UPPSALA
UNIVERSITET

UPTEC W 22009
Examensarbete 30 hp
Maj 2022

Water Quality Assessment for Potential Recreational Use of the Hot Spring Mawira Sitima, Malawi

Utvärdering av vattenkvalitet och potential för fritidsbruk av den varma källan Mawira Sitima, Malawi

---

Maja Skotte
Anna Skoglund

Civilingenjörsprogrammet i miljö- och vattenteknik

ABSTRACT

Water Quality Assessment for Potential Recreational Use of the Hot Spring Mawira Sitima, Malawi

Anna Skoglund & Maja Skotte

Mawira Sitima is a thermal spring located in the village Sitima outside of Liwonde, Malawi. The spring is used by many of the local villagers to take baths, play around and wash clothes. Washing using detergents in springs may cause harm to the aquatic ecosystems and worsen the water quality, which might pose a health risk to people swimming in the spring. This study compared physico-chemical properties of Mawira Sitima and the soil and plants around it with standards, guidelines and other studies to assess the water quality of the spring. The water quality of another hot spring, Mawira Liwonde, was also assessed and compared to Mawira Sitima to investigate the potential for recreational use of Mawira Sitima. The findings were then used to produce recommendations for future monitoring of relevant variables in the spring. The results indicate that the current water quality of Mawira Sitima is of no concern for the local health and has all basis to be of recreational use. A monitoring system including electrical conductivity, water temperature, pH, total phosphorous, copper, manganese, and iron was recommended based on correlations and trends. Monitoring of extreme meteorological conditions, such as heavy rainfall or drought, were also recommended.

Keywords: hot spring, thermal spring, water quality, water quality monitoring, Malawi, bioindication

Department of Ecology and Genetics, Limnology, Uppsala University.
Norbyvägen 18 D, SE 752 36 Uppsala, Sweden.
ISSN 1401-5765

REFERAT

Utvärdering av vattenkvalitet och potential för fritidsbruk av den varma källan Mawira Sitima, Malawi

Anna Skoglund & Maja Skotte

Mawira Sitima är en varm källa belägen i byn Sitima utanför Liwonde, Malawi. Källan används av lokalbefolkningen för att bada, leka och tvätta kläder. Att tvätta med tvättmedel i källor kan skada de akvatiska ekosystemen och försämra vattenkvaliteten vilken kan leda till hälsorisker för de som använder källan. I denna studie jämfördes fysikaliska och kemiska parametrar i Mawira Sitima, och jorden och plantor runtom den, med standarder, riktlinjer och andra studier för att utvärdera vattenkvaliteten i källan. Vattenkvaliteten i en annan källa, Mawira Liwonde, utvärderades också och jämfördes med Mawira Sitima i syftet att undersöka potenitalen för fritidsbruk av Mawira Sitima. Undersökningsresultaten användes sedan för att föreslå ett framtida övervakningssystem av relevanta variabler i källan. Resultaten i studien visar på god vattenkvalitet i Mawira Sitima och stora möjligheter för fritidsbruk. Övervakningssystemet föreslogs innefatta elektrisk konduktivitet, vattentemperatur, pH, totalfosfor, koppar, mangan och järn baserat på korrelationer och trender. Även extremväder såsom stora mängder regn eller extrem torka rekommenderades ingå i övervakningssytemet.

Nyckelord: varm källa, vattenkvalitet, övervakningssystem, Malawi, bioindikation

Institutionen för ekologi och genetik, Limnologi, Uppsala Universitet.
Norbyvägen 18 D, SE 752 36 Uppsala, Sverige.
ISSN 1401-5765

PREFACE

This master thesis was written within the Master Programme in Environmental and Water Engineering at Uppsala University and Swedish University of Agricultural Sciences. It was performed as a Minor Field Study in collaboration with University of Malawi Chancellor College in Zomba, Malawi.

The field study was carried out November 2021 to January 2022 at University of Malawi Chancellor College. The supervisor on site was Associate Professor Jonas Mwatseteza at the Department of Chemistry at Chancellor College, University of Malawi, who provided invaluable support and guidance before, during and after the stay in Malawi.

Academic supervisor of the project was Researcher Dolly Kothawala at the Department of Ecology and Genetics, Limnology, Uppsala University, whose guidance, engagement and encouragement was indispensable.

A special thanks to Chief Technician Timothy Mghunta at the Department of Chemistry at Chancellor College, University of Malawi who provided great support and guidance in the field as well as the laboratory.

And lastly, a big thank you to all lab technicians who always took their time to help with analyses in the lab.

The majority of the study was done in collaboration, but the processing of data and discussion was divided between the students. Anna was responsible for the overall water quality assessment and potential for recreational use including analysis of plants and soil. Maja was responsible for the land use survey and recommendations for future monitoring including meteorological data and biondication.

UPTEC W 22009, ISSN 1401–5765
Digitally published at the Department of Earth Sciences, Uppsala University, Uppsala,
2022.

POPULÄRVETENSKAPLIG SAMMANFATTNING

I Malawi, ett av världens fattigaste länder, saknar många landsbyggdsområden tillgång till vatten. Detta gör att de naturliga vattenresurserna är extra viktiga för dagliga aktiviteter som bad och tvättning av kläder. I den lilla byn Sitima, kilometer utanför staden Liwonde, Malawi, ligger den varma källan Mawira Sitima som används just i just detta syfte av runt 7000 människor. Källan utgör en viktig resurs för byn och det är därför viktigt att den håller god kvalitet.

Syftet med detta projekt har därför varit att undersöka vattenkvaliteten i källan och utvärdera potentialen att använda källan för fritidsbruk, samt att ta fram ett förslag på ett övervakningssystem. Detta gjordes genom att vid fem tillfällen och fyra olika platser ta prover från källan och sedan analysera dessa i labb för att få fram flera olika vattenkvalitetsvariabler. Dessa värden jämfördes sedan med vattnet från en borrad brunn i närheten, tidigare studier på andra varma källor och svenska riktlinjer för vattenkvalitet. Extra fokus lades på jämförelse mellan Mawira Sitima och den närliggande varma källan Mawira Liwonde som enligt uppgifter har planerats att användas för fritidsbruk under flertal tillfällen. Mawira Sitimas roll i byn skulle ökas ytterligare om detta skulle genomföras då det skulle kunna bidra med en extra inkomst om turister betalar för att besöka källan. För att ta fram ett förslag till övervakningssystem beräknades sambanden mellan olika variabler för att begränsa antalet variabler som bör kollas på i ett övervakningssystem.

Resultatet visade att Mawira Sitima höll god status gällande vattenkvaliteten jämfört med vattnet från den borrade brunnen, de andra källorna och de svenska riktlinjerna. Jämförelsen med Mawira Liwonde visade på en bättre vattenkvalitet i Mawira Sitima vilket ledde till att slutsatsen att Mawira Sitima är lämplig för fritidsbruk drogs.

Övervakningssystemet, som kan införas för att se till att källan fortsatt håller god vattenkvalitet, bestämdes till att inkludera mätningar av elektrisk konduktivitet, temperatur, pH, totalfosfor, koppar, mangan och järn. Dessa variabler hade antingen samband med många andra variabler och kan därför vara bra representationer för dessa, eller anses de vara hälsofarliga eller ge bra indikationer på förändring av vattenkvalitet. Systemet bör även inkludera meteorologiska variabler som regn och temperatur då dessa också påverkade en del variabler.

För att få ännu mer information om Mawira Sitima bör fortsatta studier göras under längre tid och då även inkludera den period då gödslingsmedel används vid flertal olika grödor runt källan och kan ha stor påverkan på vattenkvaliteten. Detta kunde tyvärr inte inkluderas under detta projekt. Projektet lyckades dock med den viktigaste delen, att avgöra att källan har potentialen att användas för fritidsbruk och hur den kan fortsättas användas för det genom att övervaka källan under en längre tid. Mawira Sitima, som har haft en viktig roll i området i hundratals år, kan förhoppningsvis med hjälp av resultatet i detta projekt fortsatt ha en viktig roll lika länge till.

Contents

1 INTRODUCTION

Malawi is one of the poorest countries in the world and a lot of the rural areas lack adequate access to clean water (Kadzamira 2021). This leads to the natural resources in the country being especially valuable as they can be utilised in several different ways. One of these natural resources are thermal springs, which are common in the country (Atekwana et al. 2015) and are being used for hygienic purposes (Mwatseteza 2021). Washing using detergents in the springs may cause harm to the aquatic ecosystems and worsen the water quality, but it is an highly unexplored area (Gordon et al. 2009). Not only may this affect the water itself but it may also pose a health risk to the people swimming in the spring if the water quality is poor (World Health Organization 2003a). Water quality refers to physical, chemical and biological characteristics of the water in respect to its suitability for particular purposes such as recreational use (Sanctuary n.d.).

Mawira Sitima is a thermal spring located in the village Sitima outside of Liwonde, Malawi. The spring is used by many of the local villagers to take baths, play around and wash clothes (Mwatseteza 2021). The purpose of this project was to investigate physico-chemical properties of the spring and the plants and soil around it to asses the water quality of the spring and any potential threats to the public health. Due to limited time and equipment, biological characteristics were not part of this study. From the findings a proposal for how a long term monitoring system can be set up was made and also an investigation to how suitable the spring is for recreational uses. If the spring is properly characterised, it could hopefully offer ecotourism with involvement of the local communities and lead to extra income.

1.1 RESEARCH QUESTIONS

The research questions to be answered in the study are as follows:

- What is the current water quality in Mawira Sitima?
    - What are the values in Mawira Sitima of commonly measured variables in other hot springs, and how do they compare to values in soil from the area?
    - How do the values compare to guidelines, hot springs used for recreational purposes, and a reference site?
- Can Mawira Sitima be used for recreational purposes?
    - How does the water quality in Mawira Sitima compare to Mawira Liwonde, another spring considered for recreational use?

    - How do plants and soil in Mawira Sitima compare to Mawira Liwonde and can the soil explain any potential differences in water quality of the two springs?

- What is the best way to set up a monitoring system for Mawira Sitima?
    - How do the measured variables correlate to each other?
    - What temporal trends (Nov 2021-Jan 2022) do the measured variables show?
    - Does activity and meteorological conditions (precipitation and air temperature) in the area affect the quality of the hot spring and are therefore relevant to monitor?
    - Can bioindication, water quality assessment based on plants characteristics, be used to monitor the water quality of the hot spring?

2 BACKGROUND

2.1 THERMAL SPRINGS

Hot springs are naturally occurring geological phenomena that are likely to exist where heat and water meet, most often in volcanic areas (Des Marais et al. 2019). They are distinguished by their elevated temperature, low levels of dissolved oxygen (DO), and radioactivity (Dash et al. 2013). Hot spring waters are diverse in their chemical composition, and the thermal gradients and chemical deposition at their outlets help to sustain diverse microbial communities. The springs are potent chemical reactors which lead to geological preservation of these communities due to deposits of minerals. The environments of thermal springs contain all essential chemical blocks of life. Hence, hot springs are of interest to both biologists and geologists and are also highly relevant in the search for present and ancient life on other planets (Des Marais et al. 2019).

Thermal springs are utilised in many different countries for purposes such as aquaculture, generation of power, industrial processes and direct space heating. Since before 2000 BC they have been used for religious and medicinal purposes and usually develop into religious and cultural centres (Olivier et al. 2011). The presence of sulphur and sulphate ions make hot spring water suitable for skin therapy (Ghilamicael et al. 2017). Hence, the physico-chemical characteristics of a thermal spring largely determines its optimal use and over the past decades there has been an unprecedented interest in this resource. This is mainly due to the diversification in application of waters, leading to thermal springs being increasingly used for power generation, bottled water and extraction of rare elements (Olivier et al. 2011).

2.2 MALAWI

Malawi is a landlocked country boarded by Zambia, Tanzania and Mozambique and has a population of approximately 19 million people (The World Bank 2020a). The climate in Malawi is subtropical which means it is strongly seasonal with 95% of the annual precipitation occurring during the wet season. The cool, dry season stretches from May to October with mean temperatures of 17-27 °C and the warm, wet season from November to April with average temperatures of 25-37 °C (Ministry of Forests and Natural Resources 2021). The country is mainly occupied by forests and woodlands which covers about one third of the country, and Lake Malawi which covers about one fifth of the country (Kadzamira 2021).

Malawi is one of the poorest countries in the world with a GDP per capita of 1591.6 US$ in 2020 compared to The United States GDP per capita of 63593.4 US$ in 2020 (The World Bank 2020b). Agriculture is a big part of the country's economy where tobacco is the main contributor but also tea, sugar and cotton. Most of the population works within agriculture and lives in rural areas (The World Bank 2007). In 2020 Malawi was ranked 174 out of 189 countries on the human development index (UNDP 2020). The water resources in Malawi are large but some rural areas lack access to clean water and only a fraction of the population have access to electricity in their homes, making them dependent on firewood for energy supply (Kadzamira 2021).

Malawi is located at the southern end of the Western branch of the East African Rift System, which causes the it to have multiple hot springs spread over the country (Dulanya et al. 2005). The East African Rift system is made up of three branches, the eastern, the western and the southeastern branch which can be seen in Figure 1. The rift stretches from the Afar triangle in the north to Biera, Mozambique in the south and the length of the whole rift is about 4000 km long (Omenda 2021). The branches are characterised by thousand kilometres long rift valleys. Divergent movements of the tectonic plates causes faults in the Earth's crust as the lithosphere extends and magma production increases (Chorowicz 2005; Omenda 2021). Geothermal activity in these areas lead to fumaroles and hot springs (Omenda 2021). Lakes in the East African rift system are often characterised by an anoxic hypolimniom that makes up a large part of the water mass (Talbot 2005). Malawi currently heavily relies on hydroelectricity for power generation but the hot springs caused by tectonic motion have the potential to be an alternative source of geothermal energy (Dulanya et al. 2005).

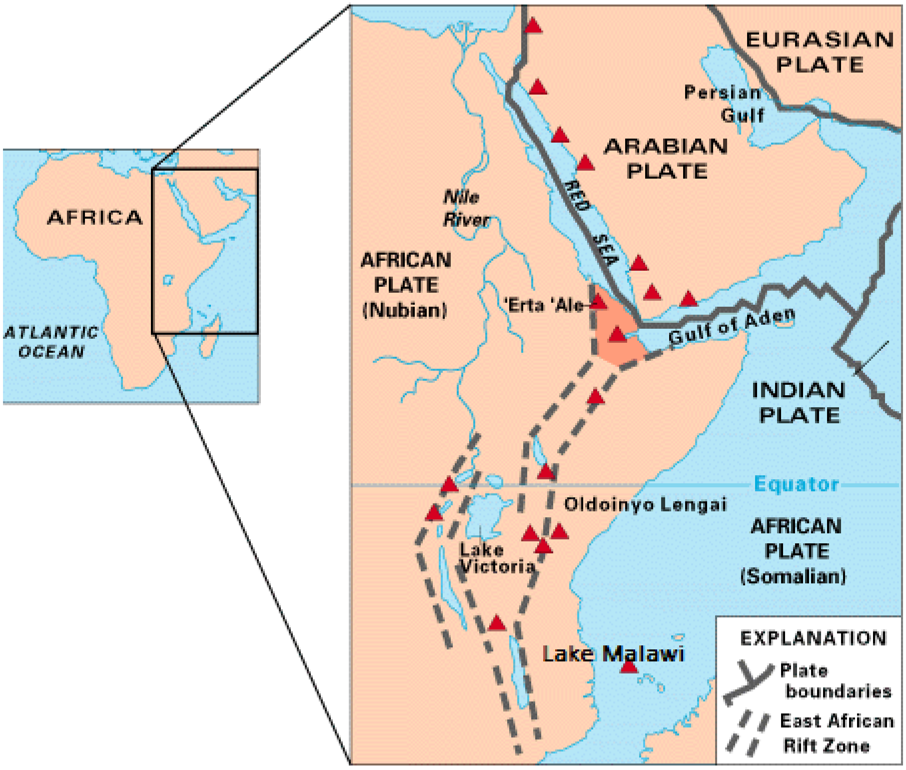

Figure 1: The East African rift system (USGS 1999). Malawi is located by Lake Malawi which can be seen as the bottom lake in the figure.

2.2.1 Location Description

Liwonde is a city located in the Southern Region of Malawi that serves as a crossroad between four districts; Balaka, Zomba, Mangochi and Machinga. It is considered to be the centre of transportation in Malawi but is mostly known for Liwonde National Park in close proximity to the city centre (Maps of World 2021). Approximately 5 km from Liwonde, the village Sitima is located.

In Sitima the local community is pursuing small-scaled agricultural activities, and animals such as goats and chickens walk freely. Drinking water comes from groundwater and there are multiple boreholes in the village were the locals can go and get water, the closest one to the spring being about 500 meters away. The water is untreated when it comes out of the pump and no treatment is done before consumption [1].

The subject of this study is the hot spring Mawira Sitima and the location of the spring can be seen in Figure 2. The spring is located in Sitima and has a temperature of approximately 37 °C (Mwatseteza 2021). Studies have been conducted on the chemistry of other hot springs in the country, including springs close to Sitima, but Mawira Sitima itself has been minimally studied (Dulanya et al. 2005; Mwatseteza 2021). Evaluating the spring will play an important role in making sure the spring can continue being used by the local community for washing without risking the users health.

---

[1] John Moses, Village Chief in Sitima, Interview 2021-11-23

Figure 2: The location of Mawira Sitima in Malawi.

The water of the spring is thought by the locals to originate from a swamp about 200 meters from the spring [1]. The water from the supposed source is directly beneath a thin layer of vegetation and soil of about one decimetre. In the spring, the water comes up from the ground in the middle, which is the only known inlet. The spring consists of three to four pools with decreasing temperature as it moves further from the inlet. The pool where the inlet is located is used by the men in the village to wash themselves and clothes. The water moves from the men's pool through tall grass before it reaches the second pool which is used by the women in the village. The women wash themselves and laundry washing using soap is more frequent than in the men's pool. The water then moves through more tall grass before finally reaching the last pool. This pool is only used by grazing animals to drink and cool down. From this pool the water goes out to the Shire river [2].

The geology of the site consists mostly of sedimentary rocks such as pelite and siliclastics.

---

[2] This information is based upon observations by the authors

It also contains some metamorphic rocks such as gneiss and schist (Dill 2007; Haundi et al. 2021).

Around 5 km from Mawira Sitima is another hot spring called Mawira Liwonde. The hot spring is located in central Liwonde and is used much the same way as Mawira Sitima. Local people come there to wash themselves and do laundry. The hot spring has been considered for recreational use several times and attempts to build a structure so that tourists can pay an entrance fee to swim in the spring has been made [3].

2.3 EFFECTS OF ANTHROPOGENIC ACTIVITIES ON WATER QUALITY IN RURAL AREAS

Waters can be affected by both natural and human factors that can lead to worsened water quality. As the world's population increases, water is becoming scarcer. The contaminants that frequently affect water quality in rural areas are both inorganic and organic compounds coming from anthropogenic activities. These activities do not only affect the water quality, but also the habitat of flora and fauna, leading to loss of ecosystems (Khatri et al. 2015).

Agriculture activities, including irrigation and application of fertiliser, have a big impact on water quality. The most common impact is top soil being washed from fields and carried by rainwater to be deposited in lakes and streams nearby. The soil carries fertilisers, pesticides, heavy metals and other pollutants into the waters as these pollutants stick to the soil particles. The pollutants can then cause algal blooms and deplete oxygen which threatens aquatic life (Khatri et al. 2015). The main pollutants from agriculture is nitrate, phosphorous, pesticides, soil sediment particles, salt and pathogens. This can lead to poor drinking water as well as damage to ecosystems (Parris 2011).

Grazing animals such as cows, sheep and goats, can have both negative and positive effects on water quality. The positive effects include minimising soil erosion through good management of forage crops. The negative effects occur when nutrients from urine and faeces dropped by the animals lead to erosion and sediment transport into surface waters. The primary nutrients of concern are phosphorous and nitrogen but pathogens is also of big concern and have been known to be a larger concern when the animals are not fenced out from streams and form ponds (Hubbard et al. 2004).

Detergents enter streams and lakes through different anthropogenic activities, one of them being direct washing of clothes in the water bodies themselves. The consequences of these detergents are mostly unexplored when it comes to rural areas in low-income countries, where direct lake and river washing is common (Gordon et al. 2009). A study done in Balfour River in South Africa found that the concentration levels of detergent were highly variable. They found high levels near the washing site but low levels downstream the washing site (Gordon et al. 2009). One of the known consequences of high concentrations of detergents in water, is that it can cause foam to be created in the surface. This can cause

---

[3] Jonas Mwatseteza, Interview 2022-01-19

lower levels of DO which will in turn affect aquatic life. The detergents can also change chemical and physical parameters of the water like turbidity, pH and salinity. Detergents will increase the pH which can then affect both fish and plants in the water (Chirani et al. 2021).

2.4 WATER QUALITY VARIABLES

2.4.1 Physico-chemical variables

The physico-chemical characteristics of a thermal spring largely determines its optimal use (Olivier et al. 2011), which makes it relevant for this study as it might conclude that the water is unsuitable for the current activities.

Electrical conductivity (EC) is used to measure the water's ability to pass an electrical current. Dissolved salts and other inorganic chemicals conduct electrical currents which means that the EC of the water will increase with higher concentrations of these chemicals (US EPA 2013a). Temperature also affect EC with warmer water giving higher EC, as it makes surrounding rocks more easily dissolved (USGS n.d.). EC is a useful way to measure changes in water quality and is therefore a good variable to look at when it comes to monitoring water quality. This is because significant changes in EC can indicate that some sort of pollution has affected the water (US EPA 2013a).

The temperature of the water does not only influences the EC, but it also has a major influence on biological activity and growth as well as the water chemistry. All aquatic species have a preferred temperature range, which leads to water temperature governing the composition and diversity of species. The rate of chemical reactions is also largely governed by the temperature, with higher rates for higher temperatures (USGS n.d.). Measuring the water temperature might offer explanations to other variables and indicate the quality of the spring.

Similarly to EC, total dissolved solids (TDS) describes the inorganic salts that is dissolved in water, but also the small amounts of dissolved organic matter. The solids originate from natural sources as well as sewage, agricultural and urban run-off. TDS concentrations from natural sources vary a lot depending on the solubility of geological minerals in the region (World Health Organization 2003b). Depending on what type of inorganic salts the water contains it might be harmful with high levels of TDS (World Health Organization 2003b).

Sodium (Na) is the sixth most abundant element on Earth and there are significant deposits of sodium-containing minerals in most of the world. It is a normal component of the body, which main source for human exposure is salt in food, and at some levels it is required for good health. However, very high oral doses are shown to cause nausea, convulsion, muscular twitching and death. The primary health effect of long-term low level exposure is hypertension in both humans and animals. Anthropogenic sources of sodium salts is, among others, chemicals, agriculture, food processing, personal care products and medications (US EPA 2003).

Potassium (K) is an essential element to humans which occurs widely in the environment, including natural waters and all animal and plant tissue. The main source for general intake is through food, particularly fruits and vegetables (World Health Organization 2009). High concentrations of potassium in surface and groundwater is shown to cause both environmental and health problems within high-risk groups such as people with kidney, hearth or coronary artery disease and diabetes. Research has also shown that potassium concentrations in soil solution and runoff are more sensitive to changes in fertilisation and land use than nitrogen and phosphorous levels. Other than agricultural sources, anthropogenic origins of potassium is municipal and industrial sewage and wastewater discharge (Skowron et al. 2018).

Calcium (Ca) is the fifth most abundant element occurring naturally. Calcium has only been found to be toxic in extremely high concentrations but is essential in lower concentration. A diet rich in calcium may prevent certain types of cancer and may also decrease the blood pressure of pregnant women (Health Canada 1978). High concentrations of calcium and magnesium (Mg) causes water hardness (Ansell 2005). Harder water makes it more difficult to clean items as it reduces detergency and decreases the solubility of detergents and soils (Williams 2007).

Other than affecting the hardness of the water, magnesium might also affect the taste of the water. It can also have a laxative effect but no other adverse health problems adverse been linked to it. Magnesium can been found in many different minerals and therefore occurs naturally in waters. It is also used in many industries which might increase concentrations in waters (Health Canada 1997).

Zinc (Zn) occurs in small amounts in almost all igneous rocks and is therefore usually more present in groundwater than surface water. In naturally occuring surface waters, zinc concentrations are usually below 10 μg/l. It is an essential element in all living organisms and is utilised in nearly 200 different enzymes. However, long-term exposure leads to zinc toxicosis in various mammalian species, including humans, due to copper deficiency caused by excessive zinc intake. Studies on rats also suggest that zinc has long-term carcinogenic effects. Acute toxicity arises from ingesting excessive amounts of zinc salts which leads to vomiting, fever, stomach cramps, and diarrhoea (World Health Organization 2003c). Most commonly, zinc is used to coat other metals to prevent rust and corrosion but it is also combined with other elements to form zinc compounds. Zinc compounds are widely used in industry to make paints, ceramics, rubber, and for preservation of wood. They are also used by the drug industry as ingredients in sun blocks, deodorants, diaper rash ointments, and anti-dandruff shampoos (ATSDR 2005).

Iron (Fe) is one of most abundant element in the Earth's crust which means that it will be found naturally in water bodies. But there can also be anthropological sources of iron from in industrial and domestic waste. High concentrations of iron has been known to cause health issues but it can also cause changes in water colour, odour and taste. The health issues associated with high concentrations of iron include liver cancer, diabetes and infertility (Kumar et al. 2017). Iron has also been known to cause discolouration of clothes which can not be removed by soap or detergents. Chloride and alkaline builders have been known to intensify the stains (El Azher et al. 2008).

Copper (Cu) occurs in aquatic systems due to both natural and anthropogenic sources such as geological deposits and volcanic activity or mining activities, agriculture, manufacturing, and pesticide use (US EPA 2014a). It is essential for good health but high doses can cause health problems such as gastrointestinal distress due to short-term, high level exposure. Long-term exposure can cause anaemia and disrupt kidney and liver functions (Washington State Department of Health 2016). It can also lead to adverse effects on growth, brain function, metabolism, enzyme activity and reproduction (US EPA 2014a).

Manganese (Mn) is widely distributed in Earth's crust and usually occurs with iron. It exists naturally in many surface waters and the soils that erode into the water. However, anthropogenic activities, such as traffic emissions, also contribute to manganese contamination of waters. It is essential to the proper functioning of enzymes in both humans and animals, but high doses can lead to neurological effects due to short-term exposure or changes in appetite and enzyme levels due to long-term exposure (World Health Organization 2011).

Chloride (Cl) exists mostly as a dissociated monovalent in water but can form salts with all major cations. It is an essential ion for a lot of biological processes but can be toxic at elevated levels. The toxic level is different depending on the harshness of the water (Elphick et al. 2011). Chloride in surface and groundwater originates from both natural and anthropogenic sources, such as use of inorganic fertilisers, animal feeds, irrigation drainage, and seawater intrusion (World Health Organization 2003d).

Sulphate (SO_4) is an important part of the aquatic system and sulphate reduction, where oxidation of sulphate creates hydrogen sulphide under anaerobic conditions, which can be an indication of stronger anthropogenic impact if it intensifies (**leonov_sulphate_2008**). Sulphate can cause dehydration through a laxative effect and hydrogen sulphide can be toxic to both fish and humans (Skipton et al. 2010). Sulphate reduction can also lead to pyrite which lowers the sulphate concentration. The oxidation of pyrite can cause sulphate levels to increase again, which usually happens in low pH, warm temperatures, and water with a lot of organic materials (Porowski et al. 2019).

pH is a measure of the concentration of the hydrogen ions which is connected to how acidic the water is (Trick et al. 2008). If the water becomes to acidic it will cause aquatic life to die out. Some waters can have a low pH due to natural causes such as bedrock but some waters become acidic due to acid rains or runoff (US EPA 2013b).

Salinity is measured to study the concentrations of all salts. The ecological effects of changing salinity are complex with the species diversity generally declining with increased salinity (Schlesinger et al. 2009). Salinity is essential for humans in a moderate amount but higher amounts can cause serious health effects. Salinity has increased in many parts of the world due to sea level rise and other contributing factors (Vineis et al. 2011).

Other elements that are crucial to study when assessing the water quality is macro nutrients. Phosphorous and nitrogen are both essential nutrients that are needed for all life forms (US EPA 2013c). Too much of the two nutrients lead to eutrophication and cause increased algal and aquatic plant growth, which in turn can lead to decreased levels of dissolved oxygen. High levels of phosphorous and nitrogen can also lead to algal blooms which can be toxic for aquatic life and humans (US EPA 2013c; US EPA 2013d). Phosphorous is often considered being the limiting nutrient in aquatic ecosystems, which means that the availability of phosphorous regulates the rate of which plants and algae can grow. Increased levels of nitrogen may interfere with the diversity of the ecosystem and may favour species with high intakes of nitrogen as other species decline. This can in turn change the functions of the water body (US EPA 2013d). Anthropogenic sources for phosphorous and nitrogen are mostly from agriculture and sewage (Skowron et al. 2018)

Turbidity is a measurement of the water's loss of transparency due to suspended particles. A higher turbidity is a consequence of murkier water. It can be caused by things like urban runoff, algal growth and soil erosion. Turbid waters lead to warmer waters since the particles block sunlight which in turn limits photosynthesis and lowers the level of oxygen in the water (Patel et al. 2015).

Dissolved oxygen (DO) is a measurement of how much oxygen exists in the water. DO is needed in water to be able to support aquatic life since all aquatic animals need it to survive. If DO in the water is to low this could lead to a loss of of aquatic life, especially organisms that live in the sediments (US EPA 2013e).

2.4.2 Other environmental variables

Other variables in addition to the physico-chemical, might indicate the environmental health of the spring and its ecosystems. Such variables include living organism like phytoplankton and macrophytes as bioindicators, as well as the surrounding geology.

The meteorological conditions such as air temperature and precipitation play a big role when it comes to water quality. Temperature impacts several transformations such as solubility and evaporation which means that concentrations of dissolved substances will increase while concentrations of dissolved gases will decrease. The decrease in concentration of dissolved gases is a vital point when it comes to DO. However, as the temperature of the spring is regulated by geothermal heat, air temperature might not be of as much importance as in other waters. Increased precipitation causes more runoff and more transportation of solid material into the stream (Delpla et al. 2009).

As seen in a previous study, the surrounding geology might impact the chemical characteristics of waters in the area. Quartz, sandstone and shale was proved to contribute to high sodium concentrations whereas basaltic intrusion was associated with magnesium and calcium. It was also suggested that crystalline rocks lead to less saline waters and sedimentary rocks were associated with more saline waters (Olivier et al. 2011). Waters located in areas with both sedimentary and crystalline bedrock have been found to have higher pH, electrical conductivity and concentrations of calcium, magnesium and ammonium compared to waters located in areas with only crystalline bedrock (Nelson et al. 2011).

Soil stores both essential nutrients and chemicals used by people. This means that soil can be used to provide information on wetland conditions and determine if chemicals and nutrients are available at toxic levels for plants and microorganism. If the soil contains high levels of trace elements it could be an indication of a potential stressor and pollution sources (US EPA 2014b).

Chlorophyll is used by plants to photosynthesise and chlorophyll-a is the main type of chlorophyll found in algae and green plants. Analyses of chlorophyll-a is used to measure the amount of algae growing in a water body and can be used to give an indication of the trophic condition. To much algae can cause green scums, bad odors, decreased levels of dissolved oxygen and some algae produce toxins harmful to humans (US EPA 2013f). Changes in chlorophyll levels, and hence phytoplankton levels, might also indicate rapid changes due to pollution and fertilisation (Parmar et al. 2016).

Bioindicators are organisms such as animals, plants, planktons and microbes, that are utilised to assess the environmental health and biogeographic changes at a location. Each organic entity within an ecosystem or environment indicates the health of its surroundings and for example plankton responds rapidly to changes in water quality and water pollution. Particularly Cyanophyta, a type of phytoplankton, is a powerful bioindicator for rapid eutrophication of waters (Parmar et al. 2016).

2.5 PREVIOUSLY CONDUCTED STUDIES

Water quality is important in many regards and one of them is for recreational activities such as swimming and bathing (World Health Organization 2003a). A study was done in the Netherlands on disease outbreaks associated with untreated recreational water use. The study found that untreated water caused over 700 outbreaks during 1991-2007 and involved at least 5623 patients. The conditions were mainly skin conditions and gastroenteritis and the study concluded that it is important to identify sources that might contaminate these water sources to protect public health (Schets et al. 2011).

