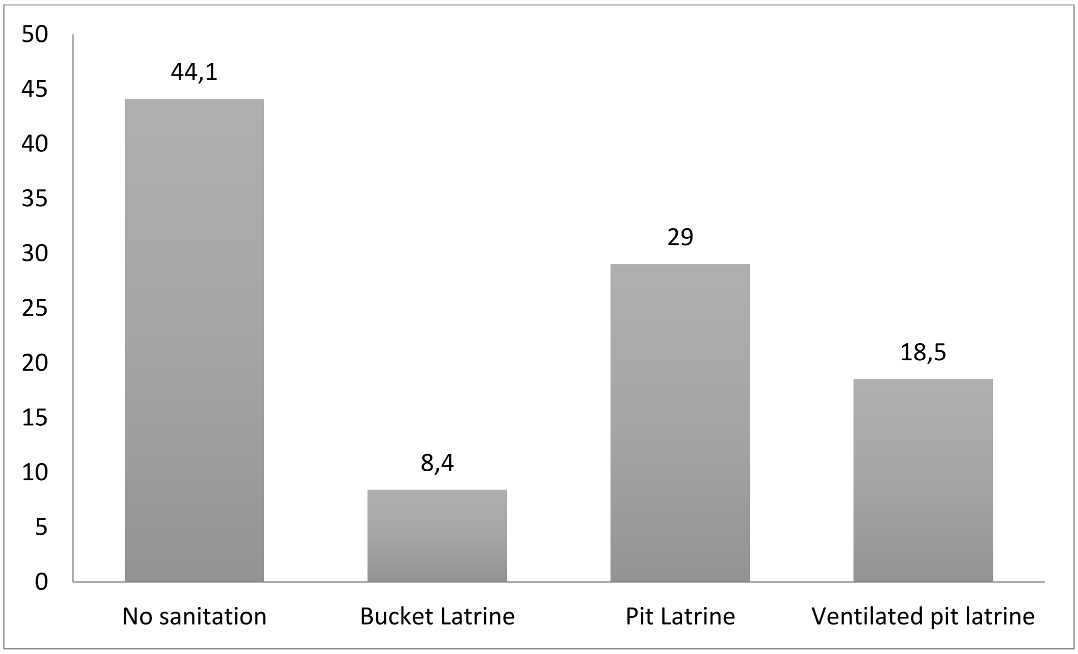

Figure 19-4: Type of sanitation in household.

19.4 Cellular phone

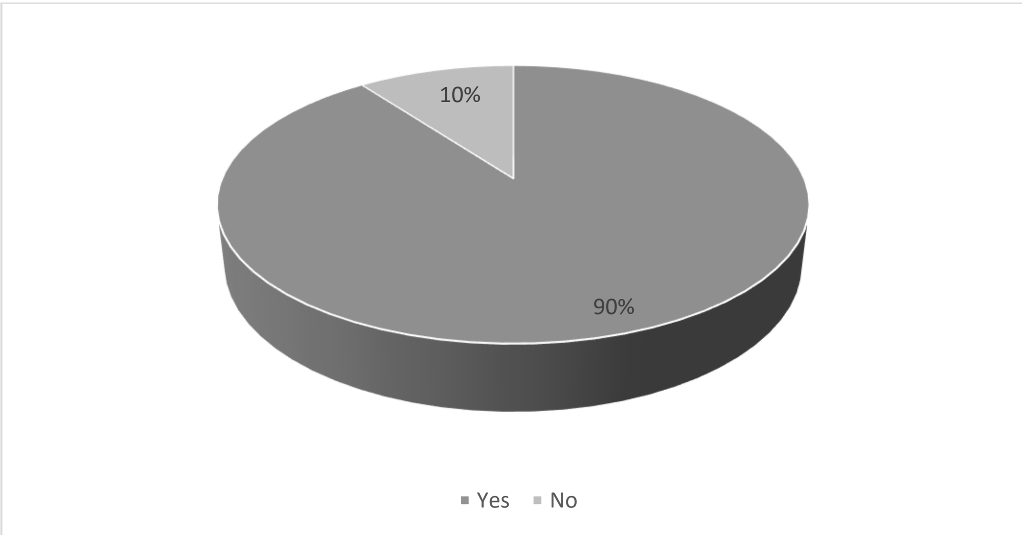

Figure 19-5: Do respondents use a cellular phone?

