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ASSESSMENT OF WATER QUALITY VARIATION IN RIVERS THROUGH COMPARATIVE INDEX TECHNIQUE AND ITS RELIABILITY FOR DECISION MAKING

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ABSTRACT

The National Sanitation Foundation (NSF) and Weighed Arithmetic Index (WAI) methods for water quality index (WQI) have been studied to evaluate their reliability in water quality assessment in rivers. Water samples were collected in various GPS predetermined points in Temi, Nduruma, Tengeru and Maji ya Chai rivers-Tanzania during wet and dry seasons and were analyzed for several water quality parameters using standard methods as per APHA. Medium to excellent water qualities were observed for pristine environment in three rivers except Maji ya Chai under NSF and WIA methods, respectively. Excellent water quality was observed in the pristine environment of Temi and Tengeru rivers during wet season. Maji ya Chai water was identified unsuitable for drinking throughout the year. Fecal Coliforms (FC), Nutrients content, BOD and Fluorides (F^-) were the major contributors to the poor water quality in Maji ya Chai whereas FC and Nutrients were a serious problem in flood-plain for other rivers. The two methods showed different overall Water Quality Indices using the same data thus, making them unreliable tools for water quality assessment when used simultaneously for the same purpose. Therefore selection of the method for water quality assessment and decision making may depend on the water use.

Key words: Water quality Index; Mount Meru Rivers;

INTRODUCTION

Water resources are of great environmental issues and studied by a wide range of specialists including hydrologists, engineers, ecologists, geologists and geomorphologists (Kumar and Dua 2009). This is because water affects not only human uses but also plant and animal life. Mount Meru is one of the major catchment areas of several rivers and streams feeding the Pangani main river (Guidance 2006). Arusha city, Monduli and Arumeru districts depend on water sources from this area which its overall quality at different river management levels is not well known (UNDP 2000, PRBMP 2006, Kihampa et al. 2013). Judgments on water quality in different water sources remain a debate due to the fact that several parameters can be used to contribute in its quality depending on the water use type. Quality of water is defined in terms of its physical, chemical, and biological parameters. However, the water quality is difficult to evaluate from a large number of samples, each containing different values for many parameters (Almeida et al. 2007).

Several approaches are used to assess the water quality in respective rivers, this includes; multivariate factor analysis for water quality assessment and water quality indices (WQI) (Qian et al. 2007, Tyagi et al. 2013). Among these, the water quality index (WQI) is the most prominent acceptable water quality scaling tool for assessment of water quality for different purposes (Brown et al. 1972, Almeida et al. 2007). Water quality index method has been developed by establishing the overall water quality using a single scale from contribution of several water parameters to a clearly and simple understood water quality scale such as excellent, poor, good, bad and so on, thus, making easy for reporting to management and the public, the status of water in understandable and consistent manner. The first WQI was proposed by Horton and it made a great deal for consideration towards development of index methods (Horton 1965). The method has undergone several modifications to fit different purposes such as inclusion or exclusion of some other factors which have potentials to different health defects such as carcinogens and weighed contributing factors balance (Debels et al. 2005, Abtahi et al. 2015). However, the basic components and purpose of WQI methods being a mathematical instrument used to transform large quantities of water quality data into a single number which represents the water quality level while eliminating the subjective assessments of water quality and biases of individual water quality experts remain unchanged. Basically, a WQI attempts to provide a mechanism for presenting a cumulatively derived, numerical expression defining a certain level of water quality (Miller et al. 1986). Several methods have been used to develop WQI for different use. The commonly used methods includes, the National Sanitation Foundation (NSF) method being the most prominent and the Weighted Arithmetic Index (WAI) Method. In this study, the two methods are used to evaluate their reliability in assessment of water quality by using Temi, Nduruma, Tengeru and Maji ya Chai Rivers and thus, its overall quality for each river will be unveiled.

MATERIALS AND METHODS

Description of study area

The study was conducted in Themi and Nduruma rivers and catchments which lay within the Arusha City together with Tengeru and Maji ya Chai Rivers which lie within the Meru District. The four rivers originate from common sub-catchments of foot hills of Mount Meru lying from the eastern part to the south west of the mountain (Fig. 1). The rivers run downstream from the mountain to the south east. The study area was divided into three regions depending on the river and land development namely, pristine (headwater) (3° 15’ 00”S to 3° 20’ 00”S), middle (3° 20’ 00”S to 3° 25’ 00”S) and flood-plain (3° 25’ 00”S to 3° 35’ 00”S) (Kitalika et al. 2018).

Sampling and analytical methods

Two liters (2 L) water samples were collected downstream from monitoring stations established by the Pangani Basin Water Office (PBWO) and other points depending on the confluence and accessibility of the riparian environment. The sampling stations and number of samples collected were dictated by the length of the rivers and their feasibilities. Therefore, eleven (11) sampling stations were identified for Temi River where as twelve (12) sampling stations were identified in Nduruma River. In addition, twenty one (21) sampling points were identified in Tengeru River together with seven (7) stations which were identified in Maji ya Chai River. The first liter was used for some chemical parameter measurements and the second liter was used for BOD and nutrients measurement. Sampling was done during the wet season (Mid-March to early April) and dry season (August) in 2015 in order to compare their seasonal quality differences and usability. Several water quality parameters were measured as explained thereafter. Temperature, pH, total dissolved solids (TDS), dissolved oxygen (DO) and electrical conductivity (EC) were measured in-situ using a HANNA multiparameter Model HI9829 where as the total hardness were measured by acid titrimetric method. Samples for nitrate analysis were collected in half liter glass sampling bottles and immediately acidified with concentrated sulphuric acid to a pH below 2 to stop any further nitrate transformation. All samples were stored in a cold box and immediately transferred to the laboratory for analysis and preservation in the second day. The analysis for BOD, nitrates (NO_3^-), fecal coliforms (FC) and total suspended solids (TSS) were done following standard methods (APHA 2012). In addition, total phosphates (TP) and soluble phosphates (SP), sulphates and chlorides were measured using HACH 2800™ while, turbidity and alkalinity were measured using a 2100Q01 HACH portable turbidimeter with formazin turbidity standard 4000 NTU in serial dilutions to the required standards and HANNA alkalinity checker HI 755, respectively.

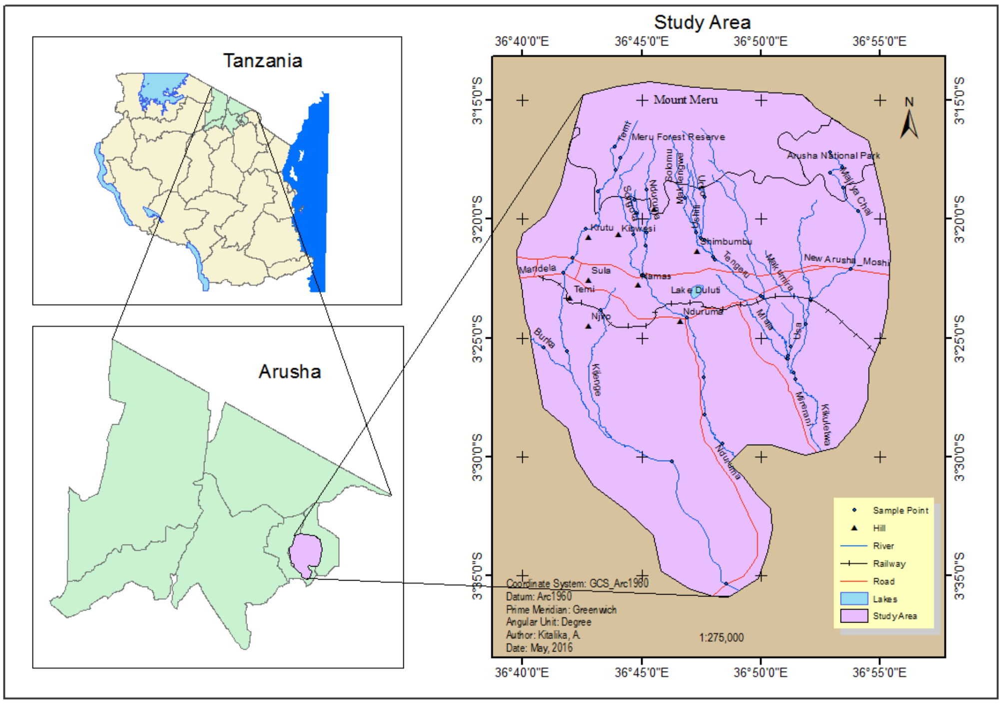


Figure 1: Location of the study area

Assessment for WQI

Two approaches for calculation of WQI, the WAI and the NSF were used to evaluate the water quality of each river. Measurements were made basing on the average value for water quality parameter of different sampling points in the respective river region.

The weighted arithmetic index method

Brown et al considered several variables for weighted arithmetic index method which follows some steps for its estimation (Brown et al. 1970, 1972).

The first step involves calculation of sub index of quality rating (*qn*);

qn is calculated basing on the number of water quality parameters involved in establishing the WQI.

Suppose there are *n* water quality parameters where the quality rating or sub index (q_n) corresponds to the nth parameter, then the number reflecting the relative value of this parameter in the polluted water with respect to its standard permissible value is given by the expression

$$q_n = 100 \times [\frac{V_n - V_{io}}{S_n - V_{io}}] \quad (1)$$

Where,

q_n = quality rating for the nth water quality parameter.

V_n = estimated value of the nth parameter at a given sampling station.

S_n = standard permissible value of nth parameter

V_{io} = ideal value of nth parameter in pure water.

All the ideal values, V_{io} are taken as zero for drinking water except for pH 7.0 and dissolved oxygen concentration of 14.6 mg/L (Tripaty and Sahu 2005).

The second step involves calculation of proportionality constant (K) for all water quality parameters which is the reciprocal of the sum of reciprocals of the standard permissible values for each parameter.

$$K = \frac{1}{\frac{1}{S_{n1}} + \frac{1}{S_{n2}} + \frac{1}{S_{n3}} + \ldots\ldots + \frac{1}{S_n}} \quad (2)$$

The third step involves calculation of unit weight (W_n) for various water quality parameters which is inversely proportional to the recommended standards for the corresponding parameters.

$$W_n = [\frac{K}{S_n}] \quad (3)$$

Lastly is to develop an equation for determination of WQI using the WAI Method which follows below;

$$WQI = \frac{\sum_{n-1}^{n} q_n w_n}{\sum_{n-1}^{n} w_n} \quad (4)$$

The excel file was prepared for all variables in equations 1 to 3 using ten (10) water quality parameters namely; pH, Dissolved oxygen (DO), Total dissolved solids (TDS), Fluorides (F^-), NO_3^-, Total phosphates (TP), water temperature (T), turbidity, Fecal Coliforms Units (FCU), and Biochemical oxygen demand (BOD) and were GIS integrated for computation of overall WQI for each sampling point.

