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Water Quality and Nutrient Loading in the Coastal Waters of Boracay Island, Malay, Aklan, Central Philippines

ABSTRACT

This study analyzed the water quality dynamics in the coastal zone of Boracay Island in relation to anthropogenic activities and natural factors. Seven sites were studied where possible sources of nutrient inputs on spatial and temporal basis were identified. Water samples were evaluated using the Philippine Department of Environment and Natural Resources (DENR) regulatory standards. The coastal water quality was generally influenced by nutrient loading coming from untreated and partially treated waste water from households and commercial establishments not connected to the sewerage system of the island. Natural cleansing mechanisms attributed to activities of autotrophs in the coastal water and biogeochemical processes of mangrove swamps are operational. Coastal waters adjacent to mangrove swamp impoverished of mangrove trees showed poor water quality, while coastal water adjacent to mangrove swamp with relatively good mangrove cover exhibited good water quality. The months of February to June with highest number of tourist arrival proved to be the critical periods. Lugotan Cove close to Mangrove Swamp 6 impoverished of trees was the critical area in the Island. Puka Beach close to Mangrove Swamp 1 with good mangrove cover showed the cleanest water quality, followed by Long Beach with most of the commercial establishments connected to the sewerage system.

Key words: *nutrient inputs, Boracay Island, water quality*

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INTRODUCTION

Boracay Island is located between 11°57' – 12°00' latitude and 121°56' - 121°57' longitude off the north-western tip of Panay in the Western Visayas (**Figure 1**). The land mass measures 6.8 km long by 3.3 km at its widest distance, rising to elevations ranging from 50 to 105 m above average sea level (asl). It has only a thin layer of topsoil covering coralline limestone called Karstic soil (*MGB 2012*), a porous material, which domestic wastes and effluents can easily penetrate and cause contamination of both the groundwater and the coastal waters (*Trousdale 1997; O'driscoll and Parizek 2009*). The topsoil is hydrosol type associated with the mangroves swamps and other wetland forms. The northern and southern portions of the island are hilly and are generally of clay loam type. The general topographic feature of the island in its present landform appears to be divided into three major sections (**Figure 2**), as follows: The northern block, which is about half of the island, is portrayed by prominent high relief reef coralline limestone at its northern and southern ends; The mid-section of the island is mainly underlain by alluvial deposits of coarse-to fine-grained sand to silt-sized, milled coralline limestone; The southwest flank of the southern block is again dominated by high relief reef coralline limestone (*Boracay Environmental Master Plan 2008*).

The island ecosystem showcases coastal sub-ecosystems of mangroves, seagrasses, coral reefs and soft bottom communities. Rapid population growth, unplanned developments, irresponsible tourism activities, and reclamation of mangrove areas are some of the major reasons of the degradation of the mangrove swamps (*DENR 6, Boracay Wetland Assessment Report 2009*). The lack of appropriate sanitation facilities and improper solid waste management practices, made the mangrove swamps as liquid and solid waste catchment areas of informal settlers. One consequence of such rapid unplanned development is the deteriorating coastal water quality manifested by reports of coliform counts, pH, Biochemical Oxygen Demand (BOD) and Dissolved Oxygen (DO) levels beyond government standards (DENR, EMB, WV. As early as 1996, scientific analysis by *Lujan* (*2003*) confirmed an excessive nutrient loading in the coastal water of the Boracay Island. The lack of proper sewage and waste water treatment system (LGU