19.5 Healthcare

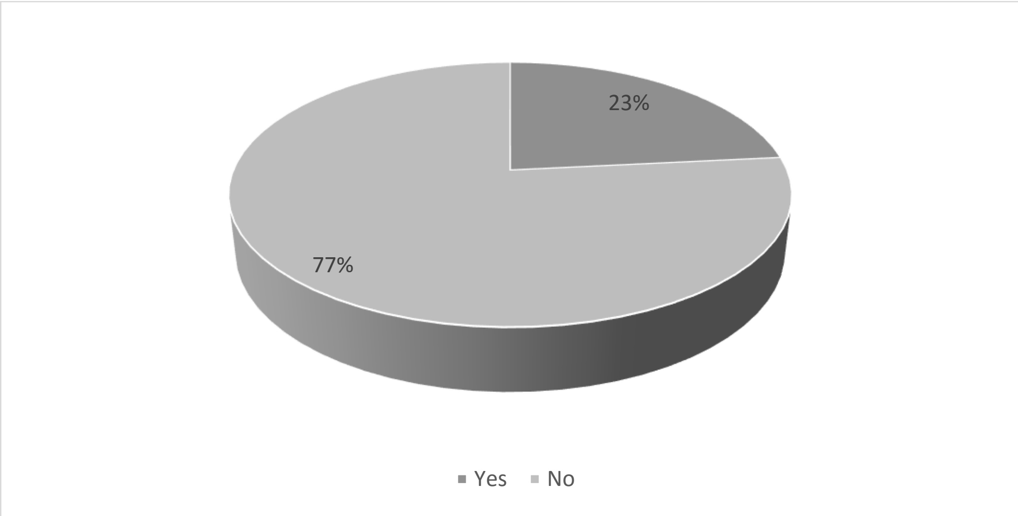

Figure 19-6: Do respondents have access to a health clinic?

Table 19-3: Do respondents have access to a health clinic? (By community)

Access to health clinic	Frequency	Percent
Ngqongweni	0	0.0
Ndzebe	2	3.4
Mqokolweni	60	100.0
Ndibanisweni AA	3	5.2
Lower Sinxaku	4	6.9

19.6 Educational amenities

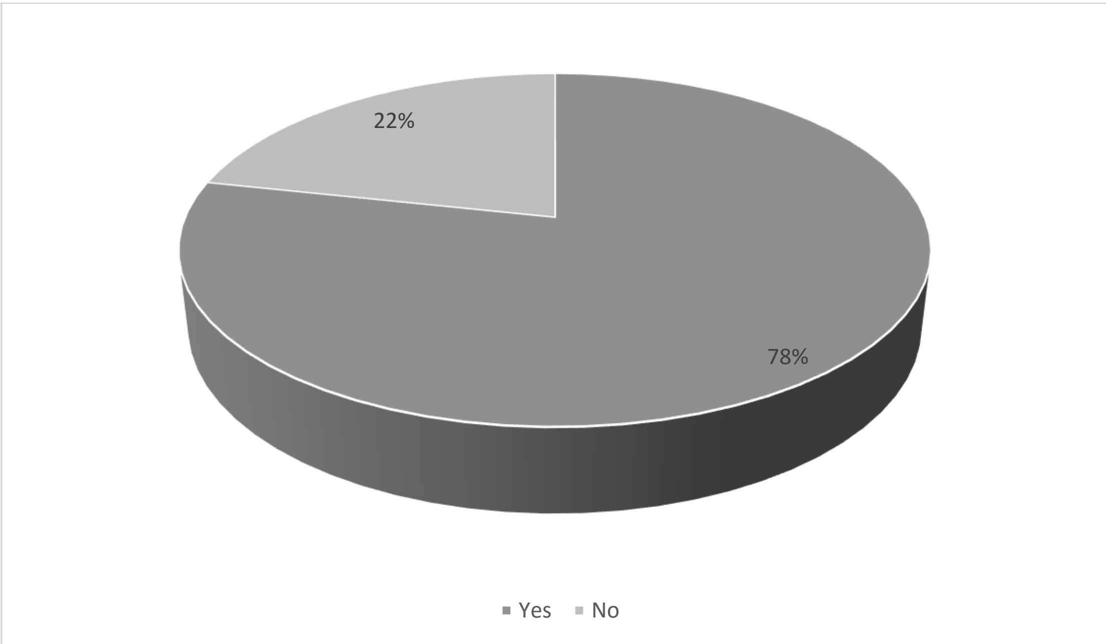

Figure 19-7: Do young people have access to a school?

Table 19-4: Respondents' affirmation of access to a school

Community	Frequency	Percent
Ngqongweni	0	0.0
Ndzebe	59	100.0
Mqokolweni	60	100.0
Ndibanisweni AA	58	96.7
Lower Sinxaku	55	96.5

Table 19-5: Means of transport to school

Means of transportation to school	Frequency	Percent
By public transport/school bus	25	1.6
On foot long walk	124	43.1
On foot short walk	139	48.2

19.7 Modes of public transport

Table 19-6: Most common modes of transport in study communities

Mode of transportation	Frequency	Percent
Buses	62	23.8
Mini bus taxis	84	32.2
Horses Van	6	2.3
Mini bus taxis and horse	2	0.8
Buses and Van	3	1.1
Van	42	16.1
Bakkie	61	23.4
Mini bus taxis and bakkie	1	0.4

Table 19-7: Perceptions of available public transport

Perceptions	Frequency	Percent
Reliable	103	34.4
Accessible	65	21.7
Affordable	110	36.8
Not affordable	148	49.5
Not reliable	169	56.5
Not accessible	114	38.1

