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BIOGEOCHEMICAL ANALYSIS IN RELATION TO WATER QUALITY OF WAWA DAM, RIZAL, PHILIPPINES

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Abstract

This paper investigates the biogeochemical components of Wawa Dam, to determine its viability for human consumption. Macro-invertebrates and geological structures were assessed in relation to water quality. Quantitative analysis on the physicochemical parameters, such as, pH, temperature, total dissolved solids, total suspended solids, biochemical oxygen demand, *dissolved oxygen, nitrates and orthophosphates were done, to compare with the standard criteria set by the Department of Environmental and Natural Resources Administrative Order 90-34, in four consecutive months, covering rainy and dry seasons. Results showed that, Class Insecta with 30.91% were the most abundant macro-invertebrates, while, sedimentary rocks, dominated the geological structures with 69.10%. Total suspended solids and total dissolved solids, revealed significant concentrations ($P<0.05$) having low levels with average mean values of 33.25 mg L^{-1} and 155 mg L^{-1}, respectively, as compared with the standard criteria for Class A (drinking water with complete treatment). Biological oxygen demand, dissolved oxygen, nitrates and orthophosphates with average mean values of 9.5 mg L^{-1}, 6.4 mg L^{-1}, 11 mg L^{-1} and 1.1 mg L^{-1}, respectively, did not meet the standard criteria. Temperature and pH were within the range of standard level. Wawa Dam with the presence of inhabitants and other sources of pollution, the water quality is deteriorating, based on these observed parameters: nutrient concentrations were quite alarming; macro-invertebrates were threatened, due to a very high biological oxygen demand, and almost in the minimum level of dissolved oxygen. Total suspended solids and total dissolved solids were significant, because of their low concentrations.*

Keywords

Environment, Water Quality, Biogeochemical, Wawa dam, Philippines

1. Introduction

Natural environment has been negatively affected by human alteration, in the name of development, which is now threatening the very existence of man, through global warming and climate change (Kripa, Prasanth, Sreejesh, & Thomas, 2013). Thus, water quality of a reservoir or any aquatic ecosystem, is very crucial when it comes to human consumption. However, soil, air and water, the primary natural resources, has become polluted and contaminated beyond tolerable limits. It is becoming a critical resource, because of the increased pressure on freshwater resources, by the rapid growth of population, fast industrial, agricultural and economic development (Maglangit, Galapate, & Bensig, 2015). In the same way, that hydrologic modifications or alterations at the global scale, will lead detrimental consequences to aquatic environment and human health (Naiman & Dudgeon, 2011; O'Toole, Hanso, & Cooke, 2009). Although, the country is enriched with abundant water resources, human consumption is becoming limited, due to natural and anthropogenic contamination and pollution (Dayrit, 2001;

Enquito, Matunog, Bala, & Villantes, 2013). The occurrence of water pollution and contamination is through natural processes, but it is mostly as a result of human activities, such as, uncollected garbage, domestic waters (particularly detergents), piggery farm, agricultural fertilizers and pesticides, industrial effluents, traffic emissions, and sanitary landfills, will eventually find their ways into rivers, and the groundwater aquifers (Dulo, 2008; Islam, Tusher, Mustafa, & Mahmud, 2012). The intensification of agriculture and rapid urbanization has resulted in reduced water quality, loss of species and their habitats and changes in ecosystem functioning (Gucker, Boechat, & Gianni, 2009; Piscart, Genoel, Doledec, Chauvet, & Marmonier, 2009; Juanir et al., 2011).

Studies on the water quality of rivers, streams and lakes in the Philippines, are now one of the priorities among researchers and funding institutions/agencies. Physicochemical and biological parameters are bioindicators of a healthy ecosystem. Recent studies on