The NSF method for water quality index

This method was developed in the early 1970's and later was adopted by NSF (Brown et al. 1970). Nine water quality parameters namely, DO, pH, temperature, TDS, BOD, nitrates, FC, TP and turbidity were considered each with its weighing factor totaling to 1. Thus, this method is specific to particular water quality parameters which were assembled by 142 water quality experts in the United States (US). The pre-established rating curves for quality index values (QI) for each water quality parameter is used to establish the overall WQI of particular water since each parameter has a fixed weighing factor. The QI value is then multiplied by weighing factor to get the WQI for that parameter (Kesharwani et al. 2004). The results are then totaled to get the Overall WQI as given by equation (5).

$$WQI = 0.17_{DO} + 0.11_{pH} + 0.10_{\Delta T} + 0.07_{TDS} + 0.11_{BOD} + 0.10_{Nitrate} + 0.16_{FC} + 0.10_{TP} + 0.08_{Turbidity} \quad (5)$$

Conversion of dissolved oxygen concentration to % saturation

All values for calculating the WQI by NSF method are used in their standards of measured values. However, the amount of DO in water is much affected by the atmospheric pressure and temperature: the two being an altitude function. These effects can be corrected by the equations (6) through (8) (Mortimer 1956, Kunz 2009). The equilibrium oxygen concentration at any pressure C_p is given by:

$$C_p = C^* \times P\left[\frac{(1-Pwv/P)(1-\theta P)}{(1-Pwv)(1-\theta)}\right] \quad (6)$$

Where;
C* = equilibrium oxygen concentration (mg L^{-1}) at standard pressure of 1 atm,
P = measured pressure, atm
P_{wv} = partial pressure of water vapour at temperature, t (atm).
$\theta = 0.00095 - (1.426\times10^{-5}t) + (6.436\times10^{-8}t^2)$
t = temperature, °C
$\ln P_{wv} = 11.8571 - (3840.70/T) - (216{,}961/T^2)$
T= temperature, K
But, the measured pressure (*P*) at altitude *h* is given by:
$\ln P = 5.25\times \ln(1-h/44.3)$ (7)
Hence, the % saturation of DO concentration (mg/L) is given by:

$$\%\ \text{Saturation} = \frac{100\times \text{DOmg/l}}{C_p} \quad (8)$$

Where DO is the measured (experimental) value.
The measured DO for each sample was corrected before including it in the calculations and the spread sheet for excel file was prepared to calculate the % DO saturation at recorded temperature.

GIS based water quality analysis

In this study, the two water quality assessment techniques (WAI and NSF) were integrated with ArcGIS to determine the overall water quality at various sampling points. Each water quality parameter was calculated in excel spread sheet using equation (4) and (5) and its components were filled in the ArcMap attribute table. The effective weights of each water quality parameter were calculated using ArcGIS analyst tool and the water quality grades were marked by quantitative classification using graduated colours based on prescribed NSF and WAI standards as shown in table 1 (Şener et al. 2017). The table shows different values for each water quality category depending on the rating method and purpose. However, despite those differences, the meaning and purpose of particular water quality grade remains similar thus it is expected that the two methods will give the similar water quality grade for the same water sample evaluated. Nine water quality parameters including BOD (mg/L), NO_3^- (mg/L), TDS (mg/L), fecal coliforms (FCU/100ml), DO (% saturation), pH, turbidity (NTU), total phosphates (mg/L) and temperature (°C) were combined in both models. Also, since the WAI method is flexible to addition of more parameters, another model which includes fluoride ions was run to assess its effect in water quality since the pollutant is available in waters of these rivers and has potential health effects in development and strength of human skeleton.

GIS based NSF technique spatial distribution

In this technique the quality index of each water quality parameter was determined from their respective rating curves. Then, the overall WQI for each GPS predetermined sampling point was calculated as per equation 5 using field calculator tool in ArcGIS software 10.1.

GIS based WAI technique spatial distribution

This technique employed both the excel spreadsheet and ArcGIS software as explained before. The Quality rating (*qn*) for the n^{th} water quality parameter for each sample point and the unit weight (W_n) for n^{th} water quality parameter were calculated in excel environment using equations (1) and (3) respectively. The standard grades used for classification of water quality by WAI and NSF method in this study are shown in Table 1. The overall WQI for each GPS predetermined sample point for both seasons was calculated using equation (4) under field calculator tool in ArcGIS 10.1 environment.

Table 1: Status of water quality based on WAI and NSF

WQI		STATUS	
NSF	**WAI**	**NSF**	**WAI**
0-25	<50	Very bad	Excellent
26-50	50-100	Bad	Good
51-75	100-200	Medium	Poor
76-100	200-300	Good	Bad
Above 100	>300	Excellent	Unsuitable for drinking and fish culture

(Brown et al. 1972, Mitchell and Stapp 1995, Ministry of Supply and Services Canada 1995, Ramakrishniah et al. 2009, Islam et al. 2011)

Principal component analysis

The Principal component analysis (PCA) is an important tool used to reduce multiple observed variables contributing to a particular property to a small number of variables called principal component (Jolliffe, n.d.). In this study the PCA for determination of the major contributing parameters (factors) in the water quality variation to the respective point was performed using OriginLab software version 8.6.The variables were supplied in the worksheet of the software and the multivariate for PCA was done as explained in the software manual (OriginLab 8.5 2010). The contributing factors were retained based on whether they could satisfy both the Kaiser and Cattell criteria graph (Kaiser 1960, Cattell 1966). The two criteria were used in order to maximize the number of stronger contributing factors to a particular water quality and thus, minimizing the errors for omitting any necessary water quality parameter. In the Kaiser criterion, contributing factors with Eigen value ≥ 1 were selected whereas using the Cattell criterion the Eigen values were plotted in descending order against the principal components to screen the variables and from the scree plot the principal components were selected basing on the significant break off of the graph (Kaiser 1960, Cattell 1966).

Reliability of WAI and NSF methods

Assessment for the test whether the two methods are consistent and could give the same result upon using the same water quality parameters were tested by comparing the results obtained after data processing. The assessment was done by comparing the water quality levels of the respective class for a particular method with expectation that it could the two methods cold give similar results.

RESULTS AND DISCUSSION

Physicochemical and nutrient spatial distribution in rivers

The parameters measured in this study involve pH, temperature, EC, DO, BOD, turbidity, FC, nutrients, TDS and TSS. In addition, fluoride ions concentrations were also measured. All these values are summarized in table 2 and 3. Water pH is a measure of how water is acidic or alkaline. It is important to monitor the pH in water since it affects plant growth, aquatic life, solubility and availability of minerals, engineering activities and water quality (Osibanjo et al. 2011). The water pH in all rivers was above 7 in both seasons an indication of slightly alkaline water. Tengeru catchment recorded the lowest pH of 7.12 ± 0.11 and 7.70 ± 0.36 during the wet and dry season seasons, respectively whereas the highest value (9.90 ±

0.14) was measured in Nduruma River downstream during the dry season. Nduruma River in the flood plain was caused by alkaline agrochemicals run off from several horticultural farms located along the river which upon furrow over irrigation the excess water drifts to the river. Maji ya Chai had the highest average pH in both seasons with the values of 8.03 ± 0.57 and 8.57 ± 0.52 for wet and dry seasons, respectively (Table 3) (Kitalika et al. 2018). The water temperature range was between 12.21 °C and 25 °C the two being measured in Nduruma River in the wet and dry season respectively. The lowest average temperature of 17.01 ± 1.80 °C was recorded at Temi River in the wet season while its highest temperature of 20.44 ± 4.22 °C being recorded in dry season. The temperature variations in all rivers were generally associated with canopy cover of the riparian environment, position of rivers with respect to Mount Meru where the leeward side had warmer water than the windward side and its elevation such that the low water temperature was measured in high elevation and canopy cover environment with the opposite being true. Electrical conductivity (EC) is related to the ability of water to allow passage of electrons when an electric current is connected in it. It is mainly associated with presence of dissolved ionic and polar substances. The lowest EC of 82 *µS/*cm was measured at the catchments of Temi River an indication of less salt being dissolved in it and the highest value of 1722 *µS/*cm was measured in the downstream of Maji ya Chai River during the dry season. High conductivity of in this river is associated with dissolved salts containing fluorides, fulvic and humic acids which together when partially dissolve in water increase the ionic strength of water. The levels for total dissolved solids (TDS) occurred concurrently with EC such that in each measurement they were half the values of EC. Similar reasons for EC variations accounts for TDS. The EC results obtained in this study are very similar to those obtained by Sener et al (2017) in their studies in river basin.

Fluoride is among the most dominant problem in water of these rivers. Daily intake of fluoride through food and or drinking water exceeding 1.5 mg/L according to WHO and 4.0 mg/L according to TBS has been associated with health complications of skeletal malformation such as dental fluorosis and enlarged skull together with alteration of some physiological activities in the body (Gorchev and Ozolins 2011, Johansen 2013, WHO 1966, 2004). The levels of fluorides in rivers had high variations ranging from acceptable levels to above the health limits as indicated in table 2 and 3. Several samples recorded low fluoride levels in Temi, Nduruma and Tengeru rivers whereas in Maji ya Chai River the levels were above the permissible heath limits in the whole river in both seasons. Therefore, presence of fluoride mineral in water has been found to be the major contributing factor for poor water quality in this river (Kitalika et al. 2018). Kijenge stream recorded the lowest fluoride levels of fluoride levels of 0.94 ± 0.07 in the dry season whereas the highest average level of 69.01 ± 0.21 mg/L was noted in Maji ya Chai River. High fluoride levels in Maji ya Chai River is caused by the fact that the river passes through lowland (foothills of Mount Meru) in the south eastern region of the mountain which is characterized by relatively high temperature incidence due to low canopy cover hence higher water temperature which accelerates the rate of rock containing fluoride dissolution (Kitalika et al. 2018). In addition, the alkaline environment which favours rock dissolution and the basaltic aquifer lithology containing high amount of fluoride mineral in this region is the main cause for such high levels (Ghiglieri et al. 2010).

