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Investigations of Physico-Chemical Parameters and its Pollution Implications of Elala River, Mekelle, Tigray, Ethiopia

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ABSTRACT

The purpose of the study was to assess the water quality parameters of Elala River found in Mekelle, Tigray, Ethiopia. Four sampling sites were chosen spatially along the water course to reflect a consideration of all possible activities that are capable of affecting the quality of the river water. The water samples were collected monthly for three consecutive months (March to May, 2014) at the four sampling sites. In order to understand the characteristics of Elala River, principal component analysis (PCA) was utilized using 22 water quality parameters: water temperature, electrical conductivity, turbidity, pH, total solids, total suspended solids, total dissolved solids, total alkalinity, total hardness, calcium, magnesium, chloride, sulfate, nitrate-nitrogen, nitrite-nitrogen, ammonium-nitrogen, total nitrogen, dissolved oxygen, biological oxygen demand, chemical oxygen demand, orthophosphate and total phosphorus. Among the 22 studied water quality parameters: electrical conductivity (904.11 to 2156.11 µS/cm), turbidity (21.07 to 34.99 NTU), total dissolved solids (700.22 to 1328.22 mg/L), total alkalinity (131.85 to 267.26 mg/L), total hardness (198.67 to 478.67 mg/L), chloride (47.32 to 259.43 mg/L), calcium (65.13 to 146.99 mg/L), chemical oxygen demand (16.02 to 32.53 mg/L), sulphate (271.82 to 384.07 mg/L), nitrate-nitrogen (6.82 to 62.38 mg/L), orthophosphate (0.03 to 0.14 mg/L) and total phosphorus (0.04 to 0.19 mg/L) were above the prescribed limit of WHO guidelines for drinking purposes, while all analyzed water quality parameters fall within the FAO standard limit for irrigation purposes. The water is thus not potable for domestic purposes without some forms of physical and chemical treatment while it is useful for agricultural purposes.

Keywords: Elala River, Water quality, Correlation Matrix, Principal Component Analysis, Mekelle, Ethiopia.

1. INTRODUCTION

Water is one of the pivotal to both natural ecosystems and human development. It is essential for various activities such as drinking, cooking, industrial, agricultural and recreational purposes. In the human body, it is also used in transporting, dissolving organic matter and replenishing nutrients while carrying away waste materials (Jayalakshmi et al., 2011).

Rivers are vital component of the biosphere that contains less than one percent of the world's fresh water with their higher ecological and social significance which are being polluted by indiscriminate disposal of sewerage, industrial waste, and by excess of human activities affecting their physicochemical characteristics and leads to various deleterious effects on aquatic organisms (Murhekar, 2011; Annalakshmi and Amsath, 2012).

Water quality provides current information about the concentration of various solutes at a given place and time. Its quality parameters provide the basis for judging the suitability of water for its designated uses and to improve existing conditions (Ali et al., 2004).There is no single or simple measure for water quality. Water may be tested for a few characteristics or numerous natural substances and contaminants depending on their needs. The nature and extent of water pollution is characterized by several physical, chemical and biological parameters. The increased anthropogenic activities due to industrialization have contributed to decline in water quality including climate and precipitation, soil type, vegetation, groundwater and flow conditions. The water quality of rivers and lakes changes with the seasons and geographic areas, even when there is no pollution presents (Chitmanat and Traichaiyaporn, 2010).

The deterioration of water quality has led to the destruction of ecosystem balance, contamination and pollution of ground and surface water resources. Water quality degradation world-wide is due to many anthropogenic activities which release pollutants into the environment thereby having an adverse effect upon aquatic ecosystems. Quality of water can be regarded as a network of variables such as pH, oxygen concentration, temperature, etc. and any changes in these physical and chemical variables can affect aquatic biota in a variety of ways (Kolawole et al., 2011). Since the quality water is directly related to health and is important for determination of water utility, it is very essential and important to test the quality of the water before it is used for drinking, domestic, agricultural or industrial purposes. The utility of river water for various purposes is governed by physicochemical and biological quality of the water (Singh et al., 2013).

Mekelle, the capital city of Tigray, northern Ethiopia is one of the fastest growing urban areas in Ethiopia. The climate of the region is generally sub tropical with an extended dry period of nine to ten months and a maximum effective rainy season of 50-60 days. Considering the rainfall, atmospheric temperature and evapotranspiration, more than 90% of the region is categorized as semi arid. The temperature in Mekelle ranges from 11,5 to 30.65^{o}C and annual rainfall varies from 24.0 to 486.0 mm/month (Mebrahtu and Zerabruk, 2011). This makes irrigation using Elala River an attractive option for the region. Thus, Elala River is extensively used for domestic, recreational, drinking and irrigation purposes in the area. To the River different municipal wastes are being disposed, cars are being washed, mostly children are using on it for showering and drink from the river. Therefore there is a need for continuous monitoring of the pollutants load in this river water so as to safeguard public health treats from using this water. Thus, the present paper tries to focus on the physicochemical quality of Elala River water and effect of pollutants.