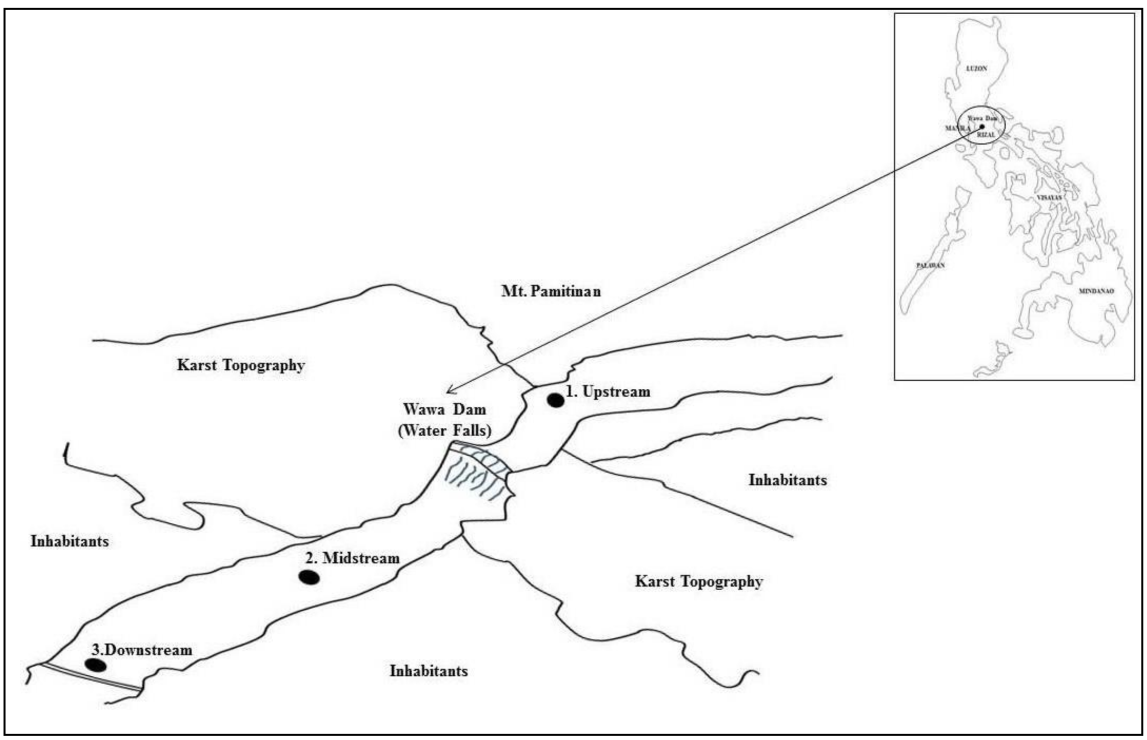

Figure 1: *Wawa Dam showing sampling stations and Philippine Map (inset).*

physicochemical parameters and nutrient concentrations were done in several river systems and lakes in Metro Manila and other provinces in the Philippines, such as, Pasig River (Gorme, Maniquiz, Song, & Kim, 2010), Manga River (Flores & Zafaralla, 2012), Carangan Estero in Ozamiz City (Enquito et al., 2013), Buhisan and Lahug Rivers in Cebu (Maglangit, Galapate, &

Bensig, 2015). Data measured were compared with the DENR Administrative Order 90-34 standard values. Findings showed that data did not meet the standard criteria set by the DENR. Water quality of Taal Lake in Batangas, Philippines had been studied and results showed that the lake is eutrophic because of the increasing concentrations of nutrients that comes from the tributary rivers and the fish cages (Hilario & Perez, 2013; Corpus, Paller, & Ocampo, 2016; Querijero & Mercurio, 2016).

Wawa Dam, is an arch, man-made dam located in Barangay Wawa, San Rafael, Rodriguez (formerly Montalban) Rizal, with coordinates of 14^{o}43'40"N and 121^{o}11'30"E (Fig. 1) bounded on the north by Mt. Balagbag, on the east by Mt. Arid, on the south by the lowlands of Antipolo and on the west by the Luzon Central Plain (Bruno, 2012). It has a length of 85 meters (m) and an average depth of 3 m. The watershed is 27,700 hectares (ha) comprises of agricultural land, hiking and spots for recreation, relocation of communities and development of subdivisions (Bondoc, 2009). It was built in 1909 during the American colonial era, and formerly the only the only source of water (Bondoc, 2009; Bruno, 2012) for human consumption (drinking, bathing, and swimming) in Manila and currently, for recreation. Wawa Dam has been stopped operation, and abandoned in 1962 when the Angat Dam was built (Cruz, 2009).

Rodriguez (formerly Montalban), is one of the largest towns in Rizal province, spans for 1,175.8 square kilometers (km2). It has a population of 223,594 inhabitants, of which 24,524 households has 115,167 people (NSO, 200). It makes up 26.6% of the entire province of Rizal, with 11 barangays. The landmass of Rodriguez is big enough to be an ideal place for many purposes, such as, agriculture, hiking and spots, relocation of communities, and development of subdivisions (Bondoc, 2009). The National Committee on Geologic Sciences, under the Ministry of Natural Resources, declared this area on September 10, 1983 as Montalban Gorge Monument, a reserved area, which has its own scientific value, as the type of locality of the lower Miocene Montalban Limestone. It is tectonically active area that may result in the deformation of the bed (Bondoc, 2009). The continuity passage of the water, along the cracks and fractures of the limestone eventually, resulted to the formation of the karst topography. Concurrently, Wawa Dam is now used for other ecosystem services, such as, recreation, mountain trekking and hiking, and tourist spots. Nowadays, there is a strong clamor to reuse the Dam, because of the insufficient water supply for Metro Manila. Hence, the study aims,

- To assess the biogeochemical components of Wawa Dam, specifically,

- To identify macro-invertebrates with their common names up to class level;
- To determine rocks that dominates the Wawa Dam; and
- To quantitatively analyze the physicochemical parameters of the water ecosystem and compare with the standard value set by the DAO 90-34 for surface water.

