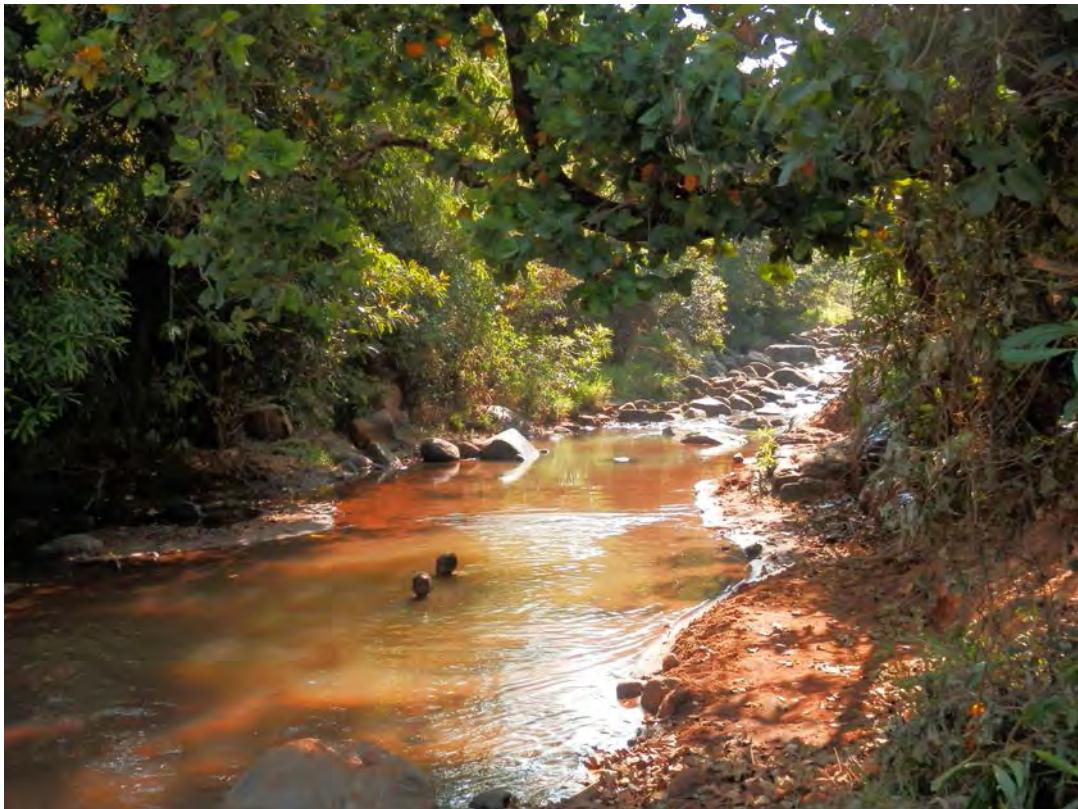




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Temporal water quality study of the heavily human-impacted Likangala River, Zomba, Malawi



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Abstract

River water is used for a range of purposes, for example irrigation, laundry, hygiene, mining of sand, as drinking water and for disposal of wastes and wastewater. These anthropogenic activities, along with agriculture and the local climate and geology will have effects on the water quality, and by extension the people living in the area. This study intends to evaluate the water quality of Likangala River, which is a perennial river in southern Malawi, during hot dry season linking it to the activities present in the direct vicinity of the urban segment of the river.

A small land use survey was carried out, and eight points for water sampling chosen for analysis of a set of physio-chemical water quality parameters. Also an estimate of the water discharge of the time was made.

It was found that most parameters were within the guidelines for drinking water set up by WHO (2011) and Malawi Bureau of Standards (MBS, 2008), although turbidity, manganese, iron, chromium and lead showed elevated levels. Some, but not all, parameters showed a trend with low values upstream the city and higher values downstream (except pH with a inverse trend), and almost all parameters were significantly higher in the effluents from the Zomba Sewage Works, and also directly afterwards.

Keywords: Likangala River, water quality, physio-chemical pollution, Zomba, Zomba Sewage Works

Referat

Flodvatten används för en rad olika ändamål, exempelvis bevattning, tvätt, hygien, utvinning av sand, som dricksvatten och för avyttrande av avfall och avloppsvatten. Dessa mänskliga verksamheter, tillsammans med effekter av jordbruk samt det lokala klimatet och geologin kommer att påverka vattenkvaliteten, och i förlängningen de människor som bor i området. Denna studie avser att utvärdera vattenkvaliteten i Likangala, som är en flod i södra Malawi, under heta torrperioden och koppla denna till de verksamheter som finns i dess direkta närhet längs den urbana sträckningen av floden.

En liten kartläggning av markanvändning genomfördes, och åtta platser för vattenprovtagning valdes ut för analys av ett antal fysio-kemiska vattenkvalitetsparametrar. Också en uppskattning av vattenföring gjordes.

Det visade sig att de flesta parametrar var inom riktlinjerna för dricksvatten som inrättats av WHO (2011) och Malawi Bureau of Standards (MBS, 2008), även om turbiditet, mangan, järn, krom och bly visade förhöjda halter. Vissa, men inte alla, parametrar visade en trend med låga värden uppströms staden och högre värden nedströms (förutom pH med en inverterad trend), och nästan alla parametrar var betydligt högre i spillvattnet från Zomba vattenreningsverk, och även direkt efteråt.

Nyckelord: Likangala River, vattenkvalitet, fysiotekniska förureningar, Zomba, Zomba vattenreningsverk

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1. Introduction

1.1 Malawi and Zomba

Malawi is a landlocked country in southeast Africa (Figure 1). The population is almost 16 million, as of 2012 (UN Data, 2014) with an area of 118 480 km², of which a fifth is Lake Malawi and the remaining 94 280 km² is land (FAO, 2014). The land

use of the vast bulk of the land area is agricultural (Figure 2), and the agricultural sector is also its main industry, with up to 90 % of the population being dependent on it for both income and as a primary food source. In 2013, United Nations Development Programme, UNDP, ranked Malawi number 174 out of 187 countries in the Human Development Index (UNDP, 2014), making it one of the least developed countries in the world. According to UNICEF more than 16 % of the population in Malawi still does not have access to improved drinking water sources, and 47 % do not have access to improved sanitation facilities (as of 2011), although the numbers are declining (UNICEF, 2013).



Figure 1. Map of Malawi, location of Zomba city marked with red arrow (About Africa Travel, 2014).

Zomba is a city of 88,314 people (NSO, 2008), situated in the Southern Region of Malawi. The climate in the region is tropical, with annual rainfall of 600-1500 mm/year, with a distinct wet season. The average monthly temperature in June is 11.5°C and the mean maximum temperature in the dry hot season in October is 29.8°C (Chidya *et al.* 2011)

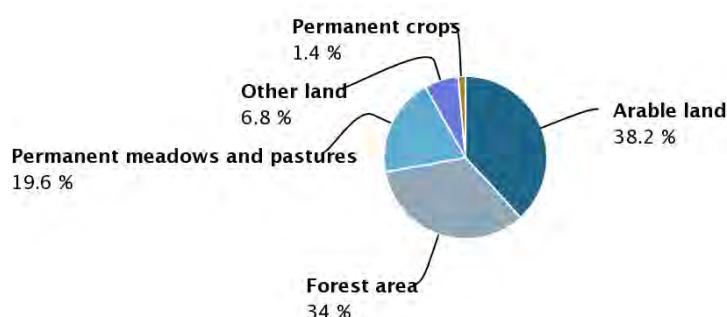


Figure 2. Land use of Malawi, as of 2011 (FAO, 2014).