Although the characteristics of all hot springs are not entirely the same, the studies presented below examined largely the same physico-chemical parameters of the waters and some have investigated biological variables as well. The latest study done on hot springs in Malawi was conducted in 2013 and investigated the chemical and isotopic characteristics of 27 springs. It was then suggested that the origin of the water in the hot springs is meteoric (Atekwana et al. 2015). Meteoric waters come from rainfall or snowfall that occur near the Earth's surface. Since they come from rainfall they tend to be acidic from dissolved humic, carbonic, and nitrous acid but if running through carbonate rocks they may be neutralised. pH in meteoric water usually remains low in swampy environments but increases in arid environments (Selley et al. 2015). Previous to the 2013 paper, the latest studies done on hot springs in Malawi were published in 1965 and 1975 and have therefore lost some relevance. In one of the studies it was concluded that the chemistry at the surface of hot springs and at greater depth may vary a lot and should be investigated further (Dulanya et al. 2005).

A study conducted in Eritrea, in northeastern Africa, examined the thermal and chemical features of five hot springs in the eastern escarpment. This was done with the purpose of determining the recreational and medicinal possibilities of the springs. The study concluded that the water in one of the springs was slightly corrosive, which was considered to be a public health concern and recreational activities were to be closely monitored. To further investigate the effect on public health, the concentration of major ions and TDS were measured and compared to water quality standards provided by the World Health Organisation (WHO). Water temperature, pH, calcium carbonate, salinity and EC was also recorded for the hot springs (Ghilamicael et al. 2017).

As in Malawi, thermal springs in South Africa is largely under-researched and underutilised. One study, conducted in the Limpopo Province in South Africa, examined the thermal och chemical features of 8 different hot springs. These springs, like the ones previously examined in Malawi, were assumed to be of meteoric origin. The study largely focused on the geographical and geological characteristics of the surroundings as well as presence of major elements and ions in the springs. From this, conclusions on the influence of the geology on the chemical characteristics were made. Quartz, sandstone and shale seemed to contribute to high sodium concentrations and basaltic intrusion could be associated with magnesium and calcium. It was also suggested that crystalline rocks lead to less saline waters and sedimentary rocks were associated with saline waters (Olivier et al. 2011).

Another study conducted in Sri Lanka analysed both water quality and biology in two hot springs and one well within the same area. Measurements of temperature, pH, salinity, EC and DO were conducted on site and for analysis of nitrate, phosphate and total hardness water samples were filtered though nitrocellulose filter papers. The samples were collected from the surface, middle and bottom of each well. The results showed that there was no significant variation of water quality at different depths or temperatures. However, pH varied based on oxygen levels and the conductivity depended on geological background of the spring (Rajapaksha et al. 2014).

Parameters such as temperature, pH, salinity, EC and DO are commonly measured in various studies studying hot springs, along with turbidity, alkalinity and major ions (Dash et al. 2013; Haki et al. 2012; Hamzah et al. 2013). In one of the studies, EC was determined to be a good indicator of the water quality and was thought to be affected by anthropogenic activities (Dash et al. 2013). Among the major ions that are commonly measured are sodium, sulphate (Haki et al. 2012; Hamzah et al. 2013), calcium, (Dash et al. 2013; Hamzah et al. 2013), magnesium, iron (Dash et al. 2013), potassium and chloride (Hamzah et al. 2013).

A study conducted in the north-east France attempted to use plant communities as bioindicators of eutrophication both in acidic and alkine waters. In each site, information about the abundance of different plants was gathered using the method defined by Braun-Blanquet (1964). The method used a coefficient of abundance dominance and from that and from information about the water chemistry, the study was able to conclude that there was a significant difference of floristic composition between the alkine and acidic waters. The study found that plants were distributed according to a trophic gradient for the two water types. The trophic gradient went from oligotrophic to eutrophic (Robachl et al. 1996).

2.6 WATER QUALITY ASSESSMENT

2.6.1 Surface Water Criteria

Classification of water quality in Sweden is done according to regulation HVMFS 2019:25. The health of surface waters is ranked from high to poor status depending on the levels of each variable. A total assessment of the lake's or stream's well-being is then done by combining all statuses (Havs- och Vattenmydigheten 2019). The Swedish regulations only concern lakes and stream and in this project the classification was done according to regulations on lakes, based on the stagnant water in Mawira Sitima.

Eutrophication or nutrients in lakes are generally classified by the levels of total phosphorous (TP) according to Table 1. However, if there are clear indications of the organic growth being dependent on nitrogen levels, experts may base their classification on the levels of nitrate, nitrite and ammonium (Havs- och Vattenmydigheten 2019).

Table 1: Classification of total phosphorus (Havs- och Vattenmydigheten 2019).

Status	**Limit (EK = reference value/measured TP)**
High	$0.7 \leq EK$
Good	$0.5 \leq EK < 0.7$
Moderate	$0.3 \leq EK < 0.5$
Not adequate	$0.2 \leq EK < 0.3$
Poor	$EK < 0.2$

As the climate in Malawi is hotter than Swedish climate and the water in the spring is stagnant, the reference value is calculated using the simplified equation for measurements in August in Sweden seen in Equation 1 (Havs och Vattenmydigheten 2019).

$$\log_{10}(\text{ref-P}) = 2.247 + 0.530 \cdot \log_{10}(\text{AbsF}) - 0{,}339 \cdot \log_{10}(\text{Alt}) \tag{1}$$

Where *ref-P* is the refernece value, *AbsF* is the absorbance at 420 nm in a 5 cm cuvette, and *Alt* is the altitude in meters above sea level.

To decide whether to look at total nitrogen (TN) instead of phosphorous for classification of nutrients, a ratio for nitrogen and phosphorous can be calculated ($\frac{N}{P}$). The limits are seen in Table 2. If the ratio is higher than 30 it usually means that there is a surplus of nitrogen and the water is therefore limited by phosphorous. If the ratio is between 15 and 30 it usually means that there is a balance between nitrogen and phosphorous. If the ratio is below 15 it usually means that there is a surplus of phosphorous and therefore the water is limited by nitrogen (Instutionen för Miljöanalys 1997).

Table 2: Designations for the total phosphorous and nitrogen quota (Instutionen för Miljöanalys 1997).

Designation	**N:P**
Nitrogen Surplus	> 30
Nitrogen-Phosphorous Balance	15-30
Moderate Nitrogen Deficiency	10-15
Large Nitrogen Deficiency	5-10
Extreme Nitrogen Deficiency	< 5

The classification of oxygen levels in Swedish lakes, seen in Table 3, differ according to types of fish in the water. Salmonids, such as salmon and trout, usually require more oxygen than other fish. The waters that harbours these types of fish are therefore placed in their own category for classification (Havs- och Vattenmydigheten 2019). In this project, classification was done according to other fish than salmonids ("warm water fish").

Table 3: Classification of oxygen levels for warm water fish (Havs- och Vattenmydigheten 2019).

Status	**Oxygen level (C) [mg/l]**
High	$C \geq 7(8)$
Good	$5 \leq C < 7$
Moderate	$4 \leq C < 0.5$
Not adequate	$2 \leq C < 4$
Bad	$C < 2$

These oxygen levels concern measurements from the deepest part of the lake during seasons of minimal mixing of the water (Havs- och Vattenmydigheten 2019).

This project focused mainly on the levels of chlorophyll-a in determining the trophic status of the thermal spring. The different trophic categories are eutrophic, oligotrophic and mesotrophic. Eutrophic means nutrient rich waters, oligotrophic means nutrient poor and mesotrophic is a state in between these two (Burkholder 2003). The Swedish regulations on chlorophyll-a differ depending on region, depth and alkalinity of the lake (Havs- och Vattenmydigheten 2019), which makes them not applicable on this project since there is no region in Sweden with similar climate to Malawi. Instead the assessment is done according to limits suggested by the Organisation for Economic Cooperation and Development (OECD), which is the most widely accepted classification of trophic status (Istvánovics 2009). The classification of chlorophyll-a levels, among others, can be seen in Table 4.

Table 4: Classification of trophic status (OECD 1982 see Istánovics 2009).

Trophic status	**Mean TP [μg/l]**	**Mean chl-a [μg/l]**	**Max. chl-a [μg/l]**
Oligotrophic	<10	<2.5	<8
Mesotrophic	10 - 35	2.5 - 8	8 - 25
Eutrophic	>35	>8	>25

2.6.2 Interpretation of nutrients and ions in soil

To interpret if the levels of certain nutrients in soil by Mawira Sitima are high or low they are compared to levels presented by Landon (2014) seen in Table 5. The levels are based on samples collected in many different countries but an assumption was made that the levels are applicable for this study.

Table 5: Interpretation of nutrient levels in soil [mg/kg] (Landon 2014).

	TP	**TN**	**Zn**	**Fe**	**Cu**	**Mn**	**K**	**Na**	**Mg**	**Ca**
Low level	6.5	2000	1	4.5	2	20	78	-	61	800
High level	22	5000	900	-	250	10000	313	230	488	2000

2.6.3 Hot springs for recreational use

Soaking in hot mineral water baths in healing purposes is called balneotherapy and is an effective method due to the hot springs richness in salt, sulphur and sulphate. In the view of this fact, a study was conducted in the State of Selangor, Malaysia, in which the water in 18 hot springs used for recreation was analysed to determine the quality of the springs. The study focused mainly on the levels of sodium, potassium, calcium, sulphur, sulphate and chloride as well as some other commonly measured variables such as EC and turbidity. The results seen in Tables 6 concluded that most concentrations complied with the requirements of bathing and other recreational activities (Hamzah et al. 2013).

Table 6: Results of measured water quality parameters in Malaysia (Hamzah et al. 2013).

Hot spring	**Temp (°C)**	**DO (mg/l)**	**EC (μS/cm)**	**pH**	**TDS (mg/l)**	**Salinity (mg/l)**	**Turbidity (NTU)**
Hulu Tamu (A)	51.7	2.93	493	7.60	311	0.23	0.22
Hulu Tamu (B)	50.6	3.07	485	7.58	307	0.23	0.26
Gombak (A)	56.9	3.00	495	8.50	311	0.23	0.19
Gombak (B)	52.3	3.50	493	7.54	311	0.23	0.65
Batu 16, Hulu Langat	67.9	2.64	369	7.86	228	0.17	0.22
IKBN, Hulu Langat	36.1	2.99	595	7.34	373	0.28	6.75
Sg Serai, Hulu Langat	45.4	2.80	560	7.73	343	0.25	1.34
Semenyih	36.7	4.91	559	7.45	364	0.27	0.83
Kuala Kubu Baru	40.0	3.94	365	7.33	225	0.16	0.20
Kerling	40.0	3.47	497	7.14	312	0.23	0.24
Setapak (A)	45.9	5.27	567	7.36	376	0.28	0.23
Setapak (B)	55.2	1.97	586	7.27	374	0.28	0.19
Hulu Yam	55.8	4.50	508	7.45	321	0.24	0.18
Selayang (A)	53.5	2.63	508	7.68	313	0.23	0.26
Selayang (B)	49.4	3.58	506	7.98	319	0.23	0.78
Selayang (C)	54.1	2.92	509	8.98	317	0.23	0.14

A similar study was conducted on four different springs (Chutrun thermal springs) in Shigar Valley, Pakistan, to evaluate their therapeutic potential. The mean value of each variable for the Chutrun springs was then compared to measured values in some of the world's renowned thermal springs, and can be seen in Table 7 (Farhat et al. 2021).

Table 7: Comparison between Chutrun hot springs and renowned thermal springs (Farhat et al. 2021).

Parameter	**Chutrun Pakistan**	**Manghopir Pakistan (Javed et al. 2008)**	**Selangor Malaysia (Hamzah et al. 2013)**	**Kusatsu Japan (Kotake et al. 1999)**	**Limpopo South Africa (Olivier et al. 2011)**	**Arkansas USA (Lund 1996)**	**Ranong Thailand (Sudjaroen et al. 2017)**
Temp °C	40–42	47	36.1–67.90	60–67	26–67.5	32–62	61.5–65.3
pH	7.21–7.8	7.2–7.6	7.14–8.98	2	7.35–9.70	4.52–7.70	7.56–7.74
TDS (ppm)	300–310	2180–2188	228-376 s	-	104.7–1385	-	210–230
Sodium (ppm)	12–18	544–555	37–81.91	53.70	10.5–156.3	4	10.2–13.8
Potassium (ppm)	3.8–4.1	21–25	1.7–56.81	16	0.99–4.25	1.5	150–189
Calcium (ppm)	80–82	80–84	3.75–19.77	72	1.31–13.73	45	18.7–20.6
Magnesium (ppm)	20	56	0.2- 0.6	39	0.00–27.6	4.8	0.36–0.51
Chlorides (ppm)	9.6–12	584–599	7.06–20.66	343	19.4–168.97	1.8	18.3–23.2
Fluorides (ppm)	3.4–3.9	-	4.0–4.2	12	0.18–6.50	0.2	0.12–0.89
Sulphates (ppm)	80–85	437–442	0.15–1.51	611	2.98–53.17	8	8.1–12.1
Bicarbonates (ppm)	260–282	395–494	60–108	-	-	165	4.3–5.7

2.6.4 Plant indicators

Plants are sensitive tools for prediction and recognition of environmental stresses, also called bioindication. Information about the environmental health can be obtained from the presence or absence of specific plants or vegetation (Parmar et al. 2016), as shown in Table 8. The life form of plants can be ecologically significant and may suggest where they are found. For example, floating-leaved, attached plants generally occur in calm and sheltered areas of lakes in slightly deeper water (0.25-3.5 m), and unattached plants might be similarly confined to quiet waters. Many eutrophic lake plants have lower root:shoot biomass ratio and produce elongate leafy stems that grow towards the water's surface where light is more available (Titus et al. 2009). This was confirmed during the study done in north-east France mentioned before where two of the plants that characterised eutrophic waters were *Ranunculusfluitans* and *Callitriche obtusangula* (Robachl et al. 1996). Emergent aquatic plants are usually found in shallow water, near the land-water interface, while submersed plants may extend all the way from the shore to considerable depths (Titus et al. 2009).

Factors such as climate change and eutrophication, which are big threats to fresh water, cause a loss of diversity when it comes to macrophytes. This means that they also threaten faunal diversity and then instead favours exotic species (Chambers et al. 2007). The diversity of species is also affected by nutrients like carbon, nitrogen and phosphorous, with the highest species richness observed for intermediate nutrient levels. This also govern the composition, occurrence and diversity of aquatic plant communities. Increasing phosphorous concentration leads to floating species or microphytes outcompeting submerged species. However, in shallow eutrophic lakes, the same phosphorous concentration can lead to domination by phytoplankton and high turbidity, or macrophytes and clear waters

(Bornette et al. 2009). Water temperature also plays a big role in plant diversity as only a limited number of plant species can handle high temperatures with the upper limit for plant growth being around 45 °C (Brock 1994).

Additionally, the availability of water nutrients governs primary production in ecosystems. Isoetids (small, slow-growing, evergreen plants), like small rosettes, belong to the group of plants that are restricted to only using carbon dioxide, and occur in oligotrophic habitats. Submerged species that are able to use bicarbonate tend to have higher growth rates and grow in alkaline waters. Free-floating macrophytes are usually found in eutrophic waters since they absorb nutrients directly from the water, while rooted plants can use nutrients from both the water column and substrate. Tall species usually occur in eutrophic water and small species in oligotrophic waters (Bornette et al. 2009).

The occurrence of macrophytes is strongly related to the water transparency which is determined by the colour of the water, the concentration of suspended solids and plankton. The transparency of the water affects the light availability which sets the depth limit for macrophytes, and promotes different forms of aquatic plants. Due to their low growth rate, rosette growth forms are limited to clear water lakes or shallow zones, while caulescent angiosperms, which are able to produce erected stems, colonise deeper waters. In waters with high turbidity, the plant communities are dominated by floating-leaved plants (Bornette et al. 2009).

Water movement can cause indirect effects on macrophytes by either resuspending nutrients or particles in moving waters, or diffusion of gas and nutrients through the boundary layer in stagnant waters. Both water movements lead to limited plant growth due to less light penetration or lower access to nutrients. Moderate water movement enhances nutrient and gas fluxes which improves plant growth and photosynthesis (Bornette et al. 2009).

A summary of all mentioned bioindicators can be seen in Table 8.

Table 8: Summary of bioindications.

Bioindicator	**Indication**
Floating-leaved plants	High turbidity/eutrophic water
Emergent plants	Shallow water
Submerged plants	Alkaline water
Tall plants	Eutrophic water
Small plants	Oligotrophic water
Rosette growth form	Clear/shallow/Oligotrophic water
Leafy stems and low root:shoot ratio	Eutrophic waters
Diversity of species	Intermediate nutrient levels
Limited plant growth	Moving/stagnant water
Improved plant growth	Moderate water movement

Not only does the water affect the aquatic plants located in the water, aquatic plants may profoundly influence the physico-chemical environment of waters by steepening light attenuation and temperature gradients and reduce turbulence to the extent that promotes sedimentation. The uptake and release of toxic metals and the mineral nutrients that drive primary production may also affect the water quality. Additionally, the metabolic activity of submersed plants may lead to changes in the profiles of pH, redox potential, carbon dioxide and oxygen within the water column and into the sediment. Floating-leaved plants connect aquatic and atmospheric realms by exchanging gases through their stomata and provide surfaces on which complex biofilm communities develop. Their biological role and abiotic impacts make aquatic plants interesting in water quality investigations (Titus et al. 2009).

2.7 Water quality monitoring

Monitoring of water quality can be properly done with less than 20 chemical, physical or biological variables. The variables that need to be included depends on what the use of the water will be. One of the simplest monitoring systems is to measure temperature, pH, EC, TDS and DO. This gives the minimum of information about the water and can be used to roughly make an assessment of the water quality. Other variables to be looked at can depend on already known pollution in the water. The time interval for the sampling deeply depends on the water itself and needs to be adjusted according to the circumstances. In the beginning it might have to be more frequent and then, if a lot of variables are constant, it can become less frequent. For issues other than eutrophication, a minimum of one time per year is recommended for lakes and reservoirs (Bartram et al. 1996).

3 METHODS

3.1 LIMITATIONS

The project had limitations in both time and equipment which led to exclusion of variables that would have been preferable to include. The time limitation meant that a limited amount of samples could be taken and only during 2 months of the year. The number of sampling occasions were also limited by the rain season as the roads to the spring were not accessible during and after heavy rainfall. Some variables that would have been preferable to measure were not possible to include due to lack of access to certain equipment. These variables included radioactivity, bacteria and fluoride.

Swedish Surface Water Standards were used in assessing the water quality of the hot spring. Malwian Drinking Water Standards were considered to be evaluated, but as the spring water is not currently being used for drinking, comparison to those standards was considered irrelevant. Malawi does not have any other water standards applicable to this study.

3.2 WATER QUALITY OF MAWIRA SITIMA

From the previously conducted studies presented above, combined with the available laboratory equipment, an assessment was done of which variables were most relevant to study in this project. The variables and sampling source can be seen in Table 9.

Table 9: Variables examined during the study in water, plants and soil.

Variable	**Water**	**Plants**	**Soil**
Total Nitrogen (TN)	X	X	X
Total Phosphorous (TP)	X	X	X
Chlorophyll-a (Chl-a)	X		
pH	X		
Water Colour (Col)	X		
Dissolved Oxygen (DO)	X		
Sodium (Na)	X	X	X
Potassium (K)	X	X	X
Calcium (Ca)	X	X	X
Magnesium (Mg)	X	X	X
Zinc (Zn)	X	X	X
Iron (Fe)	X	X	X
Copper (Cu)	X	X	X
Manganese (Mn)	X	X	X
Chloride (Cl)	X		
Sulphate (SO_4)	X		
Turbidity* (Turb)	X		
Electrical Conductivity* (EC)	X		
Salinity*	X		
Total Dissolved Solids* (TDS)	X		
Temperature* (Temp)	X		

*Measurements directly in the field.

3.2.1 Interview with chief of village

An interview with the chief of the village, John Moses, was conducted during the second visit to the hot spring. The questions asked during the interview were:

- How many people utilise the spring?
- Are any detergents and/or soaps used in the spring?
- Are there any agricultural activities near the spring and if so, what is farmed there?
- Are any fertilisers used during farming?
- Have there been any noticeable changes in the hot spring and the surrounding area, like changes in water colour, smell, vegetation et cetera?

The questions were translated from English to Chichewa and the answers were then condensed and translated back from Chichewa to English.

3.2.2 Land use survey

A land use survey of the area surrounding the spring was conducted to get a better understanding of how the usage of the area might affect the hot spring and its water quality. This was done by mapping the area by foot using a GPS and noting what the land use of the area was. Coordinates were taken for each measuring site around the spring and at the limits of specific land uses in close proximity of the spring. The coordinates were then used in QGIS to construct a map of the area. The surface area of the hot springs and agricultural land was estimated by constructing polygons from the measured coordinates and satellite pictures. The distance between the springs and the different land uses were then assessed by creating a line layer and measuring the length of each line. To assess what direction the runoff from each agricultural field would go, a raster was created using the elevation data for each coordinate.

3.2.3 Sample preparation and analysis of water quality

When visiting the hot spring the first time it was decided that there would be five sampling occasions and that the sampling of water would take place at six different sampling sites for each occasion: four samples from the within spring, one from a suggested source of the spring water, and one sample from a borehole used as a reference site. For each occasion four 500 ml bottles of water was taken at each site; one for nutrients, sulphate, and water colour, one for DO and chloride, one for chlorophyll-a and one for the cations. After doing the chlorophyll analysis the first time it was decided that two bottles were to be taken for this from each site for this analysis to ensure proper results, making it a total of five 500 ml bottles. The bottle for the ions were acidified directly in the field using approximately 1 ml nitric acid while the other samples remained untouched.

Three beakers were filled up with water for in situ measurements of turbidity, temperature, TDS, salinity and EC. The turbidity was measured using a Oakton T-100 turbidimeter. The temperature, TDS, salinity and EC was measured using a S-100 meter. All the measurements were done 3 times for each site and the mean values were calculated.

The pH of the six different samples sites were measured in the lab using a Biobase 930. It was first calibrated using a buffer solution of pH 7 and the pH-meter was then put in one sample and the value was noted when the figures had stabilised. This was repeated for all samples using deionised water to clean it in between measurements.

To analyse the chlorophyll-a, one sample from each site (six in total) was shaken and then filtered through a glassfiber filter using a filtration equipment (47 mm) and a vacuum pump in the lab. The filtration was done until the glassfiber filter was clogged and water was no longer going through. After that, the filter paper was put in a plastic tube and filled up with 25 ml ethanol (95%). The samples were then left in the refrigerator over night. The next day, the samples were filtered through 0.45 µm filters using a disposable syringe filter. After that, a spectrophotometer (UV/VIS) was used at 750 nm and 665 nm to measure the absorbance of each sample. Ethanol was used to zero the meter in both wavelengths. After measuring the absorbance of the sample, 0.1 ml hydrochloric acid was added to the sample to react. After waiting a minute, the absorbance was measured again. The chlorophyll-a concentration was then calculated using Equation 2.

$$\begin{cases} A = A_{665} - A_{750} \\ A_a = A_{a,665} - A_{a,750} \\ C_{chlorophyll}\ (\mu\text{g/l}) = (A - A_a) \cdot K \cdot \frac{V_e}{V_s} \end{cases} \tag{2}$$

Where A_{665} and A_{750} is the absorbance at 665 nm and 750 nm before adding acid, $A_{a,665}$ and $A_{a,750}$ is the absorbance at 665 nm and 750 nm after adding acid, K is a constant of 29.6, V_e is the volume of ethanol added to the filter paper (ml), and V_s is the volume of the filtered sample (l).

The water colour was measured by filtering water from each sample through a 0.45 µm filter and then putting it in 1 cm cuvettes. The UV/VIS was then used to measure the absorbance at 420 nm. Deionised water was used to calibrate the meter. All the measurements were done twice for each sample, and the mean values of the absorbance was calculated. After this the water colour was calculated using Equation 3.

$$Col\ (\text{mg Pt/l}) = Abs \cdot 540 \cdot 5 \tag{3}$$

Where Col is the colour and Abs is the measured absorbance. 540 is a constant to convert into colour, and 5 is to account for the length of the cuvette.

To measure total phosphorous a reagent mixture was prepared using sulfuric acid, ammonium molybdate, ascorbic acid and potassium tartrate. A phosphate stock solutions was prepared by drying potassium dehydrogen phosphate in 105 °C during 1.5 hours. The dried chemical was then measured to 4.392 g, then dissolved in 1 ml chloroform and diluted in 1000 ml deionised water. To make the calibration solution the phosphate stock solution was diluted 100 times. This was done by taking 1 ml stock solution and adding 100 ml deionised water. For the sample preparation the samples were shaken well and then 100 ml were added in a conial flask. After this 20 ml of 5% potassium persulphate was added in each water sample as well as the calibration and a blank containing deionised water. The potassium persulphate was done by taking 10 mg of pulverised potassium persulphate dissolving it in 200 ml of deionised water. The samples, the calibration and a blank were then brought to a boil on hotplates and were kept boiling for 1 hour. They were then left to cool over night. The next day 6 ml of the samples, the calibration and the blank were put in separate plastic tubes. 1 ml of the reagent mixture was added. After 30 min the absorbance was measured using a UV/VIS 882 nm. The phosphorous concentration was calculated using Equation 4

$$C_{TP}\ (\mu\text{g P/l}) = \frac{C_{calibration} \cdot V_{calibration} \cdot (A_{sample} - A_{blank})}{V_{sample} \cdot (A_{calibration} - A_{blank})} \tag{4}$$

Where $C_{calibration}$ is the concentration of the calibration solution (μg/l), $V_{calibration}$ is the volume of the calibration solution (ml), V$_{sample}$ is the volume of the sample (ml), A_{sample}, $A_{calibration}$ and A_{blank} is the absorbance of the sample, calibration and blank respectively.

For the nitrogen measurements, a calibration using ethylenediaminetetraacetic acid (EDTA) was prepared by dissolving 1.329 g in deionised water and then diluting it to 1000 ml. Four different calibrants were done containing 0.5, 1.0, 1.5 and 2.0 mg EDTA/l. 100 ml of the blank, the samples and the calibration was then added to separate conical flasks. After this 15 ml of 6 % potassium persulphate was added in each water sample as well as the calibration and a blank containing deionised water. The potassium persulphate was done by taking 12 mg of pulverised potassium persulphate dissolving it in 200 ml of deionised water. The samples, the calibrations solution and a blank were then brought to a boil on hotplates and were kept boiling for 30 minutes. The samples where then left to cool over night. The next day 5.75 ml of the samples, the calibrations and the blank were put in plastic tubes and 0.12 ml 10 M hydrochloric acid was added to each sample. The absorbance was then measured using a UV/VIS at 220 and 275 nm. Using the standards, and plotting against the measured absorbance, an equation for the linear connection between nitrogen and absorbance was obtained. This equation was then used to calculate the nitrogen concentration for the samples.

For DO analysis it was made sure in the field that the bottles were properly filled so that no extra oxygen could dissolve into the water and no oxygen from the water could escape. In the lab, each water sample was added to three new bottles with 20 ml water sample in each, and diluted to 250 ml with deionised water. 1 ml manganese sulphate and 1 ml alkaline iodide-sodium azide solution was then added to all samples which caused colour change and deposition. 1 ml thiosulfurous acid was then added which dissolved the deposition. Titration was done using 0.025 M sodium thiosulphate and starch indicator solution. Sodium thiosulphate was added to 25 ml water sample until the sample was almost clear, then 2-3 drops of starch was added which caused colour shift again. Titration continued until the sample was completely clear, and the volume of added titrant was noted. This was done three times for each sampling site and the mean volume for the site was then calculated. The DO concentration was calculated using Equation 5.

$$C_{DO}\ (\text{mg DO/l}) = \frac{V_{titrant} \cdot N \cdot 8 \cdot 1000}{V_{sample}} \tag{5}$$

Where $V_{titrant}$ is the volume of sodium thiosulphate added to the sample (ml), N is the concentration of sodium thiosulphate (0.025 M) and V_{sample} is the volume of the water sample (25 ml). 8 and 1000 are constants.

For analysis of the chloride concentration approximately 50 ml of each water sample was first filtrated through 125 mm filters. From each of the filtered samples, 10 ml was added to three different flasks. Titration was done using 2 drops of potassium chromate in each sample as an indicator and then adding 0.01 M silver nitrate until the colour changed, and the volume of the silver nitrate added was noted. This was done three times for each sampling site and the mean volume was calculated for titration. From the results of the titration, the chloride concentration could be calculated using Equation 6.

$$C_{Cl}\ (\text{mg/l}) = \frac{C_{AgNO_3} \cdot V_{AgNO_3} \cdot 1000 \cdot 35.5}{V_{sample}} \tag{6}$$

Where C_{AgNO_3} is the concentration of silver nitrate (0.01 M), V_{AgNO_3} is the volume of the added silver nitrate (ml), V_{sample} is the volume of the water sample (ml).

The concentration of sulphate in the samples were measured using a turbidimetric method. This method uses the principle that sulphate ions precipitate in a hydrochloric acid and barium chloride. This creates barium sulphate crystals of uniform size. The absorbance of the crystals was then measured using a UV/VIS. Colour and suspended matter may interfere with this method if they are present in large amounts but some of the suspended matter can be removed through filtration. No other ions than sulphate will form crystals with barium under the strongly acidic conditions. The minimum concentration that can be detected is approximately 1 mg/l sulphate (American Public Health Association et al. 1976). Calibration solutions were made by dissolving 147.9 mg natriumsulphate in dionised water and diluting it to 1000 ml. After that 10, 15, 25, 30 and 40 ml of the solution was diluted to 100 ml each to make standards with concentrations of 10, 15, 25, 30 and 40 mg/l. A conditioning reagent was made by mixing 50 ml of glycerol with a solution containing 30 ml of concentrated hydrochloric acid, 300 ml dionised water and 100 ml 95% ethyl. 5 ml of this reagent was added to 100 ml of each sample and was then mixed with a stirrer. After this barium chloride was added to the sample while it was being stirred. The stirring went on for exactly one minute and after that the absorbance of the sample was measured using a UV/VIS at 420 nm. The absorbance was measured for 4 minutes with 30 second intervalls. Using the standards, an equation for the linear connection between sulphate and absorbance was obtained. This equation was then used to calculate the sulphate concentration for the samples.

The analysis of the cations (sodium, potassium, calcium, magnesium, zinc, iron, copper, and manganese) was done using an Atomic Absorption Spectrophotmeter (AAS). The acidified water from the field was filtered and then but into plastic tubes of about 20 ml each. The samples were then put in an autosampler that was connected to the AAS. When analysing calcium and magnesium, the samples were diluted 10 times with 2000 ppm strontium solution to make sure only calcium and magnesium was detected in the AAS. The sodium samples were diluted 10 times with deionised water to get a lower, detectable concentration. The AAS then used 10 ppm standards of each cation, which was diluted to different concentrations directly in the autosampler, to create calibration curves and the concentrations of the cations was calculated from the measured absorbance.

All measured variables (nutrients, ions and physical characteristics) were then compared to the guidelines and previous studies presented in section 2.5 and 2.6 as well as the reference site (borehole) in close proximity to Mawira Sitima. This was done in box plots where the measured values were displayed in boxes and the guidelines and mean value from the reference site was displayed as a line. The line represented the mean value for specific variable at the reference site. The values from previous studies were presented as a span in blue. To make sure the reference site had good water quality and a suitable comparison, the values from the reference site was compared to the Malawi standards for borehole water quality (Board 2005).

The ecological status was decided based on total phosphorous and DO. For the total phosphorous, the EK-value was calculated for each sampling site using Equation 1 and both this and the DO was plotted in boxplots. The boxplots also included the guidelines (Table 1 and 3) for the different statuses. The trophic status was decided using the mean value of total phosphorous for all sites, mean value for chlorophyll and the maximum value for chlorophyll for all sites and comparing it to the categories from OECD (Table 4). The N:P ratio was calculated using the mean values for total phosphorous and nitrogen and was then compared to the designations for the quota (Table 2).

3.2.4 Sample preparation and analysis of soil

Soil samples in the area around Mawira Sitima were collected and brought back to the lab to dry. Once dry, the soil was sieved and 2 g of each sample was measured and put in a furnace to be ashed. This was done at 600 °C for 5 hours. After this the samples were placed in conical flasks and 2 ml concentrated nitric acid was added. The flasks were then put on a hot plate to boil until the fumes from the samples were clear. After this, 2 ml of concentrated hydrochloric acid was added which caused the samples to change colour. The samples were again put on boil until the liquid was clear. After cooling, the samples were diluted to 100 ml and filtered. 50 ml was then used for phosphorous analysis and 50 ml for analysis of cations.