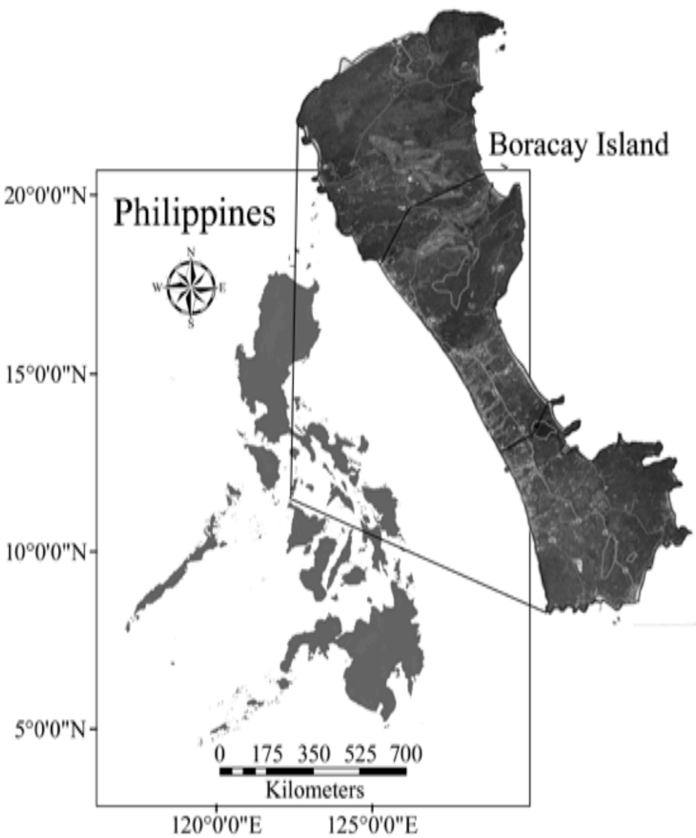

Figure 1. Map of the Philippines showing the location of Boracay Island (2012).

2012; BIWC, 2012; Boracay Master Plan 2008) was one of the identified causes of this environmental problem which if not properly addressed will cause further deterioration whereby the above mentioned parameters exceed the marine water quality thresholds. Leaching of nutrients from the source to coastal waters can reach up to 150 m, a characteristic of the hydrological chain in Karstic soil (*O'driscoll and Parizek 2009*) which compose the Boracay Island (*Mines and Geo-sciences Bureau 2012*).

In 2012, a total number of 340 resorts, hotels, cottages, lodging house and apartments in the Island are registered in the Municipality of Malay (*LGU Malay 2012*). Many of them are connected to BIWC sewerage system except for some big hotels and resorts that have their own Sewerage Treatment Plant (STP). As per DENR record, there are 77 establishments that are conducting monthly desludging activity, while there are ten big resorts that were issued with discharge permit. There are still six others with standing application (*DENR, EMB Region VI 2012*).

The coastal water quality of Boracay Island is everybody's interest considering its status as renowned tourists' beach destination in the world. Its environmental condition can make or unmake Boracay Island. It is considered the gem of tourism not only in the Philippines but globally. It remained on the top as one of the most visited tourists' beach destinations in the world (*Trousdale 1999*). In 2015, tourism contribution (where Boracay tourism is a stellar performer) to Gross Domestic Product is 8.2% (*Recide 2016*). Thus, government and private sectors are interested to address the environmental problems confronting the island to sustain the tourism industry.

This study tried to determine the sources of coastal water pollution and how nutrient loading and other relevant factors affect the coastal water quality of the Island. It is expected to provide empirical data that can serve as guide to policy makers and implementors on proper actions and proactive management measures to rehabilitate and improve the water quality, and help identify priority sites where the reductions would be the most beneficial.

MATERIALS AND METHODS

Conduct of Ecological Survey

Boracay Island coastline was once covered with considerable area of mangroves. However due to massive unplanned developments it is now left with patches of mangrove swamps. Wetland assessment conducted by DENR, Region VI in 2009 revealed remnants of four mangrove swamps showing varied biophysical condition. Some areas have relatively profuse growth of mangrove trees with slight development while other areas are highly impoverished. Thus selection of the study sites was based on the type of the adjacent land use of coastal area in terms of mangrove swamp condition and the presence of households and commercial establishments connected or not connected to the sewerage system. These conditions served as basis for comparing the coastal water quality at the different study sites (**Table 1**).

A periphery of 150 meters around the mangrove swamps and 150 meters from the shoreline were used as reference points, respectively for the mangrove swamps and beaches (Puka Beach, Bulabog Beach and Long Beach) in the determination of sources of pollution to the studied sites. The reckoning point was based on the study of *O'Driscoll and Parizek* (*2003*), stating that a Karstic soil has a 150 meters distance of hydrological chain. Parameters to characterize the biophysico-chemical quality of the coastal waters were analyzed.

Site 1 (**Figure 2**) is mangrove swamp 1 or wetland 1 (referred to as source) per DENR VI survey map of wetland areas in 2009. It is located at 11°59'47.7"N; 121°54'55.1"E and is adjacent to the main road of Yapak Village and has

Table 1. Summary of the salient features of the seven study sites in Boracay Island, (2012).