2. MATERIALS AND METHODS

2.1. Description of the Study Area

The study was carried out in Elala River in and around Mekelle, Tigray, northern Ethiopia. The four sampling points of the study area were randomly selected using GPS (global positioning systems) (Fig 1). Site 1, Feleg-Daero, approximately the source of the river enters to the city; Site 2, bridge of Mekelle-Adigrat road; Site 3, place where waste disposal enters to the river and some metal work takes place around it and Site 4, a place where the river leaves the city.

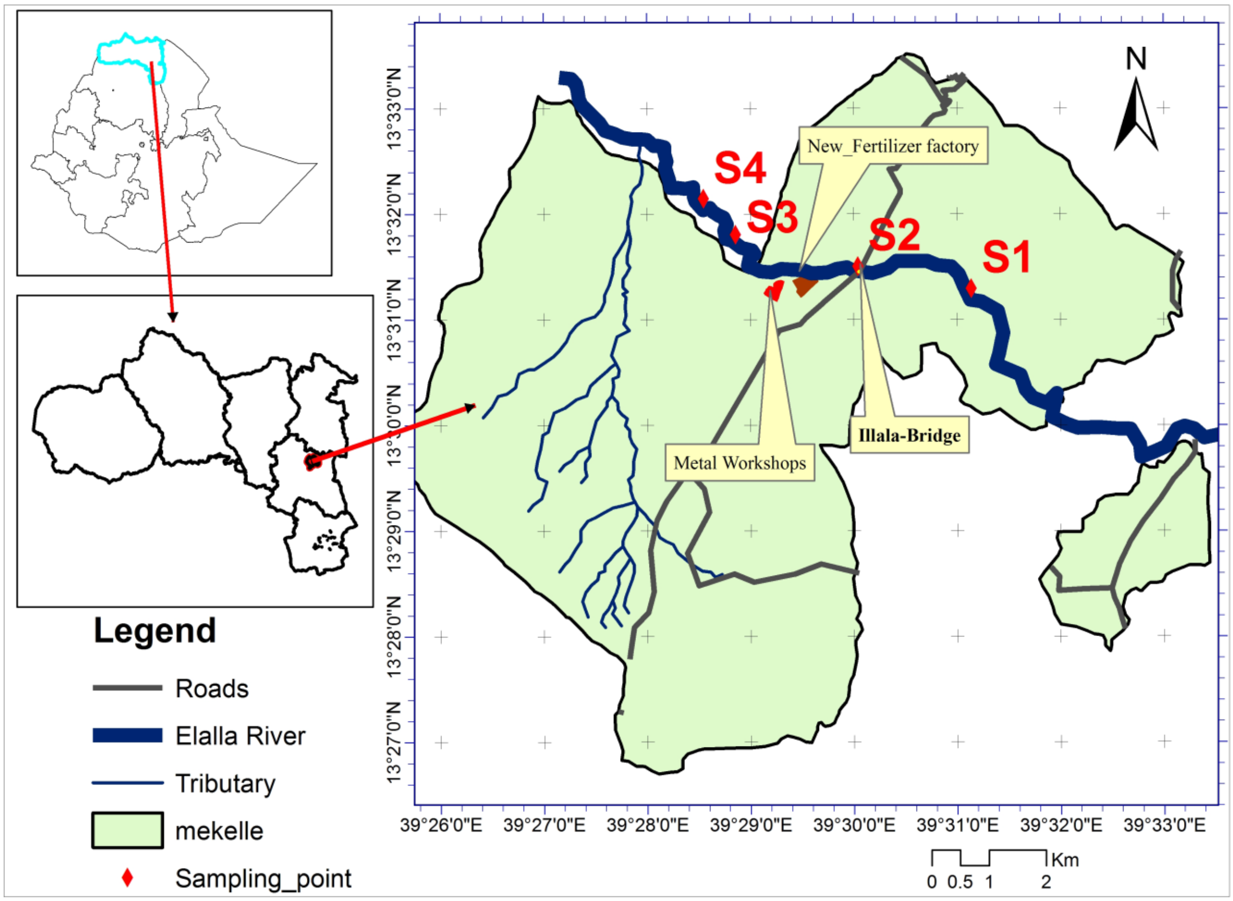

Figure 1. Map of the study area with water sample sites, Elala River, Mekelle.

2.2. Sample Collection

A water sample from Elala River was collected for this study following standard procedure as described by APHA (1998). Pre-washed 500 mL sizes of PVC plastic bottle was used to collect water sample for water quality analysis. Sample containers were labeled on the field using appropriate codes and water samples were temporary stored in ice packed cooler and transported to the laboratory and stored in a refrigerator at about 4^0C prior to analysis (Gangwar et al., 2012). These samples were collected on a monthly basis consecutively for a period of three month (March 2014 to May 2014).