Table 2: Physico chemical, nutrients and biological data for Temi and Nduruma rivers during wet and dry seasons in 2015

Temi River																				
Point	**F^-_W**	**F^-_D**	**FC_W**	**FC_D**	**Turbi_W**	**Turbi_D**	**NO_3^-_W**	**NO_3^-_D**	**TP_W**	**TP_D**	**BOD_W**	**BOD_D**	**DO_W**	**DO_D**	**TDS_W**	**TDS_D**	**T_W**	**T_D**	**pH_W**	**pH_D**
Te1	1.02	1.60	500	300	0.00	0.01	0.23	25.00	0.06	0.18	1.00	0.00	10.10	9.16	88.00	41.00	15.56	14.95	7.89	7.79
Te2	1.40	1.87	600	300	0.00	1.85	14.20	25.00	0.06	0.18	1.00	0.00	9.63	8.95	97.00	91.00	16.54	20.15	8.05	7.84
Te3	1.19	1.83	900	600	0.00	1.13	9.10	17.50	0.07	0.22	11.00	5.00	8.90	7.21	97.00	102.00	17.02	24.46	8.07	8.12
Te4	0.61	0.94	500	300	0.00	0.01	2.60	21.60	0.05	0.15	7.00	3.00	9.04	7.51	99.00	108.00	20.00	21.71	8.01	7.94
Te5	1.26	1.83	2000	1100	6.81	0.06	3.30	12.50	0.07	0.22	17.00	5.00	8.70	7.46	101.00	114.00	15.77	24.40	7.54	8.52
Te6	1.41	2.15	7100	4800	6.32	0.02	2.50	15.00	0.05	0.16	22.00	4.00	8.40	7.48	102.00	131.00	17.81	20.94	7.58	8.60
Te7	1.54	2.68	3100	2000	5.20	0.04	1.83	40.00	0.13	0.41	18.00	9.33	8.60	6.99	103.00	147.00	19.30	26.17	7.52	9.00
Te8	1.36	3.38	2300	800	9.48	0.02	2.90	15.00	0.14	0.43	23.00	8.00	8.13	7.13	108.00	153.00	19.06	25.09	7.32	9.70
Te9	1.36	1.96	900	400	1.72	0.04	2.42	0.00	0.04	0.04	2.30	0.40	9.05	7.82	102.00	141.00	15.04	14.95	7.71	8.14
Te10	1.02	1.27	7800	1200	0.59	1.73	97.40	60.00	4.16	4.74	34.00	24.67	7.91	4.20	351.00	563.00	14.95	15.36	7.47	7.78
Te11	1.37	2.01	8300	1700	11.59	1.45	81.70	92.50	2.46	2.91	16.00	15.33	8.88	6.18	390.00	656.00	17.97	21.21	7.47	9.01
Te12	1.27	1.39	10200	1900	4.60	0.22	12.50	180.00	1.70	1.99	19.00	12.67	8.51	6.44	400.00	698.00	15.07	15.87	7.80	7.37

Nduruma River

Point	**F^-_W**	F-_D	**FC_W**	**FC_D**	**Turbi_W**	**Turbi_D**	**NO3-_W**	**NO_3^-_D**	**TP_W**	**TP_D**	**BOD_W**	**BOD_D**	**DO_W**	**DO_D**	**TDS_W**	**TDS_D**	**T_W**	**T_D**	**pH_W**	**pH_D**
N1	2.01	2.94	1700	1100	0.00	0.00	6.30	0.18	0.38	0.02	9.00	25.00	5.38	7.54	95.00	106.00	12.21	12.01	7.88	8.11
N2	2.81	2.22	2100	1200	0.00	0.00	4.90	0.70	0.22	0.29	17.00	29.00	5.90	6.29	101.00	116.00	14.42	14,7	7.93	8.00
N3	1.60	1.78	5900	4000	2.38	0.00	44.00	2.34	0.12	0.54	23.00	7.00	4.90	8.22	83.00	81.00	16.62	17.40	7.63	7.62
N4	1.13	1.34	1000	700	0.00	0.00	5.00	0.07	0.39	0.42	15.00	15.00	7.20	7.80	76.00	84.00	16.56	17.34	7.67	7.59
N5	1.39	1.69	2300	1800	0.80	0.01	60.00	0.05	0.16	0.41	14.10	13.00	8.54	7.93	80.00	105.00	16.90	19.21	7.71	7.40
N6	2.16	2.90	4700	3400	2.13	1.80	5.80	0.26	0.77	0.51	18.00	20.00	5.38	7.67	80.00	121.00	17.91	22.00	7.80	9.90
N7	0.92	1.02	900	600	0.00	0.00	5.30	0.01	0.46	0.36	23.00	9.00	5.24	8.16	97.00	100.00	17.20	17.18	7.90	8.06
N8	1.59	2.68	4400	3700	1.89	0.65	7.10	0.05	0.66	0.59	18.00	17.00	5.70	7.78	89.00	120.00	18.51	22.11	7.91	8.16
N9	1.59	2.16	9000	600	2.86	0.00	41.30	0.02	0.26	0.35	18.00	14.00	7.20	7.81	71.00	132.00	17.40	19.25	8.12	7.84
N10	1.67	2.43	1100	500	3.31	0.00	40.00	0.04	0.29	0.21	15.00	20.00	7.80	7.65	104.00	147.00	20.48	24.32	8.15	8.40
N11	1.82	2.65	9700	900	1.40	1.26	39.40	0.02	0.45	0.64	9.00	26.00	9.24	6.44	108.00	154.00	18.34	18.34	8.01	8.26
N12	1.71	2.45	11000	1100	3.73	1.73	50.20	0.01	0.74	0.92	9.00	31.00	10.58	6.16	104.00	148.00	19.92	19.86	9.04	9.32

Note: All concentration values are in mg/L except for turbidity (NTU), FC (FCU/100mL sample), T (°C) and pH is unitless.   W - Wet, D - Dry.

Table 3: Physico chemical, nutrients and biological data for Tengeru and Maji ya Chai rivers during wet and dry seasons in 2015

Tengeru River																				
Point	**F^-_W**	**F^-_D**	**FC_W**	**FC_D**	**Turbi_W**	**Turbi_D**	**NO_3^-_W**	**NO_3^-_D**	**TP_W**	**TP_D**	**BOD_W**	**BOD_D**	**DO_W**	**DO_D**	**TDS_W**	**TDS_D**	**T_W**	**T_D**	**pH_W**	**pH_D**
T1	0.94	1.45	1300	1200	0.00	0.00	2.50	3.08	0.19	0.31	0.00	0.20	9.37	7.74	37.00	42.00	15.00	14.00	7.13	7.33
T2	0.24	1.25	2100	1600	0.06	0.00	1.40	1.72	0.10	0.16	3.00	5.00	9.34	7.20	77.00	93.00	16.47	14.83	7.19	7.23
T3	0.68	1.11	2000	1300	0.00	0.00	6.90	8.49	0.25	0.41	13.00	14.00	9.19	7.28	58.00	97.00	17.39	18.40	7.28	7.88
T4	1.44	1.17	1900	1400	0.00	0.00	1.60	1.97	0.18	0.29	10.00	12.67	9.29	7.21	77.00	76.00	16.47	17.04	7.19	7.50
T5	1.48	1.51	2000	1200	0.00	0.00	3.80	4.67	0.07	0.12	10.00	12.67	9.28	8.38	84.00	94.00	15.60	16.40	7.34	7.62
T6	0.66	0.97	1500	200	0.00	0.00	2.60	3.20	0.14	0.23	14.00	3.33	9.28	7.76	80.00	96.00	17.74	18.81	7.31	7.92
T7	1.50	1.32	2400	1700	0.00	0.00	3.20	3.94	0.20	0.33	16.00	4.00	8.67	7.45	82.00	95.00	16.55	17.07	7.36	7.38
T8	0.92	1.14	1400	400	0.00	0.00	3.80	4.67	0.14	0.23	19.00	11.25	8.11	6.84	84.00	98.00	16.61	18.46	7.42	7.92
T9	1.02	1.28	1900	700	7.37	0.00	1.06	1.30	0.09	0.15	31.00	19.38	6.56	6.98	85.00	93.00	16.77	18.97	7.12	7.83
T10	1.56	1.20	2700	1900	8.03	0.00	0.80	0.98	0.08	0.14	18.00	17.50	8.15	7.45	87.00	98.00	16.94	19.34	7.51	8.06
T11	1.13	1.34	2100	1400	10.47	0.00	2.50	3.08	0.13	0.21	14.00	11.00	9.18	7.45	101.00	123.00	17.53	18.05	7.58	8.03
T12	1.53	1.27	7900	6200	33.90	11.98	18.40	22.63	0.17	0.28	10.00	8.00	8.99	8.02	146.00	172.00	18.67	20.15	7.52	8.14
T13	1.27	1.53	1400	1100	2.72	0.00	1.20	1.48	0.11	0.18	11.00	5.63	9.23	6.66	102.00	117.00	18.71	19.89	7.32	7.96
T14	2.30	5.96	6100	300	14.04	0.86	10.30	12.67	0.16	0.26	15.00	4.00	8.76	7.94	260.00	243.00	18.67	19.50	7.40	8.34
T15	3.13	2.19	6900	600	5.71	1.16	12.70	15.62	0.29	0.48	17.00	4.00	8.31	7.56	195.00	181.00	18.81	19.35	7.41	7.94
T16	2.03	2.64	4100	3800	8.16	3.08	14.70	18.08	0.15	0.25	6.40	7.00	9.29	7.63	200.00	197.00	18.66	17.01	7.44	8.59
T17	1.47	1.89	4700	800	16.15	1.27	1.90	2.34	0.25	0.42	16.00	5.63	8.56	7.60	110.00	181.00	18.32	16.05	7.47	7.75
T18	1.10	1.40	1600	1300	27.39	1.42	16.32	20.07	0.19	0.32	44.90	31.00	6.45	7.91	129.00	131.00	18.52	18.50	7.30	8.05
T19	1.31	1.53	9800	9	19.27	16.92	2.70	3.32	0.22	0.36	12.00	4.00	9.23	8.25	125.00	174.00	18.27	16.65	7.21	8.51
T20	1.77	1.92	7900	2100	32.80	12.44	10.40	12.79	0.24	0.40	14.00	3.00	9.17	8.24	127.00	174.00	18.24	19.49	7.40	7.92
T21	3.13	2.33	11500	1400	16.02	8.98	10.10	12.42	0.24	0.40	25.00	3.00	7.85	7.21	81.00	185.00	18.29	21.00	7.34	8.10

