Water Quality Survey,
Ruvu River Basin, Tanzania

Tanzania Integrated Water, Sanitation and Hygiene (iWASH) Program

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SUMMARY

This document synthesizes all known historical water quality records for sites in the Ruvu Basin and is a presentation and analysis of new data collected during a water quality survey in October, 2013.

Historically, bacterial pollution has been the primary pollutant of concern in the Ruvu Basin. From 2006 through the last major sampling event in 2009, all surface water samples have exhibited high fecal coliform levels (>200 cfu/mL). The highest levels are consistently found at Duthumi and Kikundi River. The high levels of fecal coliforms coupled with higher than average levels of ammonia at the Duthumi site is a clear indication of human and/or animal waste contamination in the river. During the most current survey in October, 2013, the Ngerengere River has shown higher levels of bacterial contamination than it has shown in the past.

Unsurprisingly, industrial effluent sites have higher levels of contaminants than the surface water sampling sites. However, certain industries have been improving the quality of their waste water and those changes have been detected in the most recent effluent samples.

Water quality was the most varied among sites during the 2006 sampling campaign. Since then, water quality has improved at many sites, although it has deteriorated at Kikundi River. Temporal comparisons for many sites are not possible since they have only been sampled once or twice in the last four years.

Mindu Dam and Kikundi River are two sites that have consistently shown poor water quality, as evident by multiple water quality parameters. Both sites are drainages close to Morogoro town.

Low temperatures coupled with high nutrient levels at Mzinga Bridge are a clear indicator of industrial effluents entering the river. Levels appear to be increasing since past sampling events.

Currently, EFA Site 1 (Ruvu at Kibungo) appears to have the best water quality while EFA Site 4 (Ngerengere at Mgude) has the lowest. EFA Site 2 (Mgeta at Dutumi) is plagued by heavy pastoralist use while EFA Site 5 (Ruvu at Kongo) is strongly influenced by ocean conditions. EFA Site 3 (Ruvu at Kidunda) represents equal mixing of the conditions from the Mgeta and Upper Ruvu (EFA Sites 1 and 2).

OBJECTIVE

The objective of this document is to summarize all known historical water quality information from the Ruvu Basin, present new data from recent surveys, and analyze the data for trends and useful information that can be used to assist with the setting of the environmental flow requirements for the Ruvu River.

DATA COMPILATION AND ANALYSIS METHODS

Historical water quality data was received from Mr. Stanely Daudi, Water Quality Officer from the Wami Ruvu Basin Water Office.

Relevant data was extracted from Microsoft Word documents and sorted in Excel spreadsheets. Several of the site names changed throughout the different years of water quality sampling. Some of the changes are easily recognized and others are not. When possible, I have matched the historical name with the current name and I only refer to it as the current name in the analysis.

Table 1: Water Quality Analysis Historical and Current Site Names

Historical Name	Current Name
Moruwasa	Mindu Dam
Ngerengere Tlai Confluence	Morogoro Industrial Area
Kinole W/S	Kinole Intake
Ruvu at Kibungo	Kibungo Bridge
Mlali	Mlali/Mzumbe
Kikundi River	Kikundi M/Mpya

Data was then imported into R (2.15.1) through RStudio (0.97.314). Summary information was presented using the ggplot2 library comparing the industrial sites and the surface water river sites. Summary information was also graphically presented illustrating general water quality trends for each of the river sites temporally and on a site basis. Hierarchical clustering was performed using Euclidean distance and Ward's method after the data was normalized to group similar site samples together.

Many gaps were present in the full datasheet due to non-consistency in the parameters measured during the different sample years. The largest amount of information was available for the primary river sites and four water quality parameters; pH, electrical conductivity, nitrates and phosphates. Using those primary sites and those four water quality parameters, a Principal Components Analysis was computed utilizing the "prin_comp" function from the

Vegan library to group similar sites together and illustrate general water quality trends over time.

SITES

All geographic position information has been converted to decimal degrees. Location information for the primary sample sites over the historical record are presented in Table 2. EFA sites have been noted in the table. All EFA sites are previously sampled sites except for EFA Site 5, Lower Ruvu at Kongo. No historical data exists for that site. GPS information was not available for Industry sample sites. Most of those sites are situated near Morogoro town.

Table 2: Primary Sample Sites

Longitude	Latitude	Name	Comments
37.8094	-7.0237	1H5 Ruvu at Kibungo	EFA Site 1
37.6726	-6.7696	Morogoro Industrial Area	
38.2172	-7.2696	1H3 Ruvu at Kidunda	EFA Site 3
38.6939	-6.6904	1H8A Ruvu at Morogoro Rd. Bridge	
38.8698	-6.3971	Ruvu in Estuary	
37.5667	-7.0333	1HB2 Mgeta at Mgeta	
37.7766	-7.4117	Local MgD, Mgeta at Duthumi	EFA Site 2
37.9177	-7.2403	1HC2A Mvuha at Tulo School	
37.6723	-6.8455	1HA8A Morogoro at Morogoro	
37.7576	-6.7518	1HA3 Ngerengere at Kingolwira	
38.1445	-6.7637	1HA15 Ngerengere at Mgude	EFA Site 4
37.6140	-6.8554	Mindu	
37.5616	-6.9012	Mlali/Mzumbe	
37.6369	-6.9042	Mzinga/ Luhungo	
37.6121	-6.8886	Mzinga/ Bridge	
37.6679	-6.8230	Kikundi M/Mpya	
38.0379	-6.6514	Bwawani Ngerengere	
37.7693	-6.9249	Kinole Intake	
38.8207	-6.5389	Lower Ruvu at Kongo	EFA Site 5

The sample sites are reasonably well spaced throughout the basin, with most of the sites positioned near Morogoro town (Figure 1).

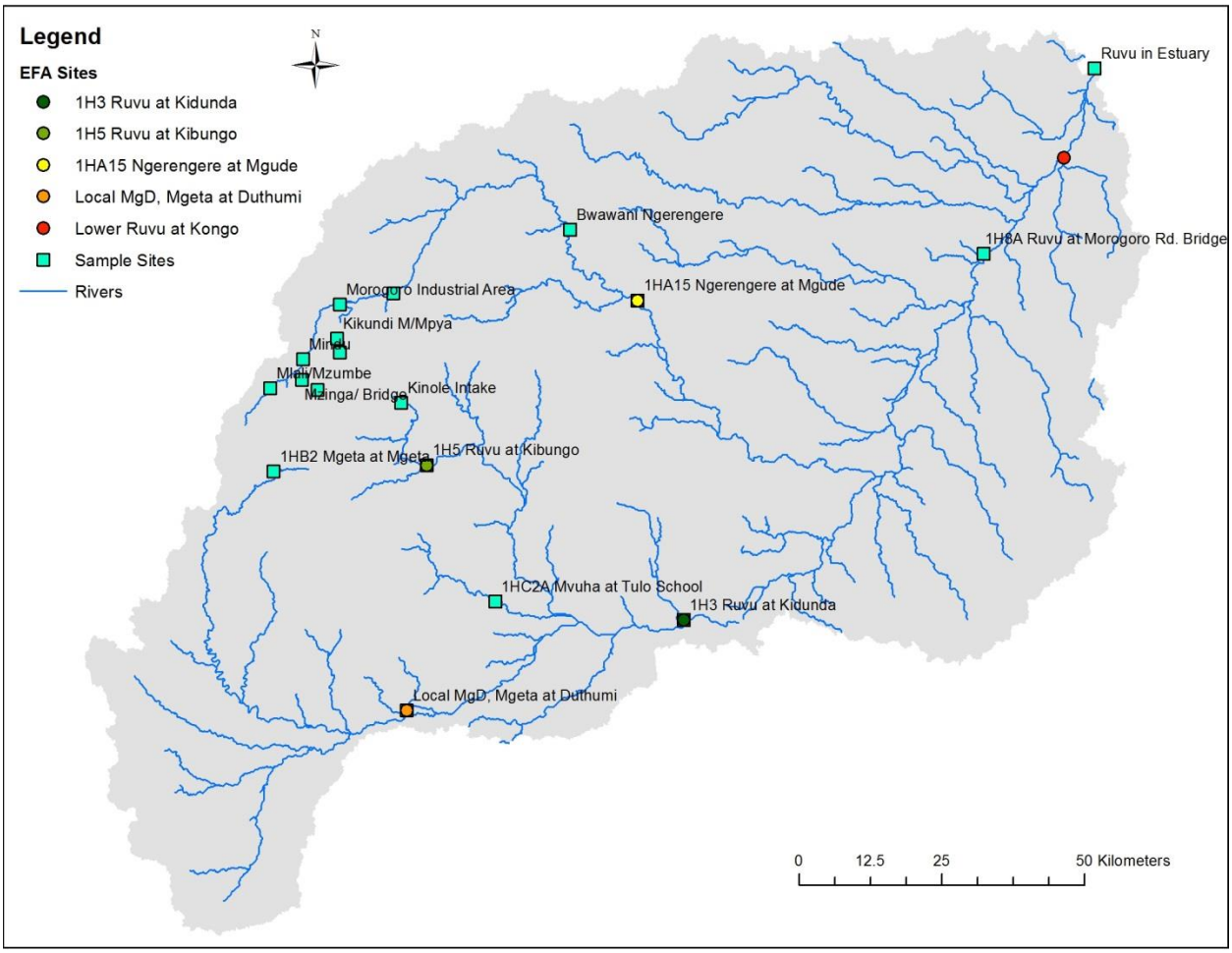

Figure 1: Sample and EFA Sites

WATER QUALITY STANDARDS

The Government of Tanzania sets water quality standards for receiving waters. The most common standards applicable to this study are presented in Table 3. The rest of the standards are provided in Appendix 1.

Table 3: Common water quality standards for receiving waters in Tanzania

Substance/ Characteristic	Unit	Maximum Permissible Concentration		
		Category 1	Category 2	Category 3
Suspended Matter (turbidity)	mg/l (as Si02)	Discharge of effluents shall not cause formation of sludge or scum in the receiving water.		
Colour	Number (pt-Coscale)	Discharge of effluents shall not cause any change in the natural colour of the receiving water.		

Substance/ Characteristic	Unit	Maximum Permissible Concentration		
		Category 1	Category 2	Category 3
Taste and odour	-	Discharge of effluents shall not cause change in the natural taste or odour of the receiving water.		
Temperature	ºC	Discharge of effluents shall not raise the temperature of the receiving water by more than 5ºC.		
Total dissolved solids	mg/l	2,000	2,000	No Limit.
pH	-	6.5-8.5	6.5-8.5	6.5-9.0
Dissolved oxygen	mg/l	6	5	3
Oxygen solution	%	80	60	40
Nitrates (NO3)	mg/l	50	50	100
Nitrites (NO2)	mg/l	As low as is required to prevent eutrophication or excessive weed growth if nitrogen is a limiting.		
Phosphates (PO43-)	mg/l	Nutrient in waters which are susceptible to eutrophication or excessive weed growth, or in rivers and streams draining into such waters, the lowest possible concentration should be aimed as if phosphorous is a limiting nutrient.		
Sulphates (SO42-)	mg/l	600	600	600

The Tanzania Environmental Management Act sets the standards for allowable industry effluents. The most common physical and inorganic parameter standards are presented in Table 4.

Table 4: Tanzania industrial effluent standards

Parameter	Limit
BOD5 at 20 oC	30 mg/l
COD	60 mg/l
Colour	300 TCU
pH range	6.5-8.5
Temperature range	20-35oC
Total Suspended Solids (TSS)	100 mg/l
Turbidity	300 NTU
Aluminium (as Al)	2 mg/L
Arsenic (As)	0.2 mg/L
Barium (Ba)	1.5 mg/L
Cadmium (Cd)	0.1 mg/L
Chlorides (Cl-)	200 mg/L
Chromium (total)	1 mg/L

Parameter	Limit
Chromium VI	0.1 mg/L
Cobalt (Co)	1 mg/L
Copper (Cu)	2 mg/L
Fluorides (F-)	8 mg/L
Iron	5 mg/L
Lead (Pb)	0.1 mg/L
Manganese	5 mg/L
Mercury (Hg)	0.005 mg/L
Nickel (Ni)	0.5 mg/L
Nitrates (NO3-)	20 mg/L
Phosphorus Total (as P)	6 mg/L
Selenium (Se)	1 mg/L
Silver (Ag)	0.1 mg/L
Sulphate (SO4)	500 mg/L
Sulphides (S-)	1 mg/L
Tin (Sn)	2 mg/L
Total Kjeldahl Nitrogen (as N)	15 mg/L
Vanadium	1 mg/L
Zinc (Zn)	5 mg/L

The Government of Tanzania has also set standards for organic pollutants as well as standards for specific industries such as the chrome tanning industry, the vegetable tanning industry and the fertilizer industry. Those standards are presented in Appendix 2.

PART I – HISTORICAL DATA

The Wami-Ruvu Basin Water Office began a water quality survey program in 2006. As part of that program, several water quality and industry effluent sites are sampled once per year to help inform on water quality trends in the basin. Due to limited funding, there have only been four water quality sampling events since the inception of the program.

The basin water office water quality sampling program collects information on the following parameters

- Dissolved Oxygen
- pH
- Electrical Conductivity (TDS)

- Temperature
- Phosphates
- Nitrates
- Sulphates
- Ammonia
- BOD
- COD

Sample processing routinely[1] occurs in the field for pH, temperature, and electrical conductivity (total dissolved solids). Dissolved oxygen, phosphates, nitrates, sulphates, and ammonia are all analyzed at the water quality office in Morogoro. BOD and COD are analyzed at the head water quality laboratory in Dar es Salaam. Detailed methods information is provided in Appendix 3. Turbidity, color, calcium, alkalinity, hardness, chloride, fluoride, iron and manganese have been analyzed infrequently.

Two types of sample sites are routinely sampled from during the water quality surveys; industry and river. Industry sites are typically effluent discharge canals that have just entered the main river. River sites are typically surface water sites with no apparent industry nearby.

Discharge and/or rainfall data are not available or published with the water quality survey reports. Some of the temporal differences noted could be a result of an increase or decrease of average discharge during that hydrological year.

The major findings from the four historical water quality sampling events are summarized here:

2006 - 2007 Sampling Year

- All rivers sampled exhibited high amounts of fecal coliforms (350 -50,000 cfu/100mL).
- Several surface water samples exhibited phosphate values in excess of the Tanzanian standard (> 10mg/L)
- Industry discharge points had high levels of BOD and COD.
- Human activities were determined to be the major cause of pollution in the basin.

2007 – 2008 Sampling Year

- All sampled rivers were again found to contain high levels of fecal coliforms (250 -75,000 cfu/100mL).
- Several surface water samples exhibited high nitrate values.
- All surface water samples had phosphate values below the Tanzanian standard.

[1] Small variations in the sampling method have been reported each year due to equipment availability or the adoption of new methods.

- All surface and ground water samples were found to have minimal chemical pollution (due to low values of pH, conductivity, sulphates, phosphates, ammonia and nitrate).
- Most industries visited did not have waste water treatment leading to high BOD and COD in their effluent.

2008 - 2009 Sampling Year

- All groundwater samples were within Tanzanian standards.
- All surface water samples had high fecal coliform counts (320 – 4,800 cfu/100mL)
- Several industries have begun to rehabilitate their infrastructure.

2009 – 2010 Sampling Year

- pH and conductivity measurements were within Tanzanian standards for all surface and groundwater samples.
- Industry effluent samples exhibited characteristics of organic pollution (exhibited by low dissolved oxygen and high BOD and COD).
- Fecal coliforms remain a primary concern, with all sites exhibiting levels above the Tanzanian standards (250 – 5400 cfu/100mL).
- The effluent from several industries now meets Tanzanian standards (MORUWASA, DUWASA (SWASWA WSP) and Mtibwa Sugar Estate WSP).
- Several industries continue to discharge untreated waste water directly into the river (Serengeti Breweries, MMI Industries, BIDCO, Muzah Mill, Royal Textile and KTM textile).
- All groundwater samples were found to be within Tanzanian standards.

Synthesis

Comparison Between Industrial and River Sampling Sites

Electrical conductivity is almost always higher at effluent sites. Average electrical conductivity at river sites is approximately 380 us/cm compared to 2700 us/cm for industrial sites.

