Short communication

A preliminary assessment of the chemical and microbial water quality of the Chunies River – Limpopo

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Abstract

The aim of this study was to do a preliminary assessment of the chemical and microbial surface water quality of the Chunies River. For this purpose sampling was undertaken on 25 and 26 May 2002, and a range of chemical (macro-elements, micro-elements and heavy metals) and microbial variables (HPC, total coliforms and faecal coliforms) were measured. The chemical water quality of the second section of the river, fed by base-flow, was poor and unacceptable for both domestic and agricultural use. The microbial water quality was unacceptable for domestic use throughout the course of the river due to faecal and coliform pollution. The most significant finding of this study was that the chemical water quality of the Chunies River, at the time the samples were taken, was acceptable and fit for agricultural and domestic use.

Keywords: chemical water quality; microbial water quality; Chunies River

Introduction

Being a semi-arid country, one of South Africa's most limited and precious resources is water. This is especially evident when considering that the average yearly rainfall in South Africa is about 497 mm, compared to the world average of 860 mm (Cowan, 1995). The situation is made worse by inefficiencies in use and the growing demands of the economy, which makes the optimum and sustainable use of South Africa's water resources one of the most pressing issues. The South African National Water Act (Act 36 of 1998) recognises that water should be used in an environmentally sustainable manner, and has the long-term protection and sustainable management of our water resources as one of its main objectives. The Chunies River in the Limpopo Province of South Africa is a subsidiary of the Olifants River primary catchment. It runs through commercial farmland and rural communities before its confluence with the Olifants River. No studies have, however, been done on the water quality with regard to its chemistry and microbial activity. This would be of importance, since platinum mine is being planned in the Chunies River catchment, and a platinum smelter is in the final stages of construction.

When interpreting chemical water quality, it is of great importance to understand the factors influencing water chemistry. Gibbs (1970) proposed that rock weathering, atmospheric precipitation, evaporation and crystallisation control the chemistry of surface water. When interpreting chemical water quality on a catchment scale, a more detailed explanation of the factors influencing the stream and river water chemistry would be useful. Since the catchment as a whole (including the catchment atmospheric and climate characteristics) provides input to the water chemistry of the streams and rivers draining the particular catchment, it follows that the factors influencing water chemistry can be discussed in terms of the characteristics of the catchment. The main catchment characteristics influencing water chemistry are geology, geomorphology, soils, climate, vegetation, land use and land cover, and pollution.

The influence of geology on chemical water quality is widely recognised (Gibbs, 1970; Langmuir, 1997; Lester and Birkett, 1999), as is the geochemistry, which has successfully been used as the basis of a model predicting stream-water chemistry (Smart et al, 2001). The influence of soils on water quality is very complex and can be ascribed to the processes controlling the exchange of chemicals between the soil and water, as well as the spatial heterogeneity of soils (Hesterberg, 1998). The most important soil properties influencing water chemistry, are the mineralogy (especially that of the clay fraction), organic matter, depth and drainage, pH and redox potential of the soil (Hesterberg, 1998). Land use and its associated land cover can therefore have a serious influence on water chemistry through modifying the geomorphology, soils, vegetation and hydrology of an area.

In terms of microbial water quality, a wide variety of viruses, bacteria and protozoa that can be transmitted via water are of concern. These micro-organisms have been associated with diseases such as gastroenteritis, cholera, hepatitis, typhoid fever, dysentery, salmonellosis, and eye, skin and nose infections (DWAF, 1996). The majority of the above disease-causing pathogens are transmitted by the faecal-oral route (DWAF, 1996), and the reservoirs for these micro-organisms could be animals, humans or the environment itself (Hurst et al., 1997). The faecal contamination of South Africa's water resources is becoming an increasing threat (DWAF, 2000). It is, however, technically and economically impractical to test for the full range of pathogenic micro-organisms due to the sheer numbers of pathogens that may be present in water (DWAF, 1996; Hurst et al., 1997). For these reasons indicator organisms are generally used to monitor the potential presence of micro-organisms, although no single indicator organism can be used with absolute confidence (DWAF, 1996). It is therefore recommended that combinations of indicators, each with their own

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TABLE 1
The geology, geomorphology, soil and vegetation of the Chunies River catchment