Measured data of the physicochemical parameters, will be compared with the Class A (drinking water for complete treatment) and Class B (recreation) standard criteria, set by the Department of Environment and Natural Resources Administrative Order 90-34 (DAO 90-34). The significance of the study is to have baseline information for government and stakeholders, to formulate policies and vital management strategies, for economic sustainability on ecosystem services, such as, ecotourism, recreation, livelihood and water supply services of Wawa Dam.

2. Materials and Methods

2.1. Study Sites

Three sites were established in Wawa Dam (Fig. 1) based on the observed characteristics of the dam, which would have a remarkable contribution of nutrient concentrations. Water samples for physicochemical parameters, such as, pH, total dissolved solids (TDS), total suspended solids (TSS), biochemical oxygen demands (BOD), dissolved oxygen (DO), orthophosphates (O-PO_4) and nitrates (NO_3) were collected from the midstream of Wawa Dam. Rocks and substrates of different types, and macro-invertebrates, were collected and observed from the upstream, midstream and downstream, which were designated as station 1, station 2 and station 3 (Fig. 1), respectively.

Wawa Dam (Fig. 1) is bounded by karst topography with trees at the sides of the dam, and cottages at the other side (opposite), built for tourists and inhabitants (informal settlers). Different cobbles and pebbles of rocks were observed along the river banks, and the river beds. Multiple uses have been observed, such as transport (organic food) using raft, laundry, washing and bathing. Along the river banks were uncollected garbage and trashes from inhabitants. Upstream, the station 1 (Fig. 1) is located approximately one (1) km East from the water falls of the dam. It has an average mean area of 8.47 square meters (m^2), and an average mean stream flow of 0.41 cubic meter per second (m^3 s^{-1}) (Table 1). It has mud with pebble substrate, and brown to turbid kind of water during rainy season, then blue to green color during dry season. Water flows slowly going towards the falls. Midstream, station 2 (Fig. 1) is located approximately one (1) km West from the water falls. It has an average mean area of 5.99m^2, and an average stream flow of 1.32m^3 s^{-1} (see Table 1). It has huge boulder, cobble and pebble rocks of limestone, seen embedded in the water. Cobbles and pebbles of different types of rocks were observed at the bottom of the water. During dry season, cottages were built in front of the falls

Table 1: *General Profile of Wawa Dam, Manila, Philippines. October 2015 – January 2016*

Station	Flow Velocity	Depth	Width	Area	Streamflow
Midstream	**(m s^{-1})**	**(m)**	**(m)**	**(m^2)**	**(m^3 s^{-1})**
October	0.17	0.75	9.14	6.80	1.16
November	0.27	0.68	10.36	6.99	1.88
December	0.18	0.76	8.84	6.71	1.20
January	0.30	0.60	5.75	3.45	1.04
Mean Values	**0.23**	**0.70**	**8.52**	**5.99**	**1.32**
Upstream					
October	nd	nd	nd	nd	nd
November	0.17	0.44	9.75	4.29	0.73
December	0.02	1.70	10.36	17.60	0.28
January	0.07	0.55	6.40	3.52	0.23
Mean Values	**0.09**	**0.90**	**8.84**	**8.47**	**0.41**
Downstream					
October	0.30	0.40	10.00	3.95	1.19
November	0.25	0.70	9.75	6.87	1.72
December	0.20	0.83	7.62	6.32	1.26
January	0.18	1.00	5.18	5.18	0.95
Mean Values	**0.23**	**0.73**	**8.14**	**5.58**	**1.28**

for tourists. However, during rainy seasons, cottages were washed away, because of the pressure of water falls from the upstream. The downstream, station 3 (Fig. 1) is located approximately one (1) km West from the midstream. It has an average mean area of 5.58 m^2, and an average mean stream flow of 1.28m^3 s^{-1} (Table 1). A hanging bridge is seen approximately 50 m away from the station 3. A few macro-invertebrates were observed from the upstream, midstream and downstream, such as snails, clams, dragonflies, crickets, grasshoppers and earthworms.

Data of the depth, velocity, width and area, and stream flow were recorded. Depth and width were measured and estimated, by using a meter stick, while velocity was measured indirectly, by tracing the time for an object (*dalanghita*) in the water to travel, at a given distance. Area was computed, as the product of the depth and the width, while stream flow was computed by multiplying the area by the velocity of the river.

Water samples were taken every month for four (4) consecutive months, from October 2015 to January 2916, to cover the rainy season (October) and (November – January) dry seasons.

2.2. Sample Collection

2.2.1. Macro-invertebrates

Macro-invertebrates were collected (using D-shaped dip net), observed, counted and released them back into the stream. Dragon flies, crickets and grasshoppers were seen and some snails were attached to small rocks in the downstream. In the midstream, there were a few big and small snails attached to rocks, while in the upstream, there were shells, clams and earthworm that were embedded in the muddy substrate.