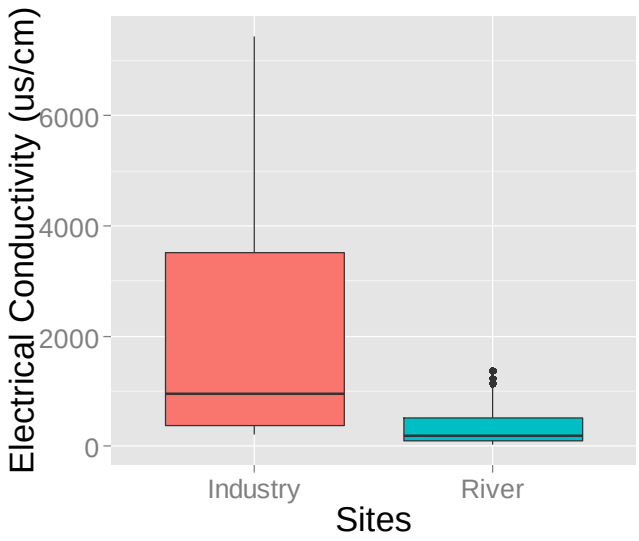

Figure 2: Industry and River Sites – Electrical Conductivity (us/cm)

pH is also consistently higher at industrial sites than river sites.

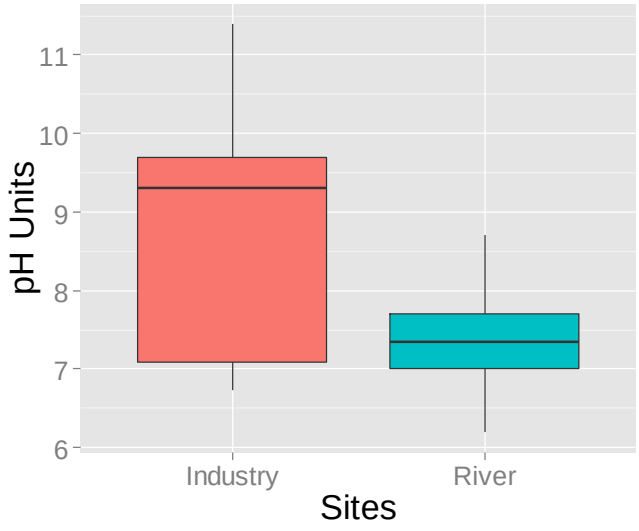

Figure 3: Industry and River Sites – pH Units

Dissolved Oxygen is significantly higher at river sites when compared to industrial effluent sites.

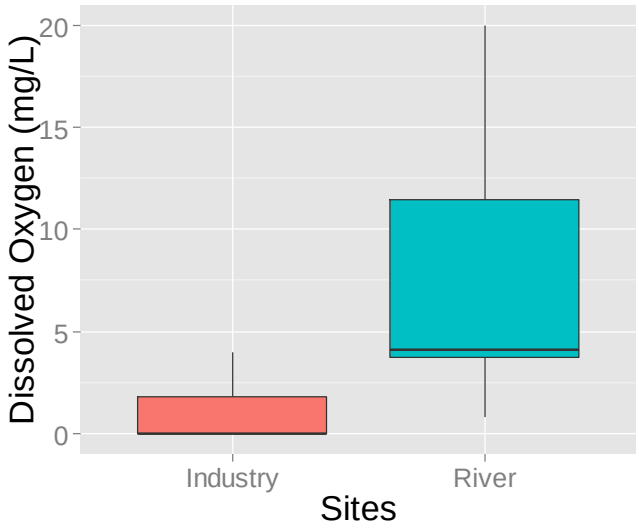

Figure 4: Industry and River Sites - Dissolved Oxygen (mg/L)

Almost all industrial effluent sites regularly exceed the allowable amount of ammonia in their effluents. Most of the river sites have low levels of Ammonia due to the relatively quick conversion from Ammonia to Nitrites and Nitrates.

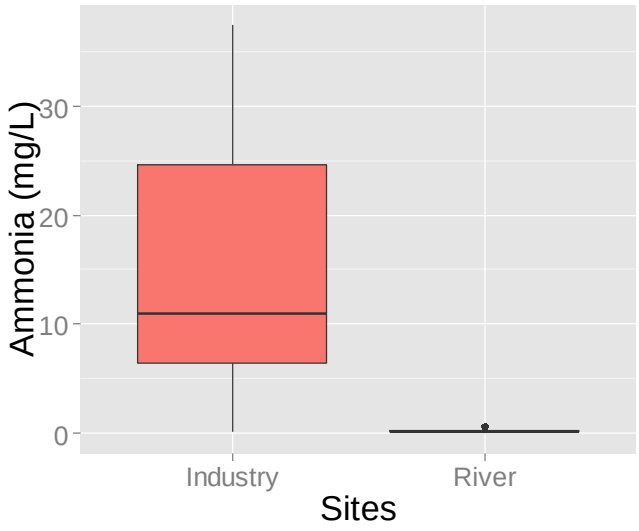

Figure 5: Industry and River Sites – Ammonia (mg/L)

Phosphates are generally low at industrial and river sites. Mzinga Bridge has exhibited phosphates levels over 10 mg/L.

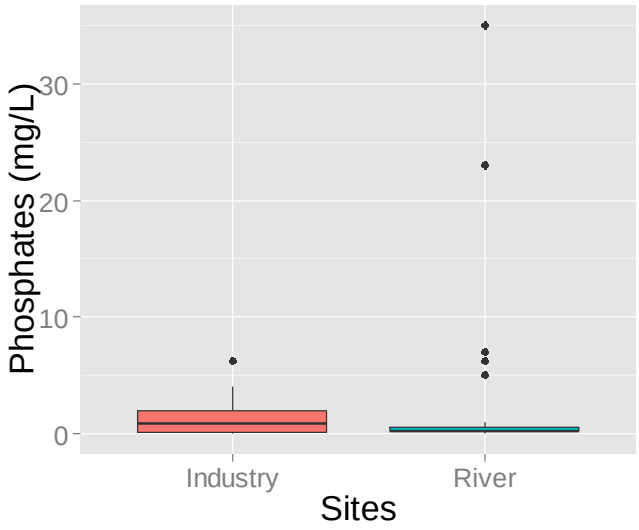

Figure 6: Industry and River Sites – Phosphates (mg/L)

Basin-Wide Trends

Basin-wide trends are summarized only for river sites. Industry sites are not presented here.

Electrical Conductivity varies throughout the basin. The highest levels are routinely recorded at Mindu Dam and Kikundi River. Both of those sites are drainages from Morogoro town.

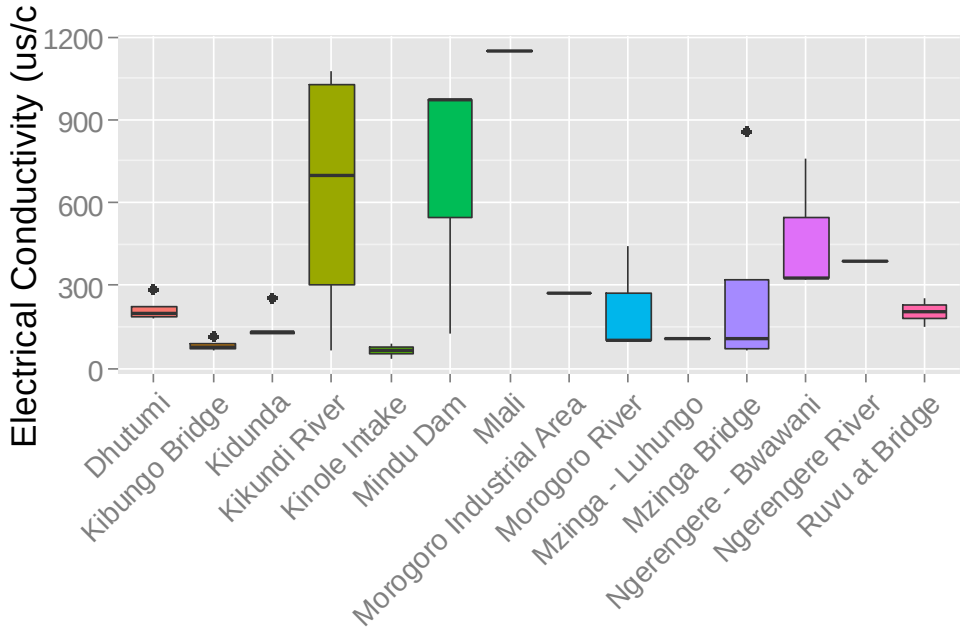

Figure 7: River Sites – Electrical Conductivity (us/cm)

Dissolved Oxygen in the rivers within the Ruvu Basin averages approximately 7.5 mg/L. Unfortunately, there are many data gaps for this parameter so it is difficult to identify strong trends. The lowest value recorded was 0.8 mg/L from the Kikundi River in 2009.

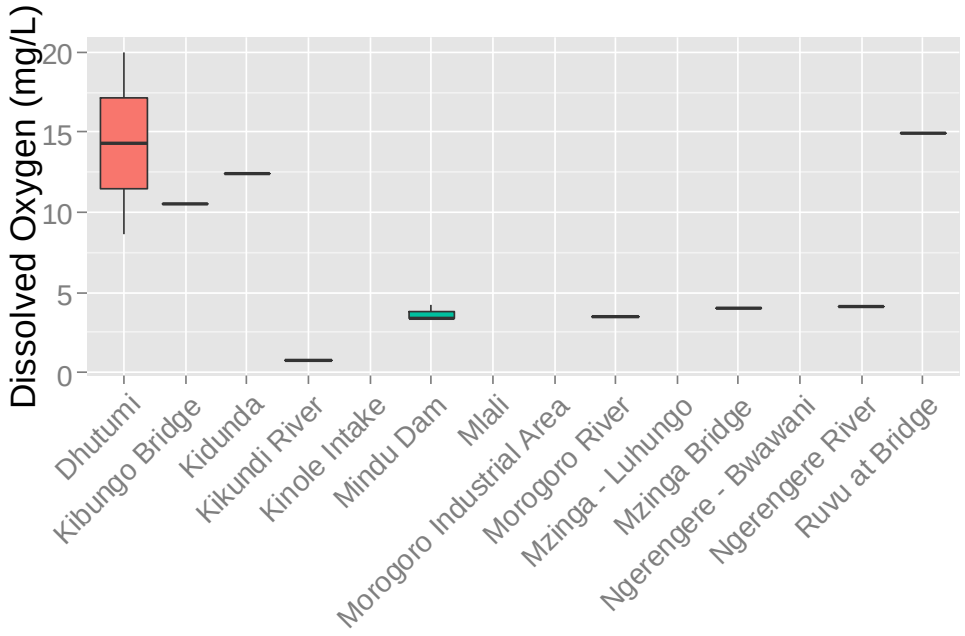

Figure 8: River Sites – Dissolved Oxygen (mg/L)

Temperature is highest at Dutumi, Kibungo Bridge and Kidunda (EFA Sites). Temperature is lowest at Kikundi River and Mzinga Bridge.

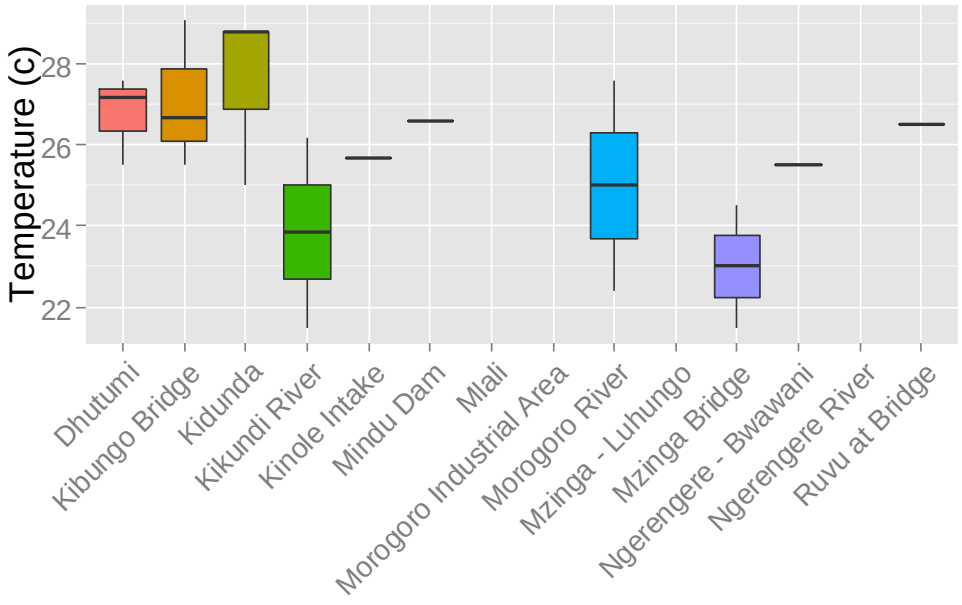

Figure 9: River Sites – Temperature (c)

pH varies throughout the basin with the lowest values consistently recorded at the Ruvu Morogoro Bridge. The highest pH values are consistent found at Mindu Dam and the Ngerengere River, drainages of Morogoro town.

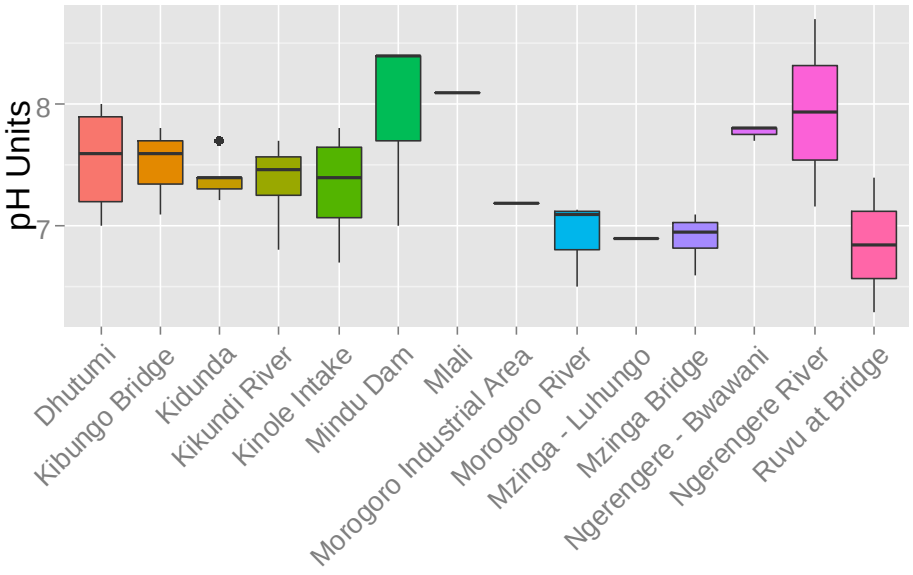

Figure 10: River Sites – pH Units

Mzinga Bridge and Mindu Dam have the highest phosphate levels in the basin.

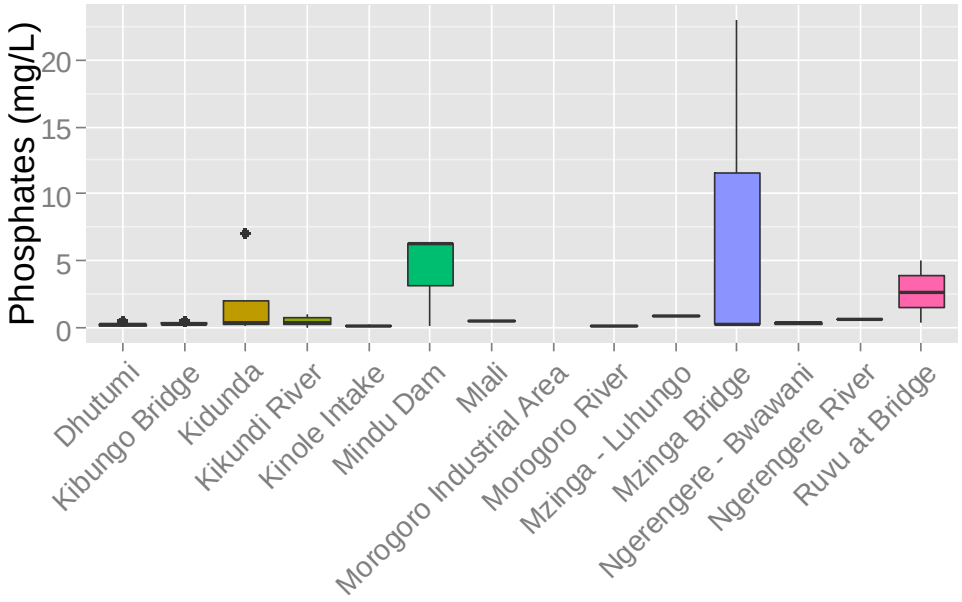

Figure 11: River Sites – Phosphates (mg/L)

Fecal coliforms exceed Tanzanian standards at all sites where data has been collected. Levels routinely recorded at Dutumi and Kikundi River are extremely high.

