A PRELIMINARY CITIZEN SCIENCE WEATHER STATIONS MONITORING NETWORK FOR EARLY WARNING RESILIENCE

Report to the
Water Research Commission

by

Michael G. Mengistu[1,2], Henerica Tazvinga[1], Miriam Murambadoro[1], Abiodun M. Adeola[1,4], Siphamandla Daniel[1], Nosipho Zwane[1], Katlego Ncongwane[1], Thato Masithela[1], Jaco de Wit[1], Sarah Malatji[1], Ides Masingi[1], Joe Matsapola[1], Lulama Menze[1], Wiseman Dlamini[1], Ayanda Dube[2], Joel O. Botai[1,2,3], Christina Botai[1]

[1]South African Weather Service, Private Bag X097, Centurion, South Africa
[2]School of Agricultural, Earth and Environmental Sciences, University of KwaZulu-Natal, South Africa
[3]Department of Geography, Geoinformatics and Meteorology, University of Pretoria, South Africa
[4]School of Health Systems and Public Health, Faculty of Health Sciences, University of Pretoria.

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Obtainable from
Water Research Commission
Private Bag X03
Gezina
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orders@wrc.org.za or download from www.wrc.org.za

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EXECUTIVE SUMMARY

Background

Climate change and variability currently, and will in the future, continue to cause disruptions to socioecological systems with impacts on socio-economic development and environmental sustainability. Future projections in Africa and over the developing regions such as South Africa highlight the potential negative impacts of continued climate change, especially on climate-sensitive sectors including agriculture, water, health, human settlements, and energy. These key sectors are also key in driving the economy to meet the National Development Goals as well as the global Sustainable Development Goals. Extreme weather and climate events such as flooding, drought, heatwave, and wildfire are projected to increase in frequency, duration, and severity. The impacts also present opportunities for multiple actors (including communities) to take action for possible mitigation and adaptation. The Sendai Framework for Disaster Risk Reduction (DRR) and the United Nations Conference of Environment and Development (UNCED) highlight the need for citizen participation and engagement in the climate response. The Sendai Framework emphasises explicitly that all social engagements and partnerships for participation should be voluntary, empowering, inclusive, accessible, and non-discriminatory.

It is therefore imperative, to develop the human and social capital required, especially at the community level for citizens to be more proactive and build their resilience to extreme weather events. The focus of this project was to develop appropriate citizen science interventions that promote bottom-up and top-down knowledge sharing and learning on early warning systems to support community resilience. The citizen science approach was used to enable learners at two schools in the City of Tshwane and in uMgungundlovu District Municipality to collect local weather information, co-design, co-implement appropriate early warning and environmental management initiatives to mitigate the impacts of extreme weather and climate events. To ensure that all learners and community volunteers understood the key concepts of weather and climate and to encourage their participation (mobilisation) the most common local languages in each site, i.e. Tswana and Zulu were used during the workshops. This initial work needs to be sustained and provides an avenue for mainstreaming indigenous and traditional knowledge to support early warning through for example scenario planning and an increased understanding of the key risks, livelihood activities, drivers of change, and the desired adaptation futures at the community level.

Objectives

The project aimed to develop a monitoring network as a citizen scientists' tool for the early detection of disasters related to changing weather and climate to mitigate their impacts on livelihood. The following were the specific objectives of the project:

1. Re-package the highly technical concepts and information on disaster for citizen scientists' early warning
2. Strategically design and pilot test a weather and climate change monitoring network
3. Cost the network based on selected cost-effective indicators, their spatial distribution, data management system and reporting
4. Through workshops/dialogues, train citizen scientists to engage, empower and enhance resilience to weather and climate changes.

Methodology

The first exercise of the project was to conduct a review study to identify the best practices on the concepts and information on disaster for citizen scientists' early warning findings which are presented in chapter 2. Following this, the initiation phase of the project identified two schools in the two study sites namely, Swayimane High School in uMgungundlovu in KwaZulu-Natal Province and two Viva Foundation schools in the City of Tshwane (Mamelodi and Cullinan campus). Participants from Viva Foundation were mainly primary school learners between grades 3 and 7 whilst Swayimane volunteers included both high school learners in grades 8 to 11 and youth in the area.

Facilitated workshops were used in the development phase as a social learning tool to create a shared vision to enhance water resource management and resilience to extreme weather events that affect the sustainability of livelihoods in the two sites. The citizen scientists received simplified weather and disaster risk reduction information to ensure that there is a shared understanding of the risks while also allowing for informed participation of the citizen scientists in sharing their knowledge of their local weather, experiences of extreme weather events, and the impacts on communities and livelihoods. The participants also shared knowledge on the state of rivers, how they access water and related challenges, possible disaster risk management measures, and effective means to share early warning and weather information in their respective communities. The workshops also included a component of building career interest amongst the youth and school children in meteorology so that more students are registering for meteorology at universities and this was done through sharing of life experiences by scientists and researchers from SAWS and UKZN. The last component of the project activities was the live/participatory science phase which commenced after the installation of weather stations. The citizen scientists are monitoring and collecting local weather information which will be validated against SAWS datasets. This information will also be integrated with indigenous knowledge on seasonal forecasts and future climate projections to support communities to plan and make decisions relating to their livelihoods and day-to-day activities.

Results and Discussion

The study reviewed and examined best practice and the latest weather and climate change knowledge on disaster for citizen science, locally and internationally. The findings from this review were used to design and pilot test a weather and climate-change monitoring network at the two study sites. Citizen scientists were trained and engaged through workshops, follow-up meetings and visits to enhance resilience to extreme weather events and climate change. Participants from Swayimane indicated that their community experienced floods, snow, hail, high temperatures, droughts, and storms that affected agricultural activities and human settlements. The citizen scientists added that water used in their households was mostly from springs, river and community taps; however, there were challenges with water quality and water pollution – a challenge also noted in reports on the Greater Umgeni River Catchment. In terms of interventions that can be used to disseminate weather and climate information, the participants suggested that posters, SMS, and television were other media platforms that can be used by communities to receive weather information in Swayimane.

In the City of Tshwane, the citizen scientists shared that they experienced extreme weather events such as heatwaves and thunderstorms that result in flooding, strong winds, hail, and extreme temperatures in winter. The state of rivers in Mamelodi and Cullinan were described by participants as dirty and unsafe for drinking and poses an increased risk of water-related diseases in the two communities. The citizen scientists suggested that there should be community awareness-raising projects to reduce water pollution and also provide chemicals to treat water so that it is safe for drinking. Weather and climate information in Tshwane can be disseminated through TV, cell phone, radio, and different online platforms.

An implementation plan to sustain a state-of-the-art weather station was also developed to assist citizen scientists and decision-makers for climate-related adaptation, risk reduction and resilience. The implementation plan report consists of core players and roles in supporting citizen scientists. It also highlights data acquisition, resources and storage requirements, budget, risks and mitigation mechanisms needed to acquire, implement and sustain weather and climate change stations. A user-friendly guideline manual has also been developed and provided for effective replicable installation, data acquisition and storage, and maintenance of AWS by citizen scientists.

Overall, the study enabled citizen scientists including school learners, youths and community-based groups to anticipate and mitigate extreme weather events as well as improve their understanding of water resource management. This project, therefore, highlights the best practice and latest weather and climate change knowledge on disaster for citizen science locally and internationally. It also comprises an implementation plan to maintain and sustain a state-of-the-art weather station and train school learners who are weather and climate champions "Citizen Scientists" that can facilitate climate change awareness-raising, adaptation and consequently impact their communities.

Conclusions and Recommendations

Weather and climate play a key role in informing different social, economic and environmental processes and activities. Citizen science provides an opportunity for local communities to get more involved in the weather and climate science as these impact their lives and livelihoods. The role of citizen scientists in the early warning is a field that is still growing in South Africa hence there is a need for more studies illustrating how the communities collect, interpret weather and climate information and how this is translated into disaster risk reduction and climate change response. Community volunteers have the potential to support national and international actors' efforts in building the resilience of communities to extreme weather events and climate change through mitigation and adaptation. The outcomes of this project are therefore critical to the two communities as this is expected to form the basis for decisions regarding water resource management and resilience to extreme weather events that affect the sustainability of local livelihoods. This will also enable decision-makers to understand the current situation with regard to the adaptive capacity of the communities to respond to the frequent extreme weather events.

Overall, the project found that early warning systems are essential for climate-related adaptation, risk reduction and resilience and that communities are willing to volunteer and assist in building resilience and awareness campaigns. For the successful use of the citizen science approach in South Africa, it is empirical that the best practices for citizen science in environmental monitoring, including weather and climate science as reported in this project be adopted.

Based on the outcomes of the project, the following recommendations are put forward:

- There is a need to engage actors at the community and local municipality levels to understand the social and environmental vulnerabilities within the country. Community volunteers provide many forms of expertise that can be used to identify disaster-prone areas based on past and current climate and extreme weather events as well as the impacts on the livelihoods. These actors can also provide a systems understanding of drivers of vulnerability, appropriate response actions and the needs of the communities.
- Future studies should focus on extending the weather and climate change monitoring network to other vulnerable communities and increasing the density of climate monitoring networks whilst also ensuring that they derive social benefits from participating in the studies.
- Efforts to develop citizen scientists should continue as these actors require sustained support and resources to facilitate the development and growth of a scientifically educated public who can also confidently integrate indigenous knowledge in early warning and climate change adaptation.
- Human capital development at the community level for citizens is important to enabling them to be more proactive and build their resilience to extreme weather events through citizen science which promotes bottom-up and top-down knowledge sharing and learning. As demonstrated in this project, co-designing and piloting a network for weather and climate change monitoring is, therefore, a good starting point for the development of human capital within communities, particularly where no such networks exist.

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Reference Group	**Affiliation**
Mr Bonani Madikizela	Water Research Commission (Chairman)
Dr Jean-marc Mwenge Kahinda	Council for Scientific and Industrial Research
Mr Ramogale Sekwele	Department of Water and Sanitation
Ms Dududzile Songinga	Department of Forestry, Fisheries and the Environment
Mr Barney Kgope	Department of Forestry, Fisheries and the Environment
Ms Namhla Mbona	South African National Biodiversity Institute
Dr Andre Pretorius	Consultant
Ms Nolusindiso Jafta	Department of Water and Sanitation
Others	**Affiliation**
Staff and learners	The Viva Foundation of South Africa
Staff and learners	Swayimane High School
Mr Lindokuhle Khanyile	uMgungundlovu District Municipality

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

ACRONYMS & ABBREVIATIONS

AWS	Automatic Weather Stations
AWS-LC	Low-Cost Automatic Weather Station
CBM	Community-based monitoring
CoCoRaHS	Community Collaborative Rain, Hail, and Snow Network
CPU	Central Processing Unit
CS	Citizen Science
DRR	Disaster Risk Reduction
EWS	Early Warning Systems
GHG	Greenhouse Gas
ICT	Information and communications technology
IKS	Indigenous Knowledge Systems
MiniSASS	Mini Stream Assessment Scoring System
mPING	Meteorological Phenomena Identification Near the Ground project
RCP	Representative Concentration Pathway
SAWS	South African Weather Service
UKZN	University of KwaZulu-Natal
UNCED	United Nations Conference of Environment and Development
UNEP	United Nations Environmental Programme
UNISDR	United Nations International Strategy for Disaster Reduction
WMO	World Meteorological Organisation

GLOSSARY

The term **citizen science** is confined to studies on environmental monitoring including weather and climate change. The term is used in this context to refer to the engagement of non-professional volunteers in scientific investigations, commonly in data collection, asking questions, quality assurance, data analysis and interpretation, problem definition and the dissemination of results (Gura, 2013; Bonney et al., 2014; Turrini et al., 2018).

Climate refers to weather conditions prevailing in an area in general over a long period (SAWS Dictionary, 2021).

Climate change describes the change of climate which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is in addition to natural climate variability observed over comparable periods.

Climate variation is a significant and lasting change in the statistical distribution of weather patterns over periods ranging from decades to millions of years (SAWS Dictionary, 2021).

A **volunteer or citizen scientist** is a person who participates in a project by helping define its focus, collecting and/or analysing data at the local level and this work is unpaid.

The term **resilience** is used to describe the ability of a social or environmental system to absorb disturbances such as climatic hazards (e.g. drought, floods) while retaining the same basic structure and ways of functioning, the capacity for self-organization and the capacity to adapt to stress and change (UNEP, 2017).

Weather is the state of the atmosphere, particularly concerning its immediate effects upon human affairs, plants, animals and to a lesser extent upon the inanimate objects and processes (SAWS Dictionary, 2021)

Box 1: Atmospheric and Meteorological terminology in Tswana, Xitsonga, Sepedi, IsiZulu and Afrikaans

Climate: Tlelaemete/Tlilayimete/Tlelaemete, bosatelele/Isimomvama sezulu/Klimaat

Climate change: Phegotlelaemete/Ncincatlilayimete/Phetogotlemaemete, phetogobosotolele/Uguquko lwesimomvama sezulu/klimaatsverandering; klimaatverandering

Climate variation: Dipharologanotlelaemete/Ncincancinco wa tlilayimete/ Pharologanyobosotelele/Ukuquguquka lwesimomvama sezulu/Klimaartvariasie; klimaatsvairisie

Weather: Bosa/Maxelo/Boso/Isimo sezulu/Weer

(Source: SAWS Dictionary, 2021)

1. Background

1.1. Introduction

Extreme weather and climate events such as intense storms, heatwaves, and droughts affect the livelihoods of people globally, as well as climate sensitive sectors such as agriculture, water, health, human settlements, and energy. The impacts of such events depend heavily on the vulnerability of the area and are likely to be felt the most at the community level. In South Africa, due to the triple challenges of inequality, poverty, and unemployment a significant proportion of the communities in both rural and urban areas have limited adaptive capacity to respond to the frequent extreme weather events such as floods and hailstorms. It is therefore important to develop the required human capital, especially at the community level for citizens to be more proactive and build their resilience to extreme weather events through citizen science which promotes bottom-up and top-down knowledge sharing and learning.

Most disaster risk reduction activities emphasize that citizens need to be an integral part of managing and reducing the risk caused by extreme weather events (Wisner et al., 2001; Kelman et al., 2011 and Scolobig et al., 2015). However, these approaches are not referred to as citizen science but “people centred DRR” as they focus on citizen empowerment and involvement in managing their risk in the long term (Hicks et al., 2019). Studies by Mille-Rushing et al. (2012) illustrated the role of citizens in ecological research based on the non-scientific records collected by communities, and understanding of changes that have occurred in ecosystems. According to Chari et al. (2019), the involvement of voluntary community members in environmental monitoring has occurred for a long time and has enabled scientists and academia to make scientific advancements that inform policy and decision making. Aspects of citizen science identified as important include enhancing public understanding of science, building social capital through the enhancement of community capacity to work toward identified goals, helping to build an equal relationship between scientists and citizens or non-scientists, filling knowledge gaps, driving policy changes and community policing to ensure adherence to regulatory frameworks (Kimura and Kinchy, 2016).

Current and future projections indicate that climate change and variability will have a significant impact, especially on climate sensitive sectors. Projected changes in climate also pose exacerbated risks to the sustainability of the ecosystem, specifically on water and food security, biodiversity conservation, control of climate and disease and health. Extreme weather events such as intense storms, heatwaves and increases in the number of very hot days usually affect the health and livelihoods of vulnerable communities. However, many communities in South Africa are often unaware and unprepared for extreme weather events. Undoubtedly, there is a need to engage citizens and build their capacity and decision-making tools to provide innovative solutions that will guide the effective development of climate change adaptation and mitigation strategies for a sustainable society and economy.

Significant amounts of research and products have been produced to support disaster preparedness and climate change response. This includes the work by the South African Weather Service (SAWS) which has the mandate to provide extreme weather, natural disasters and climate action. Forecasting severe weather hazards has improved significantly over the last few decades due to scientific developments in this field. Despite this improvement, accurate and timely warnings of an approaching severe weather hazard do not imply a good response leading to the safety of life or preventing major economic disruption. Therefore, severe weather warnings need to provide useful, timeous and relevant information to the users (disaster managers and the public) on the expected severity and the associated likely level of the adverse impact of the hazard to support their decision-making on the most appropriate actions. Tweedle et al. (2012) suggest that citizen science can be used to raise awareness of non-professionals to environmental issues in their community and allows for like-minded people to get involved. This process requires citizens to co-design, co-produce and co-implement knowledge around climate extremes, i.e. citizen science that allows for social and cultural constructs of risk to be integrated into disaster risk reduction.

This project used a case study approach to support citizens in two selected study sites to create a shared vision to enhance water resource management and resilience to extreme weather events that affect the sustainability of local livelihoods. The approach involved simplifying the technical language around weather and disaster risk reduction to ensure a shared understanding of the risks while also allowing for informed participation in designing and implementing risk management measures. The study also included a component of building interest amongst the youth and school children in meteorology so that there are more students registering for meteorology at universities. Furthermore, the project also included the installation and monitoring of weather stations that the citizens use to collect local weather information which can be integrated with indigenous knowledge on the seasonal forecast and future climate projections.

1.2. Project Aims

The project aimed to develop a monitoring network as a citizen scientists' tool for the early detection of disasters related to changing weather and climate in order to mitigate their impacts on livelihood. The following were the specific objectives of the project:

1. Re-package the highly technical concepts and information on disaster for citizen scientists' early warning
2. Strategically design and pilot test a weather and climate change monitoring network
3. Cost the network based on selected cost-effective indicators, their spatial distribution, data management system and reporting
4. Through workshops/dialogues, train citizen scientists to engage, empower and enhance resilience to weather and climate changes

1.3. Scope and Limitations

The project focused on two communities in the City of Tshwane and KwaZulu-Natal to develop a monitoring network that would enable citizens such as schools, youths and community-based groups to anticipate and respond to extreme weather events as well as support water resource management. Specifically, the project targeted the Greater Umgeni and Crocodile River catchments systems. The study was limited to two sites that have experienced extreme weather events that caused damage to agricultural fields, affected water resources, homes, and other infrastructure. Besides, the basis for the selection of these sites was that the SAWS and the University of KwaZulu-Natal (UKZN) were leveraging on an already established partnership on ongoing work to develop an integrated climate driven multi-hazard early warning system. The work involved the use of both indigenous and scientific knowledge on early detection of disasters and possible mitigation of the impacts on the community and livelihoods. The project was impacted by the COVID-19 pandemic and resulted in delays in both physical engagements with the communities and the installation of the weather stations.

For this project, a total of four deliverables were completed to address the aims of the project. These deliverables were combined into this final report, consisting of three sections, and the training manual and other supplementary materials used in the project are provided in the Appendices section.

2. Best-Practice and Latest Weather and Climate Change Knowledge Report

2.1. Introduction

The impacts of climate change and variability are becoming inevitable and future projections indicate that the impact, especially on climate-sensitive sectors including agriculture, water, health, human settlements, and energy presents opportunities for multiple actors (including communities) to get involved. The participation of voluntary community members or citizen scientists in environmental monitoring has occurred for a long time and has enabled scientists and academia to make scientific advancements that inform policy and decision making (Chari et al., 2019). Among the global initiatives to support climate change and disaster risk the Sendai Framework for Disaster Risk Reduction and the United Nations Conference of Environment and Development (UNCED) Principle 10 highlight the need for citizen participation and engagement in climate response. The Sendai Framework emphasises explicitly that all social engagements and partnerships for participation should be voluntary, empowering, inclusive, accessible and non-discriminatory (Wahlström, 2015).

Addressing climate change in developing contexts such as South Africa is not easy as this is juxtaposed against the triple challenges of inequality, poverty, and unemployment. Consequently, a significant proportion of the South African communities in rural and urban areas have limited adaptive capacity to respond to frequent extreme weather events such as floods and hailstorms. Undoubtedly, there is a need to develop the required human capital and decision-making tools to provide innovative solutions that will guide the effective development of climate change adaptation and mitigation strategies for a sustainable society and economy. It is imperative, therefore, to develop the human capital required especially at the community level for citizens to be more proactive and build their resilience to extreme weather events through citizen science which promotes bottom-up and top-down knowledge sharing and learning. Citizen science enables the communities to co-design, co-implement weather and environmental management initiatives to mitigate the impacts of extreme weather events. Additionally, it can also support the integration of indigenous and traditional knowledge in scenario planning through an increased understanding of the key livelihood activities, drivers of change and the desired adaptation futures.

Citizen science or the participation of non-scientists in scientific research is not a new concept. Non-scientists have been collecting scientific data from as far back as the 19th century, and early scientific inventions and discoveries were made by non-scientists in fields such as biology, astronomy and physics, and the environmental sector (Silvertown, 2009; Roy et al., 2012). Citizen science is a field that is growing in significance and importance because of its participatory nature and promotes environmental education, increased interactions between scientists and non-scientists as well as environmental monitoring at the local level (Bonney et al., 2009a; Rory et al., 2012). The work by Kimura and Kinchy (2016) suggests at least seven distinctive virtues of citizen science that promote its increased usage, i.e. enlarging samples sizes studies at a lower cost, enhancing public understanding of science, building social capital through the enhancement of community capacity to work toward identified goals, helping to build an equal relationship between scientists and citizens or non-scientists, filling knowledge gaps, driving policy changes and community policing to ensure adherence to regulatory frameworks.

Several research works have emphasized the need for citizens to be an integral part of managing and reducing the risks caused by extreme weather events (Wisner et al., 2001, Kelman et al., 2011, Scolobig et al., 2015; Marchezini et al., 2018). Disaster risk reduction and climate change response encompass aspects such as forecasting, climate projections, early warning, risk assessment and communication, emergency preparedness and response for current and future weather-related risks. Building the resilience of communities requires communities to also engage in monitoring the changes and impacts at the local level, resources and infrastructure to record, communicate warnings and respond. Two approaches for early warnings systems have been adopted that focus on i) hazard-centred and top-down and; ii) people-centred and bottom-up (Kelmann and Glantz, 2014; Marchezini et al., 2018). Citizen science promotes bottom-up and top-down knowledge sharing and learning. In South Africa, many communities are often unaware and unprepared for extreme weather events. Extreme weather events such as intense storms, heatwaves, and increases in the number of very hot days usually affect their livelihoods, human settlements as well as human health. As such, there is a need to engage citizens and build their capacity to respond by providing simplified tools that can support citizen engagement to mitigate the impacts of extreme weather events. This includes a weather station that citizens can use to collect local weather information which can be integrated with indigenous knowledge on the seasonal forecast for example to plan for planting seasons.

This report provides insights into the evolution of the concept of citizen science, best practices for citizen science in environmental monitoring, including weather climate science, challenges and opportunities from a review of the literature. Furthermore, the report also provides a synopsis of weather and climate information in the two case study sites of Swayimane in the Umgeni catchment and Mamelodi in the Crocodile Catchment selected to enhance water resource management and resilience to extreme weather events that affect the sustainability of local livelihoods.

2.2. Citizen Science: Concept, Bibliometric Analysis and Case Studies

2.2.1. Concept of citizen science

Citizen science is defined as the engagement of non-professional volunteers in scientific investigations, commonly in data collection, asking questions, quality assurance, data analysis and interpretation, problem definition and the dissemination of results (Gura, 2013; Bonney et al., 2014; Turrini et al., 2018). This definition of the citizen science concept is well established; however, several other definitions exist and are under debate in the scientific community (Buytaert et al., 2014; SWD, 2020). Heigl et al. (2019) proposed an international definition of citizen science based on quality criteria for projects. However, Auerbach et al. (2019) argue that specified minimum quality criteria should not be used, instead, they propose collaboration among all engaged actors and encourage the citizen science community and associated collaborators to determine the best design specifications which fit the unique contexts of the project.

Authentic citizen science projects can be distinguished from more general projects that engage with the public and stakeholders by the relative level of active participation throughout the project, which is underpinned by one or more motivational aspects (Paul et al., 2018). Citizen science is an approach whereby non-scientists are actively involved in the generation of new scientific knowledge from which they also actively benefit either intrinsically or extrinsically (Buytaert et al., 2014). Haklay (2013) defined a framework as a typology that focuses on four levels of citizen science participation. The successive participatory levels include the progression from primary data collection (crowdsourcing, Level 1) through to distributed intelligence (citizens as basic interpreters, Level 2), to participatory science (Level 3), and collaborative science (Level 4) which includes defining the research question and scope, data collection and data analysis.

The Science Communication Unit, at the University of the West of England (2013) stated two common interpretations of the term 'citizen science': the first is related to forms of knowledge beyond the scope of professional science, often referred to as lay, local and traditional knowledge; and the second interpretation is related public participation in science, which in practice is closer to simple crowdsourcing. According to Bonny et al. (2009a), there are different types of environmental citizen science initiatives; the majority are 'contributory' (designed by academics/research organizations, involving the collection of monitoring data by volunteers); 'collaborative' projects (designed by researchers, with volunteers contributing data, refining project design, analyzing data and/or disseminating findings) and 'co-created' initiatives (volunteers and researchers work together throughout).

Traditionally, the application of citizen science is well established within the fields of conservation, ecology, and environmental monitoring (Bonney et al., 2014, 2016; Kosmala et al., 2016, Kullenberg and Kasperowski, 2016; Forrester et al., 2017). A steady increase in the number of studies is also noted in the application of citizen science to the field of Earth Science (Paul et al., 2018; Lee et al., 2020). Although the majority of citizen science projects are carried out in the fields of biology, conservation, and ecology which are presented in the bibliometric analysis in the following section, citizen science projects are expanding in other areas such as climate sciences and meteorology (Liu et al., 2020). In meteorology, citizen science projects invite citizens to provide and analyse weather information. Some examples of the citizen science projects include the Cyclone Centre; the Community Collaborative Rain, Hail, and Snow Network (CoCoRaHS); and the Meteorological Phenomena Identification Near the Ground project (mPING) all of which invite citizens to provide or analyse storm information (Liu et al., 2020).

