Physico-Chemical Assessment of the Jalaur River System, Iloilo, Philippines

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The Jalaur River System was studied for the quality of its water because water quality is a significant and powerful determinant of the health of aquatic ecosystems. This study aimed at investigating the physico-chemical parameters, nutrient load, heavy metal concentrations and pesticide residues of the Jalaur River system. One of the purposes of this study was to develop a database on the seasonal changes in these river characteristics.

Quantitative samples of water, sediments, algae and fish were collected and analyzed during the rainy season (July-September 2009) and the dry season (January-March 2010) from five sampling stations representing upstream, midstream and downstream sections of the 123-kilometer long river. Based on the water quality standard and water classification adopted by DENR, the Jalaur River stretch can be classified as class C and D. Class C water is for propagation and growth of aquatic resources while class D water is for agriculture, irrigation, livestock watering, and industrial cooling and processing.

The detected levels of metal contamination, mainly Cr, and Pb, in sediments of Jalaur River were found to exceed the geochemical background or threshold levels. Lead and chromium were also detected in filamentous algae (lumot), *Azolla*, and tilapia (*Oreochromis niloticus*) sampled at Moroboro sampling site. No organochlorines, organophosphates, carbamates, and pyrethroids pesticides were detected at the detection limit of the analyses for both water and sediment samples.

The deterioration in the physico-chemical quality and rise in the nutrient levels observed in this study is alarming, and periodic monitoring and preventive measures are required to save the aquatic system from eutrophication. Heavy metal contamination of bottom sediments, algae and fish samples is also a cause for alarm because these heavy metals pose threats to human health. The findings have important implications for the development of effective water management strategies and as guide to remediation efforts for the Jalaur River system.

KEYWORDS: aquatic ecosystem, Panay Island, physico-chemical, river system

INTRODUCTION

The Jalaur River Basin is the largest in Iloilo draining over 1,800 square kilometers of the province. The Jalaur River begins in the mountains west of Calinog and flows eastward through rolling hills to the town of Passi where it combines with Lamunan River at the North. Jalaur River is connected to Jagdong River at Dingle, and Sauge River at Pototan, then turns south, finally reaching its mouth at the Iloilo Strait in the Leganes area. The river water travels 123 kilometers from its source to its mouth in the Iloilo Strait (Figure 1). The river is of great economic importance to the province of Iloilo. It provides irrigation to farmlands in the province and constitutes a source of potable water for its inhabitants.

Rivers have important multi-usage components, such as sources of drinking water, irrigation, fishery and energy production (Ischen, Emiroglu, Lihan, Arsian, Yilmaz, & Ahiska, 2008; Prat & Munné, 2000). In the recent past, expanding human population, industrialization, intensive agricultural practices and discharges of massive wastewater

Figure 1. Map of Iloilo province showing the location of the sampling sites.

into the rivers and streams have resulted in the deterioration of water quality. The impact of these anthropogenic activities has been so extensive that the water bodies have lost their self-purification capacity to a large extent (Adomiec & Helios-Ryleicka, 2002; Sood, Singh, Pandey, & Sharma, 2008; Wahaob & Badawy, 2004).

Water quality is a dominant factor in determining the adequacy of any supply to satisfy the requirements of these uses. Essentially, all water will contain substances derived from the natural environments or from the waste products of human activity. These chemical constituents are basic criteria in the determination of water quality. In addition, the various properties of water imparted by the constituents serve to further define the quality of water.

A river is an open system with strong interactions with its drainage basin. Various abiotic and biotic processes, such as tectonic dynamics, weathering, erosion and sedimentation, evaporation, biological activity, adsorption, and desorption, flushing, and so on, as well as human interference, interact within the watershed, river floodplains, the riparian zone and water body, determining its aquatic composition and ecological character (Petts & Calow, 1996).

The size and nature of the area drained by the Jalaur River makes it more prone to pollution that impacts aquatic life and the industries that depend on the river. If damage to the river and dependent industries is to be prevented or reversed, current levels of pollution and the present productivity of the river must be investigated.

Assessment of the water quality of a river system is an important factor for the characterization of water resources. This would provide better understanding of the physico-chemical properties of the river water. These data would provide useful information for the future users and developers of the river. The information obtained can be used to minimize the amount of industrial and agricultural waste discharge into the river and to develop an effective tool to protect the water quality of the river and is useful for environmental control.

Objectives of the Study

This study was conducted to assess the water quality of the Jalaur River system. Specifically, the objectives were [1] to determine the physico-chemical water quality parameters such as pH, temperature, dissolved oxygen (DO), salinity, chlorides, hardness, total dissolved solids (TDS), total suspended solids (TSS), alkalinity, ammonia, nitrites, and phosphates of river waters; [2] to assess the heavy metal (Cd, Pb, Cr) contamination of river waters, sediments, algae and fishes; and [3] to assess the pesticide contamination of river waters, and sediments.

METHODS AND MATERIALS

Sampling Sites

Strategic sampling points were established along the river to cover the upstream (Calinog), midstream (Dingle) and downstream (Leganes) sections of the Jalaur River (Figure 1). Then at each river section, one barangay per sampling point was chosen except for the midstream section where three barangays were selected. The barangays chosen were: Upstream (Calinog)-Brgy. Banban Pequeño; Midstream-Brgy. Imbang Pequeño, Passi (near Sugar Central), Brgy. Licuan, Dingle (near NPC), Brgy. Moro-boro, Dingle, Iloilo; and Downsteam-(Leganes), Brgy. Nabitasan, Leganes, Iloilo.