19.8 Electricity

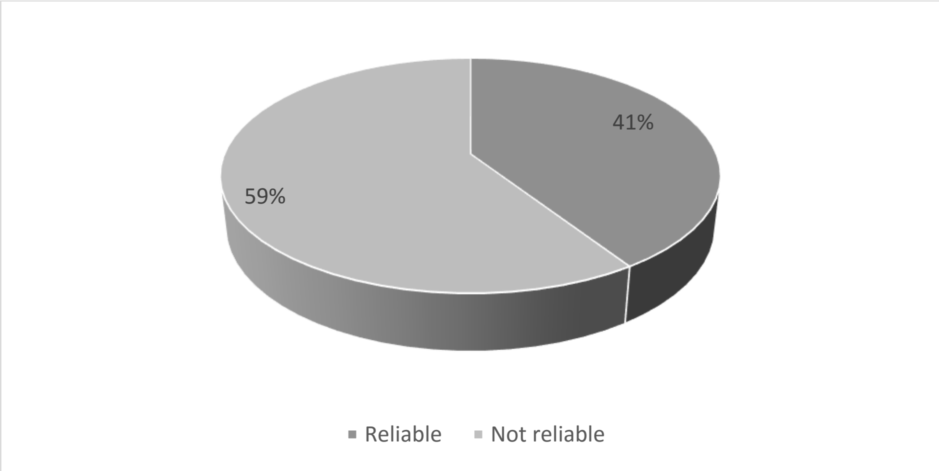

Figure 19-8: Perceptions of electricity supply

Table 19-8: Perceptions of electricity supply (by community)

Community	Perception: Reliable	Perception: Not reliable
Ngqongweni	26 (46.4)	30 (53.6)
Ndzebe	42 (73.7)	15 (26.3)
Mqokolweni	28 (46.7)	32 (53.3)
Ndibanisweni AA	11 (19.6)	45 (80.4)
Lower Sinxaku	10 (17.2)	48 (82.8)

19.9 Available social amenities

Table 19-9: Available social amenities

Amenities available	Frequency	Percent
Buses	29	9.7
Mini bus taxi	67	22.4
Electricity supply	166	55.5
Refuse removal	2	0.7
Park/open spaces	8	2.7
Police station	1	0.3
Post office	1	0.3
ATMs	1	0.3
Library	1	0.3
Government office	0	0.0
Sport field	133	44.5
Cemeteries	37	12.4
Connectivity to internet	0	0.0
Community hall	67	22.4
Street lighting	3	1.0
Shops	88	29.4
Clinics	75	25.1

Table 19-10: Available social amenities (by community)

Amenities	Ngqongweni	Ndzebe	Mqokolweni	Ndibanisweni AA	Lower Sinxaku
Buses	22 (36.7)	2 (3.4)	0 (0.0)	1 (1.7)	4 (6.7)
Mini bus taxi	4 (6.7)	0 (0.0)	0 (0.0)	49 (81.7)	14 (23.3)
Electricity supply	56 (93.3)	58 (98.3)	30 (50.0)	17 (28.3)	5 (8.3)
Sport field	56 (93.3)	28 (47.5)	31 (51.7)	16 (26.7)	2 (3.3)
Cemeteries	0 (0.0)	23 (39.0)	0 (0.0)	1 (1.7)	14 (23.3)
Community hall	0 (0.0)	25 (42.4)	0 (0.0)	42 (70.0)	0 (0.0)
Shops	7 (11.7)	14 (23.7)	18 (30.0)	25 (41.7)	24 (40.0)
Clinics	0 (0.0)	15 (25.4)	59 (98.3)	1 (1.7)	0 (0.0)

20 ECOLOGICAL INDICATORS, RISK AND VULNERABILITY

20.1 Disasters

Table 20-1: Experience of disasters

Disaster	Frequency	Percent
Flooding	117	39.1
Mud slide	78	26.1
Fire outbreak	177	59.2
Strong wind	208	69.6
Lightning	209	69.9
Heat wave	43	14.4
Drought	141	47.2
Tsunami	4	1.3

Table 20-2: Experience of disasters (by community)

Disaster	Ngqongweni	Ndzebe	Mqokolweni	Ndibanisweni AA	Lower Sinxaku
Flooding	23 (38.3)	28 (47.5)	20 (33.3)	6 (10.0)	40 (66.7)
Mud slide	20 (33.3)	1 (1.7)	18 (30.0)	0 (0.0)	39 (65.0)
Fire outbreak	59 (98.3)	29 (49.2)	39 (65.0)	5 (8.3)	45 (75.0)
Strong wind	41 (68.3)	38 (64.4)	40 (66.7)	37 (61.7)	52 (86.7)
Lightning	38 (63.3)	51 (86.4)	55 (91.7)	28 (46.7)	37 (61.7)
Heat wave	3 (5.0)	0 (0.0)	1 (1.7)	0 (0.0)	39 (65.0)
Drought	21 (35.0)	34 (57.6)	24 (40.0)	7 (11.7)	55 (91.7)
Tsunami	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	4 (1.3)

20.2 Diseases

Table 20-3: Experience of disease outbreaks

Disease outbreak	Frequency	Percent
Cholera	97	32.4
Dysentery	40	13.4
Diarrhoea	90	30.1
Scabies	42	14.0
Chicken pox	159	53.2
Malaria	46	15.4
No disease outbreak	80	26.8

Table 20-4: Experience of disease outbreaks (by community)