There were different substrates observed from the three stations. Upstream have muddy with pebbles substrate, while midstream has huge boulder, cobble and pebble rocks. Downstream have cobbles and pebbles substrate.

2.2.2. Rocks and Substrates

Most of the rocks were collected, from the midstream and downstream of Wawa Dam. Huge rocks were tested with reactivity test, using 10% hydrochloric acid (HCl) *in situ*, to determine the presence of calcium carbonates of the rocks, thus, identified to be a limestone. Small rocks were collected from the three sites and brought to the Emilio Aguinaldo College – School of Arts and Sciences (EAC-SAS) research laboratory. Rocks and substrates were initially identified by using different tests adapted from Rasmussen (2012). The rocks that were initially identified were verified and confirmed, by the Geological Division of the National Museum in Manila.

2.2.3. Water Samples

Plastic bottles (acid-washed, 1 liter (L) capacity) were used to collect water samples for physicochemical analyses at the subsurface of station 2, midstream of Wawa Dam. Measurements of water temperature were done *in situ* using a thermometer. Various physicochemical parameters, such as, orthophosphate (O-PO4) and pH, were analyzed using

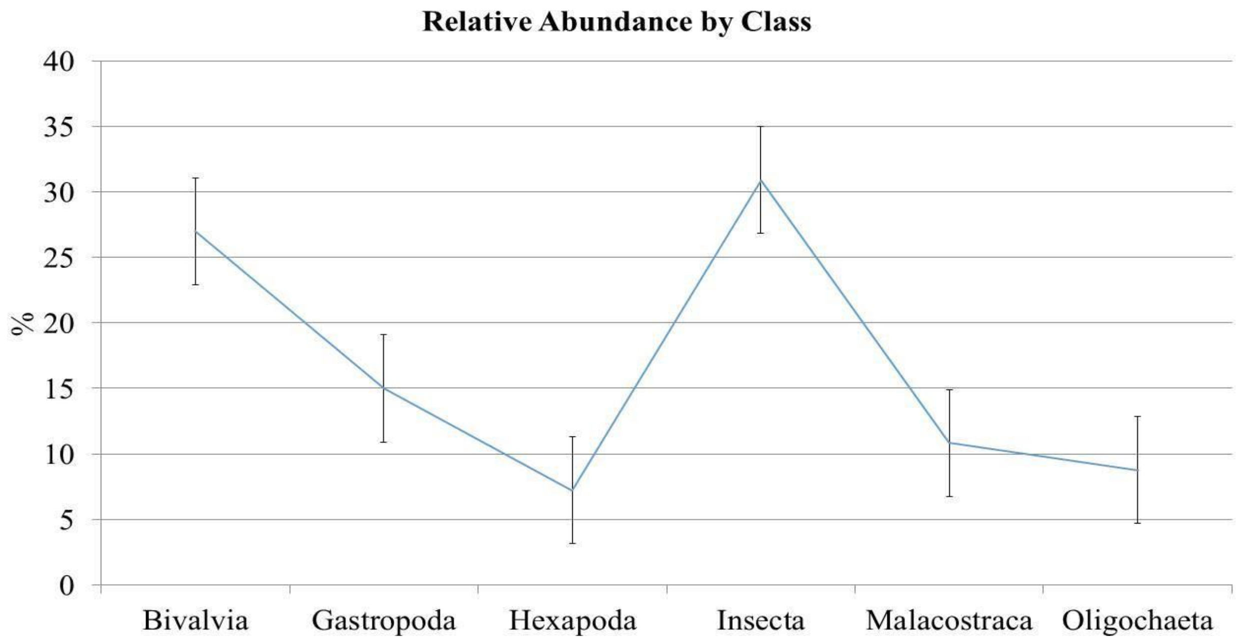

Figure 2: *Relative abundance of macroinvertebrates per class level. Wawa Dam, October 2015-January 2016. Data are means ± SE*

colorimetric and electrometric methods (APHA 2005), respectively, at the Natural Sciences Research Institute – University of the Philippines, Diliman (NSRI-UPD). DO, BOD, and NO3 were analyzed using DO meter, Oxitop BOD5 measuring device and ion chromatography (APHA, 2012), respectively, at the Philippine Institute of Pure and Applied Chemistry – Ateneo de Manila University (PIPAC-ADMU). TDS and TSS were analyzed using gravimetric method (USEPA, 2002) at the Emilio Aguinaldo College – Pharmacology Laboratory (EAC Pharma Lab). Physical parameters were considered, to establish a record on the present condition of the dam.

One (1) liter (L) plastic bottles were used to collect water samples from the midstream for physicochemical analyses. Bottles were previously rinsed three times with the water, and then placed in an ice chest to maintain a temperature of 277^{o}K until further analyses in the laboratory.

