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Spatial Variation of Water Quality in the Densu River Basin, Nsawam-Adoagyiri Municipality, Ghana

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Abstract
The Nsawam-Adoagyiri Municipality stretch of the Densu River Basin serves a population of 86,000 and flows into major river basins in parts of Accra. The study assesses the spatial variability of the physico-chemical quality of the Densu River Basin at seven selected points with reference to WHO guideline standards. Water samples were collected and analyzed from November 2015 to June 2016 to ascertain the variations in water quality parameters with respect to physicochemical parameters and selected heavy metals. Analysis of water quality showed electrical conductivity of 214.00µs/cm - 369.00µs/cm, total dissolved solids 235 to 658 mg/l, exceeding the WHO guideline values at some sampling locations. Heavy metals such as arsenic, lead and iron indicated that at some locations exceeded the WHO guideline limits while copper, manganese and mercury concentrations where found to be within threshold at all locations during the period.
Keywords: anthropogenic, densu river, spatial variation, water quality
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1.0 Introduction

Water quality plays a significant role in the maintenance of a well-balanced ecosystem. Regular monitoring of water bodies with mandatory number of parameters in relation to water quality prevents the outbreak of diseases and occurrence of hazards. The quality of drinking water is a powerful environmental determinant of health and for that matter water safety plan is a foundation for the prevention and control of waterborne diseases (WHO, 2011).

Physicochemical and bacteriological qualities of water for drinking and for other socio-economic activities are considered to be some of the concerns of both the general public and water suppliers. Extensive pollution of the Densu River Basin was reported as a result of various anthropogenic activities such as mining, agriculture, industrial as well as municipal sources in the form of garbage and wastewater. With increasing scarcity of treated public water supply, fresh river water has become the alternative source for these purposes (Bruggen, 2006).

Integrated Water Resources Management (IWRM), which is a comprehensive approach to the development of water resources, addresses their management both as resources and within the framework of providing water services. It can be adopted as a practical step in improving the quality of water bodies.

The IWRM plans and strategies prepare not only the overall purpose of addressing major problems at a river basin level related to water resource management and environmental/ecosystem sustainability but also ensures the provision of quality of water safe for domestic consumption and ecological balance. This makes it necessary to couple the scientific quality assessment of the Densu River together with the existing institutional and management plans in order to carve the way forward in finding lasting solution to the problem of pollution in this major water body.

The river has several reservoirs along its course of which the Weija Dam in Accra, located at the lower course of the river is the largest. It is therefore a source of raw water for potable purposes to a population of over 86,000 people living within the Nsawam-Adoagyiri Municipality where it takes its course and travels beyond. The information in this study is extremely desirable due to extensive use of the river for various anthropogenic purposes and due to the growing water pollution problems in this part of the country. This study therefore assesses the spatial variation of water quality of the Densu River Basin through its course within the municipality making reference to WHO standards.

2.0 Materials and Method

2.1 Study Area

The Densu Basin is located at the South Eastern part of Ghana and lies within longitudes 10 30'W -10 45'W and latitudes 50 45'N - 60 15'N. It shares its catchment boundary with the Odaw and Volta Basins to the east and north, the Birim in the northwest and the Ayensu and Okrudu in the west. The Densu River Basin has an area of 2,490 km^2 and spans 11 Local Government Assemblies in three regions (i.e. Central Region, Eastern Region and the Greater Accra Region) including the Nsawam-Adoagyiri Municipality. The specific areas considered during the study stretched from P1 (Latitude 5.84, Longitude -0.35) an area closer to the Ntoaso community to P7 Latitude 5.79, Longitude -0.36 at the border of the municipality.