For the phosphorous analysis of soils, a reagent was added to all the samples and standards with concentrations of 0.5, 1, 1.5, 2, and 2.5 ppm phosphorous. The UV/VIS was then used at 880 nm to measure the absorbance of the samples. The concentrations were calculated using a standard curve and they were then adjusted from mg/l to mg/kg using the dilution volume and starting mass.

The analysis of the cations was done using an Atomic Absorption Spectrophotmeter (AAS). When analysing zinc, manganese, copper, iron and potassium 20 ml of the samples were poured into plastic tubes. The ashed and diluted samples were then put in an autosampler that was connected to the AAS. When analysing calcium and magnesium, the samples were diluted 10 times with 2000 ppm strontium solution to make sure only magnesium and calcium was detected. The sodium samples were diluted 10 times with deionised water to get a lower, detectable concentration. The calibration was done as explained earlier. The given concentrations for calcium, magnesium and sodium were then multiplied by 10 to account for the dilution. All samples were made into duplicates and the mean value of the measured concentrations were calculated.

For the analysis of nitrogen 1 g of each soil sample was measured and put into a volumetric flask. 1.5 ml of water and 5 ml of sulphuric acid was then added to the flasks along with 1.7 g of a mixed catalyst consisting of anhydrous potassium sulphate, cupric sulphate and selenium powder. The samples were then brought to a boil until the content of the flasks turned green. After cooling the samples were diluted to 50 ml and distilled. The distillation was done by pouring 5 ml boric acid and three drops of red indicator consisting of methyl red, bromcresol green and ethyl alcohol into conical flasks. Using a nitrogen distillation unit, the flasks were then connected by a tube to one part of the unit and 10 ml sample, 10 ml sodium hydroxide and approximately 10-20 ml deionised water was poured into the other part of the unit. The samples were then distilled for 5 minutes each which caused liquid to transfer into the conical flask and the colour of the indicator changed from red to turquoise. After 5 minutes, the distilled samples were titrated with hydrochloric acid until the colour changed back to pink and the volume of titrant was noted. The total nitrogen concentration was then calculated using Equation 7.

$$\mathrm{C}_N \text{ (mg N/kg soil)} = \frac{(V_{sample} - V_{blank}) * N * 14 * 1000}{m_{sample}} \tag{7}$$

Where C_N is the concentration of nitrogen in soil, V_{sample} and V_{blank} are the volume of acid used during titration for the sample and blank respectively (ml), m_{sample} is the sample weight (g) and N is the normality of the acid (M). 14 and 1000 are constants.

The results were then compared to commonly measured levels in other soils, presented by Landon (2014), to interpret if the levels by Mawira Sitima were within the normal range.

3.3 POTENTIAL FOR RECREATIONAL USE OF MAWIRA SITIMA

To investigate Mawira Sitimas potential for recreational use, the water quality, adjacent plants and soil and location were compared to the closely located Mawira Liwonde. Water samples from Mawira Liwonde were collected two times and the same analyses mentioned above (section 3.1.3 and 3.1.4) for Mawira Sitima were used to asses the water quality. Coordinates were taken by the spring using a portable GPS. Boxplots for the water quality variables in Mawira Sitima were then made and compared to the mean values of the same variables in Mawira Liwonde. The location for each hot spring was investigated and compared using the measured coordinates and satellite images in QGIS. Two plants of similar origin was collected nearby Mawira Sitima and Mawira Liwonde and analysed the same way as previously described for soil samples. Soils from the location where one of these plants grew, were also collected at both hot springs. Instead of soil being sieved, the plants were cut into small pieces before ashing. After the analyses were done, they were compared to each other in barplots.

The ecological status was decided based on mean values of total phosphorous and DO. The EK-value was calculated using Equation 1 and that value and DO was compared to guidelines (Table 1 and 3) for the different statuses.

The trophic status was decided using the mean value for total phosphorous and compared to the categories from OECD (Table 4). The N:P ratio was calculated using the mean values for total phosphorous and nitrogen and was then compared to the designations for the quota (Table 2).

3.4 LONG TERM MONITORING SYSTEM

To make a proposal for a potential long term monitoring system, a statistical test was done to test the correlation between all variables measured at all sampling sites at Mawira Sitima, called Kendall's rank correlation. The null-hypothesis was that there is no correlation between the variables (Puth et al. 2015) and the p-value was chosen to be 0.05, meaning that for $p < 0.05$ the null-hypothesis is discarded. The test also gave a coefficient called Kendall's τ which gives an indication if the correlation is negative or positive (Puth et al. 2015).

All measurements were then plotted in barplots to detect possible spatial or temporal trends (November 2021-January 2022) for each variable. Any trends and correlations that were detected in the barplots were then further investigated in graphs. The variables that correlated according to Kendall's test were put in the same graphs.

3.4.1 Meterological data

Meteorological data (daily precipitation and air temperature) for the concerned time period (November 2021 - January 2022) was obtained from University of Malawi Chancellor College. The measurements were done on campus in Zomba, approximately 40 km from Liwonde. The meteorological data and all variables were plotted together over time to compare temporal trends and patterns to determine any correlations.

3.4.2 Bioindication

Plants found in and around the hot spring that were less common or did not have a counterpart at Mawira Liwonde grounds were photographed and then identified by comparison to literature. After being identified, the plants were used as bioindicators for the health of the hot spring and were compared to the results of the physico-chemical analyses to assess the possibility to use bioindication as part of a long term monitoring system.

4 RESULTS

4.1 WATER QUALITY OF MAWIRA SITIMA

4.1.1 Interview with chief of village

QUESTION: How many people utilise the spring?
ANSWER: The spring is used by the villagers but also by people from nearby villages. The chief estimated it to around 7000 people [4].

QUESTION: Are any detergents and/or soaps used in the spring?
ANSWER: Yes, they are used frequently [4].

QUESTION: Are there any agricultural activities near the spring and if so, what is farmed there?
ANSWER: Yes, there are multiple farming fields nearby where things like maize, sweet potato, and sorghum are being farmed [4].

QUESTION: Are any fertilisers used during farming?
ANSWER: Yes, fertilisers containing nitrogen, phosphorous and potassium is used during farming [4].

QUESTION: Have there been any noticeable changes in the hot spring and the surrounding area, like changes in water colour, smell, vegetation etc?
ANSWER: No changes have been noticed during the chiefs lifetime [4].

4.1.2 Land use survey

In Figure 11 the area around Mawira Sitima, including the borehole used for reference, the adjacent swamp and agricultural land, is shown. The linear distance from the reference site to the inlet of the hot spring is estimated to be approximately 453 m and the distance from the spring to closest agricultural field is approximately 44 m. From Mawira Liwonde to Mawira Sitima the linear distance is approximately 5423 m. The sampling sites can be seen in Figure 3. The first sampling site was at the only known inlet to the spring which is located in the men's pool. The second sampling site was at the middle of the men's pool. The third sampling site was at the inlet of the women's pool, where water from the men's pool enters through a big area of tall grass. The fourth sampling site was at the outlet of the women's pool to a larger pool that was not used by the community. The fifth sampling site was the swamp that was suggested by the locals to be the water source for the spring. This site was excluded from all analyses due to the lack of information which made it irrelevant for the study. The sixth sampling site was the borehole used as a reference where the locals got their drinking water.

---

[4] John Moses, Village Chief in Sitima, Interview 2021-12-08

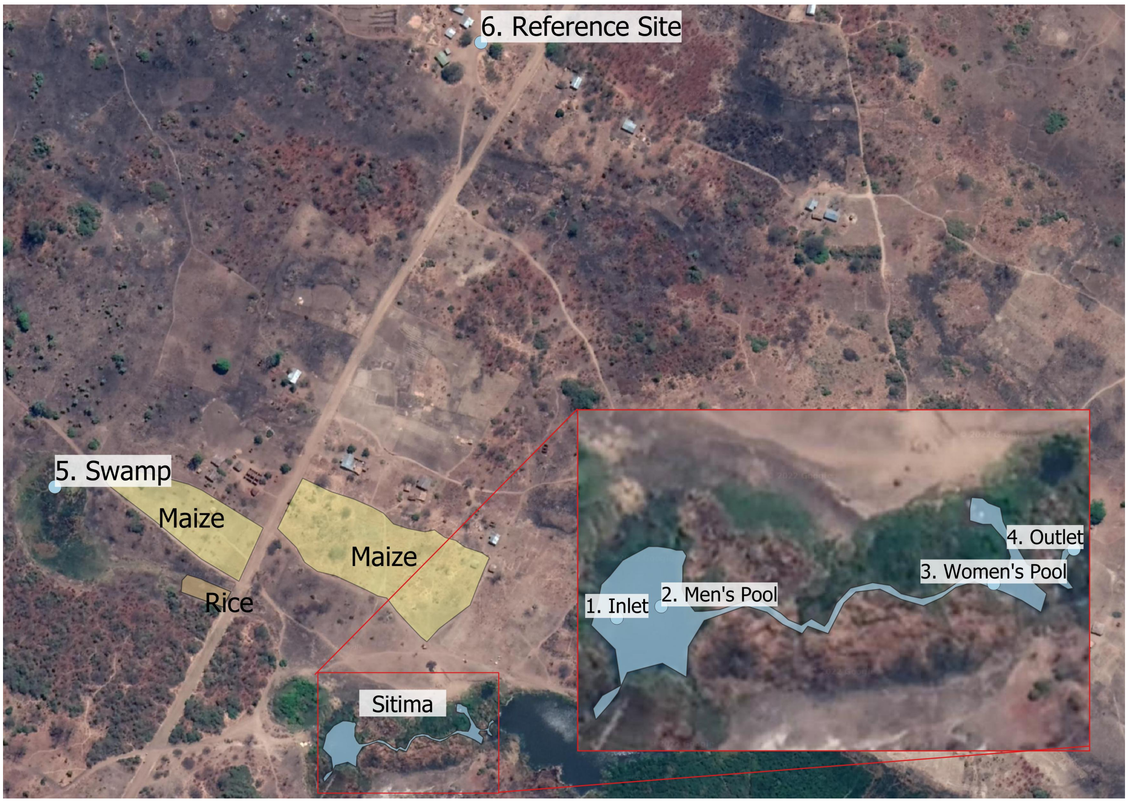

Figure 3: The area around Mawira Sitima.

The elevation of the area around Mawira Sitima can be seen in Figure 4. The lowest point of the area was at the rice field and the outlet, and the highest point of the area was at the swamp.

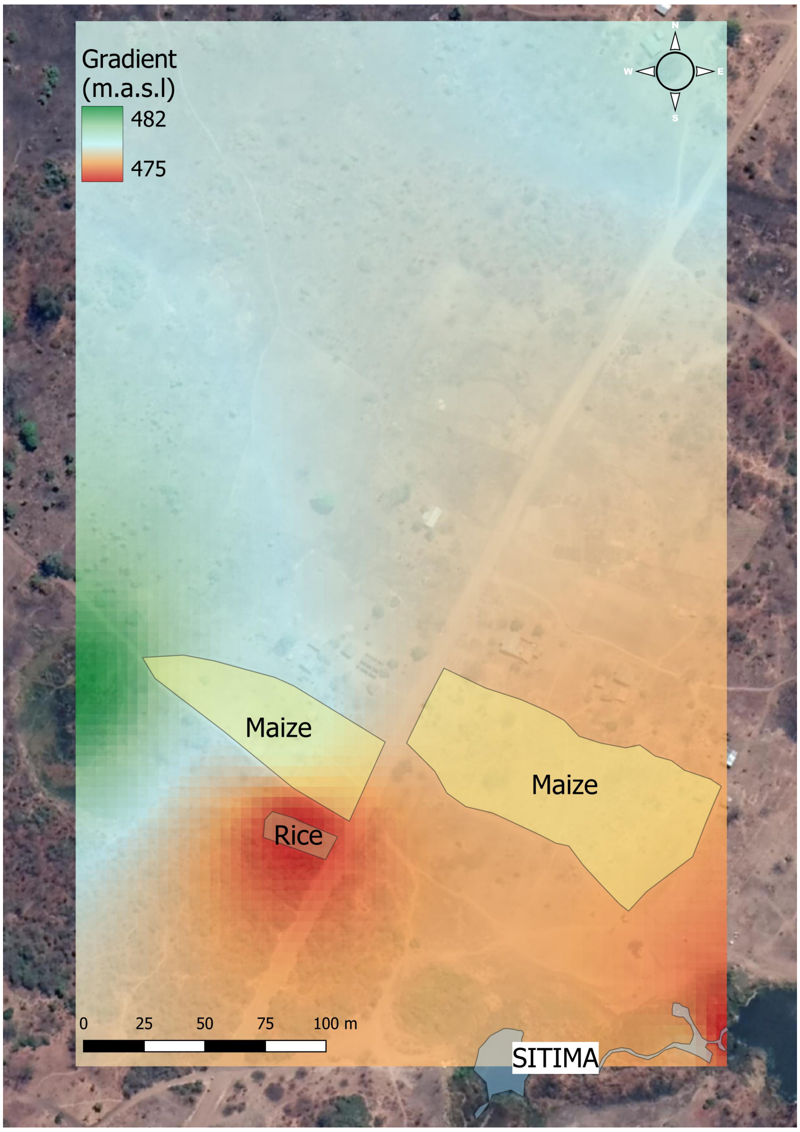

Figure 4: The elevation of the area around Mawira Sitima in meters above sea level.

4.1.3 Analysis of water quality

All measurements from each sampling occasion can be seen in Appendix A. Figures 5 - 8 show box plots of all measured values in Mawira Sitima compared to the reference site and, if available, other hot springs that are known to be used in recreational purposes (section 2.6.3). The values from the references site were all within acceptable range compared to the standards for borehole quality (Board 2005). The variables that did not have any comparisons from other hot springs are presented in Figures 5-6 and were all relatively close to the levels at the reference site except for iron, colour and temperature. The iron concentrations were a bit higher in the spring compared to the concentrations in the reference site (Figure 5). The temperatures and colour in the spring were also higher compared to the temperature at the reference site (Figure 6).

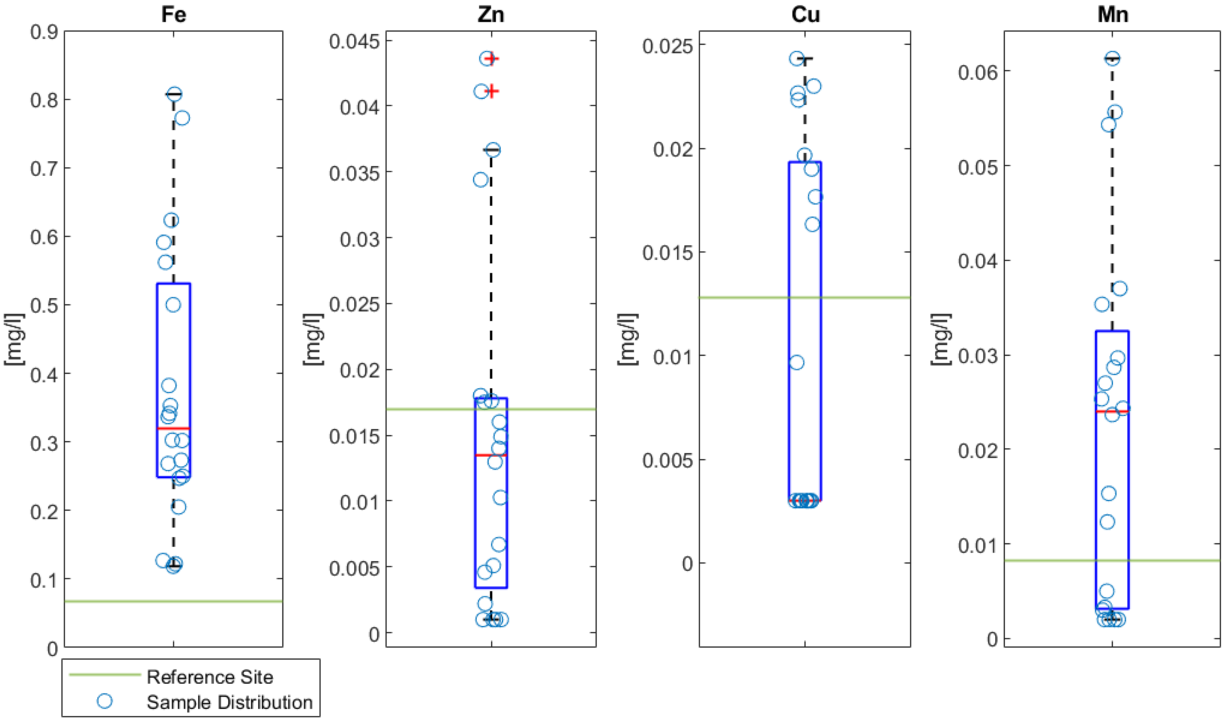

Figure 5: Boxplots for iron, zinc, copper and manganese with reference site. The red lines are the median values for the variables and the red crosses represents outliers.

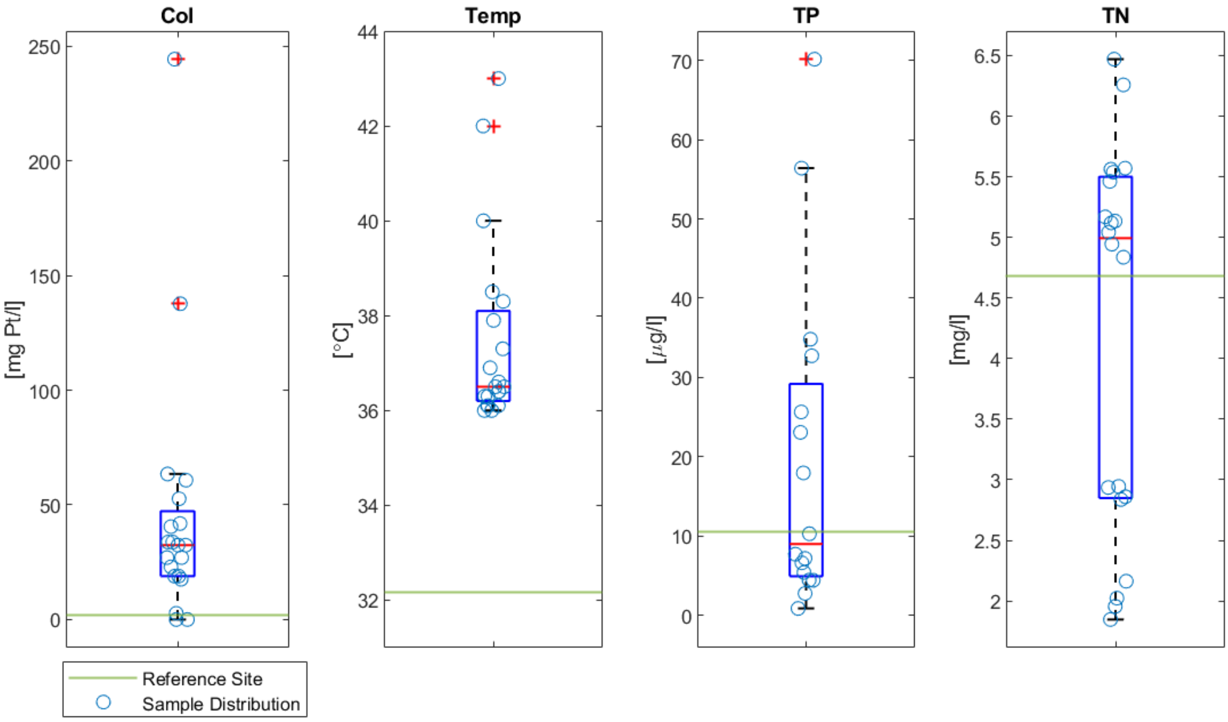

Figure 6: Boxplots for colour, temperature, total phosphorous and nitrogen with reference site. The red lines are the median values for the variables and the red crosses represents outliers.

The variables from Mawira Sitima that could be compared to the other hot springs are presented in Figures 7- 8 and were mostly within the range for hot springs except for turbidity, DO, pH and EC. EC only had one outlier that was not within the range of other hot springs and the same was true for pH (Figure 8). Turbidity and DO was mostly higher in Mawira Sitima compared to the other springs (Figures 7 - 8).

Comparing the same variables in Mawira Sitima to the reference site shows that EC, TDS and chloride were all higher at the reference site compared to the spring (Figure 8). The values for calcium, magnesium, sodium and DO in the spring were all close to the values at the reference site (Figure 7), although magnesium and sodium differ slightly from the reference site. Turbidity, pH and potassium were all lower at the reference site compared to the spring (Figures 7 - 8).

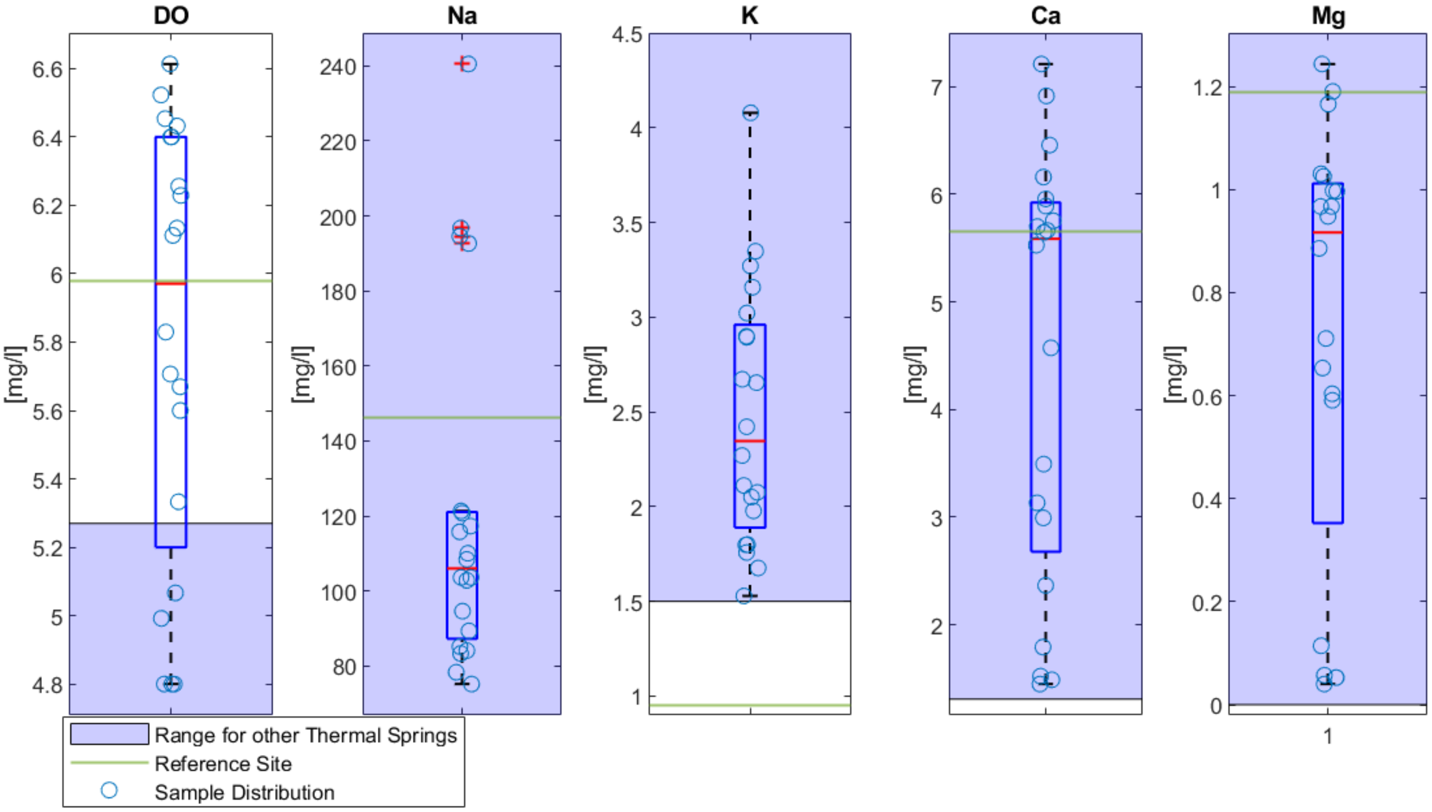

Figure 7: Boxplots for dissolved oxygen, sodium, potassium, calcium and magnesium with reference site and range for other hot springs. The red lines are the median values for the variables and the red crosses represents outliers.

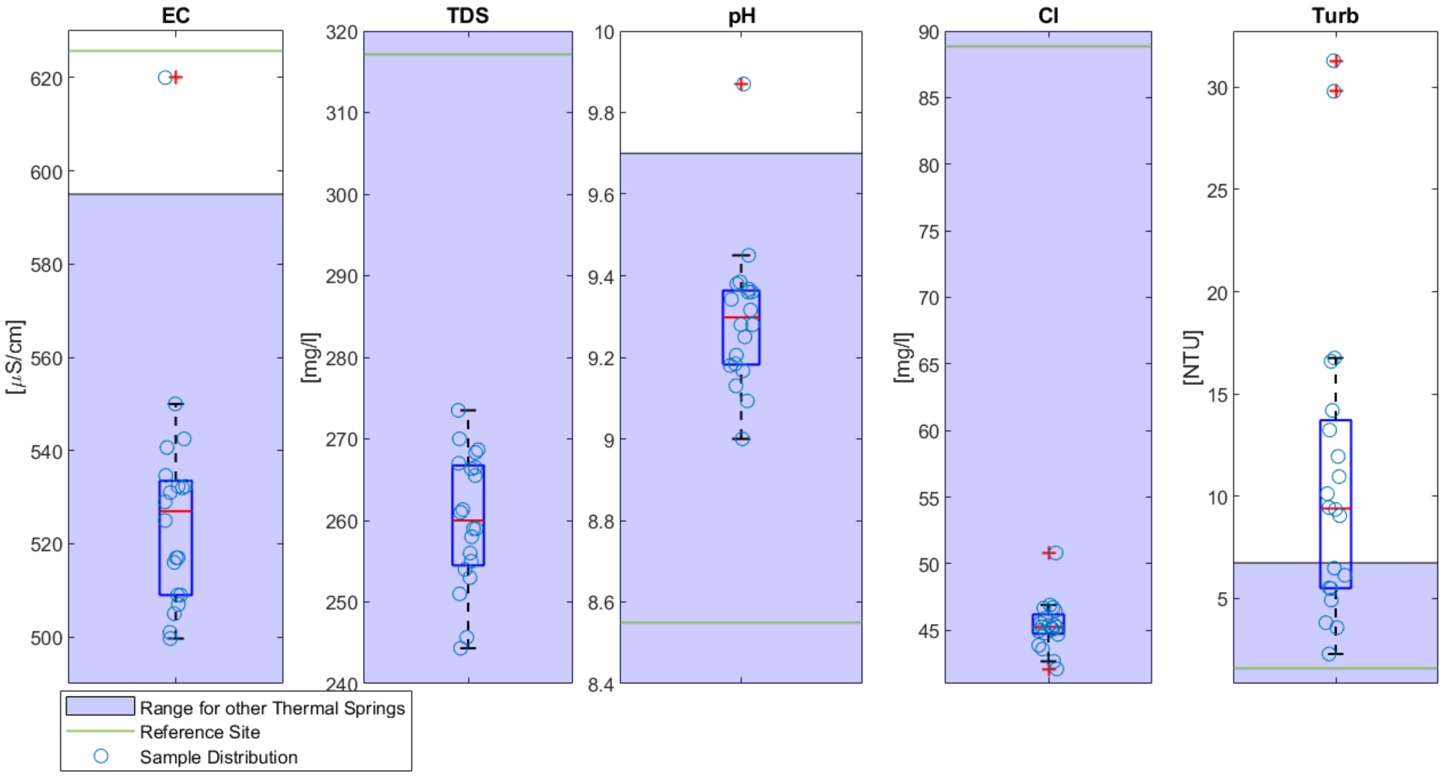

Figure 8: Boxplots for electrical conductivity, total dissolved solids, pH, chloride and turbidity with reference site and range for other hot springs. The red lines are the median values for the variables and the red crosses represents outliers.

The mean value for chlorophyll was calculated to 1.49 mg/l and the maximum value for chlorophyll was 2.96 mg/l which can be seen in Figure 9. This makes the status according to the Swedish Surface Water Standards oligotrophic as seen in Table 4. The values for chlorophyll were all higher or equal to the reference site (Figure 9).

The mean value for total phosphorous was calculated to 19.4 μg/l which makes the status mesotrophic according to the Swedish surface water standards in Table 1. The EK values for total phosphorous were dominantly above the lower limit for moderate status according to the Swedish Surface Water Standards and the median is considered good status according to the standards (Figure 9). Most measured values for DO were dominantly above the lower limit for good status and so was the median (Figure 9).

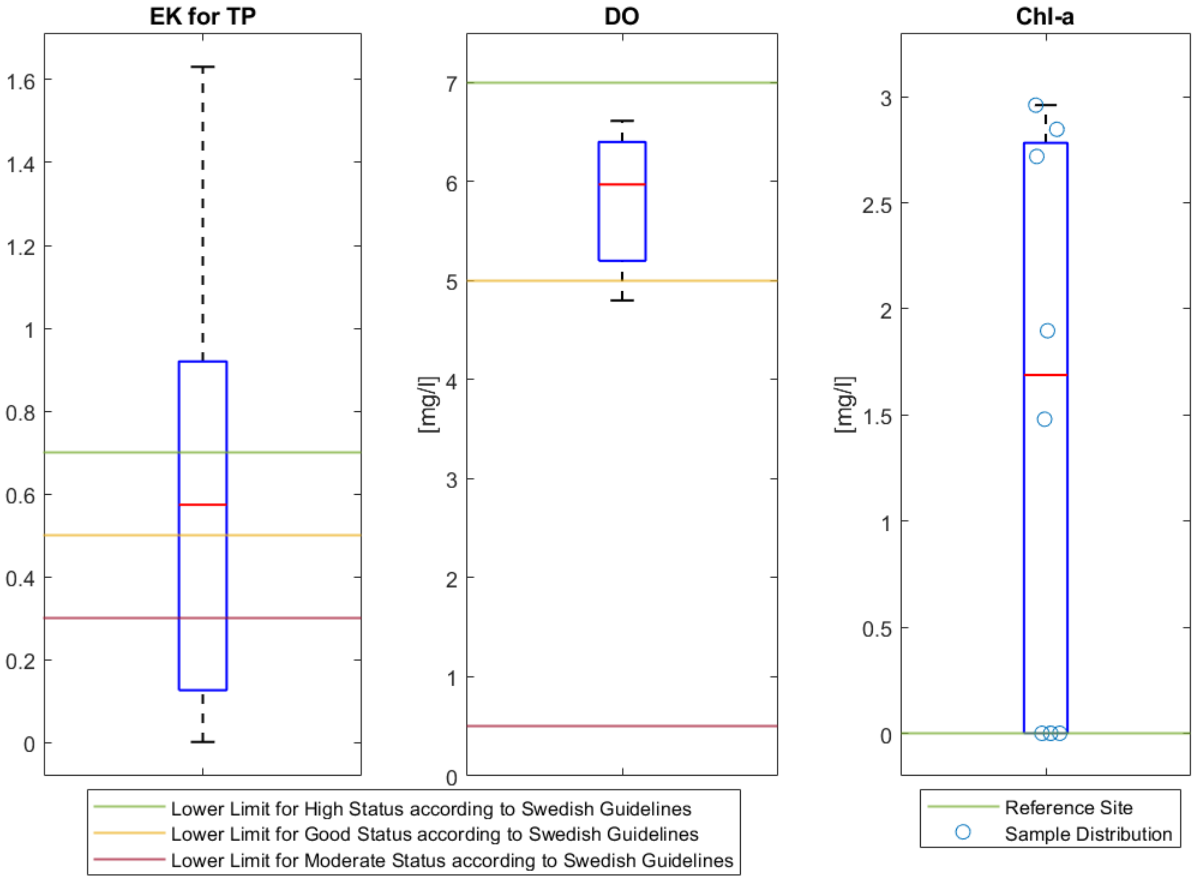

Figure 9: Boxplots for chlorophyll with reference site and EK-values for total phosphorous and dissolved oxygen including the lower limits according to the Swedish standard.

The N:P ratio was calculated to 218 and that means a designation of nitrogen surplus (Table 2) which means that the limiting nutrient is phosphorous.

4.1.4 Analysis of soil

In Table 10 the measured levels of total phosphorous, total nitrogen and different cations in soil were compared to levels presented by Landon (2014) (Table 5) and interpreted as normal, high or low. Levels of the same variables in Mawira Sitima were compared to the reference site and interpreted as high or low. The levels for iron were high in both the soils and the spring as was the potassium.

Table 10: Interpretation of levels in soil inside and outside of Mawira Sitima according to Landon (2014) and levels in the water according to the reference site and other hot springs.