Study Sites	Descriptions	Salient Features
Study Site 1	Mangrove swamp 1 as referred in this study. This is wetland 1 per DENR 6-Survey of wetland areas in Boracay Island.	Adjacent to Puka Beach, Brgy. Yapak Area = 5.31 ha Approximately 49% (2.58 has) of the mangrove swamp was converted into residential areas Approximately 51% (2.73 has) was still covered by mangrove trees
Study Site 2	Referred as "Source" in this study Puka Beach located in Yapak Village.	Adjacent to mangrove swamp 1 Named after "puka" shells abundantly found on the beach. No houses and big resorts immediately adjacent to the beach.
Study Site 3	Bulabog Beach located in Balabag Village Also called the back beach	Covered with vast area of seagrass beds Discharge area of two drainage outfalls of Balabag Village and Manoc-manoc Village. BIWC outfall of treated sewage, 850- m away from the beach. Docking area of boats.
Study Site 4	Referred to as "Source" in this study Mangrove swamp 6 per DENR 6, Survey of wetland areas in Boracay Island	An abandoned fishpond area Approximate area of 3.70 has, 10% of the area is covered with mangroves A creek is discharging to the wetlands. Commonly called by the local people as Dead Forest - impoverished of mangrove trees.
Study Site 5	Referred to as "Transition Area" in this study, located in Balabag Village	Fishpond dike under the bridge Exit and entrance of water from the mangrove swamp 6 during low tide and entrance of sea water during high tide
Study Site 6	Lugotan Cove, located in Manoc-manoc Village. Referred to as the repository area of waters from mangrove swamp 6	It is an embayment. Mangrove forest lined the mouth area of the cove. Approximately covered by 3 hectares of seagrass bed Outfall of drainage canal of Manoc-manoc Village
Study Site 7	Long Beach	4- km fine white sand starting from Angol Point in Manoc-manoc to Fridays area in Yapak Village Divided into 3 stations (1, 2, and 3). Frequently visited by tourists. Most populated portion of Boracay Island

an area of 5.31 ha. It is 10 masl. About 49% (approximately 2.58 ha) of the mangrove swamp was developed into a residential area by the claimants. The natural creek which previously connected the mangrove swamp to Puka Beach was covered due to developments. The remaining undeveloped portion of the area [51% (2.73 ha)] is a forested wetland containing mangrove forest. It serves as water catchment of flood water during heavy rains from four catchment areas located at the East, West and South portions of the wetland (*DENR VI, Wetland Assessment Report 2009*). There are more or less 260 households with an estimated population of 1,560 within the 150 m periphery of the mangrove swamp. Also found in the area are 42 stores, and six restaurants. Moreover, there are only two big establishments located near the mangrove swamp that drained their treated effluent to the wetland (*DENR VI-PAWCZMS Wetland Assessment Report 2009*).

Site 2 (**Figure 2**) Puka Beach is the adjacent coastal area of the mangrove swamp 1 in Yapak Village. Its water sampling point is approximately 127 m away from Site 1, situated at 11°58'37.3"N; 121°55'25.8"E. The area has relatively few establishments compared to other sites which composed of native cottages, 12 souvenir mini-shops and one restaurant located at the entrance of the beach.

Site 3 is the Bulabog Beach, or the back beach at Balabag Village (**Figure 2**). It is located at 11°58'37.5"N; 121°58'37.5"E. The beach is mostly covered by the vast area of seagrasses. It serves as docking area of pump boats during East-North-Eeast wind. Aside from hotels and resorts, commercial establishments engaged in water sports are located in the area. Two drainage outfalls that contained untreated and partially treated sewage discharged to the beach. The outfalls are waste waters from households and commercial establishments in Manoc-manoc Village and Balabag Village not connected to Boracay Integrated Water Corporation (BIWC) sewerage system. Likewise, the outfall of the sewage from BIWC is also situated 850 m away from the shoreline.

Site 4 (referred to as source or wetland 6), (DENR VI, 2009) is a mangrove swamp located at 11°57'30.9"N; 121°55'45.9"E (**Figure 2**). It is commonly called "Dead

