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Impacts of Human Activities on the Quality of River Water: A Case Study of River Densu in Nsawam Adoagyiri of the Akwapim South District, Eastern Region of Ghana

Albert Ebo Duncan[1], Jonathan Oti[2], Melvin Enam Potakey[3]

[1]Department of Chemistry, School of Physical Sciences, University of Cape Coast, Cape Coast, Ghana
[2]Institute of Water and Energy Change including Climate Change, Pan African University, Tlemcen, Algeria
[3]Nsawam Adoagyiri District Assembly, Nsawam, Ghana
Email: aduncan@ucc.edu.gh, bert_ebo@yahoo.com

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Abstract

Activities in and around River Densu Basin poses a threat to the quality of the river. This study, therefore, assesses the impact of human activities on the water quality of River Densu from 2010 to 2015 using the Water Quality Index (WQI) and Nemerow's Pollution Index. Twenty-five (25) physicochemical parameters were used in measuring the water quality to establish the extent of deterioration resulting from human activities. The data for the assessment was secondary data (2010-2015) obtained from the Ghana Water Company Regional laboratory in Weija Accra Ghana. The results of the study indicate that twelve out of the 25 parameters were above the guidelines set by WHO. Among the physicochemical parameters analyzed, turbidity, ammonia (NH_3), iron (Fe), phosphorus (P), and aluminium (Al) exceeded the permissible limit in all the study years. The concentration of copper (Cu) exceeded the WHO standard for all the years except in 2011. Manganese concentration was above the WHO standard for all the years except 2010 and 2013. Nitrite exceeded the WHO standard in only 2015. Among the parameters which exceeded the WHO standard for all the years, turbidity recorded the highest increase and in the percentage range of 380% - 6891.1%. According to the NPI results, five parameters namely turbidity, NH_3, Fe, P, and Al were the principal pollutants from 2010 to 2015 whereas As, Mg, Zn, and Pb were found not to contribute to the pollution effect. The metal Cu did pollute the river in all the years except in 2011 whereas Mn didn't pollute 2010 and 2013. The water quality index confirms that the water quality is fair between 2010 and 2011; marginal among 2012 to 2014 and poor in 2015. The water quality results indicate that the water quality is frequently threatened or impaired between 2010 to 2014 however, the quality of the river is almost always threatened or impaired in 2015. Generally, catchment activities such as illegal mining, farming along the banks of the river, and discharge of untreated waste are the main processes polluting the Densu river which is a serious threat to the health of inhabitants in villages which still use the water for cooking activities. The investigation recommends continuous monitoring of the above-mentioned activities which goes on in the catchment to arrest the deteriorating water quality.

Subject Areas

Hydrology

Keywords

Human Activities, Water Quality, Impacts

1. Introduction

Water is life and essential for all forms of growth and development. Water also plays a very vital role in sustaining human economic activities [1]. Unfortunately, most of the activities such as industrialization and urbanization undertook to enhance human life have impacted negatively on water bodies. The key to the survival of all civilizations has been the provision of water in the desired quantity and quality, at the right time and place. No other natural resource aside water has had such an overwhelming influence on human history [2]. The desire for a better standard of living resulted in the advancement of agricultural technologies, urbanization, industrialization and high growth in the human population. This has not only increased the demand for freshwater [3] but has also affected water security. Most of such demands and human activities result in the deterioration of the quality of the fresh water source especially rivers leading to negative health consequences. In recent years, there has been an increasing amount of literature on the consequences of industrialization, urbanization and population growth on water resources. For instance, [4] reports a crude and refined oil spill from tanker ships that damaged the vulnerable ecosystem and the Gulf of Mexico. Globally, wastewater produced annually is six times more than the waters in the rivers [5]. Unfortunately, most of these wastewaters generated in most developing countries find their way into the environment untreated. According to [6], most untreated wastewater discharged into the environment depending on the various toxic sources have been shown to affect aquatic life depending on their chemical specificity, toxicity, bioavailability, and uptake by organisms. Rapid population growth and anthropogenic activities have led to the release of large quantities of heavy metals into rivers [7] [8] [9].

These activities alongside climate change threaten to cause a major alteration in the hydrological cycle [10] resulting in an imbalance in the natural ecosystem. In Ghana, most of the rivers have been used for water abstraction as well as repositories for wastes since ancient times. Human settlement and land clearance for food production has been an integral part of Ghana's history and has contributed to the deterioration in the quality water [11] [12]. Similarly, there are several human activities in the Densu basin area which threatens the quantity and quality of the water resources. These activities cut across agriculture, industry, urban and domestic. Both commercial and subsistence farming is practiced in the basin. Unfortunately, majority of the farmers practice the traditional bush fallowing method where slashing and burning is done resulting in serious deforestation in the basin. This is a major contributor to the reduced forest cover from 40% to 20% from 1990 to 2000 [13]. Another contributor to the reduced forest cover is the logging of timber for export and industrial activities as well as harvesting of fuelwood for domestic activities. This has strong consequences on evaporation, infiltration, and surface runoff during rainfall.

The Densu River is under serious threat of eutrophication, algal toxicity with related health hazards, resulting from indiscriminate disposal of waste, flooding, improper use of agro-chemicals, illegal fishing methods, leaching from waste dumps, effluent discharge and accidental spills from industries [13]. For instance, [14] reported that six different types of fish species sampled from the Densu river were all contaminated with various forms of pesticides. The river is further threatened by bauxite mining from where the river takes its sources as well as unregulated or illegal mining of gold in and around the river. In addition, available information from [13] indicates that the basin environment has experienced rapid change from rural to urban leading to an increase in population and volumes of potable water usage. The use of large volumes of potable water even though according to the millennium development goal 7 target 10 is a sign of improvement, is not really the case in this basin. This is because about 75% - 85% of the potable water used domestically in the basin end up as waste and eventually join the water bodies in an untreated form.

Furthermore, there is also a temperature rise of 1˚C within a period of 30 years and a projected reduction in rainfall (10% - 20%) and run-off (15% - 20%) over the coming 20-year period [13]. There are at least 5 irrigation systems in the basin, and the demand for irrigation agriculture within the 20-year period will also increase by 50%.

The fast deteriorating quality in addition to the demands on the available river will make the maintenance of 47% population within the catchment with access to pipe water a very big challenge. Meanwhile, the safety of the riparian communities which still depend on the river for domestic activities is uncertain. This study, therefore, assesses the impact of human activities on the quality of River Densu from 2010-2015 using the Water Quality Index (WQI) and Nemerows Pollution.

2. Study Area and Methodology

The Densu River Basin covers an area of 2490 km^2 located at the South Eastern part of Ghana and it lies within longitudes 10 30'W - 10 45'W and latitudes 50 45' - 60 15'N (**Figure 2**). It spans through 12 Local Government Assemblies in the Central, Eastern and the Greater Accra region. The main Densu River takes its source from Atewa Range near Kibi and flows for 116 km into the Weija Reservoir before entering the Gulf of Guinea. The Densu River is of specific importance because it serves as the raw water source for the Weija Water Treatment Plant. This plant supply water to about 47% of the population in the Accra Metropolitan area and its environs. In addition, 16.8% of the population in the basin depend on the rivers, streams, ponds, and dugout [13]. The Basin is bordered to the east by the Akwapim hills and the Kwahu-Mampong scarps. It shares its northwestern boundary with the Birim Basin and the western boundary with Ayensu and Okrudu basins [13]. There are 3 administrative regions and 12 districts (**Figure 1** and **Figure 2**) within the basin. Approximately 72% of the basin (the northern portion) lies within the Eastern Region, 23% within the Greater Accra Region and the remaining 5% within the Central Region. The area occupied by Yilo Krobo and Kwaebibirem districts in the north of the basin is only about 1%. The economic benefits of the water resources in the basin for domestic, agriculture and industrial purposes can't be underestimated. Agriculture is the main economic activity in the area and it provides employment for the majority of the people especially those in the rural communities. Majority of the communities around the river use the water extensively for drinking and other domestic purposes without any treatment [15].

2.1. Study Area

Figure 1 shows an overview of the districts and the route of the River Densu in the Densu Basin.

Figure 2 is the map of the study area within the Densu Basin.

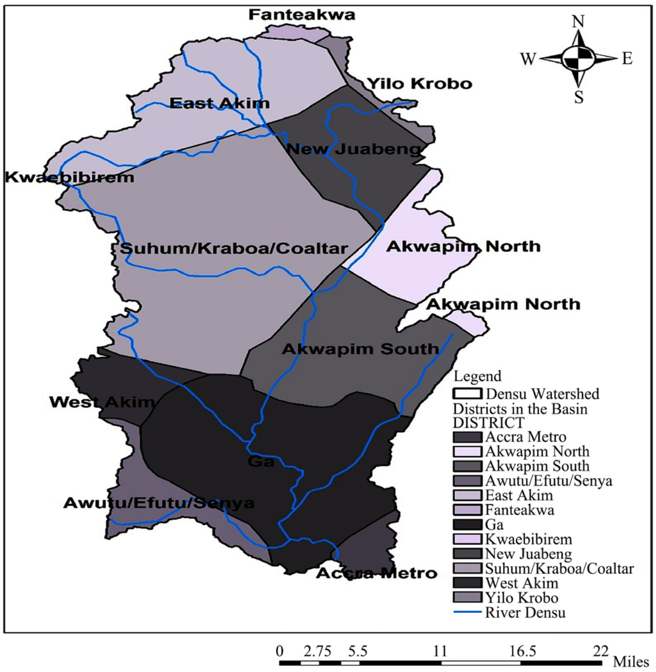

Figure 1. Districts within the densu basin.

