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ASSESSMENT OF THE SPATIO-TEMPORAL QUALITY OF THE QUIAOIT RIVER WATERSHED IN ILOCOS NORTE, PHILIPPINES

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ABSTRACT

This study reports the spatio-temporal changes in water quality of the Quiaoit River watershed. Stream water samples were collected at eleven sampling stations weekly from July to December 2012 and were analyzed for five water quality parameters. Results showed distinct spatial and temporal variations of water quality measurements and spatial heterogeneity in terms of surface water pollution was attributed to anthropogenic factors. It was found out that water quality declined as the water moved downstream due to waste input from household and agricultural discharges. The mean dissolved oxygen concentrations are all below the standard minimum dissolved oxygen (6.0 mg/l) and minimum dissolved oxygen for fish spawning (7.0 mg/l). Likewise, mean nitrate-N concentrations within the test watershed ranged from 0.1 ppm to 3.4 ppm. Spatially, it was observed that nitrate-N concentration was highest in areas near agricultural areas. The above results suggest the need for proper management measures to restore the water quality of the Quaioit River. It also highlights the importance for objective ecological policy and decision-making process to ensure a healthy and sustainable aquatic ecosystem.

Keywords: Quaioit River, water quality, watershed, spatio-temporal changes

1. INTRODUCTION

Water is one of the most valued resources in a watershed. It is used for a wide variety of purposes and is often referred to as one of the basic resources that drive development. However in many watersheds in the Philippines, surface water resources are now in various stages of degradation (Cruz 2012). Many rivers invariably exhibit extreme low and high flows that make water resources management a difficult task. Likewise, surface water quality of rivers is experiencing various degree of degradation.

Both anthropogenic activities and natural processes affect surface water quality (Carpenter et al. 1998). Natural processes influencing water quality include precipitation rate, weathering processes, and sediment transport whereas anthropogenic activities include urban development and expansion, industrial, and agricultural practices. Increasing exploitation of water resources in catchment is responsible for much pollution load (Guler et al. 2002; Singh et al. 2005; Pandey 2006).

Spatial and temporal variability in water quality in rivers and streams is directly related to different factors. Spatial heterogeneity within the stream is due to local environmental conditions (e.g., light, temperature, discharge, and water velocity) that change through time and differences in local channel form (Chakrapani 2005) whereas degree of temporal variability of surface water chemistry varied as a function of stream/river type and depended on the chemical parameter of interest. This variation may also form both hydrologic inputs which can originate from precipitation, direct overland flow, sub-surface flow and through shallow soils, drainage from shallow and deep aquifers and in stream processes which include dilution, metal release and adsorption from sediment, as well as precipitation. Seasonal variations in precipitation, surface runoff, interflow ground water flow, and pumped in and outflow have a strong effect on river/streams discharge and subsequently on the concentration of pollutants in surface water (Singh et el. 2005).

Growing population, increased economic activity and industrialization has resulted in an increased water demand. In addition, rapid urbanization is changing patterns of consumption and has caused severe misuse of water resources. Pollution of rivers and its tributaries is more severe and critical near urban stretches due to the huge amount of pollution load discharged by urban activities. Indiscriminate discharge from industrial, municipal and agricultural activities containing toxic substances into aquatic environment aggravates water pollution problems rendering water no longer fit for drinking, agriculture and aquatic life.

At the Quiaoit river watershed, disposal of wastewater generated from municipal and household sources with no treatment prior to discharge is commonly practiced. This practice is not unique to the study area and is commonly practiced in many river watersheds in the country today. Continuous discharge of point and nonpoint pollutants into the aquatic environment is putting the integrity of streams and rivers at risk. Consequently, the surface water of rivers and streams is facing the threat of environmental degradation.

As part of the national research and development program on watershed management, which aims to establish database on the watershed characteristics, this study was conducted to monitor the spatio-temporal quality of surface water of the Quiaoit River watershed. The main objective of the present study is to assess the quality of the river to establish baseline information on watershed water quantity and quality. It also tries to identify pollution sources that influence surface water quality. Identification and quantification of influences, both natural and anthropogenic, and understanding the contaminant sources are crucial to the planning, mitigation, and cleaning process as well as in establishing future management strategies.

2. MATERIALS AND METHODS

2.1 Study Area

The Quiaoit River watershed has a total land area of 190.18 km^2 covering the city of Batac and the municipalities of Paoay and Currimao in Ilocos Norte (Figure 1). About 70% of the total watershed area is located within the city of Batac. The watershed is composed of three geologic formations namely, (1) upper miocene-pilocene sedimentary rocks which are mostly found on higher elevation of the watershed; (2) pilocene-pleistocene limestone found on lower elevation at the northern part of the watershed; and (3) recent alluvial deposits on the central part of the watershed, which generally consist of unsorted, unconsolidated detrital assemblage of clay, silt, sand, and gravel (BSWM 1985).

At present, the pattern of cultivation is closely related to the slope or landform. The level lowland areas are intensively cultivated and planted with rice during the wet season. During the dry season, corn, tobacco, and vegetables are planted. On the upland and hilly areas, agricultural activities are also common along the river, tapping the river for irrigation especially during the dry season. Most of the commercial activities are concentrated in the central and western part of the watershed.