1.2 Background of the project

The drinking water supply in Zomba city comes from the dam up on nearby Zomba Mountain that feeds Mulunguzi River, and is supplied by the Southern Region Water Board. The supply is irregularly distributed, where only the formally planned housing areas have adequate access to piped water (27 %) that is considered safe for human consumption. The majority of the population however, live in impoverished informal settlements where they mainly rely on communal water points, and sometimes if these run dry are forced to use non-controlled potentially unsafe water sources (wells, streams etc.) to cover their water needs (UN Habitat, 2011). Such an unprotected water source is Likangala River that flows through the southern part of the city.

The management of sanitation and removal of waste in the city is poor according to UN Habitat (2011), especially outside the high-income areas. The residents of the informal settlements do not have access to waste collection at regular intervals, and the bulk of the waste ends up in rubbish pits, in and around the rivers, in traditional pit latrines and along the roadsides (Figure 3). Buildings for public institutions such as hospitals, Zomba Central Prison and the university, along with a fraction of the residential houses are connected to a gravity-fed sewer system, transporting wastewater through the local wastewater treatment plant (WWTP) to the Likangala River (UN Habitat, 2011). This wastewater treatment plant however, has shown poor performance in treating the water, as proved by previous studies (Chidya *et al.* 2011; Lundgren, 2013).



Figure 3. Example of unsatisfactory waste management, where indiscriminate waste is accumulated along roadsides.

The Likangala River is a perennial river and flows east to the closed Lake Chilwa (i.e. no natural outlet), a designated wetland ratified by Ramsar Convention in 1997 (UNESCO). The nature of a closed lake makes it vulnerable to changes in nutrient and pollution load; hence water quality management within the catchment is crucial.

The characteristics of water quality of the Likangala River depends on a multitude of parameters, such as climate, seasonal variations, geology, topography as well a range

of anthropogenic factors. This study aims to connect anthropogenic activities in the direct vicinity of the stretch of the river that flow through Zomba city, with the physiochemical characteristics of the water samples.

1.3 Previous studies

Previous studies, looking at the full stretch of Likangala River, have shown that the physio-chemical characteristics of the water at several sites were well within the limits for use as drinking water. However, the levels of fecal coliforms and of some toxic elements were above the World Health Organisation deeming it unacceptable for human consumption without treatment, especially in the urban segment. The study also mentions a surprisingly high turbidity and ionic content reflected in elevated values of electrical conductivity. Further, elevated levels of several pollutants in effluent from Zomba wastewater treatment plant suggests that the treatment process is not sufficiently effective (Chidya *et al.* 2011). The water quality of the river is irregularly studied, with no continuous water quality testing by the Southern Region Water Board.

1.4 Objectives

The main objective is to understand current anthropogenic factors affecting water quality in the middle section Likangala River, where it flows through Zomba city. The specific objectives were to:

- draw a current land use map describing the current land use and specific activities that take place within the middle stretch of Likangala River.
- determine of water discharge at the time of collection of water samples.
- analyse water quality analyses within the study site with respect to the land use map.

1.5 Research questions and hypothesis

Research questions were as follows:

- How are the sources of nutrients and metals within the city distributed?
- Is the outlet from the WWTP affecting the river water quality, and to what extent?
- How does water quality in Likangala compare with acceptable surface water quality standards (national and international) during dry period?

The hypothesis for this study is that the spatial differences of land use and activities along the river will be reflected in the water quality data, either by site specific peaks in concentration (or corresponding unit) or by an over all trend.

1.6 Limitations

Due to resource limitations, no analysis of biological oxygen demand (BOD), alkalinity, hardness, chloride concentration, pesticide residuals and content of faecal coliforms were conducted, although these parameters give important information about the water quality of a river.

2. Theory and literature review

2.1 Characteristics of surface waters

Surface water can either be flowing water, like springs, streams or rivers, or larger bodies of water such as ponds, lakes and seas. There is a strong relationship between surface water, groundwater and atmospheric water, regarding water tables, flux, temperature and chemical characteristics. Natural processes such as weathering of rock will affect the surface water, as well as proximity to wetlands, forests and seasonal variability in temperature and precipitation. Also deforestation, urbanisation, agriculture and other anthropogenic activities will affect the characteristics of the surface water. Along with climate change, poor waste management, rapid population growth together with urbanisation, and poor forestry and agricultural practices, this constitutes a potential threat for future fresh water resources (Svenskt Vatten 2010; Lidström, 2013).

2.2 The effect of land use and activities on water quality

Perennial rivers provide a steady and readily available source of water for people living in the area. However, depending on the purpose of the water usage, this might impact the water quality in a negative way.

Sandmining

Sandmining is the action of removing sand from a riverbed for further use in construction and related purposes. The most common sources are river channel deposits, floodplain alluvial deposits and residual soil deposits. Tan Peck Yen and Rohasliney (2013) reported effects such as negative change of water quality in the river, especially regarding total suspended solids (TSS), turbidity, nitrate concentration along with bank erosion and degradation of the riverbed. One result of this is poor and stressful conditions for the aquatic life. Sand and smaller particles stirred up by sand mining activities can be transported a long way, depending on the nature of the stream and the size of the particles, causing high turbidity and deposition of sediments downstream.

Furthermore, Sreedharan and Damodaran (2011) conclude that the lack of adequate information on the environmental impact of river sand mining is a major challenge regarding regulatory efforts and management in many developing countries. This means that a satisfactory scientific assessment is a pre-requisite in formulating management in such areas.

Laundry activities

Washing of clothes, as well as personal hygiene, directly in, or nearby rivers and streams is common in many parts of the world. Often some sort of soap or detergent containing surfactants is used, meaning soapy water being expelled directly into the water often resulting in high concentrations of surfactant in urban streams close to emission points. Gordon *et al.* (2009) studied the concentration of the commonly used anionic surfactant linear alkylbenzene sulphonate (LAS) in a small South African river. The study showed that LAS concentration was very variable, both spatially and temporally, although generally very low ($<11 \mu\text{g L}^{-1}$), suggesting that the molecule was dissipated rapidly by a combination of dilution and degradation. A way of decreasing the chemical load of the river is to discard the laundry water on the riverbank rather than directly in the water, having it infiltrate the soil. Furthermore, a big concern of detergent in natural waters is the high content of phosphates (sodium tripolyphosphate), leading to eutrophication. Many countries have banned or are about to ban the use of these in favour of zeolites (Yamane and Nakazawa, 1986).

Use of fertilizers in agriculture

Inorganic, commercial fertilizers are commonly used to increase yield in crops. In Malawi, a farm input subsidy programme (FISP), was implemented in 2005-2006 to enable poor farmers to buy farm inputs, including fertilizers, at reduced prices. The major inorganic fertilizers used in agriculture are nitrogen, phosphorus, potassium and sulphur fertilizers. If insufficiently absorbed by plants and soil or washed away by heavy rains, these fertilizers can enter ground and surface water possibly causing eutrophication or pose a threat to drinking water sources (Farhadinejad *et al.* 2014).

Domestic wastewater

Domestic wastewater is mixture of all household wastewater from a community, including toilet water, showers, dish washing and laundry. This means that the content will vary from large floating material such as toilet paper, to small suspended particles and dissolved substances. Besides the fats, proteins and carbohydrates that primarily make up faeces and urine, wastewater also contains great quantities of intestinal bacteria and parasites. Some varieties of these can cause health problems for people if they end up in a water source. Wastewater contains elevated concentrations of nutrients, such as different forms of nitrogen, phosphorous, sulphur and potassium (Jönsson *et al.* 2005, Svenskt Vatten 2010).

Irrigation

Water quality is of uttermost importance when taking water from a river for irrigation usage, with the most important parameter, for the sake of soil health, being salinity. Saline water can accumulate salt in the soil profile if the precipitation is not sufficient and regular. If the salt content is higher than recommended, the crop's ability to absorb water and nutrients is interfered. The main concern for the watercourse is however the change in flow rate and water discharge, which can be considerable in a small stream, causing problems downstream (Laycock, 2007).