Sampling site	Geology	Slope	Soils	Vegetation
Site 1	Gneiss/ Turfloop Granite	0 - 9%	Red-yellow apedal. High base status. < 15% clay	Sourish Mixed Bushveld
Site 2	Turfloop Granite	0 - 9%	Red-yellow apedal. High base status. < 15% clay	North-Eastern Mountain Sourveld
Site 3	Turfloop Granite	0 - 25%	Miscellaneous land classes. Undifferentiated deep deposits.>35% clay	Degraded Mixed Bushveld
Site 4	Gabbro	0 - 9%	Dominant prismacutanic and/or pedocutanic diagnostic horizons.B-horizons not red. 15-35% clay.	Mixed Bushveld

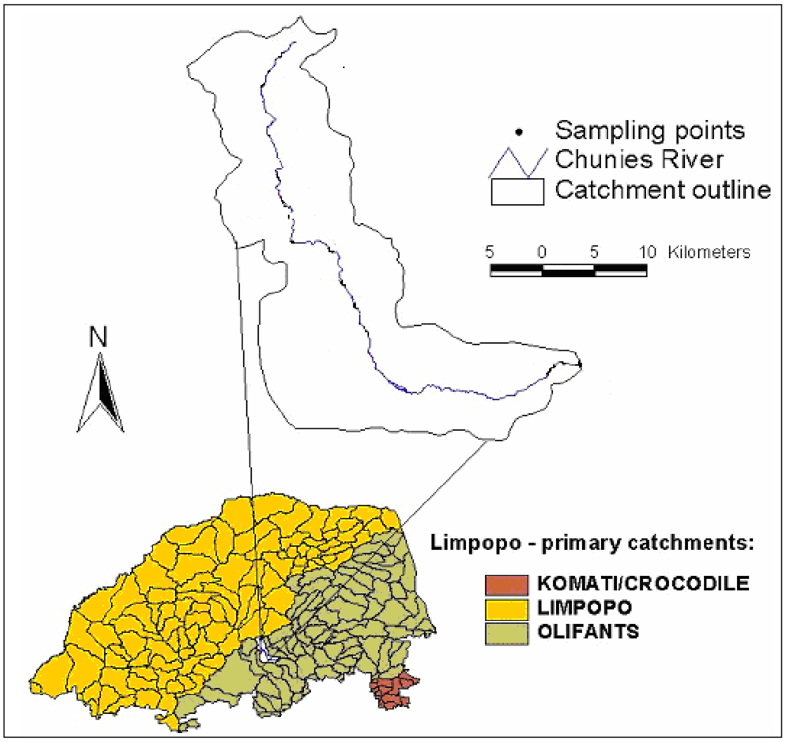

Figure 1
Map of the Chunies River catchment indicating sampling sites and the geographical location of the Chunies River catchment within Limpopo Province

advantages and disadvantages, be used when assessing microbial water quality.

Many groups of coliforms are poor indicators of faecal pollution as they can exist and grow naturally in both soil and water, and are thus more useful as co-indicators of the general microbial condition of water. The faecal coliforms are a subgroup of total coliforms and are a much better indicator of faecal pollution (Hurst et al., 1997). The terms 'thermo-tolerant coliforms' can also be used for this group of coliforms, of which the vast majority are E. coli. Faecal coliforms have a very high correlation with faecal pollution, and can be used with confidence to directly infer faecal pollution of the water (Hurst et al., 1997).

The heterotrophic plate count (HPC) is used to estimate the total amount of bacteria in water and indicates the overall microbial status of the water (Hurst et al., 1997).

The aim of this research project is to serve as a preliminary assessment of the chemical and microbial surface water quality of the Chunies River in the light of the proposed platinum mining and smelter activities. Such information can therefore provide a basis on which a catchment management strategy for the Chunies River could be built in the future. An assessment of the chemical and microbial water quality of the river would thus act as a base-line study against which the effects of future anthropogenic activity on water quality could be measured.

Material and methods

Sampling sites

During May 2002 four sampling sites (with six replicates each) were selected along the Chunies River, from the headwaters to the confluence with the Olifants River. Sampling at Sites 1 and 2 was undertaken on the 25^{th,} and at Sites 3 and 4 on 26 May 2002. These were selected so as to be representative of the land use in the catchment, and were numbered Sites 1 to 3 in a downward stream direction. A 4th sampling site was located in the Olifants River at the point where the Chunies River enters the Olifants River. The locations of the sampling sites are depicted in Fig. 1.

The Chunies River is located in the Limpopo Province of South Africa and its geographical location can be seen in Fig. 1. The geology, geomorphology (in terms of slope), soil, and vegetation occurring in the catchment are summarised in Table 1 (using *Environmental Potential Atlas*, 2001 data). The surface water catchment area of the river is 541.4 km^2 with a surface water runoff and precipitation of 6.43 x 10^6 and 277.72 x 10^6 m^3/a, respectively. It has a potential volume of evaporation of 1 018.64 x 10^6 m^3/a, with a cost of R4.00/m^3 and a value of water from runoff of R25.70 m/a.