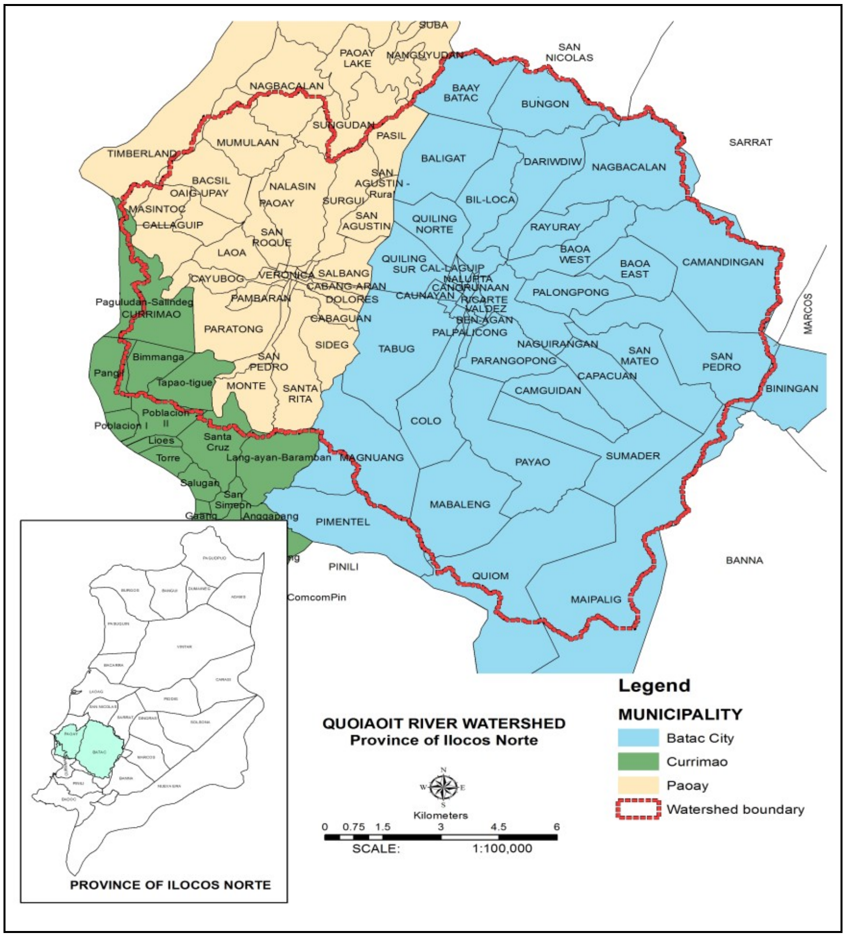

Figure 1. Quiaoit river watershed boundary showing the administrative boundaries covered and its relative location in the province of Ilocos Norte

2.2 Monitoring of stream velocity and discharge

The spatial and temporal variation of stream velocity and discharge within the watershed was monitored in 11 monitoring stations along the stretch of the Quiaoit River. Monitoring of stream flow and sediment yield was done on a weekly basis. To measure the stream flow in particular station, the river cross-section was subdivided into equal strips. In each strip, the stream velocity was measured using a stream flow meter (Swoffer model 3000-1). For deep flow, which is defined as flow having a depth of more than 0.5 meter, velocity reading was obtained at 0.2d and at 0.8d where d is the depth of flow in the particular strip. For shallow flow, the velocity reading was obtained at 0.6d. From this reading, the total discharge of the river was then computed as $Q = \sum_i^n (A_i)\overline{V_i}$ where Q is the stream discharge, A_i is the area of the strip *i* of the stream section and $\overline{V_i}$ is the average velocity in strip *i* and *n* is total number of strips the stream section is subdivided. The average velocity for a strip was computed as $\overline{V_i} = \frac{V_{0.2d}+V_{0.8d}}{2}$ or $\overline{V_i} = 0.6\ V_{0.6d}$.

In addition to the weekly monitoring of stream velocity and discharge, a water level sensor installed at the upstream part of the watershed was used to monitor and record water level depth every 10 minutes.

2.3 Monitoring of sediment yield

Along with stream flow monitoring, the sediment yield was also monitored in eleven monitoring stations along the stretch of the Quiaoit River (Figure 2). Water samples for sediment yield analysis were collected using an integrating sediment sampler. Using this instrument, representative water samples were integrated from the bottom to the surface of the river by gradually filling up a 1 liter sampling bottle. The water samples collected were brought to MMSU research laboratory for sediment yield analysis.

To measure the sediment present in the collected samples, the water was filtered using #40 Wattman Filter paper. The filtered sediment was then oven-dried for two days at 105 °C and then the oven-dry weight was obtained. From these data, the sediment yield was computed as: $S_c = \frac{W_{sf} - W_f}{V}$ where Sc is the sediment concentration in g/L, W_{sf} is the oven dry-weight of sediment and filter paper (gram), W_f is the weight of filter (gram), and V is the volume of water sample (liter).

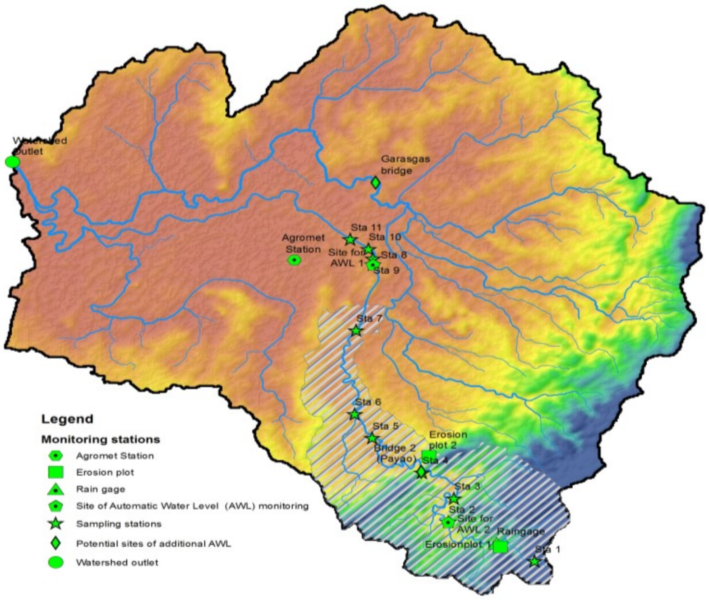

Figure 2. Location of weather stations, water sampling stations, erosion plots, and proposed site of automatic water level monitoring instruments