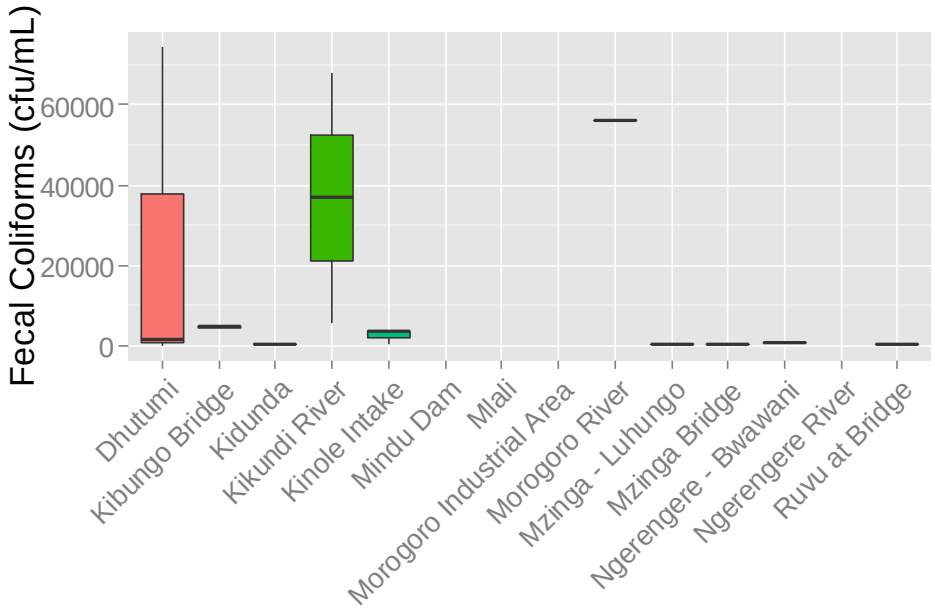

Figure 12: River Sites – Fecal Coliforms (cfu/mL)

Ammonia levels are generally high throughout the basin. Dhutumi has some of the higher levels found in this basin followed by Mzinga Bridge.

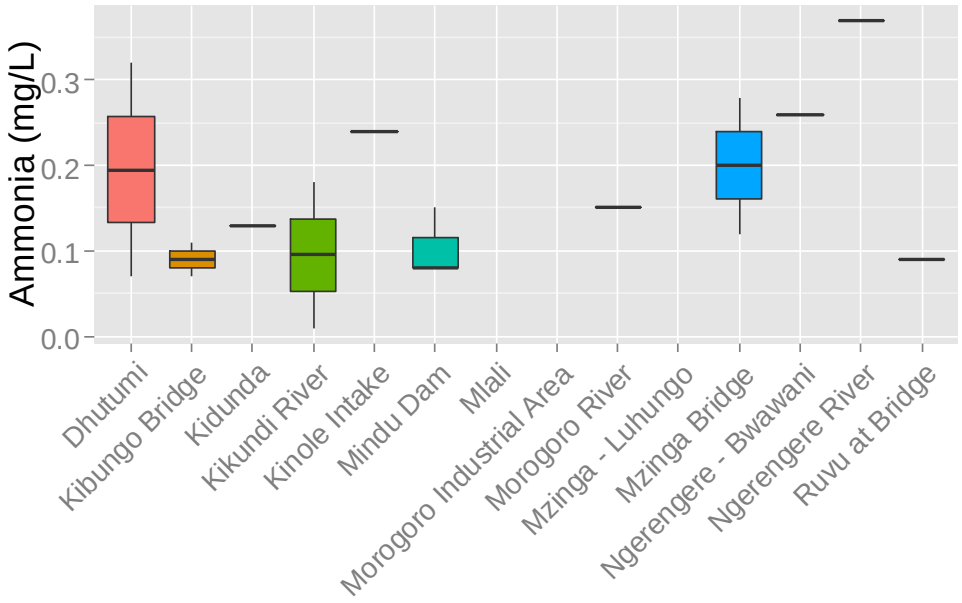

Figure 13: River Sites – Ammonia (mg/L)

Nitrate levels vary throughout the basin with the highest levels consistently found at Dutumi and Kikundi River.

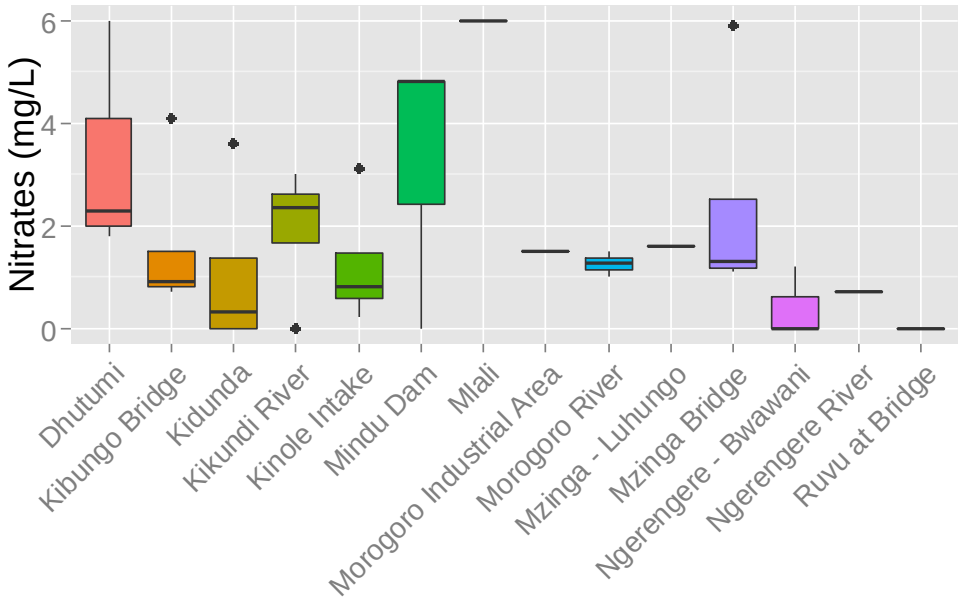

Figure 14: River Sites – Nitrates (mg/L)

TEMPORAL TRENDS

Electrical Conductivity has increased over time at Kikundi River, Mzinga Bridge and Mzinga-Luhungo.

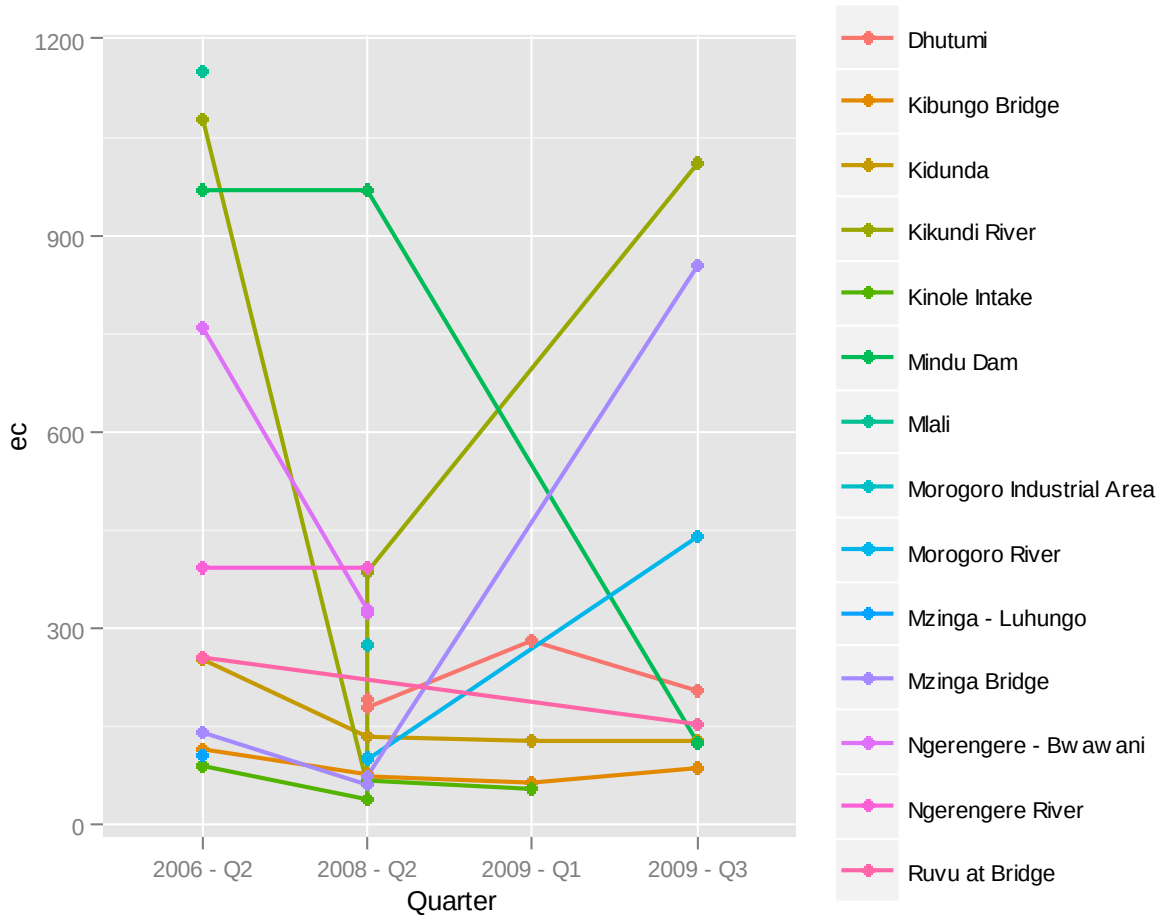

Figure 15: Temporal Trends – Electrical Conductivity (us/cm)

pH was more varied in previous sampling campaigns. During the last samples taken in 2009, pH units ranged from 7 to approximately 7.6 units.

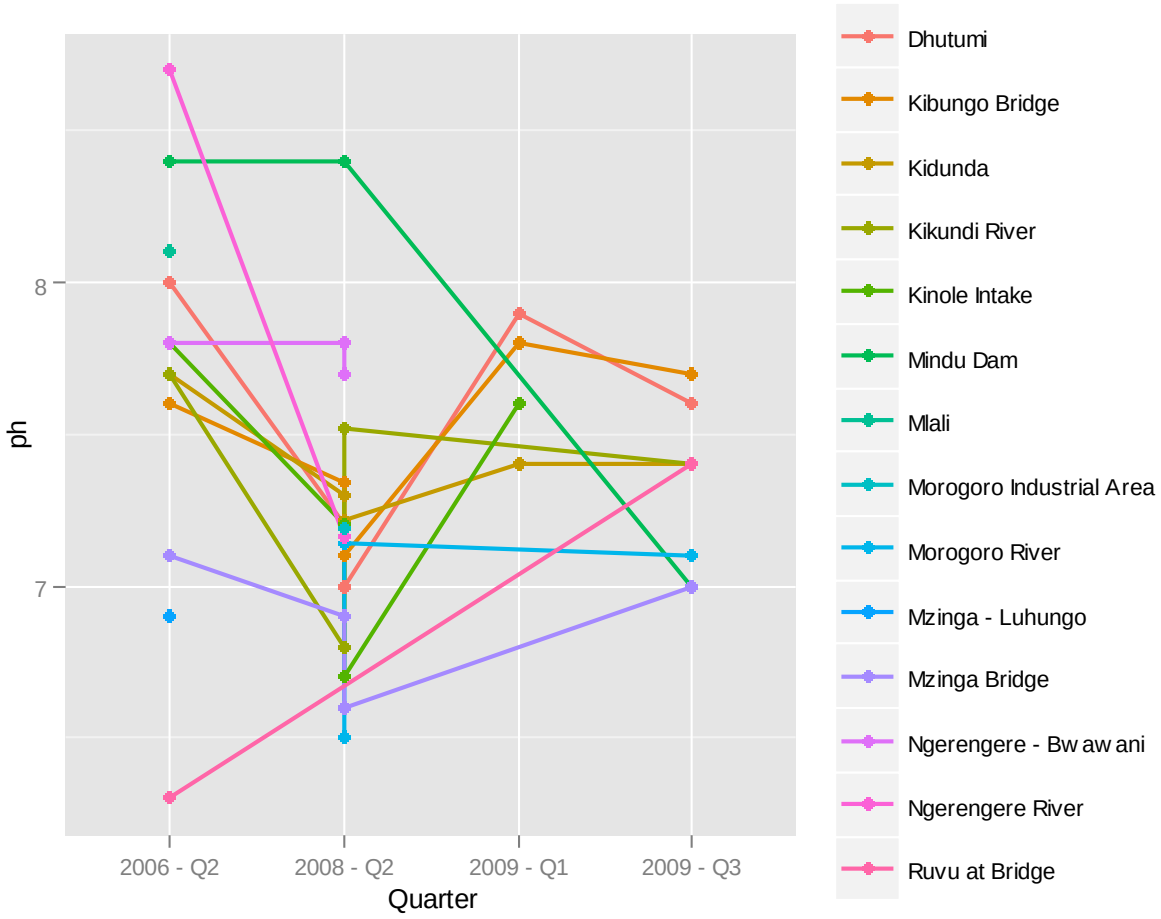

Figure 16: Temporal Trends – pH Units

Nitrate levels have been decreasing among all sites.

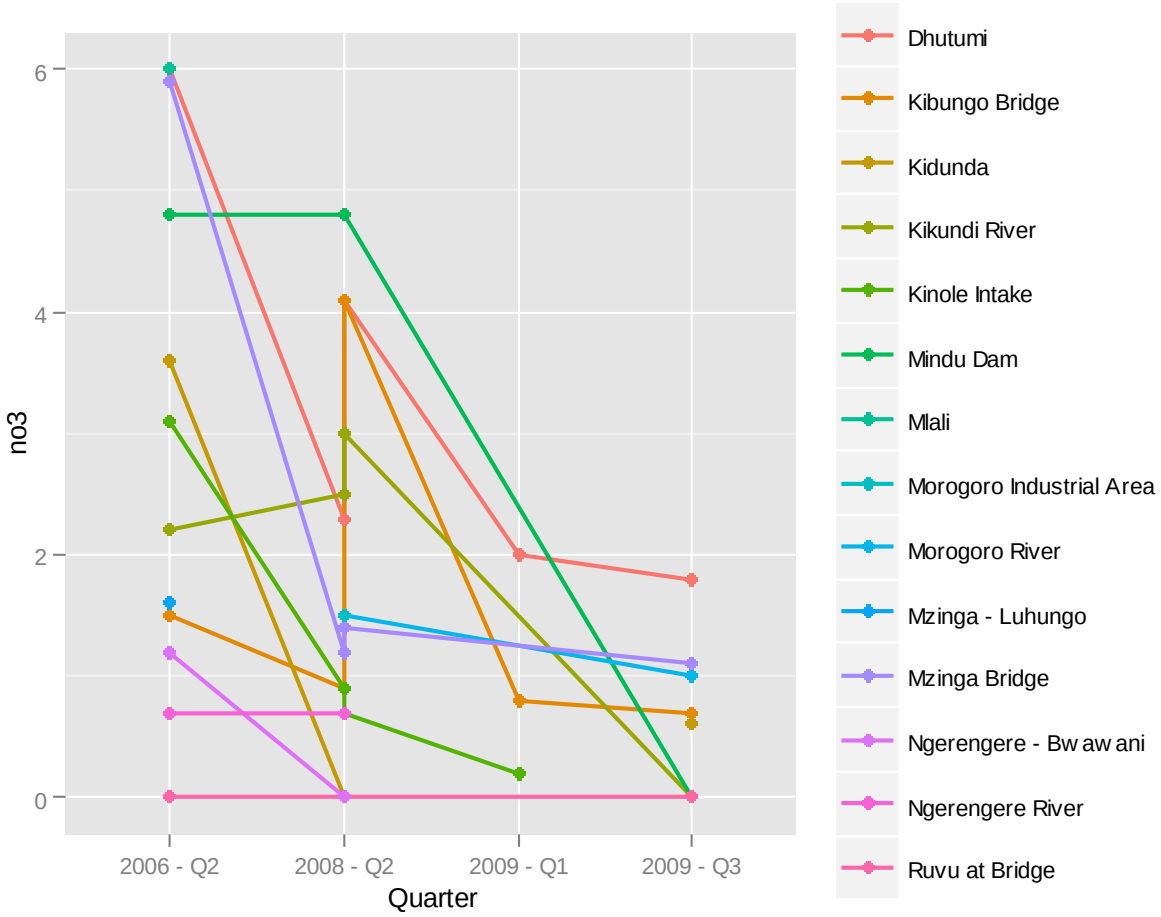

Figure 17: Temporal Trends – Nitrates (mg/L)

Hierarchical clustering identified three main groupings of sites based on their water quality. The samples taken from the sites identified on the right of the chart had relatively good water quality. The samples taken from the sites identified on the left side of the chart had relatively poor water quality.