Holding time of the water samples collected was observed at a minimum to avoid contamination and deterioration.

All numerical data gathered were subjected to statistical analysis (SPSS) with bivariate correlations to compare the significance of the mean values obtained between the parameters. Differences having P-values <0.05 were considered significant. Relative frequency of macro-invertebrates and rocks were computed by number of species or rocks divided by the total number and multiply with one hundred.

3. Results and Discussion

3.1. Macro-invertebrates

A total of 6 classes and comprising 194 individuals were observed and counted from the sampling stations. In Wawa Dam, Class Insecta with 30.91% were the most abundant macro-invertebrates during the study period followed by Class Bivalvia (27%), Class Gastropoda (15%), and the rest, Classes Malacostraca, Oligochaeta and Hexapoda with 10.82%, 8.76% and 7.21%, respectively. Macro-invertebrates are bioindicators of stream health (Kripa, Prasanth, Sreejesh, & Thomas, 2013), because its biodiversity means healthy stream, source of food for many fish, have little mobility, spend up to one long year in the stream, and generally abundant. Sedimentation, habitat loss and chemical pollution, are potential threats to macro-invertebrate diversity. Dragonflies of Class Hexapoda (7.21%), and clams of Class Bivalvia (27%) are pollution tolerant. While gilled snails are pollution sensitive but pouch snails are pollution tolerant. The pH of the water during the study period ranged from 7.4 -8.10 which is within the range of pH (7.5-9.0) (Sharma & Rawat, 2009) that support aquatic life such as snails, clams, and mussels. Aquatic worms and midge larva are pollution tolerant and can tolerate low DO, lower or higher pH and warmer water (USEPA 2002).

3.2. Rocks and Substrates

Limestone dominated the rocks in Wawa Dam with 22.76% (Fig. 3) of the total collected rocks. Most limestone is composed of skeletal fragments of marine organisms, such as, corals, forams and mollusks. Limestone forms many erosional landforms, such as, karsts, limestone pavement, pot holes, caves and gorges, because it is partially soluble in acid (Kranjc, 2006). Andesite (15.45%), diorite (4.88%), and basalt (10.57%) (Fig. 3), were among the identified igneous rocks collected from Wawa Dam. Andesite and basalt are extrusive (volcanic) igneous rocks while diorite is an intrusive (plutonic) igneous rock. Intrusive igneous rocks when solidifies within the earth's crust, it cools slowly forming coarse textured rocks like diorite. Extrusive igneous rocks cool and solidify quicker than intrusive igneous rocks (Foulger, 2010) and formed by the cooling of magma on the earth's surface which is brought to the surface, through fissures or volcanic eruptions, solidifies at a faster rate, hence, such rocks are smooth,