Disease outbreak	Ngqongweni	Ndzebe	Mqokolweni	Ndibanisweni AA	Lower Sinxaku
Cholera	0 (0.0)	43 (72.9)	10 (16.7)	4 (6.7)	40 (66.7)
Dysentery	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	40 (66.7)
Diarrhoea	2 (3.3)	26 (44.1)	13 (21.7)	9 (15.0)	40 (66.7)
Scabies	0 (0.0)	0 (0.0)	1 (1.7)	1 (1.7)	40 (66.7)
Chicken pox	32 (53.3)	50 (84.7)	23 (38.3)	29 (48.3)	25 (41.7)
Malaria	1 (1.7)	0 (0.0)	3 (5.0)	1 (1.7)	41 (68.3)
No disease outbreak	27 (45.0)	2 (3.4)	14 (23.3)	23 (38.3)	14 (23.3)

20.3 Fire incidence

Table 20-5: Experience of fire incidence

Incidence	Frequency	Percent
Veld fire	183	61.2
Fires caused by faulty electrical	9	3.0
Fires caused by candle, paraffin stove	47	15.7
Uncontrolled cooking fire	66	22.1

Table 20-6: Experience of fire incidence (by community)

Incidence	Ngqongweni	Ndzebe	Mqokolweni	Ndibanisweni AA	Lower Sinxaku
Veld fire	47 (78.3)	43 (72.9)	33 (55.0)	35 (58.3)	25 (41.7)
Fires caused by faulty electrical	5 (8.3)	0 (0.0)	0 (0.0)	0 (0.0)	4 (6.7)
Fires caused by candle, paraffin stove	3 (5.0)	11 (18.6)	14 (23.3)	14 (23.3)	5 (8.3)
Uncontrolled cooking fire	19 (31.7)	5 (8.5)	25 (41.7)	2 (3.3)	15 (25.0)

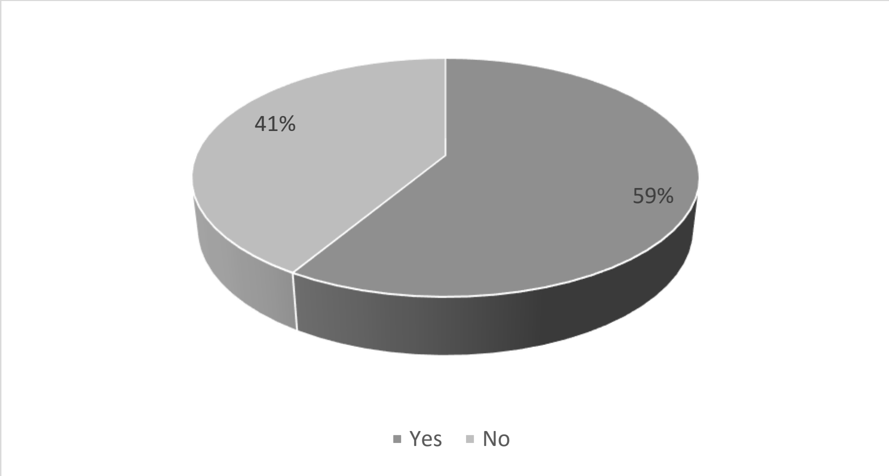

Figure 20-1: Any major losses suffered due to fire incidence?

Table 20-7: Any major losses suffered due to fire incidence (by community)

Village	Frequency	Percent
Ngqongweni	56	93.3
Ndzebe	43	72.9
Mqokolweni	10	16.7
Ndibanisweni AA	34	68.0
Lower Sinxaku	24	42.9

20.4 Ecological and agricultural assets

Table 20-8: Major crops cultivated

Crop	Frequency	Percent
Maize	253	84.6
Spinach	7	2.3
Cabbage	21	7.0
Potatoes	17	5.7
Wheat	1	1.3
Beans	3	1.0
Peach	1	0.3
Green pepper	1	0.3
Onion	1	0.3
Carrot	2	0.7

Table 20-9: Other crops cultivated

Crop	Frequency	Percent
Vegetable	75	25.1
Potato	111	37.1
Peach tree	9	3.0
Cabbage	89	29.8
Carrots	30	10.0
Onion	6	2.0
Tomato	14	4.7
Beans	28	9.4
Maize	23	7.7
Spinach	61	20.4
Pumpkin	11	3.7
Green pepper	4	1.3
Fruits	1	0.3
Beetroot	5	1.7

Table 20-10: Crops of yesteryears (10-20 years before survey)

Crop	Frequency	Percent
Maize	214	71.6
Peach tree	12	4.0
Vegetable	5	1.7
Potatoes	46	15.4
Sorghum	12	4.0
Spinach	24	9.4
Cabbage	28	9.8
Onion	4	1.3
Tomato	17	5.7
Pumpkin	17	0.3
Wheat	9	3.0
Carrot	3	1.0