2.3 Water quality parameters

The quality of water has impact on human health, particularly when ingested as drinking water, and on the environment. In organisms, elements can be essential to sustain life or toxic, sometimes both depending on amount. The effect on humans of the parameters studied in this project is listed below (EPA, 2014).

2.3.1 Anions

Nitrate

In waters and wastewaters the forms of nitrogen of greatest interest are nitrate, nitrite and ammonia. Nitrate in water, especially if collected from a well, could indicate contamination from agricultural runoff or septic systems.

Phosphorus

Phosphorus occurs in natural waters and is in wastewater mostly in the form phosphate. Phosphorus is essential to the growth of organisms and can, depending on the content of other macronutrients, be limiting the primary productivity of a body of water. Phosphate is not directly toxic to humans, but a high concentration in natural waters can contribute to eutrophication.

Sulphate

In large amounts, sulphate can give a bitter taste to water. Concentrations above 250 mg/l can have a laxative effect although 500 mg/l is considered safe (EPA, 2014).

2.3.2 Metals

Several metal ions such as calcium, potassium, sodium and magnesium are essential to sustain biological life. Additionally manganese, iron, copper and zinc are essential for optimal reproduction and development, although in smaller amounts.

Heavy metals (cadmium, zinc, copper, iron, manganese, lead and chromium) are toxic and can be very harmful to humans and animals, even in small concentrations. High aluminium levels are associated with Alzheimer's disease. Arsenic is highly toxic and so is cadmium and lead. Presence of iron or copper can cause unpleasant taste. High concentrations of iron can also lead to reddish brown staining of clothes when washing. Chromium has shown adverse effects on fresh and saltwater aquatic life, and is associated with stomach cancer in humans (Zhitkovich, 2011).

2.3.3 pH

pH is a measure of the acidity or basicity of an aqueous solution. Changes of pH in natural waters are correlated with alkalinity. When a small volume of acid is added to distilled water, the pH of the water will change considerably. The same volume of acid is added to a natural water with a moderate content of alkalinity, then the addition of acid may have a comparatively small effect on the pH. A solution whose pH tends to remain constant when small amounts of acid or base are added is called buffered (Hem 1985).

2.3.4 Electrical conductivity

A material's ability to conduct electric current is called electrical conductivity (EC). The conductivity of a liquid is related to the concentration of dissolved salts, a potential salinity hazard. In irrigation, salt concentrations needs to be very low, meaning the corresponding electric conductivity being 75 mS/m or less (Mara, 2003).

2.3.5 Turbidity

Turbidity is a measure of the clarity of water, and it is, in a natural body of water, an important clue to its condition and productivity. Turbidity in water is caused by fine suspended matter such as clay and silt along with small grains of organic and inorganic matter. Also plankton and other microscopic organisms can increase turbidity. Turbid waters are not necessarily dangerous to drink, but indicate that the water needs treatment (APHA, 1999).

3. Materials and methods

3.1 Site description

Likangala River flows from west to east, through the southern parts of Zomba city (Figure 4) towards Lake Chilwa. In this project, the middle section of the river is studied, where it passes the city. The studied stretch measures just under 6 km, passing near a mental hospital, the central hospital, commercial and residential areas and the wastewater treatment plant, from which effluents are expelled. The river is perennial, with a large difference in water discharge over the year, with a peak in wet season, which normally occurs around November until April. The field data and water samples are collected during October, which is in the dry hot season.

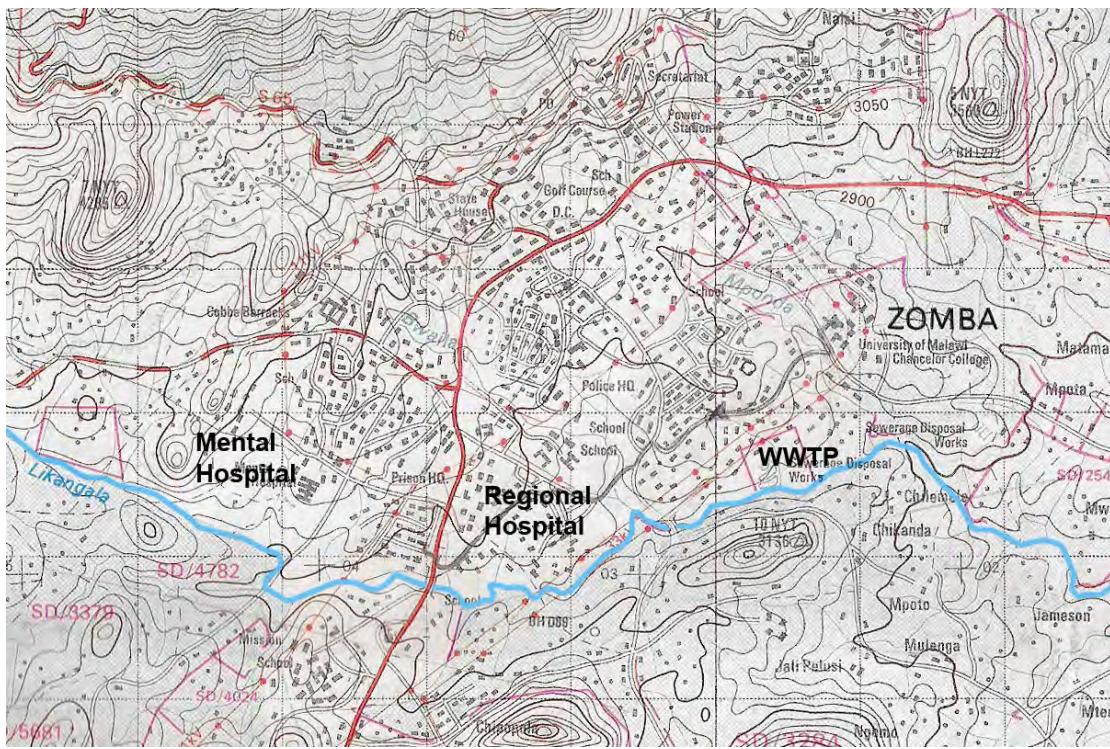


Figure 4. Topographic map of Zomba city, showing the flow of Likangala River (Department of Surveys, 1980).

3.2 Land use and activities survey

In order to come up with a land use map, a reconnaissance tour of the study area was undertaken, spanning over one day during the hot dry season. The tour was conducted on foot, covering most of the study site, however some passages of the river were deemed impassable due to difficult topography. Activities and observations of land use in direct proximity to the river (within 100 metres) were noted and photographed. GPS-points where taken for later construction of a map using Arc GIS.

During this tour, eight suitable locations along the river were purposefully selected, for later analysis of water quality (Table 1). The distance in the table was measured in ArcGIS. Sample point 7 is situated in the effluent stream from the wastewater treatment plant and not in the river, to describe what characteristics the effluent water has when it joins Likangala River.

Table 1. Coordinates of chosen sample points along Likangala River.

Sample point	Coordinates (UTM/UPS, ARC 1950)			Altitude [m]	Distance from S1 [m]	Notes
	36L	746408	8296218			
S1	36L	746682	8296090	924	325	
S2	36L	748113	8295801	897	2454	Just downstream road construction
S3	36L	748409	8295705	894	2783	By irrigated farming and sewage ditch
S4	36L	749703	8296192	875	4891	Next to bridge, close to market
S5	36L	750337	8296424	870	5589	Upstream sewage effluent outlet
S6	36L	750479	8296420	867	5742	In sewage effluent stream
S7	36L	750620	8296415	863	5894	Downstream sewage effluent stream

3.3 Water discharge measurement

By observing the time (t) it takes for a floating object to travel with the water flow down a segment of known length (l) and cross sectional area (A), the water discharge (Q) of a stream or river can be estimated (Figure 5). The method only gives a rough estimate of the water discharge (error between 30 and 70%), but it is a simple and affordable procedure that needs very little equipment and can be conducted by one or two people. An adjusted value of the maximum surface velocity (v_{max}) gets to represent the average velocity of the whole section.

$$Q = k \cdot v_{max} \cdot A \quad (1)$$

The constant k in (1) is a value usually between 0.5 and 0.9, where a low number represents a section with high bottom roughness and a high number a section with low bottom roughness (SMHI/SNV, 1979).