2.4 Monitoring of water quality

Surface water qualities such as pH, temperature, dissolved oxygen, salinity, and electrical conductivity were monitored weekly *in situ* using a multi-parameter water quality meter. Nitrate-N was measured at the laboratory using spectrometric methodology. To accomplish this, a 500 ml composite water sample taken from 11 sampling stations along the stretch of the river were collected, and refrigerated at 4^oC while waiting for analysis.

2.5 Statistical analysis

Means and standards deviation were used to describe the various water quality parameters of the river. Spatial and temporal variations of each water quality parameters were analyzed and presented in graphical form to show spatial and temporal variations between and among sampling points. When necessary, line graphs were used to show trends of water quality variations.

3. RESULTS AND DISCUSSION

3.1 Steam flow and sediment concentration

Stream velocity, discharge, and sediment concentration were monitored in the 11 monitoring stations along the stretch of the test watershed. The measured data are summarized in Tables 1 and 2. Generally, the stream flow is increasing downstream due to the accumulation of river flow from the different contributing tributaries. Streamflow conditions of the Quiaoit River follow a seasonal pattern. Low-flow conditions typically occur in October to June, with the start of the rainy season generally beginning mid to late May. As the rainy season starts, the stream flows begin to rise and increase to peak streamflow condition in August. Occasional increases in flow are due to rainfall events within the watershed.

Table 1.Temporal and spatial variation of stream velocity (m/s) and discharge (m^3/s) in the test watershed

DATE	STA1	STA2	STA3	STA4	STA5	STA6	STA7	STA8	STA9	STA10	STA11
	STREAM VELOCITY (m/s)										
24-Jul-12	0.227	0.174	0.246	0.239	0.178	0.800	0.356	nd	nd	nd	nd
6-Aug-12	0.200	0.507	0.570	0.361	0.425	0.579	0.572	nd	nd	nd	nd
13-Aug-12	0.168	0.341	0.257	0.295	0.319	0.815	0.458	nd	nd	nd	nd
20-Aug-12	0.715	0.828	nd	nd	nd	nd	nd	nd	nd	nd	nd
3-Sep-12	0.502	0.355	0.677	0.428	0.394	0.695	0.735	0.598	0.839	1.107	0.761
10-Sep-12	0.333	0.127	0.535	0.306	0.203	0.405	0.505	0.237	0.243	0.228	0.305
17-Sep-12	0.243	0.155	0.249	0.303	0.247	0.395	0.478	0.355	0.423	0.196	0.210
15-Oct-12	0.170	0.103	0.119	0.329	0.116	0.231	0.376	0.119	0.148	0.206	0.165
26-Oct-12	0.177	0.095	0.151	0.275	0.119	0.191	0.528	0.100	0.182	0.211	0.211
29-Oct-12	0.149	0.0542	0.159	0.291	0.125	0.204	0.438	0.065	0.153	0.175	0.115
5-Nov-12	0.165	0.020	0.079	0.298	0.097	0.138	0.379	0.100	0.173	0.153	0.151
12-Nov-12	0.140	0.051	0.080	0.307	0.057	0.098	0.331	0.147	0.115	0.133	0.141
19-Nov-12	0.093	0.029	0.074	0.208	0.092	0.112	0.360	0.072	0.107	0.095	0.109
26-Nov-12	0.095	0.012	0.068	0.180	0.038	0.100	0.336	0.070	0.146	0.094	0.102
3-Dec-12	0.087	0.043	0.115	0.170	0.030	0.044	0.288	nd	nd	nd	nd
10-Dec-12	0.078	0.122	0.031	0.088	0.020	0.056	0.244	nd	nd	nd	Nd
	STREAM FLOW (m^3/s)										
24-Jul-12	0.119	0.209	0.392	0.562	0.466	0.722	0.792	nd	nd	nd	nd
6-Aug-12	0.120	1.084	0.649	1.528	1.344	1.520	1.999	nd	nd	nd	nd
13-Aug-12	0.083	0.627	0.803	1.196	0.938	1.539	1.171	nd	nd	nd	nd
20-Aug-12	0.492	2.706	nd	nd	nd	nd	nd	nd	nd	nd	nd
3-Sep-12	0.262	0.747	0.705	1.621	1.116	2.073	7.607	8.224	9.626	11.517	11.691
10-Sep-12	0.186	0.476	0.542	0.567	0.567	0.873	1.522	4.810	2.158	1.760	4.830
17-Sep-12	0.093	0.226	0.249	0.429	0.646	0.799	0.821	7.489	3.285	1.127	3.228
15-Oct-12	0.069	0.121	0.095	0.311	0.199	0.399	0.536	2.172	1.138	1.166	2.319
26-Oct-12	0.053	0.074	0.157	0.510	0.206	0.293	0.684	1.750	1.321	1.140	2.699
29-Oct-12	0.050	0.042	0.176	0.138	0.240	0.308	0.523	0.982	1.015	0.886	1.426
5-Nov-12	0.037	0.022	0.127	0.149	0.107	0.170	0.295	0.838	1.031	0.729	1.797
12-Nov-12	0.015	0.036	0.074	0.173	0.098	0.126	0.181	1.087	0.622	0.603	1.616
19-Nov-12	0.007	0.022	0.053	0.079	0.163	0.124	0.188	0.490	0.427	0.347	1.225
26-Nov-12	0.009	0.003	0.049	0.064	0.077	0.130	0.169	0.723	0.523	0.328	1.125
3-Dec-12	0.009	0.004	0.061	0.059	0.032	0.037	0.115	nd	nd	nd	nd
10-Dec-12	0.004	0.011	0.007	0.025	0.026	0.024	0.074	nd	nd	nd	nd

nd – no data

Table 2. Temporal and spatial variation of sediment concentration (kg/m^3) in the test watershed