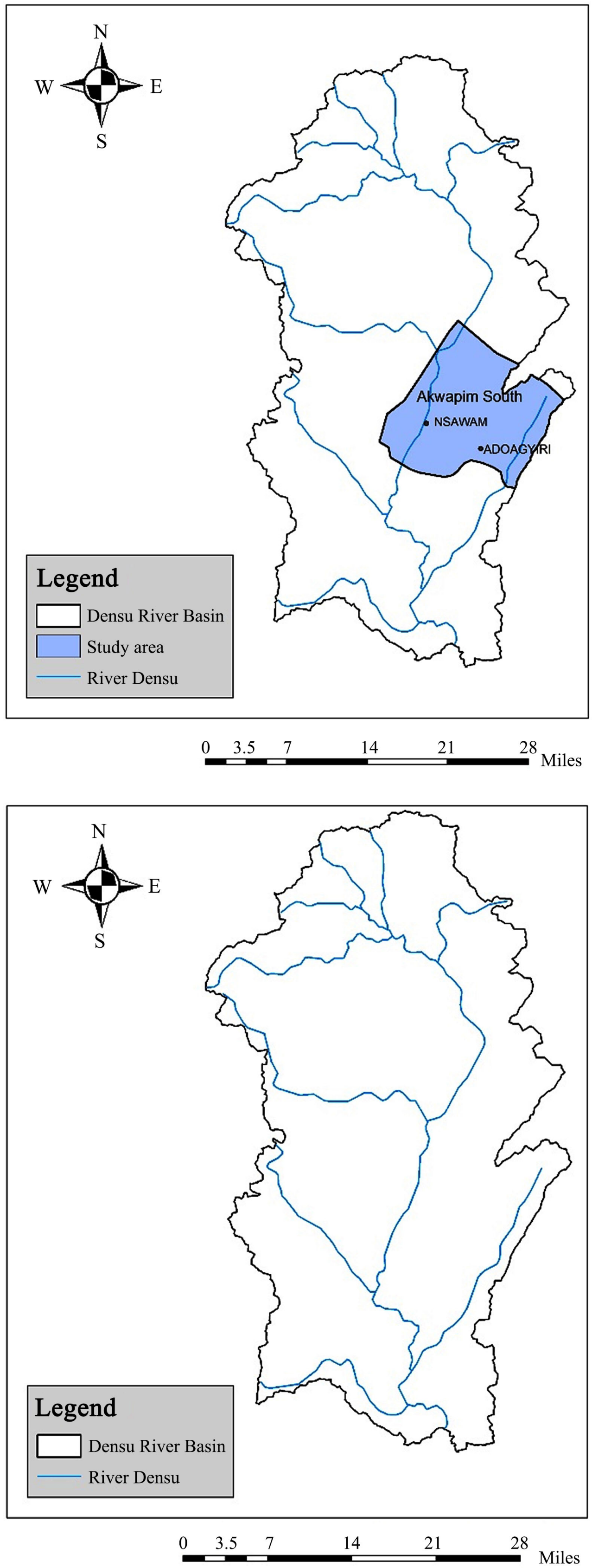

Figure 2. Study area in the densu basin.

2.2. Data Collection and Analysis

In order to assess the water quality of River Densu from 2010 to 2015, secondary data for all the parameters analyzed in this study was collected from Ghana Water Company Limited Regional Laboratory Weija Accra and analyzed using SPSS and Excel software. The SPSS and Excel were used to determine the mean and standard errors. A monthly data for a six-year period (2010-2015) on water quality of River Densu was collected and 25 physicochemical parameters including some selected metals were analyzed. The raw water data for the six-year period are attached as an **Appendix**. For the calculation of the WQI, each year was divided into four and the mean for all parameters calculated using excel. Each group has 3 months; example January to March. The data collected was complemented with field observation.

2.3. Water Quality Index (WQI)

A water quality index is a classification tool used to determine the state of a water source for a certain period. It summarizes sets of water quality data for a certain period into a single number and gives it a rating base on the type of the index. The index classifies the water quality into one of the following categories: excellent, good, fair and poor. The index thus indicates the degree to which the natural water quality is affected by human activity. The index can be used to describe the state of water quality as a whole in a body of water. There are various forms of the index, however, in this study, the Canadian Council of Ministers of the Environment's Water Quality Index (WQI) was employed. This index summarizes the overall quality of water by considering the number of variables not meeting the water quality objectives (scope); the number of times these objectives are not met (frequency) and the amount by which the objectives are not met (amplitude). The scope, frequency, and the amplitude together can provide a single value (0 - 100) that describes the quality of the water. Once the CCME WQI value has been determined, the water quality can be classified as Excellent (95 - 100), good (80 - 94), fair (65 - 79), marginal (45 - 64) and poor (0 - 44) [15]. The water quality classification is further explained in **Table 1**. The CCME WQI provides a mathematical framework for assessing ambient water quality conditions relative to water quality objectives. In the mathematical framework, there should be at least a minimum of four sampling times with at least four variables; however, there is no limitation to the maximum numbers in the areas specified.

F_1 (Scope) represents the percentage of variables that do not meet their objectives at least once during the time period under consideration ("failed variables"), relative to the total number of variables measured. F_1 is mathematically expressed as:

$$F_1 = \frac{\text{Number of failed variable}}{\text{Total number of variables}} \times 100 \quad (1)$$

F_2 (Frequency) represents the percentage of individual tests that do not meet objectives ("failed tests"). It is mathematically expressed as:

Table 1. Classification of water quality index.

Rank	Category	Explanation
95 - 100	Excellent	water quality is protected with a virtual absence of threat or impairment; conditions very close to natural or pristine levels
80 - 94	Good	water quality is protected with only a minor degree of threat or impairment; conditions rarely depart from natural or desirable levels
65 - 79	Fair	water quality is usually protected but occasionally threatened or impaired; conditions sometimes depart from natural or desirable levels
45 - 64	Marginal	water quality is frequently threatened or impaired; conditions often depart from natural or desirable levels
0 - 44	Poor	water quality is almost always threatened or impaired; conditions usually depart from natural or desirable levels

$$F_2 = \frac{\text{Number of failed tests}}{\text{Total number of tests}} \times 100 \tag{2}$$

F_3 (Amplitude) represents the difference in amount between the failed test values and their objectives. The F_3 calculation involves three steps. The first step is to estimate the number of times the individual concentrations are greater than (or less than, when the objective is a minimum) the objectives (excursion). This is mathematically expressed as:

$$\text{excursion} = \frac{\text{Failed test value}}{\text{Objective}} - 1 \tag{3}$$

For the cases in which the test value must not fall below the objectives, the excursion is calculated as:

$$\text{excursion} = \frac{\text{Objective}}{\text{Failed test value}} - 1 \tag{4}$$

The ratio of the sum of excursions to the total test is referred to as the normalized test of excursion or nse.

$$\text{nse} = \frac{\sum_{i=1}^{n} \text{excursion}}{\text{number of tests}} \tag{5}$$

F_3 is then calculated by an asymptotic function that scales the normalized summed of the excursions from the objectives (nse) to yield a range between 0 and 100.

$$F_3 = \frac{\text{nse}}{0.01\text{nse} + 0.01} \tag{6}$$

After calculating for the three Fs, CCME WQI can be calculated as:

$$\text{CCME WQI} = 100 - \frac{\sqrt{F_1^2 + F_2^2 + F_3^2}}{1.732} \tag{7}$$

2.4. Nemerows Pollution Index (NPI)

Nemerow's pollution index measures the pollution potential of individual pollutants in a sampled area with reference to its standard value [16]. However, the WQI provides the general quality of the water, Nemerow's index identifies and establishes the extent of pollution of individual parameters at each sampling period. It is mathematically expressed as:

$$\text{NPI} = \frac{C_i}{L_i} \quad (8)$$

where C_i is the observed concentration of the i^{th} parameter; L_i is the permissible limit of the i^{th} parameter. Each value of the calculated NPI represents the relative pollution contribution by a single parameter. The calculated NPI when is less than or equal to 1 indicates the absence of pollution and any value above 1 indicate pollution.

3. Results and Discussion

Table 2 present the results obtained from the descriptive statics of the average values over the six-year period. The pH of aquatic systems is one of the most important water quality parameters because it is closely linked with biological productivity [17]. It is a measure of the concentration of hydrogen ions in the water. The solubility and bioavailability of chemical constituents such as nutrients and heavy metals depend on the pH of the water [15]. The pH values recorded for the Densu River kept fluctuating every year for the six-year period, however, it was still within the recommended range of 6.5 - 8.5 for the proper functioning of aquatic organisms [17]. The average pH increased from 7.22 in the year 2010 to 7.50 in the year 2015 (**Table 2**). The observed pH is also within the range that can reduce the solubility of heavy metals in water hence making it less toxic to aquatic lives [18]. This is notwithstanding, the 2010 pH (M = 7.22, SE = 0.03) was significantly different from that of 2015 (M = 7.50, SE = 0.08).