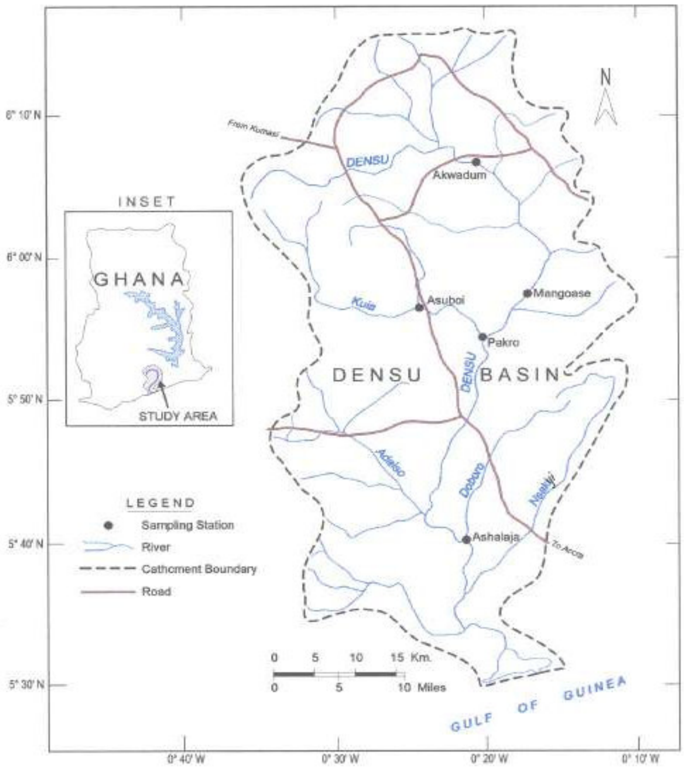

Figure 1: Map of Nsawam-Adoagyiri Municipality
Source: Ghana Statistical Service, 2010

The main ecological zones identified in the Municipality are the semi-deciduous forest and coastal savanna grassland. About 90 per cent of the Municipality is covered with forest. The geology of the Municipality is mainly sedimentary rocks metamorphosed to quartzites, schist, shale and philate, forming the Akuapem - Togo ranges (GSS, 2010). The Densu Basin is generally low lying with undulating topography and isolated ridges forming the characteristic landscape features in many places.

Weather conditions in the Municipality are generally cool due to its location in the wet semi- equatorial climate, coupled with the double maxima rainfall, which records an average annual rainfall of between 125cm and 200cm. The first rainy season is usually between May to June, with the heaviest rainfall experienced in June and a second rainy season between Septembers to October. This usually account for an entire year farming practice. The highest temperatures averaging 30˚ C are recorded between March and April. With the lowest average temperature of 26^{o} C recorded in August (GSS, 2010).

Sampling and Field Work

A total of 22 samples were purposively collected based on equal distance apart on river flow with in the municipal limits between December, 2015 and June, 2016. A distance interval of approximately 2 kilometers was observed between each sampling point. Samples were replicated to find the mean and SD. The geographical coordinates of each sampling point will be obtained using a GPS (Garmin GPS map 60CSx) and were coded as P1, P2, P3, P4, P5, P6 and P7 respectively to help track later sample collection.

Table 1: Sampling Points and their Geographical Locations

Sampling Point	GPS Reading	Area Name
P1	Lat 5.84, Lng -0.35	Ntoaso (upstream)
P2	Lat 5.83, Lng -0.35	Water works
P3	Lat 5.82, Lng -0.35	Duadekye
P4	Lat 5.82, Lng -0.35	Adoagyir Zongo
P5	Lat 5.81, Lng -0.35	Densu Bridge
P6	Lat 5.81, Lng -0.36	Sakyikrom
P_7	Lat 5.80, Lng -0.36	New Road (downstream)

Sampling Points

This study was designed to investigate the hydrological profile of the water course of the river, the physicochemical quality of the river upstream, municipal and downstream locations. The location of sampling points upstream, municipal areas and downstream was selected based on distance throughout the length of the river in the municipality. Seven (7) sampling points were located along the river course as follows:

1. Upstream Location, P1

The upstream location (Point 1) is characterized by presence of vegetation around the river with few farming activities near the banks of the river. Least human anthropogenic activities occur at this point of the river, least suspended solids and low turbidity occurs here. The kind of soil present in this location is the loamy type which supports farming activities.

2. Municipal Area Sampling Locations (P2-P6)

These consist of five sampling points where human activities thrive most. Most of the anthropogenic activities within the municipality are at its peak at these sampling locations. Adoagyiri Zongo Bridge sampling point is one of the populated communities within the municipality. These areas are characterized by fewer farming and pastoral activities and a close proximity to the central business district if the town noted for major trading and waste accumulation activities.

3. Downstream Sampling Point, P7

The last point of the river within the municipality is located at the New Road. This area is inhabited by a relatively new community with few infrastructure and human activities. This area is also common with few farming activities which are located at reasonable distances from the river itself.