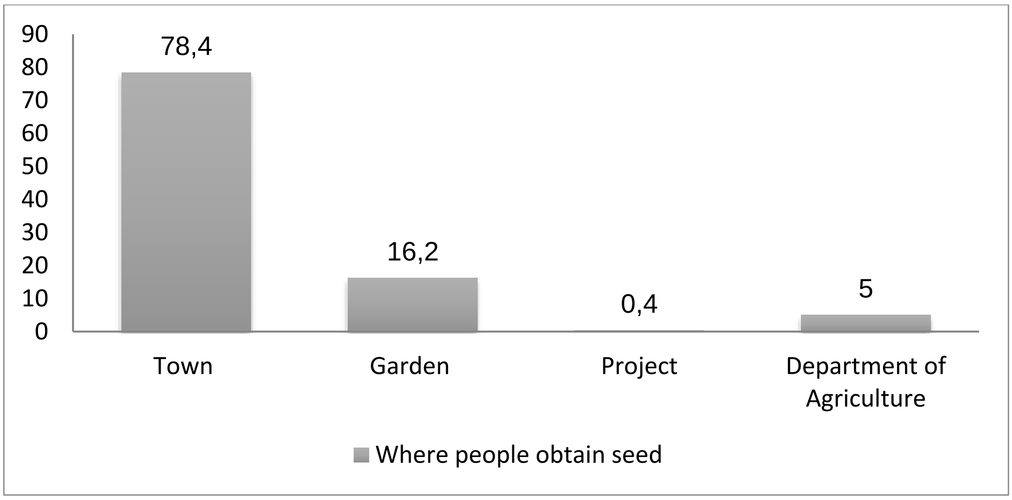

Figure 20-2: Sources of seeds for cultivation

20.5 Fertiliser use

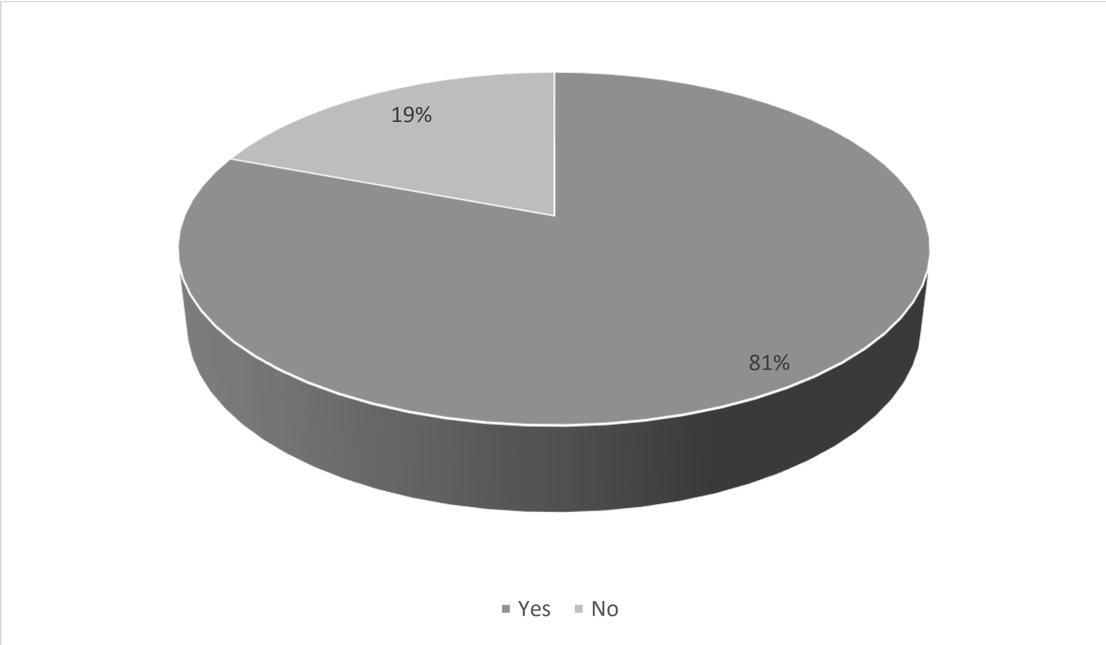

Figure 20-3: Do the farmers use fertilisers in cultivation?

20.6 Crop yield

Table 20-11: Typical crop yield

Crop	Sum (bags)	Range	Mean (SD)
Potato (n = 141)	2142	1-72 bags	15.2 (14.7)
Cabbage (n = 84)	627	1-50 bags	7.5 (9.2)
Beans (18)	91	1-16 bags	5.1 (4.9)
Maize (204)	3698	1-100 bags	18.1 (18.0)
Tomatoes (n = 8)	196	2-60 bags	24.5 (24.0)
Spinach (n = 34)	290	1-30 bags	8.5 (9.3)
Carrot (n = 28)	287	1-30 bags	10.3 (8.0)
Pumpkin (n = 11)	160	1-30 bags	14.6 (10.5)
Green pepper (n = 1)	35	35 bags	35
Wheat (n = 2)	6	33 bags	33 (0.0)
Sorghum (n = 1)	1	1 bag	1
Onion (n = 4)	25	1-9 bags	6.3 (3.6)
Peach (n = 7)	68	1-30 bags	9.7 (12.4)
Beetroot (n = 6)	36	1-21 bags	6 (7.7)