	TP	**TN**	**Zn**	**Fe**	**Cu**	**Mn**	**K**	**Na**	**Mg**	**Ca**
Soil in pool	High	Low	Normal	High	Normal	Normal	High	High	High	Normal
Soil outside pool	High	Low	Normal	High	Normal	Normal	High	High	High	Normal
Mawira Sitima	Normal	Normal	Normal	High	Low	High	High	Low	Low	Normal

4.2 POTENTIAL FOR RECREATIONAL USE OF MAWIRA SITIMA

As seen in Figure 10, Mawira Liwonde is located close to the city centre of Liwonde while Mawira Sitima is located approximately 5 km from the centre. The size of Mawira Sitima is approximately 28 times bigger than Mawira Liwonde with an area of 739 m^2 respectively 26 m^2. The layout of Mawira Sitima includes several smaller pools which allows men and women to bathe and wash separately, which is seen in Figure 11, while Mawira Liwonde consists of a single pool seen in Figure 12.

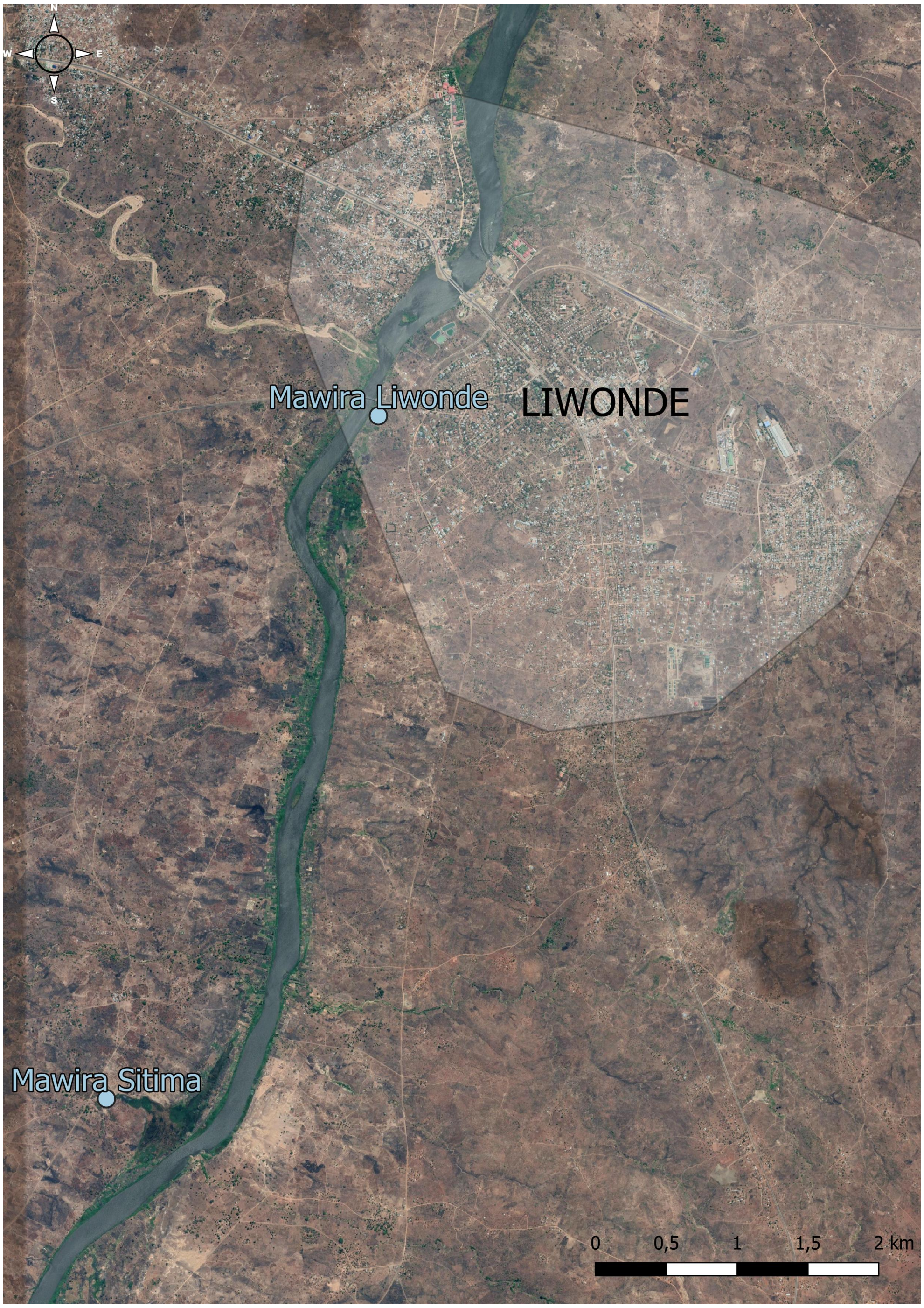

Figure 10: The city of Liwonde and the springs Mawira Sitima and Mawira Liwonde.

(a) Women's pool.

(b) Men's pool.

Figure 11: Mawira Sitima.

Figure 12: Mawira Liwonde.

Boxplots of all values in Mawira Sitima compared to the mean values in Mawira Liwonde are seen in Figures 13 - 15. EC, TDS, chloride, colour and temperature were all higher in Mawira Liwonde than Mawira Sitima, while pH was lower (Figure 13). Total phosphorous, turbidity and potassium were also higher in Mawira Liwonde, while DO, sodium and total nitrogen were relatively similar in the springs (Figure 14). The same goes for magnesium and manganese which were very similar, while calcium and iron were higher in Mawira Sitima and zinc and copper were higher in Mawira Liwonde (Figure 15).

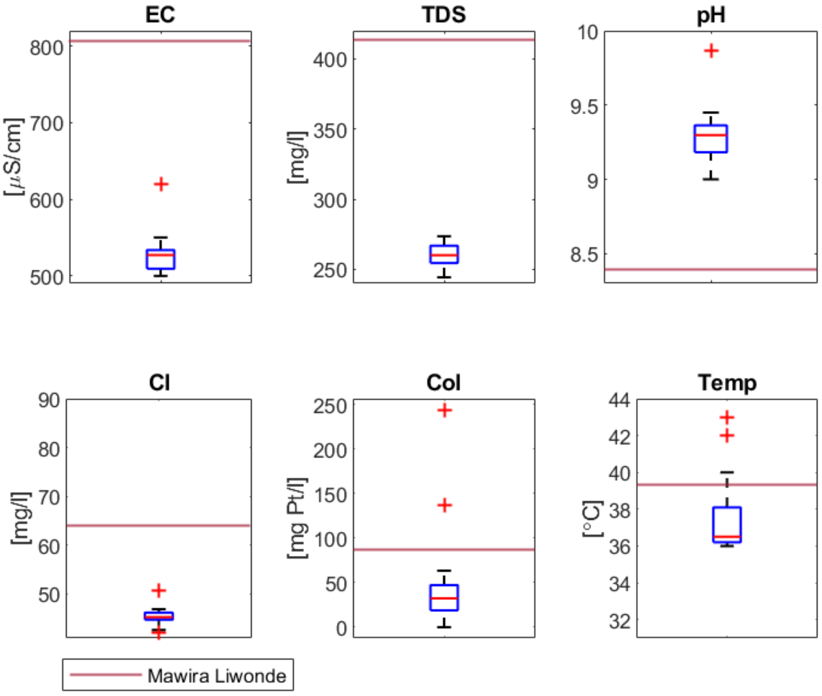

Figure 13: Values for electrical conductivity, total dissolved solids, pH, chloride, colour and temperature for Mawira Sitima compared to values from Mawira Liwonde. The red crosses represents outliers and the red line represents the median for the specific variable.

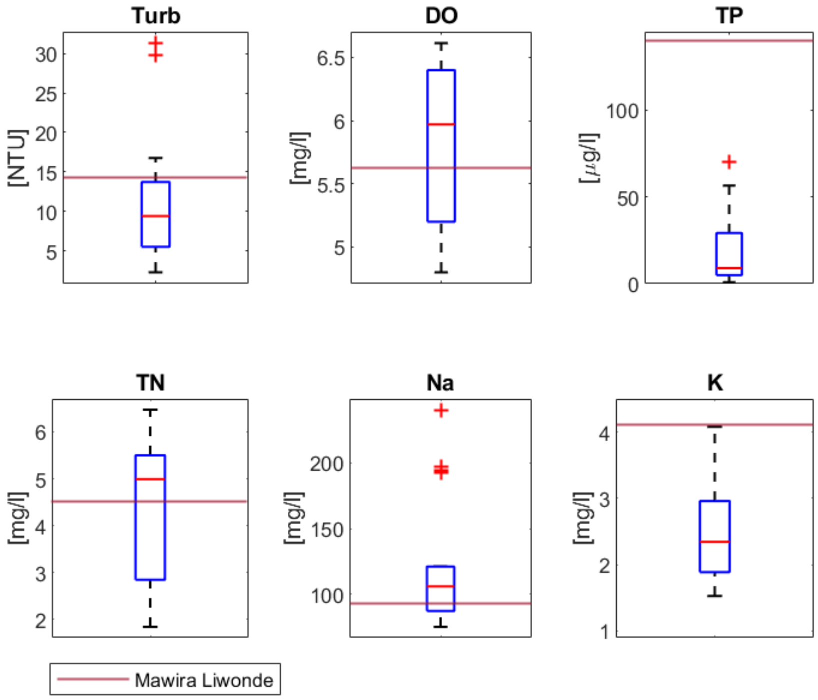

Figure 14: Values for turbidity, dissolved oxygen, total phosphorous, total nitrogen, sodium and potassium for Mawira Sitima compared to values from Mawira Liwonde. The red crosses represents outliers and the red line represents the median for the specific variable.

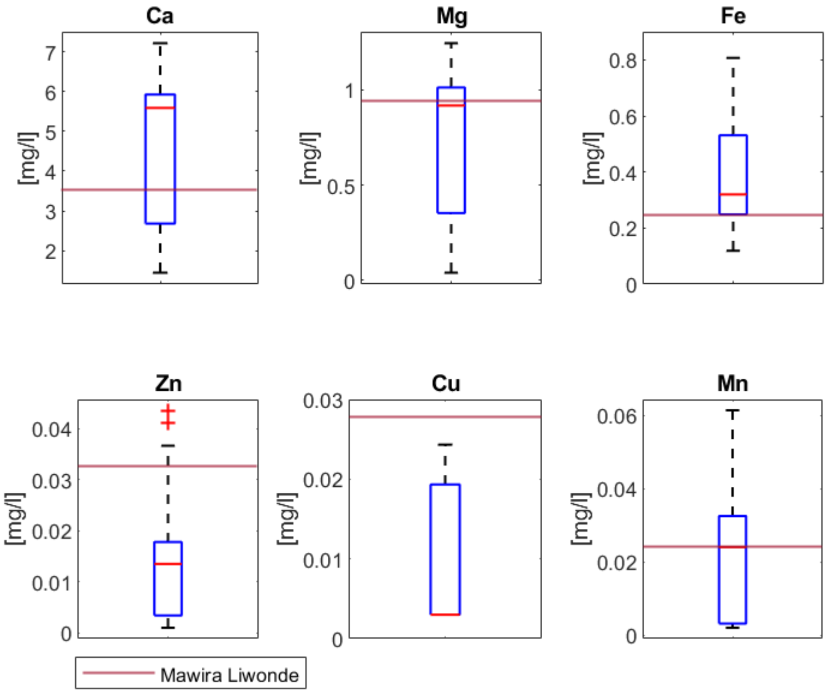

Figure 15: Values for calcium, magnesium, iron, zinc, copper and manganese for Mawira Sitima compared to values from Mawira Liwonde. The red crosses represents outliers and the red line represents the median for the specific variable.

The N:P ratio for Mawira Liwonde was calculated to 32.3 which suggests that the limiting nutrient in the spring is phosphorous. The ecological status based on DO and phosphorous seen in Figure 11 was good and poor respectively. The trophic status was decided to be eutrophic.

Table 11: Designation for N:P ratio, status for DO and EK based on total phosphorous as well as trophic status for Mawira Liwonde.

Parameter	Designation/status/category	Value
N:P ratio	Nitrogen surplus	32.3
DO	Good	5.63 (mg/l)
EK based on TP	Poor	0.0598
Trophic status based on TP	Eutrophic	140 (μg/l)

In Figures 16 - 18 the comparison between soil and plants by Mawira Liwonde and by Mawira Sitima can be seen. The levels of manganese, total nitrogen and sodium were higher in the soil by Mawira Liwonde compared to Mawira Sitima, while the levels of iron and magnesium were much higher by Mawira Sitima (Figure 16). Similarly, the iron levels in plant 1 are much higher by Mawira Sitima along with total nitrogen, zinc, copper, potassium and calcium (Figure 17). The levels of sodium and total phosphorus are higher by Mawira Liwonde for both plant 1 and 2 (Figures 17 - 18). In plant 2 the levels are also higher for total nitrogen, potassium, magnesium and calcium by Mawira Liwonde, while zinc and manganese are higher for Mawira Sitima (Figure 18).

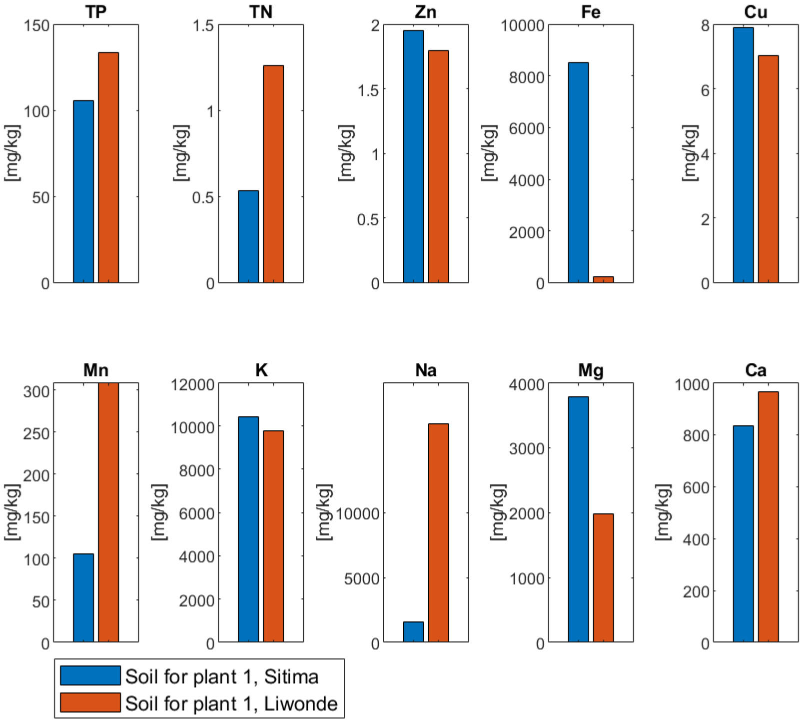

Figure 16: Nutrients in the soil for plant one for both Sitima and Liwonde.

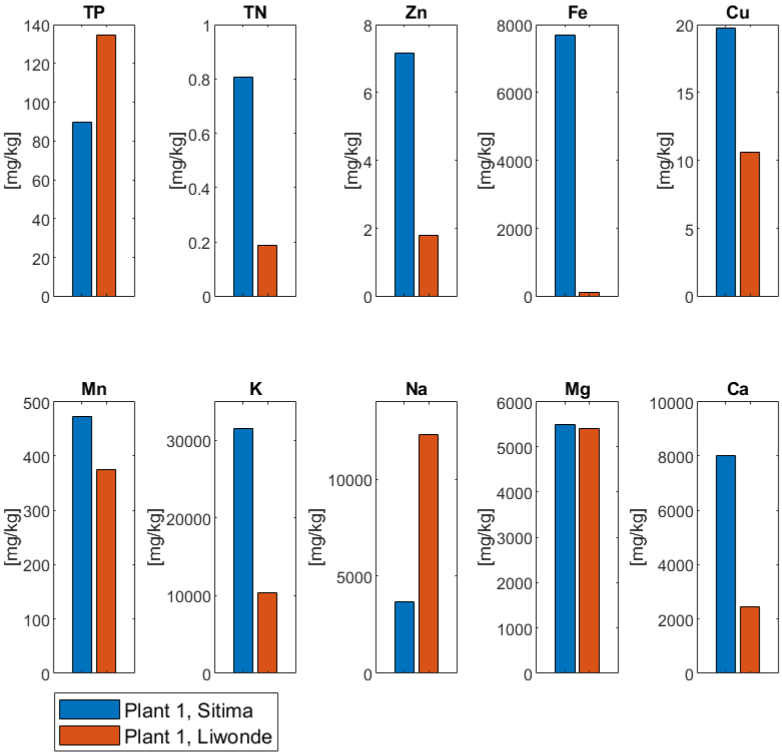

Figure 17: Nutrients in plant one for both Sitima and Liwonde.

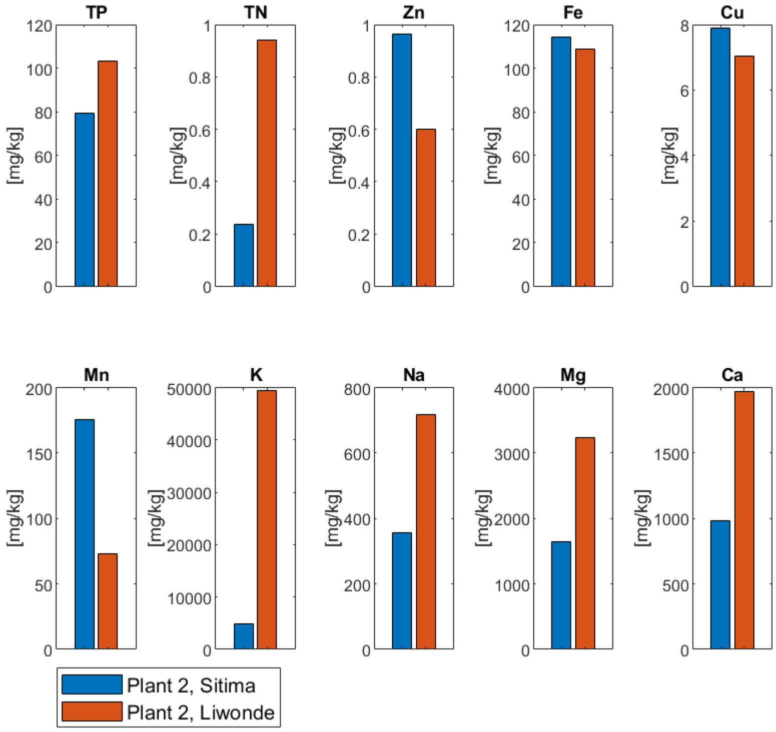

Figure 18: Nutrients in plant two for both Sitima and Liwonde.

4.3 LONG TERM MONITORING SYSTEM

In Table 12 the correlation between all different variables in Mawira Sitima are shown. The levels of manganese and copper correlated with seven variables, which is the most amount of variables to correlate with in this study. Chloride and pH were the only variables that did not correlate with any other variables.

Table 12: p-values and τ from Kendall's correlation test,
n=16 for total phosphorus and n=20 for all other variables.

τ p	**DO**	**Temp**	**pH**	**TDS**	**EC**	**Turb**	**Col**	**Cl**	**N**	**P**	**Na**	**K**	**Ca**	**Mg**	**Fe**	**Zn**	**Cu**	**Mn**
DO		-0.00542	-0.193	0.293	0.332	0.0532	0.113	-0.0745	-0.277	0.464	-0.106	-0.149	-0.160	-0.138	0.0106	-0.0432	0.271	-0.0649
Temp	0.974		0.0324	-0.323	-0.0757	0.0697	-0.0652	-0.209	0.499	0.638	-0.198	0.123	0.198	-0.424	0.145	-0.158	-0.363	-0.289
pH	0.241	0.854		-0.117	-0.171	-0.228	-0.280	-0.0265	0.196	-0.209	0.164	-0.313	0.292	-0.0265	-0.292	-0.210	-0.220	-0.0701
TDS	0.0735	0.0505	0.474		0.713	-0.164	-0.0642	0.0792	-0.121	0.550	-0.459	-0.290	-0.586	-0.121	-0.0792	0.220	0.745	-0.145
EC	0.0434	0.648	0.298	$1.32\mathrm{x}10^{-5}$		-0.00531	-0.0860	0.186	0.111	0.616	-0.249	-0.133	-0.536	-0.281	0.0796	0.124	0.541	-0.189
Turb	0.745	0.672	0.162	0.314	0.974		0.560	0.137	-0.0421	0.0833	0.253	0.389	0.242	0.305	0.768	0.235	-0.281	0.503
Col	0.494	0.695	0.0901	0.696	0.602	0.000636		0.112	-0.208	0.203	0.080	0.101	0.165	0.304	0.421	0.125	-0.0886	0.347
Cl	0.649	0.204	0.871	0.626	0.255	0.399	0.495		0.147	0.200	-0.168	-0.116	-0.200	0.137	0.137	0.193	0.169	150
N	0.0908	0.00245	0.229	0.455	0.495	0.795	0.205	0.364		-0.0167	0.326	0.0421	-0.0842	-0.274	0.0842	0.0107	-0.0562	-0.310
P	0.0129	0.297	0.260	0.00296	0.000978	0.653	0.278	0.280	0.928		-0.350	-0.417	-0.350	-0.133	0.100	0.326	0.552	-0.109
Na	0.515	0.000106	0.314	0.00474	0.127	0.119	0.626	0.299	0.0443	0.0586		0.232	0.463	-0.189	0.274	-0.278	-0.556	0.0428
K	0.363	0.454	0.0551	0.0742	0.417	0.0164	0.537	0.475	0.795	0.0244	0.153		0.200	0.221	0.453	0.128	-0.381	0.332
Ca	0.329	0.228	0.0738	0.000314	0.00103	0.136	0.313	0.218	0.604	0.0586	0.00430	0.218		0.242	0.158	-0.193	-0.692	0.342
Mg	0.398	0.101	0.871	0.455	0.0850	0.0599	0.0637	0.399	0.0916	0.471	0.243	0.173	0.136		0.305	0.385	-0.156	0.717
Fe	0.948	0.379	0.0738	0.626	0.626	$2.17\mathrm{x}10^{-6}$	0.0102	0.399	0.604	0.589	0.0916	0.00527	0.330	0.0599		0.342	-0.219	0.503
Zn	0.794	0.343	0.203	0.181	0.453	0.152	0.452	0.241	0.948	0.0788	0.0901	0.434	0.241	0.0189	0.0370		0.247	0.332
Cu	0.124	0.0412	0.211	$2.15\mathrm{x}10^{-5}$	0.00212	0.108	0.617	0.335	0.748	0.00506	0.00149	0.0295	$7.44\mathrm{x}10^{-5}$	0.372	0.212	0.162		-0.279
Mn	0.695	0.0829	0.671	0.379	0.253	0.00219	0.0365	0.361	0.0587	0.558	0.794	0.0433	0.0370	$1.26\mathrm{x}10^{-5}$	0.00219	0.0458	0.115	

In Figures 19 - 24 the variables that were found to correlate in Table 12 and showed a clear trend when plotted are presented. The variables that did not show clear trends can be seen in Appendix B. In Figure 19 it is seen that the levels of total phosphorous and copper clearly increased over time, while the levels of calcium decreased over time. The trend for DO, EC and TDS is less clear from the figure.

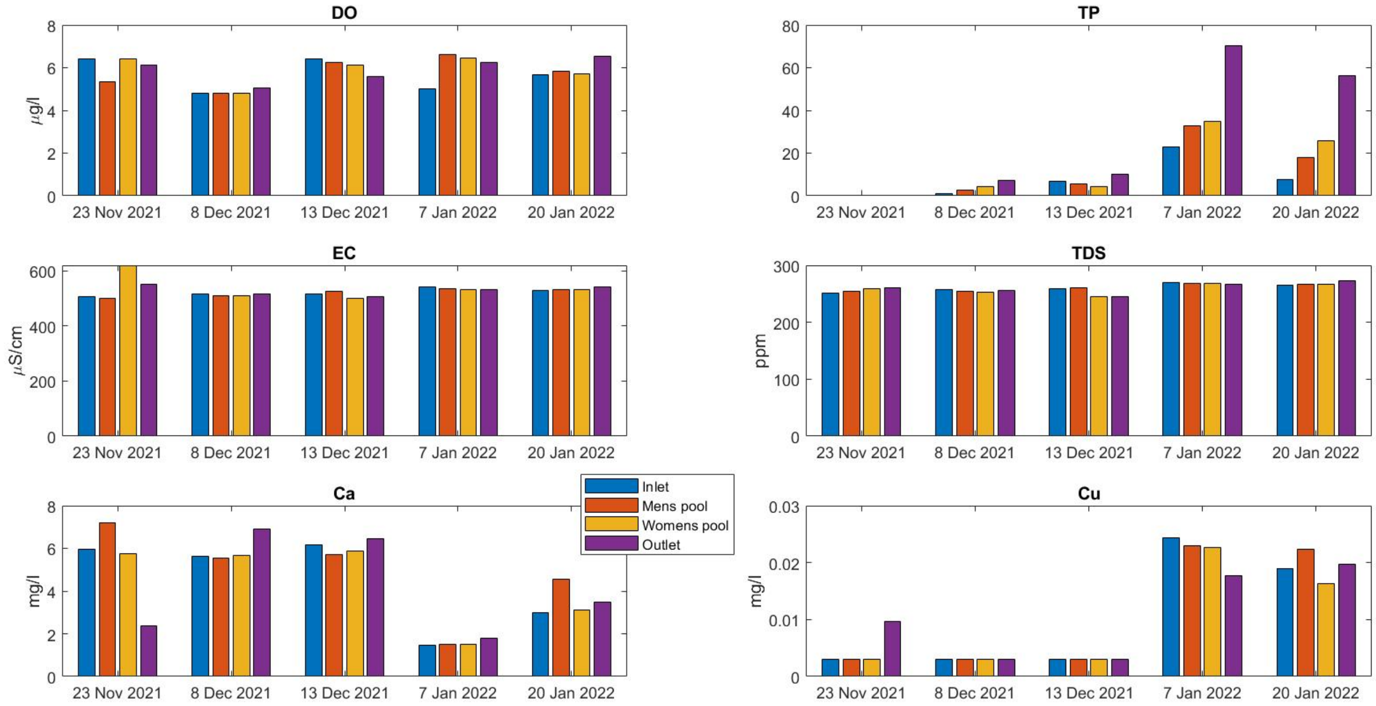

Figure 19: Total phosphorous, dissolved oxygen, electrical conductivity, total dissolved solids, calcium and copper between sites and over time.

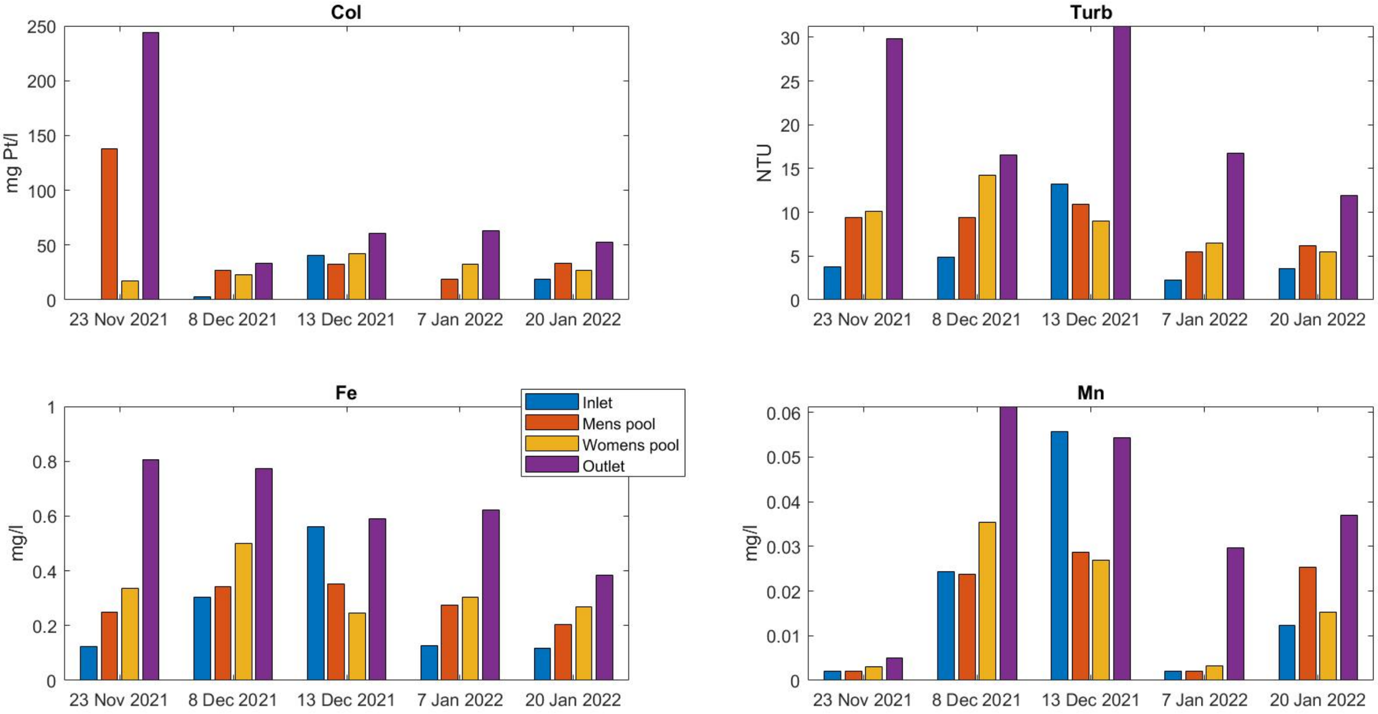

Figure 20: Colour, turbidity, iron and manganese between sites and over time.

The trends are shown more clearly in Figures 21 and 22 where the correlated variables are put in the same graphs. In Figure 21 it is clearer that the TDS increased over time while it was still hard to detect a clear trend for EC and DO. In this graph sodium is also included as it correlates to TDS, calcium and copper. It showed a negative trend over time.

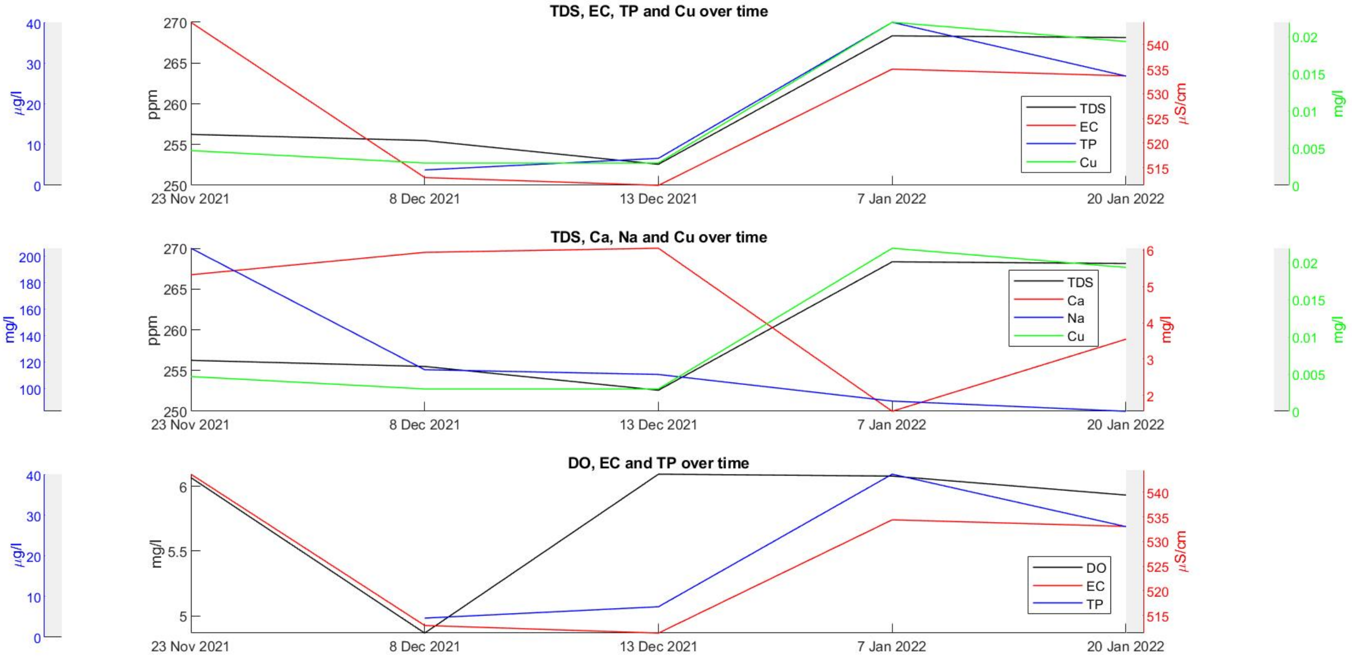

Figure 21: Total phosphorous, dissolved oxygen, electrical conductivity, total dissolved solids, calcium, sodium and copper in Mawira Sitima over time.