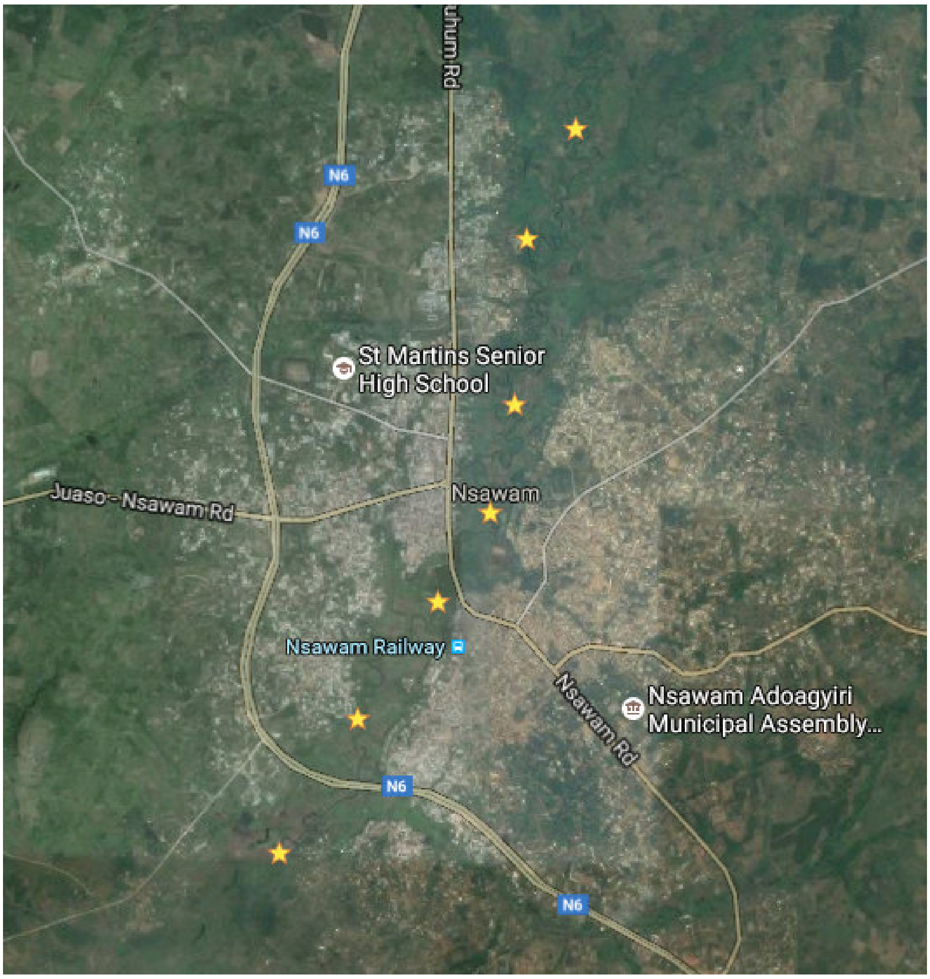

Figure 2. Satellite image of municipality showing water sampling points
Source: Google Earth Pro, (2016)

Water samples for physico-chemical analyses were collected at a depth of 20-30cm in the river directly into 1-litre plastic bottles (high density polyethylene containers), previously washed with nitric acid and rinsed with distilled water. Each sampling bottle was then rinsed three times with the lake water prior to sampling. pH was measured *in situ* using portable 72 HANNA pH meter. Samples for trace metal analysis were preserved with 3-ml of concentrated HNO^3 acid per litre in the field and kept until they were analyzed.

Samples for some of the analyses were stored in an ice-chest at a temperature of < 4°C and transported to the, Ecological Laboratory, University of Ghana, and analyzed within one week. The heavy metals including As, Fe, Cu, Pb, Hg, Mn and Zn were determined using PerkinElmer PinACCLe 900T Atomic Absorption Spectrophotometer. Total coliforms were estimated using the most probable number method (MPN). The collection, preservation, storage and preparation protocols of water samples followed those outlined in APHA (1998). Results were statistically analyzed and displayed using Statistical Package for Social Sciences (SPSS) and Microsoft Excel Software version (2010).

3.0 Results and Discussion

The results of laboratory analysis for various parameters were recorded and the mean values of these parameters obtained from each sampling location was calculated. Spatial variations of some physicochemical parameters in Densu River at various selected locations are presented in Tables 1 and 2. The various sampling locations where these parameters where sampled are categorized into three sectors with different characteristics: upstream, municipal area and downstream. The fluctuations observed in indicators may be mostly due to increased industrial and human activities with progress downstream.