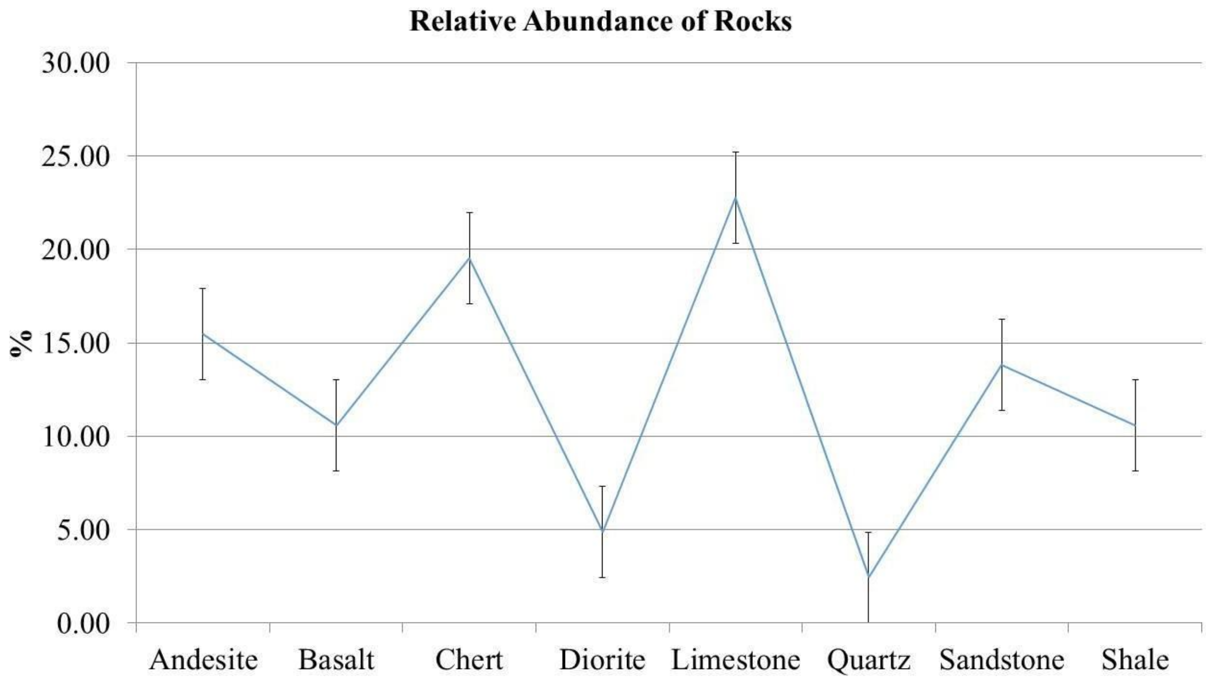

Figure 3: *Relative abundance of rocks in Wawa Dam. October 2015 – January2016. Data are means ± SE.*

crystalline and fine grained, like, andesite and basalt (Prothero & Schwab, 2004). The most abundant classification of rocks in Wawa Dam is sedimentary rocks with 69.10% followed by the igneous rocks with 30.90% (Fig. 4). Among the sedimentary rocks that were identified were limestone (22.76%), chert (19.51), sandstone (13.82%), shale (10.57%) and quartz (2.44%). Hence, Wawa Dam is famous with its karst topography and caves, these features develop in limestone rocks, due to their solubility in dilute acidic groundwater, and in addition, limestone in water and weak acid solutions leads to karst landscapes. Limestone is less resistant than igneous rocks, but more resistant than most other sedimentary rocks (Ehrlich & Newman, 2009).

Stream substrate is the material that rests at the bottom of a stream. It is one of the important factors, controlling local community structure and functional processes (Graca, Ferreir, Firmiano, Franca, & Callisto, 2015). The station one of the study site, which is the upstream, has mud (silt and clay) bottom with pebble and cobble classification of sediments. Substrate serves as habitat on which a plant or animal lives. It affects the life within the stream habitat. Muddy streams generally have more sediment in the water, reducing clarity (Vasconcelos & Melo, 2008). Wawa Dam during the rainy season (October), the water was turbid because of the silt in the river beds, and eroded soil, but the rest of the month (November, December and January), the water was clear. Midstream and downstream which is the station 2 and station 3, respectively, has huge rocks embedded in the water together with boulder, and

Table 2: *Physico-chemical mean values of Wawa Dam as compared with the DAO 90-34 Class A (drinking water for complete treatment) and Class B (recreation) standard for*

Parameters (mg L^{-1})	Month				Mean Values	Class B Recreation	Class A Drinking Water (Complete Treament)
	Oct	Nov	Dec	Jan			
Nitrate	4	11	18	11	**11**		10
Orthophosphate	nd	0.9	1.3	1.2	**1.1**	0.2	0.1
BOD	10	9	9	10	**10**	5	5
DO	6.0	8.4	6.1	5.0	**6.4**	70(5.0)	70(5.0)
pH	8.1	7.8	7.8	7.4	**7.8**	6.5-8.5	6.5-8.5
Temperature (°K)	300	299	299	298	**299**	276(3°C)	276(3°C)
TSS	66	63	1.2E-05	4	**33**		50
TDS	274	316	2.8E-05	30	**155**		1,000

cobble classification of substrate. Cobble substrate are structurally more complex than sand (Barnes, Polvani, & Sobel, 2013; Graca et al., 2015), hence, capable of housing a large number and variety of individuals when compared with sandy substrate (Graca et al., 2004; Vasconcelos & Melo, 2008). Water volume in Wawa Dam during October was high but abruptly decreased during the month of November, December and January because it was dry season.

3.3. Physicochemical Parameters

The results obtained in the physicochemical analyses were compared with the criteria set for surface water by the Department of Environmental and Natural Resources Administrative

Order 90-34 (DAO 90-34) specifically for Class B (recreation) and Class A (drinking water for complete treatment) (Table 2).

NO_3 and O-PO_4 concentrations were slightly above the level of standard for recreation (Class B), and for drinking water (Class A) (Table 2), set by the DENR for surface water. N and P are essential plant nutrients, but in excess amounts can cause significant water quality problems. During the dry season (November and December), the concentrations of NO_3 and O-