Alkalinity for aquatic life is important because it buffers the pH of water within the system: resisting changes in pH after the small addition of acid or base. Alkalinity range of 20 mg/L - 200 mg/L is required to stabilize the pH of a stream [19]. The mean alkalinity range of 38 - 127 mg/L (**Table 2**) recorded from 2010 to 2015 is within the recommended alkalinity for stable pH of streams. However, there is a significant difference in 2010 alkalinity (M = 38.25, SE = 1.42) and 2015 alkalinity (M = 127.08, SE = 24.01). For this reason, the alkalinity of the river needs monitoring because apart from the year 2013 where the alkalinity reduced, there is a continuous increase from a low value of 38 mg/L in 2010 to as high as 127 mg/L in 2015. The danger is that if not monitored this could go beyond the recommended range in the years ahead considering the observed trend. Exceeding the recommended alkalinity will affect aquatic plant growth [20] and also raise the cost of water treatment. The increased in the alkalinity may be due to the mining activities within the river which has led to the disturbance of the bedrocks releasing carbonates into the water. Urbanization within the basin could be a reason for the increase in alkalinity as cement and other urban construction materials may wash into the river during rain runoffs. Wastewater discharges from surrounding homes also contribute to the increase in the alkalinity.

Table 2. Water quality parameters for evaluation (2010-2015).

Parameter	2010	2011	2012	2013	2014	2015
	Mean ± SD	**Mean ± SD**	**Mean ± SD**	**Mean ± SD**	**Mean ± SD**	**Mean ± SD**
pH	7.22 ± 0.09	7.12 ± 0.22	7.31 ± 0.15	7.38 ± 0.16	7.45 ± 0.14	7.50 ± 0.26
Turbidity NTU	19 ± 2.33	23.09 ± 6.16	264.84 ± 182.62	276.34 ± 141.05	327.42 ± 171.82	344.56 ± 130.58
Temperature ˚C	25 ± 0.51	25.41 ± 0.30	25.41 ± 0.30	25.51 ± 0.80	25.76 ± 0.83	27.71 ± 2.58
Conductivity ms/cm	356 ± 35.64	370.56 ± 15.91	330.67 ± 38.84	330.67 ± 38.84	299.11 ± 33.31	313.75 ± 85.56
TDS mg/L	183 ± 13.91	333.16 ± 522.22	231.47 ± 27.19	231.47 ± 27.19	209.38 ± 23.32	217.88 ± 58.86
Ammonia mg/L	1 ± 0.81	1.20 ± 0.47	1.25 ± 0.53	1.32 ± 0.51	1.37 ± 0.67	1.42 ± 0.71
Nitrite mg/L	0.05 ± 0.02	0.30 ± 0.20	0.65 ± 0.25	2.82 ± 5.62	0.70 ± 0.62	3.80 ± 1.83
Nitrate mg/L	1 ± 0.08	2.05 ± 0.19	19.53 ± 2.77	20.75 ± 4.54	21.53 ± 4.65	24.18 ± 4.21
Chloride mg/L	16 ± 0.65	15.25 ± 1.15	24.21 ± 12.53	18.92 ± 3.73	20.08 ± 2.91	27.73 ± 6.58
T A mg/L	38 ± 4.93	57.75 ± 5.46	60.00 ± 4.88	58.17 ± 4.00	65.25 ± 7.59	127.08 ± 83.20
T H mg/L	85 ± 7.68	85.25 ± 5.19	80.75 ± 7.01	84.3533 ± 9	82.75 ± 4.11	94.92 ± 26.12
CaH mg/L	37 ± 5.84	33.25 ± 7.90	58.50 ± 6.62	27.83 ± 11.68	49.75 ± 5.94	59.33 ± 12.15
MgH mg/L	48 ± 5.40	47.83 ± 9.47	22.25 ± 6.61	27.83 ± 11.68	33.00 ± 8.15	35.58 ± 16.18
Ca mg/L	13.30 ± 3.1	15 ± 2.34	23.40 ± 2.50	22.60 ± 2.09	19.90 ± 2.38	22.67 ± 4.69
Mg mg/L	14 ± 1.57	13.87 ± 2.75	6.79 ± 0.73	6.55 ± 0.60	9.57 ± 2.36	8.74 ± 3.21
Arsenic mg/L	0 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0 ± 00	0.00 ± 0.00	0.00 ± 0.00
Copper mg/L	0.21 ± 0.17	0.16 ± 0.11	1.26 ± 0.79	1.61 ± 1.58	0.36 ± 0.14	2.38 ± 0.77
Lead mg/L	0 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
Total Iron mg/L	0.95 ± 0.41	1.21 ± 0.24	1.68 ± 0.48	1.73 ± 0.48	1.68 ± 0.64	1.69 ± 0.95
Zinc mg/L	0.42 ± 0.18	0.66 ± 0.78	0.66 ± 0.78	0.66 ± 0.78	0.69 ± 0.55	2.35 ± 0.50
Fluoride mg/L	0.43 ± 0.44	0.28 ± 0.17	0.95 ± 0.47	0.66 ± 0.44	0.70 ± 0.19	1.33 ± 0.43
Sulphate mg/L	47.26 ± 12.90	17.95 ± 10.11	21.91 ± 2.75	13.83 ± 3.74	15.70 ± 4.10	16.92 ± 6.27
Phosphate mg/L	16.46 ± 5.57	19.15 ± 2.40	22.21 ± 3.90	23.34 ± 4.35	24.55 ± 5.08	27.34 ± 4.71
Al mg/L	0.59 ± 0.72	0.23 ± 0.13	0.69 ± 0.54	2.29 ± 6.52	0.53 ± 0.22	0.34 ± 0.14
Mn mg/L	0.25 ± 0.12	0.52 ± 0.19	0.43 ± 0.24	0.35 ± 0.13	0.53 ± 0.15	1.38 ± 3.39

Cond = conductivity; TDS = total dissolved solids; TH = total hardness; TA = total alkalinity; CaH = Calcium hardness; MgH = magnesium hardness; Ca = calcium; Mg = magnesium; Al = Aluminium; Mn = manganese.

According to the World Health Organization (2011), water with total dissolved solids (TDS) less than 600 mg/L is considered to be good. The total dissolved solids for River Densu was in the range of 183 mg/L to 333.16 mg/L within the six-year study period (Table 2). There was virtually no significant difference in TDS between 2010 and 2011: TDS for 2010 (M = 182.58, SE = 4.01) and 2011 (M = 183.83, SE = 3.72) at p = 0.05. However, there is a significant difference in 2010 TDS (M = 182.58, SE = 4.04) and 2015 TDS (M = 228.51, SE = 33.48) at p = 0.05. This difference may be due to fluctuations observed (Table 2) as the years progressed. The fluctuations may be influenced by the intensity of the agricultural, industrial, domestic [17] and mining activities taking place upstream within the period. Although the TDS concentrations have not exceeded the recommended value, precautionary measures should be put in place to stabilize the fluctuations of TDS in the water before it escalates beyond the recommended value in the years ahead. The concentration exceeding recommended value has a high potential to affect the health of those depending on the water directly for consumption should the ions be toxic or carcinogenic. This could also affect aquatic lives and the cost of water treatment.

Electrical conductivity is actually a measure of the ionic activity of a solution in terms of its capacity to transmit current [17]. The electrical conductivity of water estimates the total amount of solids dissolved in water: water bodies have fairly constant conductivity; hence a sharp change in conductivity could be a sign of possible pollution [15]. The results indicate fluctuating conductivity of the water over the six-year period and this is highly influenced by the dissolved solids in the water. Though there were fluctuations in the monthly recordings for the various years, the average conductivity was increasing with increasing total dissolved solids and vice versa every year over the study period.

The chloride concentrations in the River Densu was recorded to be far below the acceptable limit of 250 mg/L. The pattern of occurrence was fluctuating for each year, recording between the ranges of 15 - 28 mg/L (**Table 2**). This notwithstanding, there is a significant difference between 2010 chloride (M = 15.75, SE = 0.18) and 2015 chloride (M = 27.72, SE = 1.89) at p = 0.05. Untreated industrial waste discharge and saltwater intrusion may account for the presence of chlorides in the water. It may also be due to the presence of chloride-mineral materials in the river.