DATE	SEDIMENT CONCENTRATION (kg/m^3)										
	STA1	STA2	STA3	STA4	STA 5	STA 6	STA 7	STA 8	STA 9	STA 10	STA 11
7-Aug-12	5.2	4.0	2.8	5.6	12.0	20.4	10.2	9.0	13.2	nd	nd
13-Aug-12	1.4	1.6	3.0	3.6	2.8	3.0	2.0	2.2	4.8	4.2	nd
21-Aug-12	2.2	4.0	4.8	4.8	5.4	3.8	7.2	6.4	7.0	6.8	8.8
29-Aug-12	2.8	4.2	5.8	4.2	4.4	3.2	5.8	7.6	7.8	6.6	9.6
3-Sep-12	2.6	4.4	1.8	4.2	5.2	4.2	4.4	4.4	4.8	5.2	5.4
10-Sep-12	7.0	7.8	7.4	7.6	9.0	6.4	7.4	8.2	7.8	8.4	6.6
18-Sep-12	3.2	4.2	4.4	4.4	4.8	4.0	4.8	4.8	4.6	5.6	8.6
26-Oct-12	2.4	2.6	3.4	4.0	3.2	2.8	3.6	2.8	4.6	6.2	5.0
29-Oct-12	2.8	3.6	2.2	3.8	3.2	3.8	4.6	2.8	2.6	5.8	6.4
5-Nov-12	2.6	3.2	2.8	2.2	2.4	4.2	5.4	3.0	3.2	4.2	4.4
12-Nov-12	4.2	6.2	3.4	5.6	3.0	7.2	4.0	3.6	3.2	4.6	5.6
19-Nov-12	1.8	3.2	4.4	3.2	3.0	4.2	3.0	4.2	5.0	2.4	2.8
26-Nov-12	2.6	3.2	3.8	2.8	2.2	2.0	2.4	3.2	3.0	3.0	2.4
3-Dec-12	3.0	3.6	5.6	4.4	7.4	5.2	3.6	6.4	5.6	6.8	6.2
10-Dec-12	1.6	2.4	4.0	3.0	4.4	3.2	6.4	5.4	2.8	5.2	6.4

nd – no data

Figure 3 shows the stream hydrograph of the Quiaoit river watershed measured in Station 1. In the future, the stream hydrograph in some key gaging stations along the Quiaoit River will be developed. Through this, we will be able to have a better prediction of the stream flow and sediment concentration in the river.

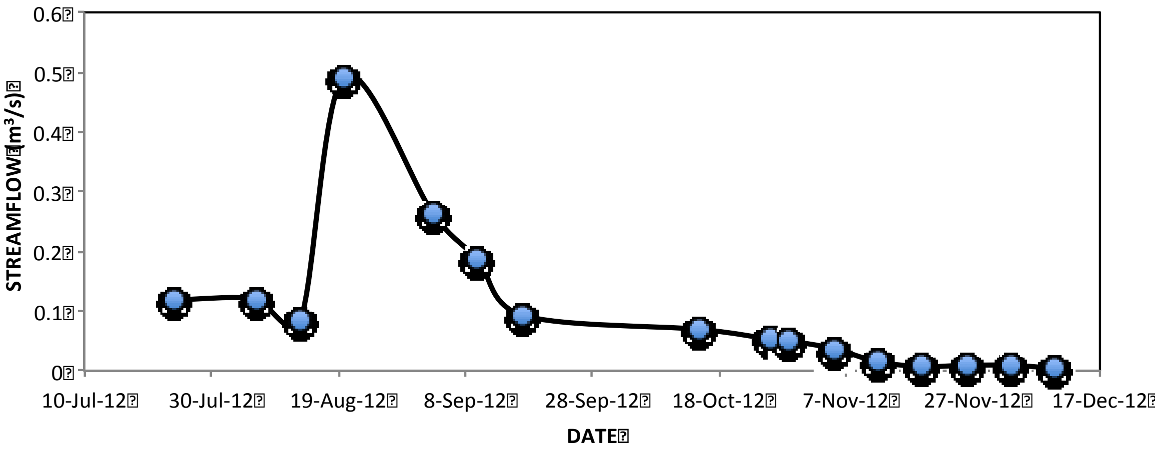

Figure 3. Stream hydrograph of the Quiaoit River in Station 1

3.2 Spatio-temporal water quality of the Quiaoit River

pH. The pH is an important property of water that can limit the diversity and quantity of biota of aquatic communities (Allan 1996) and can be a controlling component of solubility (Stumm and Morgan 1996). The pH is calculated as the negative log10 of hydrogen ions concentration occurring between 0 and 14 (Brown and other 2006). The pH is a measure of how acidic or basic a solution is. Acids are represented by values 0-7 and bases represented by values 7-14; a value of 7 is neutral. Lower pH can contribute to increased solubility of metals (Hem 1989).