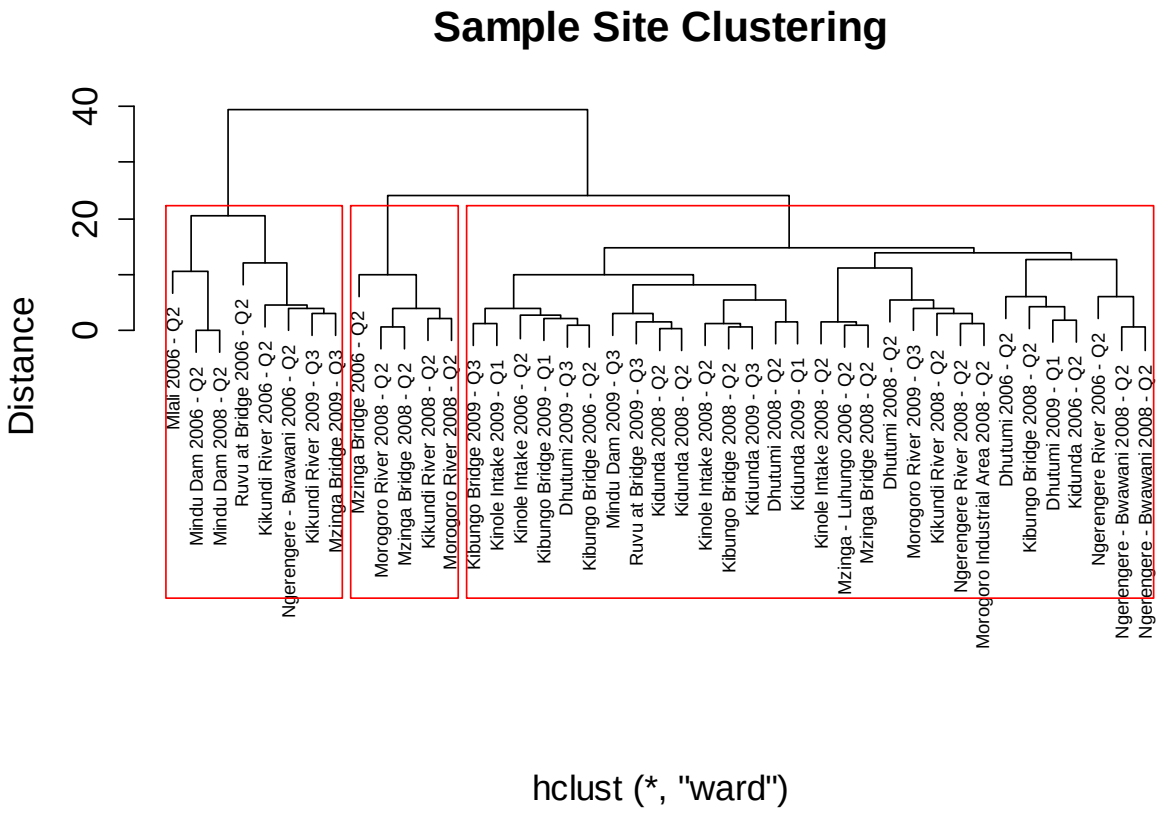

Figure 18: Sample Site Clustering

A principal components analysis (PCA) was utilized to illustrate how the water quality has changed in the basin over the last four years.

According to the PCA and the four parameters (pH, electrical conductivity, nitrates and phosphates) utilized to create it, the water quality in the basin was more varied in 2006/earlier sampling periods than it is now. The outer red circle represents the 95% probability confidence interval that any other site sampled from Q2 2006 would fit within that circle. In the later sample years, the circle becomes more condensed. In addition, the centroid of the probability circle moves up and to the right in the PCA biplot. This indicates that water quality between sites in the basin is becoming less varied in the more recent sample years and that the overall water quality has improved.

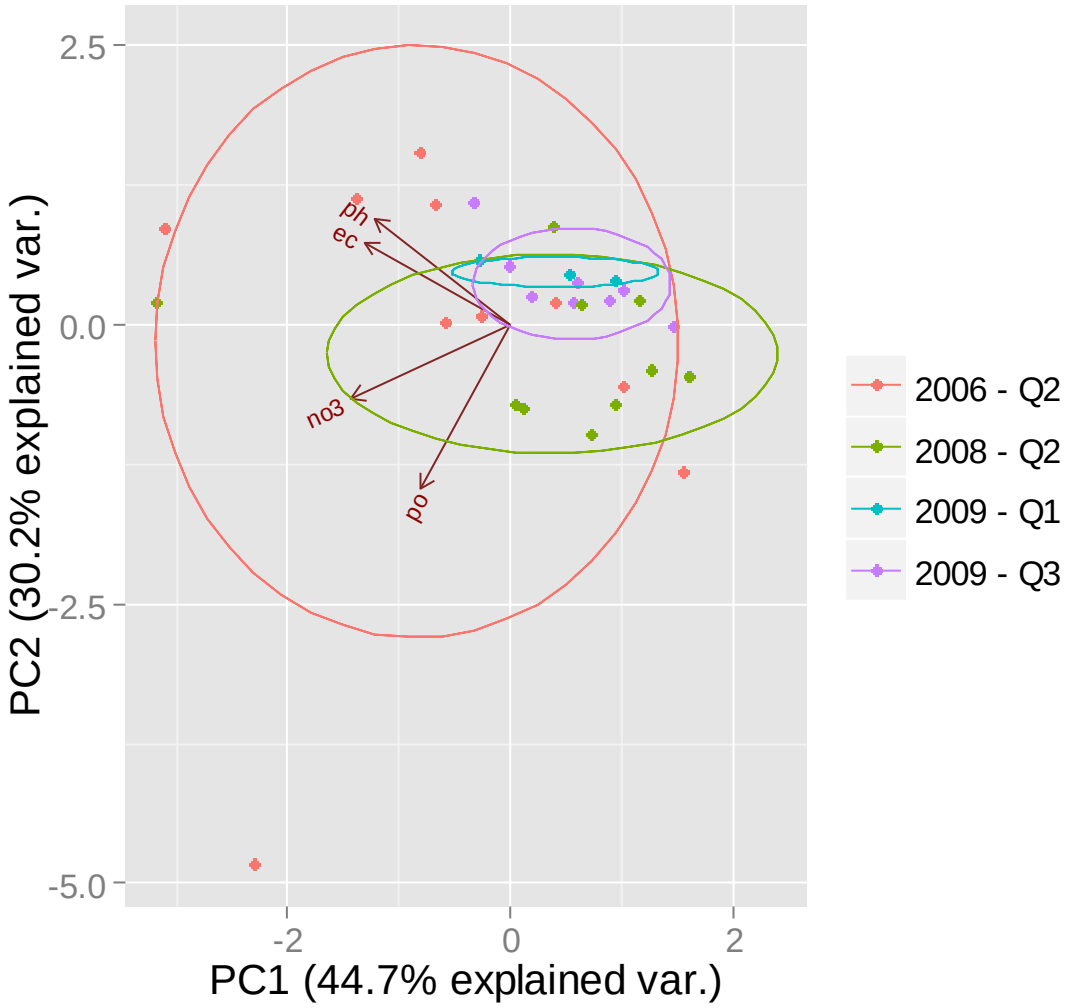

Figure 19: PCA Plot with 95% Confidence Intervals

The PCA can also help us to quickly identify the poorest water quality sites. Sites that are further to the left side of the plot have the poorest water quality. The direction and strength of the arrows for phosphates, nitrates, electrical conductivity and pH all go in a general left direction. As those values increase, the sites end up further on the left side of the graph. Mlali, Mindu Dam and Mzinga Bridge have the poorest water quality compared to the other sites.

Sites that are closer together on the plot also have similar water quality.

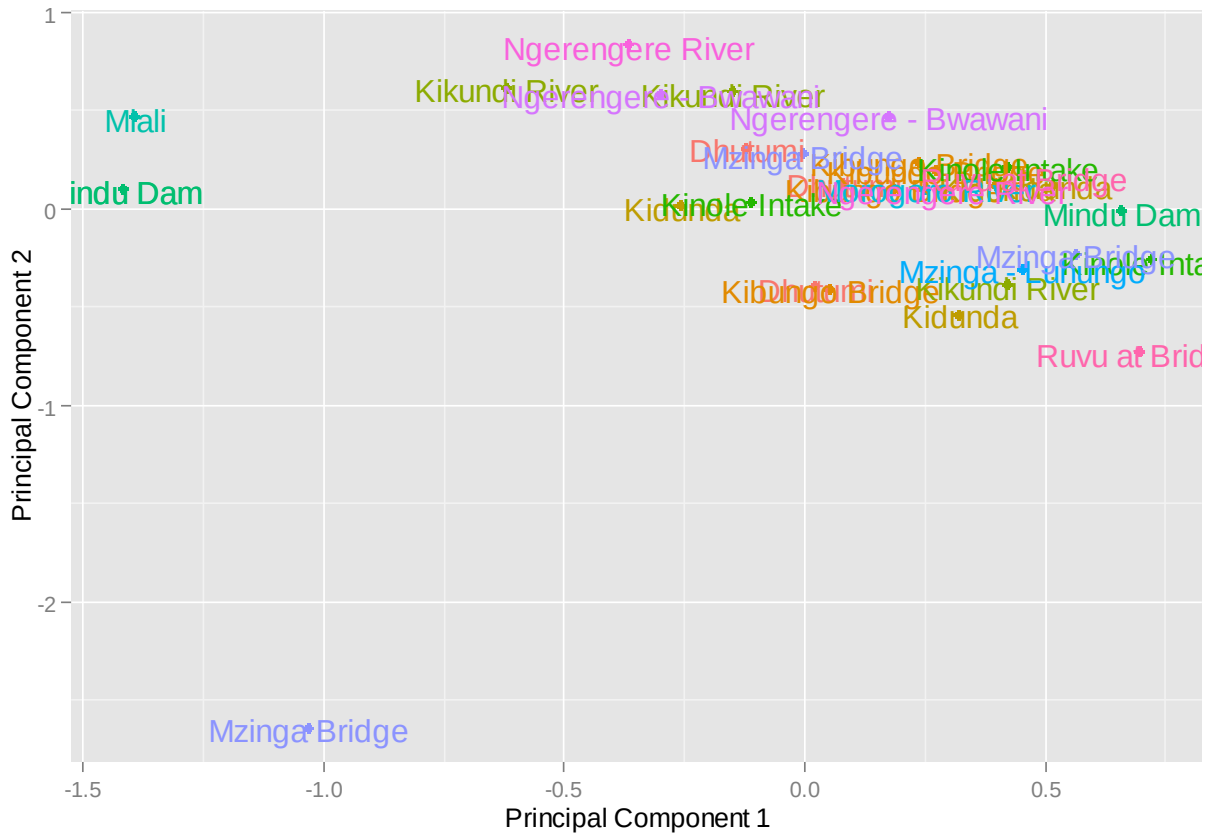

Figure 20: PCA Plot with Site Names

The following plot is the same PCA focused in the upper right hand corner. Mzinga Bridge has similar water quality to Dhutumi. Kikundi River is similar to Ngerengere Bwawani.

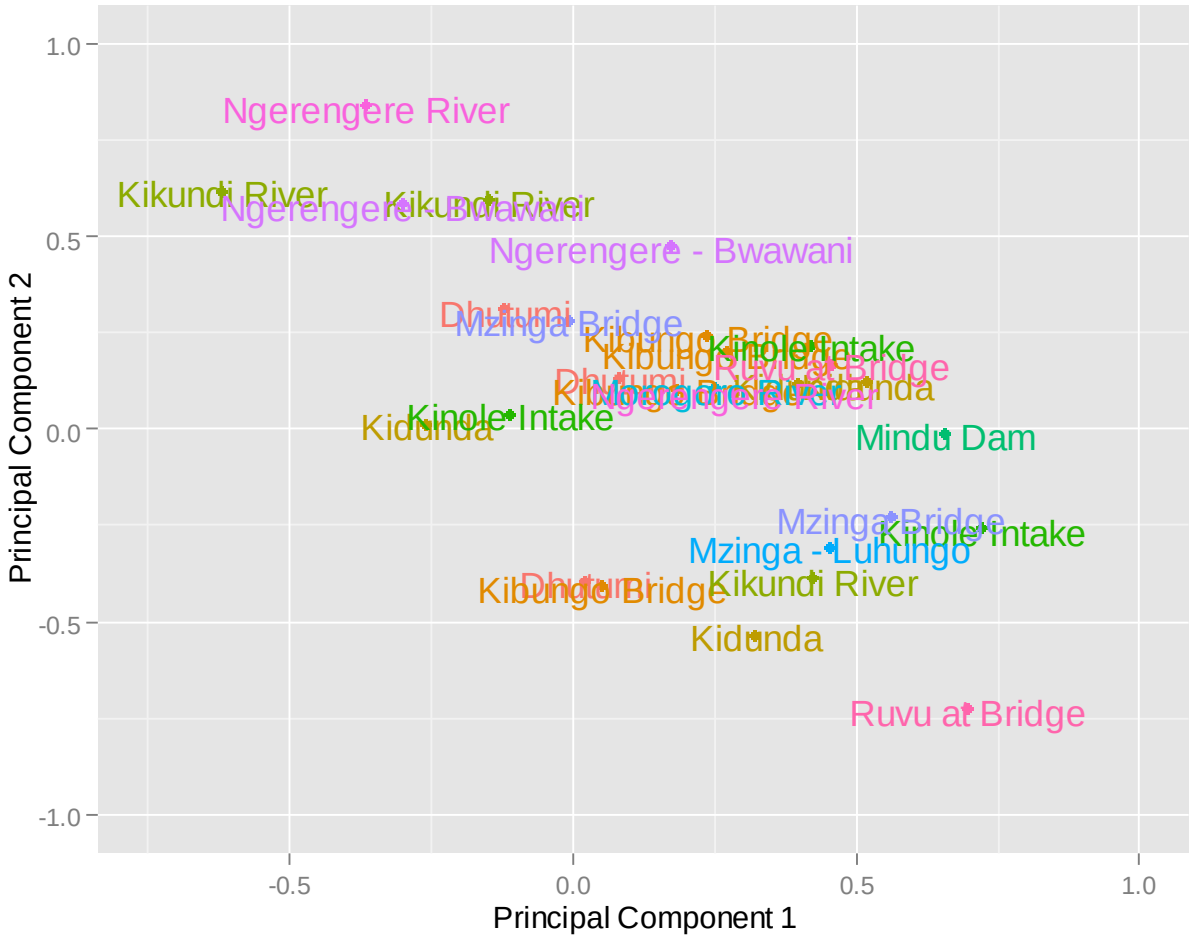

Figure 21: PCA Plot with Site Names – top right grouping

PART II - CURRENT DATA, 2012 - 2013

The WRBWO carried out a water quality survey of the primary polluters in the Ruvu Basin in August, 2013. That data has currently been lost on a stolen hard drive. Efforts are currently underway to reconstruct the data and make it available for analysis.