3.1 Upstream Location Characteristics

The upstream location (Point 1) is characterized by presence of vegetation with generally least human anthropogenic activities. The mean pH recorded at this location during the study period was relatively high with a value of 7.9 ± 0.085 which was succeeded by a mean pH of 8.14±0.290 at location P2. This can be attributed to the kind of soil, sediment and geology type in this part of the region. The slightly alkaline pH of the water at this location has led to the encrusting of scale deposits on metal pipes meant to channel water at the water treatment plant closer.

The amount of turbidity during the period of research generally varied from 30.12±2.11 to 184.4±205.91 NTU with a mean value of 89.60 ± 59.43 NTU. Turbidity values observed upstream were relatively low (30.12±2.11NTU). This is attributed to the relatively few human activities such as industrial discharges, urban as well as less erosion as a result of the presence of vegetation cover around that location. This resulted in the reduced presence of suspended matter, which usually consists of a mixture of inorganic matter, such as clay and soil particles, and organic matter at upstream regions.

The amount of total dissolved solids in the water samples during the period generally varied from 235 to 658 mg/l with a mean value of 321.21 ± 149.77 mg/l. Upstream sampling point recorded a mean TDS value of 247.5±81.32 mg/l which is below the WHO standard and can be attributed to the absence of water polluting activities. This location is also characterized by the presence of vegetation cover which prevents the incidence of shoreline erosion.

Electrical conductivity (EC) levels in the river varied between 470±155.56 to 1316±1380.27 µS/cm with a mean of 631.28 ± 303.31 µS/cm. As expected, the mean EC levels observed upstream were relatively lower while dissolved oxygen (DO) levels were higher (9.06±3.59 mg/l) signifying the presence of most contaminants in comparison to municipal areas. The Dissolved Oxygen (DO) results identified at all the Densu River water sampling points during the period of research varied from 4.79±2.81 to 10.15±5.24 mg/l with an overall mean DO of 7.54 ± 1.70 mg/l. The high DO values suggest healthy river (Haider, 2010).

Nitrate levels varied between 1.70 mg/l to 3.7 mg/l with a mean value of 2.79 ± 0.45 mg/l for the Densu River water samples with upstream points recording a nitrate level of 2.4±1.13 mg/l. This indicates oxidation of nitrogenous compounds during the river flow.

Levels of dissolved metals such as Cu, Pb, As, Fe, Mn and Hg generally varied from below detection limits to levels above the WHO (2004) threshold levels for potable water. Iron, level is relatively high ranging from 1.20 to 4.17 mg/l with a mean of 2.42 ± 1.30 mg/l. All the sampling stations showed Fe concentrations above, 0.3 mg/l on the average except a few. In the water quality assessment of the southwestern and coastal river systems by Darko and Ansa-Asare (2014) observed that iron concentrations in the waters ranged from <0.010 mg/l to 5.62 mg/l during the study period.

3.2 Water at Municipal Area Location

Throughout the study period, the highest pH values for surface water was at Point-P2 (Water works station) while sampling Point-P6 (Sakyikrom) recorded the lowest pH as shown in Figure 1 above. A steady decline in the pH value of the river was observed down the river after P2, with slight variations. The fluctuations in the pH levels with increasing distance downstream may partly be due to dilution effect. This implies the pH of the water around the treatment plant is relatively slightly alkaline. Tay and Kortatsi (2007) reported a pH range of 4.37–7.40 in the same basin in the year 2007 indicating a slight variation in the pH observed in the past.

The greater the amount of suspended solids in the water, the murkier it appears, and the higher the measured turbidity (UNEP GEMS, 2006). The value of turbidity increased with proximity to municipal areas from P2-P6 with a peak at P5 (Nsawam-Adoagyiri Bridge) where most human activities thrive within the municipality.

TDS levels beyond upstream location saw fluctuations between 235±77.78mg/L to 271±128.69mg/l at P2 and P4 respectively. The highest TDS, 658 mg/l was recorded at P5 location, that is the area around the Nsawam-Adoagyiri Bridge where most human activities thrive within the municipality and this was recorded during the dry season where the water body seemed to be drier and had eventually accumulated a lot of silt and dirt in its seemingly stagnant waters. Studies by Anim et al (2011) revealed a mean TDS of 143.94 mg/l which is again much less closer to the averages recorded in this study.