2.2.2. Bibliometric analysis: Evolution of the concept of citizen science

This section explores the evolution and importance of citizen science in advancing weather and climate knowledge, based on a bibliometric analysis method. Bibliometric analysis is a statistical method used to assess the evolution of specific disciplines, scientific domains, or research fields over time, through a science mapping approach (Zupic and Cater, 2015; Aria and Cuccurullo, 2017). In the bibliometric analysis, a descriptive and different research-structure analysis is conducted on the scientific published data (encompassing information such as the authors, papers/documents/articles/, titles, keywords, and references, among others) collected from the bibliographic databases. Information derived from this analysis includes annual research development, the most productive authors/countries, most relevant and frequent keywords as well as the emerging hot topics in the research subject matter. In the current study, the set of analysed documents were retrieved from the Web of Science (WoS) and Scopus bibliographic databases. The literature search was restricted to citizen science awareness and advances in weather and climate information in communities. The term “citizen science” was used as a search topic in conjunction with “weather and climate” joined by the Boolean operator [AND]. An example of the document search in both WoS and Scopus was set as follows: “citizen science” AND “weather and climate” AND “knowledge”.

The combined topic search means that the term “citizen science” is identified in the title, the abstract, and/or in the keywords of the publications, the quotation marks are included to restrict the search term. Other search topics used in conjunction with “citizen science”, include “climate change adaptation”, “local governance capacity”, “disaster monitoring”, “decision-making”, “climate practices”, and “community volunteers”. The current bibliometric analysis focused on two subfields analysis, namely, the keywords co-occurrence analysis and thematic networks analysis. These subfields were visualized based on the R and VOSviewer software (Aria and Cuccurullo, 2017; Van Eck and Waltman, 2014).

2.2.2.1. Subject categories and emerging themes in citizen science

Keywords (co-word) analysis provides a descriptive assessment of subject categories and identifies the critical topics covered in the respective clusters. Keywords appearing in the same cluster/category often represent a special research topic, consequently, such keywords have essential relationships, with the strength of the relationship measured by the distance between the keywords (An & Wu, 2011; Zong et al., 2013). The keywords network depicted in the top panel of Figure 1. identifies three subject categories, grouped in three colour-coded clusters. The red cluster highlights keywords mostly used in hydrology, particularly dealing with groundwater resources management. These keywords include groundwater resources, aquifers, watershed, streamflow, hydrogeology as well as ecology. Also, in the red cluster, the aspects of citizen science are represented by the term "local participation" with the terms "climate change adaptation" and "adaptive management" representing the added value of advancing weather and climate knowledge in communities.

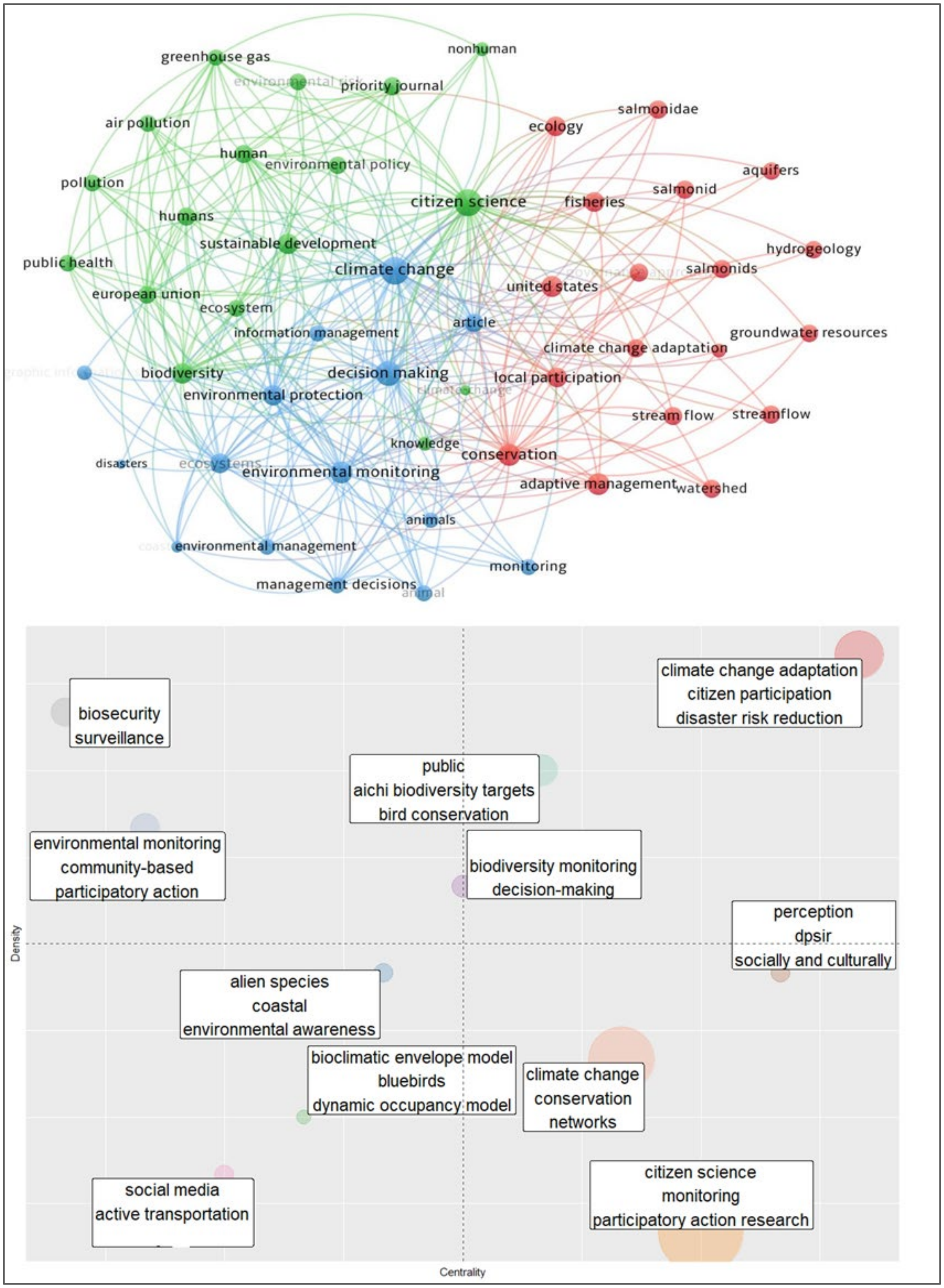


Figure 1. Frequency of keywords (top panel) and emerging themes in citizen science (bottom panel).

The green cluster is more concerned with environmental monitoring. Examples of keywords in the cluster, relating to environmental monitoring include pollution, ecosystem, biodiversity, sustainable development and greenhouse gas. The term “citizen science” also appears in the green cluster, linking other terms across the three clusters. The value of citizen science in advancing weather and climate knowledge in this cluster is to support environmental policy and mitigate environmental risks. The keywords appearing in the blue cluster imply that citizen science contributes towards environmental protection, management, and monitoring, thereby supporting decision-making and mitigating natural disasters, attributed to climate change. A thematic map, depicted in the bottom panel of Figure 1. gives four typologies of themes, defined and placed according to the position of the quadrant. Motor themes, e.g. “climate change adaptation”, “citizen participation”, “disaster risk reduction”, “biodiversity monitoring”, and “decision-making”, among others, appearing in the upper-right quadrant, have high centrality and density, suggesting that they are developed and are important in the citizen science subject matter.

Themes in the upper-left quadrant, e.g. “biosecurity”, “surveillance”, “environmental monitoring”, “community-based” and “participatory action”, have low centrality, meaning that while these themes are highly developed, they have limited importance in citizen science subject-matter. Themes appearing in the lower-left quadrant are characterized by low centrality and density (i.e. are weakly developed, and insignificant), consequently, considered to be emerging or declining. These emerging/declining themes include “environmental awareness”, “active transportation” as well as aspects of modelling, such as “bioclimatic envelope model” and “dynamic occupancy model”. Lastly, transversal themes, e.g. “climate change”, “citizen science”, and “participatory action research”, in the lower-right quadrant, are characterized by high centrality and low density. In addition, the abbreviation “DPSIR”, defined as the “*Driver-Pressure-State-Impact-Response*”, which is a proposed framework that links the driving forces (e.g. economic sectors, human activities), through pressures (emission, waste), to states (physical, chemical and biological), and impacts (on ecosystems, human health, water quality, air quality) leading to political responses (prioritization, target setting, indicators) (Kristensen, 2004), also appears in the lower-right quadrant.

This framework is an important theme that deals with the causal chain from driving forces to impacts and responses, an essential aspect that can be integrated into citizen science and weather and climate knowledge-related projects. While themes appearing in the lower-right quadrant are still in the developing stage, they are generally essential for the development of citizen science and its advancement in promoting weather and climate information and knowledge within the communities.

2.2.3. Case Studies illustrating citizen science in environmental monitoring including weather climate research

The following section presents some case studies from a review of the literature on the global and national scale summarized in Table 1 below. The case studies illustrate the role of citizen scientists in environmental monitoring which includes studies on the mapping of rainfall and groundwater to support sustainable agriculture, monitoring of volcanic activities, and spread of diseases due to climate change.

Table 1. Case studies illustrating the role of citizen science in environmental monitoring.

Area	Case Study	Description	Source
Earth Systems and Environment Sciences	Citizen scientists and environmental volcanology – **Iceland and South America _ 2009**	Citizen science fieldwork on volcanoes carried out yearly since 2008. Implications for local people include a build-up of pollutants in their crops. Unerupted magma can remain molten at shallow depths for many months and affect the local environment, and the magma movements can be detected many years in advance of the eruption. High concentrations of gases at active volcanic sites can cause heavy metal pollution of soil, water and the atmosphere. The project integrates expertise in volcano monitoring, modelling and public engagement with the delivery of comprehensive hazard awareness, preparedness and mitigation. Over 500 citizen scientists have collected geophysical and environmental data since 2000.	**https://impact.ref.ac.uk/casestudies/CaseStudy.aspx?Id=32203**
Weather, Water and climate	Measurement and mapping of precipitation (rain, hail and snow) – **United States**	Community Collaborative Rain, Hail & Snow Network (CoCoRaHS) is a non-profit, community-based network of citizens who measure and map precipitation (rain, hail and snow) in the United States. The network has an interactive website (www.cocorahs.org), where data can be uploaded and viewed. The website contains various resources to train and educate volunteers in correct precipitation measurement. It also provides guidelines and instructions on rain gauge purchase and installation, snow measurement, making hail pad instruments to record the location, time, size, quantity and hardness of hailstones. The real-time precipitation data are open to the public (e.g. national weather service, commercial entities, farmers and recreation). In 2015, CoCoRaHS volunteers submitted over 31 million daily precipitation reports and tens of thousands of hail reports, heavy rain, and snow. The demand for and use of CoCoRaHS data by professional and scientific users has increased in the past decade.	**Reges et al., 2016** **https://www.cocorahs.org**
Disease and climate change	Citizen Science and Community Engagement in Tick Surveillance – A **Canadian** Case Study	The project on the ongoing surveillance of Lyme disease, a common tick-borne disease in North America and Europe, monitors the spread of the tick vectors as their populations expand under the influence of climate change. Recruitment of volunteer researchers included members of the community and municipal leaders who provided information on tick surveillance. Citizen scientists were provided with information on the use of personal protective clothing and how to do tick checks. Tick surveillance has increased community awareness and commitment to tick bite prevention practices and decreased the risk of tick-borne disease in that community	**Lewis et al., 2018**

Area	Case Study	Description	Source
Climate change	Assessing hurricane damage and identifying priority areas for rebuilding efforts – **Caribbean island**	Multiple Caribbean island nations were struck by two hurricanes: (Hurricane Irma and Maria) – 2017. Rescue Global a non-profit disaster relief organization responded by requesting help from Planetary Response Network (PRN) to assess the damage and identify priority areas for rebuilding efforts. Over 5,000 volunteers joined, providing 650,000 classifications of images covering eight island nations. Volunteers classified various types of damage, including flooded areas and impassable roads, and identified temporary settlements. Analyses were used to produce heat maps of damage that Rescue Global used to aid in resource allocation and surveillance decisions.	**Chari et al., 2019**
Water and agriculture	Provision of information on the well water levels precipitation and status of rivers and streams by remote villages – Ga-Komape and Ga-Manamela, Limpopo **South Africa**	The project focused on supporting potato farmers in Ga-Komape and Ga-Manamela, Limpopo South Africa to monitor and efficiently use underground water. Scientists relied on farmers (non-scientists) to provide data that is otherwise inaccessible. Volunteer farmers put dip meters into the wells and provided information on the water levels in the wells, the amount of precipitation as well as sent photos to show the status of rivers and streams – whether flowing or not. The information is captured through an App on smartphones and sent to the internet to enable the farmers, households, government and tourists to see it.	https://www.news24.com/news24/columnists/guestcolumn/opinion-citizen-scientists-perhaps-without-a-degree-but-certainly-making-a-difference-20210206
Water and sanitation	Shiaybazali and the Howick Wastewater Treatment Works (HWWTW); Howick, KZN **South Africa**	The outflow of the Howick Wastewater Treatment Works in the Shiyabazali informal settlement represents a major health risk to Shiaybazali residents. EnviroChamps used a clarity tube (developed through the project) to monitor the water quality of the treated HWWTW effluent three times daily. Data collected revealed that outflow was outside of discharge limits and supported the development of tools to improve the management of wastewater and reduce health risks.	**Graham and Taylor, 2018**
Water and sanitation	Wise Wayz Water Care project – Resolving water leaks in Ezimbokodweni, Ezimbokodweni, eThekwini KZN **South Africa**	The project implemented a Door-to-Door education and communication campaign in Ezimbokodweni and Folweni in eThekwini Municipality. Volunteers were involved and received training on measuring water leaks as well as on actions to be taken when leaks are identified. The community had a water leak problem that caused major erosion between houses. The Wise Wayz Water Care team worked with the community and empowered them to repair damage on their properties.	**Graham and Taylor, 2018**

2.2.4 Citizen Science and early warning systems

Citizen science is significant and becoming effective in disaster risk reduction (DRR) and has demonstrated success, particularly in providing early warning of hazards, advancing scientific knowledge, and the assessment and management of impacts (Hicks et al., 2019; Marchezini et al., 2018). Citizen science can promote community-based local data collection on the effects of climate change, which is useful for improving the understanding of local and global patterns of climate change. Effective responses to climate change related disaster risks are still emerging at government, private sector, and community levels (Albagli and Iwama, 2022). Currently, most disaster risk management activities focus on post-disaster recovery actions and less on prevention and mitigation (Marchezini et al., 2018; Hicks et al., 2019). Albagli and Iwama (2022) have stated that policies and actions at different levels through the participation and sensitisation of the most affected and vulnerable social groups, policy makers and private actors are expected to provide communities with greater capacity and safety to tackle some of the effects of climate change.

The United Nations International Strategy for Disaster Reduction (UNISDR) conference in 2016 discussed the implementation of the Sendai Framework for Disaster Risk Reduction focusing on interdisciplinary methods, robust data collection, tools and better communication in early warning systems (EWS) (Marchezini et al., 2018). The UNISDR lacks explicit means for implementing people-centred EWS approaches, however, some working groups recognised the need for bottom-up and participatory approaches in disaster risk research, and considered co-production of knowledge and the integration of indigenous knowledge and using citizen science programs (Aitsi-Selmi et al., 2016). There are two main approaches to EWS: the hazard-centred (top down); and people-centred (bottom up) approaches (Garcia and Fearnley, 2012). This study adopted the people-centred EWS where the vulnerable communities to extreme weather events will generate knowledge and be part of the citizen science based EWS. The study will apply the four components of EWS highlighted in Marchezini et al. (2018): risk knowledge, monitoring, communication and response capability.

2.2.5 Indigenous knowledge and early warning system

Indigenous knowledge plays an important role in enabling local communities to understand or interpret environmental changes, mostly at a local level. With the current changes in weather and climate, indigenous knowledge systems (IKS) are becoming important as communities adapt to these changes through indigenous weather forecasting techniques that form part of the early warning system (Mwenge Kahinda et al., 2019). Through these techniques, communities can predict seasonal climate change, such as the onset of rainfall, and predict which areas will receive more rainfall and the end of rainfall. According to Altieri et al. (2012), IKS are forms of knowledge that have originated locally and naturally and are bodies of knowledge of the indigenous people of particular geographical areas that are unique to a given culture or society and linked to the communities that produce them. IKS have been used in many communities in various parts of the world to predict drought or flood, hailstones, good rainy seasons, cyclonic storms/disaster among other environmental changes as noted by Speranza et al. (2010), Roncoli et al. (2002), Gebresenbet and Kefale (2012), Enyew and Hutjis (2015), Egeru, 2012, and Sethi et al. (2011). According to Luseno et al. (2003) pastoralists (Ariaal, Boran, Chamus, Gabra and Rendille tribe) from northern Kenya and southern Ethiopia (Guji tribe) observe the wind speeds, movement of stars, the position of the moon and lightening to predict the next rain season while others interpret dreams or observe animal (livestock, wildlife or local flora) behaviour or read intestines of slaughtered animals such as goats, sheep and cattle to predict the period of a drought, the severity, affected areas, and disease outbreak. In West Africa, in parts of Burkina Faso, farmers mostly observe food production trees at the beginning of the rainfall season and temperatures during the dry season, and also observe winds, sky, plants, animals and the behaviour of birds and insects to predict estimate the onset date, intensity and the duration of the cold and dry season while others rely on spiritual powers inherited acquired through initiation or election by the spirits.

In South Africa, farmers in the South-Western Free State who often experience climate and weather related disasters rely on weather and climate linked indicators to predict immediate seasonal rains and droughts, including observing animal and plant behaviour, as well as observing other climatic elements (Zuma-Netshiukhwi et al., 2013). An example is the use budding of acacia Karoo and sprouting of Aloe ferox in the mountains as an indication of coming good rains. Furthermore, the farmers also observe the flowering of wild lilies in the veld and dropping of fig tree leaves (Ficus carica) which indicate the onset of summer while drying of immature fruits on the trees and dropping between September and October indicate drought. In the same vein, farmers in the Karoo (Beaufort West, Prince Albert and Oudtshoorn region), Ganyesa Village of North West observe the fauna to predict weather conditions and calves running and playing in the field in the Karoo (Beaufort West, Prince Albert and Oudtshoorn region and in the South Western Free State indicate the coming of rain in few days (Tlhompho, 2014). Furthermore, the collection and storing of food by black ants, the presence of red ants and a rapid increase in the size of moist anthills, the appearance of reptiles like snakes moving up and down in the mountains between August and September, appearance of red dominated rainbow colours between June and July as well as increased libido in goats are used as signs of good rains in the Karoo and the South Western Free-State. Along similar lines, Rankoana (2016) points out that in the Mogalakwena community in Limpopo Province the hesitation of the cattle herd to go to graze in the veld signals the coming of rains within a few hours and the production of yellow flowers by the Senegali plant species indicates that the rains are coming and the beginning of a good season, while deep-yellow or pale flowers predict limited rainfall. Grunting of pigs indicates low humidity and an increase in temperature in the South Western Free state, and the presence of tortoises indicates thunderstorms (Ncube and Largedian, 2015). All these examples show the importance of IKS in early warning systems. The case studies also reveal that IKS can help to meet the broader objectives of society, such as conserving the environment, developing sustainable agriculture and ensuring food security, while its protection encourages the maintenance of traditional practices and lifestyles and can also play a major role in the development of weather and climate early warning systems. Understanding local skills, philosophies, technologies and knowledge is therefore important in informing decision making about aspects such as agriculture, natural disaster management, food security, and climate change. It is in this vein that the IKS component was included in this project although it could not be explored thoroughly due to COVID-19 restrictions that made engagements difficult.

2.3. Climate in the Crocodile and Umzimkulu Catchments

2.3.1. Study sites

With several setbacks to achieving the Paris target of limiting global temperatures below 2°C with existing climate change policy approaches, the adoption of the citizen science approach will facilitate citizen agency in driving policy change and influencing citizen behaviour. The approach will accelerate climate action and policies that will influence the effective development and implementation of climate change adaptation and mitigation strategies. The selected two pilot areas (see Figures 2 to 4) were used to demonstrate and provide climate change information to the citizen scientists. The process will allow for more data collection and larger scope than would be possible with the traditional model of lab-based scientific inquiry.

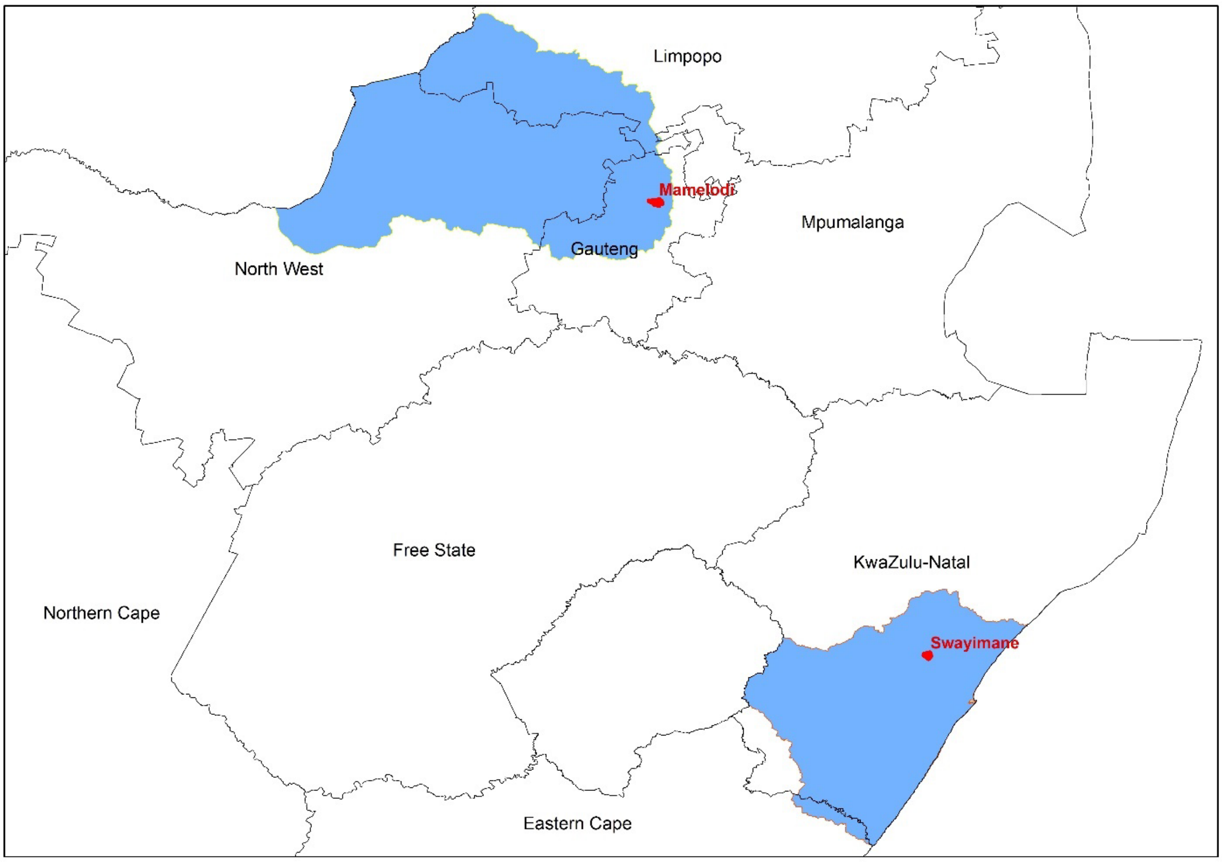


Figure 2. Location of 2 pilot areas for the implementation of Citizen Science.

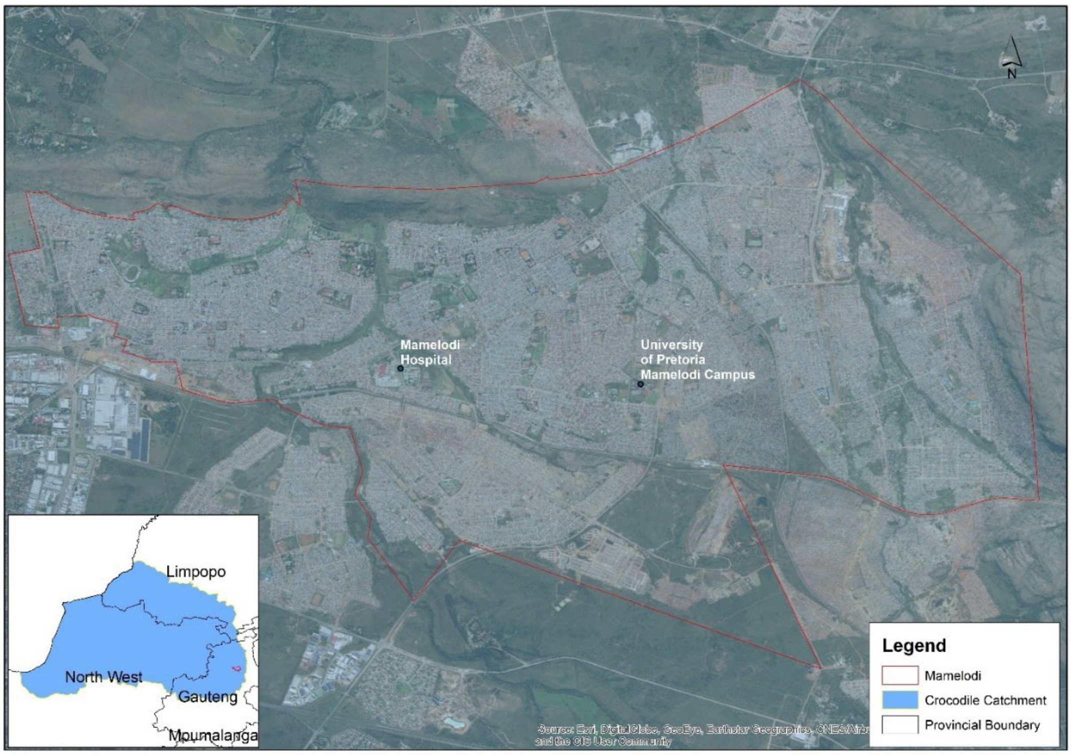


Figure 3. Location of Mamelodi, the City of Tshwane within the Crocodile Catchment.