It is seen in Figure 22 that the turbidity and iron follow much the same pattern and increased throughout the whole spring while the colour and manganese varied a bit more. However, all variables had the highest value at the outlet and were shown to increase drastically between the sites called women's pool and outlet.

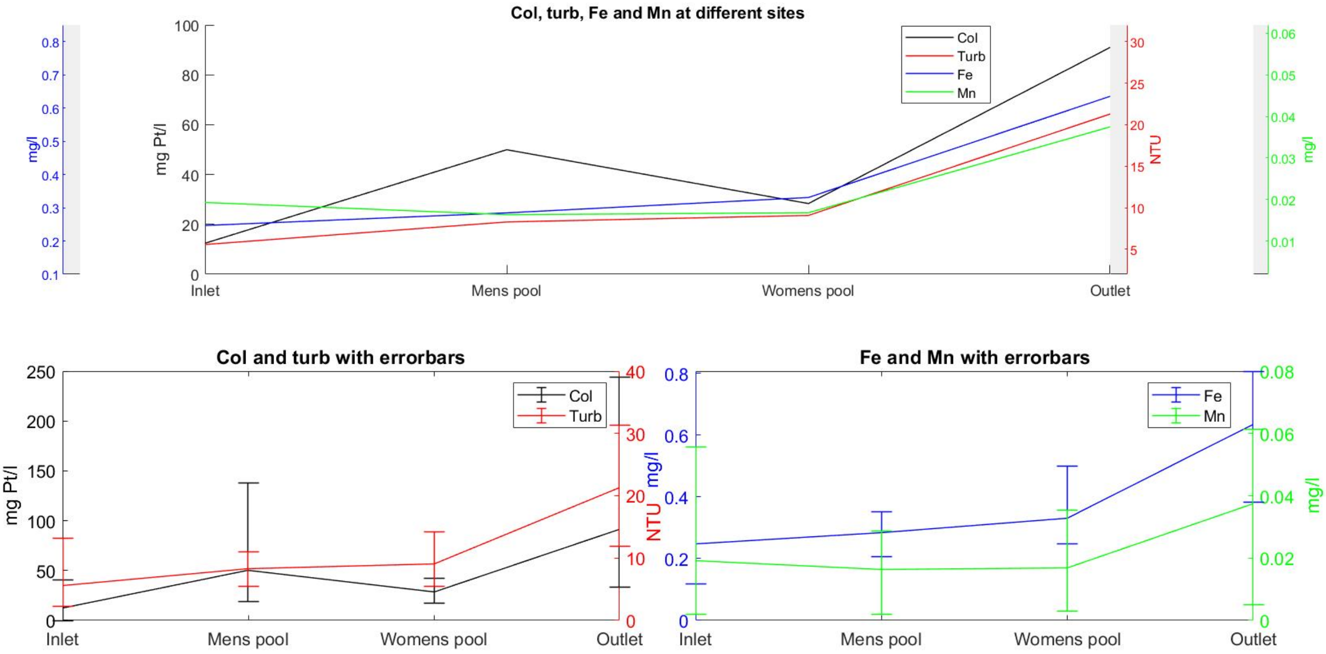

Figure 22: Colour, turbidity, iron and manganese at the different sampling sites. The distribution is displayed in errorbars.

The ions that correlate to each other are presented in Figures 23 - 24. In Figure 23 it is seen that magnesium, zinc and manganese were constant throughout most part of the spring but then increased drastically by the outlet. The same drastic change by the outlet was displayed by potassium while copper did not show a clear trend between sites. However, copper seemed to increase over time while potassium decreased. Calcium and manganese seemed to correlate over time and anti correlate between sites but they showed no clear increasing or decreasing trend for either.

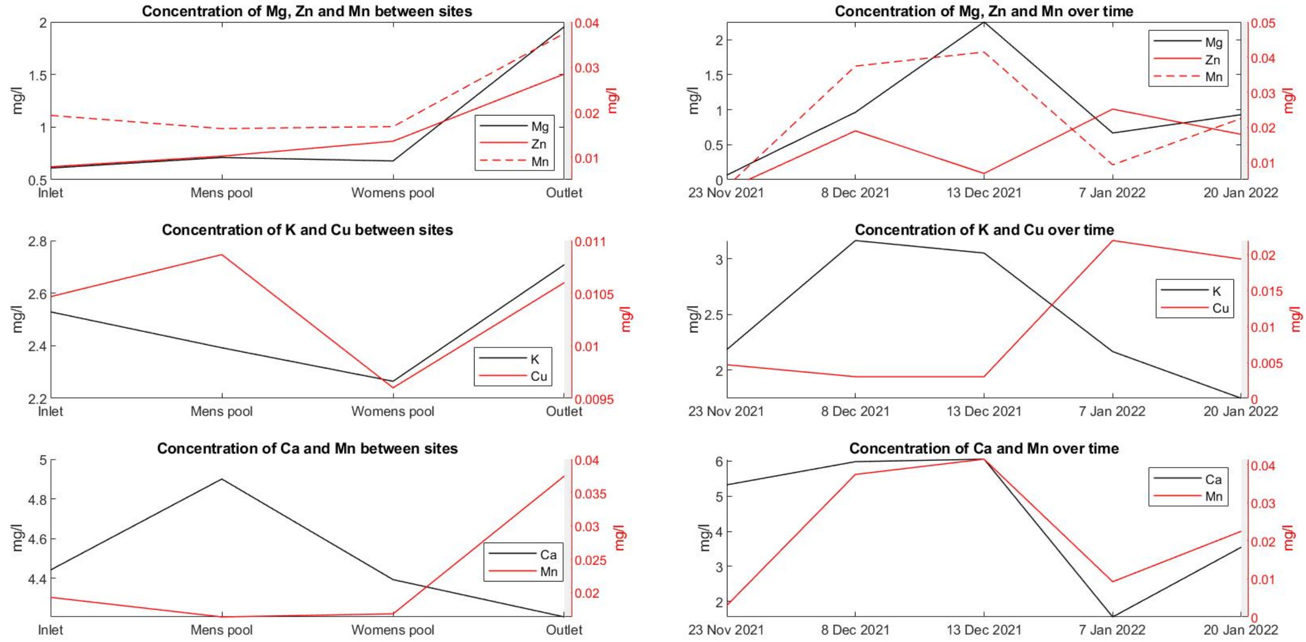

Figure 23: Trends and correlation over time and site for correlating ions.

In Figure 24 it can be seen that the concentrations of potassium, iron, zinc and manganese increased towards the outlet. Sodium, calcium and copper showed clear correlations but no significant trend over time or space.

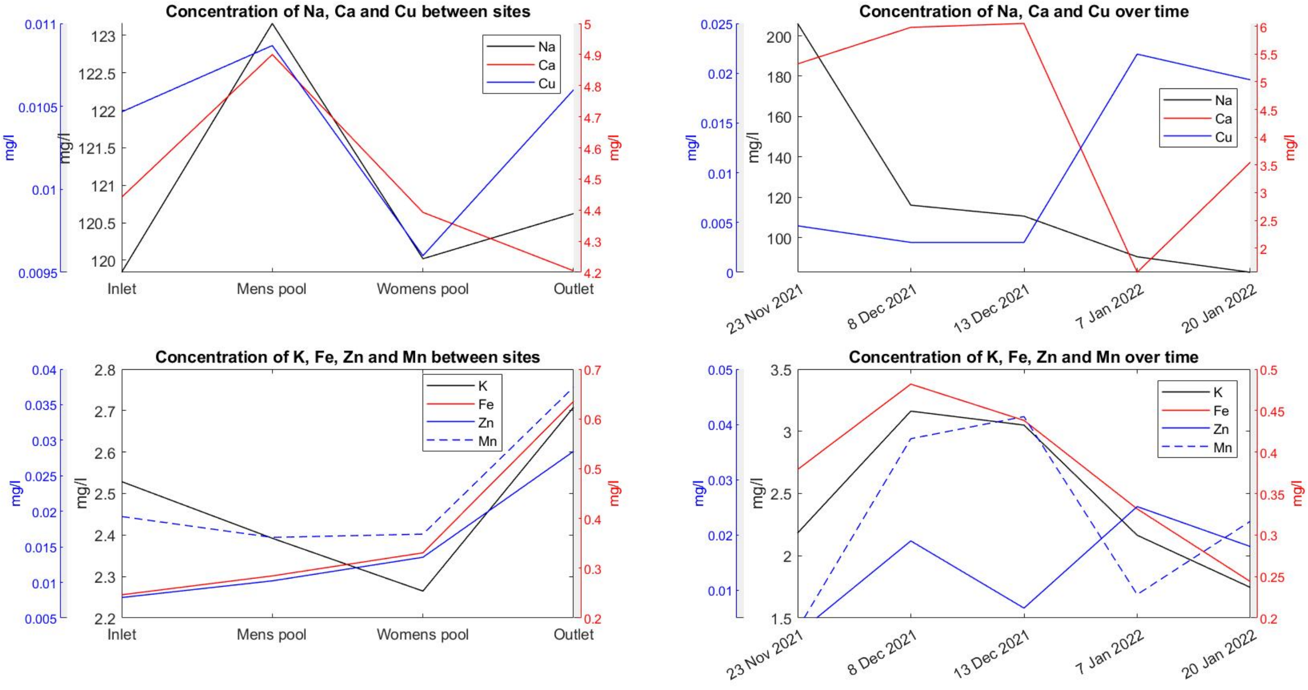

Figure 24: Trends and correlation over time and site for correlating ions.

In Figure 25 the values for TDS, DO, EC, pH, turbidity and temperature from each sampling site is presented. The mean for temperature, electrical conductivity and total dissolved solids were relatively constant for all sampling sites. The mean for pH was lower for the outlet compared to the other sites. The mean for turbidity and DO increased from the inlet to the outlet.

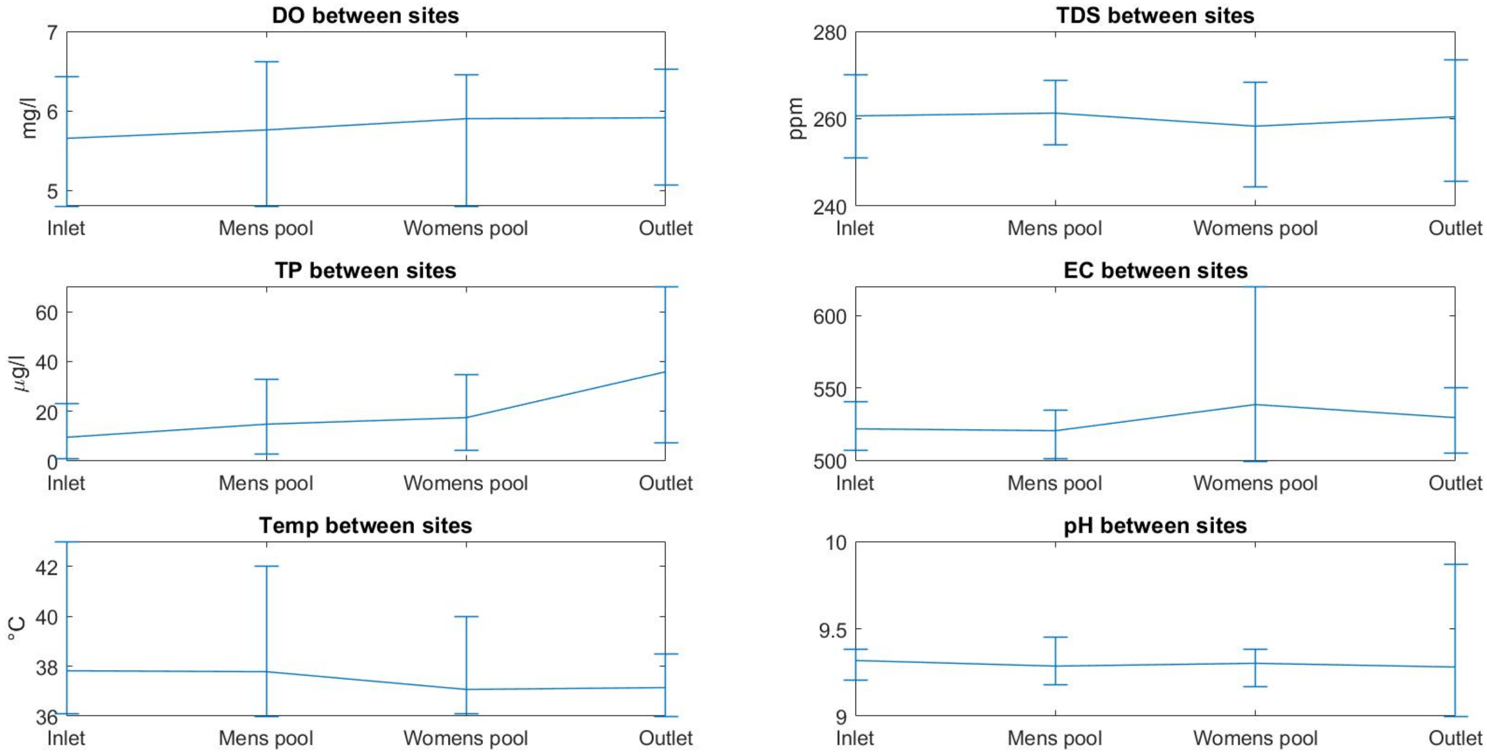

Figure 25: Plots with errorbars for dissolved oxygen, total dissolved solids, total phosphorus, electrical conductivity, temperature and pH at the different measuring sites.

4.3.1 Meteorological data

In Figures 26 - 30 daily meteorological data (precipitation, maximum and minimum air temperature) are presented with different variables. Only the variables that showed correlation or similar patterns as the meteorological data are presented here, other variables can be seen in Appendix B.

Turbidity and colour (Figures 26 and 27) are higher after periods without rainfall and lower after rainy periods.

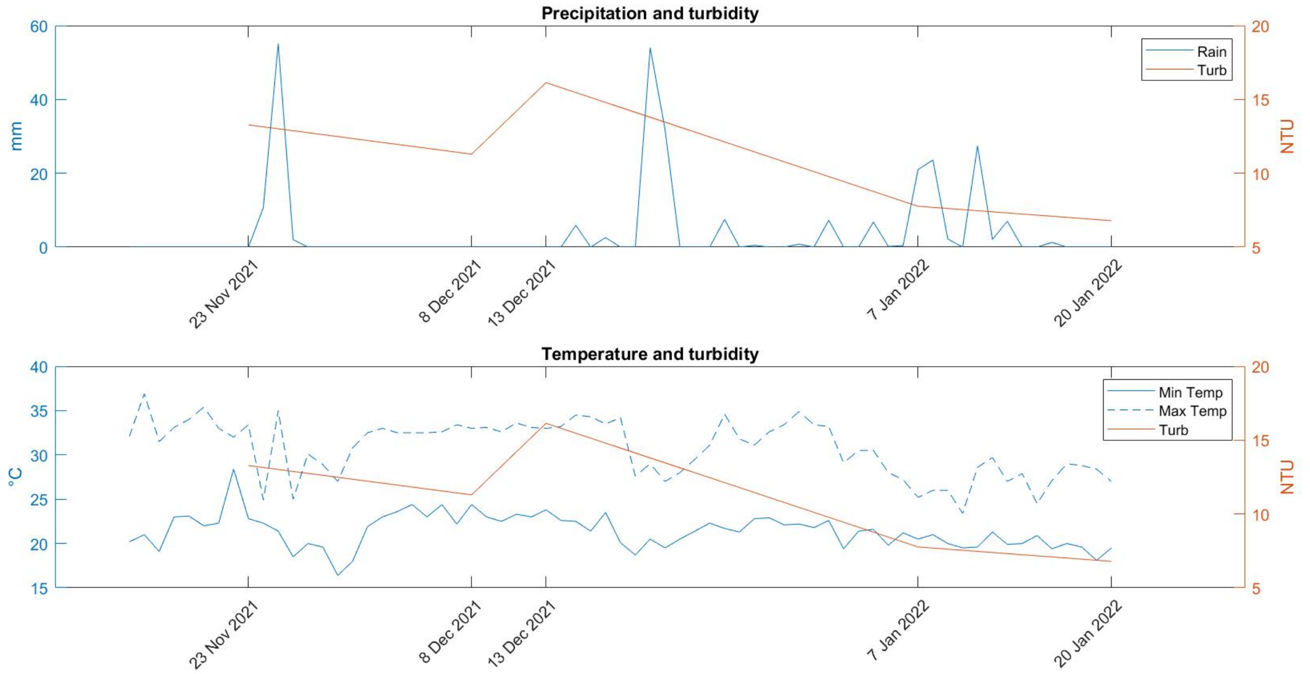

Figure 26: Turbidity, precipitation and air temperature over time.

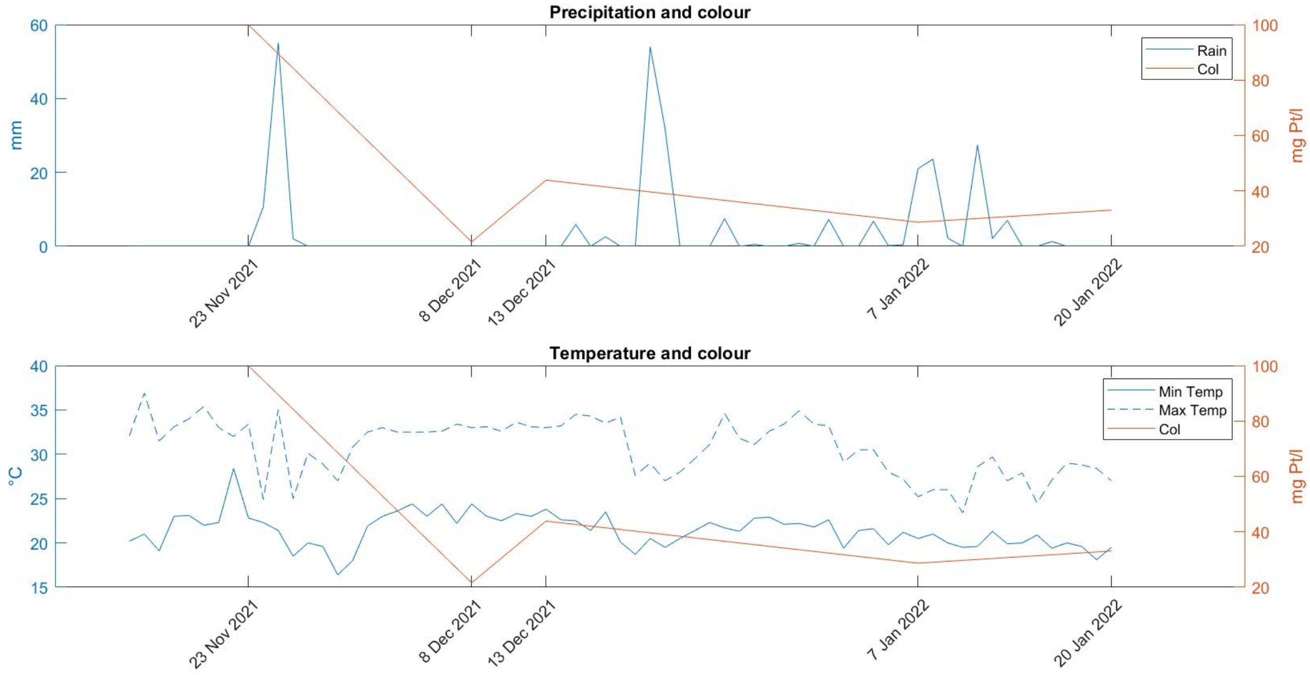

Figure 27: Colour, precipitation and air temperature over time.

Zinc (Figure 28) is generally higher after periods of rain and lower after dry periods.

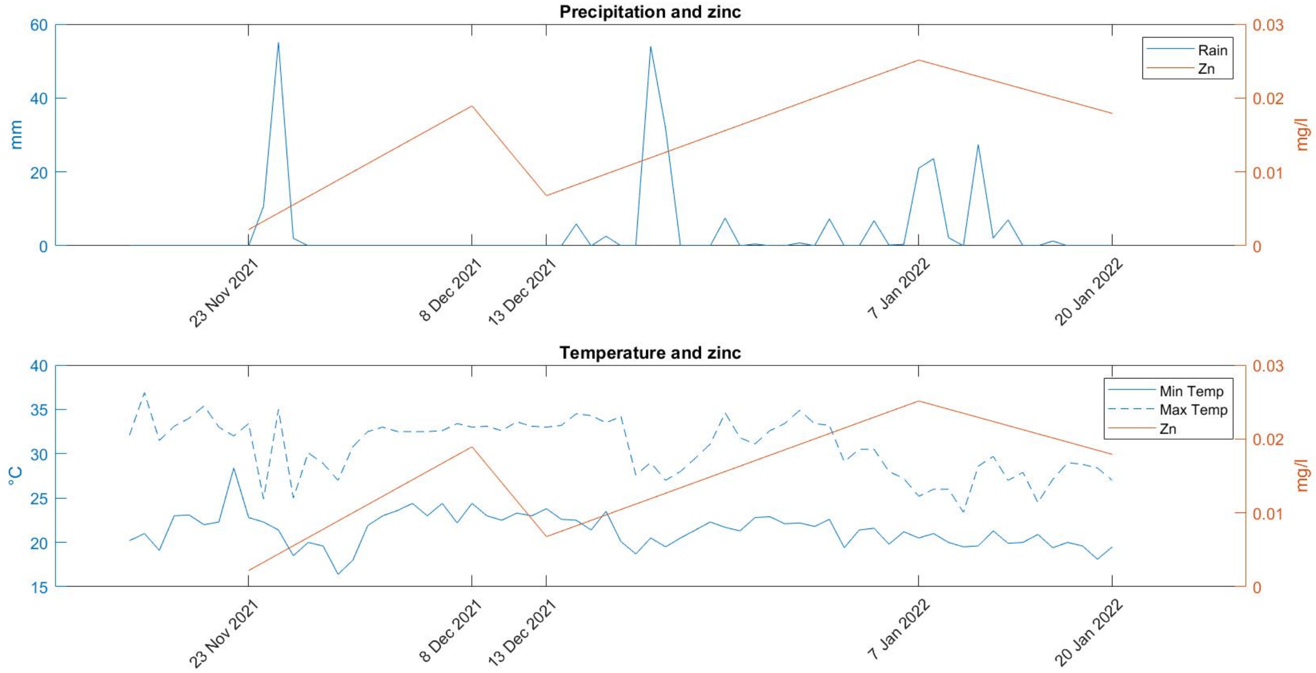

Figure 28: Zinc, precipitation and air temperature over time.

Sodium and water temperature (Figures 29 and 30) show slightly decreasing trends over time. So does the maximum and minimum air temperatures.

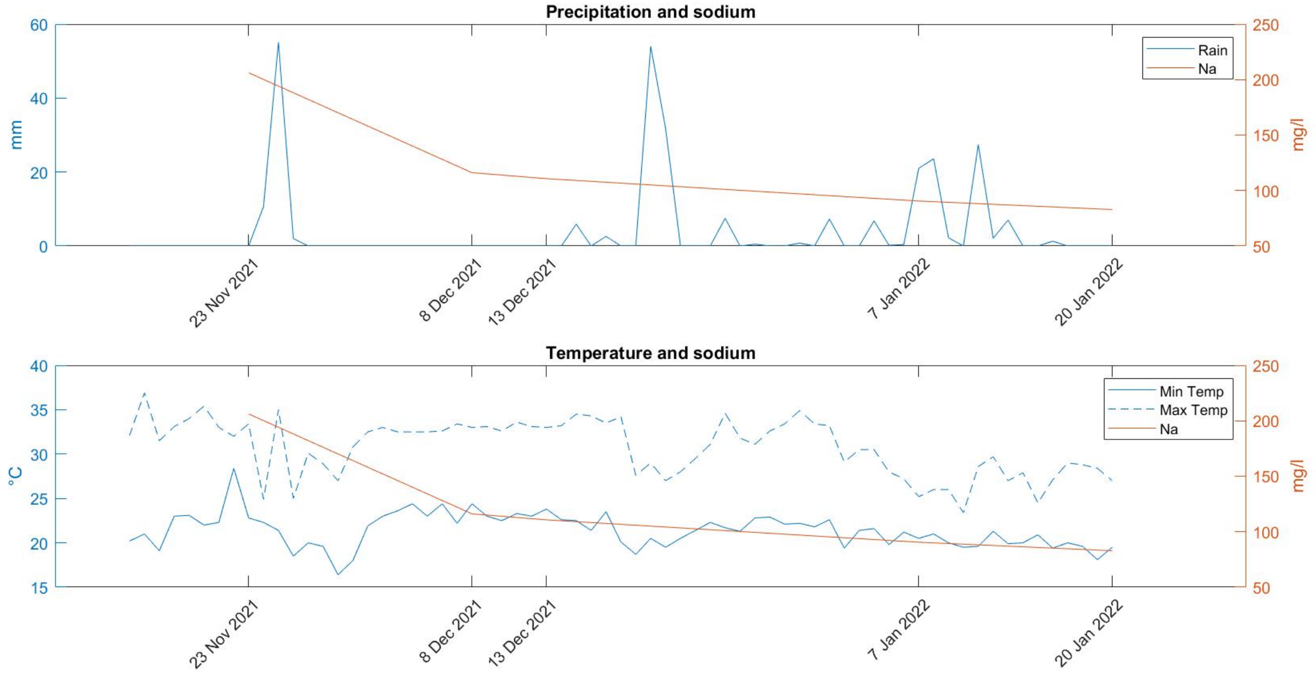

Figure 29: Sodium, precipitation and air temperature over time.

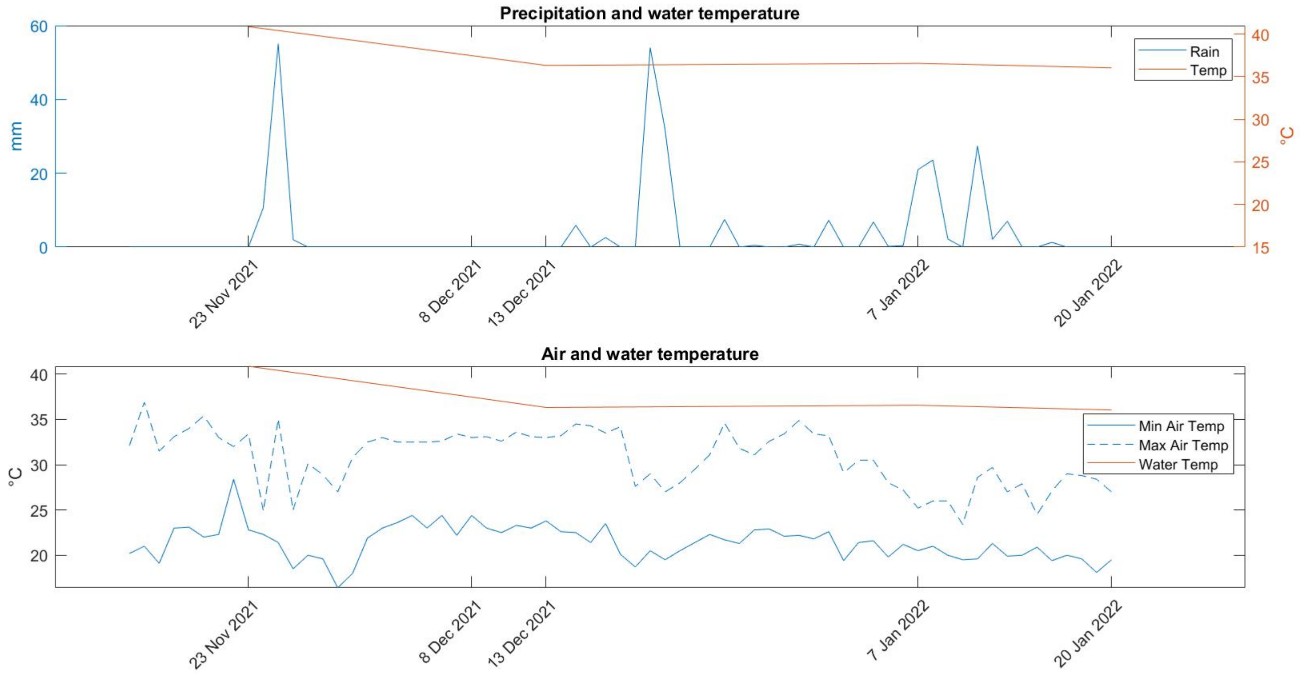

Figure 30: Water temperature, precipitation and air temperature over time.

4.3.2 Bioindication

Only two major plant species were found growing inside the spring and one surrounding it. All plants were emerged and no submerged or floating-leaved plants were found. The plants were of both short and tall character and lacked flowers. The tallest plant was identified as belonging to the genus Eleocharis using *African Plants - A Photo Guide* (Dressler et al. 2014). The smaller plant was identified as belonging to the genus Brachiaria using the same website.

5 DISCUSSION

5.1 WATER QUALITY OF MAWIRA SITIMA

5.1.1 Land use survey

As determined from Figure 4 the water from the western maize field most likely will flow towards the rice field, while water from the eastern maize field will flow towards the hot spring. This could potentially affect the water quality during rains as runoff from the field could bring nutrients to the spring. As seen in the figure, the lowest point of the hot spring is located by the outlet which might cause the water to flow directly there. This could lead to higher levels of nutrients by the outlet than the inlet, which wrongly might lead to the conclusion that the recreational use causes water quality damage.

5.1.2 Analysis of water quality

Compared to other hot springs and the reference site, the overall status of Mawira Sitima is relatively good (Figures 5 - 8). All values were within the range of other hot springs, except for turbidity and DO (Figures 7 and 8). The levels of DO in Mawira Sitima were dominantly higher than the levels in renowned hot springs, which is preferable and indicate a good environment for aquatic life. The turbidity was relatively high which might be due to runoff, algae or erosion. It might also be due to the washing and bathing activities in the hot spring with detergents being used, which was indicated since the outlet had the highest turbidity (Figure 22). The activity might also cause suspension of sediment, which might lead to higher turbidity. High turbidity can be an indicator of poor water quality especially concerning DO since it blocks sunlight and limits photosynthesis and therefore lowers DO (Patel et al. 2015), but as mentioned above, this does not seem to be a problem as Mawira Sitima had high levels of DO. This could be seen in comparison to the renowned springs but also to the Swedish Surface Water Standards where Mawira Sitima classify as having good concentrations of DO (Figure 9).

Comparing the variables in the spring to the reference site showed that the median level for copper, total phosphorous, total nitrogen, DO, and calcium were all very close to the level of the reference site (Figures 5 -7). This could be an indication that the waters come from the same source and that the variables that are different are affected by land use and activities in the water. The reference site is a borehole located at a higher altitude than the spring (Figure 4). This means that it should be fairly isolated from any activities since the water is being pumped from several meters below ground while the spring is used for daily washing and other activities. It also means that the runoff affecting the spring might not affect the borehole as the water is being naturally purified as it filters through the soil. Several farming fields are located between the borehole and the spring which means pollutants from these may flow to the lower located spring.

The medians for iron, manganese, colour, temperature, potassium, pH, turbidity and chlorophyll were all higher in the spring compared to the reference site (Figure 5- 8). Higher concentrations of iron could potentially come from dust reaching the hot spring. The dust in the area was noticeably red which can be an indication of high iron concentrations (Reynolds et al. 2011). Colour and turbidity were most likely higher due to activities and runoff. The higher pH is more difficult to explain as there were no increase along the spring (Figure 25) and therefore the washing does not seem to affect pH. It could be due to the spring being meteoric since meteoric waters in arid environments often have a high pH (Selley et al. 2015).

The medians for zinc, sodium, magnesium, EC, and TDS were all lower in the spring compared to the reference site (Figures 5,7, and 8). This could possibly be due to the spring being diluted during rains. Rain causes runoff going into the spring and diluting the water, but the borehole will not have as much runoff as it is located higher up. As mentioned in an earlier study (Olivier et al. 2011) sedimentary rocks are associated with saline waters, meaning higher levels of ions, which makes this theory likely as the area around Sitima consists mostly of sedimentary rocks (Dill 2007; Haundi et al. 2021). It should also be stated that the borehole could still be affected by rains as it reaches the groundwater, but this might only be the case if there are very heavy rains. Higher concentrations of zinc in the borehole is not unexpected as it is common for zinc to be higher in groundwater compared to surface waters (World Health Organization 2003c). EC and TDS are heavily connected to ion concentrations (Rusydi 2018) and it therefore makes sense that they follow the same patterns as the ions.

