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Assessment of Quality of Water Resource from Great Ruaha River and Allied Water Sources Serving Domestic Purposes at Pawaga Division

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Abstract

This study intended to assess water quality from Ruaha River and allied water sources serving domestic purpose in Pawaga division. By using standard methods triplicate samples from sixteen (16) different sites were collected and analyzed for physicochemical parameters and bacteriological values. The conductivity of analysed samples ranged between 1 – 286 µS/cm which is lower than the TBS threshold 2,500 µS/cm. The TDS ranges between 107 – 2235.8 mg/L during the wet season and 49.0 – 2,616.3 mg/L during the dry season. The level of Na+ ranges between 0.2 – 104.4 mg/L during rainy season and 0.8 -119 mg/L during dry season. Nitrate levels ranges between 0.4 – 101.4 mg/L during rainy season and 0.3 – 107.9 mg/L during dry season. This may be contamination from fertilizers, municipal wastewaters, feedlots, septic systems in river water. Sulphate concentration ranges between 0.3 – 93.0 mg/L during rainy season and 3.7 – 98.9 during dry season. Sulphate can also be produced by bacterial or oxidizing action as in the oxidation of organo-sulphur compounds and the more common sinks are pyrite, gypsum, and sulphate reduction. The study concluded that, water supplied by Pawaga water supply must be treated to eliminate microbial, physical and chemical pollution prior to domestic water supplies. It recommended that Government should strengthen water intervention management and carry out intervention measures to improve water quality and reduce water pollution's impact on human health. The control of water pollution can be done by increasing monitoring of wastewater disposal into rivers, carrying out an inventory and identifying water pollution sources.

***Keywords**:* *Water Treatment, Rural Water Supply, Public Health, Pawaga*

1.0 INTRODUCTION

Water resource, next to energy, is the second of human top ten problems in the next 50 years (Kumar et al., 2014). Its challenges are quality and quantity based, where different specialized professionals work on it; however, it is also unofficial or traditionally realised by unskilled but experienced water users. Water quality challenges are mainly invisible which is chemicals and microbial pollution. Anyone can analyse physical water pollution, such as unpleasant colour, odour, taste and turbidity, but chemical and microbial pollutions become

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ascertained by qualified professional scientists in the water quality laboratory fields (Mihale, 2015). It is important for water utilities to provide esthetically acceptable drinking water to the public, because our consumers always initial judge the quality of the tap water by its color, taste, and odor (Zhou, et al., 2017). In this case, clean and safe drinking water is vital for the health and wellbeing of all domestic water user populations. Water is abstracted from the surface and groundwater sources, and if it is of poor quality, it must be treated to comply with drinking water standards before domestic supply (Bhuvana and Ramesh, 2012). Such conforming water is later delivered to concerned users under an established supply network through the drinking water distribution system (DWDS). As water moves through the DWDS, water quality is likely to change and may deteriorate if supply infrastructures are poor, resulting in (i) microbiological growth, (ii) chemical reactions, (iii) interactions with deteriorating and ageing infrastructure (McClain et al., 2013). The visibility of water quantity constraints makes it a prioritised area compared to quality issues, and engineer's trade-off for the majority to have at least some water rather than missing it out. The danger of this paradigm centers on foregone concepts that without first-hand knowledge of water source quality may lead to a poor (e.g., wastewater) distribution for communities where unknowingly supply of contaminants can cause diseases occurrence (Mahmud, et al., 2019). The effects can thus reach an epidemic level, and more to children and already sick people with limited immunity. A similar reason can justify the establishment of the United Nations (UN) Sustainable Development Goal (SDG) number 6 for clean water and sanitation; and the Water Action Decade 2018-2028 (Liu, *et al.*, 2012).

The DWDS issues include the formation of biofilms which are among the ignored sources of unpleasant taste and odour in piped water supplies (Zhou et al., 2017; Perrin et al., 2019), and where the mechanism to eliminate them is a challenging task. Growth of biofilms that pose insignificant reduced pipe size, i.e., less than 1% (Kithiia, 2011), can be retarded through increased flow rates and disinfection practices, but this procedure, when realised with chloramines, yields another nitrification water quality issue (Cruz et al., 2020; Shi et al., 2020). Besides biofilm-based microbe releases, DWDS leakages, repairs, and maintenance can assimilate microbes into the supply network. Fontanazza et al., (2015) found that contaminants intrusion in DWDS occurs at pipe crack and is mainly driven by low or negative water pressures. Thus, in addition to microbial contaminations, which also have a particular case of survival means through biofilms, other pollutants of physicochemical characteristics are also introduced in the DWDS in the same way.

Water infrastructures in the Pawaga study area are not well developed; no proper water treatment, and still people are sharing the water sites with animals. Large-scale agricultural production in the Usangu basin is one of the largest consumers of water, and as a result, has the most significant influence on water stress, especially during the dry season to the users, especially in the Pawaga division (Lufingo, 2019). Pastoralists in the highlands of the Great Ruaha river have been feeding their animals along the river. Livestock has increased in the division, migrating from neighbouring regions such as Mbeya, Singida and Dodoma. This makes the number of livestocks more than 35,000 in the division, and this destructs the river banks and threatens water quality (IUCN, 2010).