Water hardness in this study is defined as the measure of the amount of dissolved calcium and magnesium in water. There are epidemiological studies which link gastrointestinal cancers to harness in drinking water [21]. There is an inverse relationship between water hardness and diseases such as coronary mortality, gastrointestinal tract cancer and cerebrovascular diseases [19]. A study by [22], indicates that there is a 42% excess risk of mortality from esophageal cancer in relation to the use of soft water. Other studies reveal the significant protective effect of magnesium intake from drinking water and the risk of hypertension and gastric cancer mortality and levels of nitrate, calcium, and magnesium in drinking water [22] [23]. With regards to River Densu, the average values recorded for the study period were low and within the acceptable limit of 500 mg/L. The highest average value for the study period is 94.92 mg/L and this is recorded in the last year of the study period (**Table 2**). Meanwhile, there is a significant difference in 2010 total hardness (M = 85, SE = 2.21) and 2015 total hardness (M = 94.91, SE = 7.54) which demands that attention is given to the continuously increasing illegal mining activities in the basin. Generally, the water from the River Densu is considered to be moderately hard [13].

The concentration of nitrate (NO_3^-) often fluctuate with the season and may increase when the river is fed by nitrate-rich aquifers and pollutants. Agricultural activities and waste disposal are other ways through which nitrate reach the water bodies [13]. Though nitrate, when present in normal levels usually does not have a direct effect on human and aquatic lives, they, however, do when in excess. [27], reports of infant methemoglobinemia for ingestion of nitrates above 45 mg/L by infants up to six months. They also reported changes in heart blood vessels over long term accumulation of nitrates. The toxicity of nitrate to aquatic animals increases with increasing nitrate concentrations and exposure times [24]. According to [24], nitrate concentration of 10 mg NO_3-N/L can adversely affect, at least during long-term exposures, freshwater invertebrates, and amphibians. Unlike marine animals where the maximum acceptable level of 20 mg NO_3-N/L is recommended, a maximum level of 2 mg/L is recommended for sensitive freshwater species. The nitrate concentration in River Densu in 2010 was as low as 1.0 mg/L; far below the WHO standard of 50 mg/L. However, there is a significant increase and difference of nitrate between 2010 (M = 0.99, SE = 0.02) and 2015 (M = 24.17, SE = 1.21) that should be of concerned to the managers of the water. This is because the 24 mg/L nitrate far exceed the recommended value of 2 mg/L for sensitive freshwater species and 10 mg/L which is known to adversely affect freshwater invertebrates [24]. The other reason had to do with future projections and the increasing concern of farming along the banks of the rivers which continues to grow continuously. The information available indicates that in the near future all the 5 irrigation schemes of which only 2 are operating will start operation and chances are that more nitrates are likely to be released into the river through the application of chemicals such as fertilizers [13]. In addition, there is an increasing farming population along the banks of the rivers [13]. This condition serves as a potential threat to the maintenance and reduction of current nitrate levels in the river. Nitrate in excess will increase eutrophication in the river and can lead to the death of fishes and other aquatic organisms.

Previous studies have reported the correlation between microbial contamination in source water, filtered drinking water and turbidity [25] [26]. The presence of suspended sediments such as clay, inorganic materials or organic materials such as algae and decaying materials can make the water turbid. Turbidity in water could also be due to suspended solids, fluorescent dissolved organic matter and other dyes [28]. There is a significant difference in the 2010 turbidity (M = 19.03, SE = 0.69) and the 2015 turbidity (M = 344.56, SE = 37.69). The turbidity of River Densu from 2010 to 2015 escalated from 19NTU to 344.56 NTU. These turbidity ranges are far above the average acceptable limit of 5 NTU. The increased turbidity observed from 2010 to 2015 may be as a result of the mining activities taking place upstream which eventually runs off the sediments into the river downstream. Also, the farming activities and wastewater discharge from domestic and industrial residence contribute to this menace. This measured turbidity has economic (cost), health and ecological implications. Economically it increases the cost of water treatment for instance in the area of disinfection for drinking purposes. Total removal of turbidity is a requirement for effective disinfection and to do that demands to increase the quantity of coagulant which raises the cost of coagulant and treatment of the water for drinking [29]. High turbidity can significantly reduce the aesthetic quality of lakes and streams, having a harmful impact on recreation and tourism. Ecologically high turbidity can: affects the movement of fishes that rely on sight and speed to feed; results in certain fishes consume suspended solids, causing illness and exposing the fish to potential toxins or pathogens; cause some fishes to experience severely impaired growth and biological chemistry changes [28]. High turbidity reduces the light available to submerged aquatic vegetation and ceases their photosynthesis activities thereby reducing the amount of dissolved oxygen available in the water [30].

Phosphorus just like nitrate is a nutrient which when present in high concentration could result in eutrophication in a river or lake. Phosphorus can appear in the dissolved or particulate form. Most wastewater which contains phosphorus is in the dissolved form. Because particulate phosphorus can change to soluble form under some environmental condition. Heavy phosphate-containing water bodies favour the growth of aquatic plants and create a negative effect on water quality and deplete oxygen by accelerating the growth of algal clump, resulting in anoxic conditions, bad odor and decoloration. Such conditions do not only make the water aesthetically unattractive but reduce its recreational potentials and may cause the death of many sensitive aquatic organisms [17]. The result of the phosphate concentration in the water is shown in **Table 2** and **Table 3**. The concentration increased as the years progressed. The increasing orders of phosphate within the study period were observed as 2010 < 2011 < 2012 < 2013 < 2014 < 2015. The measured concentrations far exceeded the standards. However, there is no significant difference in the 2010 phosphorus (M = 16.46, SE = 1.61) and the 2015 phosphorus (M = 27.34, SE = 1.35).

3.1. Metal Concentration in Water

The result of the heavy metal concentration in the water is shown in **Table 2**. The concentration of the metals varied within the study period. The concentration of the metals Zn, As, Pb, Mg and Ca was below the WHO permissible levels from 2010 to 2015. Two metals, namely iron, and aluminium exceeded their permissible levels in the water from 2010 to 2015. The mean concentration of Fe ranged between 0.95 and 1.73 mg/L. The highest iron concentration of 1.73 was recorded in 2013. That notwithstanding, there was still a significant variation in the Fe concentration between 2010 and 2015. The year 2015 showed a higher Fe concentration (M = 1.69, SE = 0.27) than 2010 (M = 0.95, SE = 0.11). The increasing iron concentration is due to the increase in the excavation of land for bauxite and gold upstream of the basin. Aluminium is one of the most widespread metals on earth and also the third most common chemical element on our planet after oxygen and silicon. The mean concentration range of aluminium was recorded as 0.23 - 2.29 mg/L. The aluminium concentrations didn't

Table 3. Pollution index and water quality index for 2010-2012.

Parameter	2010			2011			2012		
	Mean ± SD	SE	NPI	Mean ± SD	SE	NPI	Mean ± SD	SE	NPI
pH	7.22 ± 0.09	0.03	0.85	7.12 ± 0.22	0.06	0.84	7.31 ± 0.15	0.04	0.86
Turbidity NTU	19 ± 2.33	0.67	**3.81**	23.09 ± 6.16	1.78	**4.62**	264.84 ± 182.62	52.72	**52.97**
Temperature ˚C	25 ± 0.51	0.15	0.85	25.41 ± 0.30	0.09	0.85	25.41 ± 0.30	0.09	0.85
Conductivity ms/cm	356 ± 35.64	10.29	0.36	370.56 ± 15.91	4.59	0.37	330.67 ± 38.84	11.21	0.33
TDS mg/L	183 ± 13.91	4.01	0.18	333.16 ± 522.22	150.75	0.33	231.47 ± 27.19	7.85	0.23
Ammonia (NH_3) mg/L	1 ± 0.81	0.05	**1.58**	1.20 ± 0.47	0.14	**2.39**	1.25 ± 0.53	0.15	**2.50**
Nitrite (NO_2^-) mg/L	0 ± 0.02	0.01	0.02	0.30 ± 0.20	0.06	0.10	0.65 ± 0.25	0.07	0.22
Nitrate (NO_3) mg/L	1 ± 0.08	0.02	0.02	2.05 ± 0.19	0.05	0.04	19.53 ± 2.77	0.80	0.39
Chloride mg/L	16 ± 0.65	0.19	0.06	15.25 ± 1.15	0.33	0.06	24.21 ± 12.53	3.62	0.10
Total Alkalinity mg/L	38 ± 4.93	1.42	0.19	57.75 ± 5.46	1.58	0.29	60.00 ± 4.88	1.41	0.30
Total Hardness mg/L	85 ± 7.68	2.22	0.17	85.25 ± 5.19	1.50	0.17	80.75 ± 7.01	2.02	0.16
Calcium Hardness mg/L	37 ± 5.84	1.69	0.19	33.25 ± 7.90	2.28	0.17	58.50 ± 6.62	1.81	0.29
Mg Hardness mg/L	48 ± 5.40	1.56	0.32	47.83 ± 9.47	2.73	0.32	22.25 ± 6.61	1.91	0.15
Calcium mg/L	15 ± 2.34	0.67	0.07	13.30 ± 3.16	0.91	0.07	23.40 ± 2.50	0.72	0.12
Magnesium mg/L	14 ± 1.57	0.45	0.09	13.87 ± 2.75	0.79	0.09	6.79 ± 0.73	0.21	0.05
Arsenic mg/L	0 ± 0.00	0.00	0.08	0.00 ± 0.01	0.00	0.25	0.00 ± 0.00	0.00	0.00
Copper mg/L	0 ± 0.17	0.05	**1.03**	0.16 ± 0.11	0.03	0.81	1.26 ± 0.79	0.23	**6.30**
Lead mg/L	0 ± 0.00	0.00	0.00	0.00 ± 0.00	0.00	0.17	0.00 ± 0.00	0.00	0.17
Iron (Total) mg/L	1 ± 0.41	0.12	**3.15**	1.21 ± 0.24	0.07	**4.03**	1.68 ± 0.48	0.14	**5.60**
Zinc mg/L	0.42 ± 0.18	0.05	0.08	0.66 ± 0.78	0.22	0.13	0.66 ± 0.78	0.22	0.13
Fluoride mg/L	0.43 ± 0.44	0.13	0.28	0.28 ± 0.17	0.05	0.19	0.95 ± 0.47	0.13	0.63
Sulphate mg/L	47.26 ± 12.90	3.72	0.19	17.95 ± 10.11	2.92	0.07	21.91 ± 2.75	0.79	0.09
Phosphate mg/L	16.46 ± 5.57	1.61	**3.29**	19.15 ± 2.40	0.69	**3.83**	22.21 ± 3.90	1.13	**4.44**
Aluminium mg/L	0.59 ± 0.72	0.21	**2.93**	0.23 ± 0.13	0.04	**1.13**	0.69 ± 0.54	0.16	**3.47**
Manganese	0.25 ± 0.12	0.03	0.63	0.52 ± 0.19	0.06	**1.29**	0.43 ± 0.24	0.07	**1.07**
WQI	74.95			73.5			49.7		