The N:P ratio was calculated to 218 within the spring which means a surplus of nitrogen and that the limiting nutrient is phosphorous. This means that it is relevant to calculate the ecological status based on phosphorous and not nitrogen. The mean value for total phosphorous was 19.4 μg/l which indicates moderate status for the water quality in the spring. When looking at the median for total phosphorous it indicates a good status (Figure 9). The DO concentration of the spring classified as good status (Figure 9). This gives a good indication that the water quality of the spring is not of concern.

When it comes to the trophic status, the concentration of phosphorous suggested a mesotrophic classification and chlorophyll-a an oligotrophic classification. The trophic status for Mawira Sitima was therefore decided to be meso-oligotrophic which means that it is relatively nutrient poor and could explain the absence of plants and other aquatic life. However, this classification is very uncertain as the analysis of chlorophyll-a was only done twice and the results for both chlorophyll-a and phosphorous were highly variable. The method used to analyse the levels of chlorophyll-a required filtration using a vacuum pump until the filter paper was fully clogged. The pump was brought from Sweden and connected to a water tap in the lab to create vacuum. Due to unidentified issues, the vacuum was not efficient for the filtration which made the process lengthy and insufficient. During the first sampling, only 500 ml of water was collected from each site to be used for the chlorophyll analysis. For some sites where the water was poor i chlorophyll, this volume was not enough to clog the filter. Hence, during the second sampling, it was decided that 1 litre was to be collected from each site and that the samples were to be filtered until the paper was clogged or the 1 litre had been filtered. However, due to the equipment issues, the filtration was not done using vacuum which makes the results highly uncertain. This might also explain the variability between the two different times of measuring chlorophyll-a.

When analysing the nutrients, the technique that was originally used required sterilisation through autoclaving, for release of phosphorous and nitrogen bound to microbes. The technique was then adjusted to fit the available equipment in the lab, using a hot plate method where the samples were boiled to release the bound nutrients. The boiling caused evaporation of the samples, which in turn affected the concentration of nutrients. To correct for this change in concentration the samples were diluted back to the original volume after boiling, using double distilled water. This method is based on the assumption that the ions are unaffected by the boiling, which is a fairly accurate assumption. It also assumes that the distilled water does not contain any contaminants that affects the results. Using Milli-Q water would have made the method more reliable since it is considered to be purer than distilled water (Wilson 2019) and hence would affect the composition of ions less. However, Milli-Q water was not available, which made double distilled water the only option. Using this technique instead of autoclaving might have affected the final results by adding ions to the samples. The correction of the volume might also not have been complete accurate, which might have led to dilution or condensing of the nutrients.

When analysing total phosphorous for the last two samplings (2022-01-07 and 2022-01-20) the results came out a lot higher than the previous samplings (Appendix A). This seemed reasonable based on the heavy rains that might have led to nutrients being transported to the spring by runoff and the drastic change in calcium and copper at the same time (Figure 19). However, it was also noted that the measured absorbance for the calibrant was, for unknown reasons, a lot lower than for previous samplings, which might have affected the results making them unreliable.

Another factor that might have affected the final results is the method used for DO. When analysing the dissolved oxygen, the method was adjusted according to the available equipment. When collecting the samples, it was made sure that the bottles were filled all the way to prevent oxygen from entering or escaping. After the first sampling (2021-11-23) there was a delay which caused the DO to be analysed 3 days after sampling in the field. However, all other analyses were performed the day after sampling to prevent any change in the DO concentration. The small variance between the first sampling and the other samplings (Appendix A) strongly suggests that the wait did not affect the concentration. What might have caused changes however, was the pouring of the samples which was done when transferring the water from the sample bottles to glass flasks to be diluted with distilled water. The samples were first poured into a measuring glass and then into the glass flask, leaving room for oxygen to escape or enter the samples. When topping up the samples with distilled water, it was made sure that the bottle was completely full again, which might have caused different amounts of distilled water to be added to the samples. This might have led to some samples being more diluted than others, which might have affected the results. For a more accurate analysis, the DO should have been measured directly in the field.

Attempts were made to analyse the level of sulphates in the samples. However, most times the results came out inconclusive which was believed to be due to the blank reacting and changing colour throughout the analysis. Three different methods were used to perform the analysis. First the blank was treated as all other samples and the absorbance of each sample was measured every 30 seconds for 4 minutes. This caused the absorbance of the samples to increase with time, meaning that the first sample measured the lowest absorption and the last measured the highest, disregarding the actual concentration of sulphate. It was then attempted to perform the analysis using deionised water as a blank, which caused the samples to measure too high absorbances for the spectrophotometer to detect. Lastly the blank was once again treated as the samples, and the absorbance of the samples were then measured only once, 1 minute after adding barium chloride. This caused some of the samples to measure negative concentrations of sulphate. These results were then determined to be inconclusive. This could be due to the samples having sulphate concentrations lower then 1 mg/l which is the minimum detection limit. As most measurements were inconclusive, sulphates were excluded from the study.

Another variable that was exclude from the study is salinity as the instrument returned the same values for salinity as TDS. This might be due to a faulty instrument or the levels being too similar for the instrument to detect the difference, but after comparing the measured results to other studies it was decided that salinity was to be excluded from the study as they did not seem reasonable. The measured results for both salinity and sulphates can be seen in Append ix A.

Overall, the analysis of water quality variables in Mawira Sitima indicated relatively good water quality and the spring is determined to be suitable for the current use by the local population. Only DO and turbidity were out of range of other hot springs and there were no indications of this being a threat to the public health.

5.1.3 Analysis of soil

As seen in Table 10 the levels of total phosphorus were very high in the soil by the spring, while the levels of nitrogen were extremely low. This suggests that nitrogen is removed from the soil by some process. The levels of both nitrogen and phosphorous were considered to be normal (Table 10) in the spring, which suggests that phosphorous stays in the soil while nitrogen is removed by leaching. This could depend on in which form phosphorous and nitrogen are present in the soil. The low levels of nitrogen in soil could also be explained by the sources of nitrogen. The main source other than fertilisers are from breakdown and humification of organic matter. That means that if there is a low content of organic matter in the soil, it could mean that the levels of nitrogen are also low (Landon 2014).

Elevated levels of iron, potassium, sodium and magnesium were measured in the soil both in and around the spring (Table 10). These are all elements that are abundant in the Earth's crust and hence might be coming from the bed rock. This suggests that the levels measured in the spring might come from weathering bedrock and suspended sediment. Sodium and magnesium in the water are low compared to the reference site (Figure 7). If the bedrock is rich in sodium and magnesium it seems reasonable that the levels are high in the groundwater. If the soil is used for agriculture, the elevated levels could potentially cause long term health effects among the population such as hypertension (US EPA 2003). Plant uptake of iron can be inhibited by high phosphate levels, due to the insoluble compound iron phosphate (Landon 2014). The levels of phosphorous in the soil were high (Table 10) which indicates high levels of phosphates, which also could mean higher levels of iron. The levels of iron in the soil were very high which indicates that the iron uptake has been inhibited. All elements availability is usually dependent on pH (Landon 2014) and this could also explain why the levels of sodium and magnesium were so high in the soil.

The high sodium levels in the soil (Table 10) could come from bedrock or it might be another source like water table level (Flynn et al. 2011). Sodium, potassium and magnesium, which all had high levels in the soil (Table 10) are also all connected to salinity as they are elements that are regularly found in soils. High salinity is frequently linked to arid areas or semi arid areas were rainfall is low. This means that there is not enough water that can dissolve the salts which makes the salinity high. Malawi has a drought season and a wet season and the samples were taken right in the beginning of the wet season which could mean that a lot of the salts had not yet been dissolved (Provin et al. 2018).

Zinc, copper, manganese, and calcium were all within the range of soil standards and are of no concern for the public health or any future agricultural use of the land (Table 10). However, the levels of manganese were considered to be high in the spring compared to the reference site (Figure 5), which indicates impact from runoff or activity.

There is a high variability when it comes to soil analytical results. This means that the values that were gotten in this analysis may not be entirely correct and it would be good to redo it multiple times and take an average to get more correct results. There is also a high variability in the soil itself and concentration levels can vary at different times if the year (Landon 2014).

Overall, the soil analysis indicated that the soil around the spring should not be used for future crop production due to elevated levels potassium, sodium and magnesium. It also suggested that the high levels of nitrogen in the spring comes from leaching and that the main source of iron, potassium, sodium and magnesium is weathering bedrock.

5.2 POTENTIAL FOR RECREATIONAL USE OF MAWIRA SITIMA

Mawira Liwonde is located within the area of central Liwonde (Figure 10) while Mawira Sitima is less accessible, located 5 km from the city centre with dirt roads most of the way outside of Liwonde. This makes Mawira Liwonde more attractive for tourists as it easily accessed from any residence in town. However, Mawira Liwonde consist of one shallow pool intended for females only (Figure 12) while Mawira Sitima consists of two main pools intended for men and women (Figure 11). This might attract more tourists as both sexes have the possibility to use the spring.

The median for EC, TDS, chloride, colour, temperature, turbidity, total phosphorous, potassium, magnesium, zinc and copper were all lower in Mawira Sitima compared to Mawira Liwonde (Figure 13-15). This might be an indication that the water quality in Mawira Sitima is actually better than Mawira Liwonde, making it more suitable for recreational use. The median for manganese in Mawria Sitima was almost exactly the same as the concentration in Mawira Liwonde (Figure 15) but pH, DO, total nitrogen, sodium, calcium and iron were all higher in Mawira Sitima compared to Mawira Liwonde (Figure 13- 15). Higher levels of DO is preferred and further proves the suitability for recreational use of Mawira Sitima. pH, sodium, calcium and iron were all within range compared to the other renowned springs (Table 6 7) which means that they are probably not any cause of concern when it comes to the potential for recreational use of Mawira Sitima.

The trophic status for Mawira Liwonde was decided to be eutrophic (Table 11). Eutrophication can lead to toxic algal blooms which is why a mesotrophic or oligotrophic state should be preferred (US EPA 2013c; US EPA 2013d). Since Mawira Sitima was decided to be meso-oligotrophic, Mawira Sitima should be considered to have better water quality in this regard. The ecological status based on DO was good in both springs but based on phosphorous Mawira Liwonde was poor (Table 11) which means the water quality is better in Mawira Sitima where it was moderate or good. Both lakes were decided to be limited by phosphorous but Mawira Liwonde had a much lower N:P ratio (Table 11) which possibly means that it is more balanced in phosphorous and nitrogen with not as much nitrogen surplus.

No chlorophyll measurements were done in Mawira Liwonde due to problems with the equipment, which means that the trophic status was only based on the mean value for phosphorous. As mentioned above, there were problems with the phosphorous analysis during the last two tries which was when the sampling and analysis for Mawira Liwonde was done. This means that it is possible the values for phosphorous are incorrect and therefore the trophic status incorrect as well.

Concentrations in Mawira Sitima and Mawira Liwonde follow the same pattern if comparing plant one and the soil for plant one in the two springs (Figure 16 17), but a few results deviate. Total phosphorous was higher in Mawira Liwonde when looking at the soil but higher in Sitima when looking at the plant. The opposite was true for manganese and calcium. The iron concentration was noticeably higher in Mawira Sitima in both the soil and plants which could be explained by the fact that Mawira Liwonde is closer to the town of Liwonde and do not have as much iron rich soil nearby as most land is covered by concrete roads or buildings. The second plant had noticeably lower levels of nitrogen and potassium in Mawira Sitima than Mawira Liwonde (Figure 18). Both of these nutrients are used during farming nearby Mawira Sitima which makes these results unexpected. The high levels could be explained by more sewage and manure reaching Mawira Liwonde compared to Mawira Sitima but this has not been investigated further.

Overall, the concentrations differed a lot for the two different sites both in the plants and the soils. This could be an explanation to why the water quality variables also differed for the two springs. Of the variables that were mostly higher in the Mawira Sitima compared to Mawira Liwonde and that also were measured in the soil at the two sites - iron, calcium, sodium and total nitrogen - it was only iron that was higher in the soil by Mawira Sitima. This could possibly mean that the other variables are mainly coming from another source than the soil while iron is coming mainly from the soil. The total assessment indicates that Mawira Sitima is generally more suitable for recreational use than Mawira Liwonde. The location is remote from town, but the water quality is better in Sitima and the pool is suitable for all sexes.

The analysis of soil and plants around Mawira Sitima and Mawira Liwonde was only done once due to time constraints, meaning that any error in the method highly affects the results. The procedure was done with little care for accuracy concerning measurements of volume and mass, which might have affected the final concentrations.

5.3 RECOMMENDATIONS FOR FUTURE STUDIES AND MONITORING SYSTEM

When it comes to water quality there are numerous variables that are relevant to investigate and it is difficult to narrow down to just a few. This study has attempted to determine what variables are most relevant to monitor in a spring to assure good water quality and to detect any changes. This has been done by analysing trends and correlations between different variables.

TDS, EC, DO, total phosphorus, and copper all showed increasing trends over time (Figure 21) which could be an indication of meteorological impact. However, none of the variables showed any similar patterns to the air temperature or precipitation (Appendix B). EC correlated positively with DO, TDS, total phosphorous, and copper (Table 12) which means that increased EC indicates increased levels of DO, TDS, total phosphorus, and copper. EC was also highly variable in the women's pool (Figure 25) which means it might be good to track in the future. EC is also considered by the US EPA to be a useful variable when monitoring water quality (US EPA 2013a), and hence this variable is highly relevant for a future monitoring system in Mawira Sitima.

Total phosphorous also varied within the spring and a drastic increase could be seen in the women's pool (Figure 25). As shown in the land use survey, the lowest point by the spring is by the outlet (Figure 4), which could cause runoff to go that direction. Therefore, the increased levels of phosphorus in the women's pool might be due to runoff containing fertiliser from the maize field close to the spring. It could also be due to the washing using detergents that is predominant in the women's pool, which might cause phosphorous in sediment to dissolve into the water column. This should be further investigated in the long term monitoring system which should include measurements of the total phosphorus to track and avoid any negative effects such as eutrophication.

Colour, turbidity, iron and manganese also showed increased levels throughout the spring (Figure 22) which indicates effects of human activity or runoff further into the spring. The high turbidity combined with increase levels of ions suggests that particles containing iron and manganese are added to or suspended in the pool. Manganese and iron are both abundant elements in the Earth's crust and from observation it is known that the area around the spring contains a lot of dust. A possible source for the particles might therefore be dust that is transported to the spring. As the highest measurements are seen in the women's pool where most of the laundry is done, the particles are believed to be transported by dust on clothes and bodies that are washed in the spring. The washing might also cause sediment to suspend into the water column and contribute to the increased levels of particles. As iron is known to cause discolouration in clothes (El Azher et al. 2008) this might be relevant to monitor in the future to avoid clothes from being spoiled.

Monitoring the levels of manganese might also be relevant as it is correlated to most other ions included in this study (Table 12), and also causes discolouration in laundry (Nordström 2019). Manganese could be used to give an indication of the levels of potassium, calcium, magnesium, iron, and zinc which all showed an increasing trend in the spring with drastically increasing levels in the women's pool (Figures 23 and 24). This suggests that the levels of these ions are influenced by activities occurring in or nearby the women's pool. Potassium is naturally occurring and is also used in fertiliser which might cause it to be transported into the spring by runoff. However, the decrease of potassium as the rains started (Figure 23) suggests that the source is within the spring and the runoff causes dilution. The same trend was seen for calcium (Figures 23 and 24) although neither potassium nor calcium was confirmed to correlate with meteorological data (Appendix B). Potassium and calcium might be present in the bedrock within the spring and brought to the water column by erosion. The increased levels of potassium and calcium in the women's pool might be due to washing causing soil particles to suspend. The same process might also cause the increase of magnesium seen in the women's pool (Figure 23). However, as magnesium varies a lot more over time there might be another source, such as the soap used for washing. Some soap bars contain magnesium for soothing purposes (Natural Healthy Concepts 2022). Other bars contain zinc for antibacterial purposes (ubuy 2022; Schwartz 2016), which could explain the elevated zinc levels in the women's pool (Figure 24). However, it is not confirmed that any of these soaps are being used in the spring. Zinc is also used in products such as sun block and deodorant (ATSDR 2005) which might end up in the spring if they are used by the locals. Monitoring the levels of manganese throughout the spring could help in indicating if the current activities are sustainable or not. It might also be relevant to include copper in the monitoring system as it is a toxic ion that correlates to sodium, potassium and calcium and therefore can be used for further indication of these ions. Copper show no clear trend either spatially or temporally but is highly variable and therefore should be monitored.

Other variables that might be relevant to include in a long term monitoring system is pH, DO and temperature. These variables showed no clear spacial or temporal trend and correlated to few or no other variables (Table 12). However, they are easily measured and, since they are relatively constant throughout the spring and over time, drastic changes of these variables could indicate effects of external or internal activities that might affect other variables too. DO can also give an indication of the bacterial levels in the spring since bacteria consume oxygen for decomposition of organic matter (Fondriest Environmental 2013). In total, a minimum of eight variables are recommended for the monitoring system: EC, temperature, pH, total phosphorus, copper, manganese, DO and iron. To investigate if the temporal changes observed for some variables are constant or temporary, measurements of all the variables just mentioned should be done frequently as the monitoring system is implemented in the spring. If the variables are relatively constant, sampling can become less frequent but never less than once per year (Bartram et al. 1996). This study recommends sampling every three months the first year and then reassessment can be done based on the variability of the variables. Sampling during periods when fertiliser is used would also be preferable since it could not be a part of this study but could have a huge impact on the water quality.

To further investigate the spring and improve the monitoring system, variables that were not included in this study might be analysed. Fluoride concentrations is a common problem that causes teeth problem for a lot of people living in Malawi (Addison et al. 2021) and could therefore be important to look at. This is based on the assumption that some of the water is consumed while swimming in the spring, and therefore could affect the health of people's teeth. This also makes pathogens relevant for investigation. Grazing animals walk freely in the area around Mawira Sitima, which makes it very likely that manure end up in the spring through runoff. This is a health concern as it might be ingested by the people swimming in the spring and can cause illness. Measurements of faecal bacteria should be done to further analyse this.

Further improvements that can done is to measure the actual temperature that comes out through the inlet. One way to do this is to find the inlet and place a thermometer far into the soil. This would help in determining any other inlets or heat sources in the spring. Deciding the actual temperature of the water might also help in analysing the plants and species in the spring as temperature affects the distribution of species.

To determine the origin of the water, and hence get a better sense of the processes affecting the water quality, attempts can be made to confirm or discard the theory of the swamp. According to the chief of the village, site number 5 (Figure 3) is the origin of the water that goes into the hot spring. To test this theory, stable isotope analysis (SIA) can be performed. Stable isotopes (SI) are temporally stable and are therefore useful as tracers to study several aquatic processes (Sánchez-Carrillo et al. 2018). By adding SI to the swamp and then measuring the levels of that SI at the inlet, it may be determined whether the two sites are connected or not. During the first visit to the spring, the supposed origin had a detectable smell of rotten eggs, indicating presence of hydrogen sulphide. If analysis show that the spring is connected to this site, monitoring of hydrogen sulphides might be relevant for the spring.

The SI analysis can also be used to investigate if the reference site (borehole) is connected to the same groundwater as the hot spring. No attempts of this were made due to time limitations.

5.3.1 Meteorological impact

Turbidity and colour both showed clear correlation to precipitation (Figures 26 and 27) with higher values after dry spells and lower values after periods of rainfall. This indicates that the particles causing high turbidity and colour comes from within the spring, and that runoff after rainfall dilutes the water rather than brings a lot of additional particles that could contribute to higher turbidity and water colour. The particles originating from within the spring might be suspended from sediments due to the activity of the local population or come from erosion of bedrock due to water movement.

Zinc showed the reverse correlation to precipitation with higher levels after rainfall and lower during dry spells. This suggests that there is an external source of zinc that causes runoff to be rich in zinc. This is confirmed by the levels measured in the soil outside of the spring compared to inside the spring (Table 18). The cause for higher levels of zinc outside could be different composition of the bedrock. If the bedrock outside the spring contains more zinc it would lead to higher levels of zinc in the soil, which would then be transported with runoff. Zinc is also recommended in fertiliser programs for corn production (University of Minnesota Extension 2016), and might therefore be present in fertiliser applied to the soil. However, this has not been confirmed by the chief of the village.

Sodium and water temperature both showed slightly decreasing trends over time (Figures 29 and 30). As did the maximum and minimum air temperatures. This might suggest correlation between air temperature and water temperature and sodium. As the water samples were collected by the surface it seems reasonable that this temperature is affected by the air temperature. For sodium, the correlation with temperature could be due to the population's bathing habits. During warmer periods people are more likely to sweat which produces more salt (NaCl). They might also be more likely to cool themselves in the spring, and hence might cause higher levels of salt. However, it should be noted that the meteorological data was measured approximately 40 km from the hot spring and as the hot spring is located in a valley where temperature is generally higher than outside, these correlations might not be completely reliable.

Precipitation in the area might also vary from the obtained data, and hence the comparisons between variables and rainfall might be unreliable. For future studies local data should be used.

Since there are variables that seem to be affected by temperature and rainfall, like sodium, water temperature, zinc, colour and turbidity, variations in weather should also be considered in the monitoring program by setting up a weather station that monitors rainfall and temperature. This is even more important when taking climate change effects on both temperature and rainfall into account, with temperature increasing and rainfalls becoming more intense and frequent (Pauleit et al. 2015). Measurements of turbidity, colour, sodium and zinc should be done after periods of very heavy rainfall or extreme heat and drought to investigate any impact on these variables.

5.3.2 Bioindication

The presence of exclusively emergent plants indicates that the water is shallow in the spring which conforms with the observed depth. The low root:shoot ratio of the Brachiaria also indicates that conditions are eutrophic, which cannot be confirmed by the other growing plants and does not agree with the measured levels of chlorophyll and phosphorous. The different lengths of the plants give no indication of the nutrient conditions as it could mean either nutrient-rich or nutrient-poor water. The same applies for the lack of diversity of species.

The lack of floating-leaved plants in the spring could indicate either nutrient-poor water or low turbidity since floating-leaved plants are common in nutrient-rich and high turbidity waters. However, there are no other indications, such as rosette growth forms or lack of tall plants, for the water to be nutrient-poor. Looking at the measured levels of turbidity, it is also unlikely that the lack of floating-leaved plants is due to low turbidity. However, the lack could be explained by the frequent activity of the local community in the spring leading to disruption of growth or removal of existing plants.

The lack of submerged plants could indicate non-alkaline water, which might cause the spring to be sensitive to changes in pH. As the alkalinity of the water was not measured, this cannot be confirmed.

The general lack of plants in Mawira Sitima could be due to the temperature being relatively high. As stated before, the upper limit for plant growth is around 45 °C (Brock 1994), which is not far from the temperature by the inlet. Overall, the lack of plants in Mawira Sitima makes it difficult to use bioindication to assess the water quality and help in a long term monitoring system of the spring. However, keeping track of any losses or additions among the species around the spring might help in indicating changes of other variables in the spring. More studies on if bioindication can be used when it comes to hot springs should be done as this study is not enough to draw a conclusion about all hot springs.

6 CONCLUSIONS

- The results of this study indicate that current water quality in Mawira Sitima is similar to other hot springs and there are no variables in water or soil that should cause major concern as threats to the water quality. According to the Swedish Surface Water Standards the spring is meso-oligotrophic and has dominantly good water quality based on phosphorous and DO concentrations.

- The springs water quality is mostly preferable to Mawira Liwonde and it is therefore concluded that Mawira Sitima has all basis to be of recreational use. The plants and soil differed a lot for the two different sites and it did not seem to be a big connection between the soil and the water quality except for iron.

- A monitoring system made up of measurements of EC, temperature, pH, total phosphorous, copper, manganese, DO and iron is recommended based on correlation and trends. Meteorological conditions should also be monitored since they seem to have an impact on some variables. Activities like washing was determined to not have a major impact on the water quality, but no conclusion about agriculture could be drawn since there was no active use of fertilisers during the sampling period. The study also concluded that bioindication is not suitable for determining the water quality in Mawira Sitima and can not be used for future monitoring of the spring. This does not mean that it could not be used to determine water quality in other hot springs and should therefore be further investigated.

References

Addison, M., Rivett, M., Phiri, O., Milne, N., Milne, V., Mcmahon, A., Macpherson, L., Bagg, J., Conway, D., Mbalame, E., & Kalin, R. (Apr. 2021). 'Hidden Hot Springs' as a Source of Groundwater Fluoride and Severe Dental Fluorosis in Malawi. *Water*, vol. 13, p. 1106. DOI: 10.3390/w13081106.

American Public Health Association, American Water Works Association, & Water Pollution Control Federation (1976). *Standard Methods For the Examination of Water and Wastewater*. 14th.

Ansell, R. (2005). *ION-SELECTIVE ELECTRODES | Water Applications - ScienceDirect*. Available from: https://www.sciencedirect.com/science/article/pii/B0123693977002983 [12/03/2021].

Atekwana, E. A., Tsokonombwe, G. W., Elsenbeck, J., Wanless, V. D., & Atekwana, E. A. (Dec. 2015). Chemical and isotopic characteristics of hot springs along the along the Neogene Malawi rift. *AGU Fall Meeting Abstracts*, vol. 13, ss. V13C–3162. Available from: http://adsabs.harvard.edu/abs/2015AGUFM.V13C3162A [03/20/2021].

ATSDR (Aug. 2005). PUBLIC HEALTH STATEMENT Zinc (CAS#: 7440-66-6), p. 7.

Bartram, J., Ballance, R., Nations, U., & Organization, W. H., eds. (1996). *Water quality monitoring: a practical guide to the design and implementation of freshwater quality studies and monitoring programmes*. en. 1st ed. London ; New York: E & FN Spon.

Board, M. S. (2005). *Borehole and shallow well water quality Specification*. Tech. rep. ICS 13.060.10.

Bornette, G. & Puijalon, S. (Sept. 15, 2009). *Macrophytes: Ecology of Aquatic Plants*.

Brock, T. D. (1994). *Life at High Temperatures*. Available from: https://bioinfo.bact.wisc.edu/themicrobialworld/LAHT/b20.html [01/03/2022].

Burkholder, J. M. (Jan. 2003). “Eutrophication and Oligotrophication”. en. *Encyclopedia of Biodiversity*. Ed. by S. A. Levin. New York: Elsevier, ss. 649–670. DOI: 10.1016/B0-12-226865-2/00113-9. Available from: https://www.sciencedirect.com/science/article/pii/B0122268652001139 [02/17/2022].

Chambers, P., Lacoul, P., Murphy, K., & Thomaz, S. (Jan. 2007). “Global diversity of aquatic macrophytes in freshwater”. *Hydrobiologia*. Vol. 595. Journal Abbreviation: Hydrobiologia, ss. 9–26. DOI: 10.1007/978-1-4020-8259-7_2.

Chirani, M. R., Kowsari, E., Teymourian, T., & Ramakrishna, S. (Nov. 2021). Environmental impact of increased soap consumption during COVID-19 pandemic: Biodegradable soap production and sustainable packaging. en. *Science of The Total Environment*, vol. 796, p. 149013. DOI: 10.1016/j.scitotenv.2021.149013. Available from: https://www.sciencedirect.com/science/article/pii/S0048969721040857 [12/03/2021].

Chorowicz, J. (Oct. 2005). The East African rift system. en. *Journal of African Earth Sciences*. Phanerozoic Evolution of Africa, vol. 43 (1), ss. 379–410. DOI: 10.1016/j.jafrearsci.2005.07.019. Available from: https://www.sciencedirect.com/science/article/pii/S1464343X05001251 [11/09/2021].

Dash, A., Palita, S. K., & Patra, H. (Jan. 1, 2013). PHYSICO-CHEMICAL ANALYSIS OF THERMAL SPRING OF ATRI IN THE DISTRICT OF KHURDA, ODISHA, INDIA. *International Journal of Chemical Sciences and Applications*, vol. Vol 4, ss. 97–104.

Delpla, I., Jung, A. .-., Baures, E., Clement, M., & Thomas, O. (Nov. 2009). Impacts of climate change on surface water quality in relation to drinking water production. en. *Environment International*, vol. 35 (8), ss. 1225–1233. DOI: 10.1016/j.envint.2009.07.001. Available from: https://www.sciencedirect.com/science/article/pii/S0160412009001494 [01/04/2022].

Des Marais, D. J. & Walter, M. R. (Aug. 19, 2019). Terrestrial Hot Spring Systems: Introduction. *Astrobiology*, vol. 19 (12). Publisher: Mary Ann Liebert, Inc., publishers, ss. 1419–1432. DOI: 10.1089/ast.2018.1976. Available from: https://www-liebertpub-com.ezproxy.its.uu.se/doi/full/10.1089/ast.2018.1976 [03/13/2021].

Dill, H. G. (Mar. 2007). A review of mineral resources in Malawi: With special reference to aluminium variation in mineral deposits. en. *Journal of African Earth Sciences*, vol. 47 (3), ss. 153–173. DOI: 10.1016/j.jafrearsci.2006.12.006. Available from: https://www.sciencedirect.com/science/article/pii/S1464343X06002585 [01/03/2022].

Dressler, S., Schmidt, M., & Zizka, G. (Oct. 2014). *African Plants- a Photo Guide*. en. Available from: http://doi.wiley.com/10.12705/635.26 [01/05/2022].

Dulanya, Z., Box, P., Zomba, Malawi, S., & Africa (Apr. 2005). Geothermal Resources of Malawi -An Overview.

El Azher, N., Gourich, B., Vial, C., Soulami, M. B., & Ziyad, M. (Sept. 2008). Study of ferrous iron oxidation in Morocco drinking water in an airlift reactor. en. *Chemical Engineering and Processing:*

Process Intensification, vol. 47 (9), ss. 1877–1886. DOI: 10.1016/j.cep.2007.10.013. Available from: https://www.sciencedirect.com/science/article/pii/S025527010700339X [12/03/2021].

Elphick, J. R., Bergh, K. D., & Bailey, H. C. (2011). Chronic toxicity of chloride to freshwater species: Effects of hardness and implications for water quality guidelines. en. *Environmental Toxicology and Chemistry*, vol. 30 (1). _eprint: https://setac.onlinelibrary.wiley.com/doi/pdf/10.1002/etc.365, ss. 239–246. DOI: 10.1002/etc.365. Available from: http://onlinelibrary.wiley.com/doi/abs/10.1002/etc.365 [11/26/2021].

Farhat, N., Hussain, S., Faisal, F., Batool, I., & Noreen, M. (Jan. 14, 2021). Physico-chemical characteristics and therapeutic potential of Chutrun thermal springs in Shigar Valley, Gilgit-Baltistan (Pakistan). *Applied Water Science*, vol. 11 (2), p. 19. DOI: 10.1007/s13201-020-01354-5. Available from: https://doi.org/10.1007/s13201-020-01354-5 [02/02/2022].

Flynn, R. & Ulery, A. (2011). *NMSU: An Introduction to Soil Salinity and Sodium Issues in New Mexico*. Available from: https://aces.nmsu.edu/pubs/_circulars/CR656/welcome.html [03/03/2022].

Fondriest Environmental (Nov. 2013). *Dissolved Oxygen*. en-US. Available from: https://www.fondriest.com/environmental-measurements/parameters/water-quality/dissolved-oxygen/ [04/19/2022].

Ghilamicael, A. M., Boga, H. I., Anami, S. E., Mehari, T., & Budambula, N. L. M. (2017). Physical and Chemical Characteristics of Five Hot Springs in Eritrea, p. 7.

Gordon, A. K., Muller, W. J., Gysman, N., Marshall, S. J., Sparham, C. J., O'Connor, S. M., & Whelan, M. J. (July 2009). Effect of laundry activities on in-stream concentrations of linear alkylbenzene sulfonate in a small rural South African river. en. *Science of The Total Environment*. Thematic Papers: Assessment of the chemical contamination in home-produced eggs in Belgium: general overview of the contegg study, vol. 407 (15), ss. 4465–4471. DOI: 10.1016/j.scitotenv.2009.04.023. Available from: https://www.sciencedirect.com/science/article/pii/S004896970900360X [11/10/2021].

Haki, G. D. & Gezmu, T. B. (Oct. 26, 2012). Physico-chemical properties of waters from some Ethiopian hot springs and the risk to the health of the community. *Greener Journal of Physical Sciences*, vol. 2 (4), ss. 138–140. DOI: 10.5281/zenodo.3441082. Available from: https://zenodo.org/record/3441082 [11/08/2021].