The previous survey focused on the primary polluters and did not sample from the routine surface water quality survey sites. The following sites are a combination of sites proposed by JICA[2] as well as the previous water quality sites that have been sampled by the WRBWO and the five sites utilized for the Environmental Flow Assessment. These sites were sampled in October, 2013 (Table 5).

[2] These sites were proposed in their 2013 report entitled "THE STUDY ON WATER RESOURCES MANAGEMENT AND DEVELOPMENT IN WAMI/RUVU BASIN IN THE UNITED REPUBLIC OF TANZANIA".

Table 5: Proposed Water Quality Sampling Sites

Longitude	Latitude	Name
37.8094	-7.0237	1H5 Ruvu at Kibungo
37.6726	-6.7696	Morogoro Industrial Area
38.2172	-7.2696	1H3 Ruvu at Kidunda
38.6939	-6.6904	1H8A Ruvu at Morogoro Rd. Bridge
38.8698	-6.3971	Ruvu in Estuary
37.5667	-7.0333	1HB2 Mgeta at Mgeta
37.7766	-7.4117	Local MgD, Mgeta at Duthumi
37.9177	-7.2403	1HC2A Mvuha at Tulo School
37.6723	-6.8455	1HA8A Morogoro at Morogoro
37.7576	-6.7518	1HA3 Ngerengere at Kingolwira
38.1445	-6.7637	1HA15 Ngerengere at Mgude
37.6140	-6.8554	Mindu
37.5616	-6.9012	Mlali/Mzumbe
37.6369	-6.9042	Mzinga/ Luhungo
37.6121	-6.8886	Mzinga/ Bridge
37.6679	-6.8230	Kikundi M/Mpya
38.0379	-6.6514	Bwawani Ngerengere
37.7693	-6.9249	Kinole Intake
38.8207	-6.5389	Lower Ruvu at Kongo

SAMPLE PARAMETERS

The following sample parameters are important indicators of water quality. In addition, JICA[3] lists the following parameters as important for water quality monitoring in the Ruvu Basin:

Table 6: Important Water Quality Parameters - JICA Report, table 6.4

	Category	Parameters to be Analyzed
1	High Priority	Temperature, pH, Turbidity (NTU), Electric conductivity/EC (us/cm), TDS (mg/l), Suspended solids/SS (mg/l), BOD (mg/l), Dissolved oxygen/DO (mg/l)
2	Low Priority	COD (mg/l), Nitrate (mg/l), Ammonium (mg/l), Chloride (Cl-) (mg/l), Total coliform (count/100ml), Fecal coliform (count/100ml)

During this water quality survey, the following parameters were sampled:

Table 7: Sampled parameters during the water quality survey, 2013

Location	Parameter
In-Situ	Dissolved Oxygen, Temperature, Electrical Conductivity, Salinity, Total Dissolved Solids, pH, Turbidity, ORP

[3] This list was presented in the 2013 report entitled "THE STUDY ON WATER RESOURCES MANAGEMENT AND DEVELOPMENT IN WAMI/RUVU BASIN IN THE UNITED REPUBLIC OF TANZANIA".

Morogoro Laboratory	Fecal Coliforms, Total Coliforms, Nitrates, Phosphates, Sulphates, Chloride
Dar es Salaam Laboratory	BOD, COD

METHODS

Methods utilized for this survey represent the most current methods utilized by the Wami-Ruvu Basin Water Office during routine surveys.

At each site, water samples were collected from the center of the channel when possible. Water was collected in three, one liter polyethylene (PE) plastic bottles after they have been rinsed three times with river water. Sample water was also collected in a sanitized 300mL laboratory glass flask. One liter of water was immediately acidified with 2mL of Nitric Acid for measuring COD. One liter of water was placed in a cooler with ice for nutrient analysis. The last liter of water was also placed in the cooler for later measuring BOD.

A Wagtech Maji Meter (WAG-WE5100) was utilized in-situ to measure dissolved oxygen (galvanic), temperature, electrical conductivity, salinity, total dissolved solids, pH, ORP and turbidity. Measurements were taken from the same spot in the river was the water samples then recorded in a notebook.

Within six hours of taking the water sample, a sub-sample of the river water collected in the glass flask was filtered through a sterile, gridded cellulose nitrate (CN) filter. The CN filter was then placed in a prepared medium. Two different filters and mediums were utilized for each sample; one for total coliforms and one for fecal coliforms. Mediums were prepared one or two days in advance. All filter equipment was sterilized between samples. Mediums were then placed in incubation chambers for 18 hours at the proscribed temperature for each type of coliform. Colonies were counted after the 18 hour incubation period.

Samples were processed for nutrient analysis by filtering it through a cellulose nitrate filter then utilizing the Hach Reagent Kit and the spectrophotometer.

BOD and COD analysis were completed at the Dar es Salaam Water Laboratory using historically noted methods (Appendix 3).

RESULTS

Data is presented on maps of the basin in order to show the geographic location of parameters in relation to one another. All sample sites are presented on the following maps; however, only EFA sites have been labeled. I have only presented information for dissolved oxygen, electrical conductivity, turbidity, ammonia, nitrates, sulphates, biological oxygen demand (BOD, chemical oxygen demand (COD), total coliforms and fecal coliforms. Information for the other parameters are available in appendix 4. I have not presented them graphically since much of

the information is redundant (ex. TDS is derived from the electrical conductivity measurements, turbidity is similar to TSS, etc).

A “heatmap” was created for the most current survey data. A heatmap is a way to view a table of numbers but with colors relating to the values. This type of table is often useful for spotting trends between sites. I utilized all water quality variables (except dissolved oxygen) collected during the 2013 survey. Dissolved oxygen was excluded because it has an inverse relationship to water quality than the other variables; increasing values for all the other values represent declining water quality. All values were normalized prior to creation of the heat map and the sites were automatically ordered from the top of the table to the bottom of the table in relation to the overall water quality at each site. The heat map was created in R using the ggplot2 library.

DISSOLVED OXYGEN

In Figure 22 , dissolved oxygen levels are presented as a gradient from red to blue; red sites exhibiting the lowest dissolved oxygen values and blue sites exhibiting the highest values.

The lowest dissolved oxygen values were recorded near Morogoro Town, on tributaries flowing into the Ngerengere River (Kikundi, Morogoro Industrial Area and Kingolwira. By the time the water reaches EFA Site 4, the dissolved oxygen has recovered slightly. Dissolved oxygen was unusually low at EFA Site 2, given its position in the upper catchment of the Mgeta.

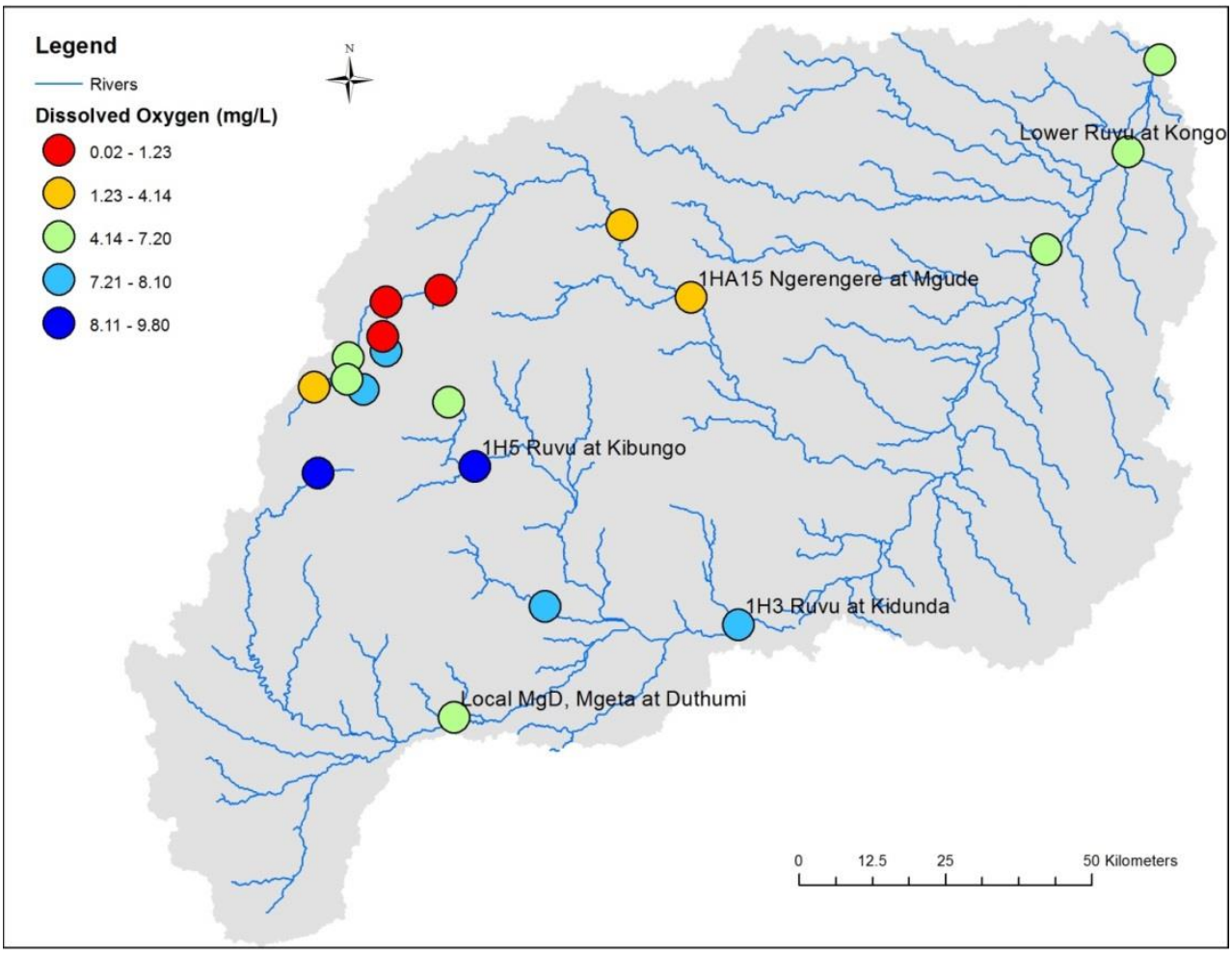

Figure 22: Dissolved Oxygen Map - Water Quality Survey 2013

ELECTRICAL CONDUCTIVITY

In Figure 23, electrical conductivity is presented as a gradient from blue to red; blue sites have the lowest electrical conductivity and red sites have the highest electrical conductivity.

Electrical Conductivity was highest in the estuary, which is unsurprising given the ocean salinity. Within the fresh water reaches of the basin, electrical conductivity was highest in Morogoro town and on the Ngerengere River at EFA Site 4. The headwaters of the Mgeta and Upper Ruvu had very low electrical conductivity.

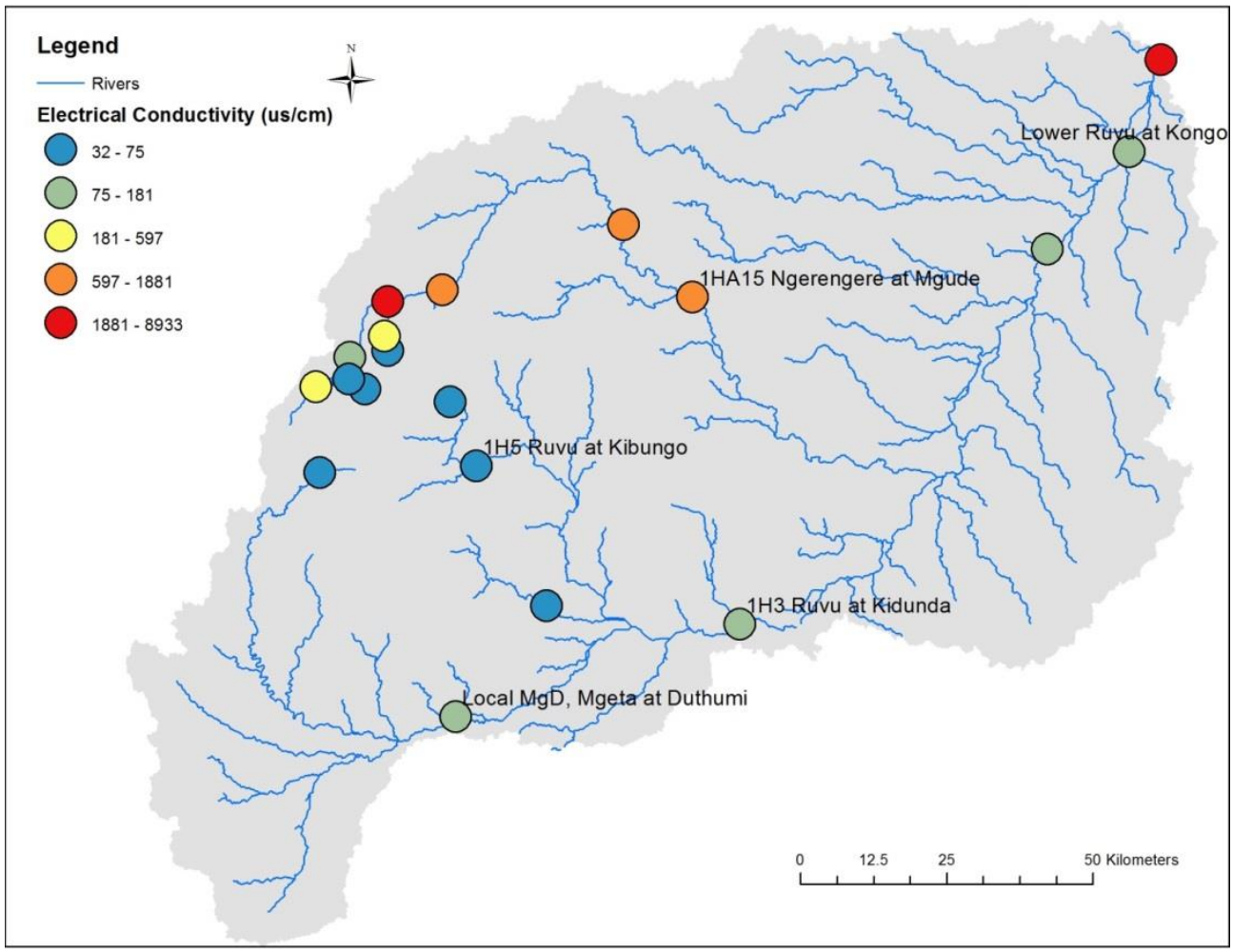

Figure 23: Electrical Conductivity Map - Water Quality Survey 2013

TURBIDITY

In Figure 24, turbidity is presented as a gradient from blue to red; blue sites have the lowest turbidity and red sites have the highest turbidity.

The lowest turbidity values were recorded near Morogoro town. Turbidity was highest at EFA Site 2, Mgeta at Dutumi.