Cond = conductivity; TDS = total dissolved solids; TH = total hardness; TA = total alkalinity; CaH = Calcium hardness; MgH = magnesium hardness; Ca = calcium; Mg = magnesium; Al = Aluminium; Mn = manganese Bolded figures are above the WHO threshold.

increase as the years progressed but instead fluctuated (Table 2). The fluctuations could be linked to the intensity of bauxite mining which occurs in the basin. In the weeks or months within the year where mining is high the aluminium levels in the water tend to be high and vice versa. An independent t-test was used to test the influence of catchment activities on the measured Al concentration in 2010 and 2015, $t(22) = 1.15$, $p = 0.01$, with 2010 showing higher Al concentrations than 2015 (2010 M = 0.59; 2015 M = 0.34). There was a variation in the Cu concentration between 2010 and 2011 but this was not significant: the year 2010

(M = 0.21, SE = 0.04) and the year 2011 (M = 0.16, SE = 0.03). However, when an independent t-test was conducted between 2010 and 2015 it was significant with higher concentrations in 2015 (M = 8.81, SE = 6.29) than 2010 (M = 0.21, SE = 0.04). The mean concentration of Mn was 0.25 and 1.38 mg/L for 2010 and 2015 respectively. There was a significant yearly variation in the Mn concentration. The year 2015 showed a higher Mn concentration (M = 1.38, SE = 1.01) than the year 2010 (M = 0.25, SE = 0.03). However, the observed mean concentrations of Mn for 2011, 2012, 2014 and 2015 were higher than the WHO guideline for drinking water (**Table 2**).

3.2. Water Quality Index

The summary of the Nemerow's pollution index (NPI) and the Canadian Council of Ministers of the Environment Water Quality Index (CCMEWQI) is presented in **Table 3** and **Table 4**. The year 2010 data (**Table A1**) is used to demonstrate the calculation of CCMEWQI as shown below.

$$F_1 = \frac{\text{Number of failed variables}}{\text{Total number of variables}} \times 100\%$$

$$F_1 = \frac{6}{25} \times 100\% = 24$$

$$F_2 = \frac{\text{Number of failed test}}{\text{Total number of tests}} \times 100\%$$

$$F_2 = \frac{22}{100} \times 100\% = 22$$

$$\text{excursions}_i = \frac{\text{failed test}}{\text{objective}} - 1 \quad \text{OR} \quad \text{excursions}_i = \frac{\text{objective}}{\text{failed test}} - 1$$

$$\text{Turbidity} = \left(\frac{17.43}{5} - 1\right) + \left(\frac{21.17}{5} - 1\right) + \left(\frac{19.23}{5} - 1\right) + \left(\frac{18.30}{5} - 1\right) = 11.23$$

$$\text{Ammonia} = \left(\frac{0.76}{0.5} - 1\right) + \left(\frac{0.70}{0.5} - 1\right) + \left(\frac{0.92}{0.5} - 1\right) + \left(\frac{0.77}{0.5} - 1\right) = 2.3$$

$$\text{Copper} = \left(\frac{0.31}{0.2} - 1\right) + \left(\frac{0.31}{0.2} - 1\right) = 1.2$$

$$\text{Iron} = \left(\frac{1.27}{0.3} - 1\right) + \left(\frac{1.31}{0.3} - 1\right) + \left(\frac{0.52}{0.3} - 1\right) + \left(\frac{0.68}{0.3} - 1\right) = 8.6$$

$$\text{Phosphorus} = \left(\frac{18.01}{5} - 1\right) + \left(\frac{19.96}{5} - 1\right) + \left(\frac{16.92}{5} - 1\right) + \left(\frac{10.96}{5} - 1\right) = 11.32$$

$$\text{Aluminium} = \left(\frac{0.32}{0.2} - 1\right) + \left(\frac{1.44}{0.2} - 1\right) + \left(\frac{0.35}{0.2} - 1\right) + \left(\frac{0.23}{0.2} - 1\right) = 7.7$$

$$\text{nse}(\text{collective sum of excursions}) = \frac{\text{summation of all excursions}}{\text{Total number of test}}$$

$$\text{nse} = \frac{11.23 + 2.3 + 1.2 + 9.17 + 8.6 + 7.7}{100} = 0.40196$$

Table 4. Pollution index and water quality index for 2013-2015.

Parameter	2013			2014			2015		
	Mean ± SD	SE	NPI	Mean ± SD	SE	NPI	Mean ± SD	SE	NPI
pH	7.38 ± 0.16	0.05	0.87	7.45 ± 0.14	0.04	0.88	7.50 ± 0.26	0.08	0.88
Turbidity NTU	276.34 ± 141.05	40.72	**55.27**	327.42 ± 171.82	49.60	**65.48**	344.56 ± 130.58	37.70	**68.91**
Temperature ˚C	25.51 ± 0.80	0.23	0.85	25.76 ± 0.83	0.24	0.86	27.71 ± 2.58	0.74	0.92
Conductivity ms/cm	330.67 ± 38.84	11.21	0.33	299.11 ± 33.31	9.62	0.30	313.75 ± 85.56	24.70	0.31
TDS mg/L	231.47 ± 27.19	7.85	0.23	209.38 ± 23.32	6.73	0.21	217.88 ± 58.86	16.99	0.22
Ammonia (NH_3) mg/L	1.32 ± 0.51	0.15	**2.64**	1.37 ± 0.67	0.19	**2.75**	1.42 ± 0.71	0.21	**2.85**
Nitrite (NO_2^-) mg/L	2.82 ± 5.62	1.62	0.94	0.70 ± 0.62	0.18	0.23	3.80 ± 1.83	0.53	**1.27**
Nitrate (NO_3) mg/L	20.75 ± 4.54	1.31	0.41	21.53 ± 4.65	1.34	0.43	24.18 ± 4.21	1.22	0.48
Chloride mg/L	18.92 ± 3.73	1.08	0.08	20.08 ± 2.91	0.84	0.08	27.73 ± 6.58	1.90	0.11
Total Alkalinity mg/L	58.17 ± 4.00	1.15	0.29	65.25 ± 7.59	2.19	0.33	127.08 ± 83.20	24.02	0.64
Total Hardness mg/L	84.33 ± 9.53	2.70	0.17	82.75 ± 4.11	1.19	0.17	94.92 ± 26.12	7.54	0.19
Calcium Hardness mg/L	56.50 ± 5.21	1.51	0.28	49.75 ± 5.94	1.72	0.25	59.33 ± 12.15	3.51	0.30
Mg Hardness mg/L	27.83 ± 11.68	3.37	0.19	33.00 ± 8.15	2.35	0.22	35.58 ± 16.18	4.67	0.24
Calcium mg/L	22.60 ± 2.09	0.60	0.11	19.90 ± 2.38	0.69	0.10	22.67 ± 4.69	1.35	0.11
Magnesium mg/L	6.55 ± 0.60	0.17	0.04	9.57 ± 2.36	0.68	0.06	8.74 ± 3.21	0.93	0.06
Arsenic mg/L	0.00 ± 0.00	0.00	0.00	0.00 ± 0.00	0.00	0.00	0.00 ± 0.00	0.00	0.00
Copper mg/L	1.61 ± 1.58	0.46	**8.06**	0.36 ± 0.14	0.04	**1.79**	2.38 ± 0.77	0.22	**11.88**
Lead mg/L	0.00 ± 0.00	0.00	0.00	0.00 ± 0.00	0.00	0.10	0.01 ± 0.03	0.01	0.83
Iron (Total) mg/L	1.73 ± 0.48	0.14	**5.76**	1.68 ± 0.64	0.18	**5.61**	1.69 ± 0.95	0.27	**5.64**
Zinc mg/L	0.66 ± 0.78	0.22	0.13	0.69 ± 0.55	0.16	0.14	2.35 ± 0.50	0.14	0.47
Fluoride mg/L	0.66 ± 0.44	0.13	0.44	0.70 ± 0.19	0.06	0.47	1.33 ± 0.43	0.12	0.89
Sulphate mg/L	13.83 ± 3.74	1.08	0.06	15.70 ± 4.10	1.18	0.06	16.92 ± 6.27	1.81	0.07
Phosphate mg/L	23.34 ± 4.35	1.37	**4.67**	24.55 ± 5.08	1.47	**4.91**	27.34 ± 4.71	1.36	**5.47**
Aluminium mg/L	2.29 ± 6.52	1.88	**11.47**	0.53 ± 0.22	0.06	**2.65**	0.34 ± 0.14	0.04	**1.71**
Manganese	0.35 ± 0.13	0.04	0.87	0.53 ± 0.15	0.04	**1.32**	1.35 ± 3.39	0.98	**3.38**
WQI	52.16			53.35			43.33		