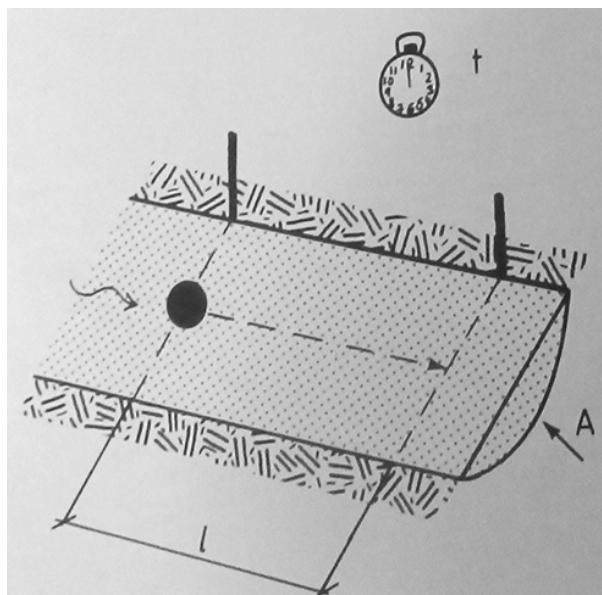


Figure 5. Measurements of water discharge with float method (SMHI / SNV, 1979)

Due to a road construction site located in the middle of the study area, where the river crosses the main road (Figure 4), a culvert was installed at the site of the temporary bridge. Since all water in the river flowed through this culvert, and the geometry being simple, this constituted a good site for measuring water discharge with the float method.

3.4 Physiochemical parameters

3.4.1 Sampling and preparations

Samples were collected at eight different locations along the studied area, see section 4. Six 0.5 l plastic bottles were filled, after first being rinsed thoroughly in river water. Samples were taken where the water was visibly flowing and well mixed. Three of the six bottles were immediately acidified with 1ml nitric acid, for later analysis of metal

concentrations. The purpose of the acid is to keep the metals in solution and to avoid adsorption to the container walls (APHA, 1999). The acidified samples were kept at room temperature while the unacidified samples were immediately chilled in cooler bag and later transferred to fridge (4°C).

3.4.2 Field measurements

A portable pH/EC/TDS/temperature meter were calibrated in the laboratory and brought to the field. The instrument was HANNA Instruments HI 991300, with range and accuracy according to Table 2. Water was taken from the river in a small container and readings were taken immediately. The procedure was repeated three times on each sampling point.

Table 2. Range and accuracy for HANNA Instruments pH/EC/TDS/temperature meter.

	pH	Temp [°C]	EC [μS/cm]
Range	0.00 to 14.00	0.0 to 60.0	0 to 3999
Accuracy	± 0.01	± 0.5	$\pm 2\%$

3.4.3 Laboratory analyses

Concentrations of calcium, sodium, potassium, magnesium, manganese, iron, aluminium, copper, chromium, lead and zinc were analysed using microwave plasma atomic emission spectrophotometer (MP-AES). Concentrations of sulphate, nitrate and phosphate were measured in filtered samples using ultraviolet visible spectrophotometry (UV/VIS). Turbidity was determined using a portable turbidimeter.

UV/VIS

All samples were filtrated by gravity through Whatman Cat No 1001-125 filter paper. Water from sample point six was especially turbid, and had to be filtrated again, this time through 0.45 μ m Millipore filter using a vacuum pump.

Sulphate concentrations was determined using the turbidimetric method described in APHA (1999), where sulphate ions are precipitated in a hydrochloric acid medium with barium to form barium sulphate crystals. The turbidity of the solution is proportional to the concentration of sulphate ions, and can be measured using UV/VIS at 420nm wavelength. A calibration curve was created using standards of known sulphate concentrations (Appendix I. A). The instrument used was a PG Instruments Ltd. T90+ UV/VIS Spectrophotometer.

Phosphate concentrations were determined using the vanadomolybdophosphoric acid colorimetric method described in APHA (1999), where yellow vanadomolybdophosphoric acid is formed in the presence of vanadium. The intensity of the colour is proportional to the concentration of phosphorus in the sample, and was measured using UV/VIS at 400 nm wavelength. Phosphorus concentrations were then converted to phosphate concentrations, assuming that all phosphorus exists as phosphate ions. A calibration curve was created using standards of known phosphorus concentrations (Appendix I. B). The instrument used was a PG Instruments Ltd. T90+ UV/VIS Spectrophotometer.

Nitrate concentrations were determined using the nitrate nitrogen ($\text{NO}_3\text{-N}$) method described in APHA (1999), which is suitable only for samples with low organic matter content. Absorbance was measured using UV/VIS at 220 nm wavelength, and the absorbance is proportional to the nitrate concentrations in the samples. A calibration curve was created using standards of known nitrate concentrations (Appendix I. C). The instrument used was a Jenway 6405 UV/Vis Spectrophotometer.

MP-AES

All acidified samples were filtrated first by gravity through Whatman Cat No 1001-125 filter paper than again through 0.45 μm Millipore filter using a vacuum pump.

Total concentrations of dissolved calcium, sodium, potassium, magnesium, manganese, iron, aluminum, copper, chromium, lead and zinc were measured with a 4100 MP-AES from Agilent Technologies, equipped with auto sampler. Calibration standards for all elements were prepared in the range 1-5 mg/l, using factory standards, and the instrument was calibrated immediately before measuring concentrations.

Turbidity

Turbidity was not measured in the field due to problems with the instrument, but later measured in the laboratory on refrigerated unfiltered samples that was shaken vigorously in order to again put solids into suspension. The instrument used was a Martini Instruments MI 415 Turbidity Meter. Formazin standards for calibration were prepared according to APHA (1999).

3.4.4. Pearson product-moment correlation coefficient

When plotting data from a multitude of parameters, it is important to be able to describe how well they correlate to each other. One approach is to calculate the Pearson product-moment correlation coefficient, or Pearson correlation coefficient for short, which is a measure of strength of linear correlation between two variables. The output from the calculations is a value r , that is a value between -1 and 1, where zero indicates no correlation, and values close to -1 or 1 indicates a strong negative or positive correlation respectively. When squared, r^2 indicates goodness of fit, another common measure of correlation strength (Laerd Statistics, 2013).

4. Results and discussion

4.1 Land use survey

The study area can be divided into two main sections. The upper part of the study area, upstream of the main road is predominantly rural (Figure 6), characterised by subsistence farming and settlements scattered over the landscapes. The area downstream of the main road is predominately urban, with houses close to the river, especially on the northern side of the river.

The upper part of the river flows along a v-shaped valley, with the gentle slope on both sides being utilized for growing crops, such as maize and beans, along with scattered fruit trees. The bulk of the active farming happens during the wet season, so during the time of this study most soil was bare (Figure 7), ordered into neat rows. The farmed soil reached all the way down to the river in some places, but mostly the river was lined with trees and bushes.