20.7 Agricultural labour input

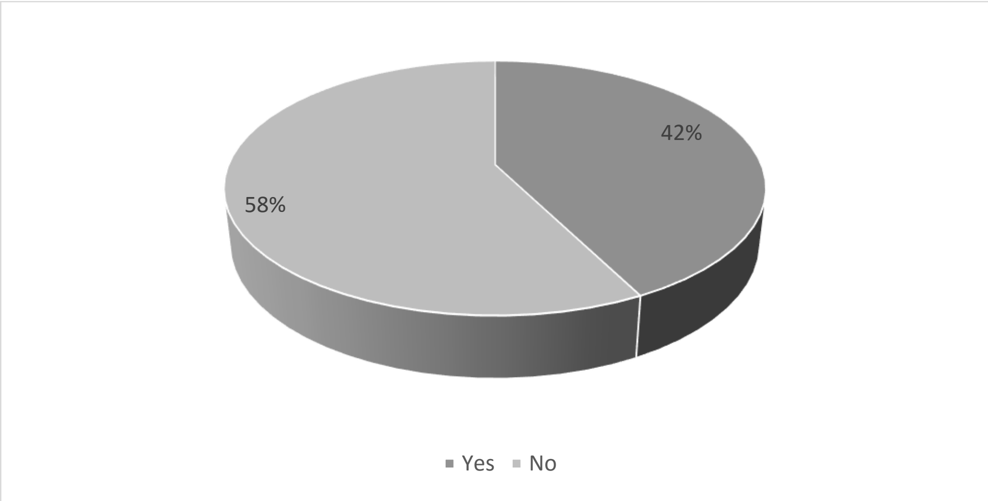

Figure 20-4: Do local farmers hire contractors?

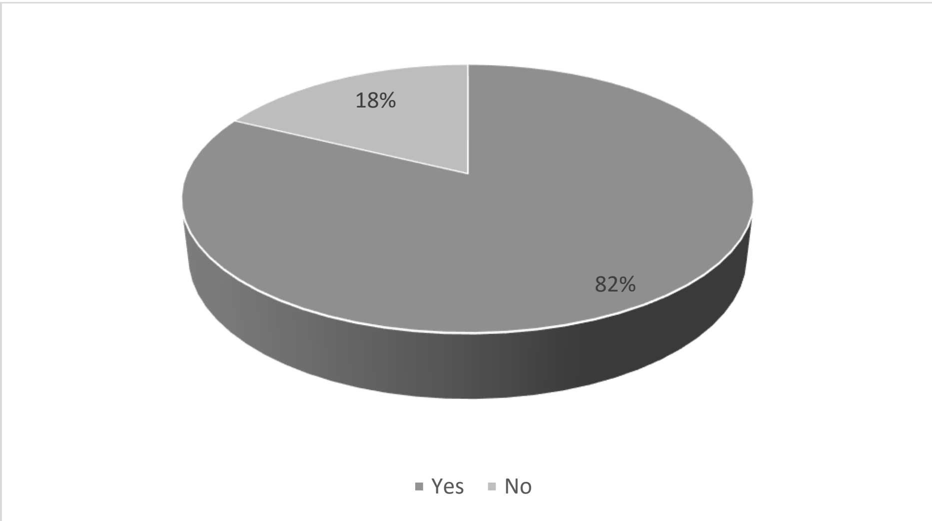

Figure 20-5: Do the producers rely on manual labour?

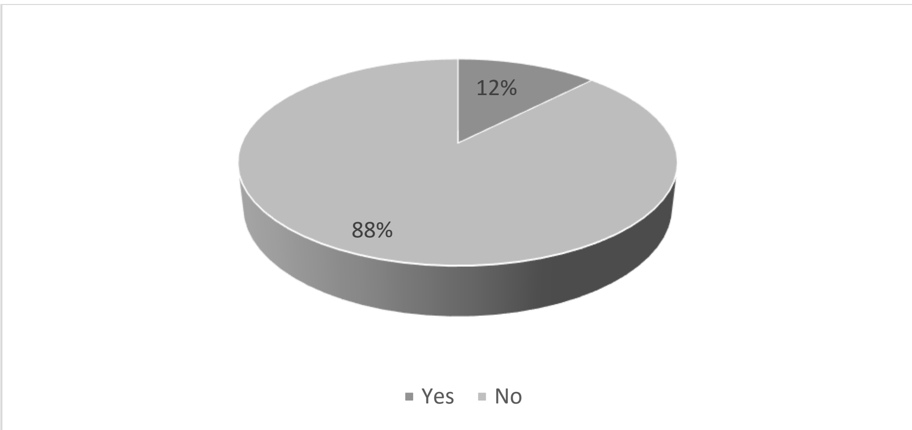

Figure 20-6: Do local farmers use traction animals?

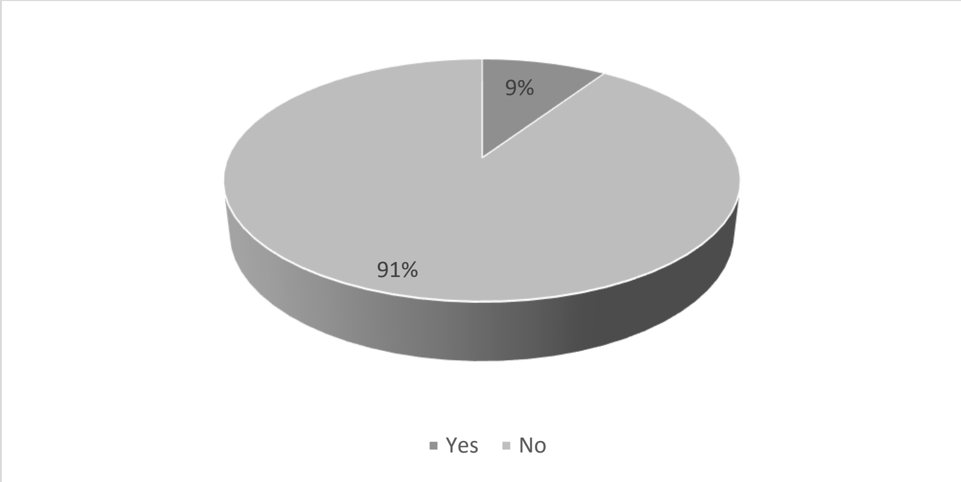

Figure 20-7: Do local farmers use tractors?