Cond = conductivity; TDS = total dissolved solids; TH = total hardness; TA = total alkalinity; CaH = Calcium hardness; MgH = magnesium hardness; Ca = calcium; Mg = magnesium; Al = Aluminium; Mn = manganese Bolded figures are above the WHO threshold.

$$F_3 = \frac{\text{nse}}{0.01(\text{nse}) + 0.01}, \quad F_3 = \frac{0.40196}{0.01 \times 0.40196 + 0.01} = 28.67$$

$$\text{The CCME Water Quality Index (CCME WQI)} = 100 - \frac{\sqrt{F_1^2 + F_2^2 + F_3^2}}{1.732}$$

$$\text{CCME WQI} = 100 - \frac{\sqrt{24^2 + 22^2 + 28.67^2}}{1.732} = 74.95$$

This method is used to calculate the WQI of the remaining years and the results presented in Table 3. The data used for the calculation of the water quality index is found in the **Appendix**.

The NPI values ranged from 0 to 68.91 for the years under study, confirming that some of the parameters did not contribute to the overall pollution effect in the years under study ($0 \leq NPI > 1$). Five parameters namely turbidity, ammonia (NH_3), iron (Fe), phosphorus (P), and aluminium exceeded the permissible limits in the river Densu for all the years under study. Of the parameters polluting all the years, turbidity was the parameter with the highest progressive pollution index from 2010 to 2015 (Table 3). This shows how human activities such as sand winning together with gold and bauxite mining in and around the river is influencing its quality. Among the metals, Al and Fe polluted in all the years under study indicating the persistence with which these metals are released into the river through human activities. Even though Cu did not pollute in 2011, it was the metal with the highest pollution index of the years under study which occurred in 2015 (Table 3). Manganese polluted in all the years under study except in 2010 and 2013. The water quality index showed progressive deterioration from 2010 to 2015. The observed water quality index showed poor water quality for 2015 (0 - 44) and marginal (45 - 64) in 2014, 2013 and 2012. Even though none of the years under study recorded good or excellent water quality, the year 2010 and 2011 recorded fair (65 - 79) water quality index. The observed water quality index for the study years confirms the polluting effects of the parameters which are purely introduced by anthropogenic activities occurring in the basin.

4. Conclusion

This study shows that the water quality of River Densu is continuously deteriorating and being polluted with turbidity, ammonia (NH_3), iron (Fe), phosphorus (P), and aluminium (Al) which is an indication of how human activities are influencing the quality of water in the basin. The deterioration and pollution are heavily influenced by the illegal mining carried out upstream of the river. Other factors contributing to the pollution and deterioration include agricultural runoffs and domestic activities in the River Basin. The study, therefore, proposes that illegal mining activities, discharge of untreated wastewater and agricultural activities such as farming along the banks of the river should be monitored and regulated and if possible halted. Relevant environmental laws should also be enforced to apprehend illegal miners and streamline the activities which go on in the basin. The water quality index confirms that the water quality is marginal to fair between 2011 to 2014 and poor in 2015. The results from the water quality index imply that generally the water is not good for domestic activities such as cooking as some communities along the river are practicing especially under water stress conditions.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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Appendix

Table A1. 2010 Mean raw water data in the densu basin.

Parameter and Unit	Jan-March	April-June	July-Sept	Oct-Dec	WHO Standard
pH	7.17 ± 0.07	7.26 ± 0.07	7.27 ± 0.04	7.17 ± 0.15	6.5 - 8.5
Turbidity NTU	**17.43 ± 1.44**	**21.17 ± 3.09**	**19.23 ± 1.91**	**18.30 ± 1.76**	**5**
Temperature ˚C	25.17 ± 0.55	25.58 ± 0.20	25.60 ± 0.62	25.52 ± 0.72	30
Conductivity ms/cm	379.00 ± 9.17	362.00 ± 15.72	366.33 ± 41.93	317.67 ± 41.06	1000
Total Dissolve Solids mg/L	189.33 ± 7.02	180.67 ± 9.87	185.67 ± 22.23	174.67 ± 15.50	1000
Ammonia (NH_3) mg/L	**0.76 ± 0.10**	**0.70 ± 0.18**	**0.92 ± 0.26**	**0.77 ± 0.18**	0.5 (EU)
Nitrite (NO_2^-) mg/L	0.06 ± 0.04	0.04 ± 0.02	0.05 ± 0.02	0.05 ± 0.02	3
Nitrate (NO_3) mg/L	1.05 ± 0.03	1.04 ± 0.06	0.95 ± 0.12	0.96 ± 0.07	50
Chloride mg/L	15.54 ± 0.69	16.29 ± 0.44	15.37 ± 0.59	15.82 ± 0.76	250
Total Alkalinity mg/L	42.80 ± 4.76	37.30 ± 5.72	37.20 ± 4.85	35.70 ± 3.32	200
Total Hardness mg/L	80.67 ± 2.08	89.00 ± 8.19	79.67 ± 2.89	90.67 ± 10.07	500
Calcium Hardness mg/L	34.67 ± 3.79	36.87 ± 4.59	34.40 ± 3.17	43.67 ± 7.64	200
Magnesium Hardness mg/L	46.00 ± 2.00	52.13 ± 4.41	45.27 ± 0.64	47.00 ± 9.64	150
Calcium mg/L	13.87 ± 1.51	14.75 ± 1.84	13.76 ± 1.27	17.47 ± 3.06	200
Magnesium mg/L	13.34 ± 0.58	15.12 ± 1.28	13.13 ± 0.19	13.63 ± 2.80	150
Arsenic mg/L	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.01	0.00 ± 0.00	0.01
Copper mg/L	**0.32 ± 0.08**	0.15 ± 0.05	**0.32 ± 0.25**	0.04 ± 0.05	0.2
Lead mg/L	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.01
Iron (Total) mg/L	**1.27 ± 0.12**	**1.31 ± 0.11**	**0.52 ± 0.38**	**0.68 ± 0.20**	**0.3**
Zinc mg/L	0.54 ± 0.31	0.31 ± 0.10	0.43 ± 0.18	0.41 ± 0.04	5 (USA)
Fluoride mg/L	0.17 ± 0.05	0.69 ± 0.49	0.66 ± 0.65	0.18 ± 0.11	1.5
Sulphate mg/L	35.07 ± 12.43	42.88 ± 11.40	51.92 ± 11.43	59.15 ± 1.78	250
Phosphate mg/L	**18.01 ± 5.71**	**19.96 ± 4.26**	**16.92 ± 6.40**	**10.96 ± 3.40**	**5**
Aluminium mg/L	**0.32 ± 0.24**	**1.44 ± 1.14**	**0.35 ± 0.06**	**0.23 ± 0.06**	**0.2 (EU)**
Manganese mg/L	0.13 ± 0.05	0.24 ± 0.08	0.34 ± 0.04	0.30 ± 0.16	0.4

Table A2. 2011 Mean raw water data in the densu basin.