This work aims at assessing the water quality of drinking water at Pawaga division. The research has considered all water sources used by the same piped water users and others during different occasions or localities, such as prolonged and distant farming sessions where piped water users switch to unpiped sources such as shallow wells, deep wells, rivers, rain, streams, or swamp water uses. The overall implication of water safety was analysed in terms of reported supply status and the influence of official or unofficial alternative sources on the general water quality status, which is weighed as per concerned DWDS.

2.0 MATERIALS AND METHODS

2.1 Study Area

The study covered the Pawaga division, the area graphically situated downstream of Ruaha Rivers and is one of the six divisions in the Iringa district Council in the Iringa region, Tanzania. The site is well shown in Figure 1. The division has the smallest land area, about 684.3 square kilometres (3.3%) of the total district land area. It has a total of 12 villages and 60 hamlets. The main economic activities in this division are agriculture and pastoralism. The climate of the Pawaga division is semi-arid to arid, with bi-modal rainfall patterns (Coppolilo et al., 2011). The amount of rainfall increases along the northeast-southwest gradient of the division, with more precipitation in the southern villages creating a wetter environment than in the northern towns (Coppolilo et al., 2011).

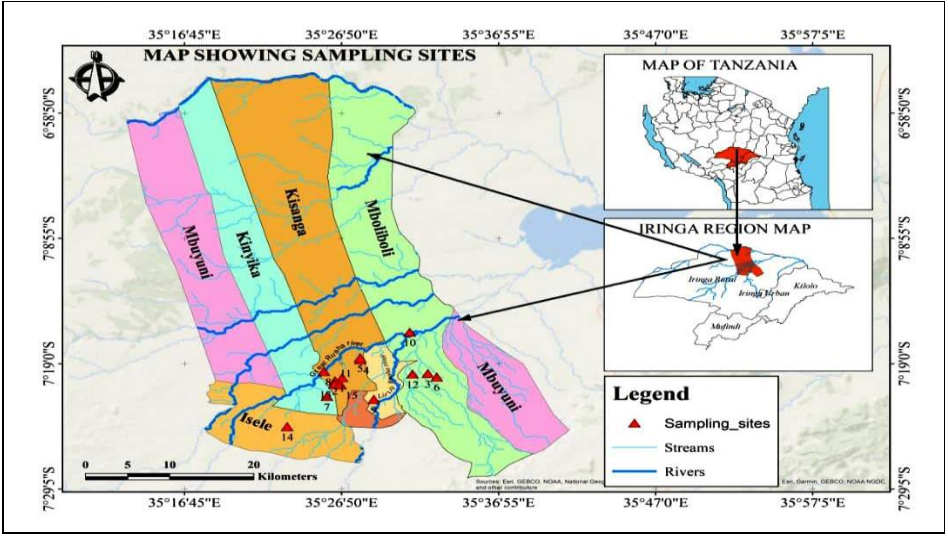

Figure 1: Map of Pawaga Division Showing Sampling Sites (reference)

2.2 Water Sampling Site and Plan

The selection of sampling sites was based on water scarcity and availability of newly developed water supply projects under several funders was the reason selection of the study sites. Furthermore, most localized water projects (at community level) at Pawaga division account for its exclusive study area suitability that reflects future implications on clean and safe water provision for all.

Table 1: The description of sampling sites

ID	Source	Sampling Point	Village
S01	Little Ruaha River	Irrigation Scheme Canal	Kinyika
S02	Shallow Dug Well	Direct	Kinyika
S03	Shallow Dug Well	Direct	Mboliboli
S04	Shallow Dug Well	Direct	Kisanga
S05	Little Ruaha River	Tap Water	Kisanga
S06	Little Ruaha River	Tap Water	Mboliboli
S07	Shallow Dug Well	Direct	Mboliboli
S08	Little Ruaha River	Tap Water	Isele
S09	Great Ruaha River	Near village	Kisanga-Kilala
S10	Swamp Water	Pawaga Sec	Pawaga
S11	Great Ruaha River	Near village	Mboliboli-Mbugani
S12	Borehole	Direct	Kinyika
S13	Rainwater	Roof Collected Water	Mboliboli
S14	Rainwater	Roof Collected Water	Kinyika
S15	Rainwater	Roof Collected Water	Isele
S16	Rainwater	Roof Collected Water	Kisanga

Water sampling followed the standard method for the examination of water and wastewater (APHA, 2017). The 1000 ml plastic bottles were washed thoroughly with distilled water and rinsed with the sample to be taken. After grab sampling (S01, S05, S06, S08, S09 and S011) near the centre of the river, proper sealing and labelling followed before storing in the cool box (around 4^{O}C) and transported to Iringa water quality laboratory for analysis. A similar procedure for river water sampling was employed, except for tap water required water flushing for about five minutes before taking a grab sample. A triplicate sample from three different locations of Great Ruaha River, three different tap water and three different wells were sampled for physical-chemical and bacteriological analysis. Well water sample was treated the same as river water except for the sampling procedure, which involved flushing water from the well for about ten minutes before obtaining a grab sample. River water sampling for microbial analysis followed method described earlier (Dobrowsky et al., 2014), where the sterilized sampling bottles were fully inverted and submerging to a depth of 0.3 m below the water surface, so as to avoid surface scums and debris.

Well water and Tap water involved pre-sterilisation of sampling insitu through the application of 99.9% ethanol followed by the flame, which lasted for about two minutes and allowed to cool after ten minutes before obtaining grab sample in sterile microbial glass bottles.