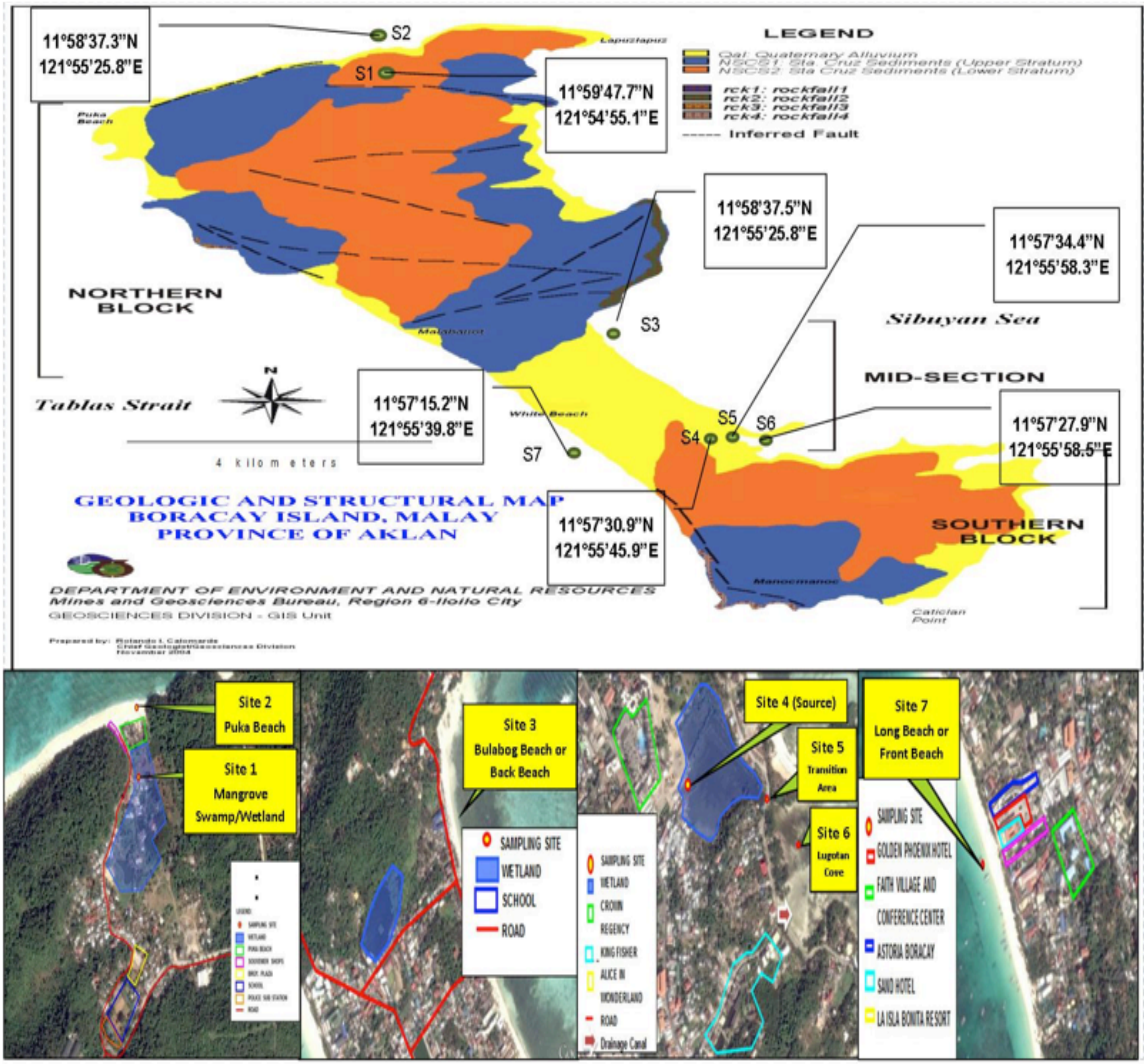

Figure 2. Geologic and structural map of Boracay Island, Malay, Aklan reflecting the seven study sites, (2012).

Forest" by the local community and only has about 10% mangrove trees along the periphery. It has an estimated area of 3.697 ha previously converted into fishpond (presently abandoned). The Dead Forest served as the catchment area of surface water, ground water, and sewage from adjacent communities within and around the mangrove swamp. A small creek at the south-western part of the Dead Forest traversing the houses and establishments drains into this wetland. Located at its elevated portion are the wet market, stores, restaurants/eatery, pawnshop/jewelry shops, and parlor and salons. All these establishments are not connected to a sewerage system, thus all their waste waters drain into the swamp via the creek.

Site 5 is a Transition Area (**Figure 2**), located after the dike connecting the Dead Forest and Lugotan Cove (Site 6) at Manoc-manoc Village. It is an embayment which is sporadically covered by seagrass bed. It is located at 11°57'34.4"N; 121°55'58.3"E and sampling area is approximately 349 m away from Site 4.

Site 6 is a Repository Area, catchment of water from Site 4 (Dead Forest/source) and Transition Area (**Figure 2**), named Lugotan Cove, located at 11°57'27.9"N; 121°55'58.5"E. The sampling point here is 58 m away from Site 5. Its mouth is located immediately after the Transition Area (Site 5) is being margined by mangrove forest.

Adjacent to it is about 3-ha seagrass bed. The seagrass bed is approximately covered by 2 m water column during high tide and is exposed during lowest low tide. A 500-m drainage canal traversing the community within wetlands 5 and 7 adjacent to wetland 6 or Site 4 is also discharging in Lugotan Cove. Sewage of some houses and restaurants and other establishments are being discharged into the drainage canal. (Although, wetlands 5 and 7 were not included in thisstudy, the residential areas and establishments within them were also accounted in the study).