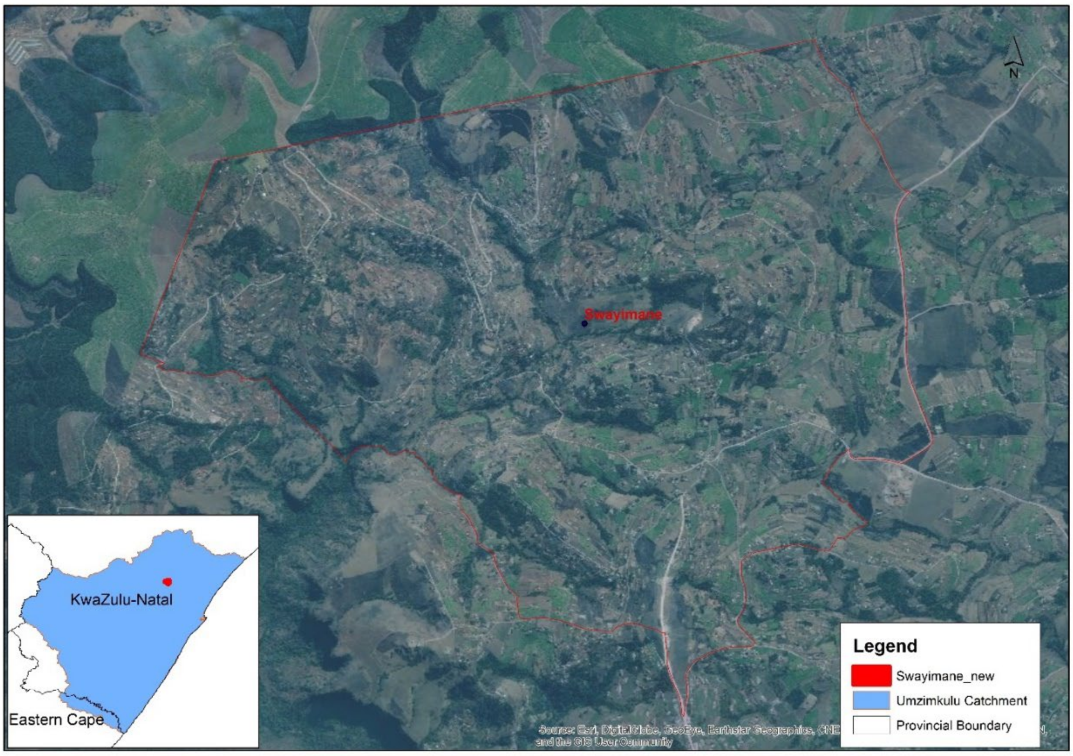


Figure 4. Location of Swayimane, UMgungundlovu in the Umzimkulu Catchment.

2.3.2. Climate Change projections

Mamelodi, City of Tshwane is located within the Crocodile catchment as shown in Figure 3 while Swayimane, UMgungundlovu is situated in the Umzimkulu Catchment Figure 4. The projected change in rainfall, minimum and maximum temperatures relative to a base period of 1976-2005 are shown in Figures 5 to 10. The projections are made for three time periods of present climate (2006-2035); near climate (2036-2065) and far distant climate (2066-2095) under two climate change scenarios of Representative Concentration Pathways (RCPs) 4.5 and 8.5. The RCP4.5 and RCP8.5 trajectories are associated with CO2 concentrations of approximately 560 ppm and 950 ppm, respectively, by the end of the century 2100 (Riahl et al., 2011). The RCP8.5, also known as "business as usual" is projected to increase even further to a CO2 concentration ceiling of approximately 1200 ppm after the year 2100, while the RCP4.5 is based on active GHG emission reduction interventions that could lead to a ceiling of approximately 560 ppm (a doubling of concentrations since the start of the industrial revolution) by the year 2100, while concentrations could stabilise or even decrease after the year 2100.

As shown in Figure 5 and Figure 8, annual rainfall is projected to significantly decrease over the two catchments for all periods and scenarios. In particular, annual rainfall is estimated to decline by almost 25 mm, 30 mm, 60 mm under the RCP4.5 and by 30 mm, 55 mm and 74 mm under RCP8.5 for present climate (2006-2035); near climate (2036-2065) and far distant climate (2066-2095) over the Crocodile catchment. A significant decrease is evident in the north-eastern and south-western (location of Mamelodi) region of the catchment with relative no change in annual rainfall over the western and central parts of the catchment. On the other hand, annual rainfall is projected to significantly decrease by about 150 mm, 250 mm, and 300 mm under RCP4.5 and by about 200 mm, 300 mm and 450 mm under the RCP8.5 5 for the present climate (2006-2035); near climate (2036-2065) and far distant climate (2066-2095) over the Umzimkulu catchment. The significant decline in annual rainfall is pronounced in the western and southwestern parts of the catchment. Annual rainfall in the northern, central and eastern parts of the catchment is projected to relatively remain unchanged.

Results of minimum temperatures are presented in Figure 6 & Figure 9 while maximum temperatures are presented in Figure 7 and Figure 10 for Crocodile and Umzimkulu catchments, respectively. Both minimum and maximum temperatures are projected to increase in the two catchments for all periods under RCP4.5 with a further increase under RCP8.5. In the Crocodile catchment, the minimum temperature is projected to increase by 1.1 °C in the present climate and to about 2.7 °C by the end of the century under RCP4.5. The minimum temperature is projected to further increase under the RCP8.5 with the minimum temperature increasing by about 1.2 °C in the present climate (2006-2035) and about 4.7 °C towards the end of the century (2066-2095). Similarly, the maximum temperature is projected to increase by about 1.05 °C, 2.04 °C and 2.7 °C and by about 1.07 °C, 2.6 °C and 4.7 °C for the period 2006-2035, 2036-2065 and 2066-2095 under RCP4.5 and RCP8.5 respectively. The minimum temperature is projected to increase more than the maximum temperature in the Crocodile catchment. Over the Umzimkulu catchment, the minimum temperature is projected to increase by about 0.85 °C in the present climate and by the end of the century minimum temperature is projected to have increased by 2.2 °C under RCP4.5 and by 0.9 °C in the present climate and further increase of about 3.8 °C by 2066-2095 under RCP8.5. The maximum temperature is projected to increase more than the minimum temperature increased by about 1 °C, 2.1 °C, 2.6 °C and 1.1 °C, 2.6 °C and 4.5 °C for the period 2006-2035, 2036-2065 and 2066-2095 under RCP4.5 and RCP8.5 respectively. The significant increase in temperatures is evident in the western part of the catchment.

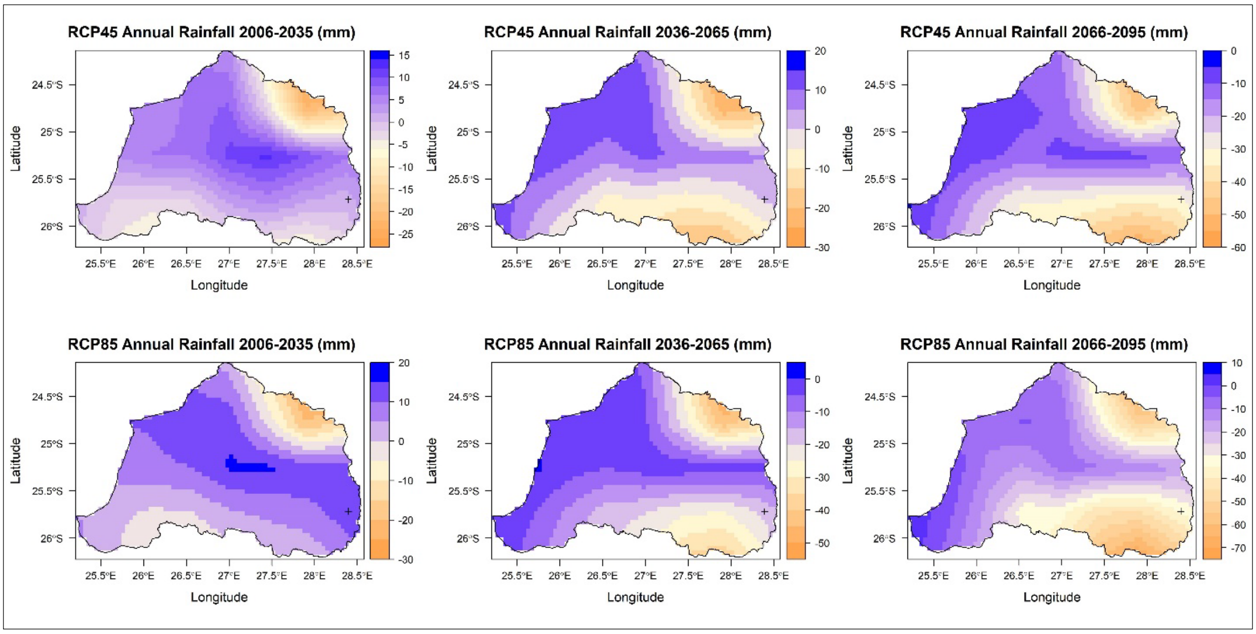


Figure 5. Projected changes in annual total rainfall for 2006-2035 (1st column), 2036-2065 (middle column) and 2066-2095 (3rd column) periods under scenarios of the RCP4.5 (1st row) and RCP8.5 (2nd row) Crocodile catchment.

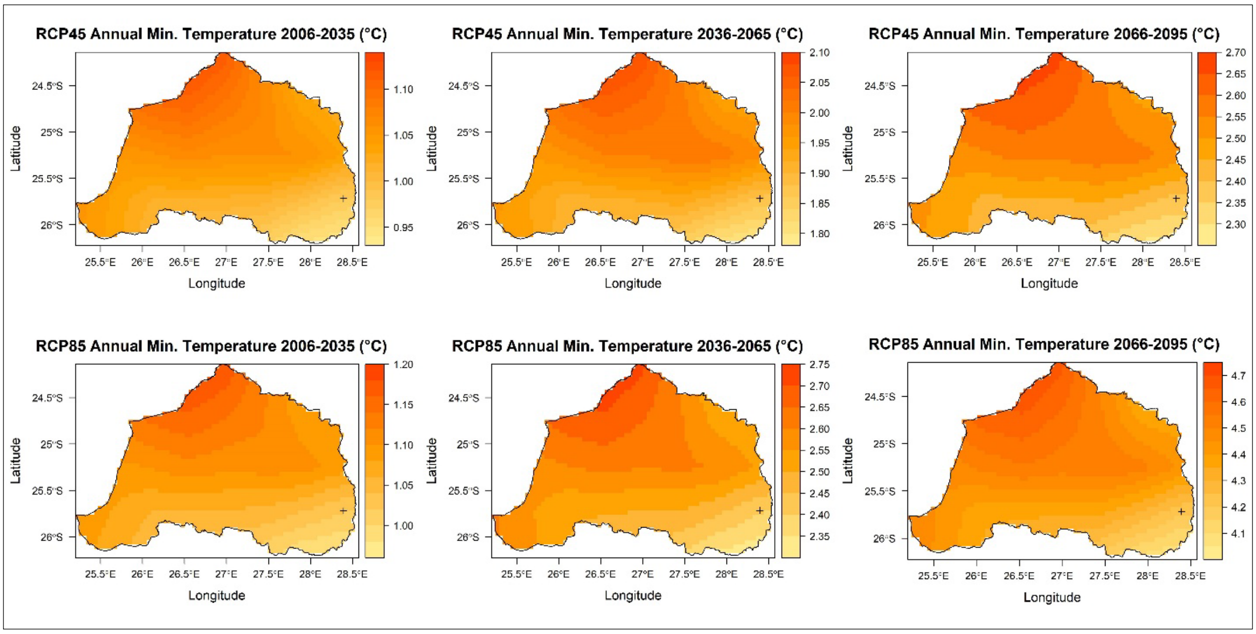


Figure 6. Projected changes in annual minimum temperature for 2006-2035 (1st column), 2036-2065 (middle column) and 2066-2095 (3rd column) periods under scenarios of the RCP4.5 (1st row) and RCP8.5 (2nd row) Crocodile catchment.

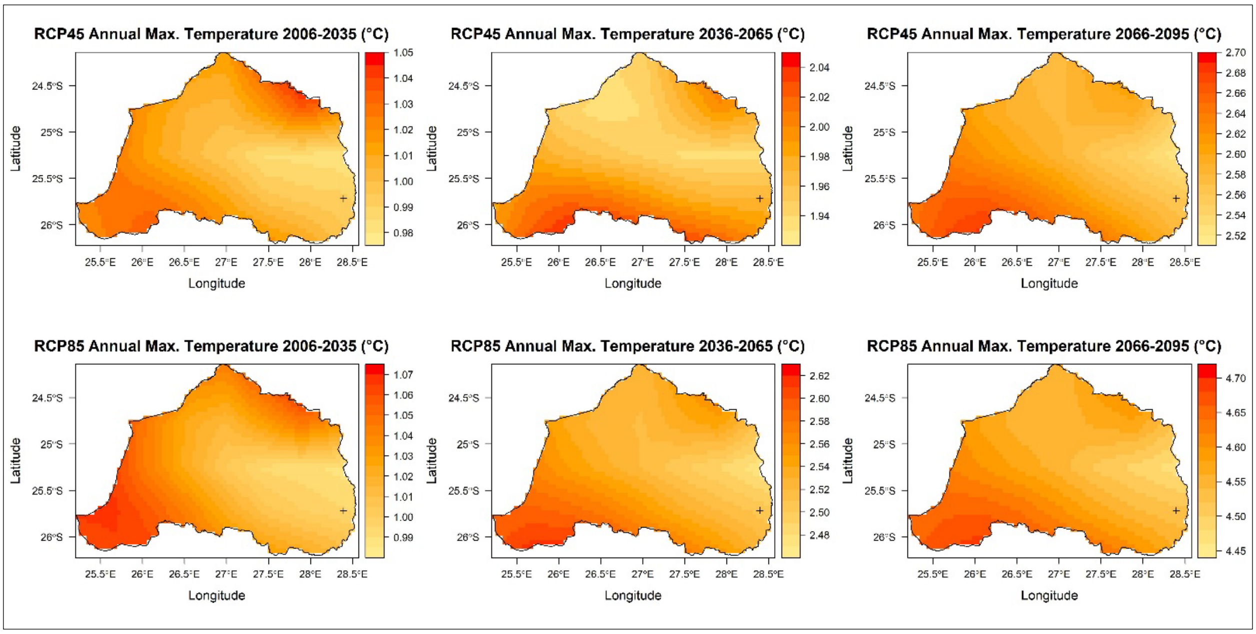


Figure 7. Projected changes in annual maximum temperature for 2006-2035 (1st column), 2036-2065 (middle column) and 2066-2095 (3rd column) periods under scenarios of the RCP4.5 (1st row) and RCP8.5 (2nd row) in Crocodile catchment.

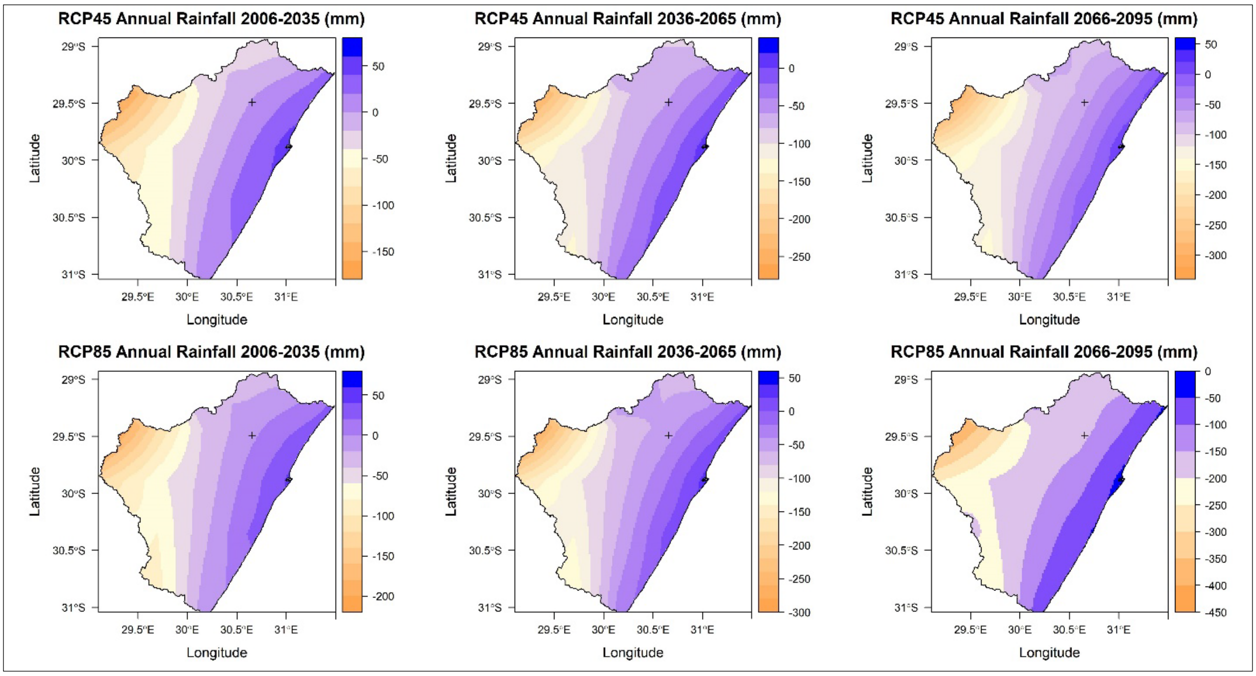


Figure 8. Projected changes in annual total rainfall for 2006-2035 (1st column), 2036-2065 (middle column) and 2066-2095 (3rd column) periods under scenarios of the RCP4.5 (1st row) and RCP8.5 (2nd row) Umzimkulu catchment.

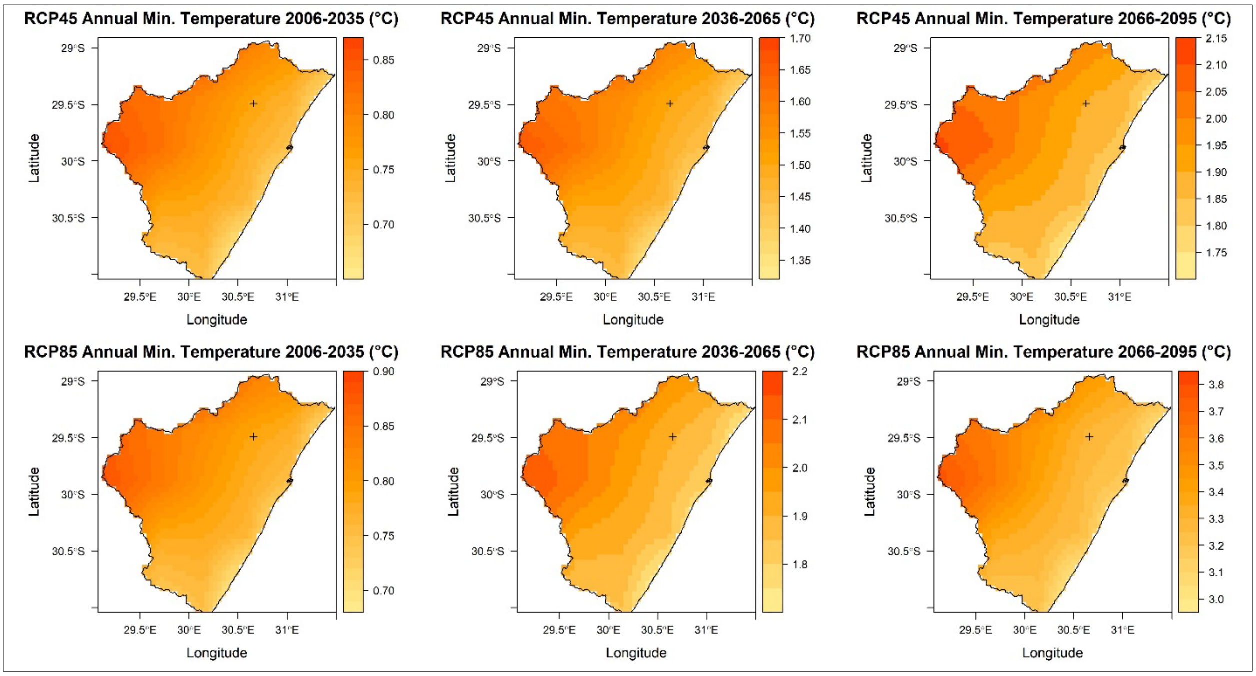


Figure 9. Projected changes in annual minimum temperature for 2006-2035 (1st column), 2036-2065 (middle column) and 2066-2095 (3rd column) periods under scenarios of the RCP4.5 (1st row) and RCP8.5 (2nd row) in Umzimkulu catchment.

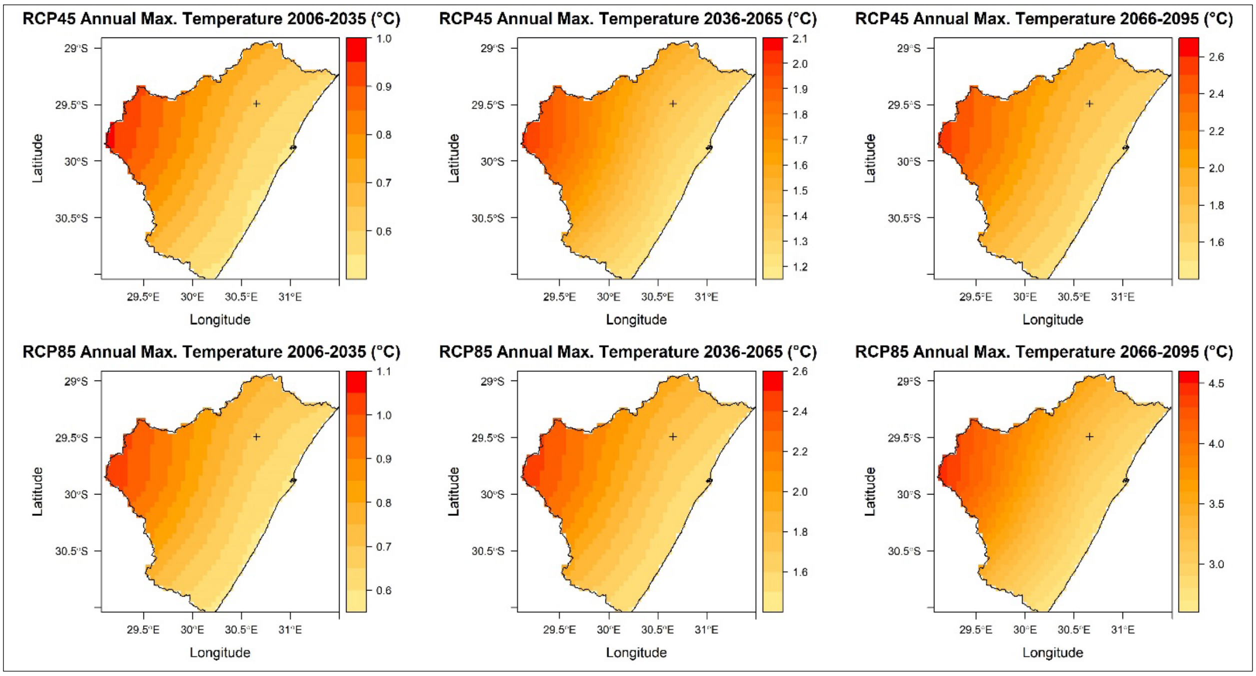


Figure 10. Projected changes in annual maximum temperature for 2006-2035 (1st column), 2036-2065 (middle column) and 2066-2095 (3rd column) periods under scenarios of the RCP4.5 (1st row) and RCP8.5 (2nd row) in Umzimkulu catchment.

2.4. Best practice of citizen science for environmental monitoring

2.4.1 Citizen science project implementation and management best practices

Citizen Science projects have the potential to support scientific discovery, engagement, and awareness-raising in key environmental challenges such as natural disasters and climate change. For purposes of this report, the best practice provided is restricted to studies in environmental monitoring including weather, climate and disaster monitoring, although some of these apply to the field of citizen science in general. While effective, the approach has often failed in some contexts due to reasons which include failure to manage the roles and needs of scientists and citizen scientists, lack of resources, non-commitment by volunteers, and complications in the use of technology. Consequently, there is a need for some best practices to support citizen science initiatives in countries such as South Africa. Eight different but complementary project implementation and management best practices have been identified that support the development of effective citizen science projects in the context of environmental monitoring:

- Understand who the users are and what are their needs, expectations and limitations.

- Define and communicate clearly from the onset the project aim, objectives and role of citizen scientists
- Adopt participatory approaches to engage communities and other stakeholders
- Obtain the required project resources
- Keep community volunteers motivated
- Ensure the project works for the benefit of everyone involved, i.e. social relevance
- Integrate evaluation into the project design
- Ensure usability of technology and infrastructure adopted and ensure it does not exclude the disadvantaged members of the community

Understand who the users are and what are their needs, expectations and limitations:
Understanding user needs include appreciating and responding to these needs in the different phases of the project. This can include the need for information to be provided in local languages to ensure full participation of citizen scientists hence where necessary, translate the information and tools into local languages so that other community members are not excluded.