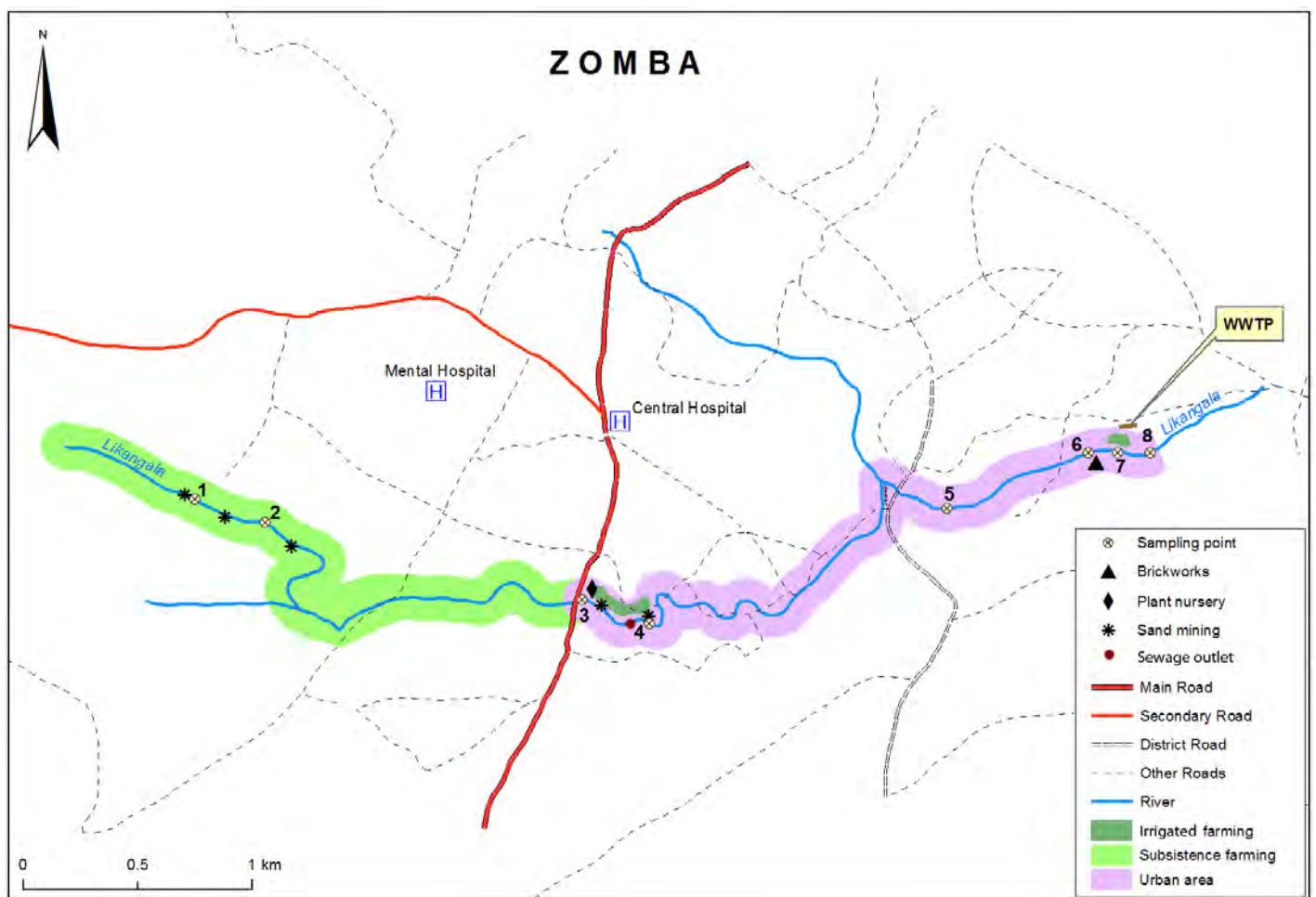


Figure 6. Map of land use and activities. Sampling points for water quality parameters are numbered from 1 to 8.



Figure 7. The slopes of the Likangala River, characterised by bare soil. The river flows in the middle of the picture, where it is lined with trees.

Spots of sand mining were observed along the entire studied stretch of the river, characterised by piles, or small fields of sand next to the water (Figure 8). A few of the notable locations are shown in Figure 6. In the urban area, people temporarily damming the water flow as a means to facilitate sand mining was observed.



Figure 8. Sand mining location. Also visible is the eroding riverbank on the far side.

Both upstream and downstream of the main road, laundry activity was observed, with fabrics being washed manually with detergent and then rinsed (Figure 9). Also people and children bathing and washing were observed.



Figure 9. Washing and bathing in the river.

The main road crosses the river in the middle of the studied area. Currently, there is major road construction taking place, upgrading and paving the road leading to Blantyre (Figure 10). Due to this, a temporary bridge is established next to the old one, with all river water being diverted through a circular culvert. The sand, gravel and dust moved around by large machinery are likely to affect the load of suspended solids in the river downstream.



Figure 10.Road construction, temporary bridge with culvert to the left.

Immediately downstream of the bridge is a plant nursery. Irrigated farming of maize, potatoes, cabbage, tomatoes among other things (Figure 11), occurs on the north side of the river. The irrigation water is taken from the river.

At this site, a small tributary to the river from the north side was observed. The water joining the Likangala here was brown and murky, and carried the distinct odour of sewage, very possible effluents from some sort of toilet facility (Figure 12).



Figure 11. Irrigated farming of maize (left) and cabbage (right).



Figure 12. Stream joining the Likangala, with appearance and odour of untreated sewage.

The next segment of the river flows through a very urban area, in the southernmost part of Zomba. The houses here are small and with little space in between. Along with laundry and bathing, the most striking feature was the indiscriminate mix of household waste scattered along the riverbank (Figure 13).



Figure 13. Indiscriminate mix of household waste along the river.

The study area ends just downstream of Zomba Sewage Works, where the wastewater from the hospital, and the settlements gets treated biologically in a succession of ponds. Some of the wastewater was used to directly irrigate maize on the site. The water in the outlet from the wastewater treatment plant into the river had a dark, blackish colour and a distinct smell of sewage (Figure 14). Downstream of the outlet substantial algae growth was observed, due to the nutrient load from the wastewater effluents (Figure 15).



Figure 14. Dark wastewater treatment plant effluents joining the clearer water of the river.



Figure 15. Algae growth downstream of the wastewater treatment plant outlet.

Just across the water from the wastewater treatment plant was a brickworks, but this likely has no effect on the water quality in the dry season.

4.2 Water discharge

The shape of the corrugated culvert was round, slightly oval, with a flatter section in the bottom (Figure 16), probably due to the pressure from above. Hence the cross sectional area of the water was approximated with the shape in Figure 17, and not with a segment of a circle. This gives a total area of 0.16 m^2 . The length of the culvert was 15 m.



Figure 16. The culvert at the road construction site, used for approximating water discharge in Likangala River.

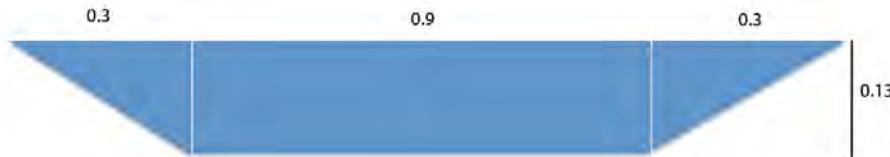


Figure 17. Approximated shape and dimensions of cross sectional area of water in culvert (m).

The floating device used was a piece of a stick found at the site, and the experiment was repeated five times, of which the average was 19.3 s and the standard deviation 1.7 s. The value of k was chosen to 0.5, due to the corrugated surface of the culvert, and hence a substantial amount of turbulence. With this data, the v_{max} was estimated to 0.78 m/s, and the water discharge to 61 l/s, using formula (1).