Sample Collection and Frequency

Parameters that could be measured on site (e.g. temperature, pH, dissolved oxygen and salinity) were immediately determined using portable meters while samples that were analyzed in the laboratory were collected and preserved. Surface water samples were collected about 10 cm below the water surface using polyethylene bottles. At the sampling sites, the clean sampling bottles were rinsed several times with the river water before the actual water samples were collected. Finally, the filled sample bottles were sealed, labeled, and taken directly to the laboratory for the analyses. The samples for physico-chemical analysis were placed in an icebox and transported to the laboratory for immediate analysis. Sampling was done two to three times from each of the five sites during rainy (July to September 2009) and dry (January to March 2010) seasons.

For the heavy metal contamination analyses, water, sediments and fish samples were taken twice (wet and dry seasons) from the five sites while samples for pesticide residue analyses were taken once during the dry season from the five sites.

Sample Processing and Analyses

Determination of physico-chemical parameters of the river waters as well as analyses of heavy metals (Cd, Pb, & Cr) and pesticide residues of river waters, sediments, algae, and some fishes followed the standard laboratory methods of EPA (2001), AOAC (2005), and APHA (1998). Heavy metals were determined using atomic absorption spectrophotometer. Carbamates were analyzed using high performance liquid chromatography (HPLC), organochlorines and pyrethroids were analyzed by gas chromatography with electron capture detector (GC-ECD) while organophosphorus pesticides were by GC-NPD.

Statistical Analysis

The values were computed, analyzed and presented as mean ± standard deviation. Two-way ANOVA was conducted to determine spatial and temporal correlations between locations and seasons respectively. Levels of significant differences in the values of the parameters determined during dry and rainy seasons were assessed. Differences were regarded to be significant at 95% confidence limit ($p \leq 0.05$).

RESULTS AND DISCUSSION

This study provides data on the physico-chemical parameters and inorganic nutrient load of the river water of the Jalaur River system. Results of the assessment of physical-chemical parameters during rainy and dry seasons are presented in Tables 1 and 2 and Figures 2 to 12. The summary of the recommended standards for various water quality parameters based on Organization for Economic Cooperation and Development (OECD) and EPA is shown in Table 3 while the water quality guidelines and classification based on DENR are shown in Table 4 and 5, respectively. These tables were used as references for evaluation of the water quality of the river.

The results of the heavy metal contamination in both water and bottom sediments are presented in Tables 6 to 9 while the concentrations of pesticide residues are presented in Table 10.

The pH values obtained from all sites ranged from 7.4 to 8.6, and there were no significant differences between seasons and sites

Table 1.

Mean ± SD of physico-chemical parameters (wet season) of Jalaur River.

Parameters	Calinog	Sugar Central	Moroboro	NPC	Leganes
pH	8.6 ± 0.2	7.7 ± 0.1	8.3 ± 0.2	8.2 ± 0.1	8.0 ± 0.1
Temp (oC)	25.5 ± 2.0	27.2 ± 1.0	28.3 ± 1.0	28.2 ± 0.4	28.6 ± 1.3
DO (mg/L)	6.1 ± 0.8	4.2 ± 0.3	5.6 ± 0.1	5.6 ± 0.1	6.1 ± 0.3
Salinity (ppt)	0	0	0	0	2.3 ± 1.5
TSS (mg/L)	1376.7 ± 2104.7	212.3 ± 11.2	144.7 ± 6.5	154.0 ± 4.0	259.2 ± 139.7
TDS (mgl/L)	183.3 ± 37.9	210.0 ± 0.0	229.3 ± 62.0	250.7 ± 1.2	7455.7 ± 6831.0
Alkalinity (mg/L)	162.3 ± 11.2	148.0 ± 3.0	152.7 ± 36.1	160.3 ± 5.5	141.3 ± 22.0
Hardness (mg/L)	126.0 ± 7.5	131.0 ± 1.0	136.7 ± 32.1	145.7 ± 4.0	1366.7 ± 1158.7
Chlorides (mg/L)	9.7 ± 0.1	9.7 ± 0.1	9.7 ± 0.1	9.7 ± 0.1	5469.3 ± 1135.0
Nitrite (mg NO2–N/L)	0.06 ± 0.02	0.08 ± 0.0	0.05 ± 0.02	0.07 ± 0.005	0.05 ± 0.01
Ammonia (mg NH3–N/L)	0.06 ± 0.02	0.09 ± 0.01	0.2 ± 0.3	0.07 ± 0.01	0.2 ± 0.1
Phosphates (mg PO4–P/L)	0.2 ± 0.1	0.21 ± 0.1	0.17 ± 0.01	0.05 ± 0.01	0.2 ± 0.06

Table 2.

Mean ± SD of physico-chemical parameters (dry season) of Jalaur River.

Parameters	Calinog	Sugar Central	Moroboro	NPC	Leganes
pH	8.4 ± 0.2	7.5 ± 0.3	8.0 ± 0.2	8.1 ± 0.1	8.1 ± 0.2
Temp (°C)	28.2 ± 2.2	28.6 ± 1.1	28.3 ± 0.5	28.1 ± 0.2	28.4 ± 0.5
DO (mg/L)	6.2 ± 1.3	4.0 ± 1.0	5.5 ± 0.9	5.9 ± 0.2	5.6 ± 0.6
Salinity (ppt)	0	0	0	0	15.0 ± 13.2
TSS (mg/L)	153.3 ± 84.7	189.7 ± 129.0	143.7 ± 73.3	145.0 ± 94.0	643.7 ± 329.0
TDS (mglL)	180.3 ± 59.1	200.3 ± 90.6	238.7 ± 40.8	224.0 ± 48.8	5009.7 ± 6976.6
Alkalinity (mg/L)	133.0 ± 32.0	144.0 ± 47.0	157.3 ± 46.6	153.3 ± 38.4	179.7 ± 90.8
Hardness (mg/L)	130.0 ± 11.1	144.0 ± 5.3	168.7 ± 7.0	160.0 ± 5.3	1143.3 ± 390.7
Chlorides (mg/L)	13.0 ± 7.0	18.2 ± 5.7	19.0 ± 8.6	17.2 ± 9.6	6561.0 ± 1219.8
Nitrite (mg NO2-N/L)	0.003 ± 0.006	0.003 ± 0.006	0.003 ± 0.006	0.003 ± 0.006	0.003 ± 0.006
Ammonia (mg NH3 – N/L)	0.04 ± 0.07	0.03 ± 0.04	0.02 ± 0.02	0.02 ± 0.02	0.02 ± 0.02
Phosphates (mg PO4–P/L)	0.12 ± 0.0	0.25 ± 0.2	0.09 ± 0.05	0.15 ± 0.11	0.22 ± 0.2

Table 3.