Maji ya Chai River

Point	F^-_W	F^-_D	FC_W	FC_D	Turbi_W	Turbi_D	NO_3^-_W	NO_3^-_D	TP_W	TP_D	BOD_W	BOD_D	DO_W	DO_D	TDS_W	TDS_D	T_W	T_D	pH_W	pH_D
M1	20.10	26.10	4300	5500	0.00	2.31	15.90	22.26	0.40	0.66	6.00	12.00	5.44	7.41	490.00	472.00	19.48	19.48	8.60	8.56
M2	65.20	69.01	4800	6000	0.00	4.61	16.50	23.10	0.51	0.75	41.00	77.00	0.54	0.10	566.00	813.00	17.00	19.64	8.49	9.60
M3	14.50	17.70	5200	6900	0.00	0.67	7.20	10.08	0.49	0.81	11.00	10.67	5.32	7.81	415.00	466.00	17.76	20.15	8.33	8.31
M4	14.80	18,2	5500	4300	0.00	3.24	3.10	4.34	0.47	0.79	2.00	17.00	8.87	6.00	422.00	448.00	17.83	21.20	8.52	8.54
M5	13.80	18.00	5900	1900	0.00	0.00	5.40	7.56	0.40	0.64	5.00	14.38	8.75	7.03	395.00	497.00	18.67	17.37	7.39	7.91
M6	11.75	16.40	6100	400	0.00	0.00	1.60	2.24	0.28	0.46	3.00	7.00	8.85	7.89	458.00	586.00	18.30	20.38	7.55	8.38
M7	10.17	15.70	6900	300	0.00	0.00	5.80	8.12	0.05	0.08	19.00	3.00	2.62	7.97	594.00	861.00	18.83	21.44	7.37	8.69

Note: All concentration values are in mg/L except for turbidity (NTU), FC (FCU/100 mL sample), T (°C) and pH is unitless, W - Wet, D - Dry.

Also, the headwater environment of the three rivers (Temi, Nduruma and Tengeru) showed low fluoride level of < 1.5 mg/L which is in line with the WHO recommended maximum permissible level in drinking water especially in the wet season. In the dry season these levels were elevated in those rivers with only one sample from Tengeru River which recorded a highest average value of 5.92 ± 0.31 which is higher than WHO and TBS maximum permissible value with the rest samples being lower than the TBS standards. Increase in concentration in the dry season is caused by increase in water temperature which in turn increase the rate of dissolution of rocks containing fluoride ions and the absence of runoff from rain water to the river which may cause dilutions of river water and therefore the main water recharge source in rivers is mainly from ground water (old water) containing more fluoride ions (Kitalika et al. 2018). Generally, low fluoride levels in the three rivers (Temi, Nduruma and Tengeru) in both seasons are mainly caused by low fluoride composition in the phonolite feldspar rocks which predominates at the upstream main catchment areas of these rivers thus discharging low fluorides amount in water (Ghiglieri et al. 2010).

DO determine the biological changes which occur in water in relation to living organisms aerobic or anaerobic organisms. It determines the nature extent of pollution in water since most water pollutants are oxygen demanding. The good water quality for aquatic life to flourish is normally between 4 to 6 mg/L (Avvannavar and Shrihari 2008). The DO in Temi, Nduruma and Nduruma River ranged between 4.20 mg/L and 10.58 mg/L thus most samples had Do values within the healthy levels with few samples being higher than expected such as Te1 (10.10 mg/L) and N12 (10.58. mg/L). These areas with high DO values had low oxygen demanding waste. Also low water temperature can be another reason for high DO values due to the fact that amount dissolved gases increase with decrease in water temperature. Maji ya Chai River had an exceptional low DO levels of 0.10 to 0.54 mg/L at Jamera (M2). This area is characterized by high amount of BOD, pH and fluoride which can be the main causes thus absence of aquatic life.

Turbidity values of the water samples were between 0.00 and 33 Nepherometric Turbidity Unit (NTU) which was insignificant to affect the water quality at large. The permissible limit of the turbidity is 12.5 NTU according to TSI 266 (2005). The obtained results show that the turbidity values were over the limit values during the wet season at T12 to T21 due to soil movement in water due to poor agriculture practices along the river. Excess nutrient encourage eutrophication in water. Also excessive intake of water containing high nitrate concentration causes blue babies or methemoglobinemia disease in infants, gastric carcinomas, abnormal pain, central nervous system birth defects, and diabetes (Varol and Davraz 2015, Vasanthavigar et al. 2010) In this study nitrates and phosphates were present in all rivers. The nitrates in the wet season ranged between 0.8 mg/L and 97.4 mg/L in the wet season whereas in the dry season it increases to 180 mg/L. The areas with high nitrates were found in just after the mixing of waste water effluents with Temi River in Lemara at Te 10, 11 and 12 and downstream to the flood plain. The levels in these locations together with N5 in Nduruma river were higher than the WHO maximum recommended levels of 50 mg/L (WHO 2011). Other parts of other rivers recorded low amount of NO_3^-. Similar trends were followed in phosphates (Table 2 and 3). The levels of TP were significantly higher in wet season with the highest level of 17.27 mg/L at Songota stream (N8) while the dry season recorded very low levels. In this study the maximum soluble phosphate was 4.16 mg/L at Te 10 whereas its total phosphate (TP) was 89.15 mg/L in wet season and TSP 4.74 mg/L at Te 10 where its TP was 94.94 mg/L at the same point in dry the season. The floodplain area of the river showed PO_4^{2-} concentration of >0.1 mg/L in both season an indication that the main phosphate source is from the improperly treated effluents from Lemara wastewater treatment system as explained above. Under normal conditions, the river that is not flowing into a lake should not drain off a total soluble phosphate (TSP) PO_4^{2-} exceeding 0.1 mg/L (Murdoch et al. 1991). In this study most areas had phosphate levels higher than the maximum stated values especially in the flood plain parts of the river. Similar temporal variations in concentration of nutrients have been reported by Tanaka et al. (2013), Shrestha and Kazama (2007) and Srivastava et al. (2011).

The oxygen demanding waste is another pollutant of interest in water quality assessment. These pollutants are determined in water through biochemical oxygen demand (BOD) measurement which is the amount of dissolved oxygen needed by aerobic biological organisms to break down organic materials. BOD in water is highly related to DO since organisms need the DO to metabolize the oxygen demanding waste thus low values of BOD entails minimum amount of oxygen demanding waste an indication of less polluted water body. In this study the BOD levels were higher in wet season than dry season due to runoff which deposited more suspended solids in rivers which need high amount of dissolved oxygen to be utilized. Also the BOD levels increased downstream in all rivers due to continuous accumulation of such wastes as a result of flooding. The BOD levels in Temi River ranged between 1.00 mg/L to 31.00 mg/L and 0 mg/L to 9.33 mg/L in the wet and dry season, respectively. The pristine environment of this river had very low BOD levels an indication of good watershed conservation practices which in turn acts as a filter for oxygen demanding waste reaching in the river. Temi River had the lowest average BOD levels compared to other rivers with exception of one location (T9) which is located in the streets which has BOD level of 31.00 mg/L. Such high levels are caused by poor sanitation of nearby households which litter their domestic wastes into the river. Nduruma River had relatively higher BOD values than Temi. The highest level of 29.00 mg/L was noted in the wet season at the pristine environment of the river (N2). The unexpectedly high BOD level in this area is caused by erosion due to the steep slope which pours its contents in the river including soil debris and other organic matters. A different case was noted in Maji ya Chai River where the sampling location (M2) also named Jamera had a considerable highest BOD levels than all other locations in other rivers. In the wet season 41.00 mg/L of BOD was recorded whereas in the dry season the values were elevated up to 77.00 mg/L. The BOD concentration in this location was the opposite to the expectation since all rivers had lower BOD values in the wet season than dry season. The reason for these results is based to the fact that this area is the only remote area found within the Arusha National Park (ANP) containing water in the dry season therefore it is used as the main drinking water source for wild animals in the dry season thus when wild animals spent their time for drinking water they litter through different means. Also this area has very low DO with absence of aquatic life as explained before. The quantified BOD levels in this study are similar to those obtained in Chillan River in Chile (Gandotra and Andotra 2008). According to European Council the unpolluted rivers should have a BOD below 1 mg/L and the moderately polluted rivers vary between 2 to 8 mg/L (EEC 1978). In this study most parts of rivers in their floodplain had higher BOD values than recommended.

Fecal coliforms (FC) were observed in all studied rivers. High FC counts in all rivers has contributed at large to the poor water quality in all rives. The FC count ranged between 300 to 6900 FCU/100 mL, 900 to 11000 FCU/100 mL, 9 to 11500 FCU/100 mL and 300 to 10200 FCU/100 mL for Maji ya Chai, Tengeru, Nduruma and Temi Rivers, respectively. Higher levels were recorded in wet season than dry season an indication of contribution of FC through runoff from other sources and poor hygienic conditions in households during wet season which include discharging of latrines waste water into rivers as a main method of emptying their sewage pits in poor families. The results obtained from this study showed higher FC counts in rivers compared to similar studies in other areas such as rivers in rural communities of Khuzestan Province, Iran and Beauport River Watershed in Quebec which had FC values < 10 FCU/100 mL and < 100 FCU/ mL, respectively (Abtahi et al. 2015, Thériault and Duchesne 2015). High FC load in the study area is an indication of poor sanitation in the environment which the four rivers pass compared to those of Iran and Quebec since FC are associated with poor treatment of primates feces. The detailed influence of all parameters in the water quality index (WQI) for respective locations in rivers have been discussed in the respective sections. In addition, Figure 2 through 4 shows the results for GIS based spatial analysis of water quality in the study area and they are thoroughly discussed in their respective sections.