> *Case study example: Mini Stream Assessment Scoring System (MiniSASS) (Graham and Taylor, 2018).*
>
> The mini Stream Assessment Scoring System (MiniSASS) a low technology tool was developed to support citizen science to monitor the health of rivers in the Umgeni Catchment. Users of the tool can use the tool to identify over ninety species from water samples collected. This information helps support communities to understand the state of the rivers and determine if the river's health is in a natural, good, fair poor, or very poor condition. The tool has been refined to meet user needs and expectations, an internet-based portal has been developed to ensure citizen science can upload data collected and contribute to knowledge production as part of the international network that monitors the health of rivers. The miniSASS tool has also been translated into IsiZulu, Afrikaans, French and Swahili, enabling more citizens to gain understating to evaluate, appreciate and share knowledge on the state of their local rivers. The tool can be accessed online at http://www.minisass.org/en/

Define and communicate clearly from the onset the project aim, objectives and role of citizen scientists:

The project aim and objectives need to be defined and communicated clearly to citizen scientists/community volunteers and manage expectations. Volunteers need to understand and agree on the overall aims and objectives of the project as well as on how the project is going to be executed at the Initiation/Crowdsourcing phase. There is a need to co-create a shared vision for the project by ensuring that citizen scientists have a clear understanding of the project objectives and their role in the different phases of the project as well as when the project team (scientists) leave the study area.

Adopt participatory approaches to engage communities and other stakeholders:

The use of participatory approaches allows for different members of the community to participate so that traditional and indigenous knowledge is also integrated into the different phases of the citizen science project. Social learning is proposed as one way through which different value systems, knowledge types and stakeholders can co-design, co-implement and co-produce knowledge, especially in the context of building climate-resilient and sustainable communities (Pelling et al, 2008; Oettle et al., 2014; Graham and Taylor, 2018).

Obtain the required project resources:

Citizen science projects although they include the use of unpaid volunteers, they are costly to implement and maintain (Tweddle et al., 2012: West and Pateman, 2016; Chari et al., 2019). One of the reasons why citizen science projects fail is the inability of the project team to secure the required resources which include funding, skilled and committed human resources, promotional and training materials, technical infrastructure, capable leadership as well as partnerships (Chari et al., 2019). It is also important for the project team to establish partnerships with influential or key stakeholders who may also be gatekeepers in communities regardless of the project needs. These relationships help improve perceptions on project credibility and may also be useful in future environmental activities and should also be extended to include the private sector can also play a key role in supporting citizen science with technical and financial support (Roy et al., 2012; Chari et al., 2019).

Case study: Deepwater Horizon BP Oil Spill in the Gulf Region (Auvil, 2010)

In 2010, the Deepwater Horizon oil spill in the Gulf of Mexico was managed with the support of partners who managed to mobilize volunteers from areas such as Louisiana, Mississippi, Alabama and Florida to clean up the mess left after the oil spill (National and Community Service, 2010; Chari et al., 2019). The partners were able to recruit at least 6000 volunteers to quickly respond to the environmental disaster and assist in spotting and cleaning distressed animals as well as the restoration of the affected coastal areas.

Keep community volunteers motivated:

Community volunteers, especially in collaborative and contributory projects that are driven by external actors, need to be kept motivated throughout the project lifecycle and beyond. Keeping participants motivated ensures buy-in and retains their involvement (West and Pateman, 2016; Lee et al., 2020). Furthermore, it can also help encourage their participation in future projects hence there is a need to understand what motivations are useful in different socio-cultural contexts as this also helps envisage the quality of participation (West and Pateman, 2016). Motivation can take different forms and includes providing feedback, opportunities for learning and training as well as incentives. The process needs to build volunteers' capacity to analyse data, interpret, visualize and co-produce communication materials such as workshops and pamphlets (Buytaert et al., 2014). Graham and Taylor (2019) also note that building the capacity of citizen scientists helps them grow confidence in understanding the objective of actions such as environmental monitoring. Sen (1999) capabilities approach suggests that having confidence is also tied to increased competency to undertake environmental monitoring activities in local contexts.

Ensure the project works for the benefit of everyone involved, i.e. social relevance:

When using the citizen science approach one must consider how best to get the community or volunteers (including males, females and youth) and key stakeholders involved and how they will benefit from the project. Citizen Science needs to benefit the community rather than just the scientists who initiate the project in the case of contributory projects and collaborative projects. Community volunteers participate in science-oriented research or projects for various reasons, which include the need to contribute to science or something valuable (Haywood, 2015; Liu et al., 2020), increase understanding of societal problems and how to address them as well as an interest in learning with other community members (Domrose and Johnson, 2017). Therefore, the relationship between the scientists and citizen scientists needs to be managed well and address power dynamics that may emerge to ensure that the project provides mutual benefits for all those involved (Liu et al., 2020).

Integrate evaluation into the project design:

Citizen science projects like other development-oriented projects, need to integrate evaluation into the project design to ensure that the Development, Live, or Participatory science and Reporting phases meet the project objectives. In addition, the evaluation process should also allow for feedback that may require the project activities to adapt where necessary (Tweddle et al., 2012). Volunteers need to get feedback on how their information is addressing knowledge gaps and should also be allowed to give feedback, including what they want to change (Hill et al., 2012; West and Pateman, 2016).

Ensure usability of technology and infrastructure adopted and ensure it does not exclude the disadvantaged members of the community:

Technology and infrastructure used in citizen science include data tools, web-based hosting portals and communication equipment. The use of technology in citizen science although it enhances communication and data collection, for example, can also exclude some people who are not tech-savvy. Additionally, South African communities have mobile disparities in connectivity, particularly with the recent innovations in 4G and 5G connectivity (and beyond). These differences increase the gap between the well-connected urban areas and the marginalized rural communities (Roy et al., 2012). A significant proportion of the population in rural areas such as Swayimane have limited access to Information and communications technology (ICT) and the costs of data for cellular phones are also beyond the reach of many to rely on internet-based sources of information. Therefore, when developing technology-based citizen science interventions there is a need to consider how to ensure the information also reaches all community members. Data tools and related infrastructure needs to support citizen scientists so that they can share the data on different community platforms (Chari et al., 2019) and where possible, translate the information to the local language the community understands.

2.4.2 Best practice processes of citizen science for weather and climate change knowledge

The participatory approach and processes used in Dorward et al. (2015) will be adopted in this study for the two proposed sites for best practice of citizen science on weather and climate change knowledge. The key components of CS in weather and climate knowledge for this study should include:

- Provision of weather and climate information (historical records, real-time data collection, and forecasts and projections);
- Analysis and interpretation of weather and climate information with volunteer citizen scientists;
- Develop a participatory tool to enable citizen scientists to use weather and climate data in planning and decision making.

The first steps of the participatory integrated climate services approach focus on what citizen scientists are doing now and how climate and weather influence them. The following steps enable citizen scientists to use weather and climate information for planning and decision making. The process is divided into the following steps (Dorward et al., 2015):

1) What do the citizen scientists currently do?
    - Understand what the main livelihood activities of the citizen scientists are.
    - Explore ways of using weather and climate.
2) Is the climate changing?
    - Provide citizen scientists with historical climate information to investigate what has been happening to the climate. Where does the historical climate information come from? How is the historical climate information recorded and presented?
    - Understanding and interpreting historical climate information and comparing it with the citizen scientists' perceptions of change.
3) What are the opportunities and risks?
    - Use weather and climate information to help make informed decisions.
4) What are the options for citizen scientists?
    - Explore options that may be suitable for the local weather and climate.

5) Identify and select possible responses.
    - Enable citizen scientists to plan within the context of the weather and climate information and make suitable adjustments.

2.5. Challenges and opportunities for advancing citizen science

The role of citizen science in fostering science literacy and public scientific discovery across a wide range of disciplines is increasingly acknowledged (Bonney et al., 2009b; Starkey et al., 2017). The scientific literacy and knowledge gain represent growth in human capital, particularly important in addressing some of the sustainable development issues at the fore (Moczek et al., 2021). As a concept, citizen science enhances understanding and appreciation of science and stronger bonds with nature (Ganzevoort et al., 2017), among others. Citizen science has been widely credited with the potential social benefits of promoting active public engagements, collaboration, participation, and empowerment of local communities (Bonney et al., 2009b; Shirk et al., 2012). Through their participation, communities can understand the complexities of their environment and actively participate in addressing those through innovative thinking (Woolley et al., 2010; Buytaert et al., 2014). This also provides the platform for sharing indigenous knowledge to address broader environmental challenges faced by local communities (Walker et al., 2020). In the context of community-based monitoring (CBM) and experimentation (Conrad and Hilchey, 2011; Lowry and Fienen, 2013; Wehn and Almomani, 2019) or what would be called crowdsourcing (See, 2019), citizen science has presented cost-effective and economical means of bringing scientific data collection to scale, providing ways for communities to contribute to the research processes.

It is a recognised fact that data acquisition, in general, is costly, and as a consequence, there is limited data available at the local level hence data from citizen science projects can be used to address these knowledge gaps (Wehn and Almomani, 2019). The significance of meteorological data cannot be overstressed. They are required to monitor atmospheric changes enabling scientists to better understand weather data and climate change patterns and to address evolving climate change threats. They are important also in satellite validation (Loew et al., 2017) and forecast verification (Zheng et al., 2016). As stated by Buytaert. (2014), citizen's involvement in data collection and information sharing ultimately leads to greater preparedness against abrupt changes, and can potentially provide an additional buffer for dealing with shocks and stresses that are likely to be brought about as climate change and variability becomes exacerbated. The data can be used to develop solutions and other application tools such as early warning systems to ensure preparedness and timely response from the affected communities. Lastly, data collected through citizen science have the significant potential to co-create new knowledge necessary in cooperative planning and decision-making that can support informed and demand-driven policy responses that are more inclusive. Because the communities are involved from the onset in the scientific process, they have a much broader role in decision making as part of a bottom-up, participatory process.

While citizen science has demonstrated its potential to change knowledge production for the better, providing beneficial insight into many societal challenges, it is also essential to recognize and be aware of its limitations and challenges. For example, compromised data quality due to the use of different equipment, less frequent sampling, and a less trained workforce (Cohn, 2008; Devictor et al., 2010; Riesch and Potter 2013), which may result in improper data use and interpretation. Aspects of data ownership are also a concern (Ganzevoort et al., 2017). Secondly, the lack of funding to ensure sustainable support for such projects often leads to the closure of projects and, thus a decline in human capital (Walker et al., 2020). The lack of adequate training for volunteers to maintain the capacity to fully exploit the co-creation and co-generation of knowledge (Freitag et al., 2016). The lack of interested volunteers and low recruitment or declines in participation as a limitation often leads to projects ceasing (Morais et al., 2013; West et al., 2016). Again, involving various stakeholders can provide some benefits in the co-creation of knowledge. It can also pose problems, such as missing common grounds (Skarlatidou et al., 2019). Lastly, the lack of commitment of the scientific communities who feel citizens' inclusion will erode scientific excellence is a huge barrier to citizen science (Golumbic et al., 2017). The study by Golumbic et al (2017) revealed that scientists were primarily inspired by their involvement in supporting scientific research and obtaining prestigious funding. They further acknowledge that although the scientists appreciated the advantages and benefits for the society of citizen engagement, they had little inclination to interact directly with the public and would instead perform a conventional analysis without the public's intervention. Table 2 presents some of the benefits and challenges of citizen science informed by scientific literature.

Table 2. Summary of benefits and challenges of Citizen Science (Conrad and Hilchey, 2011; Mustafa et al., 2015; Marchezini et al., 2018).

Opportunities	Challenges
• Increasing environmental democracy (sharing of information)	• Lack of interested volunteers and ownership
• Scientific literacy (broader community/public education)	• Lack of financial support
• Human/social capital (volunteer engagement, agency connection, leadership building, problem-solving and identification of resources)	• Inability to access appropriate information/expertise
• Citizen inclusion in local issues	• Data fragmentation, inaccuracy, lack of objectivity
• Data provided at no cost to the government and other stakeholders	• Lack of experimental design
• Ecosystems being monitored that otherwise would not be	• Insufficient monitoring expertise/quality assurance and quality control
• The government's desire to be more inclusive is met	• Monitoring for the sake of monitoring
• Support/drive proactive changes to policy and legislation	• Gender inequality and conflicts
• Can provide an early warning/detection	• Lack of transparency

3. Weather and Climate Change Monitoring Network Report

3.1. Introduction

The impacts of climate change and variability are being experienced globally, especially in climate sensitive sectors such as water, agriculture, health, human settlements and energy. Due to the triple challenges of inequality, poverty and unemployment, a significant proportion of the South African communities in both rural and urban areas have limited adaptive capacity to respond to the frequent extreme weather events such as floods and droughts. Extreme weather events such as intense storms, heatwaves and increases in the number of very hot days usually affect their livelihoods, human settlements as well as health. As such, there is a need to engage citizens and build their capacity to respond by providing simplified tools that can support citizen engagement to mitigate the impacts of extreme weather events.

Citizen science refers to the engagement of volunteers in scientific investigations, which can include asking questions, collecting data, or interpreting results. The citizen science approach includes simplification of the technical language around weather and disaster risk reduction to ensure that there is a shared understanding of the risks while also allowing for informed participation in designing and implementing risk management measures. Citizen science, therefore, is not just public participation based on attendance of workshops or meetings but genuine participation and contribution of non-professionals in scientific research (Mille-Rushing et al., 2012).

Many studies have indicated that indigenous and local communities have long used traditional knowledge to make different adaptive responses for generations to climate-induced hazards and risks by developing situation-specific livelihood practices and building the resiliency of their households and communities (Karki et al., 2017). Therefore, to adapt and cope with the impacts of climate change, modern scientific knowledge should move to integrate indigenous and local knowledge by learning from local communities who have long been adapting to climate and socio-economic changes (Karki et al., 2017). In this study, the learners and youth are informed about indigenous knowledge and how to gather weather information from their parents and elders in their community regarding traditional local knowledge.

This study followed a case study approach to support citizen scientists in two selected study sites to create a shared vision to enhance water resource management and resilience to extreme weather events that affect the sustainability of local livelihoods. Furthermore, there is a need to build the capacity of citizens to engage in weather and environmental management initiatives to mitigate the impacts of extreme weather events. For this, citizen scientists were trained on how to collect local weather information using automatic weather stations. The project also includes a component of building interest amongst the youth and school children in meteorology so that more students register for meteorology at universities to meet the critical skills gap. This project aims to develop a monitoring network that would enable citizens such as schools, youths and community-based groups to anticipate and mitigate extreme weather events as well as support water resource management.

3.2. Methodology

The concept of the co-created citizen science approach is used in this study, which is an open collaborative approach, where citizens have a specific problem, question, or issue they would like to investigate (Bonney et al., 2009). The project is planned to be carried out through four phases of citizen science engagement, i.e. initiation phase, development phase, live or participatory science phase and analysis and reporting phase. The initiation, development, and part of the participatory science phases are reported in this deliverable.

3.2.1. Initiation phase

The purpose of this phase is to establish a project team that will engage with all relevant stakeholders to get the necessary approvals and identify target participants and define project aims and co-create a shared vision for the project by ensuring that citizen scientists have a clear understanding of the project objectives and their role. In this study, a team of scientists from the SAWS and UKZN engaged with citizen scientists from two communities in the City of Tshwane and Umgeni catchment in KwaZulu-Natal. Two schools were selected namely, the Viva Foundation Schools in the City of Tshwane and Swayimane High School in KwaZulu-Natal. Both the City of Tshwane and Swayimane have experienced extreme weather events that have caused damage to agricultural fields, homes, and other infrastructure.

3.2.2. Development and participatory science phases

The development phase included: the designing of training approaches that would best meet the needs of the citizen scientists; resources to support the training and capacity building of citizens; development of training materials that will make weather, climate disaster management technical concepts understandable for the citizen scientists; and identifying workshop facilities and costs.

The live or participatory science phase included promoting the project through conducting workshops to establish the underlying factors influencing communities at both sites and current knowledge of climate change and early warning. The purpose of the workshops is to identify main livelihood activities as well as the mitigation measures used to enhance their resilience as well as contribute towards improved management of water resources. This phase includes data collection of weather variables such as rainfall, temperature, wind speed and direction using low-cost weather stations and community engagements to get impact-based experiences.

3.3. Workshop report on weather and climate change monitoring

3.3.1. Workshop topics and agenda Items

The project team conducted a citizen science workshop at Swayimane High School in KwaZulu-Natal on November 3, 2021. Two citizen science workshops were also conducted at Viva Foundation in the City of Tshwane on 9 November at the Viva Connect Refilwe (Cullinan) and on November 10, 2021, at the Viva Village (Mamelodi). The workshop agenda items included a practical demonstration of a weather station (Appendix A), presentations (Appendix B), breakaway sessions, and plenary sessions on developing a shared vision for early warning and climate change resilience. The project team presented the following topics to the citizen scientists:

- *Science, Citizen science background and workshop objectives;*
- *Basics of weather and climate;*
- *Weather, extreme weather and Impact based forecasting;*
- *Climate change projections.*

The breakaway sessions aimed to discuss with citizen scientists on extreme weather events; to share knowledge and experiences on climate change, early warning and disaster preparedness and response; livelihood activities and state of rivers in their communities. Questions discussed during the workshop included:

- *What extreme events they have experienced in their communities?*
- *What are the preparedness and responses for extreme weather?*
- *How would they like to receive weather information?*
- *What can be done to make sure the communities are safe?*
- *What are the livelihood activities in their community?*
- *What challenges do you have that affect your livelihood?*
- *What is your experience with water at home?*
- *What is the state of water and rivers within their communities?*
- What is Climate change?
- What has been the impact of climate change?

3.3.2. Attendance

Workshop attendees for Swayimani School and Viva Foundation schools are presented in Table 3 and Table 4, respectively.

Table 3. Swayimani School attendees.

9 November 2021 (Swayimani)	SAWS	4
	UKZN	4
	Umngeni	1
	Youth	7
	Swayimani Teachers	2
	Swayimani Students	20
	Total	**38**

Table 4. Attendees of Viva Foundation Schools.

9 November 2021 (Cullinan)	Viva Foundation staff	3
	School children	18
	SAWS staff	12
	Total	**33**
10 November 2021 (Mamelodi)	Viva Foundation staff	1
	Viva students	54
	SAWS staff	9
	Total	**64**

3.3.3. Discussion and responses from citizen scientists

3.3.3.1. Swayimani School

During the workshop, the students were asked about the extreme events they have experienced in Swaymane. Their responses were as follows:

- *Izikhukhula* – floods
- *Iqhwa* – snow
- *Isichotho* – hail
- *Ukushisa Okukhulu* – high temperatures
- *Isomiso* – drought
- *uMoya* – storm

The students were also asked: *What are the preparedness and responses for extreme weather?*

- For floods, they said that they build trenches so that the water can flow well.
- For droughts, they harvest rainwater.
- During snow and storms, they said that they stay indoors.
- During high temperatures, they mentioned that their performance is affected, and so they said that they drink a lot of water.

When asked how they would like to receive information regarding the weather, they responded as follow:

- Posters
- Cellphone (SMSs)
- TV

They were also informed that the SAWS app is another method to get information.

Another question was "what can be done to make sure that families are kept safe?" The answers were as follows:

- We could stop burning and deforesting, we need trees because they prevent strong winds from blowing a lot of sand.
- Cover shiny objects
- Don't stand under trees when there is lightning
- Don't build houses close to rivers/dams because they flood often, putting your life in danger.

They were asked about their livelihood activities, and the responses are as follows:

- Farming (subsistence and commercial). The products include sugarcane, beans, potatoes, avocadoes, maize, other vegetables as well as livestock farming.

What challenges do you have that affect your livelihood?

- The school has a vegetable garden, which is managed by the community members. There is the challenge of water scarcity.
- Two more *JoJo* tanks are required to address the water scarcity.

What is your experience with water at home?

- They use spring water and the wetlands
- They use taps but sometimes there is no water from the taps
- Make use of JoJo tanks
- Make use of stand-alone taps

"What can you tell us about the state of water and rivers within the community?"

- There is a problem of not having good water quality
- There is water pollution (nappies)
- Livestock drink the water in the river, there must be other water sources for the livestock

They also have springs, and these are some comments made about the springs:

- They have no fence
- Water is clean, drinkable
- No maintenance is required.

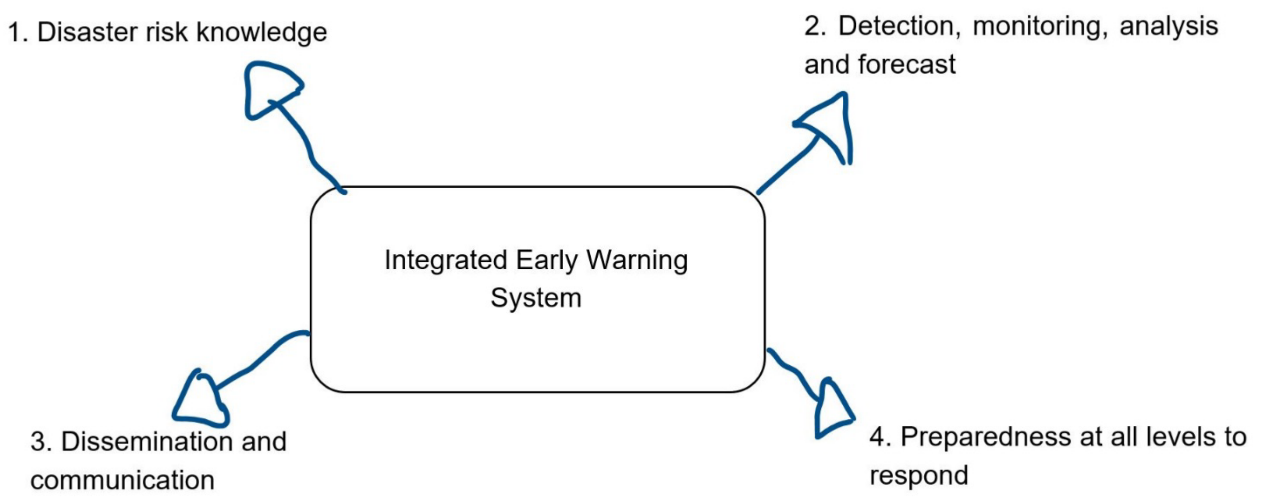
When they were asked, “What is Climate change?”

They responded by saying that it was the changing of weather conditions.

“What has been the impact of climate change?”

- There are changes in the planting dates
- Changes in the rainfall patterns
- There was a consensus that the climate has changed, and they have experienced it.
- There was also a consensus that they are experiencing high temperatures. This is affecting their crops because the crops are dying out.

The next question was “How do we adapt?” The responses are shown below:



The goals of early warning systems are to save lives and provide solutions.

3.3.3.2. Viva Foundation Schools

<u>DAY 1: Viva foundation Cullinan</u>

Examples of how weather information can be used?

- To know about the kind of clothing to wear

- Gardening
- So that they don't get sick
- Fishermen

DAY 2: Viva foundation Mamelodi

Why do you think we need information about the weather?

- To prepare an umbrella
- To prepare a raincoat
- To cover your roof
- To cover yourself from the heat
- To care for your sheep's house (pen)

Which extreme weather events have you experienced in Mamelodi?

- Flooding
- Heatwaves
- Thunderstorms
- Strong winds
- Hail (students mentioned that it occurred in 2018)
- It is getting warmer, and we are getting colder winters

What is the condition of the water bodies in your community?

- Dirty

How does this affect you?

- The water is not good for drinking
- They (the community) can get infected (by diseases)

What do you think you can do to improve the condition of the water bodies?

- Not litter
- "We can have a project to teach the community to clean water"

- We can use chemicals to treat the water so that we have clean water

How do you receive weather information?

- TV
- Phone
- Radio
- Laptop (Internet)

There was also a session where the students asked the SAWS project team questions that the project team answered during the session. Some of the questions that the students asked during the workshop include:

- Why is the weather different in the country?
- Will the temperatures be the same?
- Why are the temperatures different?
- Why are there winds?
- Do we need thunderstorms?
- Why are there different clouds?
- Why do we need to measure the weather?

3.3.4. Practical sessions

A practical demonstration of the weather station was conducted where learners were taken through the station and what parameters are measured as shown in Figure 11. The learners and the youth were organised into groups, where some of the learners would go outside with the station and others would record the measurement. The learners were able to record air temperature, wind speed, wind direction and UV. To demonstrate rainfall, a cup of water was poured into the sensor so that the learners would record the reading. Overall, all the learners and youth in Swayimani were able and comfortable to operate and record the data using the weather station.

The same practical demonstration sessions of the weather station were conducted where learners were taken through the station and what parameters are measured at the Viva Foundation Schools. Learners were able to see how air temperature, wind speed, wind direction & UV are reported in Cullinan (Figure 12). The station was taken outside for several minutes, where the learners saw how the parameters such as the temperature and UV index value changed. A fan was used in the hall to show the learners how wind speed changes. During the practical session at Mamelodi, learners showed interest in how the station works as they were actively asking questions about the station.

The AWS stations were installed at the schools and will be used as a live demonstration of weather information for geography and science lessons. The citizen science champions will also be involved in collecting data, maintenance, and sustainability of the stations. The citizen science champions at both sites will engage with their respective communities in disseminating the weather information which will be used for early warning.

Figure 11. Practical demonstration of a weather station by Mr. Siphamandla Daniel and Ms. Nosipho Zwane (project team).