Site 7 is the 4-km Long Beach and is located at 11°57'15.2"N; 121°55'39.8"E (**Figure 2**) and is divided into stations 1, 2 and 3. It is the area of great interest to the people, since it is always visited by tourists and is the most populated area.

Water Quality Laboratory Analysis

The water samples were analyzed for the following parameters: Nitrogen (nitrate), Phosphorus (ortho-phosphate), pH, Biochemical Oxygen Demand (BOD), Dissolved Oxygen (DO), Total Suspended Solids (TSS), water temperature (*APHA, AWWA, WEF 1995, Eaton et al. 1998*), *E. coli* and total coli count. Six water samplings were done bi-monthly in February, April, June, September4 (for August), October, and December 2012. Collections of samples were mostly done at the last week of the month except during inclement weather condition. Thus, samplings were done within the limit of one week before and after the set schedule, and were conducted at low tide, usually between 6:30 to 10:00 a.m.

Rainfall higher than 200 mm mo^{-1} occurred in the months of May, July, September and November, while rainfall less than or equal to 200mm mo^{-1} occurred in the months of October, December, January, February, March, April and June (**Figure 3**) (*PAGASA 2012*).

The water samples were brought to Boracay Island Water Corporation (BIWC) laboratory for the analyses of DO, BOD, TSS, nitrates, phosphates, and pH, while water temperature was taken *in situ* using a mercury-filled thermometer. The bacteriological analysis on E. coli, and total coliform (**Figure 4**) was conducted by the researcher using the Petrifilm (*http://www.3m.com/3M/enUS/company-us; Bacteriological Analytical Manual 1998*). Two dilutions with two replicates were made based on the assumed pollution level of the coastal water.

In order to determine the dynamics of the water quality in the Island Pearson *r* correlation using Minitab version 11 was done to establish association of the different biophysico-chemical parameters (**Table 2**). Comparative analysis between sites and sampling periods was done through Two-way Analysis of Variance (ANOVA) by SAS PROC GLM using SAS ver. The t-test analysis using Excel was conducted to determine the influence of seasons to the result of the parameters analyzed.

Secondary Data Gathering

Secondary data were gathered from concerned institutions. The information included the various assessments and monitoring reports from the Departmentof Environment and Natural Resources (DENR) and Department of Tourism (DOT) and Local Government Units (LGUs). The data were used to initially characterize the mangrove swamps as well as the island's coastal waters. Information on tourist arrivals and related socio-economic information were also taken from LGU Malay in 2012, Philippine Tourism Authority (PTA) and DOT. Weather and climate data such as rainfall and wind patterns were

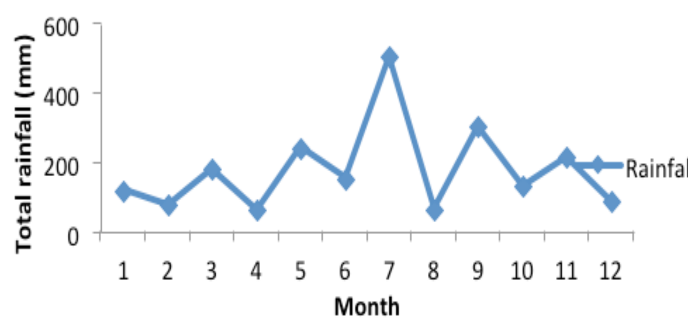

Figure 3. Amount of monthly rainfall in Boracay Island, Malay, Aklan, 2012. (Source: PAGASA, Roxas City station).

Figure 4. Petrifilm method used in the colony count of *E. coli*/other coliforms in Boracay Island, (2012).

Table 2. Summary of parameters analyzed for coastal water quality in Boracay Island, 2012.