The PCA criteria for major contributing components

Three components/parameters were retained in Temi River during wet season with Eigenvalue in brackets (4.95935, 2.19463 and 1.12749 where 82.8% are covered) and four components (4.59504, 2.43857, 1.17054 and 0.6224 where 82.04% are covered) were retained in dry season whereby, for Nduruma River three components (4.1363, 1.8552, and 1.3858 where 83.67% are covered) and four components (4.76565, 2.0851, 1.13421, 1.04259 where 90.28% are covered) were retained in wet and dry seasons, respectively. Tengeru River retained four components with (4.26557, 1.93561, 1.15874 and 0.90464 where 82.69% are covered) and (3.94866, 1.60458, 1.27979, 0.86643 where 84.80% are covered) were retained in wet and dry seasons, respectively. Maji ya chai River had two components (7.24753and 2.08298 where 97.21% are covered) and three components (5.98628, 2.7757 and 0.73816 where 97.21% are covered) during wet and dry seasons, respectively. Other components were not retained since they had less representation to the overall effect of water quality of the respective sampling point.

Water Quality Index by NSF method

The water quality in all rivers has shown to be deteorating downstream with most affected water being in the flood plain when water has already passed the human settlements (city and township areas). These changes can be caused by domestic waste entering in the rivers through runoff especially in the wet season. The established WQI by NSF was done by using nine (9) water quality parameters. However, there are other parameters with crucial importance in safe and clean water which were not included in this method. For example, in this study area, fluoride is among the major water pollutants as it causes serious health problems in human skeleton. Therefore, additional method which could accommodate more important parameters for further evaluation of the same water body is discussed in subsequent sections. Thus, the results discussed in this section are based on the nine water quality parameters and its output shown in Figure 2.

The pristine environment (headwater) in Temi River showed to have a medium water quality despite the fact that it is a conserved area. In this area the FC (11-29%), TP (2-35%) and temperature (19-31%) contributed more to the low water quality in both seasons. The presence of FC in the pristine environment of the river might be contributed by the living primates in forests such as baboons, simians and monkeys which dominate in the forest.

The pristine environment of this river have no any kind of human activities such that the most likely source of FC could be from human closely related wild animals, the primates. These animals defecate in catchment areas with their feces being transported through runoff. Also the presence of FC in the downstream with human inhabitants can be caused by transport of them from the pristine environment and open defecation of people along the river. Studies show that FC is common on surface water of Arusha City and Arumeru districts in which two studies more than 100 FCU/100 of water were reported (Lyimo et al. 2016, Kitalika et al. 2017). However, the presence of high TP can be of geological reason due to the nature of surrounding rocks. Also, dead animals buried in soil such as birds may contribute to elevated levels of phosphates.

Contributions of other parameters to high water quality are quite good with turbidity (99%) being the best contributing parameter followed by BOD (95%). The good contributions of these parameters are due to the good conservation practices of mount Meru forest reserve. Also, in the dry season NO_3^- increased due to the fact that, in this season, the water sources for wild animals is only from rivers which in turn, when they visit for drinking tend to urinate and defecate in those water sources. Despite all these, the overall water quality in pristine environment is medium and thus, pretreatment is necessary. The good water quality at Te1 can be contributed by low pollutant loads which had less effect in the water quality.

When water from the pristine environment passes the human settlements from pristine environment, its quality is maintained. This indicates low pollution inputs in the river from anthropogenic activities in both seasons. The flood-plain showed bad water quality due to low contributions from FC (20%), NO_3^- (1%), TP (2%) and BOD (15%). These inputs were much pronounced from Burka (Te12) which is a feeding tributary of the main river. Also, the bad water quality in this part of the river may be attributed by the fact that the flood-plain is connected with the waste water treatment systems at Lemara (Te9) which accumulates domestic and industrial waste and thus, raising the pollutant levels with high effects being from nutrients (Figure 5I). In addition, the low water velocity in the flood-plain (Te10 and Te11) favoured more interactions time of surface water with rocks and wastes together with groundwater surface water interactions which might have increased the pollutants loads in fresh water. Similar pollution patterns were observed in both seasons for this part of the river. Similar observation was noted by Şehnaz et al. (2017) in their study on WQI in Aksu River-Turkey which showed its water quality to be highly affected by COD and BOD wastes flowing from domestic wastes and nutrients which were mainly from agriculture runoff.

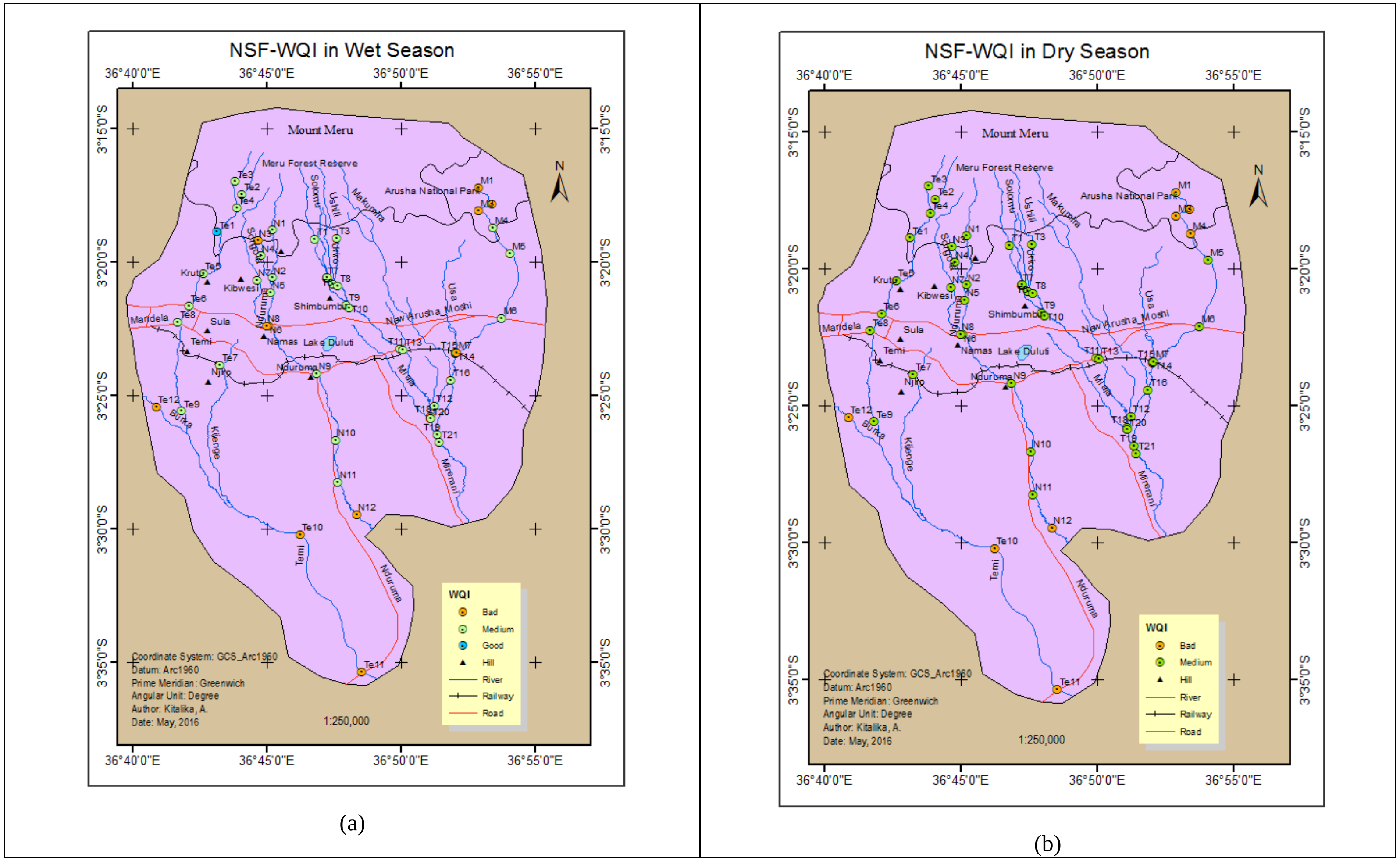


Figure 2: The NSF based water quality in (a) wet and (b) dry season

The water quality for Nduruma River was medium in the pristine environment in both seasons. It is expected that the pristine environment in this river should have excellent water quality, but that is not the case due to poor or very low quality index which is contributed by FC (19-22%) and nitrates (29%) in both seasons. While temperature is not an issue in this mountainous region, FC increase especially in the dry season can be a contribution from primates' littering since there are limited water sources in the dry season which are used by wild animals for drinking. Other factors remain of less contribution in water quality in this region.

When the river flows across the human settlement and floodplain, the water quality response in the two seasons is maintained except at one sampling point (N8) which has bad water quality due to increase in oxygen demanding wastes caused by runoff from the households during the wet season. However, this situation is recovered along as the river runs to the flood-plain where its water quality is medium. To the extreme downstream (N12), the water quality is deteriorated due to nutrients inputs from farming activities such as manure and industrial fertilizers runoff. While nutrients can be contributed by fertilizers runoff from small and big horticultural farms around it, the high BOD in such water is another problem. This phenomenon may be due to such nutrients and their associated organic wastes being high oxygen demanding.

Tengeru River had medium water quality in both seasons throughout despite of the different inputs from other several streams which had also medium water quality. This important river behavior is contributed by well conserved riparian environment of the river and its feeder streams. The water quality downstream was expected to be distorted due to contributions from Maji ya Chai River which have bad quality. However, that was not the case due to its insignificant dilution by the main river. The similar water quality throughout the river indicates constant contributions of pollutants in all areas along the river.

The headwater from Maji ya Chai River had bad water quality in both seasons. Most parameters contributed negatively to the good water quality with exception of turbidity (92-99%) which had good contribution. In this river, despite its water colour to be excessively brown due to dissolved organic carbons and hence, its name in Swahili "Maji ya Chai" meaning that tea coloured water, it is not turbid. More interestingly, this river has little or no fish lives in headwater (M2) an indication for bad water quality even for aquatic life. The larger part of this river is situated in the Arusha National Park which is among the highly conserved area. Thus, the bad water quality in the pristine environment is mainly caused by high amount of oxygen demanding wastes due to river source deterioration done by wild animals especially elephants and buffalos which dominate the catchment area. Moreover high pH (alkaline water) adds more problems to its quality. The downstream of the river have medium water quality which is a result of dilutions from streams with medium water quality (Fig. 2).