2.3. Water Quality Analysis

The water quality parameters were analyzed using standard analytical methods (APHA, 1998; Sinha and Biswas, 2011). The temperature, pH and dissolved oxygen were determined on site using HQ40d multimeter (HACH LANGE, NV), turbidity also determined on site using turbidity meter (Turner designs Aquafluor 8000-001). Biological oxygen demand (BOD) was measured based on oxygen consumed in a 5-d test period (5-d BOD or BOD_5) at 20^0C after arrival of sample to the laboratory (APHA, 1998). Nitrate-nitrogen, nitrite-nitrogen, ammonium-nitrogen, total nitrogen, soluble phosphate, total nitrogen; and chemical oxygen demand were measured using Hach Lange kits. Standard laboratory methods as described by the APHA (1998) for the examination of water samples was employed for the analysis of total solids, total suspended solids, total dissolved solids, calcium, magnesium and chlorides. Suphate (SO_4^{2-}) was determined using Nephelometric turbidity meter (TAHP, 1999). All chemicals used were of high purity and analytical grade. Fresh reagents were used and great care was taken to avoid chemical contamination.

2.4. Data Analysis

We first carried out a multivariate principal components analysis (PCA) to visually explore patterns of associations among the physicochemical variables and between variables and the sampling sites using CANOCO for windows (Version 4.5) software. In addition to the multivariate analysis, data analysis and validation were made using SAS (Version 9.1). Analysis of Variance and Student t – test at 95% confidence level were calculated and the results were presented as mean and standard deviation (Mean ± SD). Reproducibility of results was regularly checked and the validated data were recorded in triplicate at the end of each experiment.

3. RESULTS AND DISCUSSION

The PCA biplot analyses performed on the entire set of measured physicochemical parameters of Elala River showed differences among the sampling sites (Fig 2).

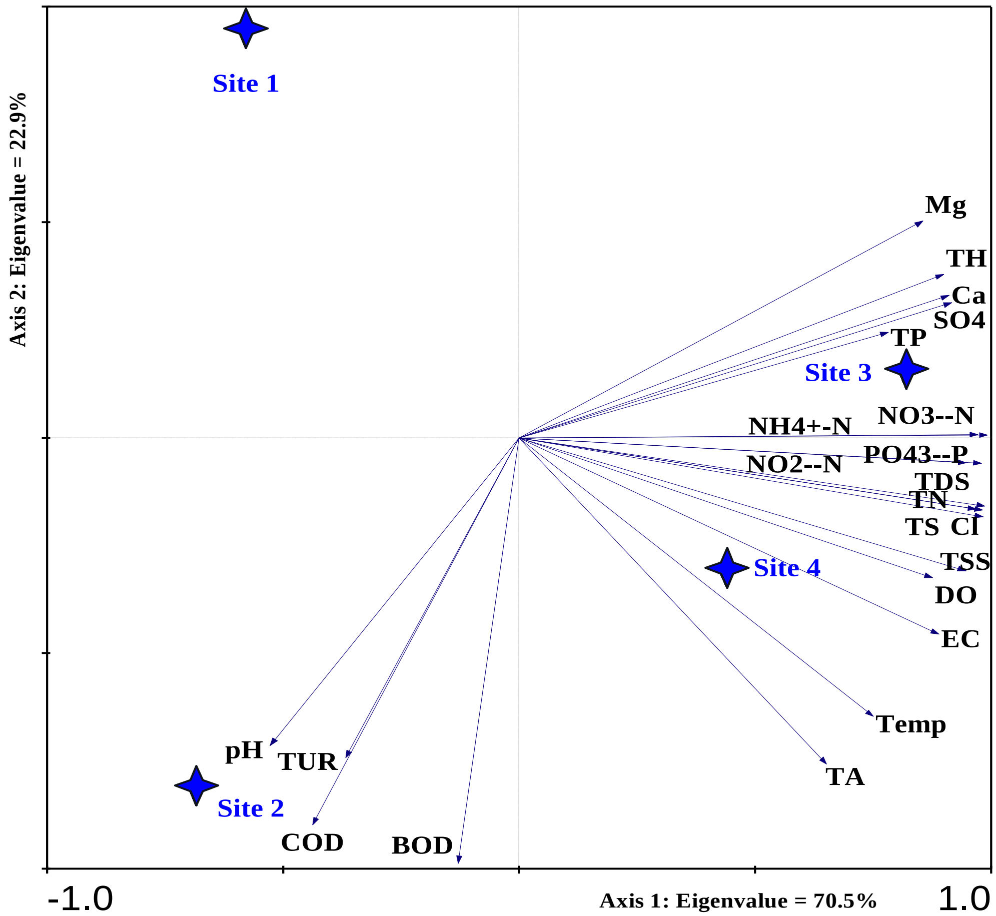

Figure 2. Biplot of a standardized PCA-analysis performed on the physicochemical parameters of Elala River. Arrows represent variables. Star filled symbols represent sampling sites of Elala River. Parameters are given in abbreviations: Temperature (Temp), electrical conductivity (EC), turbidity (TUR), pH, total solids (TS), total suspended solids (TSS), total dissolved solids (TDS), total alkalinity (TA), total hardness (TH), calcium (Ca^{2+}), magnesium (Mg^{2+}), chloride (Cl^-), sulphate (SO_4^{2-}), nitrate (NO_3^--N), nitrite (NO_2^--N), ammonium (NH_4^+-N), total nitrogen (TN), dissolved oxygen (DO), biological oxygen demand (BOD), chemical oxygen demand (COD), soluble phosphate (PO_4^{3-}-P) and total phosphorus (TP).