A water balance of the Chunies River catchment is given in Table 2 and it should be noted that a mass flux was not calculated, as the average annual total dissolved solids content of the Chunies River is still to be determined.

The land cover and its condition, along the Chunies River are closely related to the vegetation of the catchment. Woodland was is the dominant land cover in the most northern part of the catchment, and Site 1 was located in this area, while the land cover

TABLE 2
The mean concentration (±SD) of the macro-elements, pH and EC in the Chunies River and Olifants River (control)

	Ca (0-32)* -	Mg (0-30)* -	K (0-50)* -	Na (0-100)* (0-70)#	P - -	SO_4 (0-200)* -	NO_3 as N (0-6)* (< 5)#	NH_4 as N (0-1)* -	Cl (0-100)* (0-100)#	HCO_3 -	pH (6-9)* (6.5-8.4)#	EC (0-70)* (0-40)#
	mg·ℓ$^{-1}$											
Site 1	44.08±4.48^a	31.96±7.75^b	0.98±0.23^b	54.83±34.80^b	<0.01	17.12±11.89	0.07±0.03^b	0.33±0.02^b	58.47±49.50^b	309.65±45.29^b	8.1±0.2^b	63.8±15.2^b
Site 2	39.88±16.64^a	24.79±14.34^b	1.75±0.51^b	89.20±74.11^b	<0.01	23.44±14.32	0.12±0.11^b	0.32±0.05^b	99.92±97.77^b	292.12±153.54^b	8.2±0.3^b	74.3±25.8^b
Site 3	56.71±23.27^a	31.84±12.74^b	2.25±0.59^b	37.47±23.55^b	<0.01	9.52±4.94	2.67±2.20^b	0.31±0.10^b	49.91±27.05^b	315.76±103.95^b	8.2±0.3^b	68.4±15.5^b
Site 4	25.78±3.59^a	170.14±17.53^a	18.90±15.20^a	612.68±206.36^a	<0.01	238.65±81.57^a	9.69±4.23^a	0.61±0.66^a	894.05U247.46^a	697.61±71.56^a	8.6±0.3^a	331.5±173.4^a

*Domestic Water Quality Range (DWAF, 1996)
#Agricultural Water Quality Range (DWAF, 1996)
a,b Means with the same letter were not significantly different (P > 0.05)

dominating Site 2 was degraded forest and woodland. In this latter region little 'islands' of built-up residential areas occur east and immediately south and west of the Chunies Dam. An important note concerning the Chunies Dam is that the riverbanks just upstream of the dam, as well as the banks of the dam, shows severe signs of erosion. An even more serious problem is the severe erosion at the most southeasterly dam wall and the 'head-cut' erosion, which occurs at the outlet of the dam. Site 3 was situated where the river flows through the Chunies Poort and enters an area dominated by thicket and bushveld, and where small settlements with land cultivated for subsistence farming, exist. The land seems to be used predominantly for grazing (by goats and cattle) and many people were observed washing clothes in the river. A further point worth mentioning is that a nearby petrol filling station used the bank of the Chunies River as a disposal site for their empty oil cans. The final stretch of the river investigated in this study, Site 4, is characterised by degraded thicket and bushveld.

Sampling procedure and analyses

One grab sample was taken manually at each selected sampling point. The procedure entailed dipping a sterilised 1 ℓ plastic container into the river and filling it. Care was taken that no air was left in the sample. The sampling depth was not of importance since shallow lakes (< 5 m) and shallow flowing rivers fail to exhibit any sort of recognisable chemical stratification (Cowgill, 1996).

The pH (which is subject to change during storage and transport) and electrical conductivity (EC), were measured on site using a Hannah Hl 9811 pH/EC/TDS meter.

During storage and transport the samples were placed in a cooling box at a temperature of ± 4°C to keep the chemical and microbial constituents as stable as possible.

Independent accredited laboratories carried out the chemical and microbial analyses of the samples.