2.3 Water Quality Analysis

During fieldwork, there was an immediate analysis of water quality parameters with a limited maximum holding time, i.e. even if preserved (e.g. less than 24 hours). They comprised pH, Turbidity (Turb, NTU), Electric Conductivity (EC, µS/cm), Temperature (Temp, ^{0}C), Ammonia (NH_3, mg/L); Nitrate (NO_3, mg/L), Nitrite (NO_2, mg/L), Ortho-phosphate (PO_4, mg/L), Sulphate (SO_4^{2-}, mg/L) and *Escherichia* Coliform (E. Coli, Cfu/100 ml) enumeration.

The following physical-chemical parameters were included in the study: conductivity, temperature, pH and turbidity. These were selected due to their ubiquity as water quality assessment parameters globally and their ease of measurement in the field under rough conditions. Physical parameters were all measured in-situ using portable multiparameter (HANNA HI-9828, USA). The following nutrients: Nitrate-N (NO_3^-–N) and Phosphate-P (PO_4^3–P) were selected as they are typically the most common nutrients of concern in aquatic and wetland ecosystems. Specifically, they are important when present in excess amounts, as they tend to result to water pollution and ecosystem impartment. For nutrients, surface water samples were collected at the mid-channel at approximately 0.5 m depth in hydrochloric acid washed polythene bottles. Samples were preserved in a cool box at about ≤4 °C before being transported for laboratory nutrient analysis.

In the laboratory, NO_3^-–N, and PO_4^3–P were analysed using standard spectrophotometric methods described in APHA (2012). The NO_3^-–N was determined using the cadmium reduction method followed by diazotization with sulphanilamide and coupling with N-(1-naphthyl)-ethylene-diamine to form a highly coloured azo dye that measured spectrophotometrically at 545 nm wavelength. whereby PO_4^3–P was analyzed using themolybdate ascorbic acid method which results in a formation of intense blue colour measured at a wavelength of 880 nm. The quality of analytical data was assured by analysis of blanks and replicates samples with according to laboratory analytical procedure.
Calibrated Multi-parameterprobes (SevenGo pro probe and SevenGo Duo pro probe, Mettler Toledo AG, Switzerland) were used to measure electrical conductivity (EC), TDS, and pH in situ. Bicarbonate (titration using 0.02 N HCl) and chloride ions (argentometric method using 0.0141 N AgNO3) were analyzed on-site by using unfiltered samples (APHA, 1998). Meanwhile, the filtered samples were separated into two polyethylene bottles, one for the analysis of sulphate (SurfaVer 4 HACH method) and nitrate (NitraVer 5 HACH method) and the others to determine cations which were analyzed using flame atomic absorption spectrometry (FAAS, Shimadzu AA6800).

2.4 Statistical Analysis and Validity of Results

Field and laboratory quality assurance of results were employed through calibration and verification of used equipment, standardization of traceable chemicals and reagents used, proper sampling and sub-sampling practices, use of quality control samples, and employment of triplicate samples analysis. Data accuracy check for charge balance utilising major ions using Aquachem 9. The information obtained from the microbial, physico-chemical, and metal analysis of the collected samples was evaluated by using the statistical software package SPSS version 23.0 (IBM Corp, 2013; Armonk, NY, USA). Several linear and multiple regressions were performed between the concentration of *E. coli* and total coliforms physical-chemical parameters, and major elements. In all the hypothesis tests, a significance level of 5% was used as the standard. In all tests, a *p*-value < 0.05 was considered to be statistically significant.

3.0 RESULTS AND DISCUSSION

3.1 Results of Physicochemical Parameters

Water quality findings presented in Table 2 corresponds to field and laboratory works as per the wet season (March 2021). Table 3 corresponds to data collected during dry season November 2021. Table 4 summarises maximum and minimum statistics for all tested parameters; their values acquire a further comparison to TBS (2018) and WHO (2017) limits for natural potable (Untreated) water.

Table 2: Physicochemical Results - Wet Season

Sample code	E.Coli	Turb	pH	Temp	EC	TDS	HCO_3^-	Cl^-	Hardness	PO_4^{3-}	SO_4^{2-}	NO_3^+	Na^+	K^+
S01	88	93.5	6.89	25.3	348	236.6	167	9.3	171.01	2.1	18	5.9	1.8	0.1
S02	3	69.2	7.01	24.1	573.3	389.8	204.5	43.05	204.75	1.18	27.3	5.9	32.3	6.51
S03	11	72.1	6.65	25.2	456.3	310.3	171.6	20.54	162.97	0.61	22.1	24.1	28.6	3.12
S04	7	55.4	7.66	24.7	593.5	403.6	210	25	214.28	0.26	27.5	44	33.7	5.95
S05	2	48.2	7.11	23.1	169.7	115.4	65	8.89	62.93	0.1	8.06	6	9.1	1.33
S06	1	42.4	7.63	24	310.4	211.1	177.4	5.84	119.4	0.14	9.78	0.6	16.1	1.9
S07	6	62	7.55	26	678.9	461.6	431.9	4.33	266.22	0.34	12.19	1.9	28.1	8.37
S08	12	33.7	7.32	22.7	166.2	113	49.2	13	77.38	0.09	9.6	4.6	2.2	0.72
S09	124	211	7.09	24.1	176.6	120.1	51.7	11.86	76.72	0.09	13.57	4.3	5.1	0.66
S10	13	69.3	7.62	28.3	514.8	350.1	199.1	31.9	192.52	0.75	19.8	14.3	25.3	5.5
S11	111	286	7.93	25.1	158.4	107.7	49	11.6	55.76	0.13	10.2	3.1	8	3.1
S12	0	1.02	6.88	22.1	3288	2235.8	1500	145.2	1309.32	2.8	93	101.4	104.4	59.4
S13	0	2.03	7.77	22.5	22.1	15	8.2	1.58	5.77	0.02	0.29	1.2	2.3	0.24
S14	0	1.1	7.87	23.1	15.7	10.7	8.9	0.12	7.01	0.01	0.49	0.4	0.4	0.2
S15	0	3.03	7.9	24.2	18.9	12.8	8.6	0.66	8.98	0.01	0.43	1	0.2	0.04
S16	0	5.09	7.99	24.6	19.5	13.3	10.7	0.2	6.82	0.07	0.8	0.4	1.2	0.17