4.3 Water quality parameters

The results from the different analyses are presented in Table 3 together with guideline values from WHO (2011) and local drinking water standards from Malawi Bureau of Standards (MBS, 2008). Looking at all values, only turbidity, manganese, iron and lead showed elevated levels in relation to WHO and MBS, and chromium touching the limit. The levels of lead is particularly worrisome, given its well known toxicity to humans and other organisms, there is however uncertainties about the analyse method for Pb and Cr, so more studies are needed to confirm these levels. Iron in these concentrations can cause reddish brown stains on clothing if used for washing, but since water is already murky and turbid, it is unclear how major this effect is. The iron concentrations in the water could reflect the high concentrations of natural iron in the red soil in the catchment.

Naturally, the importance of the specific properties of the water depends on its intended use. The cleanliness of drinking water is more important than for example for laundry or irrigation, and it is noteworthy that the water is of significantly higher quality just upstream of the city compared to downstream, urging the people, if possible, to collect or use water as high up as possible.

Table 3. Summary of results from analysis of physio-chemical parameters for the eight different sampling points, compared to WHO (2011) and MBS (2008) recommendations for drinking water. Results from WWTP effluents marked grey.

Parameter	Sampling point								WHO	MBS
	S1	S2	S3	S4	S5	S6	S7	S8		
pH	7.94	7.85	7.66	7.67	7.41	7.40	7.14	7.27	6.5-8.5	5.0-9.5
Temp [°C]	29.0	28.1	28.8	29.0	29.1	28.9	23.3	27.0	NA	NA
EC [$\mu\text{S}/\text{cm}$]	100	108	128	129	168	166	546	238	NA	700-1500
TDS [ppm]	50	54	64	64	84	83	273	119	NA	450-1000
Turbidity [FNU]	14.87	7.6	21.1	90	17.8	307	48.2	42.2	<5	0.1-1
SO_4^{2-}	1.94	8.16	3.18	7.82	4.12	5.50	15.05	11.60	NA,250*	200-400
PO_4^{3-}	1.12	0.64	1.18	2.43	0.53	0.76	19.18	4.10	NA	NA
NO_3^-	0.81	0.79	1.52	1.99	1.15	1.77	3.12	2.14	50	6.0-10
Ca	9.70	8.64	11.29	10.79	13.18	13.03	15.76	14.10	100-300	80-150
Na	7.48	7.76	9.30	9.17	12.40	11.55	33.35	15.19	NA	100-200
K	1.02	0.93	1.04	1.12	1.90	1.98	13.51	3.52	NA	25-50
Mg	2.76	2.99	3.94	4.13	4.65	4.77	5.46	4.91	NA	30-70
Mn	0.13	0.11	0.24	0.24	0.41	0.72	0.69	0.69	0.4	0.05-0.1
Fe	0.87	0.64	0.83	1.27	1.11	3.86	3.06	1.81	NA	0.01-0.2
Al	0.33	0.18	0.39	0.97	0.30	2.99	0.63	0.64	NA	NA
Cu	0.04	0.03	0.03	0.03	0.03	0.04	0.04	0.03	2.0	0.5-1.0
Cr	0.06	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.005-0.01
Pb	0.04	0.04	0.04	0.04	0.05	0.05	0.05	0.05	0.01	0.01-0.05
Zn	bl	bl	bl	bl	bl	bl	0.05	bl	NA	3.0-5.0

Units: mg/L except when specified. bl: below detection limit.NA: data not available. WHO: World Health Organisation. MBS: Malawi Bureau of Standards. * Taste threshold value.

More specifically, Figure 18, (a-f) shows how each parameter fluctuates over the course of the studied area. pH and electrical conductivity show a clear trend, and also the nitrate levels seem to increase further down. The fourth sample point, which is collected just downstream a road works, a plant nursery and an unofficial and likely untreated sewage outlet, shows elevated levels of nitrate, phosphate and sulphate as well as turbidity. These findings could be connected to the nutrient rich wastewater joining the river. Probably this is the point of entry for untreated wastewater coming from the main hospital, mental hospital, prison and barracks whenever the main sewer line is blocked.

Sample point seven, corresponding to the outlet stream from Zomba WWTP, shows more extreme values for all parameters, except turbidity. This indicates that the treatment process is insufficient, which is also confirmed by the dark, blackish color and the foul odour of this stream. From sample point six to eight, i.e. immediately before and immediately after (100 m in each direction) the outlet, a significant rise in nitrate, sulphate and phosphate can be noted, and that cannot be explained by something other than impact of the wastewater joining the river. Given that the total discharge of the river was estimated to only 61 l/s a short distance upstream, and by visual approximation was similar (same order of magnitude) at end of studied area during the dry season, the flow from the WWTP will have a huge effect. Algae

growth was observed just downstream of the outlet, but nowhere else along the studied area, suggesting a strong effect of the expelled nutrients.

The turbidity varies a great deal, and does not show a trend, either positive or negative. Although the highest value was measured towards the end of the studied area, where the water was particularly brown and murky from suspended particles. Turbidity is likely affected by the flow regime, where local eddies and rapids stir up sediments, the presence of road works, people walking on the riverbed stirring up particles and sandmining in action.

The pH value varies with almost a full unit along a clear negative trend, indicating a continuous addition of acidic substances, or acidification processes happening instream, possibly connected with poor buffer capacity of the water. Alkalinity, along with a detailed description of possible buffering rock types in the area would be interesting to look into in another study.