The highest conductivity was recorded from sample location P5 that is at the Nsawam-Adoagyiri Bridge during the dry season as seen in (Figure 3). Tay and Kortatsi (2007) also observed a conductivity range of 134–7,780 µS/cm. The mean values of the electrical conductivity (EC) was 324.24µs/cm with an overall value range of 214.00µs/cm to 369.00µs/cm in the study conducted by Anim et al., (2011). This was in parity with the results obtained during the study. However, a 1000 µs/cm WHO guideline limit for electrical conductivity shows that P5 is highly contaminated since this threshold exceeded at this location. The variabilities in total dissolved solids and electrical conductivity can be attributed to shoreline erosion, fertilizer and pesticide run off, discharge of sewage and effluents throughout the stretch of the river giving rise to increased levels of colloidal iron and metallic salts.

DO levels were relatively high at upstream regions where least industrial, agricultural and other anthropogenic activities thrived. In contrast low DO levels where observed between P3-P5, suggesting a poor state of the river in those municipal areas.

The lowest nitrate value of the water samples analyzed was detected at the location P6 (Nsawam-Adoagyiri bridge) while the highest figure recorded was at the location P2. Nitrate values where in contrast with values observed by Tay and Kortatsi (2007) who recorded nitrate levels between 0.1 to 106.0 mg/l in the Densu Basin. The guideline provided by WHO for nitrates is 50 mg/l which implies that the levels were below permissible limits. Total coliforms pollution was extensive, and the entire river basin as sampled is not appropriate for domestic use without treatment. Total Coliform were predominant in all the sites and their levels were above the permissible limits with P5 recording the highest count of 1884.528 CFU/100 ml during the dry season.

Table 2: Comparison of mean values of physico-chemical parameters in the river at various locations

Station	Turbidity, NTU	TDS, mg/l	DO, mg/l
P1	30.12±2.11	247.5±81.32	9.06±3.59
P2	79.25±2.05	235±77.78	7.55±1.52
P3	31.60±2.11	276±121.62	10.15±5.24
P4	60.31±21.09	271±128.69	7.37±0.82
P5	184.4±205.91	658±690.14	4.79±2.81
P6	155.4±119.64	266±164.05	7.06±1.07
P7	86.15±19.59	295±134.35	6.83±0.82
WHO Standard	5.00	1000	-

Table 3: Comparison of mean values of heavy metals, nitrate and coliform counts in the river at various locations

Station	Hg, mg/l	Pb, mg/l	NO3-N, mg/l	Total Coliforms (cfc/100ml)
P1	0	0.00165±0.0009	2.4±1.13	2178.598±486.02
P2	0	0.00205±0.0015	3.7±2.69	2298.6535±777.50
P3	0	0.00315±0.0016	2.15±1.06	2138.6335±282.69
P4	0.0003±0.00014	0.0005±0.0007	3.35±2.90	2258.1605±822.04
P5	0	0.00535±0.0019	1.7±0.71	2492.2105±618.46
P6	0.0005±0.00071	0.001±0.0014	3.2±1.98	2408.787±312.39
P7	0	0.0018±0.0025	3.05±2.90	2406.8305±609.24
WHO Standard	0.006	0.01	50.00	-

Table 4: Correlation coefficients (r) for the pairs of water quality characteristics of Densu River

	Ph	*Hardness*	*EC*	*Turbidity*	*TDS*	*DO*	*NO3-N*	*Total Coliform*
pH	1.000							
Hardness	-0.287	1.000						
EC	-0.158	-0.050	1.000					
Turbidity	-0.335	0.470	0.701	1.000				
TDS	-0.147	-0.065	0.995	0.707	1.000			
DO	0.031	-0.125	-0.689	-0.866	-0.720	1.000		
NO3-N	0.293	0.299	-0.698	-0.166	-0.687	0.036	1.000	
Total Coliforms	-0.163	0.341	0.595	0.922	0.636	-0.942	-0.020	1.000

An overall average of 0.000114 $\pm 7.47 \times 10^{-5}$ was recorded for mercury, with an overall minimum of BD below detection value and a maximum of 0.001 mg/l. 71.42% of the water sampled were found to be below detection point while the remaining gave values which were still below the threshold limit.