Table 3: Physicochemical Results - Dry Season

Sample code	E.Coli	Turb	pH	Temp	EC	TDS	HCO_3^-	Cl^-	Hardness	$PO_4^{\#-}$	SO_4^{2-}	NO_3^-	Na^+	K^+
S01	51	49.73	6.89	26.8	158.2	107.6	75.9	4.23	77.925	0.71	8.18	2.7	0.8	0.05
S02	0	36.81	7.01	25.6	625.4	425.3	223.1	46.96	223.44	0.67	29.78	6.4	35.3	7.1
S03	0	38.35	6.65	26.7	497.8	338.5	187.2	22.41	177.845	0.34	24.11	26.2	31.2	3.4
S04	1	29.47	7.66	26.2	647.5	440.3	229.1	27.27	233.56	0.15	30	48	36.7	6.49
S05	6	25.64	7.11	24.6	77.1	52.5	29.5	4.04	28.6	0.09	3.66	2.7	4.1	0.61
S06	3	22.55	7.63	25.5	141.1	95.9	80.6	2.65	54.055	0.11	4.45	0.3	7.3	0.86
S07	1	32.98	7.55	27.5	709.7	482.6	451.5	4.53	278.41	0.18	12.74	2	29.4	8.75
S08	5	17.93	7.32	24.2	75.5	51.4	22.4	5.91	35.13	0.06	4.36	2.1	1	0.33
S09	67	112.23	7.09	25.6	80.3	54.6	23.5	5.39	35.095	0.08	6.17	1.9	2.3	0.3
S10	_	_	_	_	_	_	_	_	_	_	_	_	_	_
S11	88	152.13	7.93	26.6	72	49	22.3	5.27	25.46	0.1	4.64	1.4	3.6	1.41
S12	0	0.54	6.88	23.6	3495	2616.3	1595.3	154.4	1421.9	1.07	98.9	107.9	119	37.2

Table 4: Correlation Matrix

	Wet Season													
	E.Coli	**pH**	**Turb**	**EC**	**TDS**	**Temp**	**NO_3^-**	**SO_4^{2-}**	**Cl^-**	**HCO_3^-**	**PO_4^{3-}**	**Na^+**	**K^+**	**Hardness**
E.Coli	1													
pH	-0.1	1												
Turbidity	**0.9**	-0.1	1											
EC	-0.2	-0.4	-0.2	1										
TDS	-0.2	-0.4	-0.2	1.0	1									
Temp	0.2	0.1	0.3	-0.2	-0.2	1								
NO_3^-	-0.2	-0.4	-0.2	**0.9**	**0.9**	-0.2	1							
SO_4^{2-}	-0.1	**-0.5**	-0.1	**1.0**	**1.0**	-0.2	**0.9**	1						
Cl^-	-0.1	**-0.5**	-0.1	**1.0**	**1.0**	-0.2	**0.9**	**1.0**	1					
F^-	-0.2	-0.3	-0.1	**0.9**	**0.9**	0.1	**0.8**	**0.9**	**0.9**					
HCO_3^-	-0.2	-0.4	-0.2	**1.0**	**1.0**	-0.2	**0.9**	**0.9**	**0.9**	1				
PO_4^{3-}	0.1	**-0.6**	-0.1	**0.8**	**0.8**	0.0	**0.7**	**0.8**	**0.8**	**0.8**	1			
Na^+	-0.3	-0.4	-0.2	**1.0**	**1.0**	-0.1	**0.9**	**1.0**	**0.9**	**1.0**	**0.7**	1		
K^+	-0.2	-0.3	-0.2	**1.0**	**1.0**	-0.3	**0.9**	**0.9**	**1.0**	**1.0**	**0.7**	**0.9**	1	
Hardness	-0.1	**-0.5**	-0.2	**1.0**	**1.0**	-0.2	**0.9**	**1.0**	**0.9**	**1.0**	**0.8**	**1.0**	**1.0**	1