Water quality standards of surface water based on OECD and DENR.

Parameters	Standard
Water temperature (CO)	Not more than 30C rise in temperature
pH	6.5 to 8.5
Chlorides (mg/L)	200
Alkalinity (ppm CaCO3)	>100 mg/L
Hardness (ppm CaCO3)	300
DO (mg/L)	≥ 5
Salinity (ppt)	0-5
Dissolved Solids (mg/L)	500
Suspended Solids (mg/L)	100
Nitrite (mg NO2-N/L)	0.06
Ammonia (mg NH3-N/L)	0.4
Phosphorus (mg PO4-P/L)	0.2

OECD – Organization of Economic Cooperation and Development
DENR – Department of Environment and Natural Resources

Table 4.

Water quality guidelines and water classification based on DENR water body classification.

Parameters	AA	A	B	C	D
Chlorides (mg/L)	250	250	–	–	300
DO (mg/L)	5	5	5	5	3
pH (range)	6.5-8.5	6.5-8.5	6.5-8.5	6.5-8.5	4.5-9
Temperature (^{o}C)	30	30	30	3e	3e
Alkalinity (mg/L)	–	150	–	200	500
Nitrite-N (mg/L)	1.0	1.0	–	–	–
Ammonia (mg NH3-N//L)	NDA	0.5	0.5	0.5	7.5
Phosphates(mgPO4-P/L)	0.15	0.15	–	–	–
TSS (mg/L)	NDA	70	85	100	150

– no quantitative recommendation is specified
3e rise in temperature

Table 5.

Water classification based on DENR.

Water Classification	Description
Class "AA"	For source of public water supply. This class is intended for waters such as watersheds which are uninhabited and otherwise protected which require only approved disinfection on order to meet the National Standards for Drinking Water (NSDW)
Class "A"	For sources of water supply that will require complete treatment (coagulation, sedimentation, filtration, and disinfection) in order to meet the NSDW standards
Class "B"	For primary contact recreation
Class "C"	For propagation and growth and other aquatic resources
Class "D"	For agriculture, irrigation, livestock watering and industrial cooling and processing
Class "E"	For navigational use

Table 6.

Heavy metal concentration in water of Jalaur River (wet and dry season).

Sample Source	Total Cadmium *a* (mg/L)	Total Lead *b* (mg/L)	Total Chromium *c* (mg/L)
Calinog	Not detected	Not detected	Not detected
Sugar Central	Not detected	Not detected	Not detected
NPC	Not detected	Not detected	Not detected
Dingle	Not detected	Not detected	Not detected
Leganes	Not detected	Not detected	Not detected

[a] Detection limits Cd: 0.005 mg/L
[b] Detection limits Pb: 0.01 mg/L
[c] Detection limits Cr: 0.005 mg/L

Table 7.

Heavy hetal concentration in sediments from Jalaur River (wet season).

Sample Source	Total Cadmium (mg/kg)	Total Lead (mg/kg)	Total Chromium (mg/kg)
Calinog	Not detected	2.3	44.9
Sugar Central	Not detected	5.1	39.2
NPC	Not detected	3.4	36.6
Dingle	Not detected	150.7	39.1
Leganes	Not detected	2.4	32.7

[a] Detection limits Cd: 0.10 mg/kg

Table 8.

Heavy Metal Concentration in Sediments (dry season).

Sample Source	Total Cadmium (mg/kg)	Total Lead (mg/kg)	Total Chromium (mg/kg)
Calinog	Not detected	12.3	67.1
Sugar Central	Not detected	8.1	28.9
NPC	Not detected	7.8	23.0
Dingle	Not detected	8.7	33.5
Leganes	Not detected	6.9	29.4

[a] Detection limits Cd: 0.20 mg/kg

Table 9.

Heavy metal concentration in algae and fish samples.

Sample Source	Total Cadmiuma (mg/kg)	Total Lead (mg/kg)	Total Chromium (mg/kg)
Lumot (Dingle)	Not detected	5.51	29.4
Azolla (Dingle)	Not detected	3.34	5.57
Tilapia (Dingle)	Not detected	0.71	0.94
Goby (Dingle)	Not detected	Not detected	Not detected
Mullet (Dingle)	Not detected	Not detected	Not detected
Carp (Dingle)	Not detected	Not detected	Not detected
Carp (Passi)	Not detected	Not detected	Not detected

Table 10.

Pesticide Residues in Water and Sediment Samples.