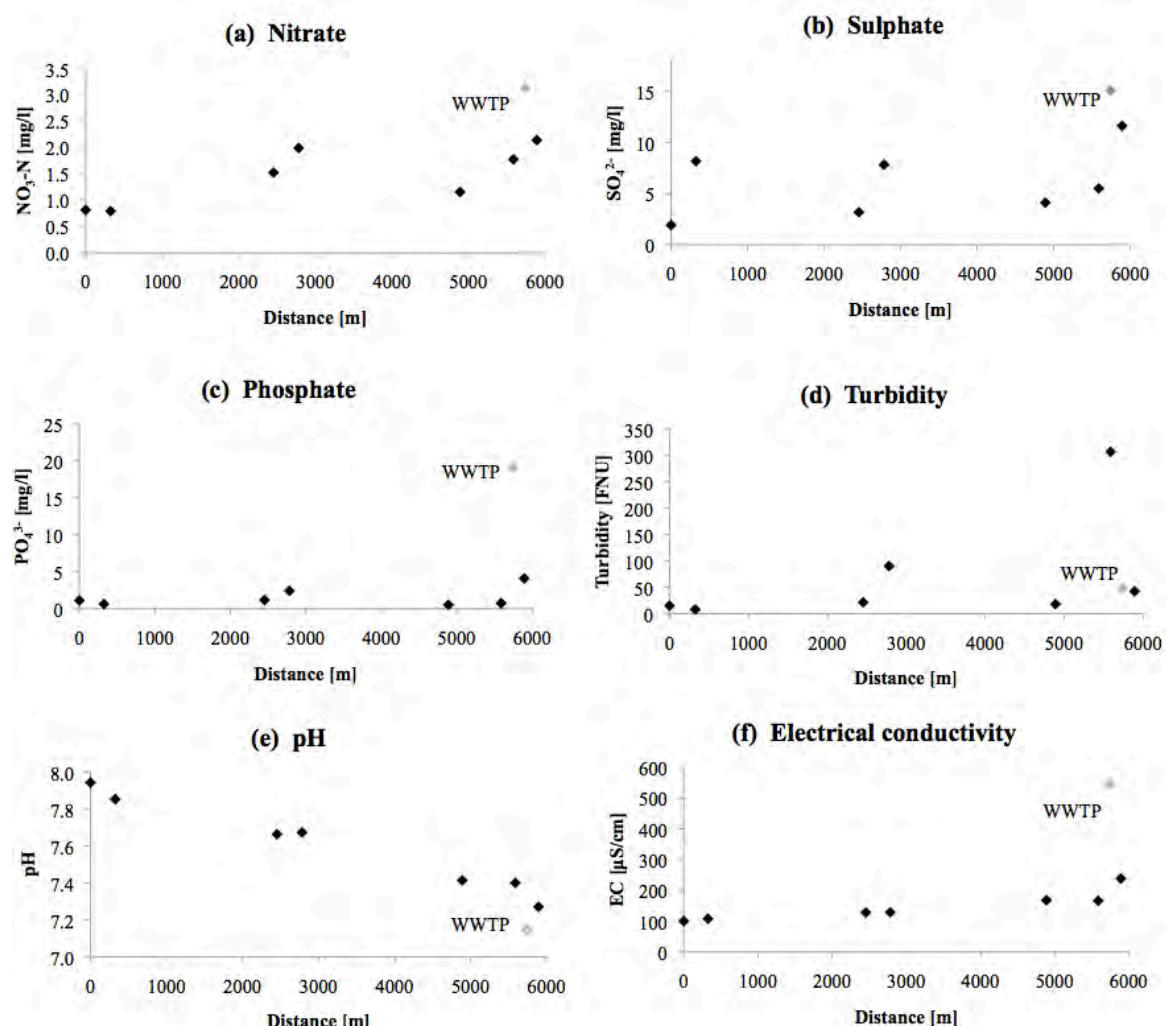


Figure 18. Spatial variations (a-f) of nitrate, sulphate, phosphate, turbidity pH and EC for the eight different sampling points. Results from WWTP effluents marked grey.

Calcium, sodium potassium and magnesium (Figure 19) all show a clear positive trend with distance, again with higher concentrations in the WWTP effluents, again showing an increase from sample point six to eight, however not as drastic as for the anions. Sodium stands out, which is reasonable, given that the salt concentration in domestic wastewater often is high. Sample point four does not stand out for these parameters, but actually decreases slightly. An possible explanation to the increase of these cations, and at the same time a clear positive trend of electrical conductivity could be enrichment due to evaporation of river water, which is significant in tropical climates like Malawi (river water temperature around 29° C).

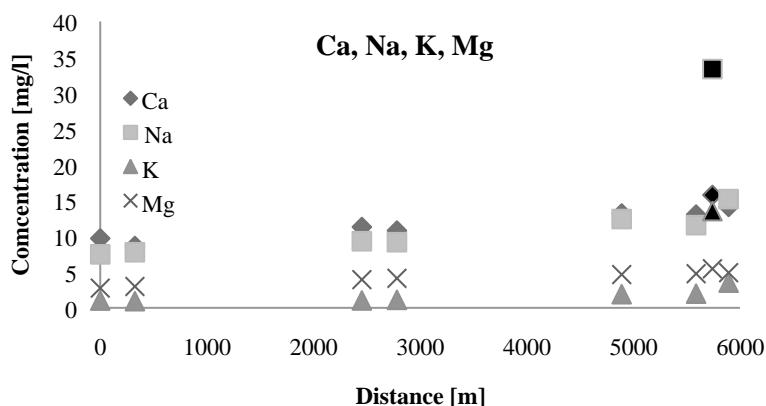


Figure 19. Spatial variations of calcium, sodium, potassium and magnesium for the eight different sampling points. Results from WWTP effluents marked black.

Of manganese, iron and aluminium, only manganese shows a significant trend with distance, whereas iron and aluminium have a maximum just before the WWTP effluents join in. This cannot be explained by the results in this study, but can possibly come from a point source of pollution.

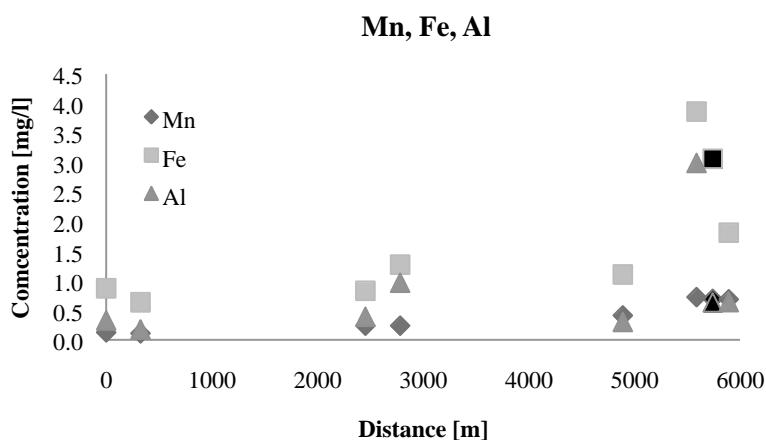


Figure 20. Spatial variations of manganese, iron and aluminium for the eight different sampling points. Results from WWTP effluents marked black.

Copper, chromium, lead and zinc remain quite constant on small concentrations with no clear trend, although lead seems to increase, however slightly (Figure 21). It is very likely that there are errors with the measurements of these elements, related to detection levels and use of an unsuitable range of calibration values.

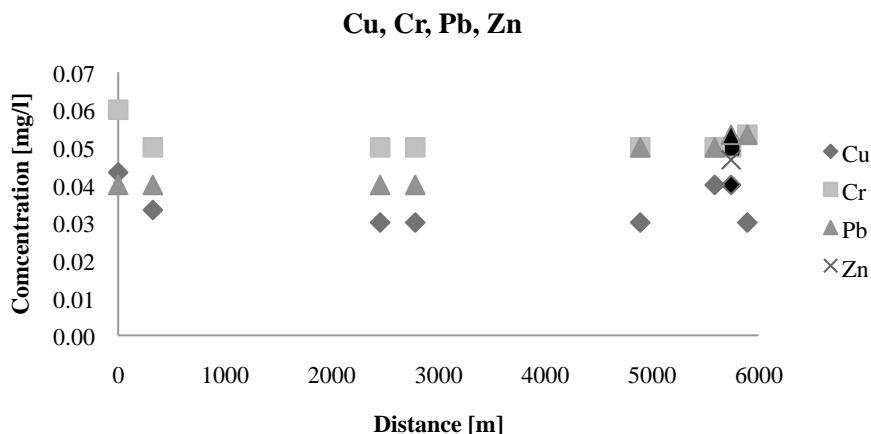


Figure 21. Spatial variations of copper, chromium, lead and zinc for the eight different sampling points. Results from WWTP effluents marked black.

Linear correlation between concentrations of sulphate, phosphate, nitrate, calcium, sodium, potassium, magnesium and pH and hydrogen ion concentrations, using the Pearson correlation coefficient are shown in Table 4. It is clear that the cations correlate well with each other, as well as with hydrogen ion concentrations, with r -values almost consistently over 0.8, a value that corresponds to $r^2 = 0.64$ and indicates a strong correlation. This supports the idea that at least some of the increase in cation concentrations over distance can be explained by evaporation of river water.

Table 4. Paerson Product-Moment Correlation Coefficient (r) for main parameters. Values of $r > 0.8$ marked grey.

r-value	SO ₄	PO ₄	NO ₃	Ca	Na	K	Mg	pH	[H ⁺]
SO₄	1.00	0.73	0.56	0.28	0.53	0.62	0.39	-0.45	0.51
PO₄		1.00	0.73	0.42	0.57	0.68	0.40	-0.43	0.50
NO₃			1.00	0.67	0.65	0.61	0.78	-0.70	0.66
Ca				1.00	0.94	0.85	0.94	-0.96	0.96
Na					1.00	0.96	0.89	-0.96	0.99
K						1.00	0.75	-0.86	0.94
Mg							1.00	-0.97	0.91
pH								1.00	-0.98
[H⁺]									1.00

Sources of error

A possible source of error in this study is the presence of turbidity in the samples used for measuring anions, even after filtration. The UV/VIS apparatus and the methods used for measuring sulphate and phosphorus are sensitive to small variations in turbidity, and this can have an effect on the results, showing as higher concentrations than actually true. Also the method for measuring nitrate is simplified and likely to give errors, compared to more accurate and intricate methods.