Hamzah, Z., Abd Rani, N., Saat, A., & Wood, A. (Jan. 1, 2013). Determination of hot springs physico-chemical water quality potentially use for balneotherapy. *Malaysian Journal of Analytical Sciences*, vol. 17, p. 436.

Haundi, T., Tsokonombwe, G., Ghambi, S., Mkandawire, T., & Kasambara, A. (June 2021). An Investigation of the Socio-Economic Benefits of Small-Scale Gold Mining in Malawi. en. *Mining*, vol. 1 (1). Number: 1 Publisher: Multidisciplinary Digital Publishing Institute, ss. 19–34. DOI: 10.3390/mining1010003. Available from: https://www.mdpi.com/2673-6489/1/1/3 [01/03/2022].

Havs och Vattenmydigheten (Sept. 25, 2019). *Bedömningsgrunder för ytvattenförekomster*. Available from: https://www.havochvatten.se/planering-forvaltning-och-samverkan/vattenforvaltning/nationell-vagledning/bedomningsgrunder-for-ytvattenforekomster.html [11/09/2021].

Havs- och Vattenmydigheten (Dec. 10, 2019). Havs- och vattenmyndighetens föreskrifterom klassificering och miljökvalitetsnormer avseende ytvatten; (HVMFS 2019:25), p. 88.

Health Canada (Sept. 1, 1978). *Guidelines for Canadian Drinking Water Quality: Guideline Technical Document – Calcium*. Last Modified: 2008-01-07. Available from: https://www.canada.ca/en/health-canada/services/publications/healthy-living/guidelines-canadian-drinking-water-quality-guideline-technical-document-calcium.html [12/03/2021].

Health Canada (Aug. 20, 1997). *Guidelines for Canadian Drinking Water Quality: Supporting Documents – Magnesium*. Last Modified: 2009-03-09. Available from: https://www.canada.ca/en/health-canada/services/publications/healthy-living/guidelines-canadian-drinking-water-quality-supporting-documents-magnesium.html [12/03/2021].

Hubbard, R. K., Newton, G. L., & Hill, G. M. (2004). Water quality and the grazing animal. eng. *Journal of Animal Science*, vol. 82 E-Suppl, E255–263. DOI: 10.2527/2004.8213_supplE255x.

Instutionen för Miljöanalys, S. (1997). *Eutrofiering*. Available from: http://info1.ma.slu.se/miljotillst/eutrofiering/Criteria_3.ssi?fbclid=IwAR11RfzopqsfmwjpKRwfT3bR2GpoMsgh7uoQLp_nP_6lFKzT4Y2NSvPhSr0 [02/16/2022].

Istvánovics, V. (Jan. 1, 2009). "Eutrophication of Lakes and Reservoirs". *Encyclopedia of Inland Waters*. Ed. by G. E. Likens. Oxford: Academic Press, ss. 157–165. DOI: 10.1016/B978-012370626-3.00141-1. Available from: https://www.sciencedirect.com/science/article/pii/B9780123706263001411 [11/10/2021].

Javed, A., Iqbal, J., Asghar, U., Ahmed Khan, F., Bano Munshi, A., Sddiqui, I., & j (Sept. 29, 2008). *A Study to Evaluate Therapeutic properties of Minerals of Manghopir Hot Spring, Karach*. Karachi.

Kadzamira, Z. D. (Oct. 2021). *Malawi*. en. Available from: https://www.britannica.com/place/Malawi [11/09/2021].

Khatri, N. & Tyagi, S. (Jan. 2015). Influences of natural and anthropogenic factors on surface and groundwater quality in rural and urban areas. *Frontiers in Life Science*, vol. 8 (1). Publisher: Taylor & Francis _eprint: https://doi.org/10.1080/21553769.2014.933716, ss. 23–39. DOI: 10.1080/21553769.2014.933716. Available from: https://doi.org/10.1080/21553769.2014.933716 [11/10/2021].

Kotake, S., Udagawa, N., Takahashi, N., Matsuzaki, K., Itoh, K., Ishiyama, S., Saito, S., Inoue, K., Kamatani, N., Gillespie, M. T., Martin, T. J., & Suda, T. (May 1999). IL-17 in synovial fluids from patients with rheumatoid arthritis is a potent stimulator of osteoclastogenesis. *The Journal of Clinical Investigation*, vol. 103 (9), ss. 1345–1352. DOI: 10.1172/JCI5703.

Kumar, V., Bharti, P. K., Talwar, M., Tyagi, A. K., & Kumar, P. (Apr. 2017). Studies on high iron content in water resources of Moradabad district (UP), India. en. *Water Science*, vol. 31 (1), ss. 44–51. DOI: 10.1016/j.wsj.2017.02.003. Available from: https://www.sciencedirect.com/science/article/pii/S1110492916300273 [12/03/2021].

Landon, J. (2014). *Booker Tropical Soil Manual*. Taylor and Francis. Available from: https://ereader.perlego.com/1/book/1554580/17 [02/28/2022].

Lund, J. W. (Feb. 1, 1996). Balneological use of thermal and mineral waters in the U.S.A. *Geothermics*, vol. 25 (1), ss. 103–147. DOI: 10.1016/0375-6505(95)00037-2. Available from: https://www.sciencedirect.com/science/article/pii/0375650595000372 [02/02/2022].

Maps of World (2021). *Liwonde City Guide*. Available from: https://www.mapsofworld.com/malawi/travel/liwonde.html [12/03/2021].

Ministry of Forests and Natural Resources (2021). *Climate of Malawi*. Available from: https://www.metmalawi.gov.mw/dccms_climate.php [12/03/2021].

Mwatseteza, J. (Feb. 22, 2021). *Degree project*. E-mail.

Natural Healthy Concepts (2022). *Magnesium Soap Bar, Life Flo*. Available from: https://www.nhc.com/magnesium-soap-bar-by-life-flo [03/10/2022].

Nelson, M. L., Rhoades, C. C., & Dwire, K. A. (Apr. 2011). Influence of Bedrock Geology on Water Chemistry of Slope Wetlands and Headwater Streams in the Southern Rocky Mountains. en. *Wetlands*, vol. 31 (2), ss. 251–261. DOI: 10.1007/s13157-011-0157-8. Available from: http://link.springer.com/10.1007/s13157-011-0157-8 [01/03/2022].

Nordström, A. (July 23, 2019). *Dricksvatten - vårt viktigaste livsmedel*. 1st ed. Studentlitteratur AB.

Olivier, J., Venter, J. S., & Jonker, C. Z. (2011). Thermal and chemical characteristics of hot water springs in the northern part of the Limpopo Province, South Africa. *Water SA*, vol. 37 (4). Number: 4, ss. 427–436. DOI: 10.4314/wsa.v37i4.1. Available from: https://www.ajol.info/index.php/wsa/article/view/71415 [11/10/2021].

Omenda, P. A. (Nov. 2021). *The Geology and Geothermal activity of the East African Rift*. Tech. rep. Nairobi: Geothermal Development Company.

Parmar, T. K., Rawtani, D., & Agrawal, Y. K. (Apr. 2, 2016). Bioindicators: the natural indicator of environmental pollution. *Frontiers in Life Science*, vol. 9 (2). Publisher: Taylor & Francis, ss. 110–118. DOI: 10.1080/21553769.2016.1162753. Available from: https://doi.org/10.1080/21553769.2016.1162753 [11/22/2021].

Parris, K. (Mar. 2011). Impact of Agriculture on Water Pollution in OECD Countries: Recent Trends and Future Prospects. *International Journal of Water Resources Development*, vol. 27 (1). Publisher: Routledge _eprint: https://doi.org/10.1080/07900627.2010.531898, ss. 33–52. DOI: 10.1080/07900627.2010.531898. Available from: https://doi.org/10.1080/07900627.2010.531898 [12/03/2021].

Patel, H. & Vashi, R. T. (Jan. 2015). “Chapter 6 - Use of Naturally Prepared Coagulants for the Treatment of Wastewater from Dyeing Mills”. en. *Characterization and Treatment of Textile Wastewater*. Ed. by H. Patel & R. T. Vashi. Boston: Elsevier, ss. 147–158. DOI: 10.1016/B978-0-12-802326-6.00006-X. Available from: https://www.sciencedirect.com/science/article/pii/B978012802326600006X [11/22/2021].

Pauleit, S., Coly, A., Fohlmeister, S., Gasparini, P., Jørgensen, G., Kabisch, S., Kombe, W. J., Lindley, S., Simonis, I., & Yeshitela, K., eds. (2015). *Urban Vulnerability and Climate Change in Africa: A Multidisciplinary Approach*. en. Vol. 4. Future City. Cham: Springer International Publishing. DOI:

10.1007/978-3-319-03982-4. Available from: http://link.springer.com/10.1007/978-3-319-03982-4 [03/08/2022].

Porowski, A., Porowska, D., & Halas, S. (2019). Identification of Sulfate Sources and Biogeochemical Processes in an Aquifer Affected by Peatland: Insights from Monitoring the Isotopic Composition of Groundwater Sulfate in Kampinos National Park, Poland.

Provin, T. & Pitt, J. (2018). *Managing Soil Salinity - How does salinity affect soil?* Available from: https://agrilifeextension.tamu.edu/library/gardening/managing-soil-salinity/ [03/03/2022].

Puth, M.-T., Neuhäuser, M., & Ruxton, G. D. (Apr. 2015). Effective use of Spearman's and Kendall's correlation coefficients for association between two measured traits. en. *Animal Behaviour*, vol. 102, ss. 77–84. DOI: 10.1016/j.anbehav.2015.01.010. Available from: https://www.sciencedirect.com/science/article/pii/S0003347215000196 [02/14/2022].

Rajapaksha, B. M. M., Maithreepala, R. A., & Asanthi, H. B. (2014). Water quality and biology of hot springs waters of Mahapelessa, Sri Lanka, p. 6.

Reynolds, R., Goldstein, H., Moskowitz, B., Till, J., Flagg, C., Kokaly, R., Munson, S., Landry, C., Lawrence, C., Hiza, M., D'Odorico, P., & Painter, T. (Dec. 2011). "Iron Oxide Minerals in Atmospheric Dust and Source Sediments-Studies of Types and Properties to Assess Environmental Effects", p. 01.

Robachl, F. & Thi, G. (1996). A reference system for continental running waters: plant communities as bioindicators of increasing eutrophication in alkaline and acidic waters in north-east France. en, p. 10.

Rusydi, A. F. (Feb. 2018). Correlation between conductivity and total dissolved solid in various type of water: A review. en. *IOP Conference Series: Earth and Environmental Science*, vol. 118. Publisher: IOP Publishing, p. 012019. DOI: 10.1088/1755-1315/118/1/012019. Available from: https://doi.org/10.1088/1755-1315/118/1/012019 [03/08/2022].

Sánchez-Carrillo, S. & Álvarez-Cobelas, M. (Mar. 2018). Stable isotopes as tracers in aquatic ecosystems. *Environmental Reviews*, vol. 26 (1). Publisher: NRC Research Press, ss. 69–81. DOI: 10.1139/er-2017-0040. Available from: https://cdnsciencepub.com/doi/full/10.1139/er-2017-0040 [02/16/2022].

Sanctuary, F. K. N. M. (n.d.). *What is water quality?* Available from: https://floridakeys.noaa.gov/ocean/waterquality.html [02/28/2022].

Schets, F. M., De Roda Husman, A. M., & Havelaar, A. H. (2011). Disease outbreaks associated with untreated recreational water use. *Epidemiology and Infection*, vol. 139 (7). Publisher: Cambridge University Press, ss. 1114–1125. Available from: http://www.jstor.org/stable/27975700 [11/11/2021].

Schlesinger, W. H. & Bernhardt, E. S. (2009). "Salinity". *Encyclopedia of Inland Waters*. Vol. 2009. Available from: https://www.sciencedirect.com/topics/earth-and-planetary-sciences/ionic-composition [11/25/2021].

Schwartz, J. R. (Feb. 2016). Zinc Pyrithione: A Topical Antimicrobial With Complex Pharmaceutics. *Journal of drugs in dermatology: JDD*, vol. 15 (2), ss. 140–144.

Selley, R. C. & Sonnenberg, S. A. (Jan. 2015). "Chapter 4 - The Subsurface Environment". en. *Elements of Petroleum Geology (Third Edition)*. Ed. by R. C. Selley & S. A. Sonnenberg. Boston: Academic Press, ss. 153–189. DOI: 10.1016/B978-0-12-386031-6.00004-7. Available from: https://www.sciencedirect.com/science/article/pii/B9780123860316000047 [11/08/2021].

Skipton, S. O., Dvorak, B. I., & Woldt, W. (2010). Sulfur (Sulfate and Hydrogen Sulfide). en, p. 4.

Skowron, P., Skowrońska, M., Bronowicka-Mielniczuk, U., Filipek, T., Igras, J., Kowalczyk-Juśko, A., & Krzepiłko, A. (Oct. 1, 2018). Anthropogenic sources of potassium in surface water: The case study of the Bystrzyca river catchment, Poland. *Agriculture, Ecosystems & Environment*, vol. 265, ss. 454–460. DOI: 10.1016/j.agee.2018.07.006. Available from: https://www.sciencedirect.com/science/article/pii/S0167880918302792 [12/02/2021].

Sudjaroen, Y., Thongkao, K., & Suwannahong, K. (Apr. 2017). Characteristics of mineral water from nature hot springs in Ranong Province, Thailand. *Annals of Tropical Medicine and Public Health*, vol. 10 (2). Place: Accra, Accra Publisher: Medknow Publications & Media Pvt. Ltd. DOI: http://dx.doi.org/10.4103/1755-6783.196588. Available from: https://www.proquest.com/docview/1936156753/abstract/3CD5E72E2DD14938PQ/1 [02/02/2022].

Talbot, M. R. (Jan. 2005). "SEDIMENTARY ENVIRONMENTS | Lake Processes and Deposits". en. *Encyclopedia of Geology*. Ed. by R. C. Selley, L. R. M. Cocks, & I. R. Plimer. Oxford: Elsevier, ss. 550–561. DOI: 10.1016/B0-12-369396-9/00493-7. Available from: https://www.sciencedirect.com/science/article/pii/B0123693969004937 [11/08/2021].

The World Bank (Dec. 2007). *Malawi : Poverty and Vulnerability Assessment, Investing in Our Future*. en_US. Tech. rep. Accepted: 2012-06-08T18:22:13Z. Washington, DC: The World Bank. Available from: https://openknowledge.worldbank.org/handle/10986/7555 [11/10/2021].

The World Bank (Apr. 2020a). *The World Bank*. Available from: https://data.worldbank.org/indicator/SP.POP.TOTL?locations=MW [04/19/2022].

The World Bank (2020b). *The World Bank*. Available from: https://data.worldbank.org/indicator/NY.GDP.PCAP.PP.CD?locations=MW-US [03/09/2022].

Titus, J. E. & Urban, R. A. (2009). *Air/water and land/water interfaces, wetlands and the littoral zone*. Bingham: Bingham University.

Trick, J. K., Stuart, M., & Reeder, S. (Jan. 2008). "CHAPTER THREE - CONTAMINATED GROUNDWATER SAMPLING AND QUALITY CONTROL OF WATER ANALYSES". en. *Environmental Geochemistry*. Ed. by B. De vivo, H. E. Belkin, & A. Lima. Amsterdam: Elsevier, ss. 29–57. DOI: 10.1016/B978-0-444-53159-9.00003-6. Available from: https://www.sciencedirect.com/science/article/pii/B9780444531599000036 [11/22/2021].

ubuy (2022). *DermaHarmony 2% Pyrithione Zinc (ZnP) Bar Soap*. Available from: https://www.ubuy.com.se/sv/search/index/view/product/B00MWB0ZGE/s/dermaharmony-2-pyrithione-zinc-znp-bar-soap-4-oz-crafted-for-those-with-skin-conditions-seborrheic-dermatitis-dandruff-psoriasis-eczema-etc/store/store/kk/dp?ref_p=dp-rp [03/10/2022].

UNDP (2020). *Human Development Report 2020*. Tech. rep. New York: United Nations Development Programme.

University of Minnesota Extension (2016). *Zinc for crop production*. Available from: https://extension.umn.edu/micro-and-secondary-macronutrients/zinc-crop-production [03/08/2022].

US EPA (Feb. 2003). *Drinking Water Advisory: Consumer Acceptability Advice and Health Effects Analysis on Sodium*. EPA 822-R-03-006.

US EPA (Feb. 11, 2014a). *Aquatic Life Criteria - Copper*. Available from: https://www.epa.gov/wqc/aquatic-life-criteria-copper [12/03/2021].

US EPA, O. (Nov. 2013a). *Indicators: Conductivity*. en. Overviews and Factsheets. Available from: https://www.epa.gov/national-aquatic-resource-surveys/indicators-conductivity [11/22/2021].

US EPA, O. (Nov. 2013b). *Indicators: Acidification*. en. Overviews and Factsheets. Available from: https://www.epa.gov/national-aquatic-resource-surveys/indicators-acidification [11/22/2021].

US EPA, O. (Nov. 2013c). *Indicators: Nitrogen*. en. Overviews and Factsheets. Available from: https://www.epa.gov/national-aquatic-resource-surveys/indicators-nitrogen [11/30/2021].

US EPA, O. (Nov. 2013d). *Indicators: Phosphorus*. en. Overviews and Factsheets. Available from: https://www.epa.gov/national-aquatic-resource-surveys/indicators-phosphorus [11/30/2021].

US EPA, O. (Nov. 2013e). *Indicators: Dissolved Oxygen*. en. Overviews and Factsheets. Available from: https://www.epa.gov/national-aquatic-resource-surveys/indicators-dissolved-oxygen [11/22/2021].

US EPA, O. (Nov. 2013f). *Indicators: Chlorophyll a*. en. Overviews and Factsheets. Available from: https://www.epa.gov/national-aquatic-resource-surveys/indicators-chlorophyll [11/22/2021].

US EPA, O. (Jan. 2014b). *Indicators: Soil Chemistry*. en. Overviews and Factsheets. Available from: https://www.epa.gov/national-aquatic-resource-surveys/indicators-soil-chemistry [11/22/2021].

USGS (May 1999). *East Africa volcanoes*. Available from: https://pubs.usgs.gov/gip/dynamic/East_Africa.html [11/10/2021].

USGS (n.d.). *Temperature and Water*. Available from: https://www.usgs.gov/special-topic/water-science-school/science/temperature-and-water?qt-science_center_objects=0#qt-science_center_objects [11/30/2021].

Vineis, P., Chan, Q., & Khan, A. (Dec. 2011). Climate change impacts on water salinity and health. en. *Journal of Epidemiology and Global Health*, vol. 1 (1), ss. 5–10. DOI: 10.1016/j.jegh.2011.09.001. Available from: https://www.sciencedirect.com/science/article/pii/S2210600611000086 [11/30/2021].

Washington State Department of Health (Aug. 2016). Copper in Drinking Water. *DOH 331-178*, p. 2.

Williams, J. J. (Jan. 2007). "B.1.II - Formulation of Carpet Cleaners". en. *Handbook for Cleaning/Decontamination of Surfaces*. Ed. by I. Johansson & P. Somasundaran. Amsterdam: Elsevier Science B.V., ss. 103–123. DOI: 10.1016/B978-044451664-0/50004-8. Available from: https://www.sciencedirect.com/science/article/pii/B9780444516640500048 [12/03/2021].

Wilson, M. (Feb. 2019). *What is the difference between distilled water and Milli Q water*. Available from: https://www.restaurantnorman.com/what-is-the-difference-between-distilled-water-and-milli-q-water/#Is_deionized_water_pure [04/19/2022].

World Health Organization (2003a). *Guidelines for safe recreational water environments Volume 1: Coastal and fresh waters*. 1. Geneva.

World Health Organization (2003b). *Total dissolved solids in Drinking-water*. WHO/SDE/WSH/03.04/16. Geneva.

World Health Organization (2003c). *Zinc in Drinking-water*. WHO/SDE/WSH/03.04/17. Geneva.

World Health Organization (2003d). *Chloride in Drinking-water*. Geneva.

World Health Organization (2009). *Potassium in drinking-water*. WHO/HSE/WSH/09.01/7. Geneva.

World Health Organization (2011). *Manganese in Drinking-water*. WHO/SDE/WSH/03.04/104/Rev/1. Geneva.

A APPENDIX

Table 12: Measurements first day in the field (23 Nov).

Variable	**Outlet**	**Women's pool**	**Inlet**	**Men's pool**	**Swamp**	**Reference site**
Nitrogen [mg/l]	0.462	0.301	0.378	0.353	0.383	0.547
Phosphorous [μg/l]						
chlorophyll-a [μg/ l]	1.90	2.85	0.00	2.72	29.6	0
Dissolved Oxygen [mg DO/l]	6.13	6.40	6.40	5.33	6.40	6.13
pH*	9.00	8.83	8.98	9.03	7.97	8.07
pH	9.00	9.36	9.38	9.45	8.48	8.63
Water Colour [mg Pt/l]	244	17.6	0.00	137.7	353.7	0.00
Sodium [mg/l]	196	197	193	241	250	269
Potassium [mg/l]	2.90	2.27	1.80	1.76	7.56	0.626
Calcium [mg/l]	2.37	5.75	5.96	7.21	9.41	7.93
Magnesium [mg/l]	0.114	0.0526	0.0403	0.0571	0.113	0.0894
zinc [mg/l]	0.00460	<0.00220	<0.00100	<0.00100	0.0105	<0.00100
Iron [mg/l]	0.807	0.337	0.122	0.250	1.03	0.0290
Copper [mg/l]	0.00967	<0.00300	<0.00300	<0.00300	<0.00400	<0.00300
Manganese [mg/l]	0.00500	<0.00300	<0.00200	<0.00200	0.0140	<0.00200
Chloride [mg/l]	50.8	45.0	45.3	42.1	60.2	85.8
Sulphate	34.9	63.5	48.7	82.7	46.2	76.3
Turbidity* [NTU]	29.8	10.13	3.82	9.36	54.0	1.50
Electrical Conductivity* [μS/cm]	550	620	507	501	604	580
Salinity* [ppm]	261	259	251	254	298	296
Total Dissolved Solids* [ppm]	261	259	251	254	294	296
Temperature* [°C]	38.5	40.0	43.0	42.0	39.7	37.6

Table 13: Measurements second day in the field (8 Dec).

Variable	**Outlet**	**Women's pool**	**Inlet**	**Men's pool**	**Swamp**	**Reference site**
Nitrogen [mg/l]	0.150	0.161	0.149	0.142	0.151	0.152
Phosphorous [μg/l]	7.16	4.42	0.842	2.74	4.63	1.89
chlorophyll-a [μg/ l]	0	1.48	0	2.96	0	0
Dissolved Oxygen [mg DO/l]	5.07	4.80	4.80	4.80	5.33	5.07
pH	9.87	9.36	9.36	9.18	9.182	8.62
Water Colour [mg Pt/l]	33.8	23.0	2.70	27.0	71.6	0.00
Sodium [mg/l]	121	116	117	103	116	141
Potassium [mg/l]	2.89	2.65	4.08	3.27	3.70	1.16
Calcium [mg/l]	6.91	5.66	5.65	5.53	5.76	6.54
Magnesium [mg/l]	1.24	0.998	0.866	0.997	1.03	1.52
zinc [mg/l]	0.0436	0.0149	0.0163	0.0175	0.0218	<0.00100
Iron [mg/l]	0.772	0.500	0.303	0.342	0.163	<0.00600
Copper [mg/l]	<0.00300	<0.00300	<0.00300	<0.00300	<0.00300	<0.00300
Manganese [mg/l]	0.0613	0.0353	0.0243	0.0237	0.0183	<0.00200
Chloride [mg/l]	45.4	45.5	45.3	45.1	47.9	87.1
Sulphate	10.7	12.6	20.4	15.9	13.2	22.5
Turbidity* [NTU]	16.6	14.2	4.93	9.45	9.83	1.48
Electrical Conductivity* [μS/cm]	517	509	517	509	506	634
Salinity* [ppm]	256	253	258	255	257	319
Total Dissolved Solids* [ppm]	256	253	258	255	257	319
Temperature* [°C]	38.3	36.4	37.3	37.9	34.2	33.3

Table 14: Measurements third day in the field (13 Dec).

Variable	**Outlet**	**Women's pool**	**Inlet**	**Men's pool**	**Swamp**	**Reference site**
Nitrogen [mg/l]	2.023	1.96	1.85	2.16	2.12	2.13
Phosphorous [μg/l]	10.3	4.40	6.60	5.38	10.5	1.22
Dissolved Oxygen [mg DO/l]	5.60	6.11	6.43	6.23	6.22	5.69
pH	9.13	9.25	9.28	9.28	9.07	8.53
Water Colour [mg Pt/l]	60.8	41.9	40.5	32.4	103	0
Sodium [mg/l]	108	104	121	110	119	154
Potassium [mg/l]	3.35	2.67	3.16	3.02	4.40	1.34
Calcium [mg/l]	6.46	5.89	6.16	5.70	6.28	6.58
Magnesium [mg/l]	1.03	1.03	0.967	0.745	0.773	1.20
zinc [mg/l]	0.0184	<0.00100	0.00670	<0.00100	0.031	<0.00100
Iron [mg/l]	0.591	0.247	0.562	0.353	0.411	<0.00600
Copper [mg/l]	<0.00300	<0.00300	<0.00300	<0.00300	<0.00300	<0.00300
Manganese [mg/l]	0.0543	0.0270	0.0557	0.0287	0.0477	<0.00200
Chloride [mg/l]	46.5	43.9	42.7	44.7	45.4	87.9
Sulphate	10.7	12.6	20.4	15.9	13.2	22.5
Turbidity* [NTU]	31.3	9.05	13.2	10.9	24.9	1.34
Electrical Conductivity* [μS/cm]	505	499	516	525	526	624
Salinity* [ppm]	246	244	259	261	261	314
Total Dissolved Solids* [ppm]	246	244	259	261	261	314
Temperature* [°C]	36.1	36.3	36.4	36.5	34.5	30.2

Table 15: Measurements fourth day in the field (7 Jan).

Variable	**Outlet**	**Women's pool**	**Inlet**	**Men's pool**	**Swamp**	**Reference site**	**Mawira Liwonde**
Nitrogen [mg/l]	5.04	4.83	5.17	4.94	5.51	5.78	5.85
Phosphorous [μg/l]	70.2	34.8	23.1	32.7	63.1	18.7	133
Dissolved Oxygen [mg DO/l]	6.26	6.45	4.99	6.61	5.96	6.42	6.02
pH	9.09	9.17	9.21	9.18	9.95	8.02	
Water Colour [mg Pt/l]	63.5	32.4	0	18.9	62.1	0	71.6
Sodium [mg/l]	104	89.3	85.2	84.1	80.9	92.8	98.6
Potassium [mg/l]	2.42	2.05	2.08	2.11	2.19	0.865	4.90
Calcium [mg/l]	1.79	1.52	1.45	1.49	1.47	2.82	2.25
Magnesium [mg/l]	0.948	0.604	0.0527	0.591	0.534	1.85	0.936
zinc [mg/l]	0.0411	0.0367	0.00513	0.0176	0.0680	0.0239	0.00717
Iron [mg/l]	0.623	0.302	0.127	0.273	0.203	0.0510	0.252
Copper [mg/l]	0.0177	0.0227	0.0243	0.0230	0.0227	0.0263	0.0253
Manganese [mg/l]	0.0297	<0.00330	<0.00200	<0.00200	<0.00200	<0.00200	<0.00113
Chloride [mg/l]	45.9	45.1	44.8	43.6	45.6	90.3	65.5
Sulphate	0	0	49.8	32.9	55.4	117	118
Turbidity* [NTU]	16.8	6.49	2.29	5.53	3.21	1.20	11.2
Electrical Conductivity* [μS/cm]	532	532	541	535	558	643	824
Salinity* [ppm]	266	268	270	269	281	330	412
Total Dissolved Solids* [ppm]	266	268	270	269	281	330	412
Temperature* [°C]	36.9	36.6	36.3	36.5	33.7	30.0	39.2

Table 16: Measurements fifth day in the field (20 Jan).

Variable	**Outlet**	**Women's pool**	**Inlet**	**Men's pool**	**Swamp**	**Reference site**	**Mawira Liwonde**
Nitrogen [mg/l]	2.84	2.95	2.94	2.86	3.22	3.39	3.18
Phosphorous [μg/l]	56.4	25.6	7.69	17.9	71.8	20.5	146
Dissolved Oxygen [mg DO/l]	6.52	5.71	5.67	5.83	5.65	6.58	5.24
pH	9.32	9.39	9.37	9.34	9.13	8.55	8.77
Water Colour [mg Pt/l]	52.7	27.0	18.9	33.8	63.5	10.8	103
Sodium [mg/l]	75.2	94.6	83.3	78.3	86.6	74.8	88.1
Potassium [mg/l]	1.978	1.68	1.53	1.80	1.82	0.764	3.31
Calcium [mg/l]	3.49	3.13	2.99	4.57	3.19	4.42	4.83
Magnesium [mg/l]	1.19	0.711	0.654	1.12	0.654	1.30	0.951
zinc [mg/l]	0.0344	0.0130	0.0103	0.0140	0.0200	0.0577	0.0583
Iron [mg/l]	0.383	0.268	0.119	0.205	0.232	0.242	0.237
Copper [mg/l]	0.0197	0.0163	0,0190	0.0223	0.0243	0.0287	0.0303
Manganese [mg/l]	0.0370	0.0153	0.0123	0.0253	0.0297	0.0333	0.0373
Chloride [mg/l]	45.4	46.7	46.7	46.9	49.0	93.0	62.5
Sulphate	0	0	10.9	20.0	0	44.7	0
Turbidity* [NTU]	12.0	5.49	3.58	6.14	26.3	2.44	17.5
Electrical Conductivity* [μS/cm]	543	531	529	532	535	675	789
Salinity* [ppm]	274	267	266	267	266	327	416
Total Dissolved Solids* [ppm]	274	267	266	267	266	327	416
Temperature* [°C]	36.0	36.1	36.1	36.0	32.3	29.7	39.4

Table 17: Measurements of soil and plants.

Variable	**Soil fr. plant 1.1**	**Plant 1.1**	**Soil fr. plant 2.1**	**Plant 2.1**	**Plant 1.2**	**Plant 2.2**	**Soil Spring**	**Soil Swamp**
Nitrogen [mg/l]	0.534	1.26	0.806	0.187	0.236	0.943	9.81	12.8
Phosphorous [μg/l]	106	133	89.6	135	79.6	103	98.1	138
Sodium [mg/l]	1536	16858	3686	12300	357	718	283	3381
Potassium [mg/l]	10410	9767	31550	10315	4806	49369	8818	11280
Calcium [mg/l]	836	966	8016	2453	979	1972	1858	1100
Magnesium [mg/l]	13780	1980	5502	5414	1640	3240	792	522
zinc [mg/l]	1.95	1.79	7.17	1.81	0.963	0.600	1.15	1.75
Iron [mg/l]	8524	222	7700	116	114	109	3230	1992
Copper [mg/l]	7.90	7.03	19.8	10.6	2.25	2.20	3.73	14.2
Manganese [mg/l]	106	309	473	375	175	72.6	121	39.9

Table 18: Measurements of samples compared to indications for levels in soil [mg/kg].