Sample	Carbamates (μg/mL)	Organochlorines (μg/mL)	Organophosphates (μg/mL)	Pyrethroids (μg/mL)
Water samples				
Calinog	< 0.005	< 0.003	< 0.005	< 0.0005
Sugar Central	< 0.005	< 0.003	< 0.005	< 0.0005
NPC	< 0.005	< 0.003	< 0.005	< 0.0005
Moroboro	< 0.005	< 0.003	< 0.005	< 0.0005
Leganes	< 0.005	< 0.003	< 0.005	< 0.0005
Sediment samples				
Calinog	< 0.01	< 0.005	< 0.01	< 0.001
Sugar Central	< 0.01	< 0.005	< 0.01	< 0.001
NPC	< 0.01	< 0.005	< 0.01	< 0.001
Moroboro	< 0.01	< 0.005	< 0.01	< 0.001
Leganes	< 0.01	< 0.005	< 0.01	< 0.001

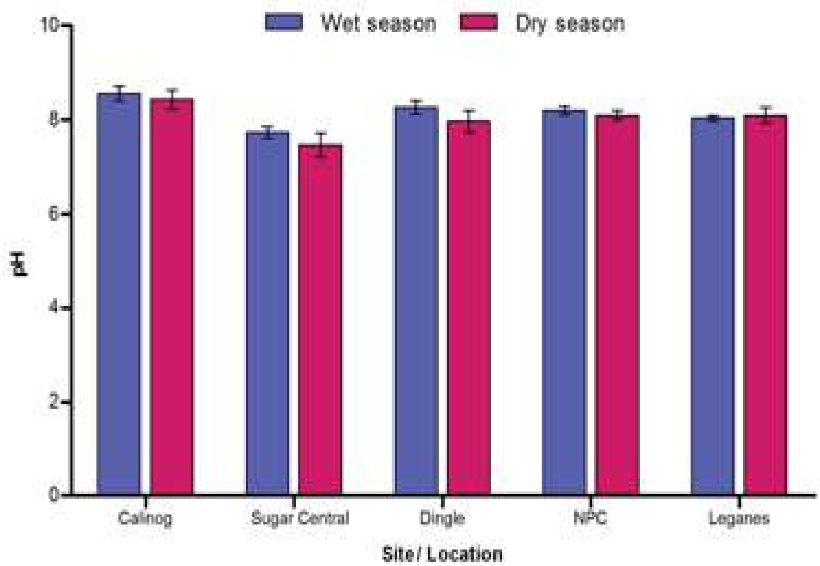

Figure 2. Mean ±SD of PH at different sites and seasons.

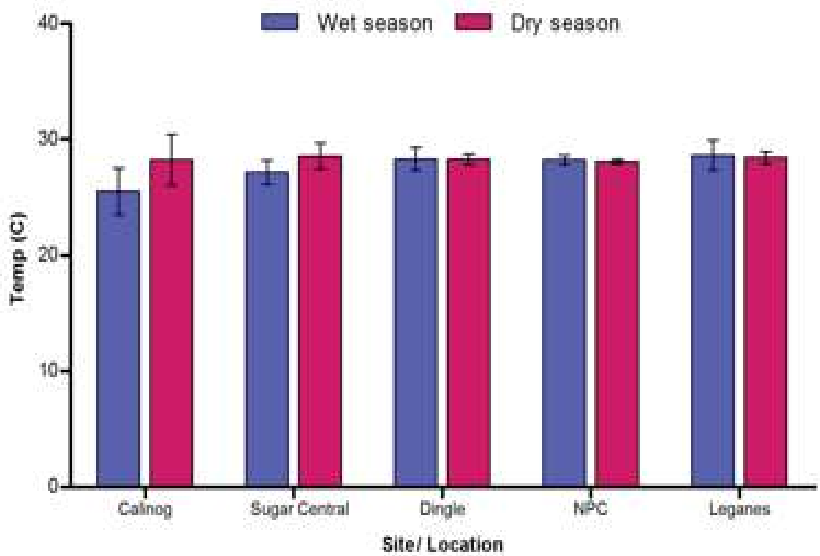

Figure 3. Mean ±SD of temperature at different sites and seasons.

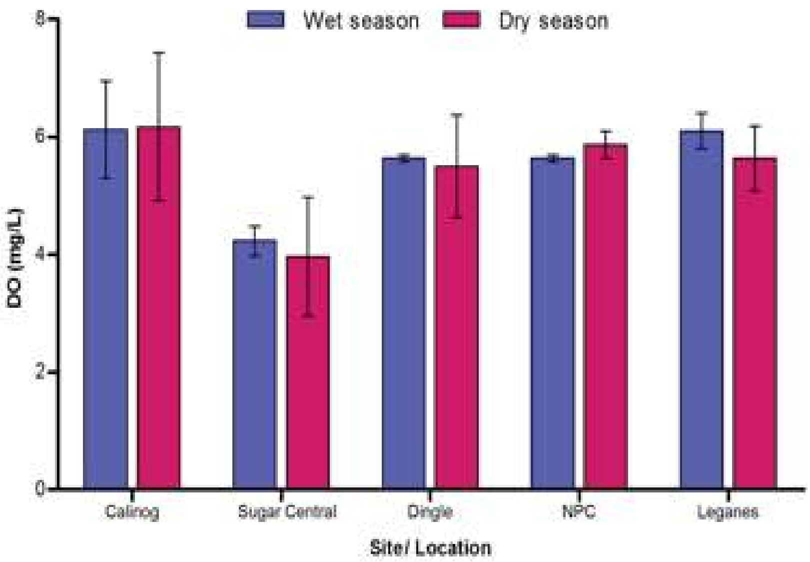

Figure 4. Mean ±SD of DO at different sites and seasons.