Parameters	Method	Reference or Manifacturer
Nitrate (mgL^{-1})	Closed Reflux Cell Test	MERCK
Phosphate (mgL^{-1})	Closed Reflux Cell Test	MERCK
BOD (mgL^{-1})	Respirometric	5210 B 5-Day BOD Test ,APHA AWWA, Standard Method for the examination of water and waste water
DO (mgL^{-1})	Glass Electrode	4500-O D, APHA AWWA, Standard Method for the examination of water and waste water
TSS (mgL^{-1})	Gravimetric Method	2540 D, APHA AWWA, Standard Method for the examination of water and waste water
pH (range)	Electrometric	4500-H^+ ,APHA AWWA, Standard Method for the examination of water and waste water
Temperature (°C)	Mercury-filled Thermometer	2550 B, APHA AWWA, Standard Method for the examination of water and waste water
E. coli (CFU mL^{-1})	Petrifilm	3M Microbiology Products
Total Coliform CFU ml^{-1})	Petrifilm	3M Microbiology Products
NPK of coastal sediment (OM-%; P-ppm; K-ppm)	OM SA Wildes, P – Olsen's Method K- Cold H_2SO_4	PCARR, 1980. Standard Methods of Analysis of Soil, Plant Tissue, Water and Fertilizer.

taken from the Philippine Atmospheric, Geophysical and Astronomical Services Administration (PAGASA) Roxas City Station, while geological data were obtained from the Office of DENR Mines and Geosciences Bureau (MGB), in Western Visayas, 2012.

RESULTS AND DISCUSSION

Sources of Pollution

The coastal water quality in Boracay Island was basically influenced by natural and anthropogenic sources namely: the inflowing underground water and surface freshwater, the sewage discharge, coastal sea water dynamics, geological and geographic characteristics of the area. The multitude of anthropogenic sources of nutrients and other forms of pollution into the mangrove swamps and coastal waters came mostly from the partially treated and untreated domestic waste water generated by the households, boarding houses, and commercial establishments particularly those not connected to a sewerage system. Other identified sources of pollution were the inorganic and organic chemical pollutants that are naturally found in the environment wherein residues and discharges were brought by floods off the mangrove swamps and to the shore. Illegal reclamation and occupation of wetlands (mangrove swamps) reduced the flood plain areas that collect wastes where natural biological and chemical processes could have diminished the organic and inorganic load of the waters before being discharged to coastal waters. There were instances that some households and residents mechanically force out flood waters to the sea through the use of water pumps (*Boracay Environmental Master Plan, 2008*).

Sewage and Toilet Connection

Sewerage system service in the Boracay Island was inadequate. Only some areas of the three villages- Manoc manoc, Balabag, and Yapak were served. There were houses and establishments that only their grey water (waste water from kitchen and bathrooms) was connected to the sewerage system. Data from Boracay Island Water Corporation (BIWC) in 2012 revealed that 28 commercial establishments and 34 residential buildings in Balabag Village located within the service area of BIWC were not connected to the sewerage system while only around 167 houses within the villages of Balabag and Manoc-manoc were connected. Similarly, 211 commercial establishments and 46 residential buildings in Manoc-manoc Village, one commercial establishment and one big resort in Yapak Village, all within the reach of the sewerage system were not also connected. No sewerage system existed in most part of Yapak Village. Almost all the toilets of houses in Mangrove Swamp 1 (Study Site 1) and Mangrove Swamp 6 (Study Site 4) were not connected to the sewerage system though most of them used septic tanks. Most septic tanks in the Island do not have a properly constructed seepage tile to further purify the effluents (*Boracay Environmental Master Plan 2008*). Most likely, high population density areas during peak tourist season may cause overflow of septic tanks, thus the grey water of residents of these establishments not connected to the sewerage system was either discharged to the ground, mangrove swamps or septic tanks and some directly to the drainage canal. All waste water percolated to the ground and was transported to the mangrove swamp due to the porosity of the Karstic soil of Boracay (*Trousdale 1997, MGB, Region VI 2012*). Organic and inorganic wastes were also brought to the coastal areas through surface runoff during rainy periods. On the other hand, most of the business establishments along the Long Beach and Bulabog Beach totaling 767 (*BIWC 2012*) were connected to sewerage system. Many of the big resorts have their own Sewerage Treatment Pond (STP). Majority of resorts and hotels within the service area of BIWC were connected to the sewerage system. Few large hotels and resorts established their own STP.

Biophysico-chemical Results and Dynamics

The physical properties and water chemistry of samples from the study sites were discussed with reference to the geographical, geological and hydrodynamics characteristics. The results of the water quality of the study sites were compared as to the purifying effect of the mangrove swamps. The water quality results were evaluated based on DENR standards per DAO 34, Series of 1990- "Standard for the Classification of Body of Water". Based on the classification of coastal water of Boracay Island conducted by DENR, EMB, Long Beach and Puka Beach were classified under Class SB - Coastal and Marine Water - Recreational Water Class (area used by public for bathing, swimming, skin diving, etc); while the Bulabog Beach was classified as Class SC- Recreational water Class II (boating, etc). The mangrove swamps were not classified by EMB Region VI, however per DAO 34, Series of 1990, mangrove swamps belong to Class SD (other areas).