Further, the calibration standards for the MP-AES were all prepared with relatively high concentrations (1-5 mg/l), which is very reasonable for elements expected to contain roughly these concentrations. For trace elements however, it is very likely that better and much more reliable results could have been obtained if standards instead had been prepared with much lower concentrations. There were however not enough time and resources to redo these analyses.

5. Conclusion

It can be concluded from the results that for some of the analysed parameters (turbidity, Mg, Cr, Pb and Fe) were present in levels above recommended guideline values when the study was conducted, but also that the physio-chemical characteristics of water at several sites were within the limits set for drinking water use, as well as other purposes. Some of the parameters show clear trends with distance as the river flows through Zomba city, with generally poorer water quality downstream than upstream of the studied area.

Elevated levels of several pollutants in effluent, along with discolouring and foul odour, from Zomba Sewage Works imply that the treatment process is insufficient and improvements of the facilities are needed. Additional analysis focusing on the microbial content of the wastewater is called for.

6. References

6.1 Published

APHA (1999). American Public Health Association, American Water Works Association, Water Environment Federation. *Standard Methods of the Examination of Water and Wastewater*, 20th ed. New York: American Public Health Association (APHA), AWWA, and WPCF.

Chidya, R.C.G., Sajidu, S.M.I., Mwatseteza, J.F., Masamba, W.R.L. (2011). Evaluation and assessment of water quality in Likangala River and its catchment area, *Physics and Chemistry of the Earth*, 36, p. 865-871

Department of Surveys (1980). Malawi 1:50,000 Topographic Quadrangle Map, Zomba area.

Farhadinejad, T., Khakzad, A., Jafari, M., and Shoaei, Z. (2014). The study of environmental effects of chemical fertilizers and domestic sewage on water quality of Taft region, central Iran. *Arabian journal of geosciences* 7, p. 221–229

Gordon, A. K., Muller W. J., Gysman, N., Marshall S. J., Sparham, C. J., O'Connor, S. M. and Whelan, M. J. (2009). Effect of laundry activities on in-stream concentrations of linear alkylbenzene sulfonate in a small rural South African river. *Science of the Total Environment*, 407, p. 4465–4471

Hem, J. D, (1985). *Study and Interpretation of the Chemical Characteristics of Natural Water*, Vol. 2254, Department of the Interior U.S. Geological Survey.

Jönsson, H., Baky, A., Jeppsson, U., Hellström, D. and Kärrman, E. (2005). *Composition of urine, faeces, greywater and biowaste - for utilisation in the URWARE model*. Report 2005:6. Chalmers University of Technology: Urban Water.

Laycock, A, (2007). *Irrigation Systems: Design, Planning and Construction*, CABI Publishing, Wallingford, Oxon, GBR.

Lidström, V, (2013). *Vårt Vatten; Grundläggande lärobok i vatten- och avloppsteknik*. Second ed. Svenskt Vatten AB.

Lundgren, S, (2013). Efficiency of wastewater treatment plants situated in Zomba, Malawi. Uppsala Universitet, ISSN 1653-5634.

Mara, D. (2003). *Domestic Wastewater Treatment in Developing Countries*, London: Earthscan

MBS (2005). *Drinking water – Specifications*, Malawian bureau of standards, MS214.

NSO (2008). National Statistical Office. Malawi Population and Housing Census 2008 Main Report.

SMHI / SNV (1979). *Vattenföringsbestämning vid vattenundersökningar*. Stockholm : LiberFörlag/Allmänna förl.

Sreedharan S. and Damodaran P. (2011). Environmental Impact Assessment of Sand Mining from the Small Catchment Rivers in the Southwestern Coast of India: A Case Study. *Environmental Management*, 47, p. 130–140

Svenskt Vatten (2010). *Dricksvattenteknik 3; Ytvatten*. Svenskt Vatten AB.

Tan Peck Yen and H Rohasliney (2013). Status of Water Quality Subject to Sand Mining in the Kelantan River, Kelantan. *Trop Life Sci Res*, 24(1), p. 19–34

UN Habitat (2011). *Malawi: Zomba urban profile*, UN Habitat, Regional and Technical Cooperation Division

WHO (2011). *Guidelines for drinking water quality - fourth ed.*, Geneva: World Health Organization

Yamane, I and Nakazawa, T. (1986) Development of zeolitefor non-phosphated detergents in Japan. *Pure & Appl. Chem.* 58(10), p.1397-1404.

Zhitkovich, A. (2011). Chromium in drinking water: sources, metabolism, and cancer risks. *Chemical research in toxicology* 24, 1617–1629.

6.2 Internet

About Africa Travel (2014). *Map and basic facts about Malawi*.

<http://goafrica.about.com/library/bl.mapfacts.malawi.htm>

[Retrieved: 2014-12-28]

EPA, United States Environmental Protection Agency (2014). *National Primary Drinking Water Regulations*.

<http://water.epa.gov/drink/contaminants/upload/mcl-2.pdf>

[Retrieved: 2015-01-30]

FAO (2014). *Country profiles: Malawi*.

<http://www.fao.org/countryprofiles/index/en/?iso3=MWI>

[Retrieved: 2014-12-28]

Laerd Statistics (2013). *Pearson Product-Moment Correlation*.

<https://statistics.laerd.com/statistical-guides/pearson-correlation-coefficient-statistical-guide.php>

[Retrieved: 2015-02-02]

UN Data (2014). *Malawi*.

<http://data.un.org/CountryProfile.aspx?crName=malawi>

[Retrieved: 2015-01-03]

UNDP (2014). *Human development index (HDI)*.
<http://hdr.undp.org/en/content/human-development-index-hdi-table>
[Retrieved: 2014-12-28]

UNESCO World Heritage Centre (2014). *Lake Chilwa Wetland*.
<http://whc.unesco.org/en/tentativelists/5604/>
[Retrieved: 2015-01-03]

UNICEF (2013). *Malawi, Statistics*.
http://www.unicef.org/infobycountry/malawi_statistics.html
[Retrieved: 2014-12-28]

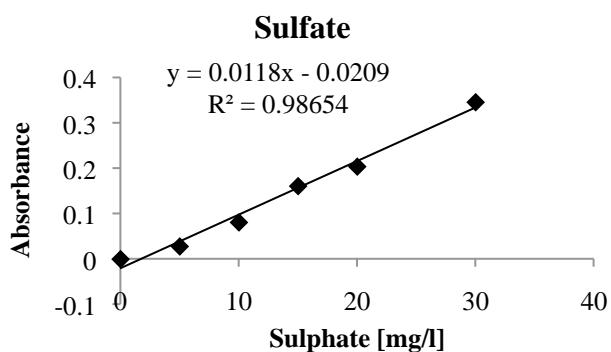
University of Regina (2014). *Regression*
<http://uregina.ca/~gingrich/regr.pdf>
[Retrieved: 2015-01-03]

WHO.int (2014). *Malawi*.
<http://www.who.int/countries/mwi/en/>
[Retrieved: 2014-12-28]

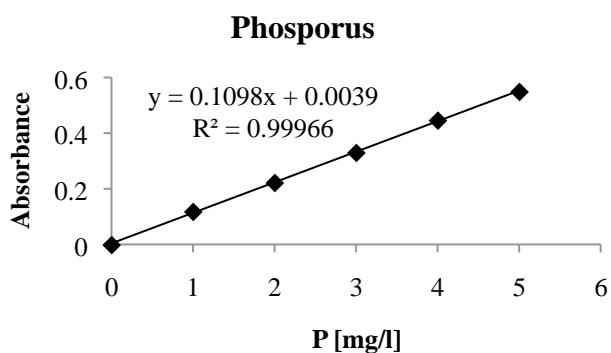
Appendix

I. Calibration curves for UV/VIS

I. A



I. B



I. C