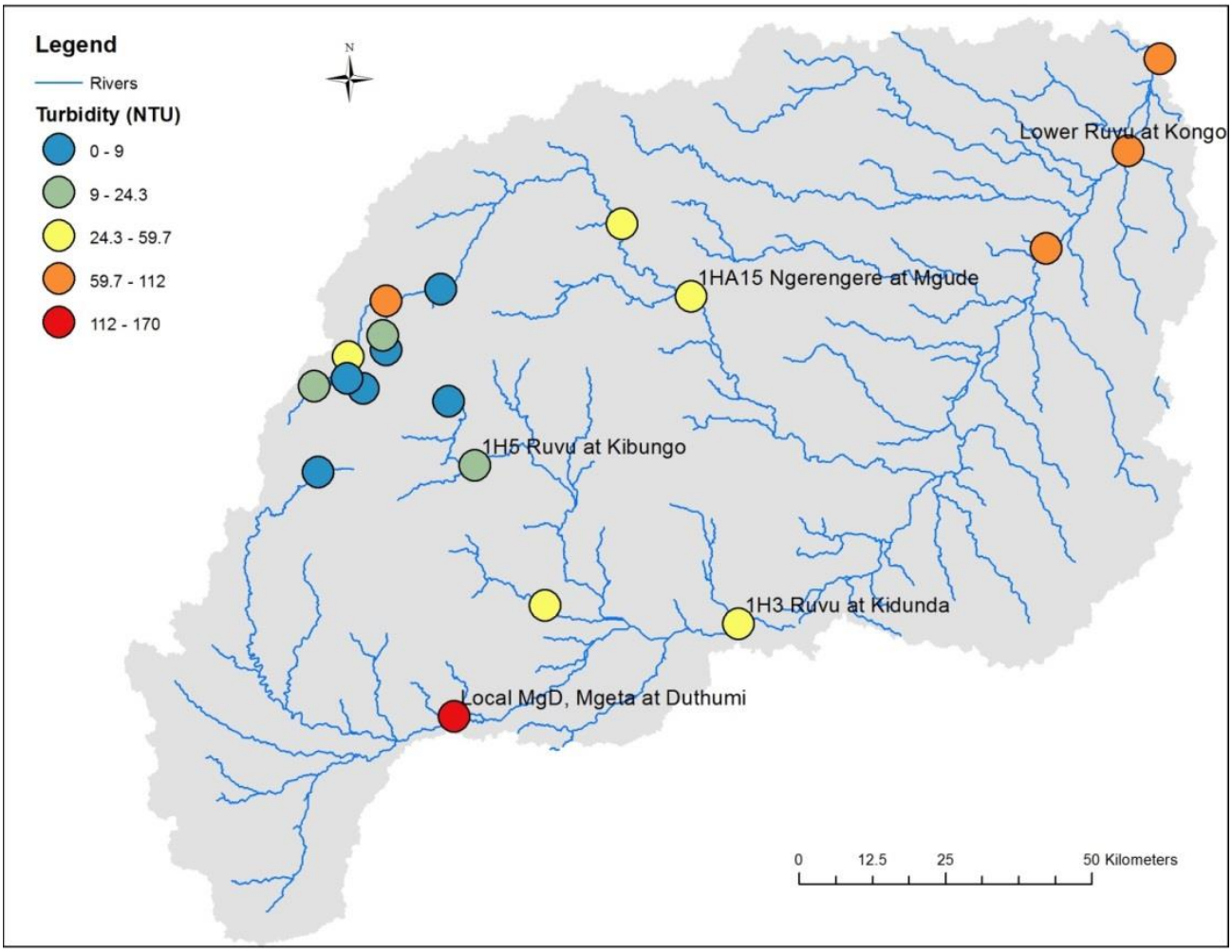

Figure 24: Turbidity Map - Water Quality Survey 2013

NITRATES

In Figure 25, nitrate levels at sites are represented by the size of the symbol in relation to the other sites; high nitrate levels are represented by large symbols and low nitrate levels are represented by small symbols.

Nitrates levels were highest in Morogoro town in the Morogoro Industrial Area (over 35 mg/L). Levels were generally high throughout the entire basin with high levels of nitrates also occurring in the headwaters of the three main catchments (Mgeta, Upper Ruvu and Ngerengere).

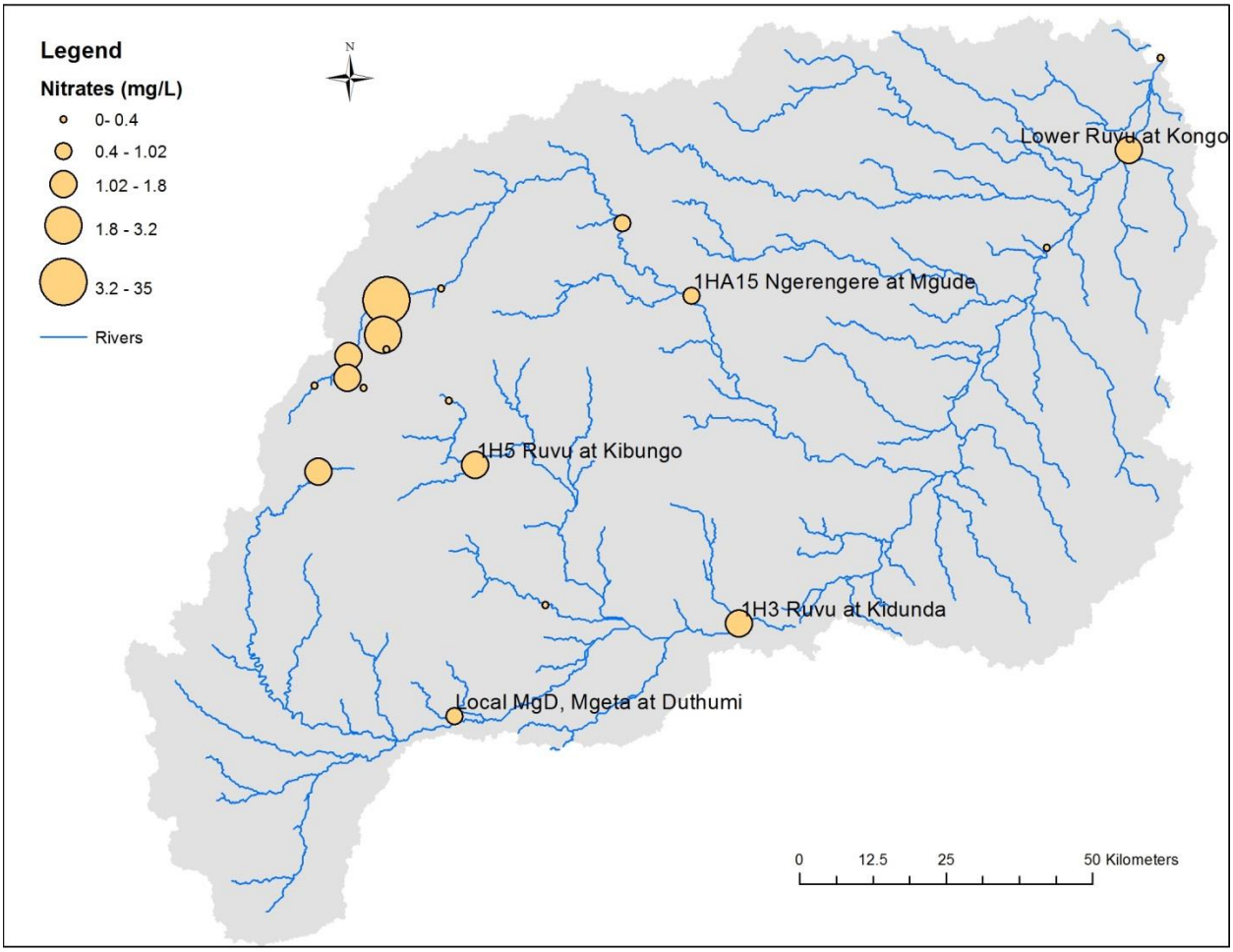

Figure 25: Nitrates Map - Water Quality Survey 2013

AMMONIA

In Figure 26, ammonia levels at sites are represented by the size of the symbol in relation to the other sites; high ammonia levels are represented by large symbols and low ammonia symbols are represented by small symbols.

Ammonia levels are high throughout the basin but their levels in and around Morogoro town are extremely high (over 20 mg/L).

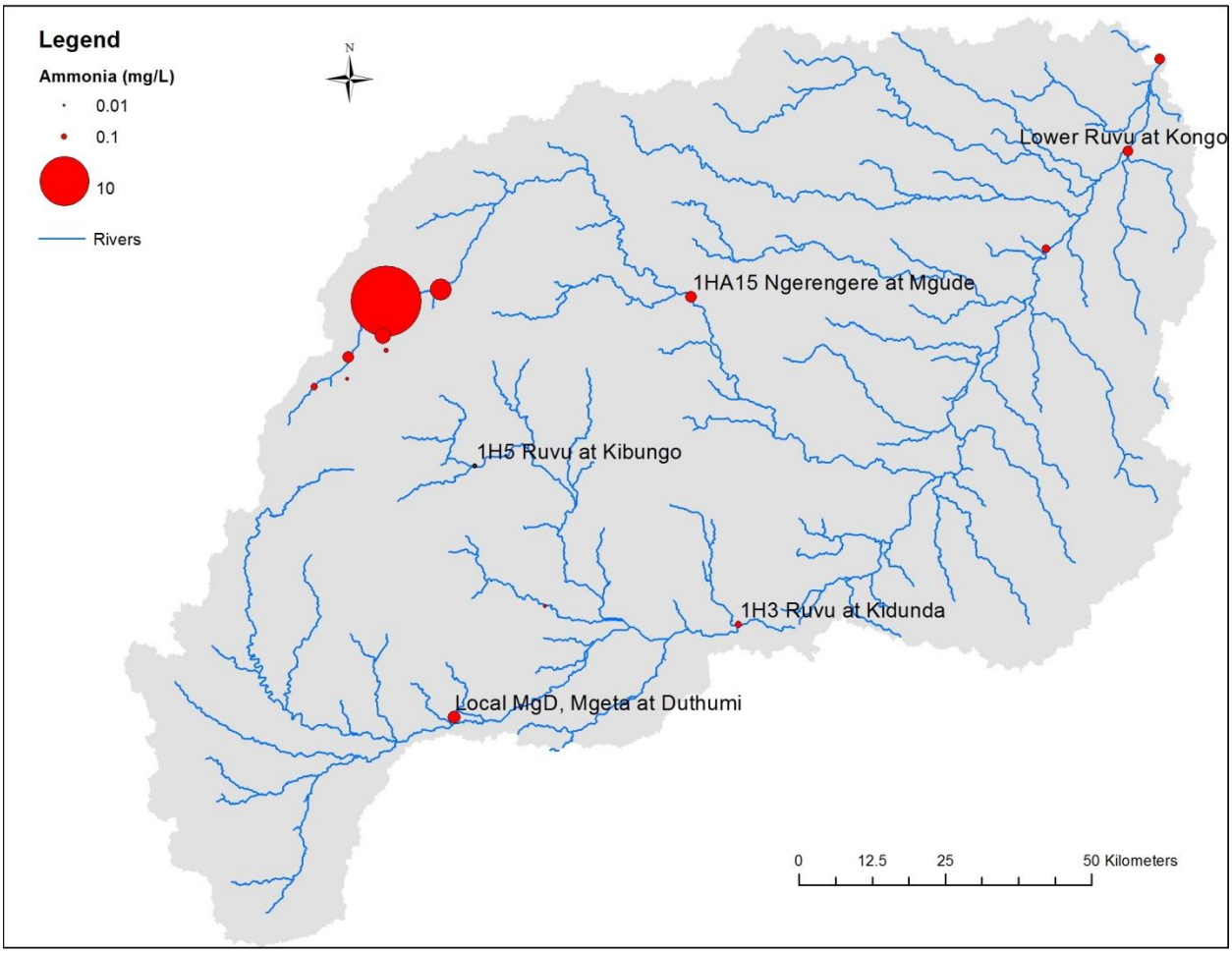

Figure 26: Ammonia Map - Water Quality Survey 2013

SULPHATES

In Figure 27, sulphate levels at sites are represented by the size of the symbol in relation to the other sites; high sulphate levels are represented by large symbols and low sulphate levels are represented by small symbols.

Only one site, Ruvu at the Estuary, had sulphate levels above the permissible limit (over 600 mg/L).

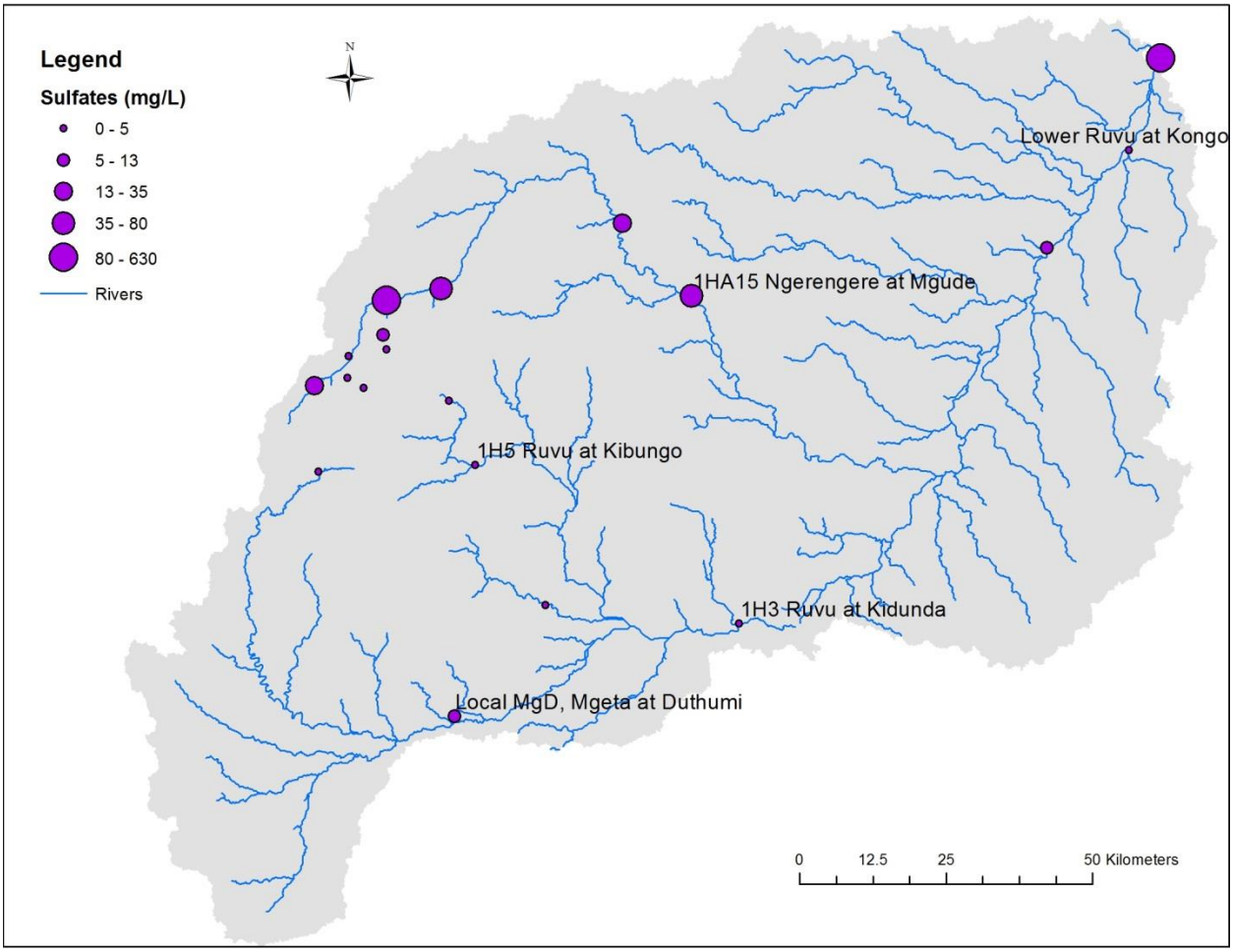

Figure 27: Sulphates Map - Water Quality Survey 2013

BIOLOGICAL OXYGEN DEMAND (BOD)

In Figure 28, BOD at sites is represented by the size of the symbol in relation to the other sites; high BOD is represented by large symbols and low BOD is represented by small symbols. Additionally, red sites are over the permissible limit (greater than 10 mg/L). Green sites are below the permissible limit (less than 10 mg/L).

BOD is highest in Morogoro town (600 mg/L) followed by Kingolwera(88 mg/L) and Kikundi (82 mg/L). The lowest BOD values were at EFA Site 2 (Mgeta at Dutumi), the Mzinga Sites, Mvuha, and Morogoro at Morogoro (all less than 1 mg/L).