Dissolved Oxygen (DO)

The DO reading (**Table 3**) was positively correlated with study site classification whether source, transition, repository coastal water (r=0.46; p=0.002) and sampling periods (r=0.31; p=0.043). The DO reading increased from the source to the transition area and to the repository area (coastal), and ranged between 0.7-11.06 mg L^{-1} (**Table 4**). Among these three sites, the lowest DO level was recorded at Site 4 (Dead Forest/mangrove swamp 6-source) and during the months of April, February and September 2012 with readings of 0.7 mg L^{-1}, 1.5 mg L^{-1} , and 3.39 mg L^{-1}, respectively, while the highest value at Lugotan Cove (Site 6) was in December 2012 that may be attributed to the presence of macrophytes (algae) and cold temperature (*Horne 1969; Saffran and Anderson 1997*) during the sampling period. The saturation values had the similar trends in other sites as indicated by the DO values. These readings were below 2.0 mg L^{-1}, the required DO level for unclassified sites (Class SD) such as mangrove swamps based on DAO 34 water (unclassified body of water). The factors that may be contributing to the low DO levels at these sites were the decomposition of organic matter, high temperature, less water movement and also may be due to small number of submerged macrophytes that can be the source of DO in the area (*Ulrich 1976; Dowling and Wiley 1986; Saffran and Anderson 1997; Huggins and Anderson 2005*).

At Site 4 – "Dead Forest" or Mangrove Swamp 6, lowest DO at almost zero was recorded in April sampling period when temperature was highest at 31°C (**Table 4**). Higher ambient water temperature recorded in this site may have caused the rapid decomposition of organic matter in dry season particularly in the month of April which could have caused this zero DO level. The super saturation values for dissolved oxygen in the site could also be explained by the prevailing water condition that enhanced evaporation or favored oxygen to leave the water surface resulting to super saturation effect. This is below the ≥5mg L^{-1} dissolved oxygen normal value for biologically alive water body (*DAO 34 1994*). In the absence of oxygen, the decomposition of organic matter by anaerobic bacteria produced many unpleasant odors, i.e. methane, ammonia and hydrogen sulfides (*Poach et al 2002; Voss et al 2011*). The researcher during the summer samplings detected rotten egg odor, indicating the presence of H_2S. High level of ammonia is toxic to marine organism and nutrients like nitrate and can have direct detrimental effects when ingested by humans. The increase of nutrients in water will degrade water qualityand alter primary producer production (*Cadwell 1975; Dunette et al. 1985; Matson et al. 1997; Smith et al. 1999*).

Table 3. Summary of parameters correlated with significant results resulting r value and p value.

Parameters Correlated	r-Value	p-Value
DO with classification of study Sites (source, transition, repository area)	0.46	0.002
DO with sampling periods	0.31	0.043
BOD with classification of study Sites	-0.42	0.005
BOD with sampling periods	-0.48	0.001
pH with study Sites	0.317	0.041
pH with sampling period	0.46	0.002
DO with pH	0.36	0.0211
TSS with temperature	0.411	0.007

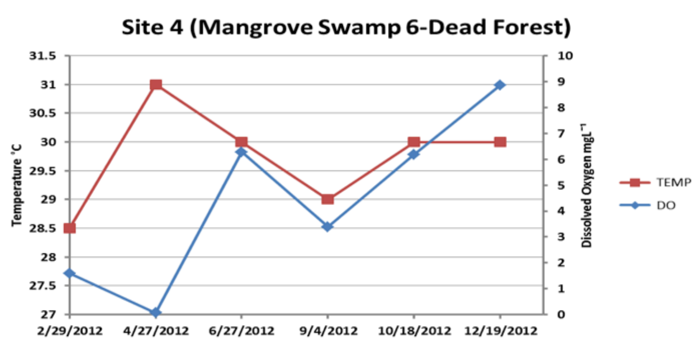

Figure 5. Dissolved Oxygen mgL^{-1} and Temperature reading in Study Site 4 (Mangrove swamp-Dead Forest) for six sampling periods 2012.

Table 4. Water Quality Results (Dissolved Oxygen (DO), Biological Oxygen Demand (BOD, Nitrate, phosphate, Total Suspended Solids (TSS), pH, and Temperature in Seven Sampling Sites at Six Sampling Periods in Boracay Island, (2012).