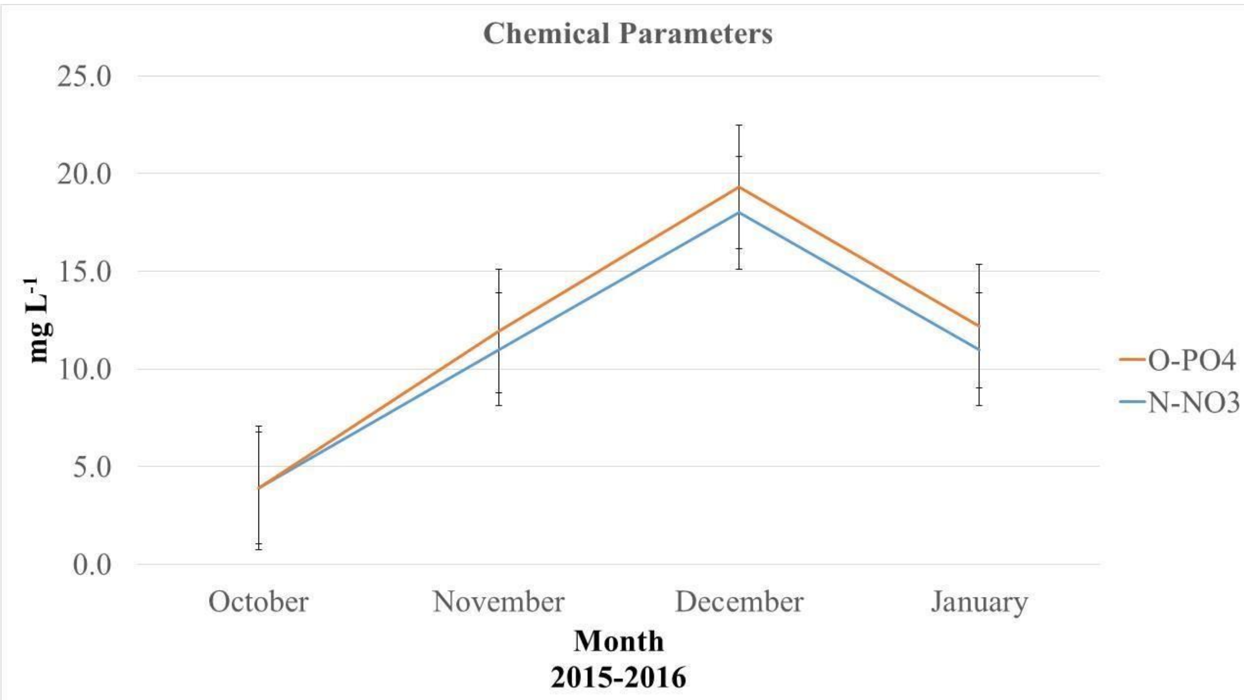

Figure 4: *Chemical parameters measured in Wawa Dam, Rizal, Philippines October 2015 to January 2016. Data are means ± SE.*

PO_4 were high (Fig. 4) in Wawa Dam with an average mean values of 11 mg L^{-1} and 1.1 mg L^{-1} (Table 2), respectively, in comparison with the standard level set by the DENR (Table 2), because of soil, sewage, manure, dredging activity, industrial effluents, weathering of boulder rocks (Hilario & Perez, 2013), runoff from fertilized lawns and croplands, and domestic water, particularly detergents. Land sources of nitrates end up in rivers and streams more quickly because they dissolve in water more readily (USEPA, 2002). Nitrogen fixation favorable in neutral pH contributes to the high levels of N in the water (Hilario & Perez, 2013). Wawa dam had a neutral pH (see Table 2 and Fig. 5) for the whole study period and slightly alkaline, because Wawa Dam is dominated by limestone kind of rocks which has calcium carbonate. It falls within the range of standard set by the DENR for Class A and Class B criteria.

TDS and TSS in Wawa Dam were significant ($P<0.05$). TDS concentration affects the water balance in the cell of aquatic organisms. A high concentration of total solids will make drinking water unpalatable, and might have adverse effect on people, who are not used to drinking such water (USEPA, 2002). TDS and TSS had low levels (Fig. 5), with an average mean values of 155 mg L^{-1} and 33.25 mg L^{-1}, respectively, compared with the standard level set by the DENR for drinking water and recreation (Class A, Table 2). A very low level of solids