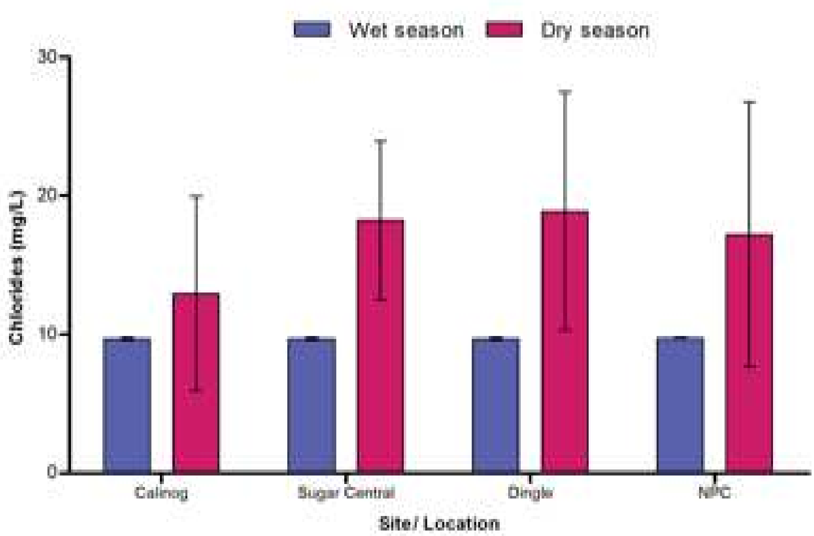

Figure 5. Mean ±SD of chlorides at different sites and seasons.

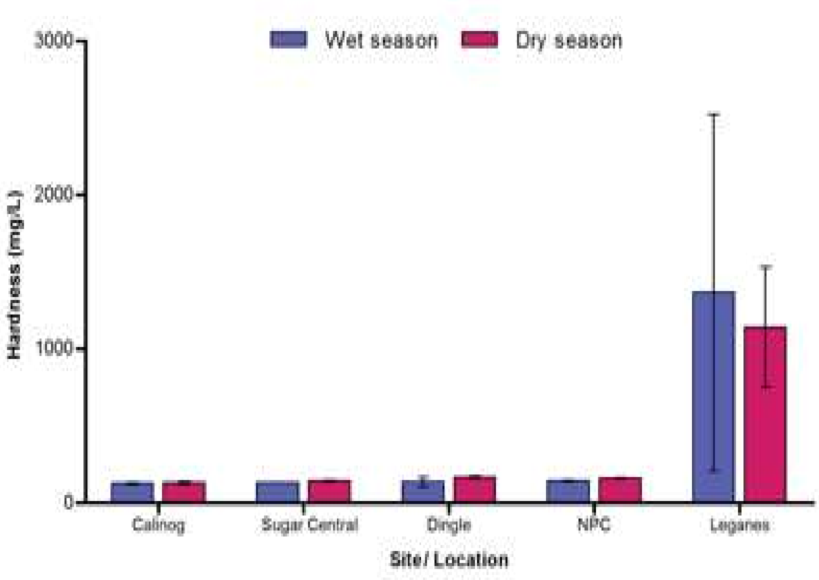

Figure 6. Mean ±SD of water hardness at different sites and seasons.

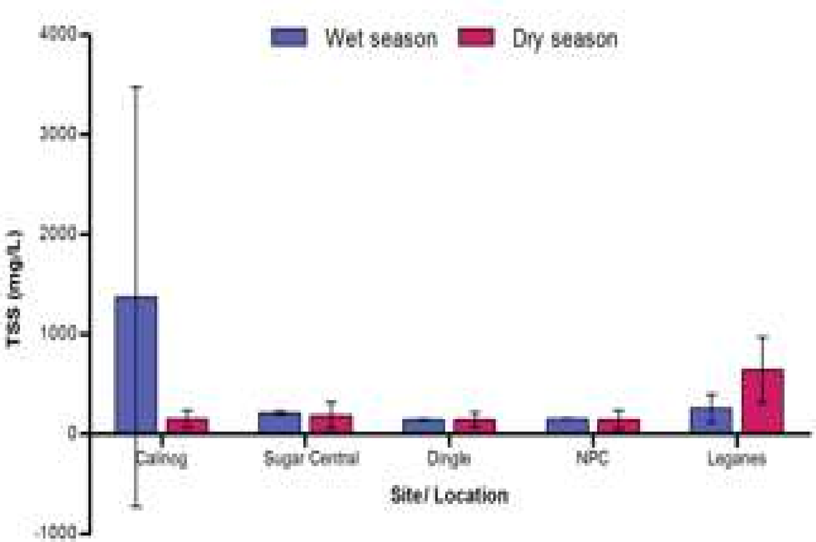

Figure 7. Mean ±SD of TSS at different sites and seasons.

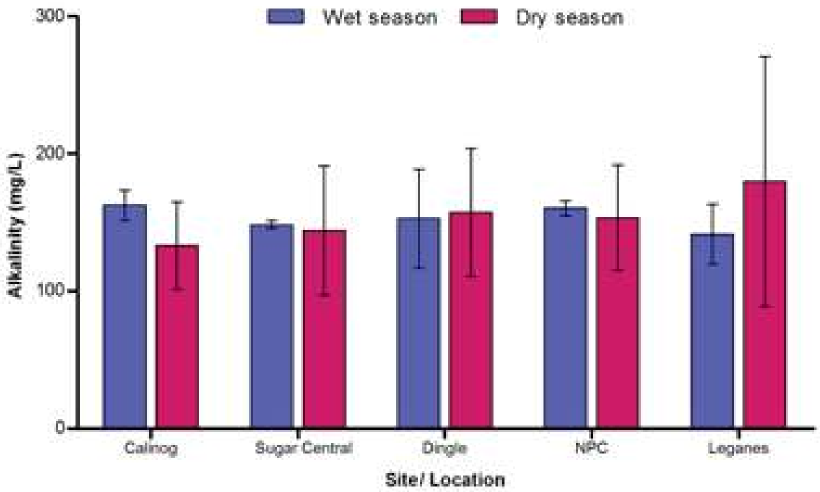

Figure 8. Mean ±SD of TDS at different sites and seasons.