The pH of a stream is affected by biological processes, geology, precipitation, and human activities. In our study, the pH of the river flow in the Quiaoit River watershed was monitored weekly in 11 sampling stations located along the stretch of the river from upstream to midstream. This was done primarily to assess the spatial and temporal variation of pH of the river flow in the test watershed. Result of our initial assessment shows an increased in pH as water moves downstream (Figure 4). Observed increase in pH can be attributed to the accumulation of dissolved mineral in water such as carbonate, which is common bedrock formation in the area. Evaluation of temporal trends of pH shows no definite pattern (Figure 5). Measured pH is within the range of acceptable values between 6.5 and 9.0 for aquatic life.

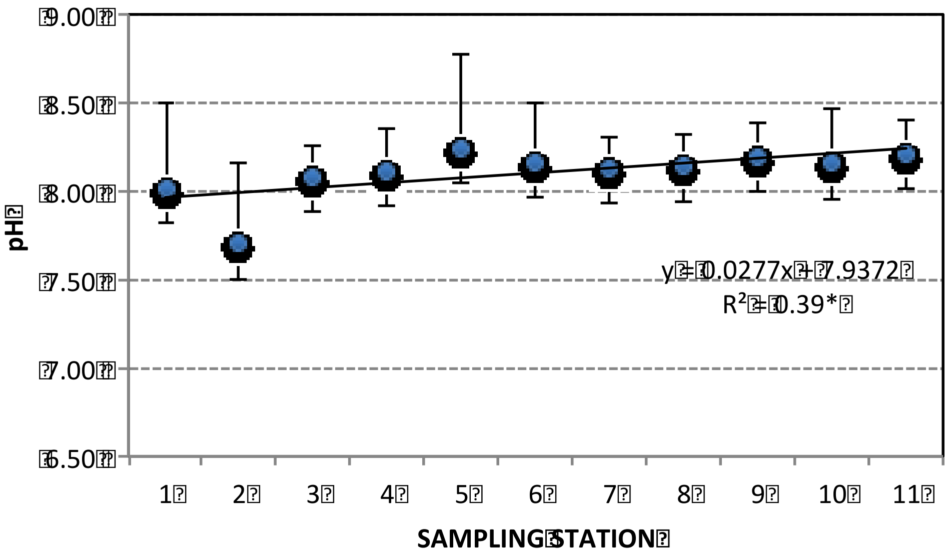

Figure 4. Spatial variation of pH in the Quiaoit River watershed. Bar indicates one standard deviation

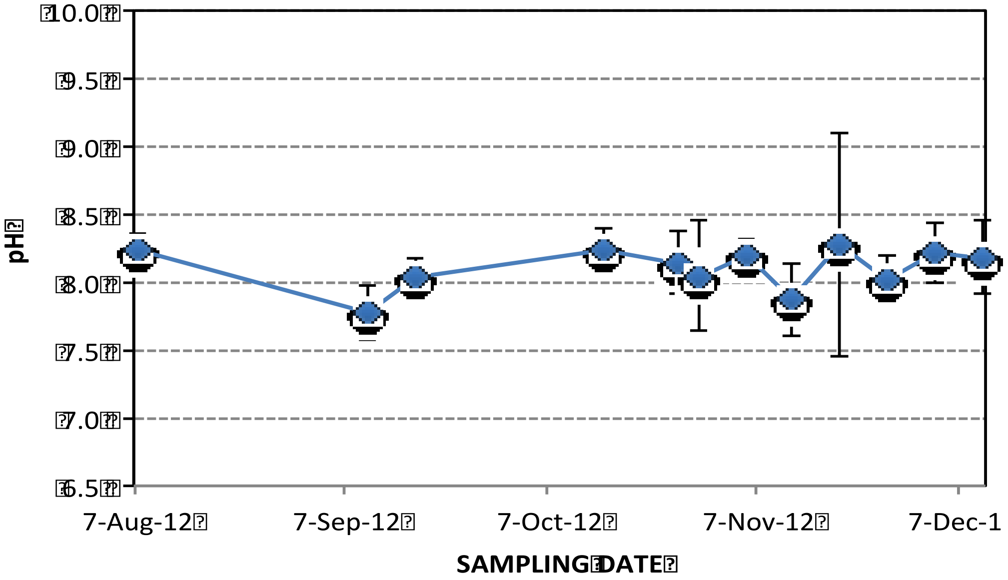

Figure 5. Temporal variation of pH in the Quiaoit River watershed. Bar indicates one standard deviation

Electrical Conductivity. Electrical conductivity is proportional to the dissolved solids concentration within the stream and has the ability to conduct an electrical current. The presence of charged ionic species in a solution makes the solution conductive. Electrical conductivity is an indirect measure of the presence of dissolved solids such as chloride, nitrate, sulfate, phosphate, sodium, magnesium, calcium, and iron, and can be used as an indication of water pollution.

Electrical conductivity in the Quiaoit river watershed was monitored in 11 stations along the stretch of Quiaoit River within the test watershed from August to December 2012, and ranged from 200 µS/cm to 980 µS/cm depending on site and time of the year. The spatial pattern shows a decrease in electrical conductivity as water moves downstream (Figure 6). Higher electrical conductivity in the upstream could be attributed to dissolved minerals of bedrocks. However, as the water moves downstream, the solution is diluted causing lower electrical conductivity. Evaluation of temporal trends shows that higher electrical conductivity is observed during the rainy season than toward the dry season (Figure 7). Again, higher concentration observed during the rainy season could be attributed to dissolved mineral bedrock, which is carried by runoff to the stream.