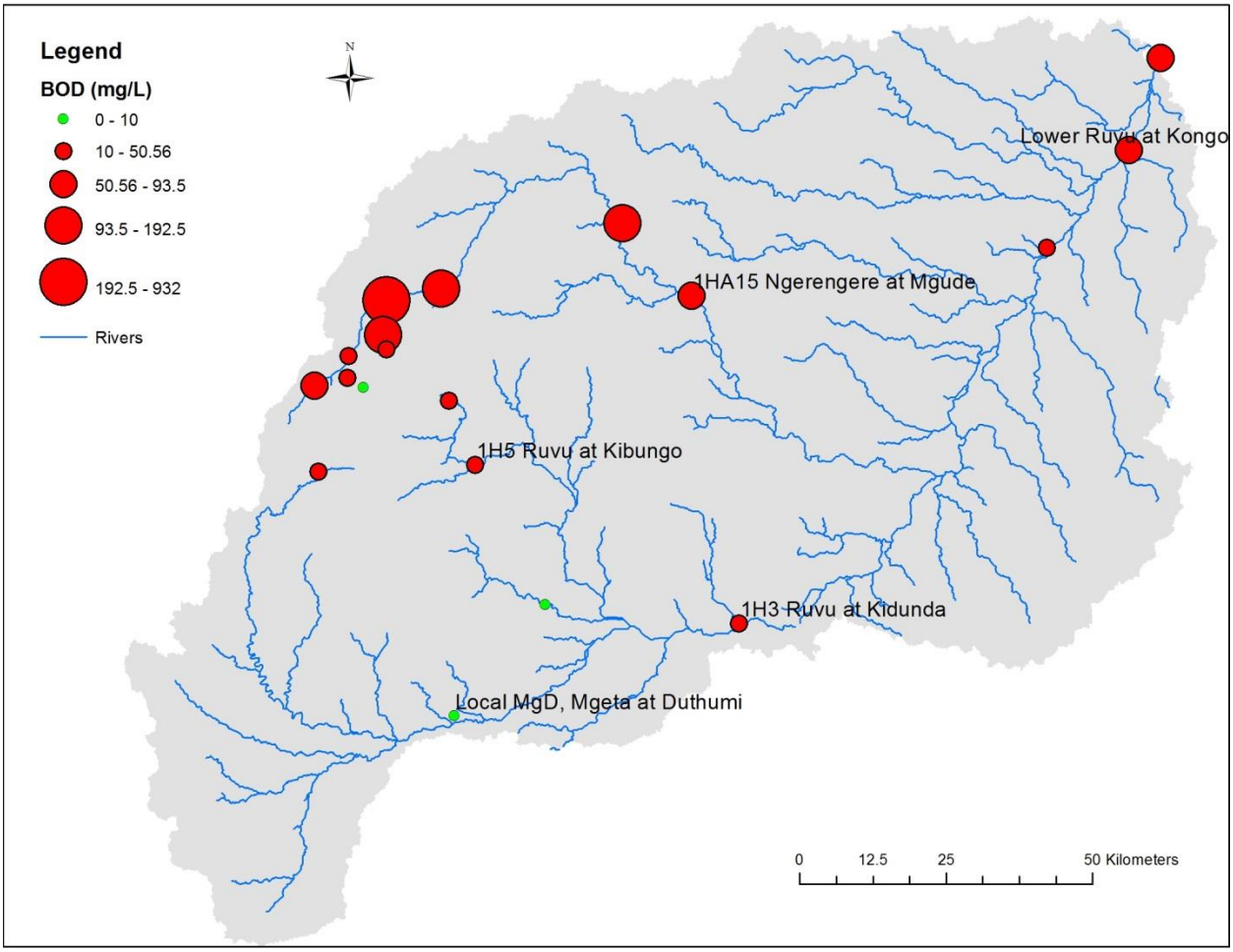

Figure 28: Biological Oxygen Demand Map - Water Quality Survey 2013

CHEMICAL OXYGEN DEMAND (COD)

In Figure 29, COD at sites is represented by the size of the symbol in relation to the other sites; high COD is represented by large symbols and low COD is represented by small symbols.

High COD levels were found throughout the basin except for Mzinga at Luhungo, Mvuha at Tulo and EFA Site 2 (Mgeta at Dutumi).

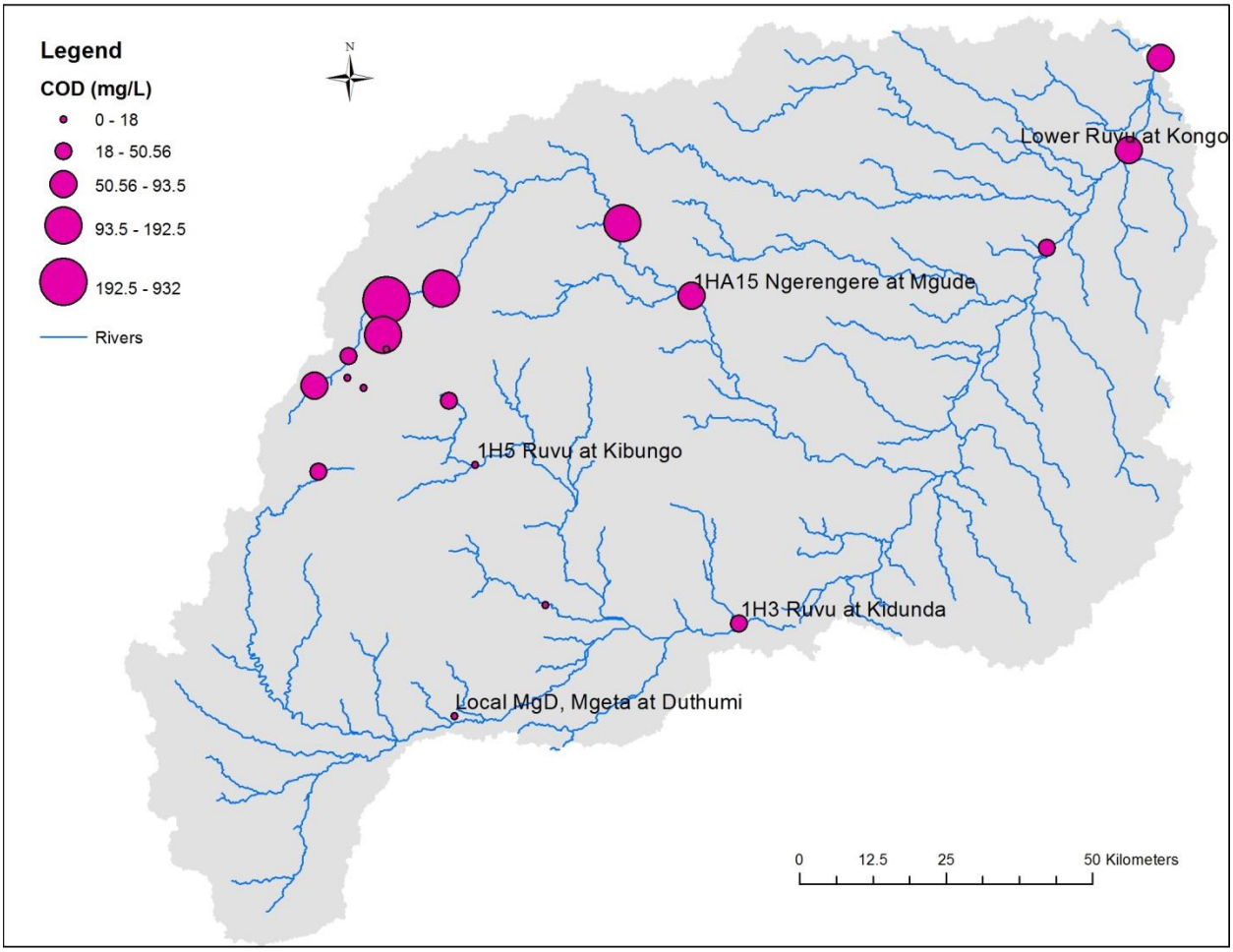

Figure 29: Chemical Oxygen Demand - Water Quality Survey 2013

COLIFORMS

In Figure 30 and Figure 31, coliform counts at sites are represented by the size of the symbol in relation to the other sites; high coliform counts are represented by large symbols and low coliform counts are represented by small symbols.

Total coliforms and fecal coliforms were extremely high throughout the entire basin. The highest levels were recorded at EFA Site 4, Ngerengere at Mgude, followed by just upstream at Ngerengere at Bwawani.

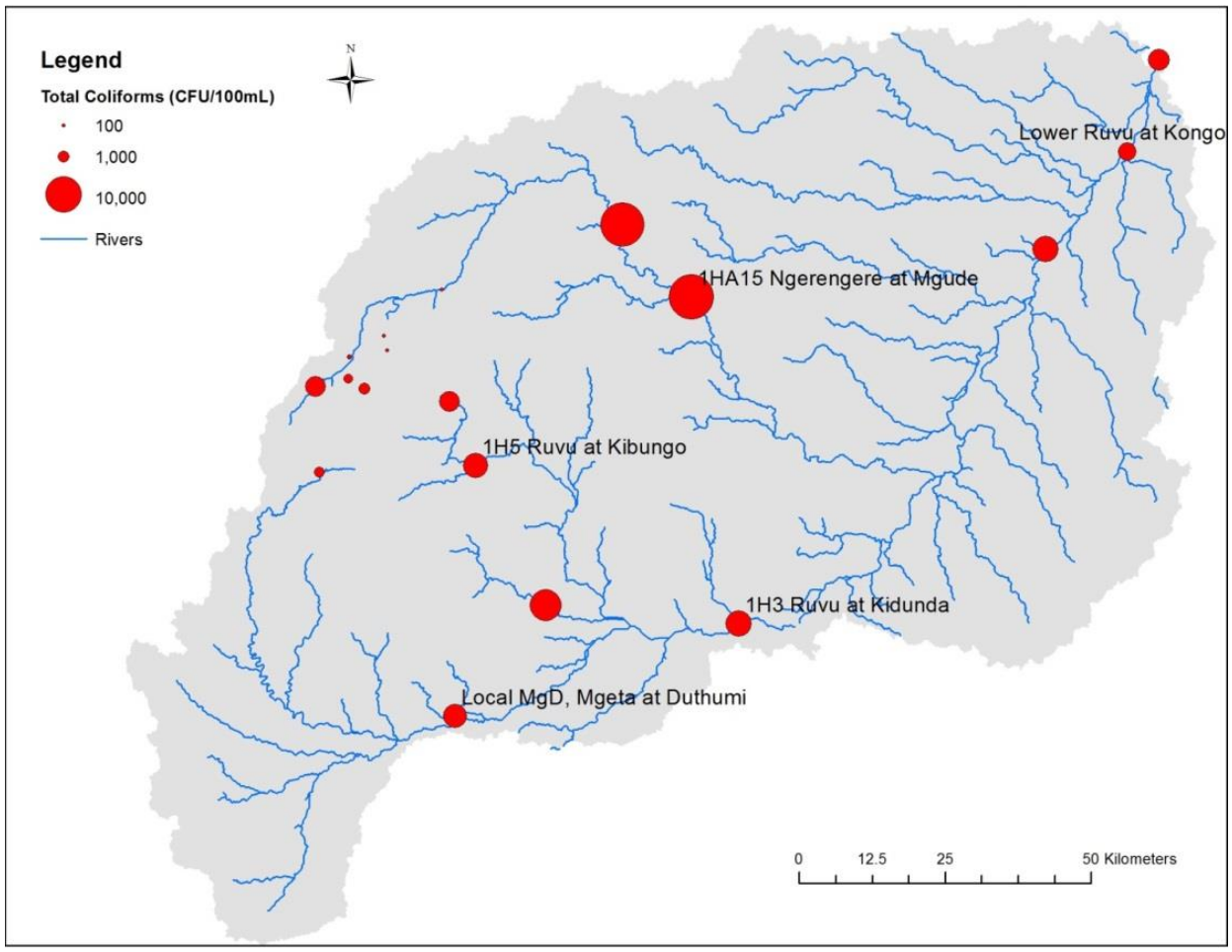

Figure 30: Total Coliforms Map - Water Quality Survey 2013

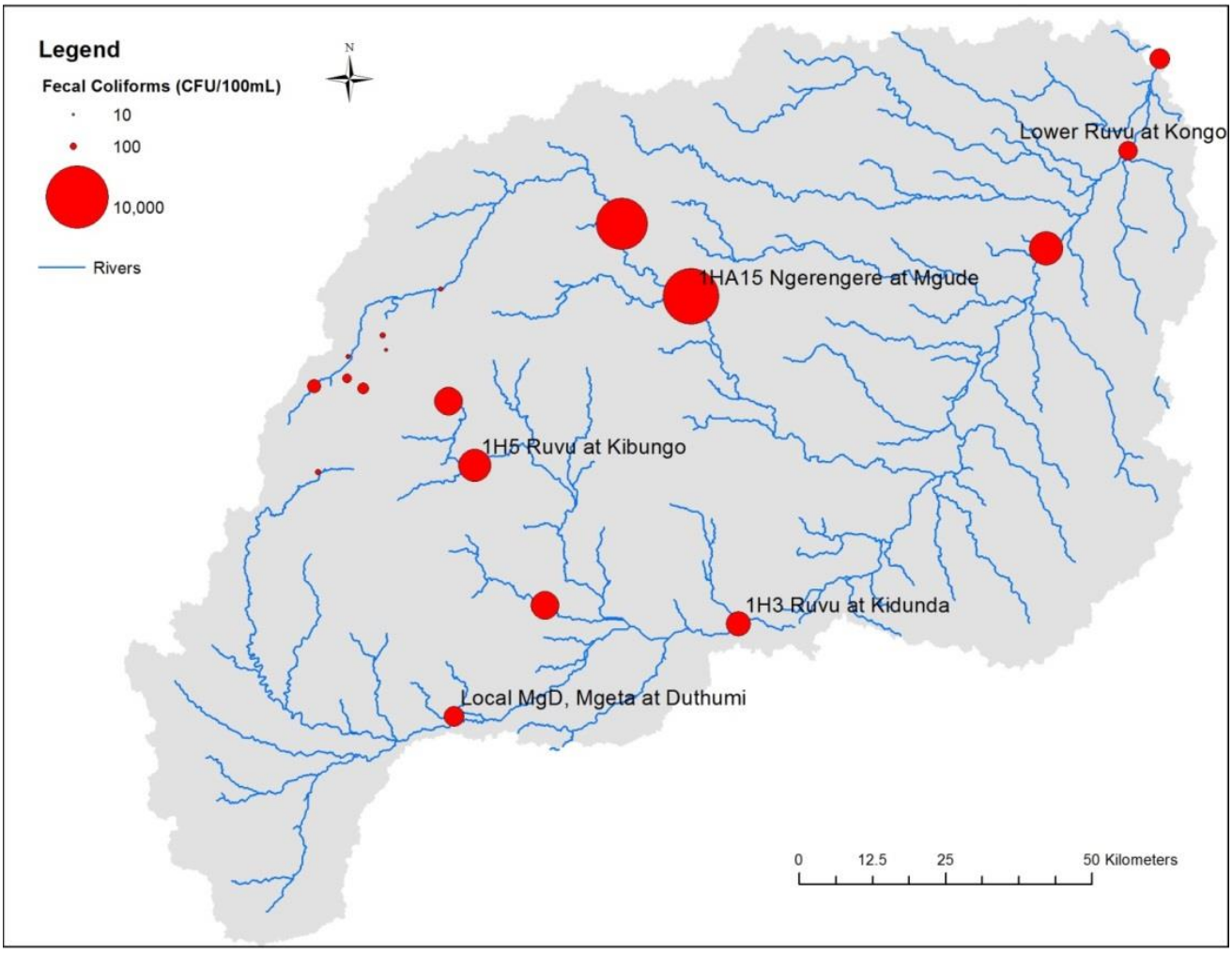

Figure 31: Fecal Coliforms Map - Water Quality Survey 2013

Water Quality Heat Map

Sites are presented in the heat map on a gradient of bad water quality to good water quality (Figure 32). Bad water quality sites are at the top of the map, good water quality sites are at the bottom.

The heat map identifies the Morogoro Industrial Area as the worst site in the basin (Figure 32). The Ruvu Estuary is identified as having the second worst water quality in the basin. This is not an appropriate finding since that site is heavily influence by the ocean and because of that, it is naturally very different than all the other sites. The Ngerengere sites below Morogoro town all have very poor water quality compared to the rest of the basin.

Mgeta at Mgeta has the best water quality, followed by Morogoro at Morogoro.