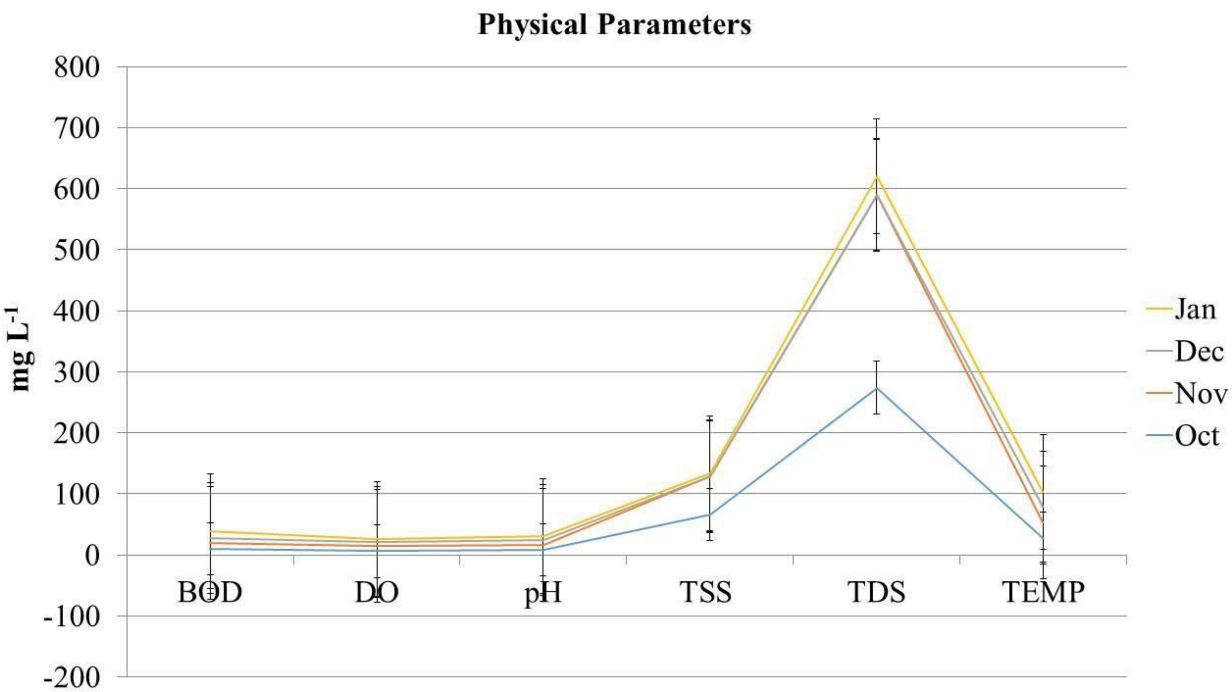

Figure 5: *Physical parameters measured in Wawa Dam, Rizal, Philippines. October 2015-2016. Data are means ± SE.*

will tend to make organism swell up, because water tend to move into its cells, which have a higher concentration of solids. Therefore, the ability of the organism to maintain the proper cell density, is affected, making it difficult to keep its position in the water column, and might float up or sink down to depth, to which it is not adapted, and might not survive (USEPA, 2002). Too high or too low levels of total solids, can reduce the efficiency of wastewater treatment plants, as well as, the operation of industrial processes that use raw water for human consumption (USEPA, 2002).

BOD level during the study period was high (Fig. 5), with an average value of 9.5 mg L^{-1}, and DO was in its minimum with an average mean value of 6.4 mg L^{-1}, as compared with the standard level set for Class A and Class B by the DENR (Table 2, Fig. 5). BOD was high because of its sources, animal manure, wastewater treatment plants, failing septic systems, urban storm water runoff and leaves and woody debris (Meerbergen et al., 2016). Wastes ended up in the receiving water making it polluted due to improper wastes disposal system at the local community level. BOD directly affects the amount of DO in rivers and streams (USEPA, 2002). DO levels was attributed to the input of organic pollutants, domestic and industrial wastewater discharges, and agricultural and urban runoff (Olatayo, 2014; Maglangit et al., 2015). Factors that influenced DO concentration in stream water, include temperature, altitude, photosynthesis, stream flow, salinity and aeration. Low DO indicates poor water quality, therefore, difficulty in sustaining aquatic lives. The higher the BOD, the more rapidly oxygen is depleted in the stream, therefore, the more organisms become stressed, suffocate and die (USEPA, 2002; Flores & Zafaralla, 2012).

Temperature had an average mean value of 298.9^{o}K (Table 2, Fig. 5) during the study period, and the reading fall within the DENR standard of not more than 276^{o}K increase in ambient temperature. The observed measurements of temperature decreases from October 2015 - January 2016 (rainy to dry season), and these results supports the findings of Hilario & Perez (2013).

4. Conclusions and Recommendations

Wawa River is a natural ecosystem that has been disturbed, due to the constructed dam that was intended as a source of drinking water for Metro Manila, Philippines, and was stopped operation and abandoned for many years. Nowadays, it has been clamored to be used again, hence this study. The presence of inhabitants (informal settles) living in the area and other possible sources of stressors and pollution, water quality of Wawa dam is deteriorating, based on these observed parameters: N and P (nutrient) concentrations were quite alarming; macroinvertebrates were threatened due to a very high BOD and almost in the minimum level of DO; TSS and TDS were significant because of their low concentration compared with the standard criteria set by the DENR for Class A (drinking water for complete treatment) and Class

B (recreation). Temperature and pH fall within the range of standard criteria, set by the DENR for both Class A and Class B.

Dominant geological structures of Wawa Dam are sedimentary and igneous rocks, specifically, limestone. Karst topography and terrain will keep on developing and transforming. Its uniqueness will make people from other places come to visit, making it an ecological tourist spot and park. Rehabilitation and proper management for this natural environment must be prioritized. Protection and preservation of the natural ecosystem is highly recommended.

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