Figure 12. Practical demonstration by Mr. Siphamandla Daniel at the Viva Foundation Independent School.

4. Implementation Plan to Sustain a State-of-the-Art Weather Station

4.1. Introduction

The environment that we live in is surrounded by the atmosphere, and all changes that occur in the atmosphere affect living organisms including humans. Weather is the present condition of the atmosphere and refers to short term atmospheric conditions while climate is the weather of a specific region averaged over a long period. According to the World Meteorological Organisation (WMO), the climate is an average of the weather parameters over at least 30 years. Weather can change in just a few minutes, hours, or days, however, climate changes over a longer period. In the past, weather patterns were easy to predict, for example, based on indigenous knowledge, nevertheless weather prediction has become difficult nowadays due to climate change (Hansen et al., 2012). Climate change refers to long-term changes in the climate.

Global environmental change as well as climate hazards including natural disasters pose a fundamental threat to socio-economic development. In general, threats and challenges attributed to such conditions cut across governments, society and science as a whole. As greater communities become more vulnerable to climate change, there is a need for effective monitoring of weather and climate conditions at different spatial scales. Early Warning Systems (EWS) are essential for climate-related adaptation, risk reduction and resilience. Such systems comprise four main interacting components, with diverse definitions based on different scholars:

(i) risk knowledge – systematic data collection and analysis of risk hazards and vulnerabilities (Marchezini et al., 2017)

(ii) monitoring and warning services – capacities for collecting dynamic data and information and for analysing them based on prior knowledge to make decisions (Marchezini et al., 2018)

(iii) dissemination and communication – the process of sharing data, information and knowledge about the climate-related risks and warning situations (Marchezini et al., 2018)

(iv) response capability – preparedness capacity to know when and how to act to mitigate the impacts, including saving lives (Marchezini et al., 2017)

Effective implementation of EWSs requires the involvement of the most vulnerable communities and sectors across different spatial scales (e.g. local, regional, national, or global). Citizen science is one of the initiatives that encourage a transdisciplinary collaboration between professional scientists and participatory stakeholders, including volunteers within communities, in the collection, analysis and interpretation of data and information (Heiss and Matthes, 2017). Such initiatives (also referred to as participatory early warning systems) are vital and provide the required support to derive and enhance policies to mitigate the impacts of climate change within the affected communities. Besides, one of the approaches to adapt to the changing weather patterns is to improve weather prediction by using weather instruments to provide accurate and timely weather data. This can be achieved using automatic weather stations (AWSs) for accurate and timely weather data collection and transmission, with an increased density of AWS networks covering large areas under observation (Cooper et al., 2008).

Generally, weather parameters are monitored and measured by observers, manual and automatic stations at several sites every day for different purposes. The most common weather parameters that are observed include solar radiation, air temperature, relative humidity, precipitation, wind speed and direction, air pressure, visibility, and clouds. At present, AWSs are available as commercial products with a variety of facilities, specifications, options, and prices. However, the high cost of available AWSs is a challenge to buy them in big numbers for most developing countries. Additionally, most commercial AWSs are normally expensive to maintain and replace. Therefore, there is a need to implement and sustain affordable AWSs without compromising accuracy, timely collection, and transmission and storage of the data.

This report presents an implementation plan for the installation of weather stations monitoring network for early warning resilience, based on the most affordable sensors.

4.2. Core-players and roles

The project used the citizen science approach which included the use of simplified technical language around weather and disaster risk reduction to ensure that there is a shared understanding of the risks while also allowing for informed participation in designing and implementing risk management measures. In addition, the project also employed simple and affordable weather stations that were installed at the two project sites that citizen scientists can use to collect local weather information. The citizen scientists were trained to collect weather information from both the weather station as well as indigenous knowledge. The study sites namely the City of Tshwane in Gauteng and Swayimane in KwaZulu-Natal have both experienced extreme weather events that have caused damage to agricultural fields, affected water resources, homes, and other infrastructure.

The project's core players included scientists from the SAWS, UKZN, and citizen scientists from two communities in the City of Tshwane and Umgeni catchment in KwaZulu-Natal. The Viva Independent Schools (Viva Foundation) in the City of Tshwane and Swayimane High School in KwaZulu-Natal are two schools that participated in the project. The core players attended the workshops held at the two schools located within the study sites during which the project activities were discussed. Local youths, SAWS and UKZN scientists, representatives from the Umgeni community, and Swayimane schoolteachers and learners were among the participants at the workshop held at Swayimane High School in KwaZulu-Natal. The core players at the Viva Independent Schools workshop included Viva Foundation staff, learners, and schoolteachers as well as SAWS staff. For this study site, two workshops were held at two Viva Foundation locations, one at Cullinan and the other at Mamelodi.

4.3. Data acquisition and storage

Automated Weather Stations (AWSs) are often used to collect weather data. According to WMO, there are four (4) categories of AWS (WMO, 2018), namely:

- Light AWS for measurement of a few variables (precipitation and/or air temperature).
- Basic AWS for the measurement of basic meteorological measurements (air temperature, relative humidity, wind speed and direction, precipitation, and atmospheric pressure).
- Extended AWS that measures additionally solar radiation, sunshine duration, soil temperature, and evaporation.
- AWS with automation of visual observations (cloud base height and present weather).

Traditionally the measurement of weather parameters and data collection have been performed by professional meteorological organisations. However, in the last decade, there has been a continuous increase in the number of low-cost AWSs which come in a variety of designs and configurations. This has enabled other organisations, industries, individuals, and citizen scientists to collect weather data for various purposes. The WMO also recognises this type of Low-Cost Automatic Weather Station (AWS-LC). These stations are characterised by their relatively low cost, low power consumption, the transmission of data in real-time (with or without logging), and their small and compact size. Generally, three types of AWS-LC are recognised by the WMO: Compact, All in One, and Stand-Alone. Compact and All in One are basic types that are mainly aimed at users who want to collect information regarding the weather locally. These two types sometimes provide the capability to transmit limited volumes of data locally but generally lack the capability of logging data (Ioannou et al., 2021). The third type (Stand-Alone instruments) uses a network of individual intelligent instruments, transmitting information using low-power and low bandwidth interfaces via Wi-Fi and Bluetooth to centralised processing servers (WMO, 2018).

4.3.1. Automatic Weather Station: Specifications and requirements

An AWS is an instrument that measures and records weather parameters using sensors, stores the data in a data logger, or automatically transmits records to a remote location via a communication link. In an AWS, the measurements are converted into electrical signals through sensors, then processed and transformed into meteorological data and finally transmitted by wire or radio or automatically stored in the data logger. The requirements for an acceptable AWS system depend on a proper understanding of the needs which include the satisfaction of both end-user and system expectations. Nsabagwa et al. (2019) analysed the requirements of a typical AWS and categorised these requirements under functional and non-functional requirements.

AWS functional requirements

Functional requirements capture the behaviour of the system and are expressed as tasks or services of the system. Nsabagwa et al. (2019) identified four AWS functional requirements:

i) An AWS should collect basic weather parameters such as precipitation, air temperature, relative humidity, pressure, wind speed and direction and many others.
ii) Process captured data: Data processing involves sensor signal processing, calculating derived information such as dew point, data compression and timestamping collected data among others.
iii) Buffer data: Primary saving of data when collected before sending it to the repository, which is a location where data is stored permanently.
iv) Transmit data from the AWS to the repository.

Non-functional requirements

The non-functional requirements include four sub-categories: External Interfaces; Attributes; Design Constraints; and Performance Constraints. The external interfaces answer questions of how the system software interacts with people, hardware and software systems. The attributes are concerned with issues like portability, correctness, maintainability and security, among others. The design constraint issues involve answering questions on whether there are any required standards in effect, implementation language, policies, resource limits and operating environment. The performance requirements are concerned with issues of speed, availability, response and recovery time of various software functions among others (Nsabagwa et al., 2019).

Although an AWS collects and transmits data automatically, an interface is required to monitor and configure its operations. To determine the accuracy of the AWS, it is necessary to benchmark the AWS to a standard instrument. Furthermore, proper siting of an AWS and sensor calibration is crucial for data accuracy and should be checked to ensure and conform to standards.

4.3.2. Data acquisition

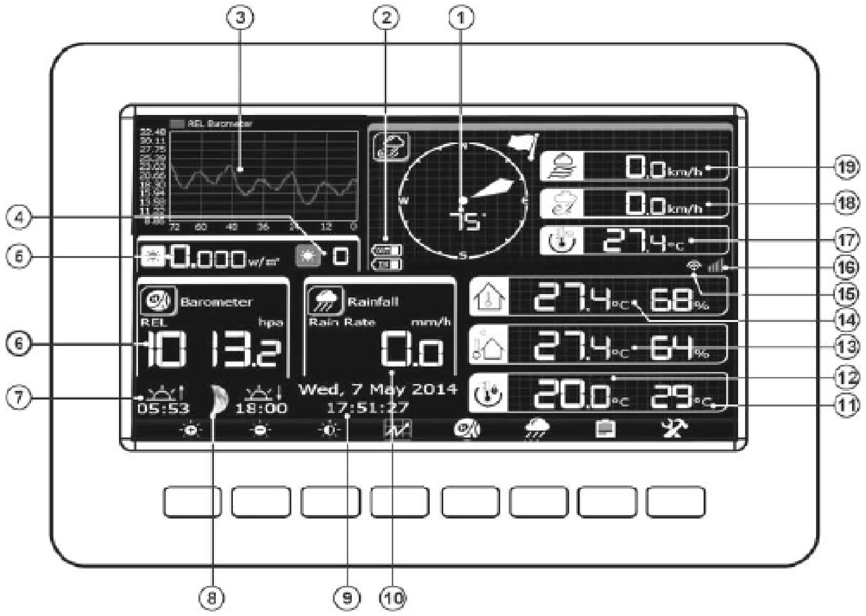
Data acquisition using an AWS involves the following main functions: data sampling, data processing, and converting the data into digital numeric values that can be manipulated by a computer or data processors. AWS should have low power consumption; powerful remote communication capability; high-precision sensor interfaces; and high reliability measures to ensure timely weather data processing. Based on the means of data acquisition WMO categorises AWSs into Offline and Online AWSs. Offline AWSs are described as stations recording data on-site without any automatic transmission. These types of AWSs are used less nowadays mainly because data are not available in real-time and stations do not allow fast detection of possible failures. Therefore, WMO recommends the use of online AWSs even for climatological data. The online data acquisition system uses wired and wireless communication technologies and should be designed having in mind the ease of change of the telecommunication interface both in terms of physical hardware and software (WMO, 2018).

Most standard AWSs collect hourly and daily basic weather parameters such as precipitation (mm), air temperature (^{o}C), relative humidity (%), air pressure (hPa), wind speed (m/s) and direction (^{o}) and many other parameters also. Generally, AWS collects sub-hourly, hourly, and daily data with a data logger measuring at a higher sampling frequency (e.g. 60 seconds interval) and data files are then transferred or downloaded in an ASCII text format. Detailed information on siting of an AWS, data quality checks, and maintenance is presented in the AWS training manual (Appendix A).

This project aimed to implement simple, low-cost, and robust AWSs that can be easily used by citizen scientists for data collection. The project team after investigating all the requirements and specifications of low-cost AWSs agreed on the use of the HP2000 Wireless AWSs for the two study sites. The HP2000 AWS can directly upload real-time data to the Internet and has the following specifications for data acquisition and storage:

- Built-in Wi-Fi for upload of live data to the internet or local connection
- Includes software for viewing and downloading data via Wi-Fi on a local PC
- 433 MHz transmission with a range of up to 100 m line of sight
- Colour TFT display with real-time graphing/trends
- User calibration and offset adjustment with restore to factory default
- Weather symbols based on the rate of change in barometric pressure
- Records minimum and maximum values with date and time
- Update time from outdoor sensors is approximately every 16 seconds
- Compact outdoor sensor array with solar panel
- Remote indoor sensor with temperature, humidity and pressure
- 3705 MB on-board memory for years of stored data
- Micro SD card slot for back-up/retrieval of data in CSV format
- USB port for operating system updates only
- Software included for access and download over Wi-Fi
- The console requires 5V/1A DC power from supplied AC/DC mains adapter

This AWS-LC is a high quality, easy-to-use weather monitoring system that reads, displays and records the weather data from internal as well as external sensors. Besides the internally measured values for indoor temperature, indoor humidity and air pressure the outdoor sensor will take data for air temperature and relative humidity, wind speed and direction, rainfall, and other parameters listed in Figure 13. The operation of these units is by wireless transmission to the Base Station.



1. Wind direction	11. Heat index
2. Low battery indicator	12. Dew point
3. Weather Forecast / rel. pressure graph	13. Outdoor Temperature &Humidity
4. UV index	14. Indoor Temperature &Humidity
5. Light	15. Internet Connectivity
6. Barometric Pressure	16. WiFi Connectivity
7. Sunrise/sunset	17. Wind chill
8. Moon phase	18. Gust
9. Time and date	19. Wind speed
10. Rainfall	

Figure 13. Normal display mode of HP2000 wireless weather station kit showing the weather parameters collected.

4.3.3 Data storage

Typically, an AWS consists of a central processing unit (CPU) for data acquisition and conversion into a computer-readable format, proper processing of data, temporary storage of processed data, and transmission of data to a central system using a modem or an interface to the telecommunication network. Weather and climate data are generally transmitted into a central system (servers or computers) for storage, archiving, and further processing. However, it is recommended that an AWS has a local data storage and an associated procedure to access the data if there is a break in the communication scheme to avoid data loss. Local data storage is no longer a problem with the recent technological advancement and flash memory components. The AWS software generally manages the data in a circular memory over a given period, replacing old data with new. The size of data storage should be compatible with the accessibility of the observing site, up to several months for a very isolated site (WMO, 2018). The WMO recommends the following procedures to access the local data:

- A transmission of old data when the telecommunication infrastructure becomes available again;
- A local transfer of the data with a portable terminal locally connected to the AWS during a maintenance operation;
- A local recuperation of a memory card (for example, a flash memory card) during a maintenance operation.

The HP2000 wireless weather station installed for this project has a 3705 MB on-board memory for storing data, a micro-SD card slot for back-up and retrieval of data in CSV format, and software for data access and download over Wi-Fi. It uses an "EasyWeatherIP" program (http://download.ecowitt.net/down/softwave?n=EasyWeatherIP) to display all indoor data as well as the weather data from the base station received from the external sensors as shown in Figure 14.

The HP2000 wireless weather station is also designed to upload data to a server using the Weather Server set up mode for public access of the station using the internet. The system is configured to send real-time data to *Weather Underground*, wunderground.com® (https://www.wunderground.com/) without adjusting the server, server and upload type by just entering the Station ID and Password (Figure 15).

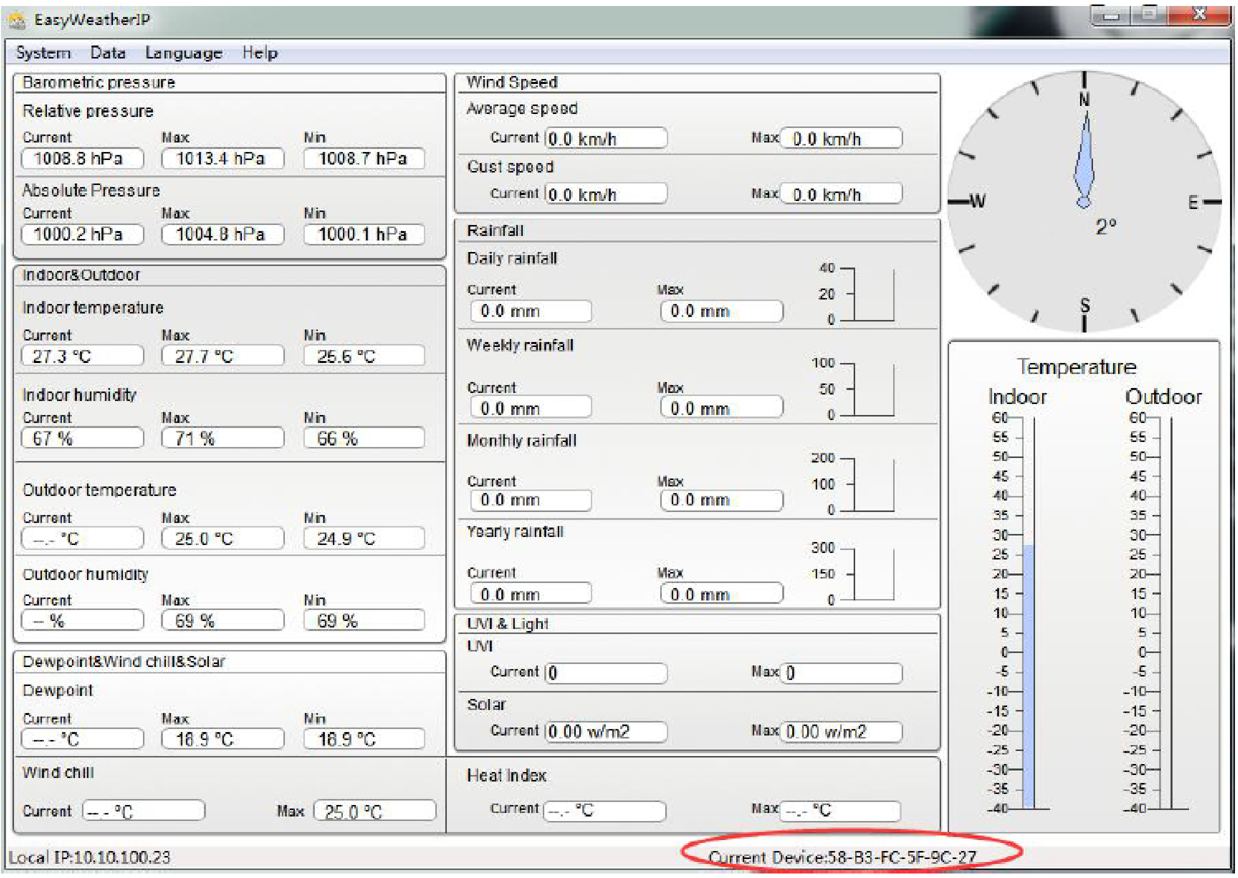


Figure 14. EasyWeatherIP program interface for data display and retrieval connected to an HP2000 wireless weather station.

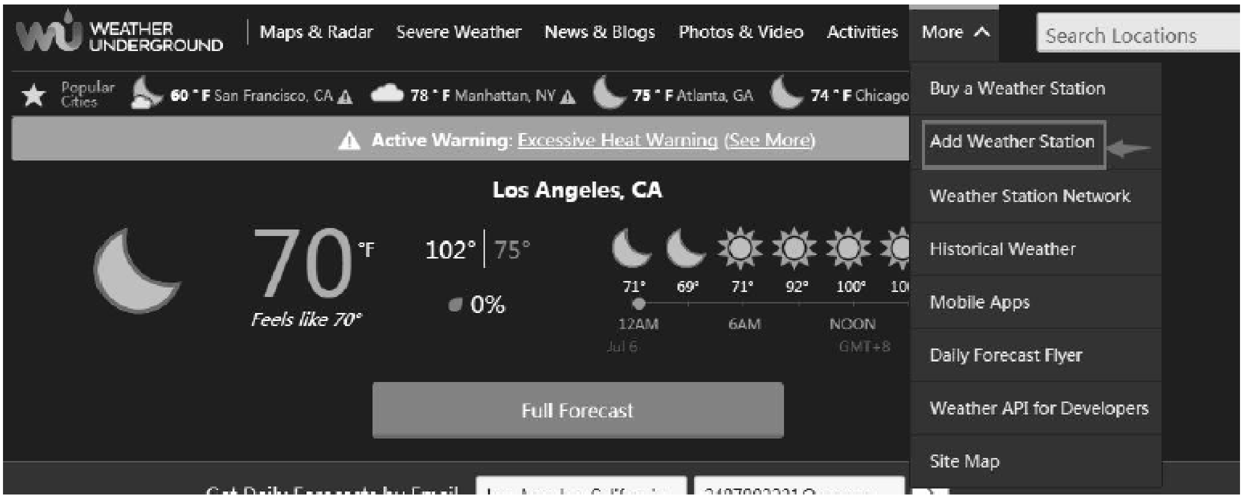


Figure 15. Weather Underground (wunderground.com®) configuration for adding a weather station.

4.4. Resources and budget

The cost of the AWS equipment, installation, development and implementation of the central collecting and processing systems, operation and maintenance have an impact on the affordability of an AWS. One way of lowering the cost is through the use of low-cost AWSs with low power consumption, easy to install, and free and open-source software for the transmission of data in real-time. According to the WMO, low-cost AWSs come in a variety of designs and configurations and range in price from USD 50 up to USD 7000. An estimated cost of the HP2000 wireless weather station kit used for this citizen science project is presented in

Table 5. Operational and maintenance costs such as travel and subsistence, workshops, and training are not included because they vary from site to site and the proximity of the AWS.

Table 5. Resources and budget.

ITEM	DESCRIPTION	BUDGET
Capital Expenses	Cost of the equipment: AWS, instruments, telecommunication modem or interface, Micro SD cards	ZAR 11,000.00
Cost of installation and installing structures	Accessories: mast, concrete.	ZAR 1000.00
Cost of a central processing system	Cost of the development and implementation of the central collecting and processing systems	-
Running expenditure communications	Telecommunications: Internet, Wi-Fi cost per year, batteries.	ZAR 3000.00 per year
Running cost	Maintenance and calibration cost of the HP2000 AWS	-
Estimated total cost		**ZAR 15,000.00**

4.5. Risks and mitigation mechanisms

The risks, impact, and mitigation mechanisms for implementing and sustaining an AWS are presented in Table 6.

Table 6. Risks and mitigation mechanisms for implementing, maintaining and sustaining an AWS.

NO.	Risk Description	Likelihood	Impact	Mitigation
1	Malfunction of equipment	Low	High	Identify citizen scientists who will report and fix any malfunction on the equipment.
2	Loss of equipment (theft and vandalism)	Medium	High	Select sites with security to ensure the safety of equipment, e.g. schools.
3	Power supply failure	Medium	Medium	Use of solar panels and other local energy sources.
4	Communication or network failure	Low	Medium	Use of Micro SD cards and other storage devices for backup and data retrieval when the network is offline to prevent data loss.
5	Damage from severe meteorological conditions	Low	High	AWS should be mounted in a proper mast and strongly fixed to the ground during installation with lightning rods to prevent damage and to withstand severe weather conditions.
6	Deterioration and ageing	Low	High	Plans to allocate funds for procuring new AWS equipment to replace an old or damaged AWS.
7	Lack of skills to operate AWS	Medium	Medium	Train citizen scientists on how to operate an AWS and the technical details and maintenance of equipment.
8	Raising stakeholder expectations/hopes/anxieties	Low	Low	Engage with community leaders and other trusted stakeholders to ensure they understand the scope of the project, benefits of monitoring weather and share this understanding with participants.

5. Conclusions and Recommendations

5.1. Conclusions

The field of citizen science is still growing, especially in South Africa where there is a need for more studies illustrating how community concerns have been translated into climate change response and disaster risk reduction. Community volunteers have the potential to support national and international actors' efforts in building the resilience of communities to extreme weather events and climate change through mitigation and adaptation. People-centred weather and climate research require citizen scientists to know the risks, effective communication and response capability to minimise the impacts of extreme weather events on communities at risk.

The project provided insights into the evolution of the concept of citizen science, best practices to be adopted in weather and climate science, challenges and opportunities available to advance citizen science in contributive, collaborative and co-created initiatives. These aspects are important for South Africa in that they inform on how to integrate citizen scientists in the work done by scientists. The study also reports on the weather and climate change monitoring network and the development of implementation plans to sustain weather stations.

The study used the concept of a co-created citizen science approach, which involved the investigation of the weather and climate information in the two case study sites (Swayimane High School and Viva Foundation Schools) to understand climate and any extreme weather events that have affected the areas in recent years. The communities at the two sites have experienced extreme weather events such as floods, droughts, heatwaves, and hail storms. Information gathered from the citizen scientists on the state of water and rivers within their communities suggests that water quality is not good due to dirt and other sources of pollution. Therefore, the outcomes of the investigations were critical as this is expected to form the basis for decisions regarding water resource management and resilience to extreme weather events that affect the sustainability of local livelihoods. This will also enable decision-makers to understand the status quo with regards to the adaptive capacity of the communities to respond to, for example, the frequent extreme weather events such as floods and hailstorms.

Overall, the project found that early warning systems are essential for climate-related adaptation, risk reduction and resilience and that communities are willing to volunteer and assist in building resilience and awareness campaigns. For the successful use of the citizen science approach in South

Africa, the best practices for citizen science in environmental monitoring, including weather climate science as reported in this project be adopted.

5.2. Recommendations

Based on the outcomes of the project, the following recommendations are put forward:

- There is a need to understand the vulnerabilities within various regions to identify disaster-prone areas based on past and current climate and extreme weather events to understand their impacts on the livelihoods of those communities and how they have dealt with these events to inform on the appropriate needs of the communities.
- Future studies should focus on extending the weather and climate change monitoring network to other vulnerable communities and integrating indigenous knowledge systems for early warning and climate change adaptation strategies.
- Human capital development at the community level for citizens is important to enable them to be more proactive and build their resilience to extreme weather events through citizen science which promotes bottom-up and top-down knowledge sharing and learning. Co-designing and piloting a network for weather and climate change monitoring as demonstrated in this project is, therefore, a good starting point for the development of human capital within communities, particularly where no such networks exist.
- Stakeholder engagements through workshops are recommended when using the citizen science approach for effective training on how to manage, monitor and report disaster information as well as for building resilience to weather and climate changes within communities.