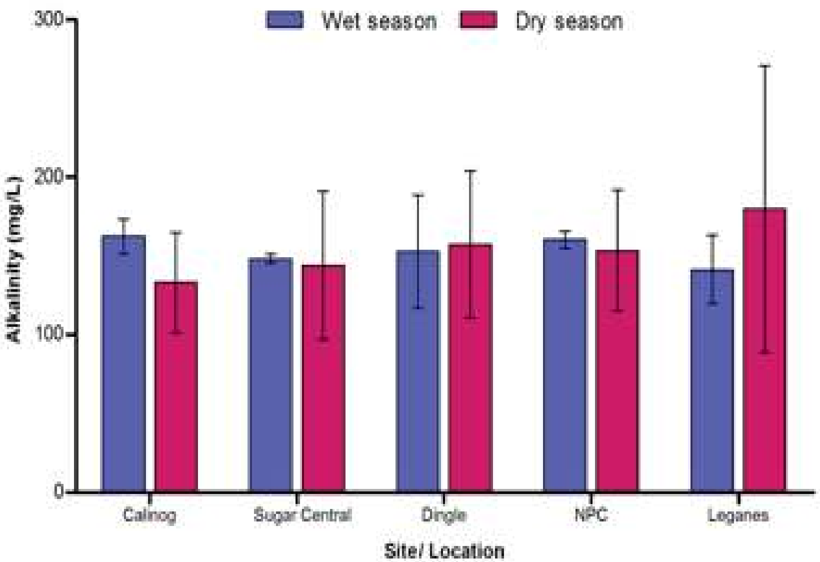

Figure 9. Mean ±SD of alkalinity at different sites and seasons.

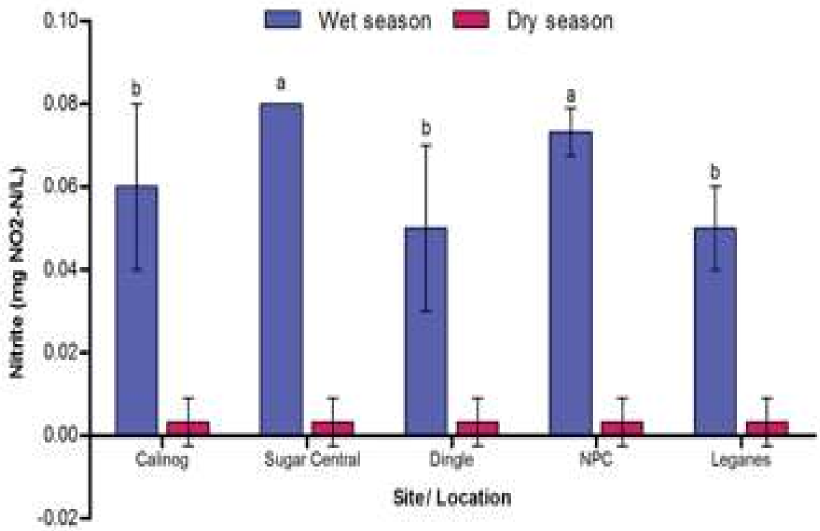

Figure 10. Mean ±SD of nitrite at different sites and seasons.

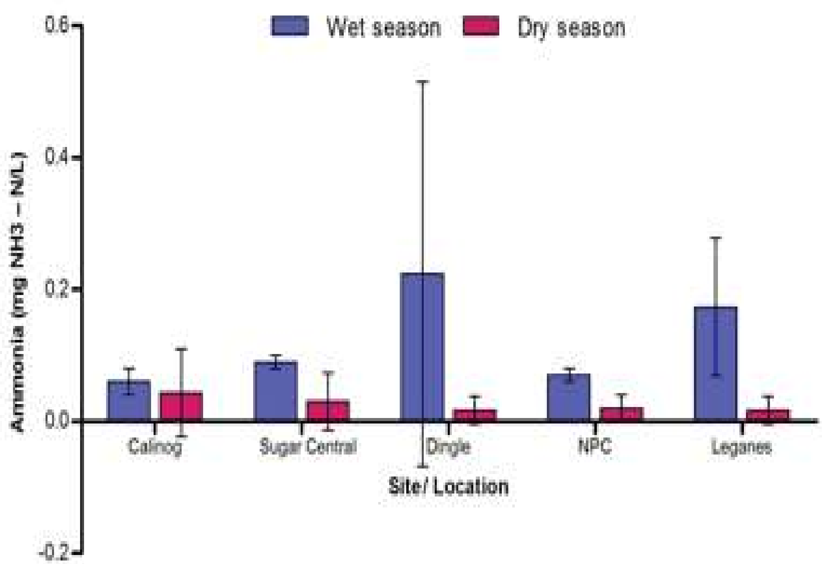

Figure 11. Mean ±SD of ammonia at different sites and seasons.

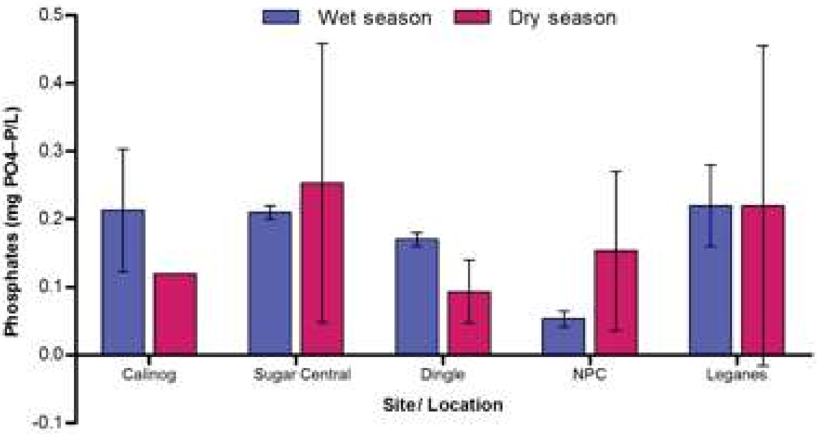

Figure 12. Mean ±SD of phosphates at different sites and seasons.