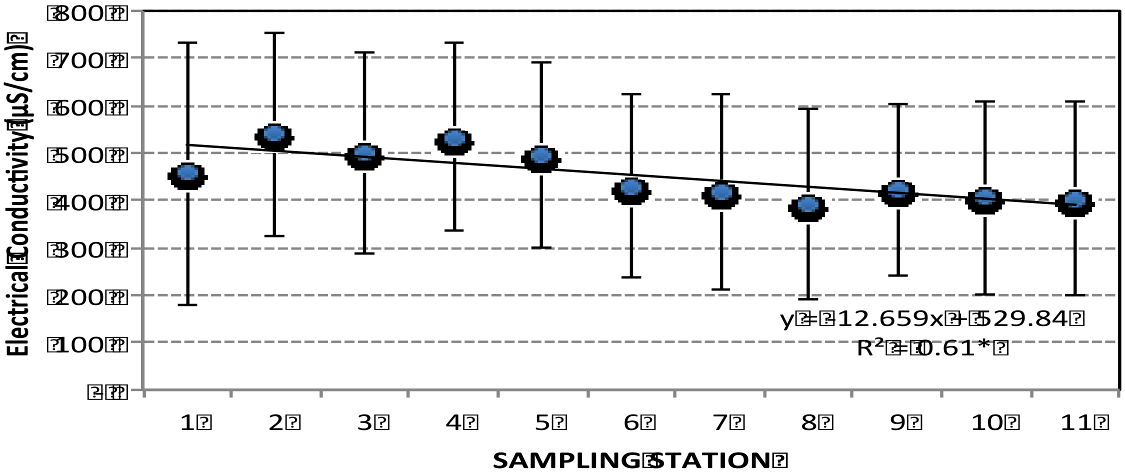

Figure 6. Spatial variation of electrical conductivity (µS/cm) in the Quiaoit River watershed. Bar indicates one standard deviation.

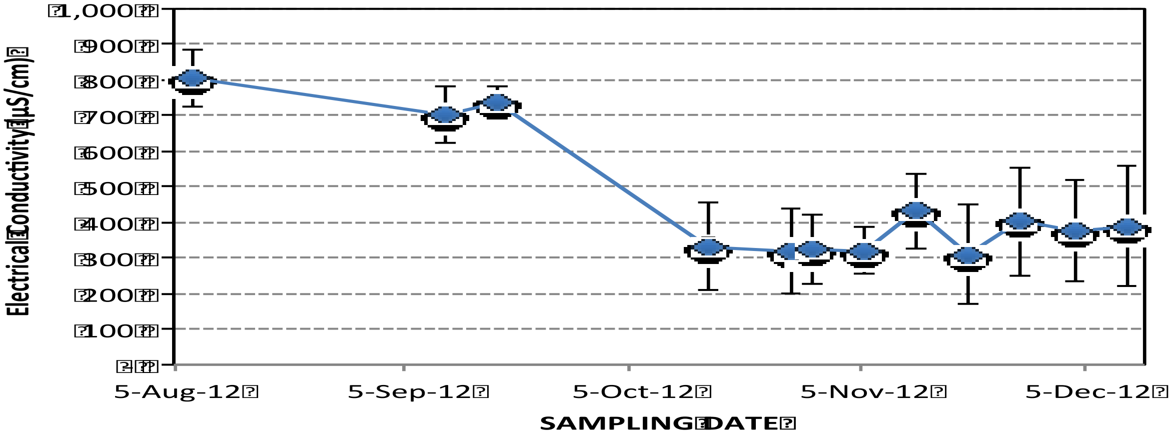

Figure 7. Temporal variation of electrical conductivity (µS/cm) in the Quiaoit River watershed. Bar indicates one standard deviation

Dissolved Oxygen. Dissolved oxygen is an important property of water that can affect both aquatic biota and chemical reactions within streams. It is important for all respiratory functions of aquatic life, including both plant and animal species. Dissolved oxygen levels are important components of oxidation-reduction reactions (redox) and can be important to oxidation states of transitions metals like copper, iron, manganese, and zinc (Stumm and Morgan 1996 as cited by Williams et al 2011).

The concentration of dissolved oxygen within a stream is dependent on many processes. Dissolved oxygen enters a stream through reactions between the stream and the atmosphere along the surface of the water, and through mechanical mixing of air and water in turbulent areas. It can be introduced directly by aquatic plants during photosynthesis. Additionally, it can also be consumed and eventually, reduced when the organic matter dies and decomposes (Williams et al 2011). This important process relates primarily to algal blooms. Dissolved oxygen concentrations are inversely related to water temperature, thus as temperature increases, the capacity of water to hold a given quantity of dissolved oxygen is reduced (Hem 1989). The dissolved oxygen concentration that was measured along the stretch of the Quiaoit River within the test watershed, ranged from 2 mg/L to 7.6 mg/l or 26 % to 99% of the saturated dissolved oxygen (Table 3). Accordingly, percent saturation values of 80-120% are considered to be excellent, and values less than 60% or over 125% are considered to poor quality water.

Table 13. Temporal and spatial variation of dissolved oxygenof the river flow of the test watershed

Station	DO, mg/L				DO, (%)		
	Mean	Minimum	Maximum		Mean	Minimum	Maximum
1	4.62	3.11	6.07		56.75	39.00	73.77
2	4.18	2.92	5.89		55.15	37.33	77.30
3	4.56	2.05	6.42		59.05	26.23	82.67
4	4.66	3.46	6.14		60.27	44.30	80.03
5	4.69	3.36	6.12		61.04	42.80	79.03
6	4.61	3.27	6.26		60.48	41.40	82.53
7	4.50	3.54	6.16		59.50	44.60	82.07
8	4.88	3.75	7.14		64.41	49.90	91.87
9	5.04	3.61	7.64		66.94	47.10	99.00
10	5.01	3.73	7.11		66.13	48.70	93.33
11	4.44	3.48	5.59		58.07	44.80	76.17

Note: Percent Saturation values of 80 - 120% are considered to be excellent, and values less than 60% or over 125% are considered to be poor.