	Dry Season													
	E.Coli	**pH**	**Turb**	**EC**	**TDS**	**Temp**	**NO_3^-**	**SO_4^{2-}**	**Cl^-**	**HCO_3^-**	**PO_4^{3-}**	**Na^+**	**K^+**	**Hardness**
E.Coli	1													
pH	0.3	1												
Turbidity	**0.9**	0.4	1											
EC	-0.3	-0.3	-0.4	1										
TDS	-0.3	-0.3	-0.4	**1.0**	1									
Temp	0.3	0.2	0.4	**-0.5**	**-0.5**	1								
NO_3^-	-0.3	-0.3	-0.4	**0.9**	**0.9**	-0.4	1							
SO_4^{2-}	-0.4	-0.4	-0.4	**1.0**	**1.0**	**-0.5**	**1.0**	1						
Cl^-	-0.3	-0.4	-0.4	**1.0**	**1.0**	**-0.5**	**0.9**	**1.0**	1					
F^-	-0.3	-0.3	-0.4	**1.0**	**1.0**	-0.4	**0.9**	**1.0**	**1.0**					
HCO_3^-	-0.3	-0.3	-0.4	**1.0**	**1.0**	-0.4	**0.9**	**1.0**	**0.9**	1				
PO_4^{3-}	-0.2	**-0.6**	-0.4	**0.8**	**0.8**	-0.2	**0.7**	**0.8**	**0.8**	**0.7**	1			
Na^+	-0.4	-0.3	**-0.5**	**1.0**	**1.0**	-0.4	**0.9**	**1.0**	**1.0**	**1.0**	**0.7**	1		
K^+	-0.3	-0.3	-0.4	**1.0**	**1.0**	-0.4	**0.9**	**1.0**	**1.0**	**1.0**	**0.7**	**1.0**	1	
Hardness	-0.3	-0.3	-0.4	**1.0**	**1.0**	-0.4	**0.9**	**1.0**	**1.0**	**1.0**	**0.8**	**1.0**	**1.0**	1

3.1.1 Multivariate Cluster Analysis

Study samples related from one another during sampling as (i) shallow wells near or within co-sampled rivers and canals, as well as (ii) all water sources, experienced collective comparable natural and anthropic influences. Figure 4.8 shows a dendrogram that depicts the hierarchical relationship from clustered samples among 16 water sources of the wet season. The remarkable similarity (~100%) occurs on S02 and S03 samples, and they are all shallow wells from Kinyika, Mboliboli and Kisanga villages. These samples share the same seasonal water valley that becomes waterless during the dry season but continues to sustain these shallow wells at relative more depth. S06 and S07 correspond to little Great Ruaha river water and a shallow well close to it and shows a similarity of more than 99% to each other.

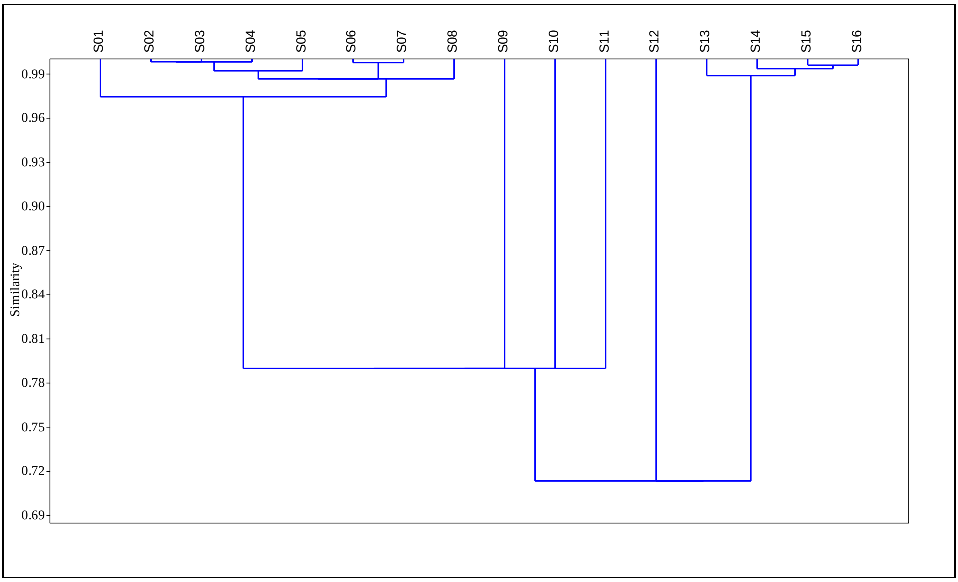

Figure 2: A dendrogram indicating wet season clustered samples

Rainwater samples S13, S14, S15 and S16 from different villages also showed variations. Contrary to S15 and S16 from Isele and Kisanga villages with a similarity of ~99%, S13 and S14 from Mboliboli and Kinyika villages had 98-99%. Another sample from the Little Ruaha river at Kisanga tap water (S05) showed a ~99% similarity to others, followed by the same tap river water at Isele (S8), which had a ~98% similarity. The irrigation water sample (S01) had a similarity of ~97% to all study samples. Water samples from the Great Ruaha River (S9 from Kisanga-Kilala village and S11 from Mboliboli-Mbugani village) and the swamp water (S10 from Pawaga division) altogether had a similarity of ~79% to others. The deep borehole sample (S12) from Kinyika village had a similarity of ~71% concerning all study samples. To summarise, the study area had excellent sample interrelations from shallow wells, tap water and the irrigation canal, except those from the Great Ruaha River, Swap and the deep borehole, which had their distinct characteristics.