(Figure 2). These values are within the optimal level recommended in the water quality standard of EPA and OECD (Table 3). Aquatic organisms are affected by pH because most of their metabolic activities are pH dependent (Wang,Wang, Chen, Liu, & Sun, 2002). Optimal pH range for sustainable aquatic life is pH 6.5–8.5 (Murdoch, Cheo, & O'Laughlin, 2001). Based on this parameter, Jalaur River can still sustain aquatic life.

Temperature variations for the entire reach of the river ranged from 25.6 to 28.6oC and no significant differences were observed between seasons and sites (Figure 3). The river is protected from extreme heating and cooling by the moderately dense vegetation.

Figure 4 presents the variations in dissolved oxygen levels at each site location, for dry and rainy seasons. No significant differences in the DO level were observed between seasons and at the other four sites, but DO level near the Sugar Central was significantly lower than in all others sites. DO level near the sugar central was also lower than the recommended value that must be ≥5.0 mg/L. The lower DO at this site indicates that the site might not be suitable for aquatic life. Findings of Iwegbue, Nwajei, and Arimoro (2007) attribute the low DO concentration of the river to the degradation of the bed of settled particulate matter and adsorbed organic matter. We had observed that at this site the water was shallow and the bottom sediments were colored black and had a foul smell.

For both wet and dry season, the salinity in the four sites was zero, but at the Leganes station, it ranged from 2 to 4 ppt during wet season and 5 to 25 ppt during dry season (Tables 1 & 2)—an indication of salt water intrusion. The salinity of the downstream section (Nabitasan, Leganes) was subject to wide variations. Heavy river inflow displaces significant volumes of saline water seaward, while lower drought flows permits the salinity of this area to increase (Powell, 1974).

Salt water intrusion at the downstream section was further confirmed with the results of chloride concentrations. At the four sites, significantly higher chloride concentrations (Ave. =18 mg/L) were obtained during the dry season compared to the wet season (Ave. =9.7 mg/L). These constituents are mostly derived from sedimentary rock materials. The chloride ion concentrations of these four sites are generally low, indicating Cl- free soils within the watershed. The observed values for the four stations are relatively low compared to the allowable limit of 200 mg/L for irrigation purposes. For the Leganes station, however, very high values of 5,500 and 6,561 mg/L, respectively during wet and dry seasons were obtained (Figure 5). These very high values compared to the four other sites are due to salt water intrusion and tidal action while the higher value during dry as compared to the wet season is due to higher evaporation rate during the dry season.

For water hardness, the main constituents analyzed were calcium and magnesium reported in mg/L. This cation group is one of the critical constituents of irrigation water which affect the changes in the physical, chemical and biological properties of the soil (Radojevic & Bashkin, 1999). Hardness of the water is strongly influenced by the weathering of the calcareous bedrocks of the river and from agricultural areas treated with lime, usually CaCO3 and MgCO3. Hardness in water can cause water to form scales and resistance to soap. Results for hardness showed that there were no significant differences between dry and wet seasons in all stations but between locations, significantly higher hardness was observed at the Leganes station (1143 to 1366 mg/L) than in the four other stations (126 -169 mg/L) (Figure 6). This high value is due principally to the periodic saltwater intrusion. The recommended maximum level for surface water is 300 mg/L. Generally, the river water samples from the upstream and midstream analyzed for hardness were good for irrigation except at the downstream section.

Total suspended solids (TSS) are composed of organic and mineral particles that are transported in the water column. TSS is closely linked to land erosion and to erosion of river channels. TSS can be extremely variable, ranging from less than 5 mg/ L to extreme of 30,000 mg/ L in some rivers (Adeyemo, Adedokum, Yusuf, & Adeleye, 2008; Gasim, Ismail, Toriman, Mir, & Chek, 2007). TSS is not only an important measure of erosion in river basins, it is also closely linked to the transport through river systems of nutrient (especially phosphorus), metals, and a wide range of industrial and agricultural chemicals. TSS values (143 to 212 mg/L) in this study showed no significant differences between seasons and locations except at Calinog where a value of 3,800 mg/L was obtained when there was a flood during Typhoon "Jolina" (Figure 7). This indicated that concentrations tend to increase with discharge. Recommended TSS value is 100 mg/L. Higher TSS (>1000 mg/L) may greatly affect water use by limiting light penetration and can limit reservoir life through sedimentation of suspended matter (Radojevic & Bashkin, 1999).

Total dissolved solids (TDS) is an expression for the combined content of all inorganic and organic substances contained in a liquid that are present in a molecular, ionized or micro-granular (colloidal sol) suspended form. Generally, the operational definition is that, the solids must be small enough to survive filtration through a sieve size of two micrometers. Primary sources for TDS in receiving waters are agricultural run-off, leaching of soil contamination and point source water pollution discharge from industrial or sewage treatment plants.

No significant differences in TSS values were observed between seasons but there was significantly higher TDS (5000–8000 mg/L) at Leganes station due to salt intrusion and tidal action (Figure 8).

Alkalinity is a measure of the buffering capacity of water. Specifically, alkalinity is the amount of HCO3 - (bicarbonate) and CO32- (carbonate) ions dissolved in the water. The higher the alkalinity, the more carbonate and bicarbonate ions, and the easier it is for the water to neutralize or buffer acid insults (acid rain, acid mine drainage, and so on). Sources of alkalinity are leached from rock (limestone), leached from minerals (dolomite and calcite), and leached from soil. There were no significant differences in alkalinity between seasons and sites. The average alkalinity value for the entire stretch of the river varied from 144 to 180 mg/L for the period of study (Figure 9). Generally, there is little variation in the total alkalinity concentrations in the whole reach of the river and the values are within the recommended level which should be > 100 mg/L.