Spatial variations in dissolved oxygen concentration show a slight increase as water moves downstream (Figure 8). The mean dissolved oxygen concentrations are all below the standard minimum dissolved oxygen (6.0 mg/l) and minimum dissolved oxygen for fish spawning (7.0 mg/l). Evaluation of temporal trends of dissolved oxygen concentration did not show definite trend (Figure 9).

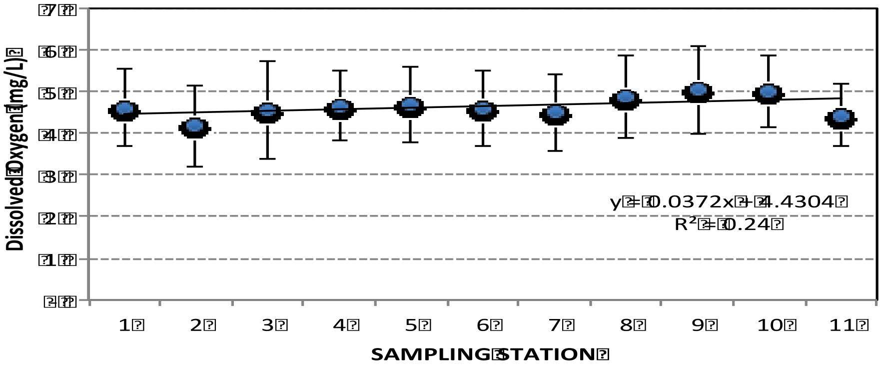

Figure 8. Spatial variation of dissolved oxygen (mg/l) in the Quiaoit River watershed.

Bar indicates one standard deviation

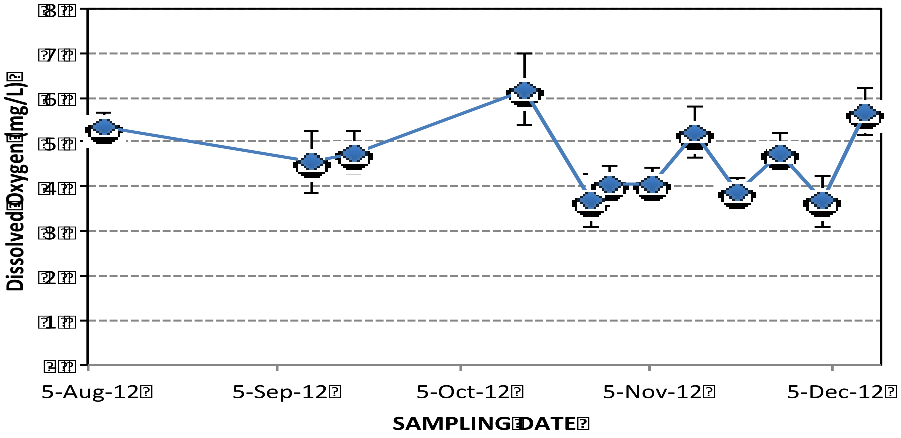

Figure 9. Temporal variation of dissolved oxygen (mg/l) in the Quiaoit River watershed. Bar indicates one standard deviation

Water temperature. Temperature is an important physical property of water that can affect aquatic biota and stream chemistry. Water temperature affects larval maturation rates and other life cycles of biota in aquatic habitats (Allan 1996). It also affects the rate of many chemical reactions in water.

Water temperature measured along the stretch of Quiaoit River within the test watershed, ranged from 24°C to about 32°C regardless of season and spatial distribution. Mean temperature for the Quiaoit River watershed generally increases in the downstream direction (Figure 10).

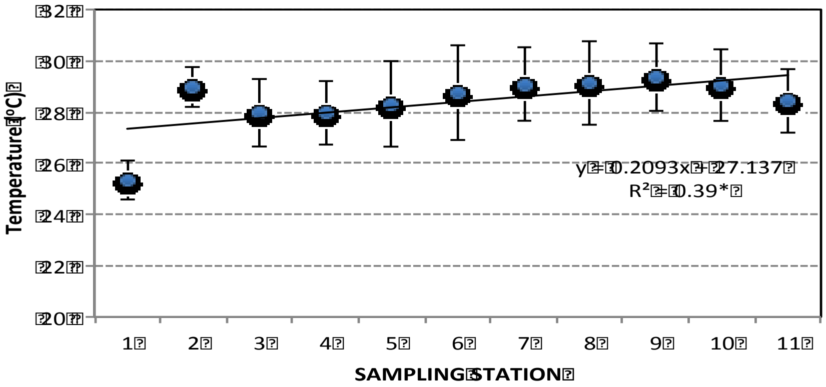

Figure 10. Spatial variation of water temperature (°C) in the Quiaoit River watershed. Bar indicates one standard deviation

Such increase could be attributed to the lesser vegetation that shades the river from sunlight downstream. Seasonal variations in the mean temperatures show that water temperature decreases toward December following ambient air-temperature pattern in the study area (Figure 11).