3.2 Discussion

3.2.1 Water physical parameters

Most parameters' mean values and standard deviations were generally higher during the dry season than the wet season. The pH values of all tested sources in both seasons are within the acceptable standards TBS (2019) (5.5 – 9.5) and WHO (2017) (6.5 – 8.5) limits. These values are in line with those detected earlier (Jia et al., 2010), ranging between 7.01 and 8.21. Turbidity, which is also related to the content of diseases causing organisms in water, is the cloudiness of water caused by various dissolved particles. The values in both seasons, except rainwater, exceeded TBS (2018) (25 NTU) and WHO (2017) (1 NTU limits). The detected values are higher than those seen earlier (Rahmanian et al., 2015), where the lowest turbidity values of 0.69 NTU and the highest value of 4.6 NTU were noted.

Electrical conductivity is the ability of any medium, water, in this case, to carry an electric current. The presence of dissolved metal or non-metal ions such as calcium, chloride, sulphate, magnesium, and many others in water samples carries the electric current through water. The analysed samples range between 1 – 286 µS/cm. These values correspond to values detected elsewhere (Rahmanian et al., 2015), where the conductivity of water samples ranges from 69.7 µS/cm to 269.3 µS/cm, and also the one detected at Mbinga (Kihampa and Ndunguru 2021), where the electrical conductivity ranges between 14.6 to121.1 µS/cm. According to Cidu et al., 2011, conductivity does not directly impact human health. It is determined for several purposes, such as determination of mineralisation rate and estimating the number of chemical reagents used to treat this water. High conductivity may lead to lowering the aesthetic value of the water by giving a mineral taste to the water. The DWDS in this study had inefficient clarification treatments and no disinfection treatments, hence EC serves as a relative real-time measure of water supply origin, chemical contamination changes and compared the quality of alternative used sources. The TDS ranges between 107 – 2235.8 mg/L with a mean of 319.2 mg/L during the wet season and 49.0 - 2616.3 mg/L with mean of 428.5 mg/L during the dry season. These values are below the permissible limits by TBS (1,500 mg/L) and WHO (1,000 mg/L).

3.2.2 Chemical parameters

Hardness Nitrate concentration is low in water samples but in the effluent of nitrifying biological treatment plants nitrate may be found in concentrations of up to 30 mg. In present study NO_3^- ranges between 0.4 – 101.4 mg/L during rainy season and 0.3 – 107.9 mg/L during dry season. The maximum levels are higher than previous study (Uddin, et al., 2014), which shows the concentration NO_3^- in water ranges from 78 to 98 ppm in dry season and 77 to 99 ppm in wet season, this is very high in respect to standard value. The higher amount contamination from fertilizers, municipal wastewaters, feedlots, septic systems in water which causes higher concentration of NO_3^-, it refers that the higher the deviation the lower the quality of water for fish and other aquatic life and for common uses (Ayers, and Westcot, 1976). Sulphate concentration ranges between 0.3 – 93.0 mg/L during rainy season and 3.7 – 98.9 during dry season. These values are lower than those detected earlier (Uddin, et al., 2014), ranged between 824 to 843 ppm in dry season and 712 to 743 ppm in wet season. According to Jailos, et al., (2021), sulphate can also be produced by bacterial or oxidizing action as in the oxidation of organo-sulphur compounds. The more common sinks are pyrite, gypsum, and sulphate reduction.

Chloride is an indication of salinity in water. Surface water containing significant amount of chloride ranges between 0.1 -145.2 mg/L during wet season and 2.7 – 154.4 mg/L during dry season. These levels are higher than those determined earlier (Jailos, et al., 2021), ranged from 0.46 to 2.68 mg/L (wet season) and during the dry season ranged from 2.02 to 5.8 mg/L. The maximum value of PO_4^{3-} was 2.8 mg/L during rainy season and 1.1 mg/L during dry season. These levels were lower than those detected earlier in recent study (Jailos, et al., 2021), where phosphate levels ranged from 0.52 to 1.25 mg/L.

Figure 3 shows a piper diagram depicting major ions (anions and cations) in the wet and dry seasons. A vertical look at both seasonal figures shows less variation on position for their apexes, thereby suggesting that inherent comparable chemical composition exists and only varies in their magnitude due to seasonal effect.

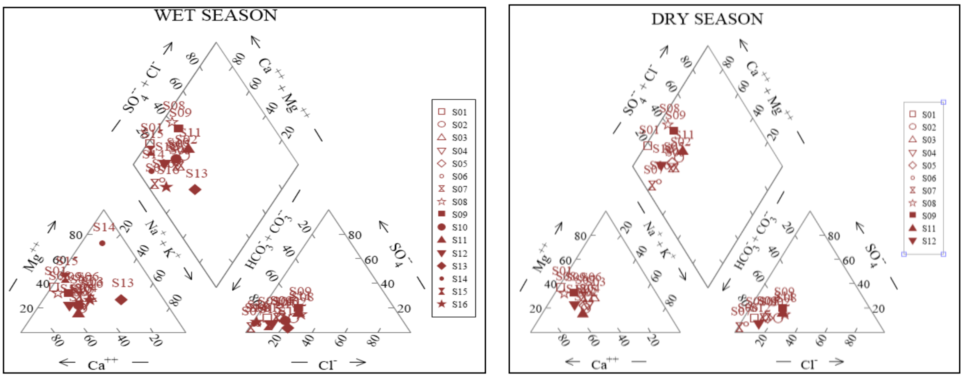

Figure 3: Piper Diagram for the Major ion Composition of Water Samples for the Wet and Dry seasons