The main sources of nitrite ion in unpolluted surface waters are the processes and organic matter mineralization, nitrification and denitrification. Results showed that at all sites, wet season values were significantly higher than the dry season values. However, comparing sites or locations, the highest value was obtained near the Sugar Central and NPC (0.08 mg/L), followed by Calinog, Dingle and Leganes (0.06 mg/L) during the wet season (Figure 10). During the dry season, the same nitrite level (0.003 mg/L) at all sites was recorded. Maximum recommended level is 0.06 mg NO_2-N/L.

Ammonia is a product of microbial activity and ammonification. The occurrence of ammonia in surface water supplies is sometimes accepted as the chemical evidence of sanitary pollution. Ammonia is an ingredient in many fertilizers and is also present in sewage, storm water run-off, certain industrial wastewaters, and run-off from animal feedlots. Ammonia can also be present in water that has suffered deoxygenation and denitirification underground. Significantly higher ammonia values (0.06 to 0.22 mg/L) were obtained during wet season than during dry season (0.02 to 0.04 mg/L) in all sites (Figure 11). Highest value was obtained at the Moroboro station. The recommended standard value should not exceed 0.4 mg NH_3-N/L.

For the phosphate anions, no significant differences were observed between seasons and sites. Values ranged between 0.05 to 0.25 mg/L (Figure 12). Ideal value should not exceed 0.20 mg PO4-P/L. The presence of phosphorus, as phosphate ion, in natural waters is one of the most serious environmental problems because of its contribution to eutrophication. A river with a concentration of below 0.010 mg/L is considered as oligotrophic, while concentrations between 0.010 and 0.020 mg/L are indicative of mesotrophic, and concentrations exceeding 0.020 mg/L are already considered eutrophic (Muller & Helsel, 1999). The main anthropogenic sources of phosphorus in the water are the discharges of raw sewage, agricultural drainage and certain industrial waste waters. The disposal of detergents is a major contribution to phosphate water pollution.

Based on the water quality standard (Table 3) and water classification (Table 4) of DENR, the Jalaur River stretch can be classified as class C and D. Class C water is for propagation and growth of aquatic resources while class D water is for agriculture, irrigation, livestock watering, and industrial cooling and processing.

Heavy metal contamination and pesticide residues

The main threats to human health from heavy metals are associated with exposure to lead (Pb), cadmium (Cd), mercury (Hg) and chromium (Cr). These metals have been extensively studied and their effects on human health regularly reviewed by international bodies such as the WHO (Jarup, 2003).

In humans, long-term exposure to Cd is associated with renal dysfunction. High exposure can lead to obstructive lung disease and has been linked to lung cancer. Cadmium may also produce bone defects (osteomalacia, osteoporosis) in humans and animals.

Low levels of chromium (Cr) exposure can irritate the skin and cause ulceration. Long-term exposure can cause kidney and liver damage and damage to circulatory and nerve tissue.

Human exposure to lead (Pb) can result in a wide range of biological effects depending on the level and duration of exposure. High levels of exposure can cause problems in the synthesis of hemoglobin, effects on the kidneys, gastrointestinal tract, joints and reproductive system and acute or chronic damage to the nervous system.

For the water samples collected during both wet and dry seasons, no Cd, Pb and Cr ions were detected at the detection limits of 0.005, 0.01 and 0.005 mg/L respectively (Table 6). Based on results for the sediment samples for the wet and dry season (Tables 7 and 8), cadmium ion was not detected but lead and chromium were present at all sites. The detected levels of metal contamination, mainly Cr, and Pb in sediments of Jalaur River were found to exceed the geochemical background or threshold values. The highest metal pollution of Jalaur River System was found to be Pb during the wet season. Results showed that the dilution, re-suspension and re-deposition processes of the extremely high water events during rainy season caused an additional increase of metal concentrations in the bottom sediments. Lead and chromium were also detected in "lumot," *Azolla,* and Nile Tilapia (*Oreochromis niloticus*) sampled at Moroboro (Table 9).

The maximum limits for water based on the WHO recommendation are lead (Pb) = 0.05 mg/L, chromium (Cr) = 0.10 mg/L and cadmium (Cd) =0.01 mg/L. For sediments, the maximum limits are: Pb = 0.06 mg/g, Cr = 0.075 mg/g and Cd = 0.006 mg/g.

For the pesticide residue analyses of both water and sediment samples, no organochlorines, organophosphates, carbamates and pyrethroids were detected at the limit of the analyses (Table 10).

The deterioration in the physicochemical quality and rise in the nutrient level observed in this study is alarming, and periodic monitoring and preventative measures are required to save the aquatic system from eutrophication. Heavy metal contamination of bottom sediments, algae and fish samples is also a cause for alarm, since this heavy metals pose threats to human health. Further work is therefore needed to determine the dynamics of the watershed's response to runoffs and land management practices under varying climatic conditions to better understand the complex physical and chemical processes causing the degradation observed in the present study. The findings also have important implications for the development of effective water management strategies for the Jalaur River system.

ACKNOWLEDGMENTS

This study was made possible from funding support from CHED through the Silliman Zonal Research Center. The institutional support from the respective schools of the authors, Central Philippine University (CPU) and Iloilo State College of Fisheries (ISCOF) is likewise acknowledged. Thanks are also due to SEAFDEC Aquaculture, Tigbauan, Iloilo, Department of Chemistry, UP-Diliman and JEFCOR Laboratories for the use of instruments for the chemical analyses.

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