The water-soluble basic cations (Ca, Mg, K and Na), micro-elements (Fe, Mn, Cu, Zn) and heavy metals (As, Se, Al, Cr, Co, Ni, Pb and Cd) were quantified by means of atomic absorption spectrometry with a Spectr. AA – 250 (Varian, Australia). The anions (F, Cl, NO_3, PO_4 and SO_4) in turn, were quantified with an ion chromatograph (Metrohm 761, Switzerland). Ammonia (NH_4) concentrations were quantified by means of the ammonia-selective electrode method as described by Banwart et al. (1972). The bicarbonate (HCO_3) content in the water was determined by means of the potentiometric titration method with an end-point pH of 4.5 and a standard 0.005M HCl solution (Skougstad et al., 1979). Boron (B) concentration was colorimetrically determined by means of the azomethine-H-method described by Barrett (1978), using a VEGA 400 spectroquant at an absorbency of 420nm. The pH value and electrical conductivity (EC) was determined in the 1:2 extract with a WTW LF92 conductivity meter, at 25°C.

The microbial analyses for the faecal coliforms, total coliforms and the heterotrophic plate count for determining the bacteriological quality of water according to the membrane filtration method, were done according to the South African Bureau of Standards (SABS-method 221, 1986).

Results and discussion

Macro-elements, pH and EC

The results of the pH, EC and macro-element concentrations are presented in Table 2. It was determined that the pH and the EC at the sampling sites fell within DWAF (1996) ranges for domestic and agricultural use, except for the pH and EC at the control site, which differed significantly ($P < 0.05$). This might, however, be explained by the fact that one of the control samples was taken from a standing pool of water in the Chunies River course, and concentration upon evaporation would thus be the most probable explanation for the rise in EC values. Drever (1982) stated that the contact time between rock and water is probably the most important variable in determining water chemistry, and the longer time period that groundwater is in contact with the geomedia allows

TABLE 3
The mean concentration (±SD) of the micro-elements in the Chunies River and Olifants River (control)

	Fe (0-0.1)* (< 5)[#]	Mn (0-0.05)* (< 0.02)[#]	Cu (0-1)* (< 0.2)[#]	Zn (0-3)* (< 1)[#]	B - (< 0.5)[#]
	$mg \cdot \ell^{-1}$				
Site 1	0.06±0.05[a]	0.02±0.01[a]	0.02±0.01[a]	0.02±0.01[a]	<0.01[a]
Site 2	0.08±0.05[a]	0.05±0.02[b]	0.01±0.01[a]	<0.01[a]	0.02±0.01[a]
Site 3	0.18±0.10[b]	0.02±0.01[a]	0.03±0.01[a]	0.02±0.01[a]	0.24±0.11[a]
Site 4	0.10±0.02[a]	0.02±0.00[a]	<0.01[a]	<0.01[a]	0.21±0.15[a]

*Domestic Water Quality Range (DWAF, 1996)
[#]Agricultural Water Quality Range (DWAF, 1996)
[a,b] Means with the same letter were not significantly different (P > 0.05)

TABLE 4
The mean concentration (±SD) of metals in the Chunies River and Olifants River (control)

	Al (0-0.15)* (0-5)[#]	Pb (0-0.01)* (0-0.2)[#]	Cr (0-0.05)* (0-0.1)[#]	Ni - (0-0.2)[#]	Co - (0-0.05)[#]	Cd (0-0.005)* (0-0.01)[#]	Se (0-0.02)* (0-0.02)[#]	As (0-0.01)* (0-0.01)[#]
	$mg \cdot \ell^{-1}$							
Site 1	0.24±0.03[a]	<0.01	0.05±0.01[a]	0.01±0.01[a]	<0.01[a]	<0.01[a]	0.09±0.07[a]	0.23±0.10[a]
Site 2	0.37±0.01[a]	<0.01	0.05±0.02[a]	<0.01[a]	0.02±0.01[a]	<0.01[a]	0.28±0.06[a]	0.47±0.21[a]
Site 3	0.24±0.10[a]	<0.01	0.05±0.02[a]	0.06±0.04[a]	0.02±0.01[a]	0.01±0.01[a]	0.34±0.13[a]	0.36±0.34[a]
Site 4	0.17±0.10[a]	<0.01	0.03±0.02[a]	0.05±0.01[a]	0.02±0.01[a]	0.01±0.01[a]	0.24±0.15[a]	0.35±0.01[a]

*Domestic Water Quality Range (DWAF, 1996)
[#]Agricultural Water Quality Range (DWAF, 1996)
[a,b] Means with the same letter were not significantly different (P > 0.05)

greater weathering and leaching of ions. The latter might also explain the significantly (P < 0.05) elevated levels of Mg, Na, SO4, NO3 and Cl at Site 4. A follow-up study, spanning a year or longer, to take seasonal changes into consideration, is proposed. With the exception of Ca, the rest of the macro-elements determined in samples from Sites 1 to 3 all fell within the proposed level., No health effects are, however, expected although scaling problems might occur if these levels exceeded 80 $mg \cdot \ell^{-1}$ (DWAF, 1996).