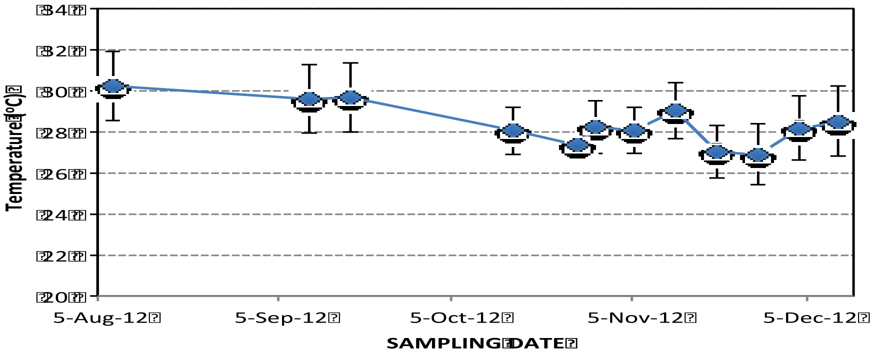

Figure 11. Temporal variation of water temperature (°C) in the Quiaoit River watershed. Bar indicates the one standard deviation

Nitrate-N. Nitrate is the most stable nitrogen form found in natural waters and can exist in a wide range of environmental conditions (Mueller et al. 1995). Natural sources of nitrogen to stream may include chemical dissolution or reaction with nitrogen-rich minerals within soils and geologic formations, decomposition of organic matter, and atmospheric decomposition. Additional sources may include human activities related to agriculture such as fertilizers, seepage from septic systems, and effluents from livestock houses.

Nitrate-N concentration was monitored in 11 stations along the stretch of the Quiaoit River within the test watershed from September 2012 to January 2013. Mean nitrate-N concentrations within the test watershed ranged from 0.1 ppm to 3.4 ppm. Spatially, it was observed that stations 6 and 8 gave the highest nitrate-N concentration (Figure 12). It was noted that it is also within these stations where agricultural areas are concentrated in both sides of the river. As such, it is possible that portion of the applied nitrogen fertilizers is carried by runoff water to the river.

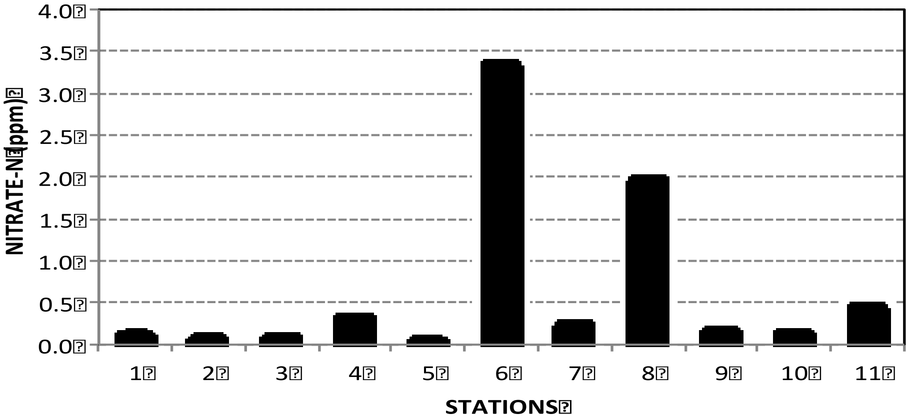

Figure 12. Spatial variation of mean nitrate-N of surface water in the Quiaoit River watershed

Evaluation of temporal trends showed an increasing trend toward the dry season especially in stations 5, 6, 7 and 8 (Figure 13). Lower concentration during the rainy season or period of high flows could be attributed more to dilution effect.

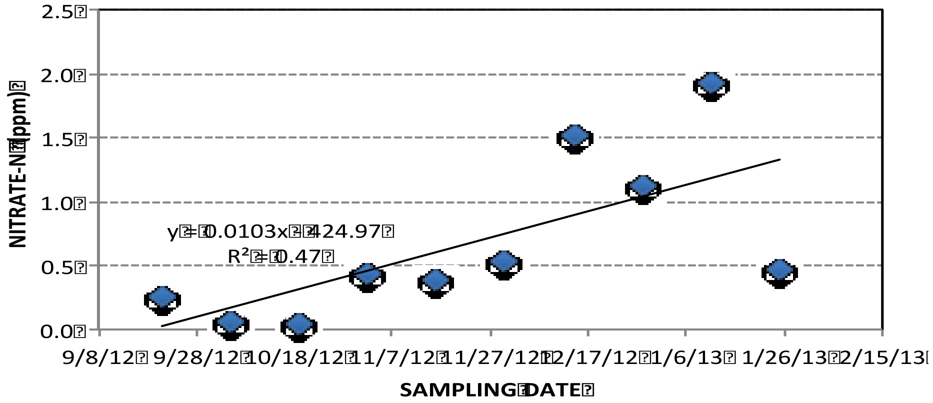

Figure 13. Temporal variation of nitrate-N of surface water in the Quiaoit River watershed

4. SUMMARY AND CONCLUSION

Present study provides important information about the spatial and temporal variations in water quality of the Quiaoit River, which is an important water source for both domestic and agricultural uses. The study identified distinct spatial and temporal variations of water quality measurements and also highlighted that spatial heterogeneity, in terms of surface water pollution, is likely related to anthropogenic factors. The upstream sites have better water quality compared to sites located downstream. The water quality declined as the water moved downstream due to waste input from household and agricultural discharges. The study showed that mean dissolved oxygen concentrations are all below the standard minimum dissolved oxygen (6.0 mg/l) and minimum dissolved oxygen for fish spawning (7.0 mg/l). Also, mean nitrate-N concentrations within the test watershed ranged from 0.1 ppm to 3.4 ppm. Spatially, it was observed that nitrate-N concentration in the river was highest near agricultural areas.

The poor water quality appeared to be linked to local pollutant inputs from untreated household and municipal wastes as well as from agricultural runoff. Strict enforcement of existing guidelines and policies (i.e. DAO 35) for the protection of the river must be implemented to prevent the discharge of untreated wastewater into the river.

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