At the very low levels manganese in drinking water is perfectly safe. An overall average of 0.0138 ±0.0053 was recorded with an overall minimum of 0.0065 and a maximum of 0.022 mg/l. Therefore all the samples evaluated were below the WHO guideline limit of 0.4mg/l and all these figures were recorded at different sampling points within the municipality. The community therefore has a lower risk of exposure to manganese.

The overall arsenic concentration fell within 0.001 mg/l and a maximum of 0.028 mg/l throughout the period of research. The lowest mean concentration was detected at P1, which is the upstream source of the water into the municipality. The highest figure of 0.0275 mg/l was detected at P5 and was the only location where the concentration of arsenic exceeded the WHO guideline limit if 0.01mg/l. Copper concentrations observed at P2 and P3 were found to be below detection limits while the highest concentration was detected at P7, the downstream location.

The highest mean concentration of mercury, arsenic, lead and iron were detected at the location P5 as seen in figure below. This can be attributed the release of waste and other contaminants different sources and the slow flow of water at this location leading to the accumulation of pollutants at this point.

3.3 Downstream Location Characteristics

This study shows a significant disparity in pH values observed by Tay and Kortatsi (2008) and the observed values in other districts which proved to be more acidic in content even though values tend to be with the WHO permissible limits. The pH of the river downstream was found to be 7.83±0.057. This implies that despite the gradual decline in pH levels throughout the municipal areas, the pH did not decline at the downstream location as expected. This could be attributed to the fluctuations in as a result of the type of soil and geology in that region of the municipality.

The state of turbidity began to recover with lower turbidity values observed from P6 to downstream points. The increase in water flow velocities at downstream also sped up the rate of recover of the more turbid water from the municipal areas. The fluctuations in turbidity can be attributed increase in surface run offs, sand winning and sewage discharge in municipal areas relative to upstream and downstream areas. All the turbidity values observed were above the WHO drinking water guideline values of 5.00 NTU hence a display of poor water quality in terms of cloudiness.

TDS levels began recover at P6 with a sharp decline to 266±164.05mg/l even though a minute rise in concentration was observed downstream at 295±134.3, signifying a poor recovery of the river at the last stretch of the river in the municipality.

The values of EC similar to TDS declined at downstream locations indicating recovery polluted water at the municipal areas during flow. DO levels were observed along municipal points suggesting high levels of pollution in these areas, but saw the natural reclamation water downstream owing to higher DO values observed.

Historical data indicated that the microbial water quality of the Densu Basin is poor (WRC, 2000). Nitrate concentrations exhibited vast variations throughout the river stretch with no particular trend to reconcile upstream, downstream and municipal areas. This may be due to variations in the kind of soil, geology, sewage discharge, fertilizer and pesticide runoffs in various areas along the river.

The concentration of heavy metals downstream followed the general trends of values below the WHO threshold with no significant difference between concentrations recorded upstream and in municipal areas. This can be attributed to the trace amounts of these chemicals in the water body.