Water quality index by WAI

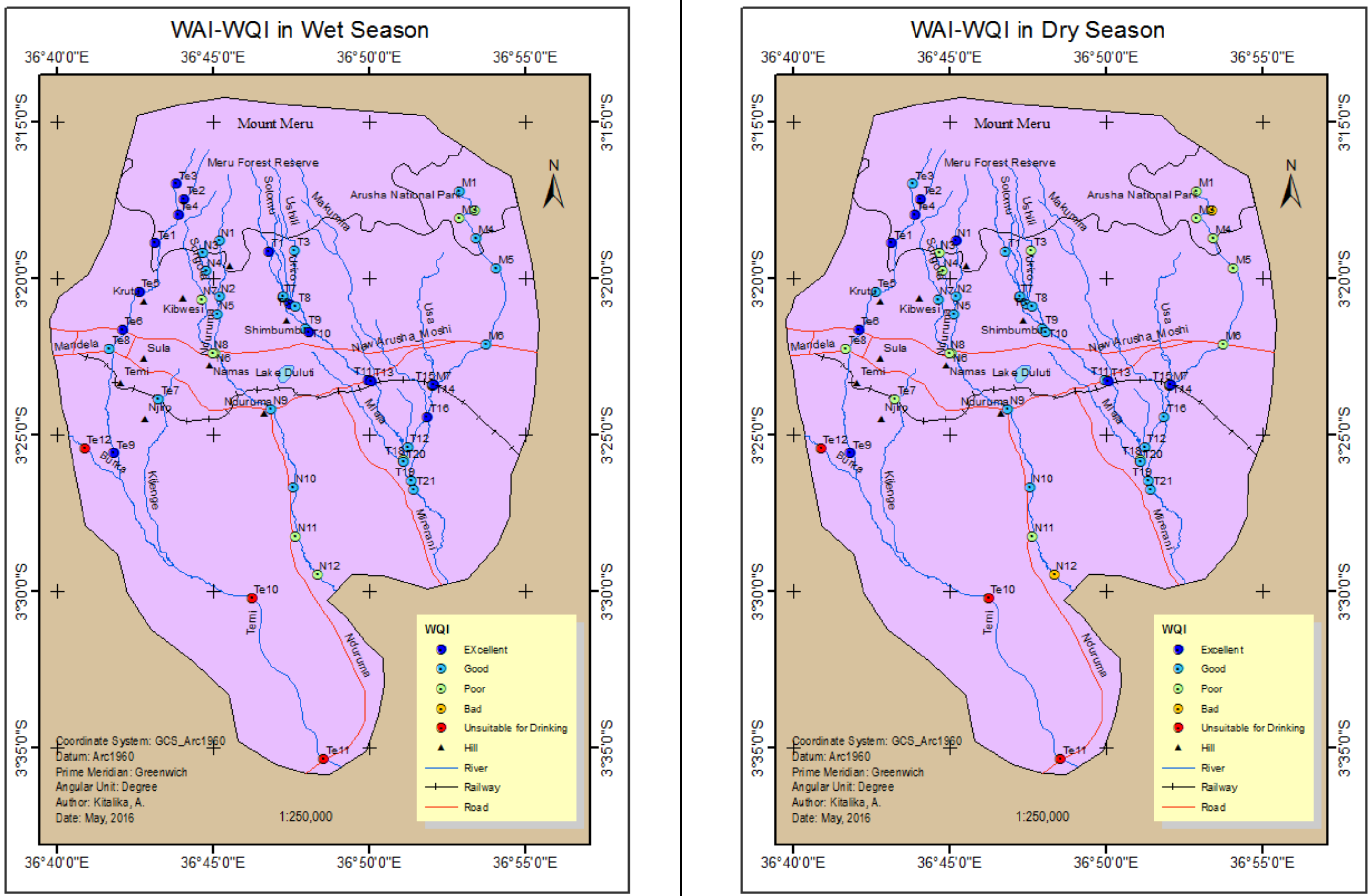
The results of water quality status by WAI in the four rivers are presented in Figure 3. Water quality index by WAI assess unlimited parameters to establish the overall water quality of a particular water body. For the purpose of reliability of the two methods, nine (9) water quality parameters used in NSF were employed for assessment by WAI. In addition, since F^- is also a serious problem in this area, a new assessment including such pollutant was done to evaluate its contribution to the overall water quality for all rivers. Despite of using the same data values in assessment, the water qualities by this method differed from NSF method such that in some areas it has been higher or lower than NSF.

Using this method, both seasons in most parts of pristine environment (headwater) in Temi River showed excellent water quality with some few points (Te3 and Te5) indicating good water quality during dry seasons whereas in comparison with the NSF method the water quality was medium in most parts. Meanwhile, the human settlement areas showed medium to poor water quality in both seasons whereby by NSF method the medium water quality predominated. While these results occurred on the upper part of the river, its flood-plain water quality appeared to be unsuitable for drinking. In this area, the water quality by NSF method appeared to be bad.

In the case of Nduruma River the WAI method showed good water quality in pristine and human settlement areas in both seasons with some few areas (N3, N4, N6 and N7) being poor in both seasons. Its flood-plain had poor (N11 and N12) to bad (N12) water quality similar to NSF scales in both wet and dry seasons respectively. Similar reasons with NSF accounts for the poor water quality in the flood-plain of this river under this technique.

Similar water quality patterns are shown in Tengeru River by WAI method in both seasons. While the overall water quality for the whole river in both seasons is medium by NSF method, WAI shows good water quality in the two areas during wet season with its wet season being excellent in some areas (T1, T8 and T10) and good for pristine and urban areas respectively. This quality rating is higher than NSF rating for the same water body. The excellent water quality in dry season may be attributed by absence of runoff which is one of the major waste input sources in rivers during wet season. However, since waters of this area contain some pollutants grading its water quality in excellent condition is questionable.

In the case of Maji ya Chai River, very high water quality rates (good) were observed by this method in the wet season whereas, in the dry season the water quality was regarded as poor throughout the river with exception of Jamera (M2) which had poor to bad water in wet and dry seasons respectively. This area is exceptional due to absence of DO and also very high pH of up to 10. It should be noted that the main water pollutants in this river are mainly fluorides and chromophoric organic matters which are naturally occurring humus in Kirurumu hill located in the western part of Jamera. The WAI method for water quality analysis was employed in different water quality studies in rivers and ponds of Egypt and Argentina and showed good and comparable results for water quality monitoring similar to this study (Kesharwani et al. 2004, Moscuzza et al. 2007, Ali et al. 2014).



(a) (b)

Figure 3: The WAI based water quality in (a) wet and (b) dry season

The WAI with fluoride pollutant

Inclusion of fluorides concentrations in establishing the WQI in the four rivers is necessary due to its prominence as the major toxin in the study area since its presence in drinking water compromises with the health of human skeleton. Their results of water quality status by this method in the four rivers are presented in Figure 4**.** The presence of fluoride among pollutants changed the whole trend of water qualities in their respective points with Maji ya Chai River being mostly affected due to its high fluoride contents.

The excellent water quality in the pristine environment of Temi River was maintained due to the low fluoride contents compared to its standard permissible values of 1.5 mg/L and 4.0 mg/L as per WHO and Tanzania Bureau of Standards (TBS), respectively (WHO 2004, 2009). However, its flood-plain part maintained its status of unsuitability for drinking. The water quality in Nduruma River was slightly affected in the dry season at N2, N5 and N8 from good to poor water quality. The situation is different for Tengeru River in the dry season where by most parts of the flood-plain, presence of fluorides decreased its water quality from good to poor. Such changes can be attributed by increase in fluorides in Makumira and Maji ya Chai rivers.

The serious changes were observed in Maji ya Chai River in both seasons whereby the water quality for most parts of the river were unsuitable for drinking. Despite the high BOD levels due to presence of high amount of humic and fulvic acids, the unsuitability of this river throughout is caused by very high fluoride concentrations of up to 69.5 mg/L which are quite higher compared to its maximum standards of 1.4 mg/L and 4.0 mg/L for WHO and TBS, respectively (WHO 2004, TBS 2009). From this observation, it is clear that including several important water quality parameters like fluorides in water quality assessment has an added advantage for understanding the actual quality of the river. Previous studies on WQI from various scholars through modified WAI in different rivers showed no significant changes in the water quality studies based on temporal but at spatial analysis level being significant (Debels et al. 2005, Abtahi et al. 2015). In this study, similar results have been observed in both modified and unmodified WAI methods as discussed above.

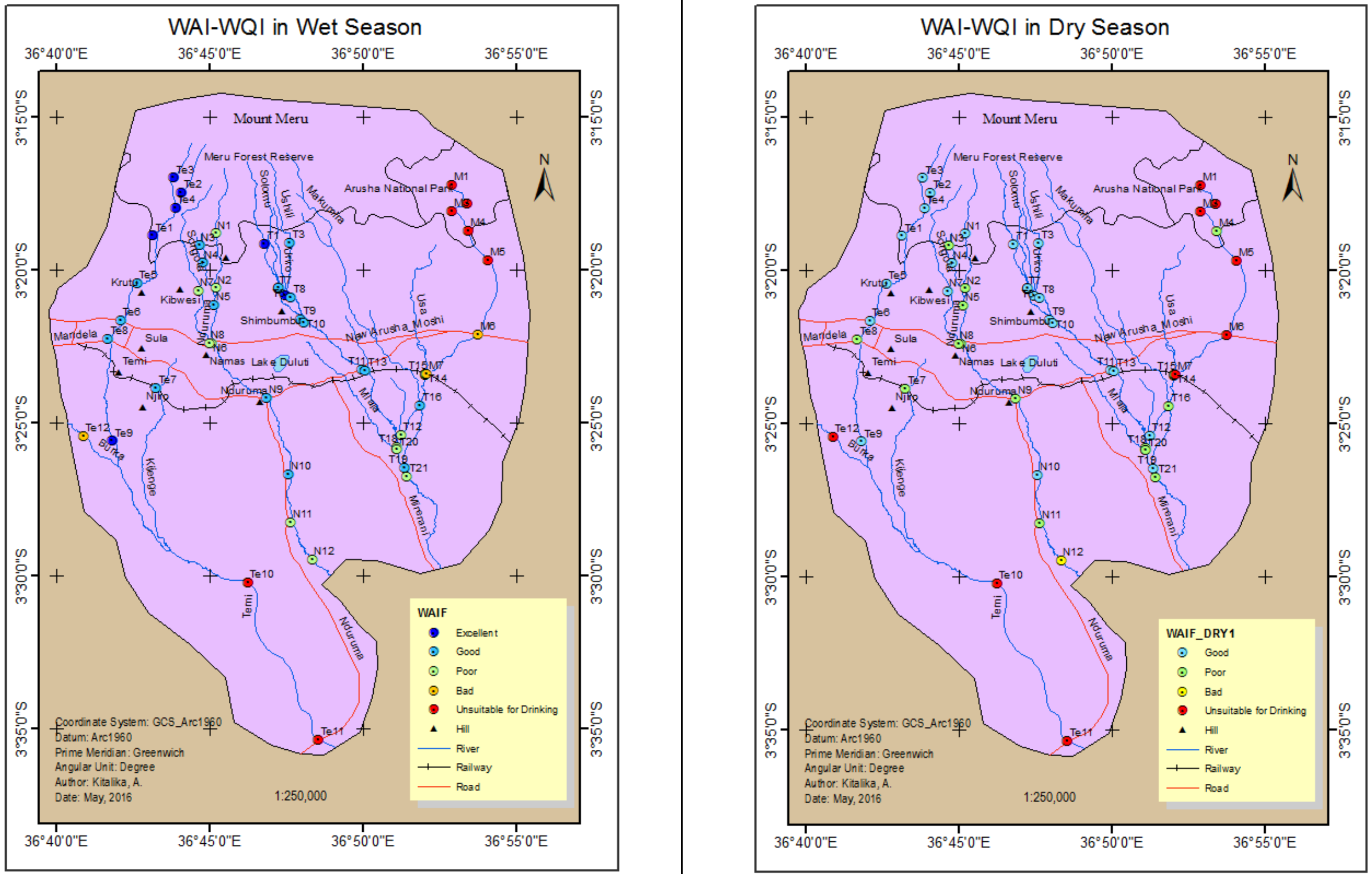
The Principal component analysis for the major contributing factors