Parameter and Unit	Jan-March	April-June	July-Sept	Oct-Dec	WHO Standard
pH	7.27 ± 0.32	6.98 ± 0.03	6.94 ± 0.05	7.30 ± 0.07	6.5 - 8.5
Turbidity NTU	**18.00 ± 1.42**	**29.57 ± 1.32**	**26.10 ± 7.77**	**18.70 ± 0.75**	**5**
Temperature ˚C	25.57 ± 0.15	25.50 ± 0.26	25.17 ± 0.46	25.40 ± 0.20	30
Conductivity ms/cm	369.33 ± 24.76	384.00 ± 13.75	369.90 ± 10.48	359.00 ± 2.00	1000
Total Dissolve Solids mg/L	174.33 ± 20.31	792.00 ± 1038.38	186.63 ± 10.17	179.67 ± 1.53	5
Ammonia (NH_3) mg/L	**1.73 ± 0.67**	**1.15 ± 0.07**	**1.04 ± 0.35**	**0.86 ± 0.13**	**0.5 (EU)**
Nitrite (NO_2^-) mg/L	0.30 ± 0.02	0.41 ± 0.29	0.31 ± 0.29	0.19 ± 0.09	3

Continued

Nitrate (NO_3) mg/L	2.01 ± 0.27	2.00 ± 0.08	2.06 ± 0.31	2.12 ± 0.05	50
Chloride mg/L	16.33 ± 0.38	16.06 ± 1.07	14.46 ± 0.73	14.15 ± 0.09	250
Total Alkalinity mg/L	53.67 ± 4.16	55.67 ± 7.02	62.33 ± 5.51	59.33 ± 0.58	200
Total Hardness mg/L	85.33 ± 4.51	86.00 ± 7.81	88.33 ± 5.13	81.33 ± 1.53	500
Calcium Hardness mg/L	38.33 ± 2.52	38.33 ± 4.16	22.00 ± 5.29	34.33 ± 4.73	200
Magnesium Hardness mg/L	47.00 ± 4.36	47.67 ± 3.79	49.67 ± 20.98	47.00 ± 3.46	150
Calcium mg/L	15.33 ± 1.01	15.33 ± 1.67	8.80 ± 2.12	13.73 ± 1.90	200
Magnesium mg/L	13.63 ± 1.26	13.82 ± 1.10	14.40 ± 6.09	13.63 ± 1.00	150
Arsenic mg/L	0.01 ± 0.01	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.01
Copper mg/L	0.17 ± 0.07	0.18 ± 0.19	0.11 ± 0.09	0.19 ± 0.12	0.2
Lead mg/L	0.00 ± 0.00	0.01 ± 0.01	0.00 ± 0.00	0.00 ± 0.00	0.01
Iron (Total) mg/L	**1.23 ± 0.30**	**1.43 ± 0.08**	**1.18 ± 0.26**	**0.99 ± 0.09**	**0.3**
Zinc mg/L	0.12 ± 0.08	0.17 ± 0.04	0.76 ± 0.97	1.61 ± 0.47	5 (USA)
Fluoride mg/L	0.13 ± 0.15	0.28 ± 0.23	0.39 ± 0.15	0.33 ± 0.05	1.5
Sulphate mg/L	12.17 ± 0.15	13.97 ± 3.49	29.67 ± 16.15	16.00 ± 2.00	250
Phosphate mg/L	**18.07 ± 0.31**	**19.01 ± 2.87**	**21.74 ± 2.01**	**17.78 ± 2.13**	**5**
Aluminium mg/L	**0.22 ± 0.08**	**0.35 ± 0.19**	**0.21 ± 0.12**	0.13 ± 0.02	0.2 (EU)
Manganese mg/L	**0.66 ± 0.19**	**0.51 ± 0.10**	0.29 ± 0.08	**0.61 ± 0.17**	**0.4**

Table A3. 2012 Mean raw water data in the densu basin.

Parameter and Unit	Jan-March	April-June	July-Sept	Oct-Dec	WHO Standard
pH	7.43 ± 0.21	7.50 ± 0.10	7.27 ± 0.15	7.33 ± 0.15	6.5 - 8.5
Turbidity NTU	**88.60 ± 15.37**	**379.60 ± 85.43**	**356.36 ± 125.65**	**280.81 ± 87.19**	**5**
Temperature ˚C	25.18 ± 1.27	25.54 ± 0.49	25.74 ± 1.02	25.58 ± 0.58	30
Conductivity ms/cm	312.15 ± 42.92	363.41 ± 31.91	331.33 ± 17.62	315.77 ± 51.69	1000
Total Dissolve Solids mg/L	218.51 ± 30.05	254.39 ± 22.34	231.93 ± 12.33	221.04 ± 36.18	1000
Ammonia (NH_3) mg/L	**0.75 ± 0.31**	**1.56 ± 0.05**	**1.55 ± 0.64**	**1.41 ± 0.51**	**0.5 (EU)**
Nitrite (NO_2^-) mg/L	0.37 ± 0.24	0.40 ± 0.14	0.50 ± 0.14	**10.03 ± 8.34**	3
Nitrate (NO_3) mg/L	21.49 ± 5.05	20.33 ± 3.87	24.29 ± 5.47	16.88 ± 0.75	50
Chloride mg/L	21.67 ± 5.86	19.67 ± 3.06	16.33 ± 1.53	18.00 ± 2.65	250
Total Alkalinity mg/L	57.67 ± 1.53	60.00 ± 2.65	56.67 ± 6.66	58.33 ± 5.03	200
Total Hardness mg/L	86.67 ± 7.57	82.67 ± 3.51	88.67 ± 9.45	79.33 ± 15.63	500
Calcium Hardness mg/L	60.33 ± 4.73	53.33 ± 4.04	53.33 ± 6.51	59.00 ± 2.65	200
Magnesium Hardness mg/L	26.33 ± 2.89	29.33 ± 4.51	35.33 ± 15.04	20.33 ± 17.90	150
Calcium mg/L	24.13 ± 1.89	21.33 ± 1.62	21.33 ± 2.60	23.60 ± 1.05	200
Magnesium mg/L	7.00 ± 0.55	6.19 ± 0.47	6.19 ± 0.75	6.84 ± 0.31	150
Arsenic mg/L	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.01

Continued

Copper mg/L	**0.61 ± 0.26**	**2.96 ± 3.01**	**1.58 ± 0.55**	**1.29 ± 0.11**	**0.2**
Lead mg/L	0.00 ± 0.00	0.01 ± 0.01	0.00 ± 0.00	0.00 ± 0.00	0.01
Iron (Total) mg/L	**1.75 ± 0.34**	**1.69 ± 0.64**	**1.95 ± 0.73**	**1.53 ± 0.28**	**0.3**
Zinc mg/L	0.12 ± 0.08	0.17 ± 0.04	0.76 ± 0.97	1.61 ± 0.47	5 (USA)
Fluoride mg/L	0.59 ± 0.06	0.35 ± 0.16	1.03 ± 0.81	0.68 ± 0.05	1.5
Sulphate mg/L	14.33 ± 0.58	11.00 ± 1.00	14.00 ± 2.65	16.00 ± 7.00	250
Phosphate mg/L	**19.05 ± 1.99**	**27.35 ± 4.24**	**26.04 ± 5.01**	**20.92 ± 2.38**	**5**
Aluminium mg/L	**0.50 ± 0.11**	**0.52 ± 0.11**	**7.93 ± 13.05**	**0.23 ± 0.11**	**0.2 (EU)**
Manganese mg/L	0.24 ± 0.10	**0.47 ± 0.17**	0.28 ± 0.06	0.39 ± 0.06	0.4

Table A4. 2013 Mean raw water data in the densu basin.

Parameter and Unit	Jan-March	April-June	July-Sept	Oct-Dec	WHO Standard
pH	7.37 ± 0.21	7.21 ± 0.09	7.30 ± 0.19	7.34 ± 0.12	6.5 - 8.5
Turbidity NTU	**64.49 ± 14.45**	**332.22 ± 143.27**	**425.66 ± 119.31**	**237.00 ± 203.64**	**5**
Temperature ˚C	25.57 ± 0.15	25.50 ± 0.26	25.17 ± 0.46	25.40 ± 0.20	30
Conductivity ms/cm	312.15 ± 42.92	363.41 ± 31.91	331.33 ± 17.62	315.77 ± 51.69	1000
Total Dissolve Solids mg/L	218.51 ± 30.05	254.39 ± 22.34	231.93 ± 12.33	221.04 ± 36.18	1000
Ammonia (NH_3) mg/L	**0.92 ± 0.26**	**1.09 ± 0.66**	**1.92 ± 0.24**	**1.06 ± 0.19**	**0.5 (EU)**
Nitrite (NO_2^-) mg/L	0.94 ± 0.23	0.66 ± 0.27	0.48 ± 0.17	0.53 ± 0.02	3
Nitrate (NO_3) mg/L	17.98 ± 0.41	17.35 ± 3.85	22.58 ± 1.17	20.22 ± 0.69	50
Chloride mg/L	20.73 ± 4.82	22.67 ± 4.73	31.33 ± 26.58	22.10 ± 2.71	250
Total Alkalinity mg/L	55.33 ± 6.43	58.33 ± 1.15	63.00 ± 1.00	63.33 ± 4.51	200
Total Hardness mg/L	89.00 ± 5.57	78.33 ± 3.06	80.33 ± 8.39	75.33 ± 2.08	500
Calcium Hardness mg/L	64.33 ± 7.64	55.33 ± 5.86	58.67 ± 1.53	55.67 ± 6.51	200
Magnesium Hardness mg/L	24.67 ± 7.02	23.00 ± 8.66	21.67 ± 7.37	19.67 ± 6.43	150
Calcium mg/L	25.73 ± 3.05	22.13 ± 2.34	23.47 ± 0.61	22.27 ± 2.60	200
Magnesium mg/L	7.46 ± 0.89	6.42 ± 0.68	6.81 ± 0.18	6.46 ± 0.75	150
Arsenic mg/L	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.01
Copper mg/L	**0.55 ± 0.31**	**1.57 ± 1.31**	**1.74 ± 0.57**	**1.19 ± 0.12**	**0.2**
Lead mg/L	0.00 ± 0.00	0.01 ± 0.01	0.00 ± 0.00	0.00 ± 0.00	0.01
Iron (Total) mg/L	**1.19 ± 0.08**	**1.52 ± 0.21**	**2.06 ± 0.52**	**1.96 ± 0.47**	**0.3**
Zinc mg/L	0.12 ± 0.08	0.17 ± 0.04	0.76 ± 0.97	1.61 ± 0.47	5 (USA)
Fluoride mg/L	0.59 ± 0.12	1.07 ± 0.47	1.50 ± 0.26	0.64 ± 0.28	1.5
Sulphate mg/L	23.00 ± 2.00	22.90 ± 4.74	20.07 ± 1.01	21.67 ± 2.37	250
Phosphate mg/L	**20.45 ± 3.20**	**24.20 ± 2.52**	**25.84 ± 3.61**	**18.36 ± 1.15**	**5**
Aluminium mg/L	**1.26 ± 0.94**	**0.45 ± 0.26**	**0.54 ± 0.10**	**0.52 ± 0.10**	**0.2 (EU)**
Manganese mg/L	**0.56 ± 0.40**	**0.41 ± 0.25**	0.38 ± 0.22	0.37 ± 0.08	0.4