PCA axes 1 and 2 together represent 93.4% of variation in the physicochemical parameters of the four sampling sites and the data clearly show that the sampling sites are consistently different in their characteristics, irrespective of the month of sampling. Axis 1 (Eigenvalue = 70.5%) mainly represents gradients in the nutrients ((NO_3^-—N; NO_2^-—N; NH_4^+-N; PO_4^{3-}—P; TN; TP); cations (Ca and Mg), anions (Cl- and SO_4^{2-}), suspended solids (TS; TSS; TDS), total hardness (TH), total alkalinity (TA), electrical conductivity (EC), temperature (Temp) and dissolved oxygen (DO) which is positively associated with almost all measured physicochemical parameters. This gradient was negatively associated with pH, turbidity (TUR), chemical oxygen demand (COD) and biological oxygen demand (BOD).

Table 1. Correlation matrix of the 22 physicochemical parameters of the Elala River.

	Temp	*EC*	*TUR*	*pH*	*TS*	*TSS*	*TDS*	*TA*	*TH*	*Ca^{2+}*	*Mg^{2+}*	*Cl$^-$*	*SO4^{2-}*	*NO3$^-$-N*	*NO2$^-$-N*	*NH4$^+$-N*	*TN*	*DO*	*BOD*	*COD*	*PO4^{3-}-P*	*TP*
Temp	1																					
EC	**0.94**	1																				
TUR	0.07	-0.1	1																			
pH	0.12	-0.2	0.51	1																		
TS	**0.83**	**0.97**	-0.3	-0.4	**1**																	
TSS	**0.91**	**0.99**	-0.3	-0.3	**0.98**	1																
TDS	**0.82**	**0.96**	-0.3	-0.5	**1**	**0.97**	1															
TA	**0.98**	**0.91**	0.26	0.15	**0.79**	**0.85**	**0.77**	1														
TH	0.56	**0.78**	**-0.7**	**-0.6**	**0.88**	**0.84**	**0.89**	0.44	1													
Ca2+	0.6	**0.8**	**-0.7**	**-0.6**	**0.89**	**0.86**	**0.89**	0.48	**1**	1												
Mg2+	0.43	**0.7**	-0.7	**-0.8**	**0.84**	**0.76**	**0.85**	0.33	**0.98**	**0.96**	1											
Cl-	0.86	**0.96**	-0.4	-0.3	**0.97**	**0.99**	**0.96**	**0.77**	**0.91**	**0.93**	**0.82**	1										
SO4^{2-}	0.57	**0.78**	**-0.7**	**-0.6**	**0.87**	**0.84**	**0.87**	0.44	**1**	**1**	**0.96**	**0.9**	1									
NO3--N	0.62	**0.83**	-0.2	**-0.7**	**0.93**	**0.84**	**0.94**	0.61	**0.83**	**0.82**	**0.87**	**0.8**	**0.8**	1								
NO2--N	**0.74**	**0.92**	-0.3	**-0.6**	**0.98**	**0.93**	**0.99**	**0.71**	**0.87**	**0.87**	**0.87**	**0.9**	**0.85**	**0.98**	1							
NH4+-N	**0.7**	**0.89**	-0.3	**-0.6**	**0.97**	**0.91**	**0.98**	0.67	**0.88**	**0.87**	**0.89**	**0.9**	**0.85**	**0.99**	**1**	1						
TN	**0.72**	**0.9**	-0.2	**-0.6**	**0.97**	**0.91**	**0.98**	0.69	**0.86**	**0.85**	**0.86**	**0.9**	**0.83**	**0.99**	**1**	**1**	1					
DO	**0.92**	**0.94**	-0.3	-0.1	**0.89**	**0.96**	**0.87**	**0.83**	**0.79**	**0.83**	0.66	**1**	**0.81**	0.66	**0.79**	**0.76**	**0.76**	1				
BOD	0.46	0.16	**0.78**	**0.84**	-0.1	0.06	-0.1	0.56	-0.5	-0.42	**-0.6**	-0.1	-0.45	-0.28	-0.17	-0.23	-0.2	0.15	1			
COD	0.16	-0.1	**0.9**	**0.83**	-0.4	-0.2	-0.4	0.29	**-0.7**	**-0.69**	**-0.8**	-0.4	-0.71	-0.46	-0.41	-0.45	-0.4	-0.2	0.94	1		
PO4^3--P	**0.7**	**0.88**	-0.2	-0.6	**0.96**	**0.89**	0.97	0.69	**0.82**	**0.81**	**0.84**	**0.9**	**0.79**	**0.99**	**0.99**	**0.99**	**1**	**0.72**	-0.2	-0.38	1	
TP	0.35	0.61	-0.2	-0.9	**0.76**	0.63	0.79	0.37	**0.71**	0.67	**0.8**	0.6	0.66	**0.95**	**0.87**	**0.9**	**0.89**	0.39	-0.4	-0.53	**0.91**	1