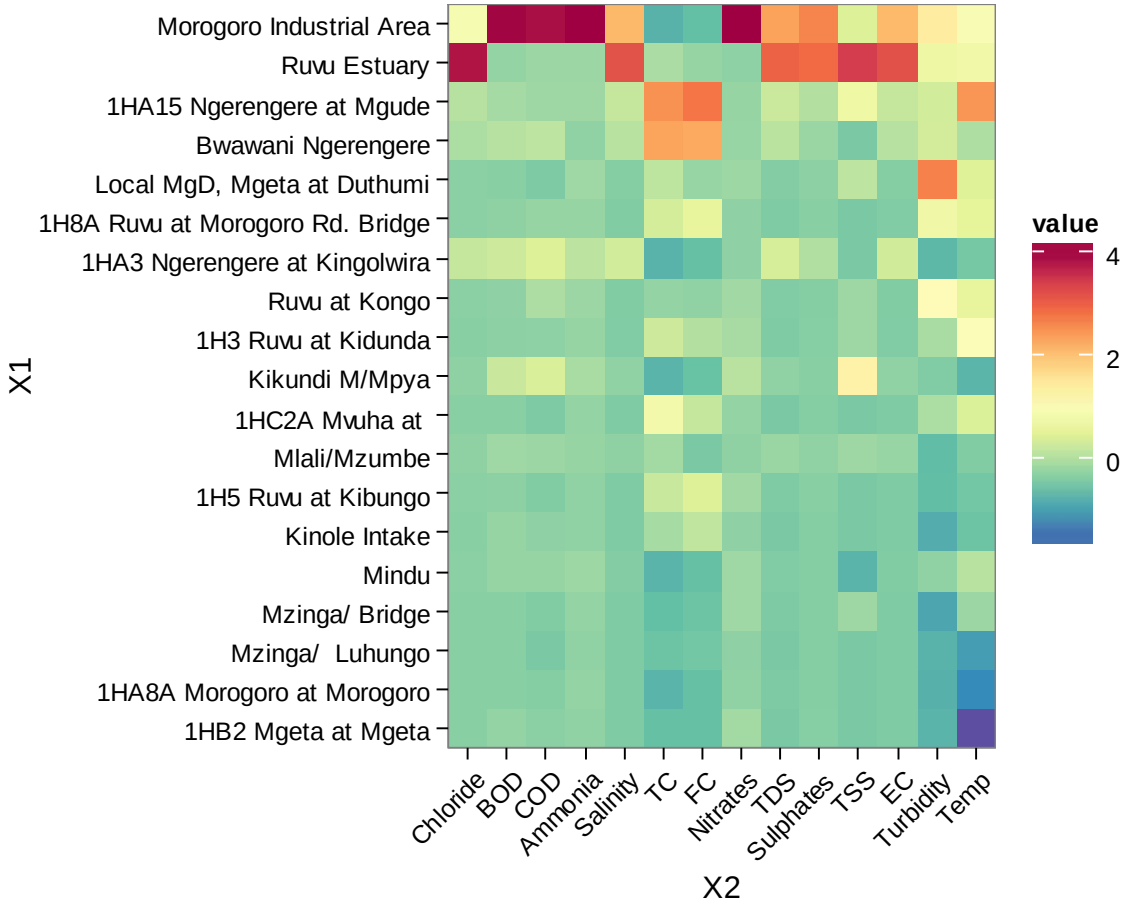

Figure 32: Water Quality "Heat" Map

Discussion

EFA Site 2, Mgeta at Dutumi, is in the upper catchment yet it has some of the worst water quality in the basin. This is unsurprising given the pastoralists reliance on the Mgeta for their domestic and livestock needs (Figure 33).

Figure 33: EFA Site 2 - Mgeta at Dutumi

The Ngerengere River has significant water quality problems associated with municipal and industry runoff from Morogoro town. Electrical conductivity is consistently high in the Ngerengere River as well as total and fecal coliform loadings.

The Upper Ruvu (EFA Site 1) has some of the best water quality in the basin compared to the other sites. Dissolved oxygen levels are high and nutrient levels are low, indicating a relatively healthy aquatic ecosystem. However, the Upper Ruvu, much like the rest of the basin, exhibits high levels of coliforms.

In terms of water quality, the five EFA sites are ranked as follows

Table 8: EFA Site Water Quality Ranking

Ranking	Site	
Best	1H5 Ruvu at Kibungo	EFA Site 1
	1H3 Ruvu at Kidunda	EFA Site 3
	Lower Ruvu at Kongo	EFA Site 5
	Local MgD, Mgeta at Duthumi	EFA Site 2
Worst	1HA15 Ngerengere at Mgude	EFA Site 4

CONCLUSIONS

Water quality in the basin is typical for a population that directly relies upon their rivers for their domestic water needs, including bathing. High coliform and ammonia levels in the basin are likely the result of livestock and human wastes entering the waterways from daily activities occurring directly in the rivers (Figure 33). Runoff from Morogoro town likely has a large influence on the water quality of the Ngerengere River, exhibited by consistently high electrical conductivity and high coliform levels.

Biological oxygen demand exceeds the permissible limit at most sites in the basin.

The EFA Site 1 (Ruvu at Kibungo) appears to have the best water quality while EFA Site 4 (Ngerengere at Mgude) has the lowest. EFA Site 2 (Mgeta at Dutumi) is plagued by heavy pastoralist use while EFA Site 5 (Ruvu at Kongo) is strongly influenced by ocean conditions. EFA Site 3 (Ruvu at Kidunda) represents equal mixing of the conditions from the Mgeta and Upper Ruvu (EFA Sites 1 and 2).

Heavy use of the rivers by the rural population through activities taking place directly in the river (bathing, washing dishes, defecating, urinating, cattle watering, car washing, etc.) is likely a significant driver of declining water quality in the basin.

APPENDIX I – RECEIVING WATER STANDARDS

Category 1: Water suitable for drinking water supplies, swimming pools, food and beverage manufacturing industries, pharmaceuticals manufacturing industries or industries requiring a water source of similar quality.

Category 2: Water suitable for use in feeding domestic animals; in fisheries, shell cultures, recreation and water contact sports.

Category 3: Water suitable for irrigation and other industrial activities requiring water of standards lower than those of water in category 1 and 2.

Table 9: Tanzania Receiving Water Quality Standards

Substance/ Characteristic	Unit	Maximum Permissible Concentration		
		Category 1	Category 2	Category 3
Suspended Matter (turbidity)	mg/l (as Si02)	Discharge of effluents shall not cause formation of sludge or scum in the receiving water.		
Colour	Number (pt-Coscale)	Discharge of effluents shall not cause any change in the natural colour of the receiving water.		
Taste and odour	-	Discharge of effluents shall not cause change in the natural taste or odour of the receiving water.		
Temperature	ºC	Discharge of effluents shall not raise the temperature of the receiving water by more than 5ºC.		
Total dissolved solids	mg/l	2,000	2,000	No Limit.
pH	-	6.5-8.5	6.5-8.5	6.5-9.0
Dissolved oxygen	mg/l	6	5	3
Oxygen solution	%	80	60	40
B.O.D – 5days, 20ºC	mg/l	5	5	10
B.O.D-5 days, 25 oc	mg/l	6	6	12
B.O.D-5 days, 30 oc	mg/l	6	6	12
B.O.D-5 days, 35 OC	mg/l	7	7	13
Permanganate Value	mg/l	20	20	30
Aluminium (Al)	mg/l	0.3	0.3	0.3
Arsenic (As)	mg/l	0.05	0.1	0.1
Barium (Ba)	mg/l	1	1	1.5
Boron (B)	mg/l	1.15	1.5	1.5
Cadmium (Cd)	mg/l	0.03	0.1	0.2
Chromium III (Cr3+)	mg/l	0.1	0.3	0.5
Chromium VI (Cr6+)	mg/l	0.05	0.1	0.1
Cobalt (Co)	mg/l	0.1	0.1	0.5
Copper (Cu)	mg/l	3	3	4
Iron (Fe)	mg/l	1	1.2	1.5
Lead (Pb)	mg/l	0.1	0.1	0.2

Substance/ Characteristic	Unit	Maximum Permissible Concentration		
		Category 1	Category 2	Category 3
Manganese (Mn)	mg/l	0.5	0.8	0.8
Mercury (Hg)	mg/l	0.001	0.001	0.005
Nickel (Ni)	mg/l	0.05	0.05	0.1
Selenium (Se)	mg/l	0.05	0.05	0.5
Silver (Ag)	mg/l	0.05	0.05	0.05
Tin (Sn)	mg/l	0.5	0.5	0.1
Vanadium(v)	mg/l	0.005	0.005	0.01
Zinc (Zn)	mg/l	0.2	0.2	1
Ammonia+Ammonium (NH3+NH4+)	mg/l	0.5	0.5	2
Chlorides (Cl-)	mg/l	200	200	400
Fluorides (F-)	mg/l	8	8	8
Cyanides (Cn)	mg/l	0.05	0.05	0.1
Nitrates (NO3)	mg/l	50	50	100
Nitrites (NO2)	mg/l	As low as is required to prevent eutrophication or excessive weed growth if nitrogen is a limiting.		
Phosphates (PO43-)	mg/l	Nutrient in waters which are susceptible to eutrophication or excessive weed growth, or in rivers and streams draining into such waters, the lowest possible concentration should be aimed as if phosphorous is a limiting nutrient.		
Sulphates (SO42-)	mg/l	600	600	600
Sulphides (S2-)	mg/l	0.01	0.01	0.1
Alkyl benzene Sulphonates (ABS)	mg/l	0.5	1	1
Aromatic and aliphatic hyrocarbons	mg/l	0.05	0.05	1
Aromatic nitrogen containing compounds (e.g. aromatic amines)	mg/l	0.01	0.01	0.1
Chloroform extract (CE)	mg/l	0.5	0.5	1
Formaldehyde	mg/l	0.2	0.2	0.5
Grease & Oils (petroleum ether extract)	mg/l	0.5	1	5
Non-volatile chlorinated compounds	mg/l	0.005	0.005	0.1
Volatile chlorinated Hydrocarbons (CI)	mg/l	0.005	0.005	0.01
Organochlorine Pesticides (CI)	mg/l	0.0005	0.0005	0.001
Other Pesticides	mg/l	0.001	0.001	0.005
Phenols	mg/l	0.002	0.002	0.1
Resins, tar etc.	mg/l	0.1	0.1	0.5

APPENDIX 2 – INDUSTRIAL EFFLUENT STANDARDS

Table 10: Tanzania Industrial Effluent Standards for Organic Compounds

Organic Compounds	Limit (mg/l)
1, 1, 2 -Trichloroethane	0.06
1,1,1 - Trichloroethane	3
1,2 - Dichloroethane	0.04
1,2 - Dichloroethylene	0 . 2
1,3 - Dichloropropene	0.2
Alkyl benzene sulfonate (ABS)	0.5
Aromatic nitrogen containing compounds (e.g., aromatic amines)	0.001
cis-1, 2 -Dichloroethylene	0.4
Dichloromethane	0.2
Oil and Grease (fatty maters and hydrocarbons)	10
Organochlorine pesticides (Cl)	0.0005
Other aromatic and/or aliphatic hydrocarbons not used as pesticides	0.05
Pesticides other than organochlorines	0.01
Phenols	0.002
Tetrachloroethylene	0.1
Tetrachloromethane	0.02
Trichloroethylene	0.3

Table 11: Tanzania Industrial Effluent Standards for the Chrome Tanning Industry

Chrome Tanning Industry	
Characteristics	Tolerance Limit
Chlorides as Cl, mg/l, max.	1000
Biochemical oxygen demand for 5 days at 20°C, mg/l max.	30
Hexavalent chromium as (Cr), mg/l, max.	0.1
pH	5.5 - 9.0

Table 12: Tanzania Industrial Effluent Standards for the Vegetable Tanning Industry

Vegetable Tanning Industry

Vegetable Tanning Industry	
Characteristics	Tolerance Limit
Biochemical oxygen demand for 5 days at 20°C, mg/l	30 - 100
Chlorides (as Cl), mg/l, max,	1000
pH	5.5 – 9.0,
Suspended solids, mg/l, max.	100
Colour and odour	Absent

Table 13: Tanzania Industrial Effluent Standards for the Fertilizer Industry

Fertilizer Industry	
Characteristics	Tolerance limit
Dissolved phosphate (as P), mg/l, max	5
Dissolved fluorides (as F),mg/l, max.	15
pH	5.5 - 9.0

APPENDIX 3 – HISTORICAL WATER QUALITY SURVEY METHODS

Table 14: Historical Water Quality Survey Methods

Parameter	Method
Dissolved Oxygen	Winkler Titration or Handheld Instrument
pH	Handheld instrument
Electrical Conductivity and TDS	Handheld instrument
Phosphate	Phosver3 method using a light spectrophotometer (DR 2000)
Sulphate	SulfaVer3 method
Nitrate	Cadmium reduction method using a light spectrophotometer (DR 2000)
Ammonia	Nessler Method
BOD	Dilution Method
COD	Dichromate Reflux Method
Fecal Coliforms	Membrane Technic Method

APPENDIX 4 – 2013 WATER QUALITY SURVEY DATA

Site	Date	Temp. (°C)	pH	EC (µS/cm)	TDS (mg/l)	ORP (mV)	DO (mg/l)	NH_3-N (mg/l)	Turbidity (NTU)	Salinity (ppt)	SO_4^{2-} (mg/l)	TSS (mg/l)	NO_3^- (mg/l)	Cl^- (mg/l)	TC (CFU/100ml)	FC (CFU/100ml)	BOD (mg/l)	COD (mg/l)
Local MgD, Mgeta at Duthumi	21/10/13	28.50	7.94	181	117		6.89	0.57	170.0	0.09	13	30	1.02	9.22	4280	1040	0.87	2.30
1HC2A Mvuha at	21/10/13	28.20	7.71	33	21		7.98	0.04	42.3	0.01	0	10	0.40	3.55	7400	2000	0.50	1.85
1H5 Ruvu at Kibungo	22/10/13	24.02	7.67	69	44	134.80	9.80	0.00	12.0	0.03	5	10	1.30	9.22	4700	2600	4.00	14.08
Kinole Intake	22/10/13	23.80	7.68	33	21		7.20	0.00	3.8	0.01	2	10	0.10	4.96	3200	1920	16.30	36.60
1HB2 Mgeta at Mgeta	23/10/13	18.30	7.80	32	20		9.03	0.00	7.1	0.01	3	10	1.50	2.84	760	60	13.19	28.16
Mlali/Mzumbe	23/10/13	24.60	7.63	597	388	93.00	3.08	0.19	11.0	0.20	22	20	0.20	26.94	3120	450	27.20	58.20
Mindu	23/10/13	26.70	7.90	139	92	105.00	7.00	0.46	31.3	0.07	1	0	1.20	6.38	110	40	16.20	48.48
Mzinga/ Luhungo	23/10/13	21.90	7.44	32	20	128.00	8.10	0.00	6.7	0.01	2	10	0.10	3.55	1000	320	0.40	1.12
Mzinga/ Bridge	23/10/13	25.50	7.29	56	36	33.40	6.81	0.04	0.0	0.02	2	20	1.20	2.84	620	200	0.70	14.08
1HA8A Morogoro at Morogoro	24/10/13	21.10	7.69	75	40	142.00	7.80	0.06	5.6	0.03	0	10	0.30	3.55	80	25	0.80	18.00
Kikundi M/Mpya	24/10/13	23.00	7.00	433	280	17.70	1.23	0.94	24.3	0.21	7	70	3.20	26.94	100	75	82.00	184.77
1HA3 Ngerengere at Kingolwira	24/10/13	24.10	7.56	1881	1223	77.70	1.20	1.83	9.0	0.94	75	10	0.10	247.44	75	40	88.40	192.50
Morogoro Industrial Area	24/10/13	30.60	9.56	6315	4109	323.80	0.02	20.40	112.0	3.16	580	40	35.00	581.38	0	0	600.00	932.00
Bwawani Ngerengere	25/1013	26.30	7.64	1288	826	52.90	2.69	0.00	59.7	0.64	35	10	0.80	140.38	14400	6880	56.00	126.40
1HA15 Ngerengere at Mgude	25/10/13	37.40	7.97	1614	1048	102.60	4.14	0.49	59.4	0.80	80	50	0.70	192.85	15200	8000	34.00	63.20
1H3 Ruvu at Kidunda	25/10/13	30.80	7.71	98	64	99.80	7.76	0.19	40.2	0.04	3	20	1.80	4.25	4960	1600	4.60	32.00
1H8A Ruvu at Morogoro Rd. Bridge	26/10/13	28.90	7.69	109	70	73.30	6.99	0.22	80.9	0.05	7	10	0.10	7.09	5230	2900	9.20	50.56
Ruvu at Kongo	26/10/13	29.00	7.51	126	81	65.20	7.12	0.36	99.0	0.06	2	20	1.30	9.22	2500	900	7.60	93.50
Ruvu Estuary	26/10/13	29.90	7.60	8933	5008	128.20	6.18	0.37	77.8	4.46	630	140	0.00	1921.30	3400	1000	12.80	58.14

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