REFERENCES

Aitsi-Selmi, A., Murray, V., Wannous, C., Dickinson, C., Johnston, D., Kawasaki, A., Stevance, A.S. and Yeung, T., 2016. Reflections on a science and technology agenda for 21st century disaster risk reduction. *International Journal of Disaster Risk Science*, *7*(1), 1-29.

Albagli, S. and Iwama, A.Y., 2022. Citizen science and the right to research: building local knowledge of climate change impacts. *Humanities and Social Sciences Communications*, *9*(1), 1-13.

Altieri, M.A., Funes-Monzote, F.R. and Petersen, P., 2012. Agroecologically efficient agricultural systems for smallholder farmers: contributions to food sovereignty. *Agronomy for sustainable development*, *32*(1), 1-13.

An, X.Y. and Wu, Q.Q., 2011. Co-word analysis of the trends in stem cells field based on subject heading weighting. S*cientometrics*. 88, 133-144.

Aria, M. and Cuccurullo, C., 2017. Bibliometrix: An R-tool for comprehensive science mapping analysis. J. *Informetr.* 11, 959-975.

Auerbach, J., Barthelmess, E.L., Cavalier, D., Cooper, C.B., Fenyk, H., Haklay, M., Hulbert, J.M., Kyba, C.C.M., Larson, L.R., Lewandowski, E., and Shanley, L.A., 2019. The Problem with delineating Narrow Criteria for Citizen Science. *PNAS*, 116(31), 15336-15337. https://doi.org/10.1073/pnas.1909278116.

Auvil, J.P., 2010. Voluntourism after the BP Oil Spill. Travel Channel. [Accessed online 11/02/2021] Available at https://www.travelchannel.com/interests/outdoors-and-adventure/articles/voluntourism-after-the-bp-oil-spill.

Bonney, R., Ballard, H., Jordan, R., McCallie, E., Phillips, T., Shirk, J. Wilderman, C.C., 2009b. Public participation in scientific research: Defining the field and assessing its potential for informal science education. *A CAISE Inquiry Group Report*, 2009, 1-58.

Bonney, R., Cooper, C.B., Dickinson, J., Kelling, S., Phillips, T., Rosenberg, K.V. and Shirk, J., 2009a. Citizen science: a developing tool for expanding science knowledge and scientific literacy. B*ioScience*, 59(11), 977-984.

Bonney, R., Shirk, J.L., Phillips, T.B., Wiggins, A., Ballard, H.L., Miller-Rushing, A.J., and Parrish, J.K., 2014. Citizen science. Next steps of citizen science. *Science*, 343, 1436-1437.

Buytaert, W., Zulkafli Z., Grainger, S., Acosta, L., Alemie, T.C., Bastiaensen, J., De Bièvre, B., Bhusal, J., Clark, J., Dewulf, A., Foggin, M., Hannah, D.M., Hergarten, C., Isaeva, A., Karpouzoglou, T., Pandeya, B., Paudel, D., Sharma, K., Steenhuis, T., Tilahun, S., Van Hecken, G., Zhumanova, M., 2014. Citizen science in hydrology and water resources: opportunities for knowledge generation, ecosystem service management, and sustainable development. *Front. Earth Sci* 2:26. https://doi.org/10.3389/feart.2014.00026.

Chari, R., Blumenthal, M.S. and Matthews, L.J., 2019. Community Citizen Science. From promise to action. RAND Corporation, Santa Monica, CA.

Cohn, J. P., 2008. Citizen science: can volunteers do real research? *Bio Science*, 58, 192-197. https://doi.org/10.1641/B580303.

Conrad, C. C., Hilchey, K. G., 2011. A review of citizen science and community-based environmental monitoring: Issues and opportunities. *Environmental Monitoring and Assessment* 176(1-4), 273-291. https://doi.org/10.1007/s10661-010-1582-5.

Cooper, P.J.M., Dimes, J., Rao K.P.C., Shapiro, B., Shiferaw, B., Twomlow, S., Jun., 2008. Coping better with current climatic variability in the rain-fed farming systems of sub-Saharan Africa: an essential first step in adapting to future climate change? *Agric.Ecosyst. Environ*. 126 (1-2), 24-35.

Devictor, V., Whittaker, R. J., and Beltrame, C., 2010. Beyond scarcity: citizen science programmes as useful tools for conservation biogeography. *Divers. Distribut*. 16, 354-362. https://doi.org/10.1111/j.1472-4642.2009.00615.x.

Domroese, M. and Johnson, E., 2017. Why watch bees? Motivations of citizen science volunteers in the great pollinator project. *Biol. Conserv*., 208, 40-47. https://doi.org/10.1016/j.biocon.2016.08.020.

Egeru, A., 2012. Role of indigenous knowledge in climate change adaptation: A case study of the Teso Sub-Region, Eastern Uganda. *Indian journal of traditional knowledge* 11(2):217-224.

Enyew, B. D., and Hutjis, R., 2015. Climate Change Impact and Adaptation in South Omo Zone, Ethiopia. *J Geol Geosci*, 4(208), 2.

Ferri, M., Wehn, U., See, L., and Fritz, S., 2019. The Value of Citizen Science for Flood Risk Reduction: Cost-benefit Analysis of a Citizen Observatory in the Brenta-Bacchiglione Catchment. *Hydrol. Earth Syst. Sci. Discuss*. [Preprint], https://doi.org/10.5194/hess-2019-627, 2019.

Firehock, K., and West, J., 1995. A brief history of volunteer biological water monitoring using macroinvertebrates. *Journal of the North American Benthological Society*, 14(1), 197-202.

Forrester, T., Baker, M., Costello, R., Kays, R., Parsons, A., and Mc Shea, W., 2017. Creating advocates for mammal conservation through citizen science. *Biol. Conserv*., 208, 98-105. https://doi.org/10.1016/j.biocon.2016.06.025.

Freitag, A., Meyer, R. and Whiteman, L., 2016. Correction: Strategies Employed by Citizen Science Programs to Increase the Credibility of Their Data. Citizen Science: *Theory and Practice*. 1(2), 12. http://doi.org/10.5334/cstp.91.

Ganzevoort, W., van den Born, R.J.G., Halffman, W. and Turnout, S., 2017. Sharing biodiversity data: citizen scientists' concerns and motivations. *Biodivers Conserv*. 26, 2821-2837. https://doi.org/10.1007/s10531-017-1391-z.

Garcia, C. and Fearnley, C.J., 2012. Evaluating critical links in early warning systems for natural hazards. *Environmental Hazards*, *11*(2), 123-137.

Gebresenbet, F., and Kefale, A., 2012. Traditional coping mechanisms for climate change of pastoralists in South Omo, Ethiopia. *Indian Journal of Traditional Knowledge*, 11(4), 573-579.

Goldin, J., 2021. Opinion: Citizen scientists – Perhaps without a degree, but certainly making a difference. News24. [Accessed online 11/02/2021] Available at https://www.news24.com/news24/columnists/guestcolumn/opinion-citizen-scientists-perhaps-without-a-degree-but-certainly-making-a-difference-20210206.

Golumbic, Y.N, Orr, D., Baram-Tsabari, A., Fishbain, B., 2017. Between Vision and Reality: A Study of Scientists' Views on Citizen Science. Citizen Science: *Theory and Practice*. 2(1): 6, pp. 1-13, DOI: https://doi.org/10.5334/cstp.53.

Graham, M. and Taylor, J., 2018. Development of Citizen Science Water Resource Monitoring Tools and Communities of Practice for South Africa, Africa and the World. Water Research Commission (WRC). Report No. TT 763/18. 141pp.

Gura, T., 2013. Citizen Science: Amateur experts. *Nature*. 496, 259-261.

Haklay, M., 2013. Citizen Science and Volunteered Geographic Information – overview and typology of participation. In: Sui, D.Z., Elwood, S., Goodchild, M.F. (Eds.), Crowdsourcing Geographic Knowledge: Volunteered Geographic Information (VGI) in *Theory and Practice*. Springer, Berlin, pp. 105-122.

Hansen J., Sato M., Ruedy R., 2012. Perception of climate change. *Proc. Natl. Acad. Sci.*, 109, 14726-14727, E2415-E2423. https://doi:10.1073/pnas.1205276109.

Haywood, B. K., 2015. Beyond data points and research contributions: The personal meaning and value associated with public participation in scientific research. *Int. J. Sci. Educ*., 6, pp 239-262. https://doi.org/10.1080/21548455.2015.1043659.

Heigl, F., Kieslinger, B., Paul, K.T., Uhlik, J., and Dörler, D., 2019. Opinion: Toward an international definition of citizen science. *PNAS*, 116(17), 8089-8092. https://doi.org/10.1073/pnas.1903393116.

Heiss, R., and Matthes, J. (2017). Citizen science in the social sciences: a call for more evidence. GAIA 26, 22-26. https://doi: 10.14512/gaia.26.1.7.

Hicks, A., Barclay, J., Chilvers, J., Armijos, M.T., Oven, K., Simmons, P. and Haklay, M., 2019. Global mapping of citizen science projects for disaster risk reduction. *Frontiers in Earth Science*, p.226.

Hill, A., Guralnick, R., Smith, A., Sallans, A., Rosemary, G., Denslow, M., Gross, J., Murrell, Z., Tim, C., Oboyski, P., Ball, J., Thomer, A., Prys-Jones, R., De Torre, J., Kociolek, P. and Fortson, L., 2012. The notes from nature tool for unlocking biodiversity records from museum records through citizen science. *ZooKeys*, 209, 219-233.

Ioannou, K., Karampatzakis, D., Amanatidis, P., Aggelopoulos, V., Karmiris, I., 2021. Low-Cost Automatic Weather Stations in the Internet of Things. *Information*, 12, 146. https://doi.org/10.3390/info12040146.

Kelman, I., 2011. Disaster diplomacy: how disasters affect peace and conflict. Routledge, Abingdon, U.K.

Kelman, I., and Glantz, M. H., 2014. "Early warning systems defined," in Reducing Disaster: Early Warning Systems for Climate Change, eds Z. Zommers and A. Singh (Dordrecht: Springer), 89-108. https://doi: 10.1007/978-94-017-8598-3_5.

Kimura, A.H. and Kinchy, A., 2016. Citizen science: Probing the virtues and contexts of participatory research. *Engaging Science, Technology, and Society*, 2, 331-361.

Kosmala, M., Wiggins, A., Swanson, A., and Simmons, B., 2016. Assessing data quality in Citizen Science. *Frontiers in Ecology and the Environment*. 14, 551-560.

Kristensen, P., 2004. The DPSIR Framework. UNEP, Kenya. (Accessed online 8 February 2021). Available at https://wwz.ifremer.fr/dce/content/download/69291/913220/.../DPSIR.pdf.

Kullenberg, C., and Kasperowski, D., 2016. What is citizen science? A scientometric meta-analysis. *PLOS ONE*, 11, e0147152. https://doi.org/10.1371/journal.pone.0147152.

Landman, W.A., Archer, E.R.M., and Tadross, M.A., 2020. Citizen Science for the Prediction of Climate Extremes in South Africa and Namibia. *Front. Clim*. 2, 5, 1-8. https://doi.org/10.3389/fclim.2020.00005.

Lee, K.A., Lee, J.R., and Bell, P., 2020. A review of Citizen Science within the Earth Sciences: potential benefits and obstacles. *Proceedings of the Geologists' Association*, 131(6), 605-617. https://doi.org/10.1016/j.pgeola.2020.07.010.

Lewis, J., Boudreau, C.R., Patterson, J.W., Bradet-Legris, J. and Lloyd, V.K., 2018. Citizen science and community engagement in tick surveillance—a Canadian case study. *In Healthcare* (Vol. 6, No. 1, p. 22). Multidisciplinary Digital Publishing Institute.

Liu, B.F., Seate, A.A., Iles, I. and Herovic, E., 2020. Eyes of the Storm: How Citizen Scientists Contribute to Government Forecasting and Risk Communication. *Weather Climate and Society*, 12: 263-277.

Loew, A., Bell, W., Brocca, L., Bulgin, C.E., Burdanowitz, J., Calbet, X., Donner, R.V., Ghent, D., Gruber, A., Kaminski, T., Kinzel, J., Klepp, C., Lambert, J., Schaepman-Strub, G., Schröder, M., Verhoelst, T., 2017. Validation practices for satellite-based Earth observation data across communities. *Reviews of Geophysics*, 55(3), 779-817. https://doi.org/10.1002/2017RG000562.

Lowry, C. S., and Fienen, M. N., 2013. Crowd Hydrology: crowdsourcing hydrologic data and engaging citizen scientists. *Ground Water*. 51, 151-156. https://doi.org/10.1111/j.1745-6584.2012.00956.x.

Luseno, W. K., McPeak, J. G., Barrett, C. B., Little, P. D., and Gebru, G., 2003. Assessing the value of climate forecast information for pastoralists: Evidence from Southern Ethiopia and Northern Kenya. *World Development*, 31(9), 1477-1494.

Marchezini, V., Horita, F.E.A., Matsuo, P.M., Trajber, R., Trejo-Rangel, M.A., Olivato, D. Trajber, R., Olivato, D., Muñoz, V. A., de Oliveira Pereira, F., and Oliveira Luz, A. E. A Review of Studies on Participatory Early Warning Systems (P-EWS): Pathways to Support Citizen Science Initiatives. *Front. Earth Sci*. 6:184. https://doi.org/10.3389/feart.2018.00184.

Marchezini, V., Horita, F.E.A., Matsuo, P.M., Trajber, R., Trejo-Rangel, M.A. and Olivato, D., 2018. A review of studies on Participatory Early Warning Systems (P-EWS): Pathways to support citizen science initiatives. *Frontiers in Earth Science*, *6*, p.184.

Marchezini, V., Trajber, R., Olivato, D., Muñoz, V. A., de Oliveira Pereira, F., and Oliveira Luz, A. E. (2017). Participatory early warning systems: youth, citizen science, and intergenerational dialogues on disaster risk reduction in Brazil. *Int. J. Disast. Risk Sci*. 8, 390-401. https://doi.org/10.1007/s13753-017-0150-9.

Miller-Rushing, A., Primack, R. and Bonney, R., 2012. The history of public participation in ecological research. *Frontiers in Ecology and the Environment*, 10(6), 285-290.

Moczek, N. Voigt-Heucke, S.L. Mortega, K.G. Fabó Cartas, C. Knobloch, J. A., 2021. Self-Assessment of European Citizen Science Projects on Their Contribution to the UN Sustainable Development Goals (SDGs). *Sustainability*, 13, 1774. https://doi.org/10.3390/su13041774.

Morais, A.M.M., Raddick, J. and dos Santos, R.D.C., 2013. Visualization and characterization of users in a citizen science project. Proc SPIE 8758, Defense, Security and Sensing, Next Generation Analyst. Baltimore MDDOI: https://doi.org/10.1117/12.2015888.

Mwenge Kahinda, J., P. Bahal'okwibale, N. Budaza, S. Mavundla, N. Nohayi, K. Nortje, and R. Boroto. 2019. Compendium of community and indigenous strategies for climate change adaptation – focus on addressing water scarcity in agriculture. Food and Agriculture Organization, Rome, Italy.

National and Community Service, 2010. The National Service Response to the Deepwater Horizon Oil Spill. [Accessed online 11/02/2021] Available at https://www.nationalservice.gov/pdf/factsheet_serviceresponse_oilspill.pdf.

Ncube, B and Lagardien, A., 2015. Insights into Indigenous Coping Strategies to Drought for Adaptation in Agriculture: A Karoo Scenario. Water Research Commission, report no. 2084/1/15. WRC, Pretoria, South Africa.

Oettle, N., Koelle, B., Law, S., Parring, S., Schmiedel, U., Archer van Garderen, E. and Bekele, T., 2014. Participatory Adaptation Handbook: A practitioner's guide for facilitating people centred adaptation. Indigo development and change Nieuwoudtville South Africa.

Paul, J.D., Buytaert, W., Allen, S., Ballesteros-Cánovas, J.A., Bhusal, J., Cieslki, K., Clark, J., Dugar, S., Hannah, D.M., Stoffel, M., Dewulf, A., Dhital, M.R., Liu, W., Nayaval, J. L., Neupane, B., Schiller, A., Smith, P.J., and Supper, R., 2018. Citizen science for hydrological risk reduction and resilience building. Wiley Interdisciplinary Reviews: *Water* 5, e1262.

Pelling, M., High, C., Dearing, J. and Smith, D., 2008. Shadow spaces for social learning: a relational understanding of adaptive capacity to climate change within organizations. *Environment and Planning* A. 40 (4), 867-884.

Rankoana, S.A., 2016. Sustainable use and management of indigenous plant resources: a case of Mantheding community in Limpopo Province, South Africa. *Sustainability*, 83, 221.

Reges, H.W., Doesken, N., Turner, J., Newman, N., Bergantino, A. and Schwalbe, Z., 2016. CoCoRaHS: The evolution and accomplishments of a volunteer rain gauge network. *Bulletin of the American Meteorological Society*, 97(10), 1831-1846.

Riesch, H., and Potter, C., 2010. Citizen science as seen by scientists: methodological, epistemological and ethical dimensions. *Public Underst. Sci* 4. 23, 107-120. https://doi.org/10.1177/0963662513497324.

Roncoli, C., Ingram, K., and Kirshen, P., 2002. Reading the rains: local knowledge and rainfall forecasting in Burkina Faso. *Society and Natural Resources*, 15(5), 409-427.

Roy, H.E., Pocock, M.J.O., Preston, C.D., Roy, D.B., Savage, J., Tweddle, J.C. and Robinson, L.D., 2012. Understanding Citizen Science and Environmental Monitoring. Final Report on behalf of UK-EOF. NERC Centre for Ecology & Hydrology and Natural History Museum.

Science Communication Unit, University of the West of England, Bristol, 2013. *Science for Environment Policy In-depth Report: Environmental Citizen Science*. Report produced for the European Commission DG Environment, December 2013. Available at: http://ec.europa.eu/science-environment-policy.

Scolobig, A., Prior, T., Schröter, D., Jörin, J. and Patt, A., 2015. Towards people-centred approaches for effective disaster risk management: Balancing rhetoric with reality. *International Journal of Disaster Risk Reduction,* 12, 202-212.

See, L. A., 2019. A Review of Citizen Science and Crowdsourcing in Applications of Pluvial Flooding. *Frontiers in Earth Science*. 7. 44. https://doi.org/10.3389/feart.2019.00044.

Sethi, S.N, Sundaray, J.K, Panigrahi, A & Subhash Chand. 2011. Prediction and management of natural disasters through indigenous Technical Knowledge, with special reference to fisheries: *Indian Journal of Traditional Knowledge* 10 (1), 167-172.

Silvertown, J., 2009. A new dawn for citizen science. *Trends in ecology & evolution*, 24(9), 467-471.

Skarlatidou, A., Suškevics, M., Göbel, C., Pruse, B., Tauginiene, L., Mascarenhas, A., Mazzonetto, M., Sheppard, A., Barrett, J., Haklay, M., Baruch, A., Moraitopoulou, E.-A., Austen, K., Baïz, I., Berditchevskaia, A., Berényi, E., Hoyte, S., Kleijssen, L., Kragh, G., Legris, M., Mansilla-Sanchez, A., Nold, C., Vitos, M. and Wyszomirski, P., 2019. The Value of Stakeholder Mapping to Enhance Co-Creation in Citizen Science Initiatives. *Citizen Science: Theory and Practice*, 4(1), p.24. http://doi.org/10.5334/cstp.226.

Speranza, C.I., Kiteme, B., Ambenje, P., Wiesmann, U. and Makali, S., 2010. Indigenous knowledge related to climate variability and change: insights from droughts in semi-arid areas of former Makueni District, Kenya. *Climatic change*, 100(2), 295-315.

Starkey, E., Parkin, G., Birkinshaw, S., Large, A., Quinn, P., and Gibson, C., 2017. Demonstrating the value of community-based ('citizen science') observations for catchment modelling and characterisation. *Journal of Hydrology*, 548 (Suppl. C) 801-817. https://doi.org/10.1016/j.jhydrol.2017.03.019.

Tlhompho, G., 2014. African Indigenous Food Security Strategies and Climate Change Adaptation in South Africa. *Journal of Human Ecology*, 48(1), 83-96.

Turrini, T., Dörler, D., Richter, A., Heigl, F., and Bonn, A., 2018. The threefold potential of environmental citizen science – Generating knowledge, creating learning opportunities and enabling civic participation. *Biological Conservation*, 225, 176-186. https://doi.org/10.1016/j.biocon.2018.03.024.

Tweddle, J.C., Robinson, L.D., Pocock, M.J.O. and Roy, H.E., 2012. Guide to citizen science: developing, implementing and evaluating citizen science to study biodiversity and the environment in the UK. Natural History Museum and NERC Centre for Ecology & Hydrology for UK-EOF. Available online: www.ukeof.org.uk.

United Nations Environment Programme, 2017. Resilience and Resource Efficiency in Cities. Available Online: https://www.unep.org/resources/report/resilience-and-resource-efficiency-cities.

Van Eck, N. J., and Waltman, L., 2014. Visualizing bibliometric networks. In Measuring scholarly impact (pp. 285-320). Springer, Cham. Available Online: www.https://link.springer.com/chapter/10.1007%2F978-3-319-10377-8_13.

Wahlström, M., 2015. New Sendai framework strengthens focus on reducing disaster risk. International *Journal of Disaster Risk Science*, 6(2), 200-201.

Walker, D., Haile, A. T., Gowing, J., Legesse, Y., Gebrehawariat, G., Hundie, H., Parkin, G., 2019. Guideline: Community-based hydroclimate monitoring. Retrieved from REACH Working Paper 5, University of Oxford, UK.

Wehn, U., Almomani, A., 2019. Incentives and barriers for participation in community-based environmental monitoring and information systems: A critical analysis and integration of the literature, *Environmental Science & Policy.* 101, 341-357, ISSN 1462-9011, https://doi.org/10.1016/j.envsci.2019.09.002.

West, S. and Pateman, R., 2016. Recruiting and Retaining Participants in Citizen Science: What Can Be Learned from the Volunteering Literature? *Citizen Science: Theory and Practice*, 1(2): 15, 1-10. https://doi.org/10.5334/cstp.8.

Wisner, B., 2001. Vulnerability in disaster theory and practice: from soup to taxonomy, then to analysis and finally tool. In International Work-Conference Disaster Studies of Wageningen University and Research Centre.

Woolley, A. W., Chabris, C. F., Pentland, A., Hashmi, N., and Malone, T. W., 2010. Evidence for a collective intelligence factor in the performance of human groups. *Science.* 330, 686-688. DOI: 10.1126/science.1193147.

World Meteorological Organisation (WMO), 2018. Guide to Instruments and Methods of Observation; Volume III—Observing Systems; World Meteorological Organisation: Geneva, Switzerland; Available online: https://community.wmo.int/activity-areas/imop/wmo-no_8 (accessed on 17 February 2022).

Zheng, Y., Alapaty, K., Herwehe, J. A., Del Genio, A. D., and Niyogi, D., 2016. Improving High-Resolution Weather Forecasts Using the Weather Research and Forecasting (WRF) Model with an Updated Kain-Fritsch Scheme, Monthly Weather Review. 144(3), 833-860.

Zong, Q.J., Shen, H.Z., Yuan, Q.J., Hu, X.W., Hou, Z.P., Deng, S.G., 2013. Doctoral dissertations of Library and Information Science in China: A co-word analysis. *Scientometrics*. 94,781-799.

Zuma-Netshiukhwi, G., Stigter, K. and Walker, S., 2013. Use of traditional weather/climate knowledge by farmers in the South-western Free State of South Africa: Agrometeorological learning by scientists. *Atmosphere*, 4(4), 383-410.

Zupic, I. and Cater, T., 2015. Bibliometric methods in management and organisation. *Organ. Res. Methods*, 18, 429-472.

APPENDIX A: AUTOMATIC WEATHER STATION TRAINING MANUAL

INTRODUCTION

An automatic weather station (AWS) is an instrument that measures and records weather parameters using sensors, stores the data in a data logger, or automatically transmits records to a remote location via a communication link. In an AWS, the measurements are converted into electrical signals through sensors, then processed and transformed into meteorological data and finally transmitted by wire or radio or automatically stored in the data logger. The most common weather parameters that are measured include: solar radiation, air temperature, relative humidity, precipitation, wind speed and direction, and air pressure. Nowadays, AWSs are available as commercial products with a variety of facilities, specifications, options, and prices. A manual is normally provided with most AWSs showing sensor specifications, calibration coefficients and certificates, power requirements, maintenance, and data quality checks. However, AWS manuals lack detailed information on siting an AWS, installation structure, field maintenance, data quality checks, and detailed operational activities. The purpose of this training manual is to provide general information to citizen scientist on AWS installation, maintenance, and data quality checks required for operational use of AWSs.

SITING WEATHER STATIONS

An AWS should be installed at an appropriate location in order to provide accurate data of all the necessary weather parameters. The weather station must be placed in a location where there is no shading and changes in shade patterns with seasons should be taken into account due to changes in earth-sun geometry during installation. It is recommended that an AWS should be placed on a relatively level surface well away from large obstacles if possible. An open location is also necessary to measure wind speed and direction. Weather stations should be isolated from large obstacles such as fences, trees, or buildings by a distance equal to 7-10 times the height of the obstacle (WMO, 2018). The proper siting of an AWS is not an easy task and the surrounding area and the obstacles close to the instruments should not decrease the representativeness of the measurements.

The AWS equipment and its components such as data logger enclosures, batteries, and solar panels have to be installed on a solid and strong supporting structure. Supporting structures may be proposed by the AWS's manufacturer. The AWS mast should be installed on a concrete base or with the use of metallic ground screws. It is important to check that the AWS instruments and other equipment are not interfering with each other. The standard measurement heights for solar radiation, air temperature, relative humidity, and wind speed and direction is 2.0 m from the ground surface, however, WMO recommends a standard measurement height of 10.0 m. The standard measurement height for the rain gauge rim is 1.0 m (WMO). Local earth electrode is needed and should be buried in the ground to prevent equipment lightning damage. Fencing of the AWS site is also recommended to prevent human and animals interference in the observing area.