The Principal component analysis (PCA) was performed to assess the principal factors (variables) which caused water quality changes in their respective points. The study shows that in wet season DO and variation in water pH were major factors for water quality changes in the pristine (headwaters) environment of Temi River whereas in the human settlement environment temperature (T), F^-, turbidity and Oxygen demanding waste were the significant cause for water quality change. In addition, the water quality in the flood-plain environment was much affected by increase in nutrients (NO_3^- and TP) loads, increase in total dissolved solids (TDS) and FCs. While the nutrients in the flood-plain are loaded from the city wastewater treatment system, increase in FC, NO_3^- and TP may be caused by loading of ineffective treated domestic and industrials wastes from the city sewage treatment system. A different situation was noted in the dry season where in the pristine environment neither the parameter contributed strongly to the water quality variation perhaps due to absence of runoff. Water temperature, FC, pH, NO_3^- and TDS were the major contributing factors in human settlement environment whereas, turbidity, fluorides, DO, and phosphates contributed much in the flood-plain (Fig. 5 I). The presence of phosphates in the flood-plain during dry season indicates poor performance of the city waste treatment system towards phosphates

(TP) removal since NO_3^- was readily removed.

There was no dominant pollutant in the pristine water in Nduruma River during wet season despite the dominance of DO, FC and NO_3^- nutrients in dry season. Pollutant dilution by precipitation in wet season can be the main cause of their low levels whereas dominance of NO_3^- and FC in dry season can be caused by pollution from animals which migrate near the water sources during dry season, and thus deteorating it since a few water sources (catchment areas) in dry season produce water for wild animals' drinking (Fig. 5II). Under such circumstances the remaining water source are used above the carrying capacity which in turn litter the water sources through defecation and other physical disturbance of the catchment areas. Similar reasons can account for this change. The water quality in the human settlement areas were compromised mainly by oxygen demanding wastes (BOD, low DO) whereas in the dry season TP, pH, turbidity and F^- were the main sources for water quality change. The flood-plain in the wet season were more affected by NO_3^- inputs, turbidity and FC loads, while in dry season TDS and oxygen demanding waste were the major issues of concern.

Interestingly, the pristine water in Tengeru River was less affected by a combination of pollutant sources. While this happened, other parts of the river were compromised by nutrients loads, F^-, FC, pH and slightly warmer water thus lowering the water quality in both seasons (Fig. 6I). The flood-plain water were much affected by oxygen demanding wastes probably due to runoff due to poor farming activities while turbid water, F^- and DO variations were significant in both seasons. Tengeru River is much associated with Maji ya Chai River, the latter feeding its waters into the former. Thus, its water in human settlement areas were similarly affected by change in DO, pH and temperature in both seasons with FC affecting much in the wet season while presence of TDS being a problem in the dry season. The pristine water was much affected by NO_3^- and oxygen demanding wastes these being expected due to the continuous loading of humus in the river (Fig. 6II). Increase in dissolved humic and fulvic acids in such water in both seasons results into increased TDS in it and hence, its brown colored of "Maji ya Chai." The previous study on stable isotopes of $^{15}N\text{-}NO_3^-$ revealed nitrate sources in the headwater to be from ground water such that the ground water containing nitrate are mixed with surface water. The NO_3^- sources in the floodplain were from nitrogenous industrial fertilizers spilling from farms through runoff especially during the wet season (Kitalika et al. 2017).


WAI-WQI in Wet Season
WAI-WQI in Dry Season
Mount Meru
Meru Forest Reserve
Arusha National Park
Lake Duluti
WAIF
WAIF_DRY1
Excellent
Good
Poor
Bad
Unsuitable for Drinking
Hill
River
Railway
Road
Coordinate System: GCS_Arc1960
Datum: Arc1960
Prime Meridian: Greenwich
Angular Unit: Degree
Author: Kitalika, A.
Date: May, 2016
1:250,000
36°40'0"E
36°45'0"E
36°50'0"E
36°55'0"E
3°15'0"S
3°20'0"S
3°25'0"S
3°30'0"S
3°35'0"S

(a) (b)

Figure 4: The WAI based water quality in (a) wet and (b) dry season with fluoride pollutant

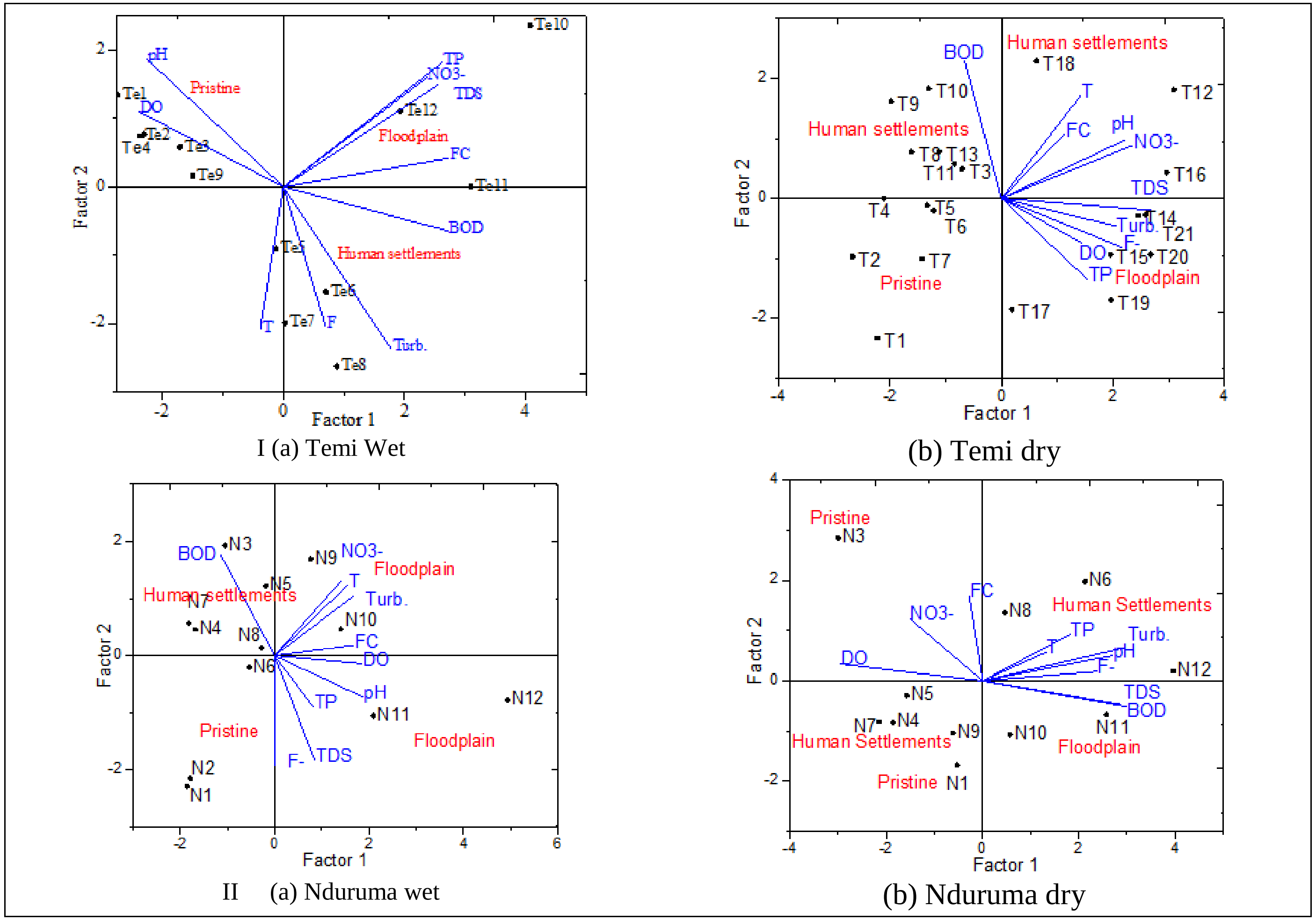
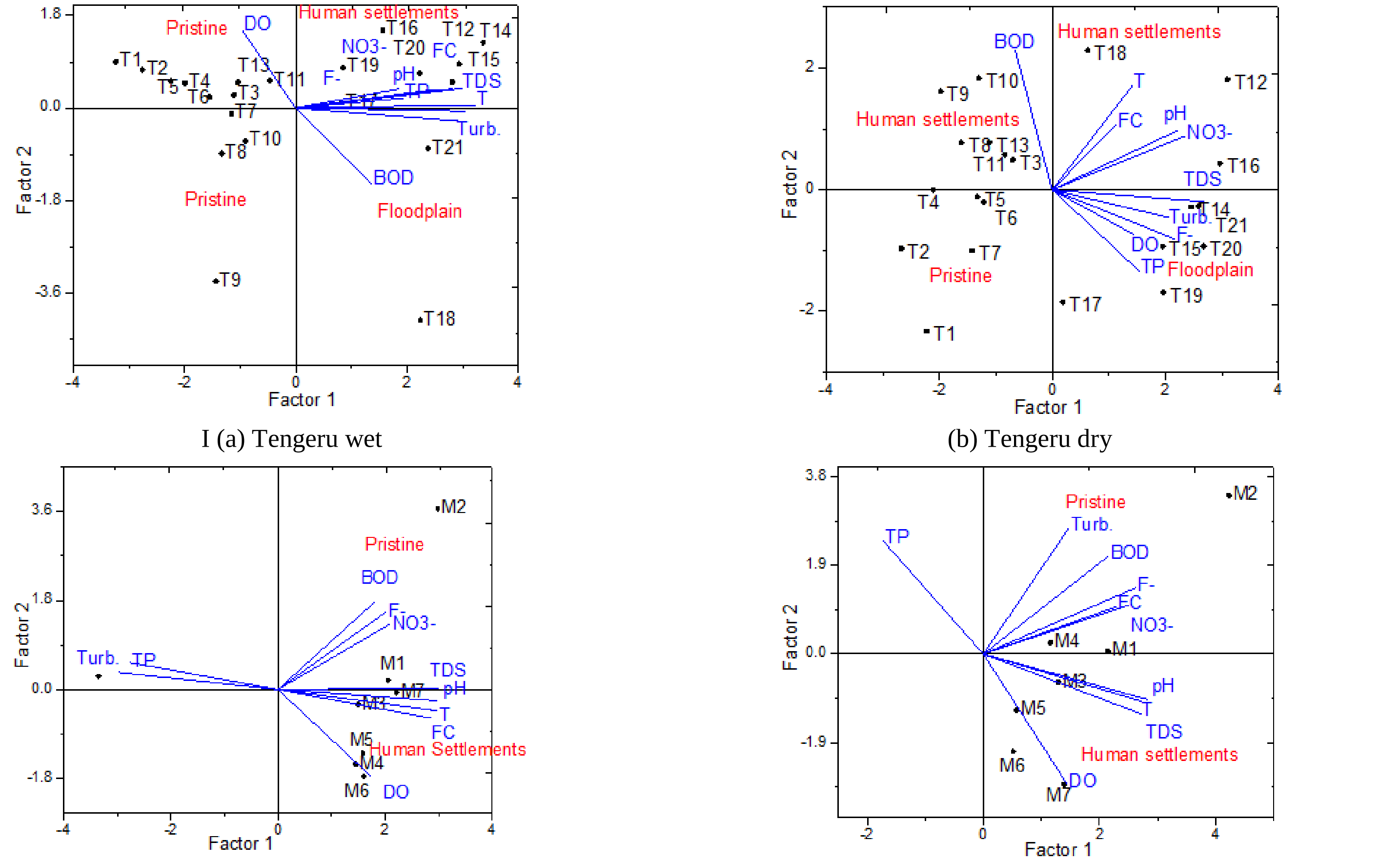