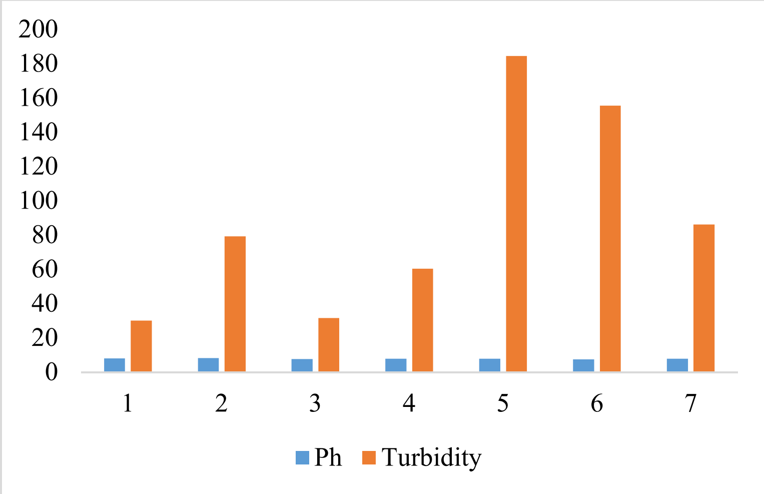

Figure 3: Mean pH and turbidity levels at various sampling points

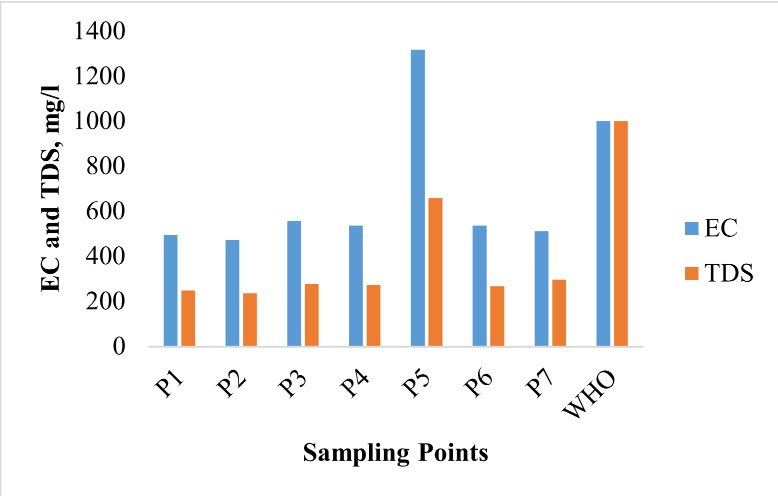

Figure 4: Mean electrical conductivity and total dissolved solids at sampling points

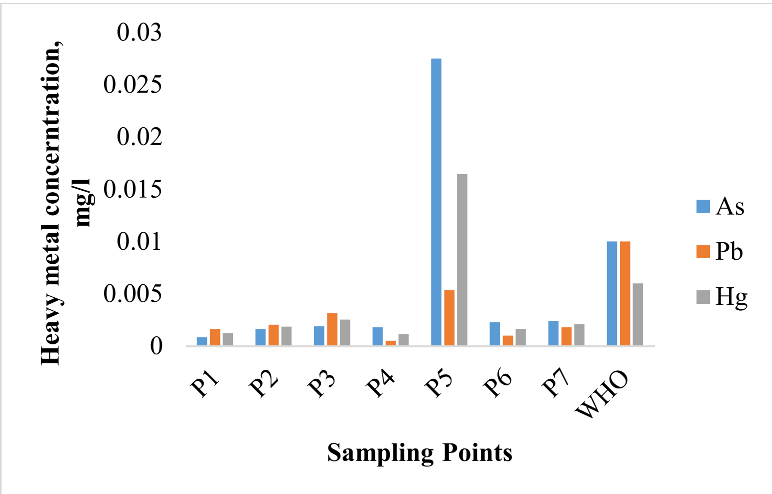

Figure 5: Heavy metal concentration at various locations

4.0 Conclusion

Following the discussions in this study, it can be concluded that various forms of anthropogenic activities such as farming, indiscriminate waste and sewage disposal, sand winning and dredging activities have affected the quality of the water resource over the period. The impact of natural activities such as rainfall and storm water flow cannot be underestimated as well. Analysis of water quality saw the levels of parameters including electrical conductivity (214.00µs/cm - 369.00µs/cm), total dissolved solids (235 to 658 mg/l), exceeding the WHO guideline values at certain sampling locations. Heavy metals such as arsenic, lead and iron saw samples at few locations exceeding the WHO guideline limits while copper, manganese and mercury concentrations where found to be within their threshold at all locations during the period. Apart from heavy metals which recorded minute concentrations and generally insignificant variation and trend, most of the physicochemical and bacteriological parameters saw spatial trend in their concentrations at the various sampling locations; upstream, downstream and municipal locations. Most of the parameters analyzed suggested a less contaminated water at the upstream location. The rate of contamination increased in the municipal area where most of the pollution causing anthropogenic activities thrive, with the highest amount of pollution at P5. A steady recovery of the river begins at P6 to the downstream point where the river stretch exists the municipality. The results obtained from the analysis showed few positive correlation and many negative correlations between the determinants. In general, results showed fewer strong positive correlation and numerous weak negative correlations between water parameters.

Studies to assess the seasonal variation in the quality of the water body however remain sparse. It is however recommended that the Municipal Assembly regulates all anthropogenic activities such as the disposal of waste, sand wining and farming around the river through the enforcement of laws.