Micro-elements

The results on the micro-elemental concentrations measured at the various sites are summarised in Table 3. From this it is clear that all the micro-elements fell within the DWAF (1996) proposed ranges, with only two significant (P < 0.05) exceptions *viz.* Fe at Site 3 and Mn at Site 2. The higher Fe and Mn concentrations would, however, have no adverse health effects, with slight taste and aesthetic problems only.

Heavy metals

The mean concentrations of the heavy metals measured in the Chunies River are presented in Table 4. Although Al concentrations were higher than proposed at all the sites, no health effects are expected for domestic use, but noticeable aesthetic effects could occur. Pb, Cr, Ni, Co and Cd concentrations were all low enough for safe domestic and agricultural use (DWAF, 1996).

Both the selenium (Se) and arsenic (As) concentrations were exceedingly high, but these results need to be viewed critically. A previous assessment of the As and Se concentrations of the Chunies River was done by consultants of Africon. Three samples where collected on 13 December 2001 and analysed for As and Se, the results of which were all under the detectable limit of 0.005 $mg \cdot \ell^{-1}$. Even when taking into consideration that these samples where collected in the wet season, the huge discrepancy in the concentrations probably point out that the As and Se concentrations presented here might be due to analyses errors in the previous assessment.

Microbial water quality

The results obtained for the microbial analysis are presented in Table 5. Collected data indicated that the microbial water quality of the Chunies River is poor. Faecal and coliform pollution was widespread and the entire river as sampled, is not suitable for domestic use, although it was significantly lower (P < 0.05) at Site 2.

In terms of agriculture, there is a definitive possibility of contamination from vegetables and other crops eaten raw. Crops and pastures not consumed raw could, however, be irrigated by any

TABLE 5
The mean microbial quality (±SD) of water collected in the Chunies River and Olifants River (control)

	Faecal coliforms 100 mℓ$^{-1}$ (0)* (0)#	Total coliforms 100 mℓ$^{-1}$ (0-5)* (-)#	HPC mℓ$^{-1}$ (0-100)* <10 000#
	mg ℓ$^{-1}$		
Site 1	6.25±2.63[b]	54.75±19.27[b]	542.50±49.58[a]
Site 2	20.75±10.51[a]	166.00±55.59[a]	7353.75±134.95[b]
Site 3	23.40±18.82[a]	127.20±57.76[a]	1064.00±119.08[a]
Site 4	40.50±20.05[a]	107.00±24.04[a]	590.00±28.28[a]

*Domestic Water Quality Range (DWAF, 1996)
#Agricultural Water Quality Range (DWAF, 1996)
[a,b] Means with the same letter were not significantly different ($P > 0.05$)

method provided that the crops and pastures are allowed to dry before harvesting and grazing. The HPC at all the sites indicated that the water might be used for agricultural purposes but would not be safe for domestic use.

Although the bacterial count is high for the Chunies River, thus rendering the water unfit for human consumption, it is low in comparison with those of the Mhlathuze River and water sources in Venda, as reported in other recent studies (Bezuidenhout et al., 2002; Obi et al., 2002).

A very important concept, which should be kept in mind during the interpretation of the microbial data, is the fact that microbial constituents have a strong non-conservative behaviour in water. The concentration of the amount entering the water could change independently through various processes such as growth, settling to the sediments, chemical reactions and decay (DWAF, 2000).

Conclusions and recommendations

The chemical water quality of the Chunies River, at the time the samples were taken from Sites 1 to 3, was acceptable and fit for agricultural use. Microbial water quality was unacceptable throughout the course of the river, making it unsuitable for domestic use due to the high faecal and coliform pollution. It is also strongly recommended that the As and Se be re-measured to clear up the issue regarding concentrations as mentioned above.

Since catchment conditions and water quality change seasonally, a proper assessment of the chemical and microbial surface water quality has to involve the assessment of samples taken both during the wet and the dry seasons. Ideally, such a study would furthermore assess samples for more than one year, to take annual variation into account.

Due to the high pH, which occurs throughout the Chunies River, insoluble heavy metals might be remobilised from the sediments if a lowering in pH occurs. An assessment of the medium to long-term chemical quality of the Chunies River would thus have to include a chemical assessment of the sediments found in the Chunies River. When considering the catchment characteristics of the Chunies River, the main factors influencing the water chemistry during the dry months, seems to be the geology and the climate (especially in terms of evaporation).

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