Figure 5: The PCA results for Temi (I a, b) and Nduruma (II a, b), Note: Turb.-Turbidity



I (a) Tengeru wet

(b) Tengeru dry

II (a) Maji ya Chai dry

(b) Maji ya Chai wet

Figure 6: The PCA results for Tengeru (I a, b) and Maji ya Chai (II a, b). Note: Turb.-Turbidity

Reliability of NSF and WAI methods

Reliability is among the necessary conditions for different scientific methods to give similar experimental results when the same data set is used. In this study the WAI and NSF methods were expected to provide similar results in overall water quality despite their differences in their approaches, however, the case is different as shown in Table 4. Despite the similarity in number and values of water quality parameters used for assessment of water quality in the two methods, yet they both showed variation in its overall water quality with WAI carrying higher grades than water qualities indicated by NSF with a few observations being similar. Also, in some other few cases the NSF method carried higher grades than WAI. Worse enough, the WAI was able to rate the water containing large number of FC to be in "excellent" conditions especially in the head water environment (Table 4). Also, from this table most parts of the river had different quality outcomes. To mention a few examples from some rivers the pristine environment of Temi River rated "excellent" water quality by WAI where as the "good" and "medium" water quality are rated by NSF method from the same water quality parameters and part of the river during wet and dry seasons, respectively (Te1, Te2, Te4 and Te6). The "excellent" water condition is normally regarded as "portable water" indicating high aesthetic value and absence of all disease causing pathogens the case which is different from the real observation. Under such conditions, the water quality assessment by WAI can be regarded as over grading since it is difficult to get the excellent water quality from its natural environment of the river. More differences are observed in the pristine environment of Nduruma River where the WAI ranked "good" water quality in both seasons while with similar quality parameters a "bad" to "medium" qualities are experienced and so on (N3, N5, N7 and N9). Also, Tengeru River has shown similar differences, for example the WAI showed "excellent" water conditions in (T10 and T13) whereas the NSF method evaluated the same water to have "medium" water quality. More else, Maji ya Chai River the "good" water quality by WAI at M1 and M2 were rated as "bad" by NSF method. From these few pointed examples we can establish a good fact of no doubts that the two methods can be good when used together to establish particular water quality but unreliable when one method is used for water quality judgments.

Table 4: Sampled examples for WQI by WAI and NSF methods

Sample Point	River	WQI WAI			WQI NSF			Reliability
		Wet	Dry	Range	Wet	Dry	Range	
Te1	Temi	Excellent	Excellent	<50	Good	Medium	51-75	Differed
Te2	Temi	Excellent	Excellent	<50	Medium	Medium	51-75	Differed
Te4	Temi	Excellent	Excellent	<50	Medium	Medium	51-75	Differed
Te6	Temi	Excellent	Excellent	<50	Medium	Medium	51-75	Differed
Te8	Temi	Good	Poor	100-200	Medium	Medium	51-75	Differed
Te10	Temi	Unsuitable	Unsuitable	>300	Bad	Bad	26-50	Differed
N1	Nduruma	Good	Excellent	<50	Medium	Medium	51-75	Differed
N3	Nduruma	Good	Poor	100-200	Bad	Medium	51-75	Differed
N5	Nduruma	Good	Good	50-100	Medium	Medium	51-75	Similar

N7	Nduruma	Poor	Good	50-100	Bad	Medium	51-75	Differed
N9	Nduruma	Good	Good	50-100	Medium	Medium	51-75	Differed
N11	Nduruma	Poor	Poor	100-200	Medium	Medium	51-75	Differed
T1	Tengeru	Excellent	Good	50-100	Medium	Medium	51-75	Similar
T3	Tengeru	Good	Poor	100-200	Medium	Medium	51-75	Similar
T7	Tengeru	Good	Good	50-100	Medium	Medium	51-75	Differed
T10	Tengeru	Excellent	Good	50-100	Medium	Medium	51-75	Differed
T13	Tengeru	Excellent	Excellent	<50	Medium	Medium	51-75	Differed
T18	Tengeru	Good	Poor	100-200	Medium	Medium	51-75	Differed
M1	Maji ya Chai	Good	Poor	100-200	Bad	Bad	26-50	Differed
M2	Maji ya Chai	Poor	Bad	200-300	Bad	Bad	26-50	Differed
M3	Maji ya Chai	Poor	Poor	100-200	Bad	Bad	26-50	Differed
M4	Maji ya Chai	Good	Poor	100-200	Medium	Bad	26-50	Similar
M5	Maji ya Chai	Good	Poor	100-200	Medium	Medium	51-75	Differed
M6	Maji ya Chai	Good	Poor	100-200	Medium	Medium	51-75	Differed

CONCLUSION AND RECOMMENDATIONS

The flexibility of WAI to accept addition of several other water quality parameters adds more advantages for its adoption than the NSF method in terms of extensive water quality examination. Moreover, addition of FC parameter adds some erroneous in the whole meaning for WAI-WQI since we cannot set its standard amount of the parasites as they have another extraordinary character, the multiplicative effect due to reproduction. The question is which method is to be adopted for decision making? The answer can be any method if the two could give similar results, but, somebody else can adopt both methods depending on water use and environmental conditions faced by the respective water body. Also, under such situations and for the purpose of decision making, we need to consider any parameter that is expected to be harmful in water and thus, the flexibility of WAI gives more advantages for use despite its higher quality rating behavior than NSF method as observed in a few shown examples in Table 4.

The water quality in the pristine environment was good in all rivers except that of Maji ya Chai River while in the flood-plain the quality was bad in all rivers in wet seasons. Bad water quality in flood-plain was mainly contributed by runoff and flooding in those areas. Maji ya Chai River showed exceptions in its water quality since it had bad quality throughout. The two methods for water quality assessment (NSF and WAI) seem to work but their differences in its overall quality should be worked separately for proper decision making depending on intended water use. Some accentuated water parameters such as FC showed to accelerate the difference between the WAI and NSF methods since it is difficult in tropical areas to find water in rivers without FC.

Furthermore, since the fully developed parts of the river indicated medium water quality, then it can be conclude that a well conserved riparian environment of the river gives a high possibility to harvest water in its fully developed areas since the water quality in those areas have shown to be equally as good as in pristine areas. By doing this practice the chances of affecting the major watersheds and catchment areas through constructions of water collection points will be reduced thus developing a sustainable river system. Also, tapping water in fully developed parts of the rivers will optimize the quantity of water harvested in rivers since they offer maximum discharge compared to the pristine environment which most parts of them contains potential springs to recharge the main river. In addition, it is necessary to establish the water quality of the whole river before deciding at what point water taping should be done to minimize water processing cost and maximize output. Moreover, standards for water temperature can be modified to start from a value just above 0 °C the temperature at which water exist as liquid instead of 35 °C which is a higher temperature since most catchment areas for many rivers start from mountainous areas which are normally colder than the established standards. Despite the observed differences, the two methods cannot be abandoned but used with precautions as reminded by the precautionary principle demanding precaution to be taken for anything harmful or seems to be harmful even if the scientific reason is not yet established as why that happened (Myers 2002). Lastly, the water quality study using WQI technique under WAI and NSF method when integrated with GIS gives more information on the river status which can be useful for management strategy of a particular place.

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