DATA QUALITY CHECKS

After proper siting of the station, it is necessary to make sure that all sensors are installed properly and working. This is achieved by checking the AWS data to ensure the quality and consistency of data output from all sensors used to measure weather parameters. Measured values should be checked if they are reasonable and fall under the absolute limits of variability. Simple checks for an acceptable rate of changes in the measurements should also be done to identify erroneous or suspicious values. It is also advisable to make real time checks of measured variables and measurement ranges based on established physical and meteorological principles as presented in Table A1.

In general, most weather parameters have hourly (high frequency) and daily (low frequency) output frequencies. Measurement outputs can be sample, mean, maximum, minimum, and/or standard deviation of the weather parameter. A sample measurement is an instantaneous measurement, and it is applied to relative humidity data or other indices such as wind chill or heat index. An average (mean) is applied to hourly measurements: solar irradiance; air temperature; and wind speed. Wind direction is degrees from north and mean is not applied. Minimum and maximum values are not normally used for hourly measurements except for wind gusts. However, minimum and maximum measurements of air temperature, relative humidity, and wind speed are determined for daily measurements (Table A2).

Table A1. Acceptable ranges for real-time measurements.

Variable	Range
Solar Radiation	0 to 1300 W m^{-2}
Relative Humidity	20 to 100%
Air temperature	-25 to 50°C
Wind Speed	0.4 to 45 m s^{-1}
Wind Direction	0 to 360°
Atmospheric pressure	980 to 1030 hPa

Table A2. Summary of the measurement statistics (Source: Savage, MJ. *Environmental Instrumentation*. SPACRU, Agrometeorology, School of Agricultural, Earth and Environmental Sciences, University of KwaZulu-Natal).

Variable	Unit	Hourly values	Daily values
Solar irradiance	W m^{-2}	average	total (MJ m^{-2})
Rainfall intensity	mm $interval^{-1}$	total (mm h^{-1})	total (mm day^{-1})
Air temperature	^{o}C	average	average, maximum, minimum
Relative humidity	%	sample	maximum, minimum
Water vapour pressure	kPa	average	average, maximum, minimum
Wind speed	m s^{-1}	wind vector (average, wind direction, standard deviation)	wind vector (average, wind direction, standard deviation)
Wind direction	^{o} clockwise from N	nothing	nothing
Wind gust	m s^{-1}	nothing	maximum

AWS MAINTENANCE AND CALIBRATION

Routine field checks at least monthly should be done to make sure the AWS is operating properly and data is accurate and representative of the atmospheric conditions of the area. The following self-maintenance checks should be carried out:

- Power and batteries of the data logger should be checked and replaced if the battery voltage is low.
- Check the rain gauge for any blockages, the top should be kept free of debris at all times. In dusty environments, it may be necessary to clean the funnel and filter regularly.
- Inspect solar radiation, UV and light sensor heads for dust, debris or animal waste. The sensor heads should be kept clean by gently wiping with a damp cloth taking care not to scratch the surface. Cleaning products containing solvents may cause damage to your sensor.
- Clean the solar panel with a damp cloth if necessary.
- The AWS mast should be level and all sensors should be levelled if necessary. The area surrounding the station should be clean and free of vegetation and debris. The surrounding vegetation may grow close to the station and could affect the measurements.

All AWS instruments with electrical output signals drift in time, therefore annual inspection and calibrations are needed. The user must refer to the sensor calibration certificates to check for any required calibrations. For detailed information on calibration the user manual provided with the specific AWS station should be referred to and procedures followed. It is also advisable to check and compare the sensors if possible with standard and reference sensors.

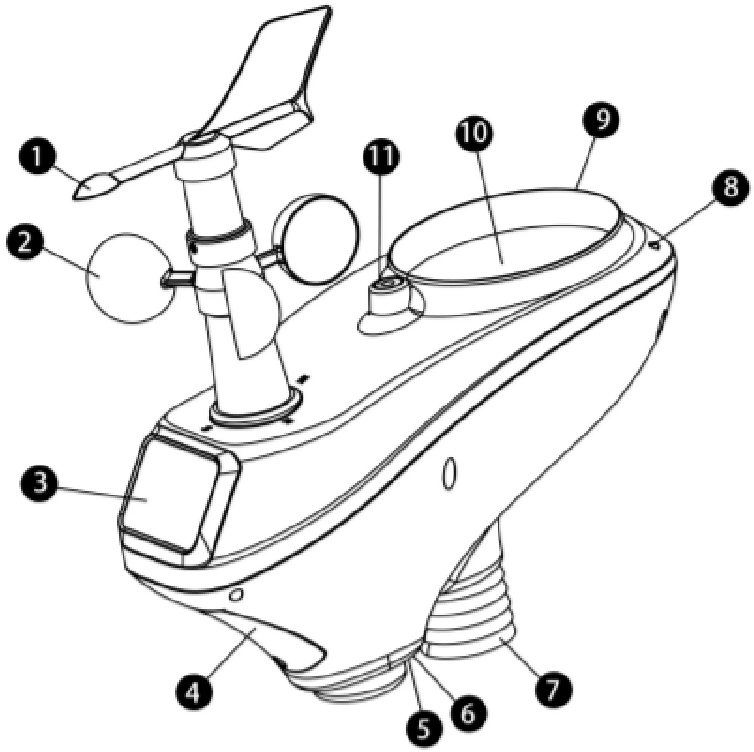
The user manual for the HP2000 wireless stations used in this project compiled from the manufacturer’s manual is presented in the following section for ease of reference.

HP2000 Professional Wireless Internet Station User Manual

(*The contents of this document are from the user manual of the Professional wireless internet station*)

Introduction

The professional wireless internet station is solar powered and sends data to the console via a low-power radio. This weather station can be used in both the Northern and Southern hemispheres. It is of high quality easy to use monitoring system that reads, display and records the weather data from internal as well as external sensors. The outdoor sensor measures the temperature, rainfall, pressure, humidity, and ultraviolet radiation, while the indoor sensor displays the temperature, pressure, and humidity. These units are operated by wireless transmission from the base station.

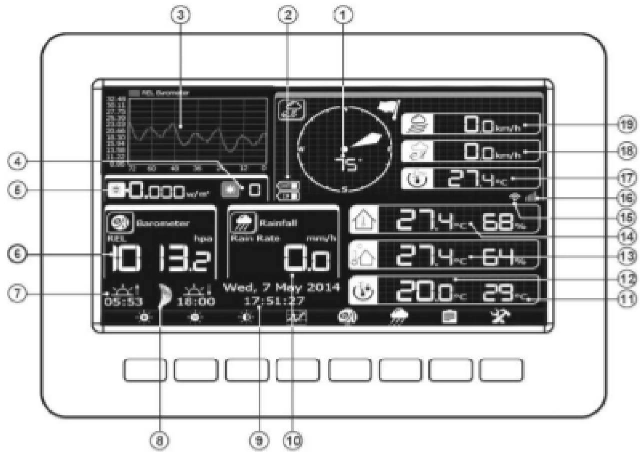


① Wind Vane
② Wind Speed Sensor
③ Solar panel
④ Battery compartment
⑤ LED Indicator: light on for 4s if the unit power up. Then the LED will flash once every 16 seconds (the sensor transmission update period).
⑥ Reset button
⑦ Thermo-hygro sensor
⑧ UV sensor
⑨ Light sensor
⑩ Rain collector
⑪ Bubble level

Figure 1. Outdoor Sensor.

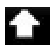
Display Console set up

- The first step is to connect the power adaptor of the display console.
- Once the display console is on, it starts to register the transmitter (outdoor sensor) then it starts to display the weather data as in Figure 2 but will not save the data on server.



1. Wind direction	11. Heat index
2. Low battery indicator	12. Dew point
3. Weather Forecast / rel. pressure graph	13. Outdoor Temperature &Humidity
4. UV index	14. Indoor Temperature &Humidity
5. Light	15. Internet Connectivity
6. Barometric Pressure	16. WiFi Connectivity
7. Sunrise/sunset	17. Wind chill
8. Moon phase	18. Gust
9. Time and date	19. Wind speed
10. Rainfall	

Figure 2. Normal display mode of the console.

- Thereafter, scan for the WIFI network, press the  or  key to select the WIFI network as in Figure 3. Press  to confirm and enter the password. Press  key to return to normal mode. Only after connecting, you can upload on the website. The WIFI icon will be displayed under wind chill.

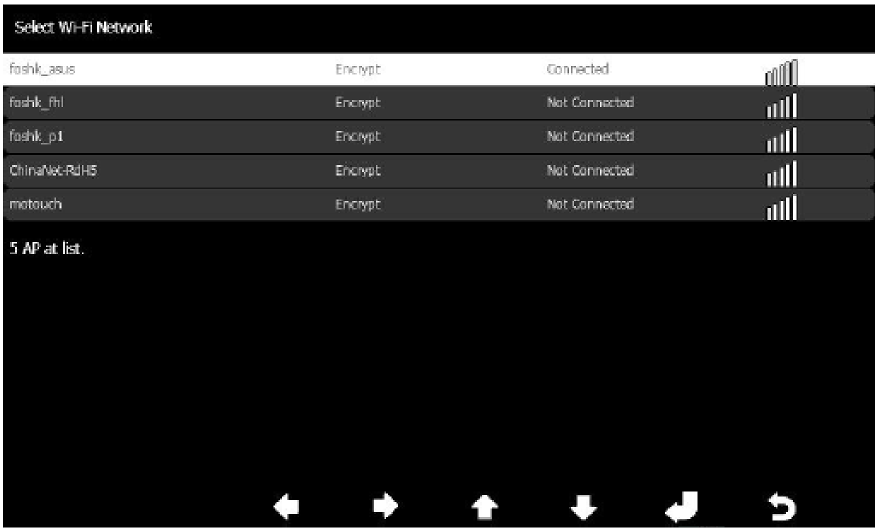


Figure 3. WIFI scan display.

Wind direction calibration

As mentioned before the station can be used in both the Northern and Southern hemispheres. The cardinal directions (N; E; S; W) are crafted on the outdoor sensor however they are indicators for the Northern hemisphere only. Therefore, the recalibration of the wind direction is essential as the sensor is calibrated for the Northern hemisphere. For the Southern hemisphere, the wind vane should point in the Southern direction as in Figure 4 of the outdoor sensor, and you will observe a wind direction of 180^{o} in the console.

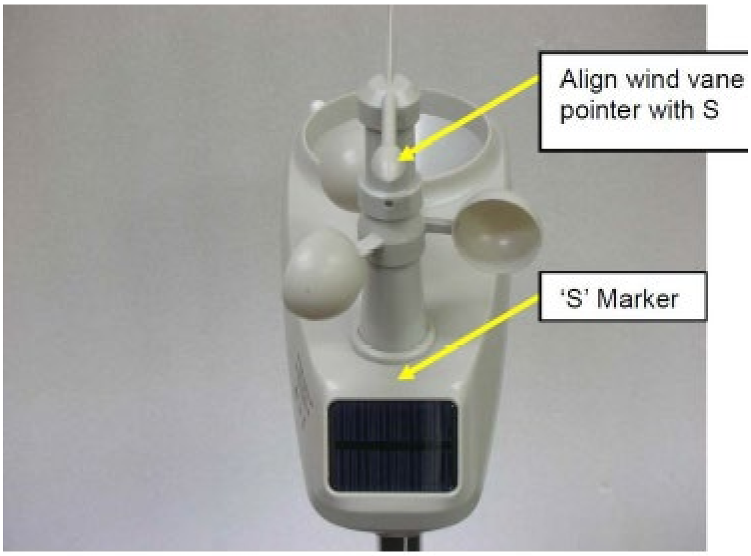


Figure 4. Outdoor sensor displaying the wind vane pointer and the "S" marker.

- To recalibrate, press the Tools/setting keys as in Figure 5.

Figure 5. Tools key.

- Press the tools key it will take you to the MENU, press it again, it will take you to ALARMS, press it for the last time, and it will take you to the calibration setting. The wind direction figure will be 180^{o} this is the figure of the Northern hemisphere. Use the up and down arrows to wind direction and set the value to 000^{o} as in Figure 6 by using the +/- and left and right keys.

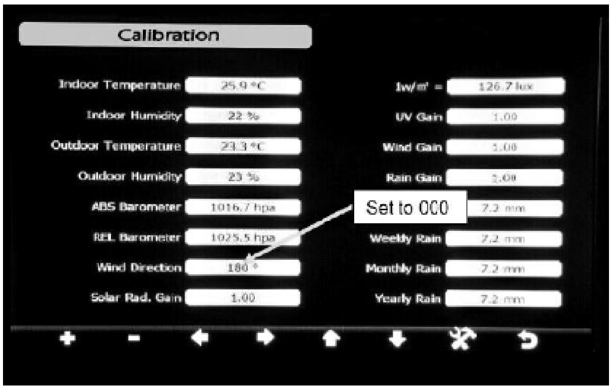


Figure 6. Wind direction change from 180 to 000.

- Now the wind direction will be zero as in Figure 7 in the console. This is now the calibrated value for the Southern Hemisphere.

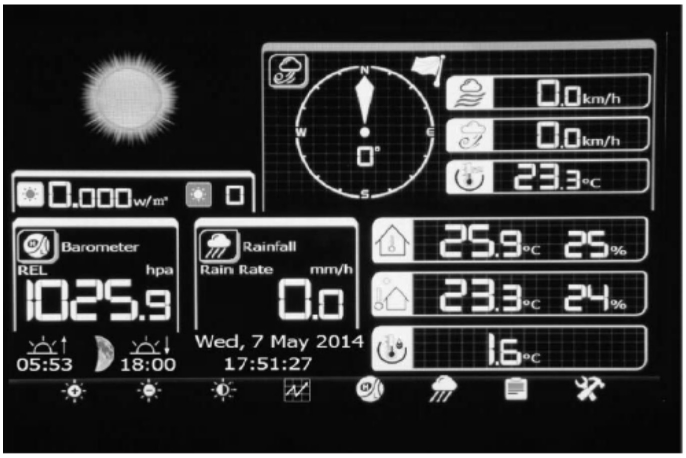


Figure 7. Wind direction is zero as displayed on the console.

Station Coordinates

Once the procedure of recalibration is done, the exact coordinates of the location have to be inserted in the console, this will enable the console to monitor the weather correctly and the sunset/sunrise function will display the correct time. Go to tools key then menu, scroll down to coordinate, and input the latitudes or longitudes. *NB: Google earth is an easier platform to get your exact coordinates.*

Installation

It is a general norm to set up a station for testing before doing so at the final destination.

The installation procedure of the outdoor sensor is as follows:

1. *Attach a wind vane*
   Attach the wind vane as shown in Figure 8 and tighten using the Allen Wrench key supplied. Do make sure that the wind vane moves freely.

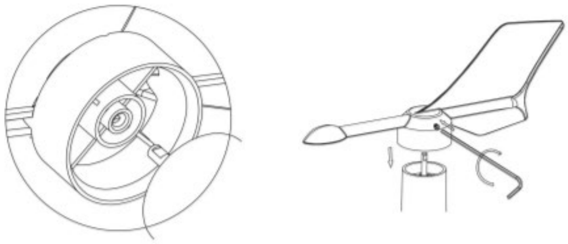


Figure 8. Wind vane installation on the outdoor sensor.

2. *Install a mounting pole*
   Install the mounting pole by inserting it to the base of the outdoor sensor as in Figure 9 and spin the lid as shown in Figure 10.

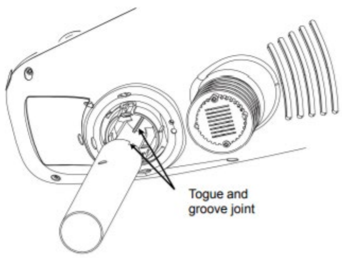


Figure 9. Mounting pole insertion on the outdoor sensor.

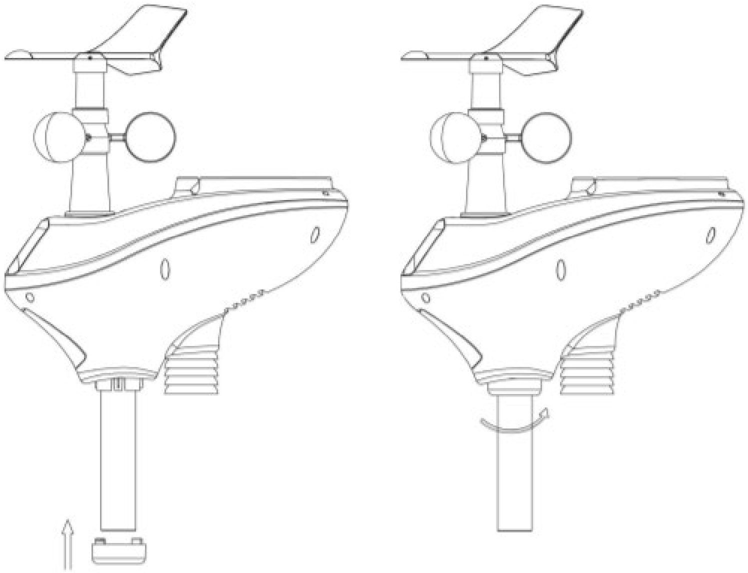


Figure 10. Securing the mounting pole with the lid at the base of the sensor.

3. *Install batteries*
   Locate the battery lid at the thermo-hydrometer transmitter as shown in Figure 11. Insert 3XAA normal alkaline batteries and the LED indicator on the back of the transmitter will turn on and flash for four seconds once every sixteen seconds.

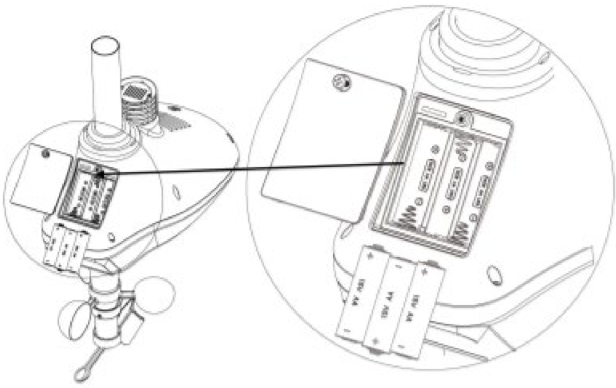


Figure 11. Insertion of batteries in the battery compartment.

4. *Mount the outdoor sensor*
   Fasten the outdoor sensor mounting pole to your mounting pole at a 2-meter height with no wind obstruction in at least 50-meter radius. Use the two U-bolts supplied to mount the pole as shown in Figure 12.

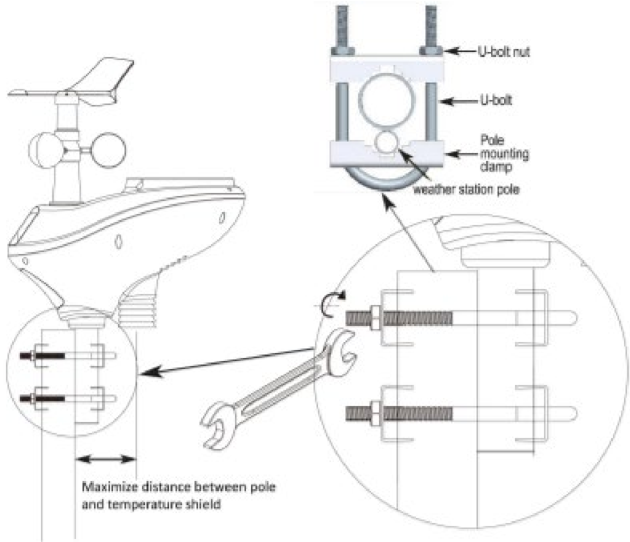


Figure 12. Mounting the outdoor sensor to a mounting pole.

Once all the steps have been done, the solar panel on the outdoor sensor should face in the north direction.

Indoor Sensor installation:

- Remove the battery door at the back of the sensor with a Phillips screwdriver. Insert two AAA batteries as shown in Figure 13 the close the lid when done. The temperature, pressure and humidity will be displayed on the screen.

Figure 13. The back of the indoor sensor battery compartment.

__Maintenance__

1. The rain gauge needs to be cleaned once every three months. These the steps to follow:

- Step 1: Make sure you record the current day value of rain received.
- Step 2: Pour water into the rain gauge to moisturize the dirt inside.
- Step 3: Use a cotton swab to clean the dirt inside. Move it on all sides so that it cleans the dirt inside as in Figure 14.
- Step 4: Remove the cotton swab and flush it with water for the remaining dirt inside.

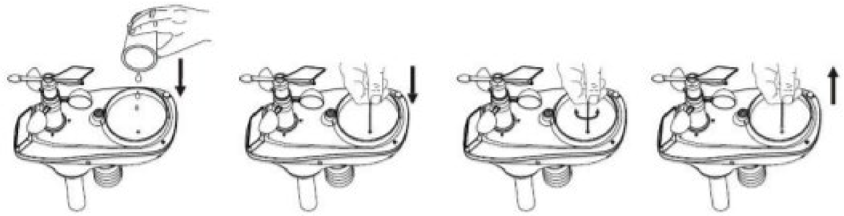


Figure 14. Rain gauge cleaning diagram.

2. The solar panel can be cleaned once in three months by using water and a towel.

3. The batteries can be changed once every two years.

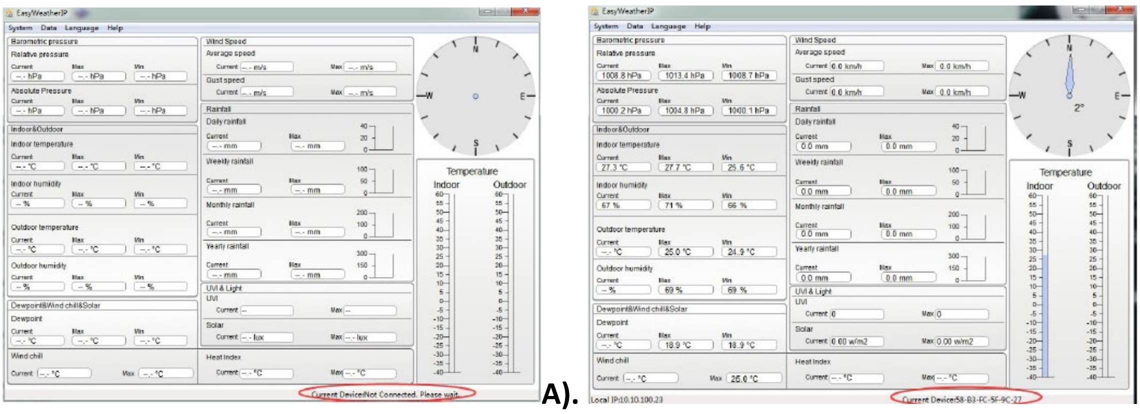
<u>EasyWeatherIP PC Software user manual</u>

This Weather Station is a high quality, easy to use weather monitoring system that records and displays the weather data from internal as well as external sensors. The operation of these units is by wireless transmission to the Base Station. To connect wirelessly, download the EasyWeatherIP program: http://download.ecowitt.net/down/softwave?n=EasyWeatherIP

Your PC will then display all indoor data as well as the weather data from the Base Station received from the external sensors.

How to use “EasyWeatherIP” program and connect the Base Station to the PC?

- Install the “EasyWeatherIP” program on this CD-ROM provided with the station.
- Connect your PC and device to the same Router, and close the firewall of the PC.
- Open “EasyWeatherIP” program, confirm the Local IP.
- Wait for the device and the “EasyWeatherIP” program to connect automatically as in Figure 15.



A). B)

Figure 15. EasyWeatheIP not connected in A and connected in B.

After the “EasyWeatherIP Setup.exe” program has been started, the following main window will appear on the PC screen. The user can set up alarms to be activated once certain levels have been reached on measurements as in Figure 16.

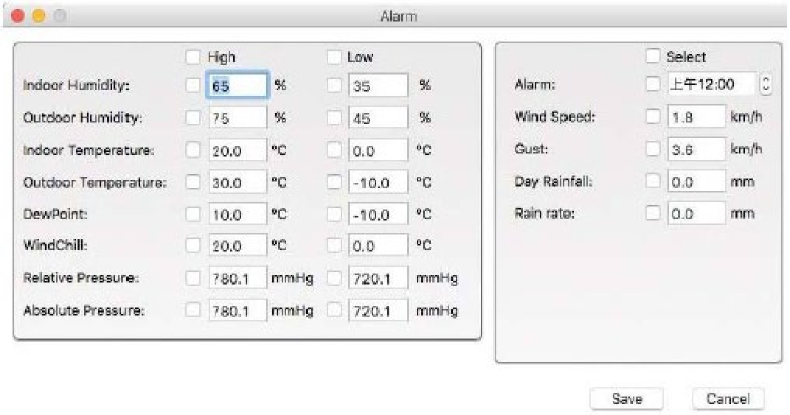
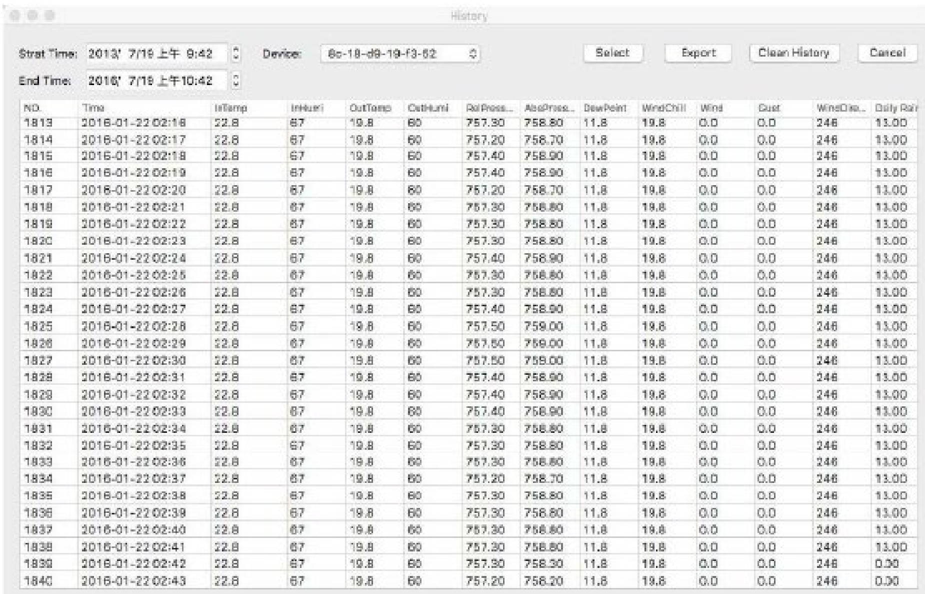


Figure 16. Alarm setting on EasyWeatherIP window.