Table A5. 2014 Mean raw water data in the densu basin.

Parameter and Unit	Jan-March	April-June	July-Sept	Oct-Dec	WHO Standard
pH	7.38 ± 0.13	7.54 ± 0.12	7.40 ± 0.17	7.50 ± 0.1	6.5 - 8.5
Turbidity NTU	**71.92 ± 19.73**	**399.12 ± 103.16**	**467.63 ± 64.13**	**371 ± 96.21**	5
Temperature ˚C	25.47 ± 0.47	25.02 ± 0.34	25.95 ± 1.00	26.61 ± 0.56	30
Conductivity ms/cm	295.29 ± 16.36	305.58 ± 33.97	306.97 ± 52.1	288.59 ± 40.15	1000
Total Dissolve Solids mg/L	**206.71 ± 11.45**	**213.91 ± 23.78**	**214.88 ± 36.55**	**202.02 ± 28.11**	**5**
Ammonia (NH_3) mg/L	**0.59 ± 0.07**	**1.52 ± 0.63**	**1.92 ± 0.67**	**1.46 ± 0.44**	**0.5 (EU)**
Nitrite (NO_2^-) mg/L	0.52 ± 0.10	0.52 ± 0.11	1.22 ± 1.22	0.52 ± 0.11	3
Nitrate (NO_3) mg/L	16.05 ± 2.05	22.57 ± 4.50	26.22 ± 3.32	21.29 ± 1.85	50
Chloride mg/L	20.33 ± 1.52	24.00 ± 1	18.33 ± 1.52	17.67 ± 2.08	250
Total Alkalinity mg/L	61.00 ± 3.46	59.33 ± 2.08	72.67 ± 11.24	68 ± 10	200
Total Hardness mg/L	83.67 ± 4.50	84.00 ± 2.64	78.33 ± 2.51	85 ± 4.35	500
Calcium Hardness mg/L	53.00 ± 8.18	45.00 ± 7	51.33 ± 4.50	49.67 ± 2.08	200
Magnesium Hardness mg/L	30.67 ± 10.26	39.00 ± 9.64	27 ± 3.46	35.33 ± 5.51	150
Calcium mg/L	21.20 ± 3.27	18.00 ± 2.8	20.53 ± 1.80	19.87 ± 0.83	200
Magnesium mg/L	8.89 ± 2.97	11.31 ± 2.79	7.83 ± 1.00	10.25 ± 1.59	150
Arsenic mg/L	0.00 ± 0	0.00 ± 0	0.00 ± 0	0.00 ± 0	0.01
Copper mg/L	**0.43 ± 0.19**	**0.26 ± 0.09**	**0.40 ± 0.16**	**0.34 ± 0.07**	**0.2**
Lead mg/L	0,00 ± 0	0.01 ± 0.01	0.00 ± 0	0.00 ± 0	0.01
Iron (Total) mg/L	**1.61 ± 0.88**	**1.95 ± 0.61**	**1.71 ± 0.92**	**1.45 ± 0.22**	**0.3**
Zinc mg/L	0.46 ± 0.16	0.41 ± 0.13	0.42 ± 0.11	1.45 ± 0.64	5 (USA)
Fluoride mg/L	0.79 ± 0.20	0.82 ± 0.11	0.68 ± 0.15	0.52 ± 0.20	1.5
Sulphate mg/L	18.11 ± 4.33	10.64 ± 1.64	18.59 ± 1.93	15.44 ± 2.72	250
Phosphate mg/L	**18.51 ± 0.88**	**27.02 ± 5.91**	**27.47 ± 4.57**	**25.22 ± 2.27**	**5**
Aluminium mg/L	**0.45 ± 0.15**	**0.41 ± 0.08**	**0.43 ± 0.18**	**0.83 ± 0.10**	**0.2 (EU)**
Manganese mg/L	**0.45 ± 0.10**	**0.64 ± 0.16**	**0.50 ± 0.10**	**0.52 ± 0.21**	**0.4**

Table A6. 2015 Mean raw water data in the densu basin.

Parameter and Unit	Jan-March	April-June	July-Sept	Oct-Dec	WHO Standard
pH	7.7 ± 0.17	7.28 ± 0.18	7.5 ± 0.3	7.53 ± 0.34	6.5 - 8.5
Turbidity NTU	**166.57 ± 82.29**	**408.06 ± 48.38**	**436.44 ± 115.18**	**367.17 ± 66.41**	5
Temperature ˚C	25.91 ± 0.93	26.21 ± 0.50	27.5 ± 2.52	**31.23 ± 1.49**	30
Conductivity ms/cm	323.87 ± 87.04	197.28 ± 23.28	378.52 ± 39.70	355.33 ± 34.29	1000
Total Dissolve Solids mg/L	**226.41 ± 60.67**	**138.09 ± 16.30**	**258.33 ± 31.54**	**248.67 ± 24.13**	5
Ammonia (NH_3) mg/L	**1.07 ± 0.28**	**1.63 ± 0.75**	**1.72 ± 1.23**	**1.26 ± 0.46**	0.5 **(EU)**
Nitrite (NO_2^-) mg/L	**4.68 ± 2.05**	**5.17 ± 2.56**	2.61 ± 0.53	2.79 ± 0.25	3
Nitrate (NO_3) mg/L	21.97 ± 2.88	23.18 ± 5.36	28.77 ± 3.27	22.78 ± 2.53	50

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Chloride mg/L	31.02 ± 7.47	20.05 ± 6.56	29.77 ± 4.02	30.07 ± 1.90	250
Total Alkalinity mg/L	68.67 ± 5.50	56.33 ± 4.16	179 ± 97.51	204.33 ± 53.79	200
Total Hardness mg/L	87.33 ± 2.51	82.33 ± 7.57	97.33 ± 37.20	112.67 ± 38.73	500
Calcium Hardness mg/L	61 ± 5.52	53.67 ± 4.16	56.67 ± 21.50	66 ± 13.07	200
Magnesium Hardness mg/L	26.33 ± 3.21	28.67 ± 8.08	40.67 ± 16.77	46.67 ± 25.69	150
Calcium mg/L	24.4 ± 2.23	21.47 ± 1.66	22.4 ± 8.60	22.4 ± 5.67	200
Magnesium mg/L	7.63 ± 0.93	8.31 ± 2.34	10.35 ± 3.68	8.67 ± 5.52	150
Arsenic mg/L	0 ± 0	0 ± 0	0 ± 0	0 ± 0	0.01
Copper mg/L	**1.34 ± 0.61**	**2.76 ± 0.40**	**3.013333 ±**	**2.38 ± 0.55**	0.2
Lead mg/L	**0.03 ± 0.05**	0 ± 0	0 ± 0	0 ± 0	0.01
Iron (Total) mg/L	**2.10 ± 0.68**	**2.43 ± 1.43**	**1.44 ± 0.15**	**0.8 ± 0.22**	0.3
Zinc mg/L	2.37 ± 0.20	2.62 ± 0.68	2.52 ± 0.25	1.88 ± 0.55	5 (USA)
Fluoride mg/L	0.76 ± 0.27	**1.83 ± 0.18**	1.42 ± 0.03	1.33 ± 0.12	1.5
Sulphate mg/L	17.33 ± 6.02	10.33 ± 4.16	24.33 ± 1.53	15.67 ± 3.21	250
Phosphate mg/L	**24.67 ± 1.46**	**31.13 ± 3.67**	**30.53 ± 3.99**	**23.08 ± 3.91**	5
Aluminium mg/L	**0.37 ± 0.17**	**0.45 ± 0.21**	**0.31 ± 0.01**	**0.24 ± 0.04**	**0.2 (EU)**
Manganese mg/L	**0.42 ± 0.15**	**0.62 ± 0. 15**	0.22 ± 0.12	**4.14 ± 6.89**	0.4