The correlation matrix (Table 1) shows a strong positive correlation between Temp, EC, TS, TSS, TDS, TA, TH, Ca, Mg, chloride, sulphate, nitrate-N, nitrite-N, ammonium-N, TN, DO, orthophosphate and TP. The correlation coefficient also shows a positive correlation between pH and that of COD and BOD and negative correlation with the other water quality (physicochemical) parameters which is similar with that of the PCA analysis. This negative correlation might be due to different pollution loads from the four sampling sites which may have different origin such as agriculture or/and other small scale activities. The results of physicochemical variables measured for the Elala River are also presented in table 2.

Table 2. Physicochemical parameters of Elala River water samples (Mean ± SD) (When ANOVA indicated significant differences between the studied sites, each site differing by the tests was given a different letter (a, b or c)).

Parameters	***Site 1***	***Site 2***	***Site 3***	***Site 4***	***WHO***	***FAO***
T (^oC)	18.72±1.35[b]	21.58±1.40[ab]	23.02±1.82[a]	23.84±1.78[a]	<40	---
EC (µS/cm)	904.11±18.15[c]	1324.33±83.15[b]	2156.11±120.46[a]	2066.89±115.33[a]	750	3000
TUR (NTU)	21.07±0.53[b]	34.99±0.67[a]	25.13±0.24[b]	21.58±0.64[b]	5	---
pH	7.62±0.12[b]	7.91±0.19[a]	7.47±0.03[c]	7.82±0.13[a]	6.5-8.5	6.0-8.5
TS (mg/L)	868±40.44[c]	950.05±62.17[c]	1606.56±98.89[a]	1417.56±99.08[b]	---	---
TSS (mg/L)	167.78±9.83[c]	192.07±8.46[bc]	278.33±3.63[a]	272.78±7.54[ab]	---	---
TDS (mg/L)	700.22±27.23[b]	757.98±71.57[b]	1328.22±46.87[a]	1144.78±23.79[a]	500	2000
TA (mg/L)	131.85±4.82[b]	233.33±2.50[a]	262.09±4.17[a]	267.26±9.88[a]	120	---
TH (mg/L)	316.67±2.36[b]	198.67±1.40[c]	478.67±2.55[a]	443.56±2.43[a]	300	---
Ca^{2+} (mg/L)	97.88±1.72[b]	65.13±1.62[c]	146.99±2.21[a]	141.68±2.32[a]	100	800
Mg^{2+} (mg/L)	17.31±0.51[b]	8.75±0.01[c]	27.01±0.67[a]	21.61±0.62[b]	120	120
Cl^- (mg/L)	47.32±0.75[b]	53.56±0.70[b]	249.75±1.89[a]	259.43±4.00[a]	250	400
SO_4^{2-} (mg/L)	321.32±1.45[b]	271.82±9.70[c]	384.07±4.88[a]	378.67±5.89[a]	250	400
NO_3^--N (mg/L)	7.43±0.32[c]	6.82±0.52[c]	62.38±0.93[a]	27.43±0.34[b]	45	50
NO_2^--N (mg/L)	0.04±0.00[c]	0.05±0.001[c]	0.22±0.008[a]	0.14±0.004[b]	1	---
NH_4^+-N (mg/L)	0.12±0.002[b]	0.12±0.001[ba]	0.14±0.001[a]	0.13±0.002[ab]	---	5
TN (mg/L)	0.81±0.007[b]	1.43±0.035[b]	12.27±0.30[a]	6.59±0.03[b]	---	---
DO (mg/L)	5.03±0.07[a]	5.17±0.44[a]	5.59±0.47[a]	5.81±0.060[a]	5.0-7.0	>4.0
BOD (mg/L)	2.34±0.034[d]	5.21±0.06[a]	3.04±0.046[c]	4.13±0.052[b]	2.0-5.0	8
COD (mg/L)	16.02±0.06[b]	32.53±0.78[a]	17.00±0.52[b]	21.15±0.88[b]	10	---
$PO4^{3-}$-P (mg/L)	0.03±0.001[bc]	0.04±0.001[bc]	0.14±0.008[a]	0.08±0.006[b]	0.1	2
TP (mg/L)	0.06±0.002[b]	0.04±0.00[b]	0.19±0.013[a]	0.06±0.002[b]	0.1	---

3.1. Temperature

Naturally water bodies show changes in temperature daily and seasonally due to different activities that can contribute to changes in surface water temperature. Water temperature obtained during the sampling period for all sites except S1 did not differ significantly at 95% confidence level. Generally, the river temperature varie from 18.72 ± 1.35^{0}C upstream of S1 to 23.84 ± 1.78^{0}C downstream of S4 and is considered lower compared to WHO maximum permissible limit (WHO, 2008). Thus, temperature of Elala River is likely suitable for aquatic lives. This result is similar to other studies reported within a range of 19.5 to 21^{0}C (Patil et al., 2012), 10.18 to 19.73^{0}C (Kar et al., 2008), 20.5 to 22^{0}C (Chiroma et al., 2012), 19.01 to 23.93^{0}C (Okweye, 2013).