The two ternary diagrams represented as triangles in both seasons shows plots for cations (Magnesium, Calcium, sodium and potassium) and anions (sulphate, chloride, carbonate and bicarbonate). Most samples in the cation triangle plots between 0 to 50 Ca^{2+} and $Mg^{2+,}$ signifying a Ca^{2+} water type. Sample S14 (rainwater) plots between 0 to 50 values of $Na^+ + K^+$ and 50 to 100 values of Mg^{2+}, indicating Mg^{2+} water type. Sample S13 plots close to the centre of the cation triangle and depicts no dominant water type. Contrary, the anion triangle had all samples plotting between 0 to 50 values of Cl^- and HCO_3^- and CO_3^{2-} that portrayed HCO_3^- water type. Figure 3 shows the projection of the two ternaries (matrix transformation of cation and anion triangles) into a top diamond plot. All samples are plotting between 0 to 50 values of Na+ + K+, and $SO_4^{2-} + Cl^-$ on diamond plot facies, which depicts that Alkaline earth (Hardness, Ca^{2+} and Mg^{2+}) exceed alkalies ($Na^+ + K^+$) as well as weak acids (such as H_2CO_3) exceed strong acids (such as HCl). Weak acid dominance accounts for observed pH trends where minimum sample pH was acidic to slightly acidic but with values at least 6.7. Strong acid dominance would have presented more low pH values, i.e. ≤ 6.7, that could invalidate potable water use suitability at values less than 5.5 and 6.5.

Excellent correlation (r = 1.0) is presented in Table 4 to all major ions with Electrical conductivity (EC) and TDS. In this regard, EC and TDS have a close relationship, as portrayed in Figure 4 for both seasons. At low Values, TDS and EC plotted close to each other for both seasons and plotted relatively apart at higher values. Lwimbo et al. (2019) realised dry and wet season water quality studies on groundwater sources and observed a comparable EC vs TDS plot trend. The EC and TDS relationship is documented in the water chemistry (APHA, 2017) as TDS = EC*k (where “k” is the conversion factor). This study had a minimum factor of k = 0.68 and a maximum k = 0.75, averaging at k = 0.71. Possible extremes values of “k” range from 0.5 to 0.9, with 0.7 as an average (Walton., 1989); thus, the EC and TDS relationship in the current study was suitable irrespective of the gravimetric method used to evaluate TDS in all water samples. Since all major ions accounted for measured EC and TDS values, their uniform influence suggests a common relationship of mineral origin during dissolution and sampled sources interrelations. For instance, HCO_3 excellently correlated (r = 1.0) with all major cations, i.e. Na, K, hardness (Ca and Mg), suggesting the existence of sedimentary evaporite deposit as the area is characterised by extremely high temperatures (Tanzania C.A.R.E, 2019) that water content lost as evaporation can’t be compensated by total rainwater and influx surface water (rivers and streams).

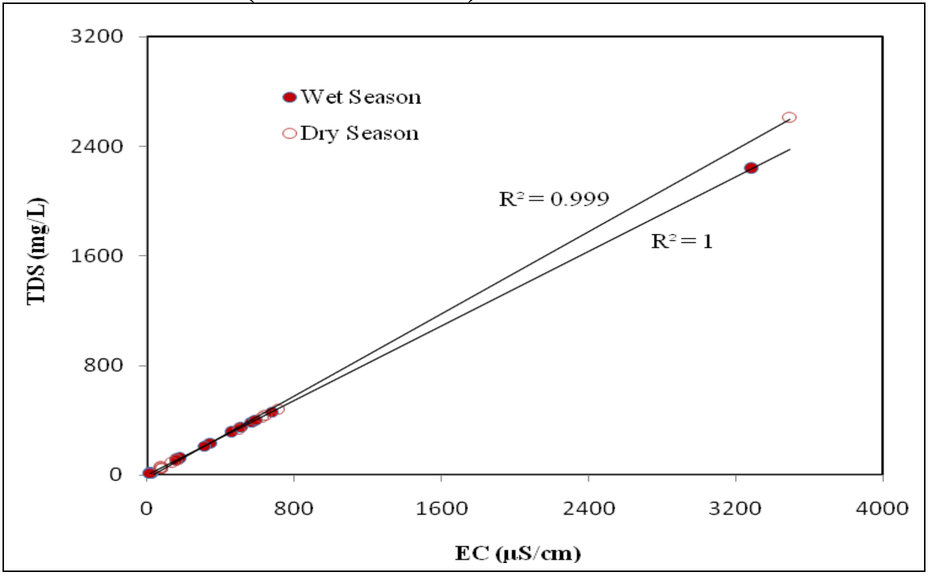

Figure 4: EC vs TDS Relationship for the dry and wet season

3.2.3 Microbial Pollution

Rainwater accounted for the wet season due to its availability and preference for domestic uses from most study area water users. Rainwater had no microbial contamination of E. coli, as portrayed on most shallow and deep wells during the dry season. All surface and groundwater sources, except a deep borehole (S12), had contaminations of E.coli. The contamination is low to absent on dry season within the same sources. Maximum E.Coli contamination was 124 Cfu/100ml, and the minimum was 88 Cfu/100ml for all studied sites in both seasons.