20.8 Farming spaces

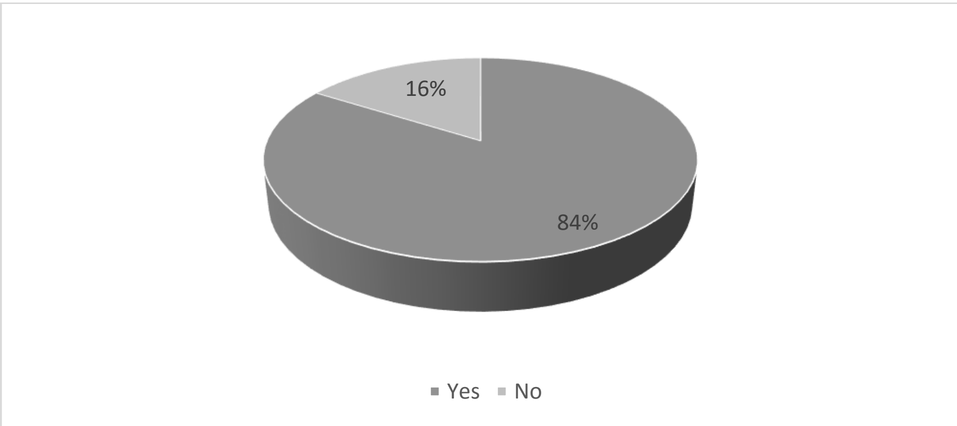

Figure 20-8: Are there vegetable gardens in the community?

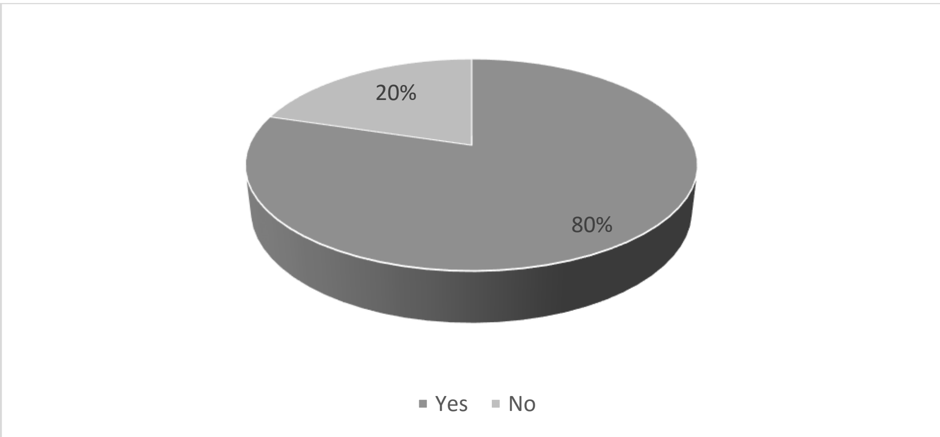

Figure 20-9: Do community members actually produce vegetables?

Table 20-12: Types of vegetables produced

Type of vegetables	Frequency	Percent
Potatoes	143	47.8
Cabbage	181	60.5
Carrots	117	39.1
Onion	38	12.7
Tomatoes	19	6.4
Maize	15	5.0
Spinach	135	45.2
Pumpkin	7	2.3
Green pepper	13	4.3
Fruits	1	0.3
Beetroot	10	3.3
Peas	8	2.7
Butternut	2	0.7

20.9 Livestock and grazing spaces

Table 20-13: Importance of livestock

Importance of livestock	Frequency	Percent
Sell them to make money	220	73.6
Ceremonial use	35	11.7
Source of wool	9	3.0
Source of meat	35	11.7
Source of milk	4	1.3
For transportation	2	0.7
Not so important	11	3.7

Table 20-14: Types of livestock kept by community members

Type of livestock	Frequency	Percent
Cows	252	84.3
Sheep	245	81.9
Goat	224	74.9
Donkey	45	15.1
Chicken	38	12.7
Pigs	35	11.7
Dogs	18	6.0
Horse	46	15.4
Cats	13	4.3

Table 20-15: Where do animals graze in the community?