3.2. Electrical Conductivity (EC)

The mean EC values significantly different from each other at 95% confidence level and are higher than the prescribed limit set by WHO for drinking purposes and below the limit set by FAO for irrigation indicating the presence of high amount of dissolved inorganic substances in their ionized form (Sankpal and Naikwade, 2012). Higher the EC, less amount of water will be available to plants, even though the soil may appear wet. This is because plants can only transpire "pure" water as the usable plant water in the soil solution decreases dramatically with an increase in EC. Therefore, irrigation water with high EC reduces yield potential. Other studies also showed EC values to be in the ranges of 225 to 3350 μS/cm (Jayalakshmi et al., 2011), 2130 μS/cm (Inoti et al., 2012) which are similar with our findings of Elala River.

3.3. Turbidity

Water turbidity, which reflects transparency, is an important criterion for assessing the quality of water. The average turbidity values ranges from 21.07 ± 5.28 to 34.99 ± 11.67 NTU. The statistical analysis at 95% confidence level indicates that water at site S2 (34.99 NTU) is significantly different from the other sampling sites. This might be due to daily disturbance of the river by washing of different vehicles and surface runoff (Alemayehu, 2001). Turbidity values obtained for the Elala River at all four sampling sites are higher than WHO which suggests 5 NTU for drinking purposes (WHO, 2008). This indicates that the entire river is generally polluted and posing problems to aquatic lives, domestic and irrigation use. This might be due to improper disposal of sewage, surface runoff and wastewater from different domestic activities. Similar higher turbidity values are also recorded by many workers as compared to the limit set by WHO (Akan et al., 2008; Joshi et al., 2009; Mebrahtu and Zerabruk, 2011; Murhekar, 2011; Pal et al., 2013).

3.4. pH

pH values vary from a minimum of 7.47 ± 0.03 and a maximum of 7.91 ± 0.19. These values are within the permissible limit of WHO and FAO set for drinking and irrigation purposes (Ayers and Westcot, 1994; WHO, 2008). But, the statistical analysis showed that there is a significant difference between the four sampling sites indicating different sources of impurities from different sites affecting the quality of Elala River.

3.5. Total Solids (TS)

It is recorded maximum at S3 (1606.56 ± 98.89 mg/L) and minimum at S1 (868 ± 40.44 mg/L). The statistical analysis at 95% confidence level also showed significant differences among the sampling points. This might be due to deposition of solid particles and domestic wastes from the city through the river course which could lead to the reduction in the volume of water. Since, there are no such activities around the rural area compared to the urban areas site S1 has lowest value of TS concentration than the other sampling sites. Similar findings are also reported by Varunprasath and Daniel (2010) with TS values 1030 to 1130 mg/L and 1630 to 1800 mg/L.

3.6. Total Suspended Solids (TSS)

Total suspended solid content of water depends on the amount of suspended particle, soil and silt which is directly related to turbidity of water. The present study shows that the average value of TSS varies from 167.78 ± 9.83 to 278.33 ± 3.63. These values are attributed to the surface runoff and disposals of domestic sewage. The experimental findings at 95% confidence level also showed no significant difference between the sites. But, slightly higher values recorded at site 3 could be attributed due to the surface runoff and disposals of domestic sewage locally. River water having TSS values greater than 100 mg/L but less than 220 mg/L is classified as medium wastewater (Akan et al., 2008). Thus, the overall TSS mean value for Elala River is 219.39 mg/L which can be considered as medium wastewater.

3.7. Total Dissolved Solids (TDS)

In the present study the average values for TDS at four sites varies from 700.22 ± 27.23 to 1328.22 ± 46.87 mg/L and exceed the maximum permissible limits of WHO for the drinking purpose and lower than the limit given by FAO for irrigation water (Ayers and Westcot, 1994; WHO, 2008). Higher TDS can be toxic to aquatic life through increases in salinity or changes in the composition of the water. Primary sources for higher TDS in the river water might be due to agricultural runoff, discharge of domestic waste from the town and other human activities like washing of different vehicle at and around the river (Annalakshmi and Amsath, 2012). Jayalakshmi et al. (2011) also reported similar TDS values (221 to 3534 mg/L) for river water.

3.8. Total Alkalinity (TA)

Total alkalinity of rivers is mainly carbonates and bicarbonates in any the samples which may be resulted due to the weathering of rocks, waste discharge and microbial decomposition of organic matter in the water body. The measured TA values from upstream to the downstream of Elala River vary from 131.85 ± 4.82 to 267.26 ± 9.88 mg/L and above the prescribed limit set by WHO (2008). Thus, the river is unsuitable for domestic purposes. At 95% confidence level, S1 was significantly different from the other three sites. In a similar study, higher TA values than the accepted values are reported by Alemayehu (2001); Sharma et al. (2013); Soni et al. (2013) and lower values by Bhattarai et al. (2008); Joshi et al. (2009); Alani et al. (2014).