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References

1. A. Van der Bruggen and L. Braeken, The challenge of zero discharge: From water balance to regeneration, Desalination 188 (2006), pp. 177–183.
2. Ackah, M., Agyemang, O., Anim, A.K. et al. 2011. Assessment of groundwater quality for drinking and irrigation: the case study of Teiman-Oyarifa Community, Ga East Municipality, Ghana. *Proc. Int. Acad. Ecol.*
3. *Environmental Sci.,* 1(3 4): 186 194.
4. Ansa-Asare O. D. (1992). Limno-chemical Characterization and Water Quality Assessment of River Densu. *IABTechnical Report No. 132, Accra, Ghana*. 40 pp.
5. Ansa-Asare O. D. and Asante K. A. (2000). The Water Quality of Birim River in South-East of Ghana.*West Afr. J.appl. Ecol.*1: 23-34.
6. APHA (1995). Standard methods for the examination of water and waste water, 19th. Ed, American Public Health Association, American Water Works Association & Water Environment Federation, Washington, DC.
7. APHA, AWWA and WEF (1998). Standard Methods for the Examination of Water and Wastewater, 20th edn. Washington, D.C.
8. Asante K.A., Quarcoopome T., Amevenku F.Y.K. (2005). Water Quality of the Weija Reservoir after 28 years of Impoundment. West African Journal of Applied Ecology, 13:171-180.
9. B. Kudu., S. Osae, A. A. Golow, D.K. Sarfo, and I.K. Kwarten Water quality assessment of the Densu River: studies on physicochemical parameters and nutrients, Elixir Pollution 45 (2012) 7999-8003
10. Bam E. K. P., Akiti T. T., Osae S, Ganyaglo S.Y, Adomako D, Gibrilla A.A, Ahialey E, and Ayanu G Major ions and trace elements partitioning in unsaturated zone profile of the Densu river basin, Ghana and the implications for groundwater African Journal of Environmental Science and Technology Vol. 5(6), pp. 427-436, June 2011
11. C. Tay and B. Kortatsi Groundwater Quality Studies: A Case Study of the Densu Basin, Ghana West African Journal of Applied Ecology, Vol. 12, 2008
12. Denutsui D., Akiti T, Osae S., Dampare S.B., Tutu A.O., Blankson-Arthur S.,
13. Ayivor J.E. and Adomako D. Assessment of Pollution into the Densu Delta Wetland Using Instrumental Neutron Activation Analysis Research Journal of Environmental and Earth Sciences 3(6): 772-781, 2011
14. Ghana Statistical Service (GSS) (2010). 2010 Population and Housing Census Reports, Analysis of District Data and Implications for Planning-Nsawam-Adoagyiri Municipality, Eastern Region. Ghana Statistical Service, Accra, Ghana.
15. Haider H., 2010. Water Quality Management Model for Ravi River, PhD Thesis, Institute of Environmental Engineering and Research, UET, Lahore.
16. Karikari, A.Y. and O.D. Ansa-Asare, (2006). Physicochemical and microbial water quality assessment of the Densu River of Ghana. *West Afr. J. Appl. Ecol*., 10: 87-100.
17. Karikari, K. (2000). Water *supply and management in rural Ghana: Overview and case studies*. In "*Water*

Management in Africa and the Middle East. Challenges and Opportunities" (Edited by E. Rached, E. Rathgeber, and D.B. Brooks, Eds). IDRC, Ottawa, Canada. 25-31pp
18. Kortatsi BK (2007a) Groundwater quality in the Wassa West district of the western region of Ghana. West Africa J Appl Ecol11:25–40
19. Kortatsi BK (2007b) Hydrochemical framework of groundwater in the Ankobra Basin, Ghana. Aquat Geochem 13:41–74
20. Schafer AI, Rossiter HMA, Owusu PA, Richard BS, Awuah E (2010) Developing country water supplies: physico-chemical water quality in Ghana. Desalination 251:193–203
21. Tay, C. (2001). Trace Metal Contamination in Water from Abandoned Mining and Non-Mining areas in the Northern Parts of the Ashanti Gold Belt, Ghana. MSc Thesis submitted to the Department of Material Science, College of Engineering,
22. United Nations Environment Programme Global Environment Monitoring System (UNEP GEMS)/Water Programme (2006). Water Quality for Ecosystem and Human Health.
23. United Nations Environment Programme Global Environment Monitoring System (UNEP GEMS)/Water Programme (2006). Water Quality for Ecosystem and Human Health.
24. Water Resource Commission- Ghana, Densu River Basin Integrated Water Resource Management Plan, May 2007
25. World Health Organization, WHO (2004). Guidelines for Drinking Water Quality, Third Edition. Volume 1: Recommendations. World Health Organization, Geneva.