The presence of E. Coli in drinking water samples indicated the highest risk of faecal pollution related to human pollution on such water sources (Ercumen et al., 217; Mahmud et al., 2019; Sasáková et al., 2021). E.Coli best correlated with turbidity (r = 0.9, for both seasons) in water samples. Since turbidity has no health effects, it usually interferes with disinfection activities and provides a medium for microbial growth. Thus, high turbidity values can indicate the presence of disease-causing organisms such as E.Coli (Smith et al., 2008), which can cause symptoms such as nausea, cramps, diarrhoea and associated headaches. Figure 5 shows that turbidity and E.Coli had a linear relationship with all samples plotting at R2 = 8 and 9. During the wet season, the association suggests that rain activities that collect terrestrial matters into water bodies and agricultural activities return used water to drinking water sources (Yu et al., 2016; Ghernaout and Ibn-Elkhattab., 2019), thereby contributing most of the high turbidity values. The dry season had a better association of E. Coli and Turbidity with relatively low values than a wet season, direct access of human to these water sources during their routine activities could be one of contaminaion route.

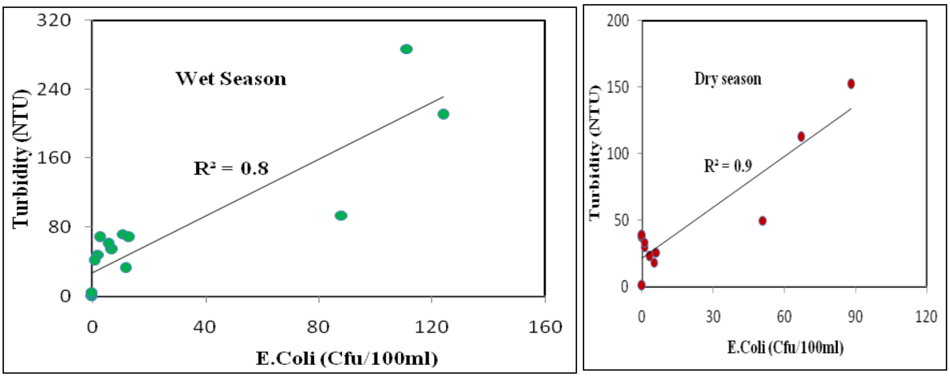

Figure 5: Behavior of E.Coli with Turbidity in Wet and Dry Seasons

4.0 CONCLUSIONS AND RECOMMENDATIONS

The levels of pollution in all water sources were severe during the wet season. The E.Coli contamination was detected in at least 68% of all wet season samples and portrays how acute diseases such as diarrhoea and typhoid are prominent to such water users during the wet season. Dry season microbial status is also not well as most samples also possess E. Coli. During the wet season, users preferred rainwater which was also confirmed free from microbial (E.Coli) contamination. While chemical pollution remained relatively uniform from the source and at distribution points, microbial contamination progressively decreased with an increase in supply network coverage. It can therefore be concluded that land-use practices largely influenced the quality of water in the catchment. These results provide new insights into the environmental quality of the catchment. They also demonstrate that, even though most parameters were within the permissible limits of drinking water standards, there is a need to take appropriate measures of pollution control by the concerned authorities to keep the water quality within the permissible limits as the population and human activities in the area are increasing.

The same applies during the dry season that users near the intake have a relatively reliable water supply than those at distant networks. Turbidity represented poor physical water quality and was severe during the wet season. Since all studied domestic water sources had no treatment before use, turbidity was the first visible water quality parameter that all users realised an upfront rejection of such water when rainwater was available. Turbidity further sustained microbial survival and could interfere with most disinfection processes.

Chemical pollution noted in all water samples threatened users' health when many values exceeded the maximum limits set by Tanzania Bureau of Standards (TBS, 2008) and Word health Organization standards (WHO, 2011). A deep borehole is generally not suitable for domestic uses due to its high unbearable salt contents. Shallow wells that serve the remote area (with no piped water supply) as water sources also present inherent pollution from anthropic activities. Rainwater possessed considerable dissolved materials instead of its ideal composition due to the semi-arid climate zones of the study area, where there are high sunny activities than rain, and wind act as a carrier of particulates to roofing material even after several flushes. Nutrient content in water bodies served as evidence of poor water quality for potable water uses and ecological health; nutrients such as phosphate are portrayed as point source water pollution from agricultural activities. In the current practice where agriculture backs up more than 90% of villagers' economic activities, water pollution is inevitable as the same scarce water resource also serves potable uses. Farmers use raw water from streams and rivers for drinking during their farming activities distant from villages. Apart from prolonged chemical intoxication (that leads to chronic effects), the situation presents their vulnerability to typhoid and diarrhoea (acute effects) due to raw water consumption, which is polluted from anthropic activities.

Pastoralist presents a group of water users in areas where there is no piped water supply. Their activities force them to live in remote areas where public water supplies are not practical. This group suffers more when it comes to clean and safe water availability. Their survival mode relies on ponds and related surface water reservoirs, and to a certain extent, they need to spend more time searching for appropriate water from village centres. This research has further confirmed that surface water quality is extremely poor to microbial contamination. Physical pollution, and to a certain extent chemical pollution, are among other disqualifying features.

While the current study assessed the Pawaga drinking water distribution systems, it was observed that there are more out of formal piped water supplies, which could pose a potential public health threat, yet the blame is under the supply management authority. Future studies shall further ascertain the extent of contamination in Pawaga historical water supply pipes, including the biofilms.

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