3.9. Total Hardness (TH)

The values ranges from 198.67 ± 1.40 to 478.67 ± 2.55 mg/L. Based on hardness, water classified into three different categories: soft water (0 to 75 mg/L), moderately hard water (76 to 150 mg/L) and hard water (151 to 300 mg/L) (Soni et al., 1013). Accordingly, Elala River categorized as hard water. The recorded values for TH for all studied sites, except S2, are higher than the permissible limit of WHO (2008). Higher TH values are mainly due to weathering of Ca and Mg-rich rocks in the area (Zeitoun and Mehana, 2014). This is related to the dominant limestone rock in the area which occupies the elevation in the topography. The data indicate that the Elala River water is unsuitable for drinking purposes. Besides, the statistical analysis at the 95% confidence level also showed a significant difference among the sampling sites. Other studies related to river water also indicated higher (Murhekar, 2011; Addo et al., 2013; Soni et al., 2013) as well as lower values for TH (Joshi et al., 2009; Pal et al., 2013; Sharma et al., 2013).

310. Calcium and Magnesium

Calcium and magnesium are among the most common constituents present in natural water and their salts are important contributors to the hardness of water. In the present study, calcium and magnesium contents in mg/L were ranged from 65.13 ± 1.62 to 146.99 ± 2.21 and 8.75 ± 0.01 to 27.01 ± 0.67, respectively. The recorded value for Ca is higher than the permissible limit of WHO (2008) and Mg concentrations lie within the prescribed limit of WHO (2008) and FAO

(Ayers and Westcot, 1994). At 95% confidence level, significance differences in the concentrations of Ca and Mg were observed among the four studied sites. Higher values for Ca are related to sewage and weathering Ca- rich rocks or cementing materials (APHA, 1998).

3.11. Chloride (Cl^-)

High chloride content in river waters may indicate pollution by sewage, industrial waste or intrusion of seawater into fresh water bodies. The values recorded for Elala River water is in the range of 47.32 ± 0.75 to 259.43 ± 4.0 (mg/L). Upstream (S1 and S2) river water is significantly different from the downstream (S3 and S4). Higher chloride concentration in the downstream might be due to the discharge of domestic sewage containing a large amount of chlorides (Addo et al., 2013). According to the guidelines of WHO (2008) and FAO (Ayers and Westcot, 1994; WHO, 2008) [13, 25], the values are within the acceptable limits except for S4.

3.12. Sulphate (SO_4^{2-})

It is one of the major anions in natural waters and is contributed by industrial and household discharges, as contaminant from tanneries, textiles, etc. This will in effect decreases pH of river water and increases bacterial load, i.e. sulphate reducing bacteria. The values for Elala River ranges from 271.82 ± 9.70 to 384.07 ± 4.88 (in mg/L), which is beyond the acceptable limit set by WHO (2008) and lower than the permissible limit of FAO for irrigation purpose. The findings also showed significant differences among the sample sites, highest at S3 and S4 with a mean value of 384.07 and 378.67 mg/L, respectively. These higher values are related to the discharge of sulphate containing municipal sewages from the city; and surface runoff that contain organic fertilizers from agricultural activities undertaking on the river side. The natural concentration of sulphates in most surface water is within the range of 2 to 80 mg/L (Manivasakam, 2005). Thus, Elala River is not safe for drinking purposes.

3.13. Nitrate (NO_3^--N), Nitrite (NO_2^--N), Ammonium (NH_4^+-N) and Total nitrogen (TN)

The concentration of nitrates is used as indication of level of micronutrients in water bodies and has ability to support plant growth. High concentration of nitrate favored growth of phytoplankton. The concentration of nitrate -nitrogen in Elala River water is ranging from 6.82 ± 0.52 to 62.38 ± 0.93 mg/L. The value of NO_2^--N obtained from the river in mg/L also ranged from 0.04 ± 0.00 to 0.22 ± 0.008. At 95% confidence interval, the values obtained from the four sites are significantly different among each other for both NO_3^--N and NO_2^--N concentrations. Higher amount of both NO_3^--N and NO_2^- -N is observed in downstream samples, especially at

S3, is related to the disposal of domestic wastes from the city and use of nitrogen containing fertilizers around the river banks (Ewers, 1991). Data indicate that the amount of NO_3^--N and NO_2^--N, except site S3, is below the WHO (2008) and FAO (Ayers and Westcot, 1994) permissible limits. The concentrations of NH_4^+-N in the four sampling sites of the river ranging from 0.12 ± 0.002 to 0.14 ± 0.001 mg/L is below the permissible limits set by WHO (2008) and FAO (Ayers and Westcot, 1994). The statistical analysis at 95% confidence level does not show any significance difference among the sampling sites. The mean values of total nitrogen (TN) in mg/L of the four sites were ranged from 0.81 ± 0.007 to 12.27 ± 0.3. At 95% confidence level, the mean values of all sites, except S3, were not also significantly different. Higher value for TN recorded at S3 is in good agreement with the high level of NO_3^--N recorded at the same site. The result obtained from the present study fall within the limit of WHO (2008) and FAO (Ayers and Westcot, 1994) showing that the river is less polluted by nitrogenous materials.