Grazing space	Frequency	Percent
Mountains	124	41.5
River	8	2.7
Farm	20	6.7
Veld	62	20.7
Ground fields	46	15.4
Forest	15	5.0
Grazing land	25	8.4

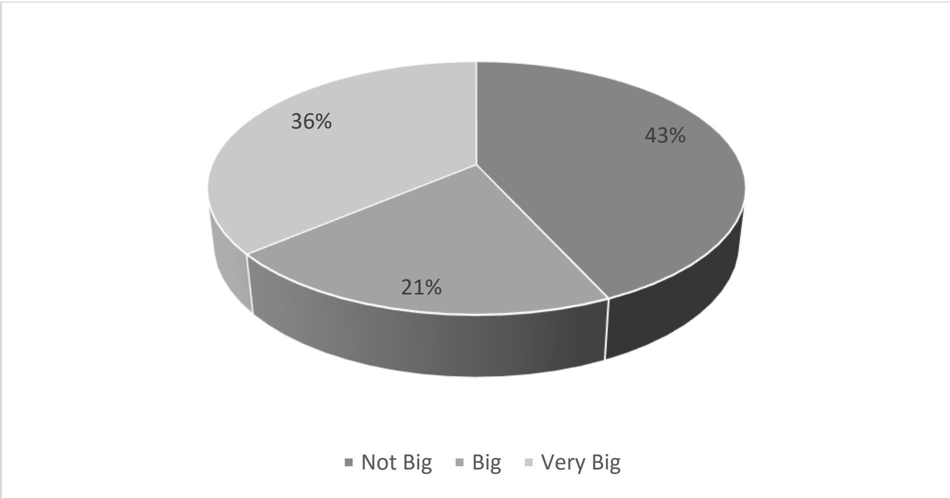

Figure 20-10: Size of grazing area

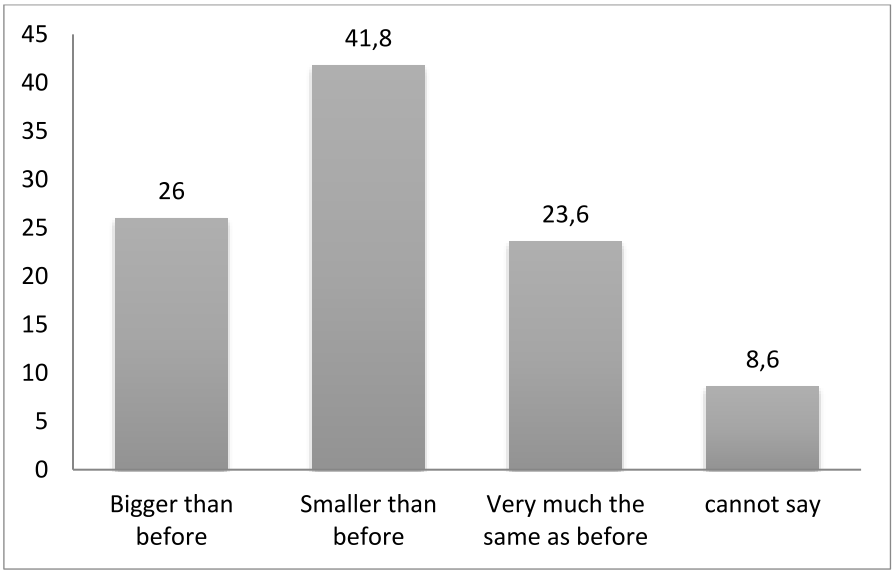

Figure 20-11: Size of grazing area in 'years gone by'

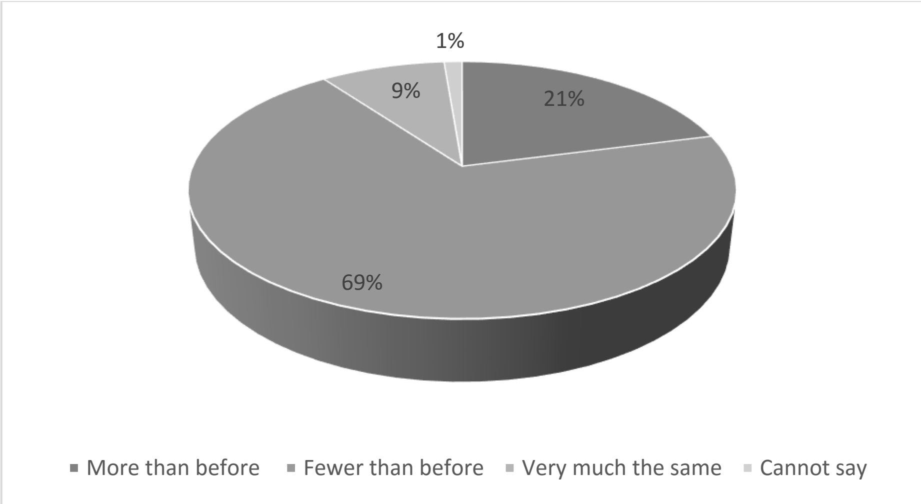

Figure 20-12: Respondents' perceptions of amount of animals owned in the community

Table 20-16: Grazing regimes

Grazing regimes	Frequency	Percent
Specific areas for specific animals	103	34.4
Specific sections of the community	73	24.4
Specific areas for specific seasons	92	30.8
No particular rule governing grazing	35	11.7

20.10 Irrigation

Table 20-17: Perceptions of irrigation impact on soil erosion

Perceived irrigation impact on soil erosion	Frequency	Percent
No impact because crops need water	59	19.7
Decreases soil erosion	109	36.5
More land for farming	11	3.7
Irrigation will be of no benefit	7	2.3
Irrigation is beneficial and should be introduced	3	1.0
Create *dongas* (water channels)	1	0.3
No response	109	63.5