	TP	**TN**	**Zn**	**Fe**	**Cu**	**Mn**	**K**	**Na**	**Mg**	**Ca**
Soil in pool	98	9.8	1.1	3230	3.7	121	8818	283	792	1858
Soil outside pool	106	0.53	2.0	8524	7.9	106	10410	1536	3780	836
Low level	6.5	2000	1	4.5	2	20	78	-	61	800
High level	22	5000	900	-	250	10000	313	230	488	2000

B APPENDIX

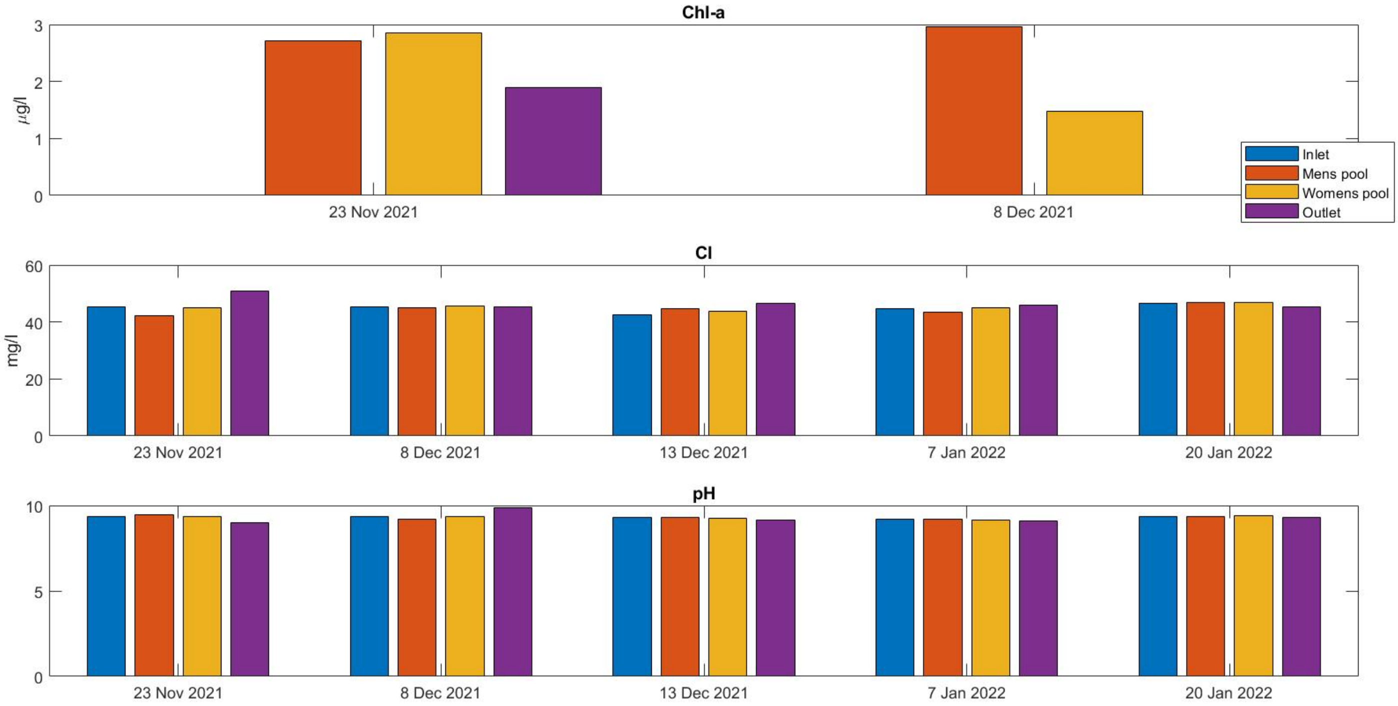

Figure 31: Chlorophyll, chloride and pH between sites and over time.

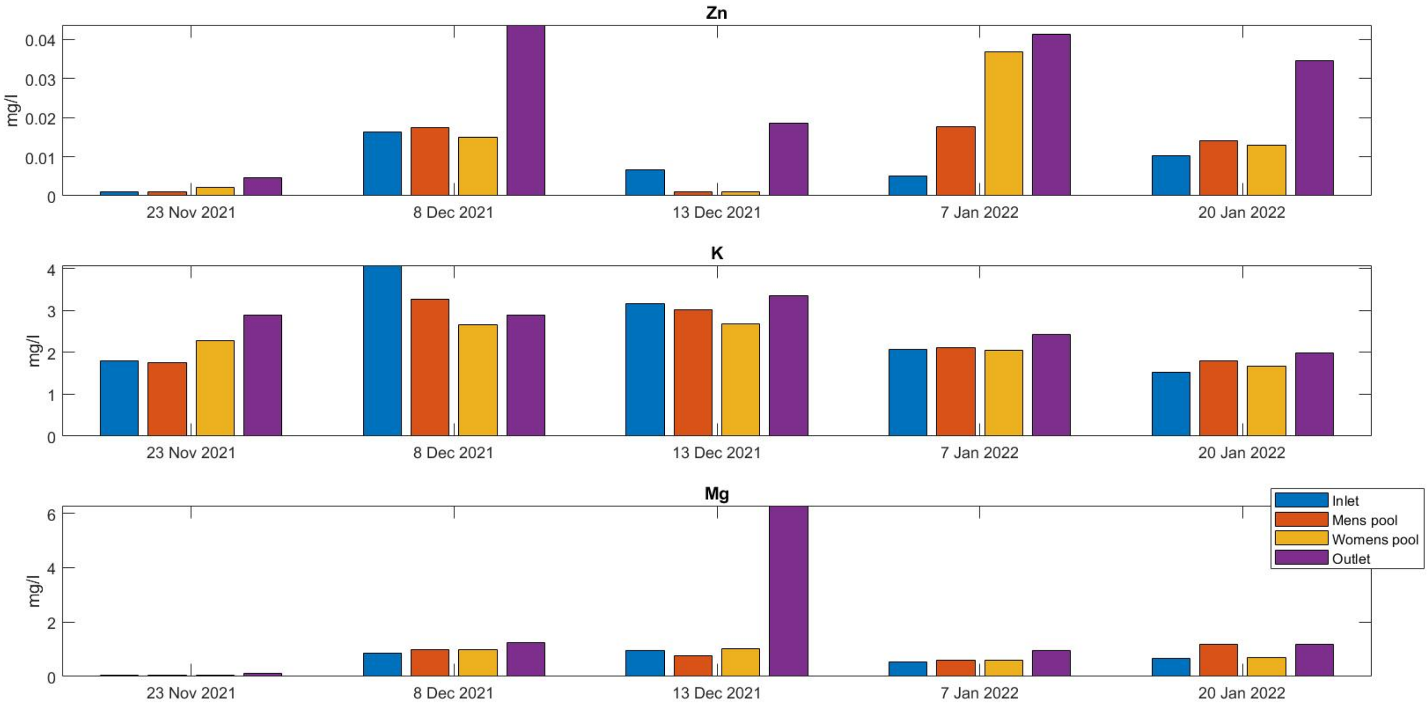

Figure 32: Zinc, potassium and magnesium between sites and over time.

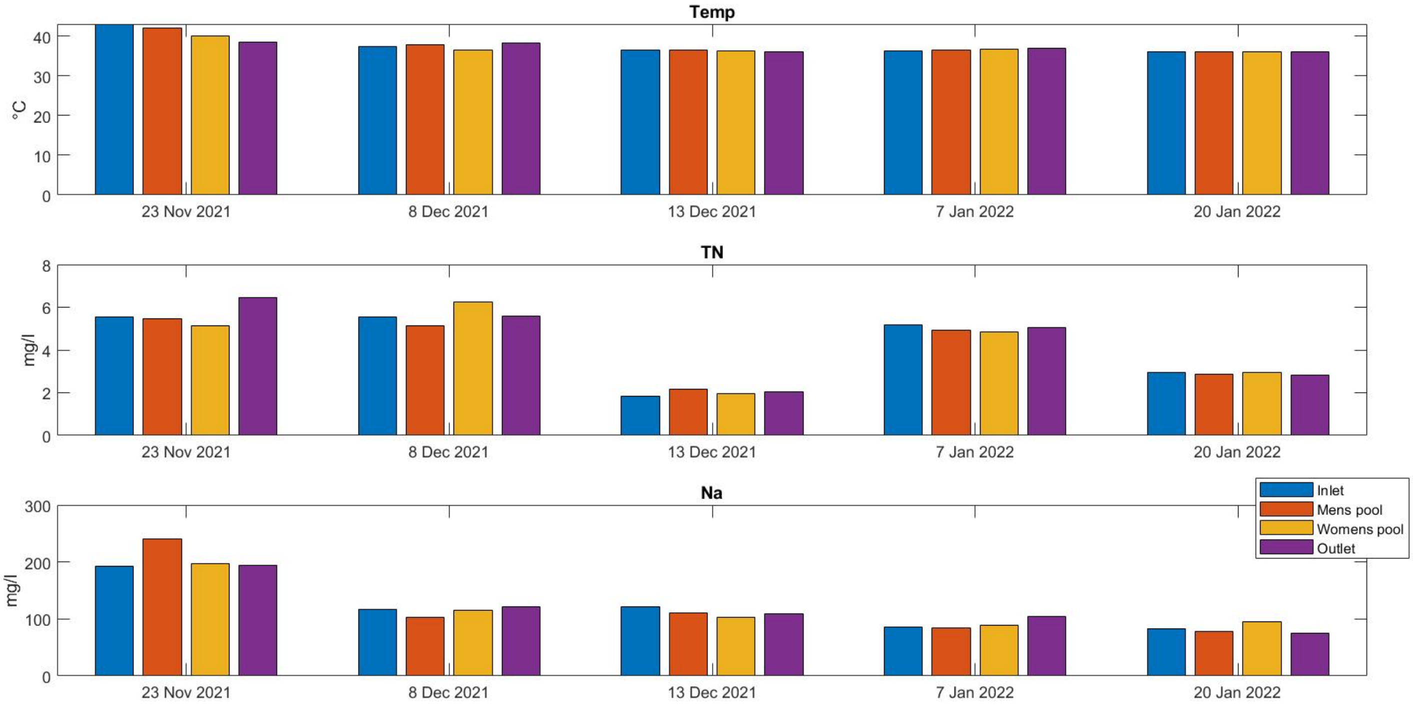

Figure 33: Temperature, sodium and total nitrogen between sites and over time.

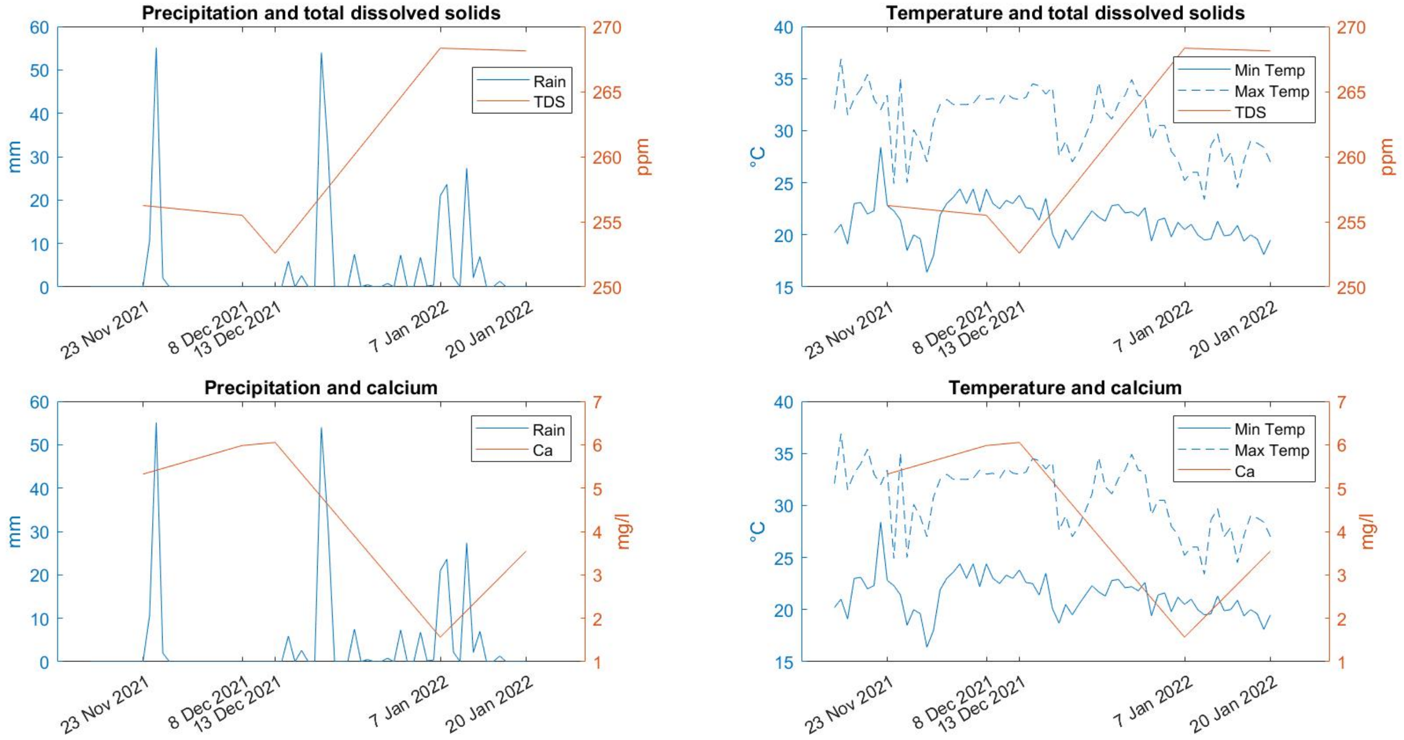

Figure 34: Total dissolved solids, calcium, air temperature and precipitation over time.

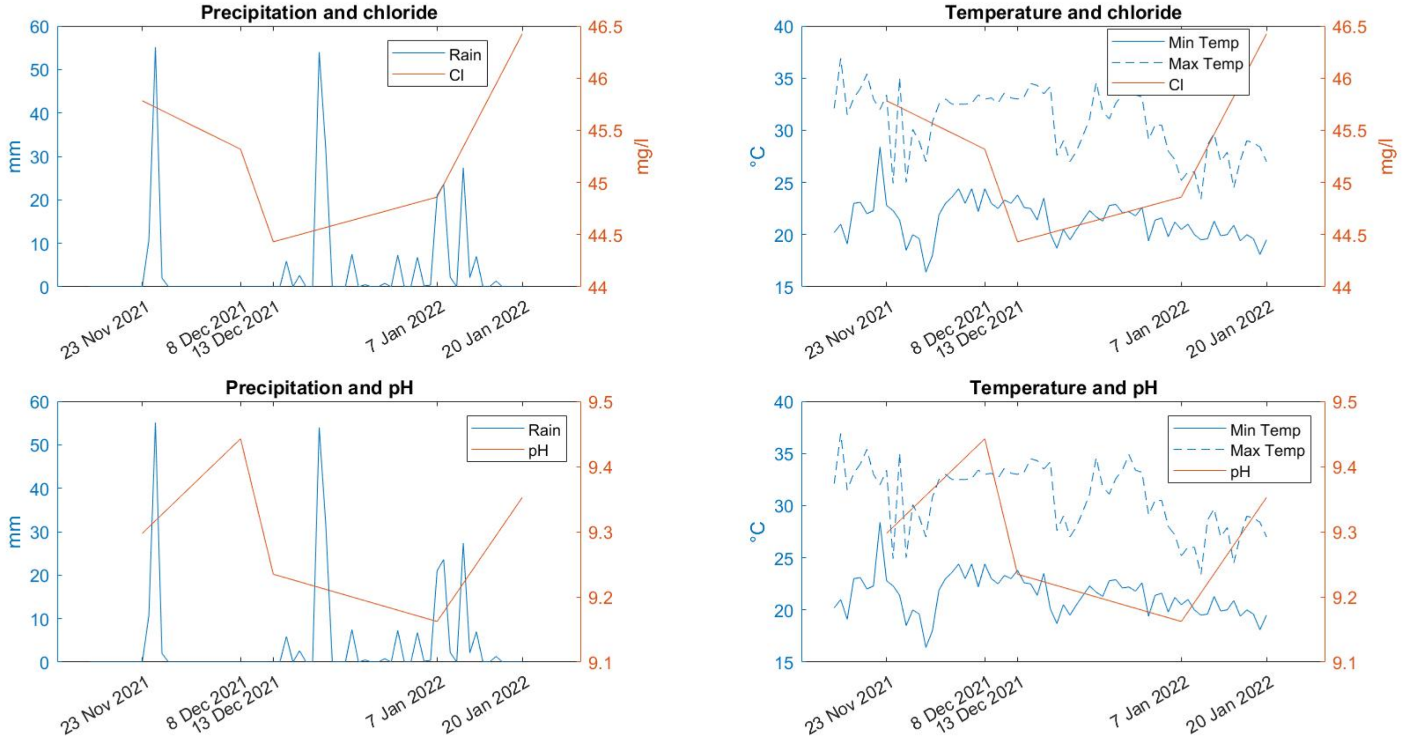

Figure 35: Chloride, pH, air temperature and precipitation over time.

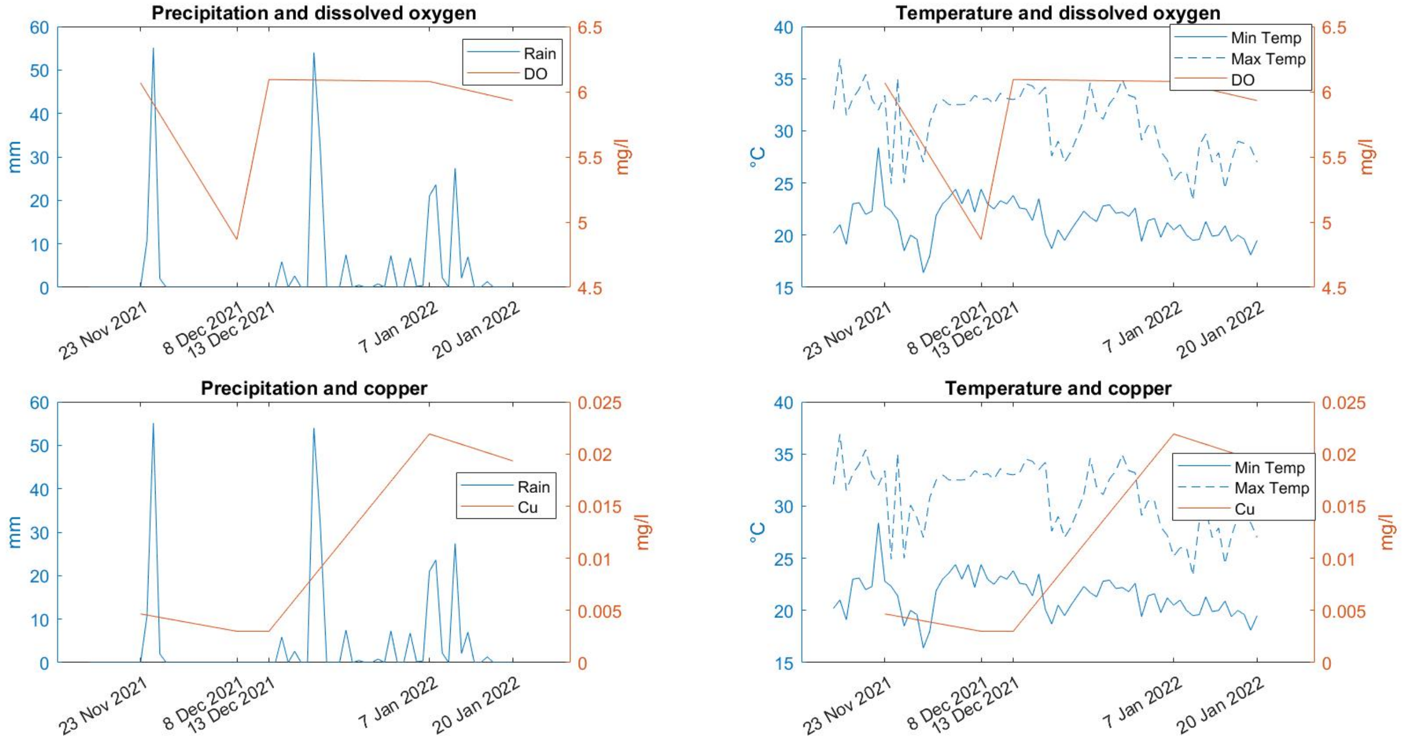

Figure 36: Dissolved oxygen, copper, air temperature and precipitation over time.

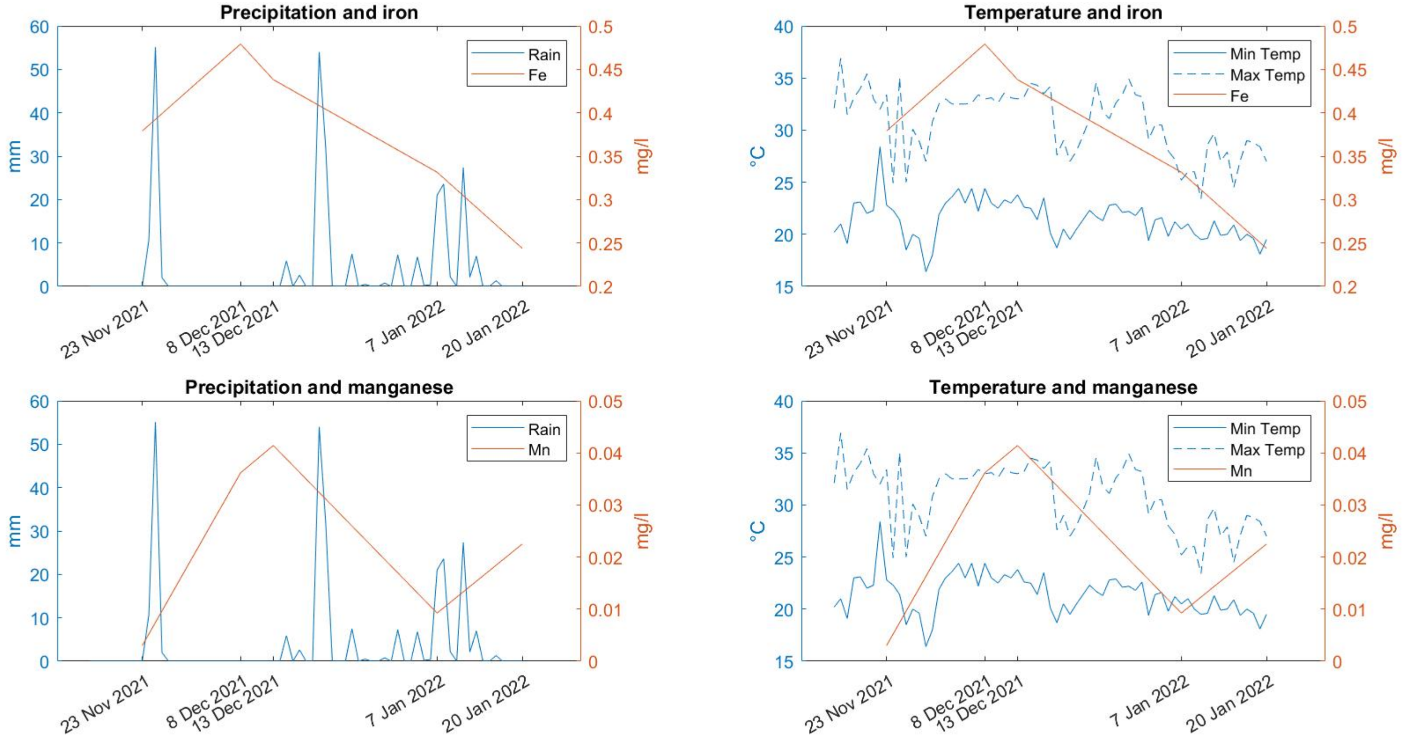

Figure 37: Iron, manganese, air temperature and precipitation over time.

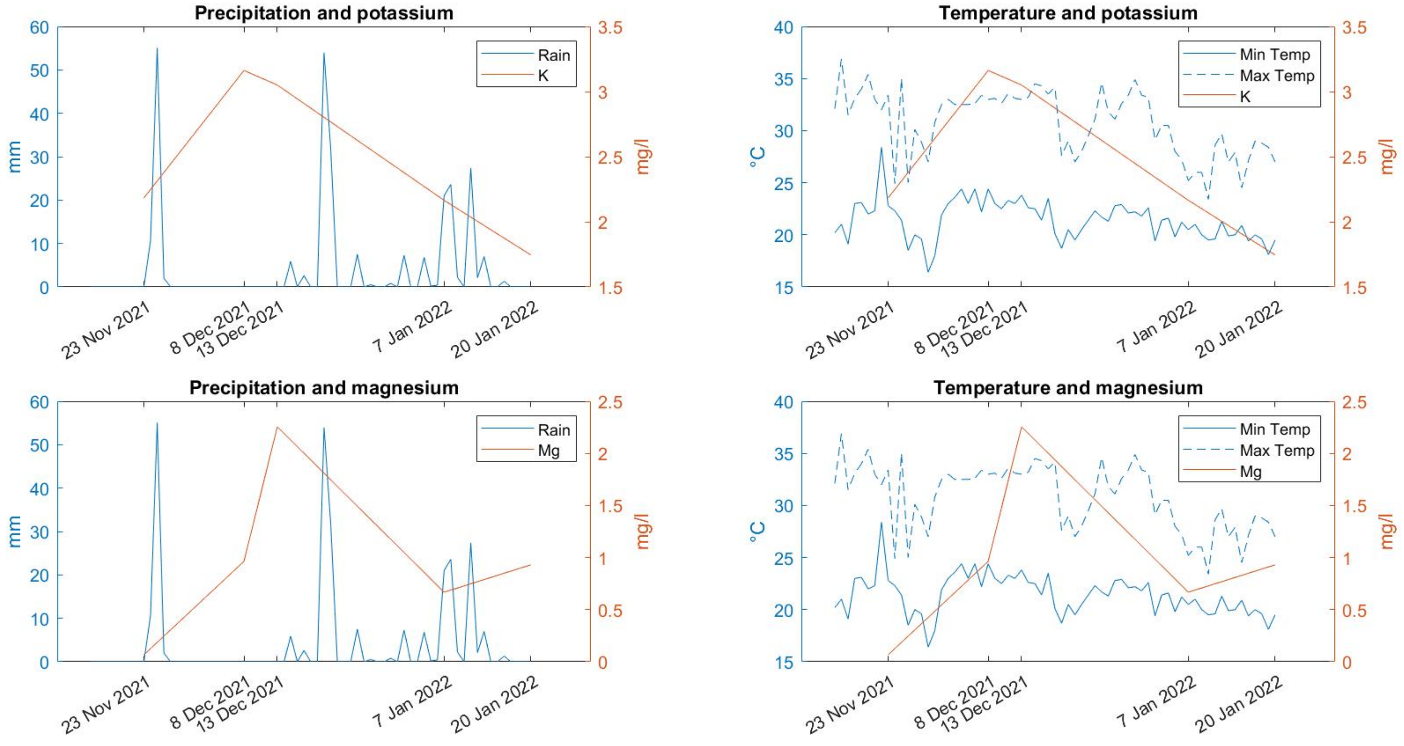

Figure 38: Potassium, magnesium, air temperature and precipitation over time.

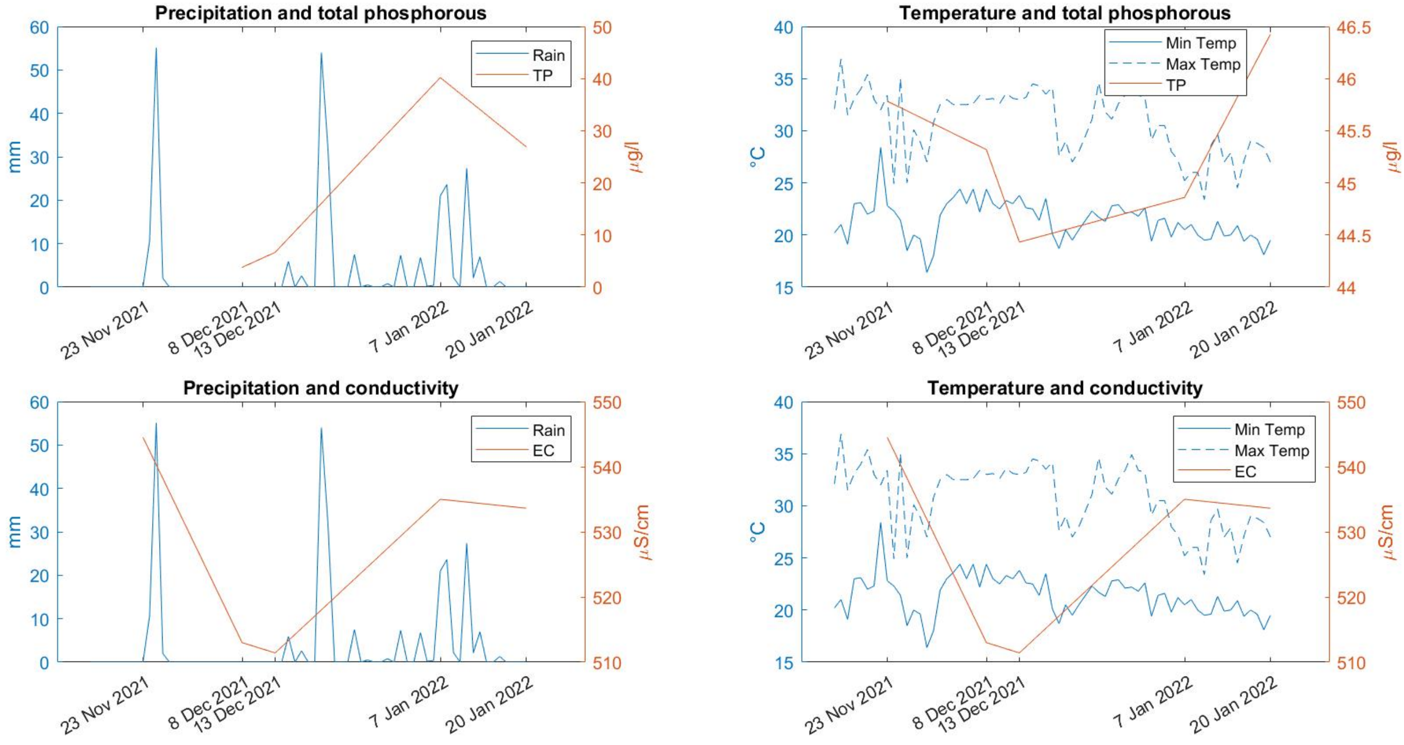

Figure 39: Total phosphorous, electrical conductivity, air temperature and precipitation over time.

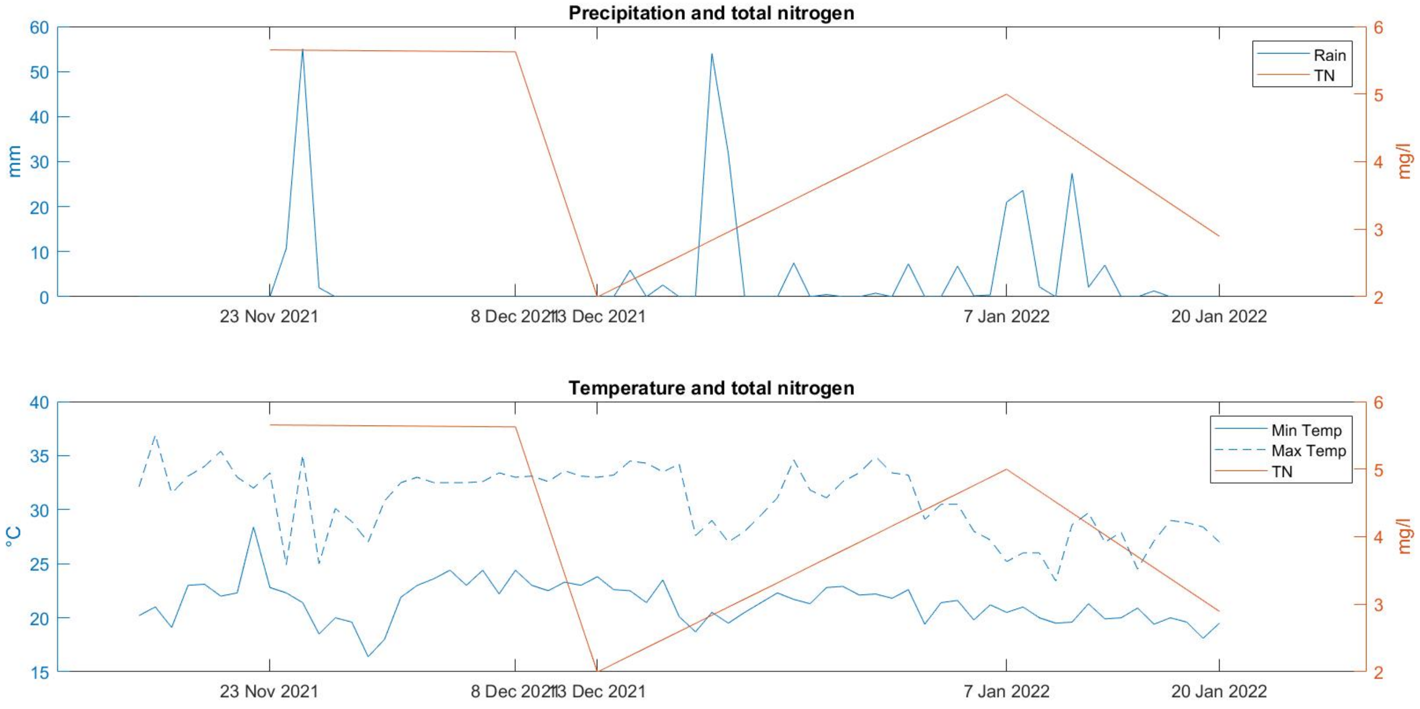

Figure 40: Total nitrogen, air temperature and precipitation over time.