3.14. Dissolved Oxygen (DO)

Dissolved oxygen is vital for aquatic life. The decomposing organic matter, dissolved gases, industrial waste, mineral waste and agricultural runoff results to get lower DO levels (Srivastava et al., 2011; Addo et al., 2013). Concentration levels of DO below 5.0 mg/L adversely affect aquatic life (Sinha and Biswas, 2011). Thus, DO values in the present study ranges from 5.03 ± 0.07 to 5.81 ± 0.06 mg/L, with an overall mean concentration of 5.90 mg/L, which is suitable for life of the aquatic ecosystem. The findings also indicate that at 95% confidence level, there are no significant differences between the sites and are within the permissible limits set by WHO (2008) and FAO (Ayers and Westcot, 1994). Others also reported similar values of DO for river water bodies (Karikari et al., 2007; Jayalakshmi et al., 2011; Addo et al., 2013).

3.15. Chemical and Biological Oxygen Demand (COD & BOD)

COD is related to organic and inorganic pollutants which causes unfavorable conditions for the growth of microorganisms. The permissible limit is 10 mg/L (WHO, 2008). Average COD concentration for Elala River water is ranging from 16.02 ± 0.06 to 32.53 ± 0.78 mg/L, higher than the WHO (2008) value. Among four samples, S2 is significantly different from other sites which may be due to the presence of chemicals that are oxygen demand in nature coming from washing of different vehicles and surface runoff. Similar kind of studies conducted in rivers like Cauvery and Arasalar in India also reported COD value in the range of 25 to 68 and 32.34 to 57.56 mg/L, respectively (Annalakshmi and Amsath, 2012). BOD which is sensitive for organic pollution ranges from 2.34 ± 0.034 to 5.21 ± 0.06 mg/L for Elala River water. The values except for S3 are within the recommended values of WHO (2008) and FAO (Ayers and Westcot, 1994). Interestingly, at 95% confidence level, there is a significant difference among the four sampling sites, highest being at S3. This could be an indication of organic pollution due to the load of waste from the market place of the city and different agricultural fertilizers brought by the runoff. Generally, the COD values are higher than BOD in the river. Increased levels of BOD and COD decrease the dissolved oxygen content in the river water (Ubwa et al., 2013).

3.16. Orthophosphate (PO_4^{3-}-P) and Total Phosphorus (TP)

It is a vital nutrient for all living things but, introduction of excessive phosphorus in form of phosphates in aquatic environment can cause eutrophication. Orthophosphate values recorded for in the river water ranges from 0.03 ± 0.001 to 0.14 ± 0.008 mg/L and are below (except S3) the permissible limits set by WHO (2008) and FAO (Ayers and Westcot, 1994). In a similar study Karikari et al. (2007) reported 002 to 0.14 mg/L values for Angawa River. Total phosphorus for Elala River water is ranging from 0.04 ± 0.00 to 0.19 ± 0.013 mg/L. At the 95% confidence level, site S3 is significantly different from the others. Decrease in TP values at S4 could be due to less pollution load of waste disposals from the surrounding or dilution effect in the downstream of the river. The results obtained from all sites are below the permissible limit of WHO (2008) except S3. Higher values for orthophosphate and total phosphorous at S3 could be due to higher disposal of phosphate from domestic sewages and surface runoff from phosphate containing fertilizers (Korostynska et al., 2012).

4. CONCLUSION

Water quality assessment on Elala River was conducted based on selective water quality parameters which are relevant to indicate the suitability of water for drinking and agricultural purposes. Present investigation concludes that most of the studied physicochemical parameter concentrations of Elala River water were found to be above the recommended limit of standards for drinking and irrigation waters. 22 different physical and chemical water quality parameters obtained in the study are above the permissible limits of WHO (2008) standards for drinking water but fall within the FAO (Ayers and Westcot, 1994) standard limit for irrigation purposes.

The high turbidity as observed in the study is often associated with disease causing microorganism such as bacteria and other parasites. The increasing values of other parameters of certain contaminants also indicate that the Elala River water will be unsafe for domestic purposes without some forms of physical and chemical treatments.

The ANOVA test also showed that there are significant differences among the different sampling sites which might be due to the different factors such as rainfall and changes in the anthropogenic activities which led to loading the river with different pollutants during the period of sampling and analysis. Thus, the study indicated that the entire river was generally polluted which poses a great danger to aquatic lives, the river and people using it for domestic purposes and other activities. This might be due to improper disposal of sewage, surface and agricultural runoff and wastewater from different domestic activities. The water is thus not potable for domestic purposes without some forms of physical and chemical treatment while it is useful for agricultural purposes.

Therefore, it is recommended that effective management of the Elala River is required in order to minimize some problems associated to human health. There is also an urgent need for public awareness on the state of the water and apply legal and relevant laws regarding proper treatment of industrial and domestic discharge before entering to the river course.

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