When the user wants to view the history of the measures, they can go to the history and display the measurements as in Figure 17. The user can also select to view them in a line graph/chart as in Figure 18.



NO.	Time	InTemp	InHumi	OutTemp	OutHumi	RelPress...	AbsPress...	DewPoint	WindChill	Wind	Gust	WindDir...	Daily Rai
1813	2016-01-22 02:16	22.8	67	19.8	60	757.30	758.80	11.8	19.8	0.0	0.0	246	13.00
1814	2016-01-22 02:17	22.8	67	19.8	60	757.20	758.70	11.8	19.8	0.0	0.0	246	13.00
1815	2016-01-22 02:18	22.8	67	19.8	60	757.40	758.90	11.8	19.8	0.0	0.0	246	13.00
1816	2016-01-22 02:19	22.8	67	19.8	60	757.40	758.90	11.8	19.8	0.0	0.0	246	13.00
1817	2016-01-22 02:20	22.8	67	19.8	60	757.20	758.70	11.8	19.8	0.0	0.0	246	13.00
1818	2016-01-22 02:21	22.8	67	19.8	60	757.30	758.80	11.8	19.8	0.0	0.0	246	13.00
1819	2016-01-22 02:22	22.8	67	19.8	60	757.30	758.80	11.8	19.8	0.0	0.0	246	13.00
1820	2016-01-22 02:23	22.8	67	19.8	60	757.30	758.80	11.8	19.8	0.0	0.0	246	13.00
1821	2016-01-22 02:24	22.8	67	19.8	60	757.40	758.90	11.8	19.8	0.0	0.0	246	13.00
1822	2016-01-22 02:25	22.8	67	19.8	60	757.30	758.80	11.8	19.8	0.0	0.0	246	13.00
1823	2016-01-22 02:26	22.8	67	19.8	60	757.30	758.80	11.8	19.8	0.0	0.0	246	13.00
1824	2016-01-22 02:27	22.8	67	19.8	60	757.40	758.90	11.8	19.8	0.0	0.0	246	13.00
1825	2016-01-22 02:28	22.8	67	19.8	60	757.50	759.00	11.8	19.8	0.0	0.0	246	13.00
1826	2016-01-22 02:29	22.8	67	19.8	60	757.50	759.00	11.8	19.8	0.0	0.0	246	13.00
1827	2016-01-22 02:30	22.8	67	19.8	60	757.50	759.00	11.8	19.8	0.0	0.0	246	13.00
1828	2016-01-22 02:31	22.8	67	19.8	60	757.40	758.90	11.8	19.8	0.0	0.0	246	13.00
1829	2016-01-22 02:32	22.8	67	19.8	60	757.40	758.90	11.8	19.8	0.0	0.0	246	13.00
1830	2016-01-22 02:33	22.8	67	19.8	60	757.40	758.90	11.8	19.8	0.0	0.0	246	13.00
1831	2016-01-22 02:34	22.8	67	19.8	60	757.30	758.80	11.8	19.8	0.0	0.0	246	13.00
1832	2016-01-22 02:35	22.8	67	19.8	60	757.30	758.80	11.8	19.8	0.0	0.0	246	13.00
1833	2016-01-22 02:36	22.8	67	19.8	60	757.30	758.80	11.8	19.8	0.0	0.0	246	13.00
1834	2016-01-22 02:37	22.8	67	19.8	60	757.20	758.70	11.8	19.8	0.0	0.0	246	13.00
1835	2016-01-22 02:38	22.8	67	19.8	60	757.30	758.80	11.8	19.8	0.0	0.0	246	13.00
1836	2016-01-22 02:39	22.8	67	19.8	60	757.30	758.80	11.8	19.8	0.0	0.0	246	13.00
1837	2016-01-22 02:40	22.8	67	19.8	60	757.30	758.80	11.8	19.8	0.0	0.0	246	13.00
1838	2016-01-22 02:41	22.8	67	19.8	60	757.30	758.80	11.8	19.8	0.0	0.0	246	13.00
1839	2016-01-22 02:42	22.8	67	19.8	60	757.30	758.30	11.8	19.8	0.0	0.0	246	0.00
1840	2016-01-22 02:43	22.8	67	19.8	60	757.20	758.20	11.8	19.8	0.0	0.0	246	0.00

Figure 17. Historical dataset.

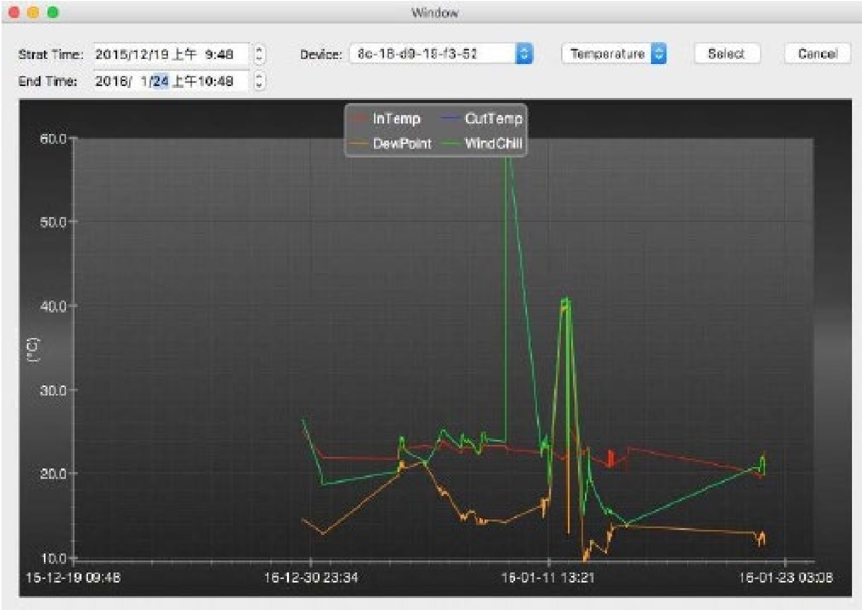


Figure 18. Line graph displaying temperature trends over a selected period.

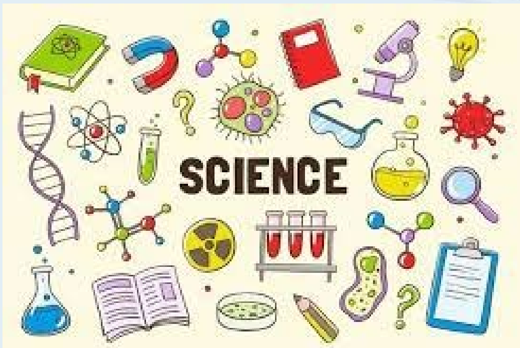
Citizen science weather stations monitoring network for early warning and resilience

South African Weather Service

1

What is science?

- The scientific process where we learn new things by observing, asking questions and experimenting
- The process follows a certain order (logic)
- It can sometimes be practiced by people who are not paid professionals(citizen scientists)



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Connection between Science and Citizen Science

Video: https://www.youtube.com/watch?v=5ijSk-QWwjw

- Science that involves people who may not be professional scientists in the scientific process e.g. sharing pictures of plants, animals or weather events such as floods
- Collaboration between scientists and those who are curious, concerned, and motivated to make a difference.
- Giving members of the public an opportunity to work in partnership with scientists to gather, record and share environmental and scientific data.
- It's how people can make an impact on issues they care about (e.g., environment, health, oceans) and contribute to science.
- A powerful tool for scientific research, education, and community development.

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3 03/14/2022 Templ ref: PPT-ISO-colour.001 Doc Ref no:

Who can participate in citizen science?

❑The answer is anyone!!!

Young people and school children

Youth groups

Community groups

Working Adults

Retired people

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CRS–CMS-PRES-001

4

Benefits of citizen science

Video: https://www.youtube.com/watch?v=o7ZyI5NBfMU –monitoring air quality

- Increase and/or improve research data collection and areas covered
- Enable the set-up of regular long-term monitoring programmes
- Help research to understand and address citizen's needs.
- Provides access to new methods and knowledge in different communities
- Brings scientists and communities closer so they work together to understand certain problems.
- Can be used for awareness-raising and education on environmental issues.
- Contribute to personal/community development.
- Support the uptake of research by practitioners and policy-makers.

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Current Citizen Science Project

❑Aims to bring science to the people and making it accessible to all through collaborations between scientists and young learners/volunteers from the community

❑Through this project, volunteers will:

- ➢collect and interpret weather data in the local community using low-cost measuring instruments.
- ➢the data collected will complement the data collected by the South African Weather Service observation network of weather stations.
- ➢learn more about how weather can affect and impact our lives.

❑The only requirement to join is an enthusiasm for watching and reporting weather conditions in your local community.

❑By being part of this project, volunteers will be one of hundreds of Citizen Scientists around the world bringing solutions to local community.

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6

Workshop objectives

- Establish what you know about climate variability and change, climate change response and early warning
- Understand the state of the environment and river catchment
- Identify main sources of income in your community
- Develop a shared vision for early warning and climate change resilience
- Explore what can be done to improve water resource management
- Identify volunteers who will collect weather and climate information in your community (Citizen scientists)

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The Basics of Weather vs Climate

Bosa vs Tlelaemete

Video: https://www.youtube.com/watch?v=YbAWny7FV3w

- Weather (Bosa) refers to the atmospheric conditions of a specific place over a short period of time, usually 24 hours.
- Climate (Tlelaemete) refers to the average atmospheric conditions over relatively long periods of time, usually 30 years.
- Forecasting is used to monitor weather in the short term (day to day, weekly and seasonal forecasts)
- Climate change modelling is used to project the long-term future climate and climate change (10 years plus)

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Weather and climate…

- Weather includes sunshine, rain, cloud cover, winds, hail, snow, sleet, freezing rain, flooding, blizzards, ice storms, thunderstorms, steady rains from a cold front or warm front, excessive heat, heat waves and more.
- Weather may change from minute-to-minute, hour-to-hour, day-to-day, and season-to-season.
- Climate, however, is the average of weather over time and space and changes in overall climate tend to be gradual

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How is the weather in your community?

Share your experiences

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Weather in Tshwane

The summers are long, warm and partly cloudy whereas the winters are short, cold, dry, and clear.

Over the course of the year, the temperature typically varies from 5°C to 28°C and is rarely below 2°C or above 32°C.

The rainy period of the year lasts for about 8 months, from September to May.

The most rain falls during January, with an average total accumulation of 96 mm.

The rainless period of the year lasts for about 4 months, from May to August.

The least rain falls around July, with an average total accumulation of 2.5 mm.

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Extreme weather events

- The condition of the air or atmosphere on our planet changes and can cause extreme weather which put people and buildings at risk (can cause damage)
- Different places experience severe or extreme weather events such as thunderstorms, hailstorms and tornadoes
- Other severe weather experienced in dry weather and can include droughts, dust storms
- The South African Weather Service monitors our weather and provides impact-based warnings for severe weather events days and even hours before they occur

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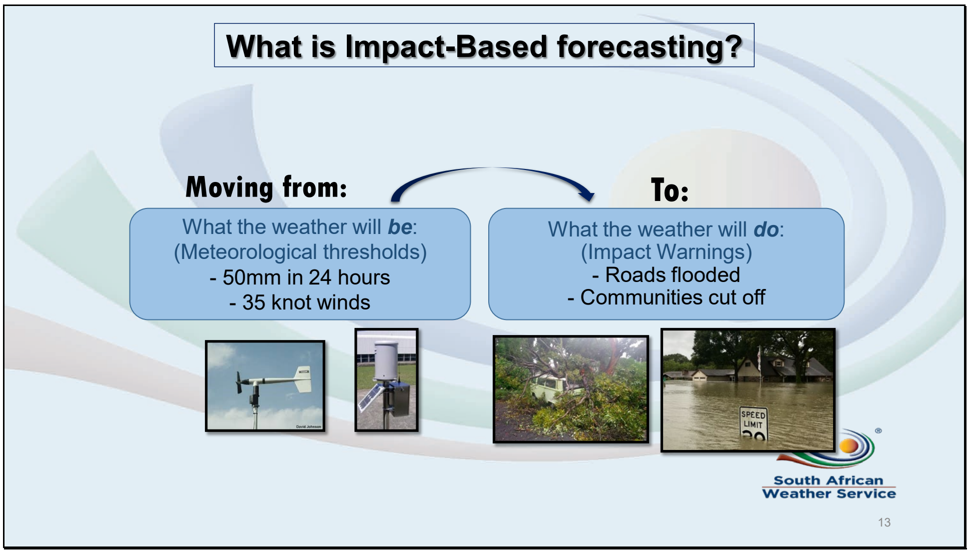
What is Impact-Based forecasting?
Moving from:
To:
What the weather will *be*:
(Meteorological thresholds)
- 50mm in 24 hours
- 35 knot winds
What the weather will *do*:
(Impact Warnings)
- Roads flooded
- Communities cut off
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13


14
Extreme weather events
• Have you or your community been affected by extreme weather events ?
• What can be done to make sure your home and community is safe from extreme weather?
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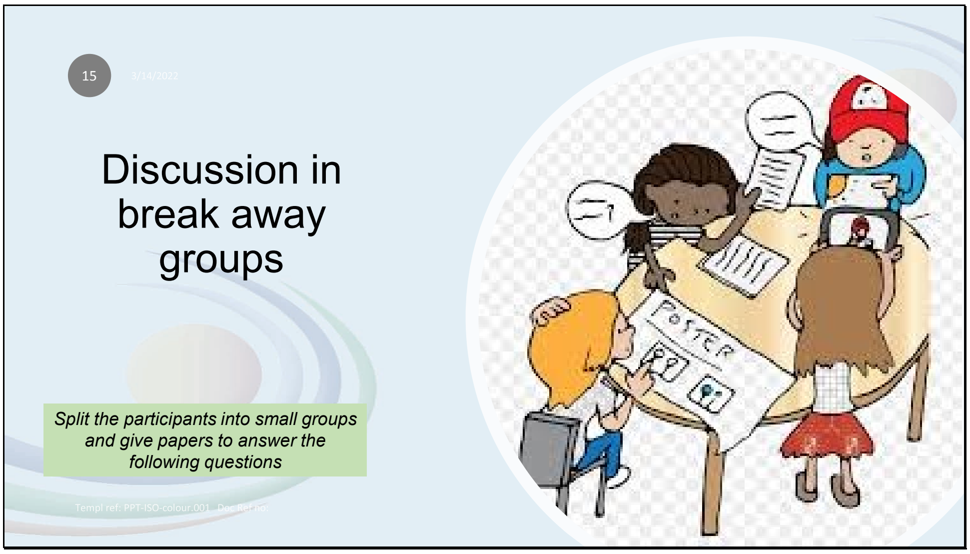
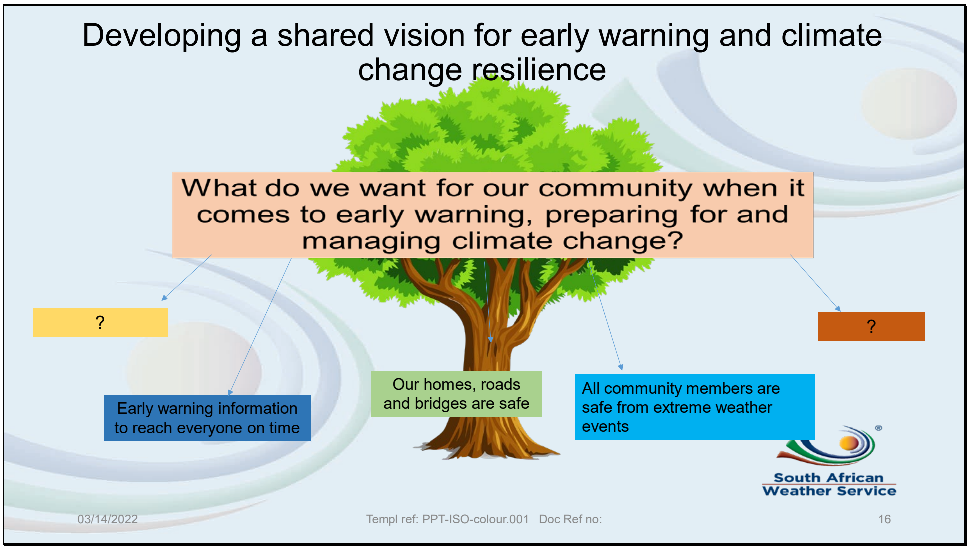
Weather Service


15
Discussion in break away groups
Split the participants into small groups and give papers to answer the following questions
POSTER


Developing a shared vision for early warning and climate change resilience
What do we want for our community when it comes to early warning, preparing for and managing climate change?
?
?
Early warning information to reach everyone on time
Our homes, roads and bridges are safe
All community members are safe from extreme weather events
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16


Sharing knowledge and experiences
Can you tell us what you know about:
• Climate change
• Climate variability
• Early warning
• Disaster preparedness and response
WHAT IS CLIMATE CHANGE?
South African Weather Service
03/14/2022
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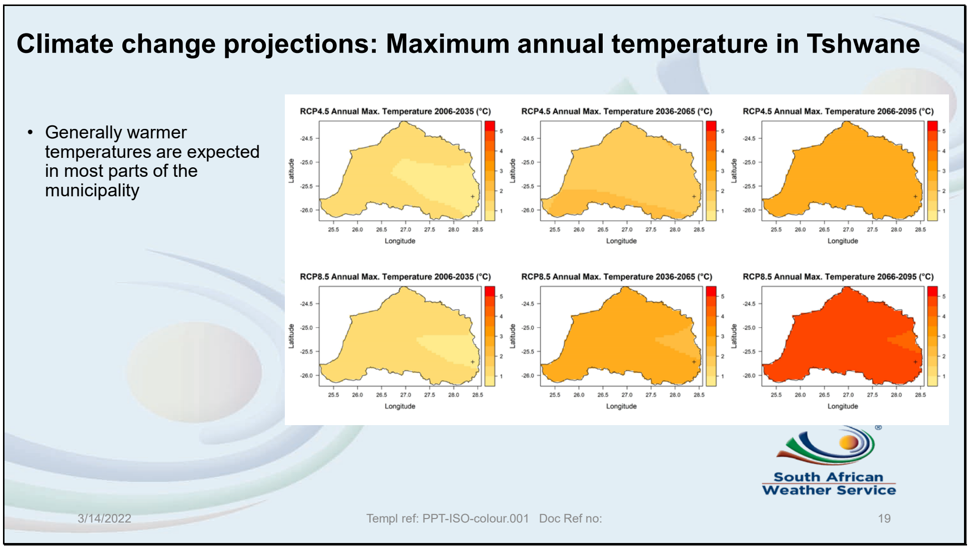
17


Climate change projections: Maximum annual temperature in Tshwane
• Generally warmer temperatures are expected in most parts of the municipality
RCP4.5 Annual Max. Temperature 2006-2035 (°C)
RCP4.5 Annual Max. Temperature 2036-2065 (°C)
RCP4.5 Annual Max. Temperature 2066-2095 (°C)
RCP8.5 Annual Max. Temperature 2006-2035 (°C)
RCP8.5 Annual Max. Temperature 2036-2065 (°C)
RCP8.5 Annual Max. Temperature 2066-2095 (°C)
Latitude
Longitude
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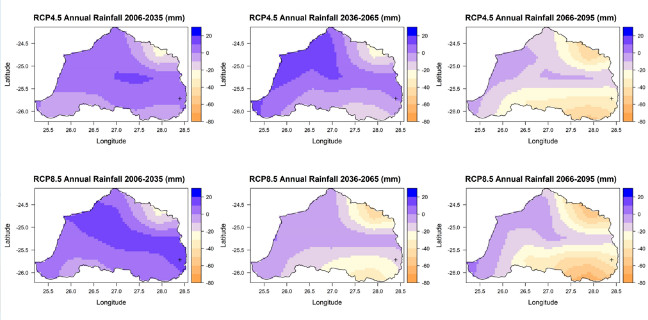
19

Climate change projections: Annual rainfall in Tshwane



- Rainfall is generally expected to become less in Tshwane particularly in the eastern parts (brown color on map)
- The west central parts are expected to have between 5-15mm more rain (dark purple color)

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Rivers in your community

- Which rivers do you have in your community?
- What can you tell us about the state of water and areas surrounding the river? Can we drink the water or use it for cooking?
- Does the river or the quality of the water and its surroundings affect you in any way?
- What can be done to improve the state of rivers in your community?

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Livelihood activities

What kind of activities do people do in your community to meet their basic needs (food, water, shelter, clothing)?

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Templ ref: PPT-ISO-colour.001 Doc Ref no: 3/14/2022 22

Practical Demonstration of Weather Stations

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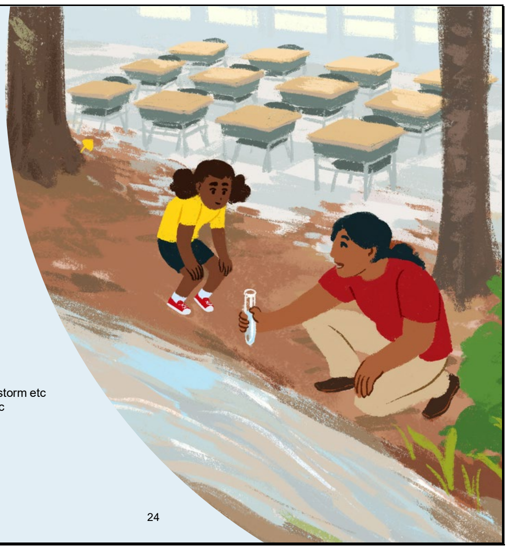
Viva Foundation Citizen scientists

Are there any volunteers from Viva Foundation who would like to be citizen scientists for this project?

What data will be collected?

- Daily weather
- Any extreme weather events: intense rainfall that causes floods, hailstorm etc
- Any damage caused by weather events- damage to roads, homes etc



26/06/2021

Knowledge-sharing-meeting-2021 24

Ethical considerations

- Participant anonymity in reporting and publication of results
- Informed consent before participation
- Voluntary participation and withdrawal at anytime without any consequences
- There will no payment for participation
- Ensuring fair representation of gender and age (female and youth)
- Adequate and appropriate communication
- Storage of research data in locked offices

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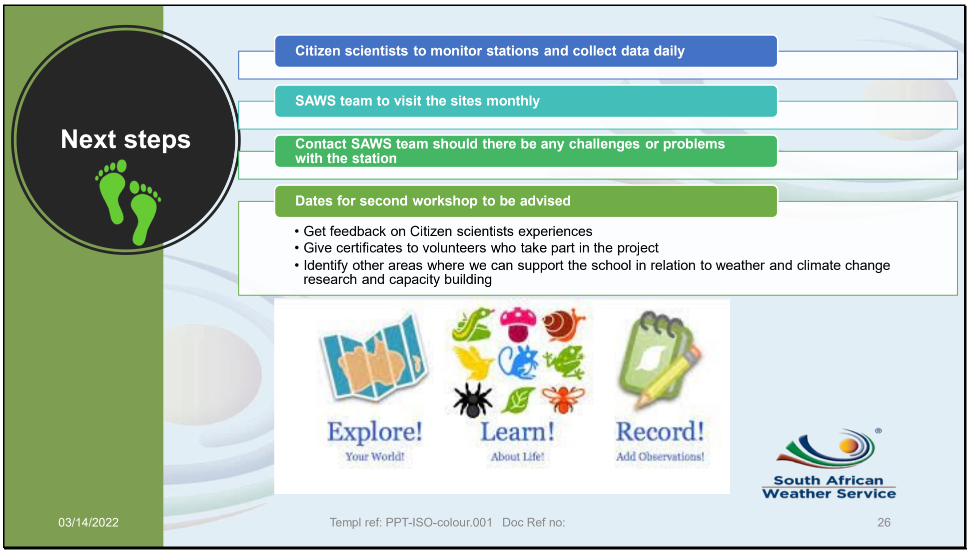
26/06/2021 Knowledge-sharing-meeting-2021 25


Next steps
Citizen scientists to monitor stations and collect data daily
SAWS team to visit the sites monthly
Contact SAWS team should there be any challenges or problems with the station
Dates for second workshop to be advised
• Get feedback on Citizen scientists experiences
• Give certificates to volunteers who take part in the project
• Identify other areas where we can support the school in relation to weather and climate change research and capacity building
Explore! Your World!
Learn! About Life!
Record! Add Observations!
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03/14/2022
Templ ref: PPT-ISO-colour.001 Doc Ref no:
26


To Viva Foundation management, learners and your team
Thank You!
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03/14/2022
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27