Water Quality Indicators	Date of Water Sampling	Site 1 (Mangrove Swamp - 49% mangrove cover)	Site 2 (Puka Beach)	Site 3 (Bulabog Beach-Front Beach)	Site 4 (tree-impoverished mangrove swamp)	Site 5 (Transition area bet site 4 and 6)	Site 6 (Lugotan Cove)	Site 7 (Long Beach-Front Beach)
DO (mg L^{-1})	February 12, 2016	6.74	7.68	7.73	1.59	6.58	8.08	7.99
BOD (mg L^{-1})		50	20	50	150	100	100	20
Nitrate (mg L^{-1})		3	3	1	5	3	1	2
Phosphate (mg L^{-1})		59	0.8	34.3	25.6	62	63.5	20.5
TSS (mg L^{-1})		799	458	455	292	315	365	480
pH		7.05	6.89	8.12	7.82	8.07	8.11	6.82
Temperature		26.8	28.8	27	28.5	27.5	27.5	29
DO (mg L^{-1})	April 27, 2012	7.14	7.98	7.49	0.07	6.55	6.19	7.19
BOD (mg L^{-1})		30	10	10	250	40	20	20
Nitrate (mg L^{-1})		3	2	3	2	6	8	6
Phosphate (mg L^{-1})		3.7	32.6	79	61.9	36.9	72.5	99.1
TSS (mg L^{-1})		153	483	427	206	313	354	488
pH		7.34	8.13	7.76	7.59	8.11	8.08	9.07
Temperature		31	28	30	31	31	30.5	30
DO (mg L^{-1})	June 27, 2012	6.8	8.38	7.23	6.28	6.48	4.98	8.03
BOD (mg L^{-1})		100	20	20	100	20	20	20
Nitrate (mg L^{-1})		1	3	1	2	1	1	0
Phosphate (mg L^{-1})		14.7	19.3	21.1	20.8	34.3	16.9	83.6
TSS (mg L^{-1})		77	479	477	290	461	463	486
pH		7.77	7.97	7.84	7.98	7.92	7.82	8.04
Temperature		29.5	29	29	30	29	29	28.5
DO (mg L^{-1})	September 4, 2012	7.70	5.29	6.53	3.39	6.10	7.39	9.70
BOD (mg L^{-1})		5	9	3	16	8	8	2
Nitrate (mg L^{-1})		3	1	3	6	6	8	3
Phosphate (mg L^{-1})		13.8	27.5	10.6	18.4	0	36.3	23.3
TSS (mg L^{-1})		435	33	25	456	405	430	402
pH		7.83	8.05	7.95	8.20	8.26	8.08	7.50
Temperature		29	29	29	29	29	28	28
DO (mg L^{-1})	October 18, 2012	7.74	8.89	6.93	6.19	6.12	7.48	7.59
BOD (mg L^{-1})		5	0	2	15	8	11	5
Nitrate (mg L^{-1})		3	2	2	2	3	2	1
Phosphate (mg L^{-1})		5.1	11.3	1.1	11.3	4.6	2.8	8.6
TSS (mg L^{-1})		64	451	465	234	296	319	315
pH		7.45	8.16	7.84	8.26	8.01	8.19	8.16
Temperature		30	30	29.5	30	29	29	29
DO (mg L^{-1})	December 19, 2012	4.29	8.15	8.22	8.86	10.46	11.06	8.75
BOD (mg L^{-1})		11	6	4	26	18	19	3
Nitrate (mg L^{-1})		1	1	1	2	2	1	1
Phosphate (mg L^{-1})		66.5	66.7	3.4	57.3	38.7	72.5	2.8
TSS (mg L^{-1})		194	472	550	448	467	482	458
pH		7.44	8.09	8.02	8.35	8.48	8.63	8.15
Temperature		28	28	28	30	29	29	28

The Lugotan Cove (Site 6-repository area) in June 27, 2012 sampling recorded a DO level of 5 ppm (**Table 4**) lower compared with Source (Site 4) and Transition Area (Site 5) at around 6 ppm. This may be attributed to the untreated sewage from the households and commercial establishments that were not connected to the sewerage system and discharged directly to the canal during the rainy season (May to October) that drained to the cove (**Figure 2**). In addition, rainy season relatively increased the volume of organic influx that included terrigenous sources, as compared to dry season (November to April). The decomposition of organic matter in untreated waste waters utilized more of the DO in the water thus, low DO level was registered in this June sampling.

Biochemical Oxygen Demand (BOD)

Higher BOD reading means presence of large amount of organic matter to be degraded by decomposers (*Marske and Polkowski, 1972; Prandi-Rosa and Farache Filho 2002; Wahid et al. 2007*). A BOD of 5 mgL-1 and below is the accepted level for Class SB water, and 10 mgL-1for Class SC water (*DAO 35 1990; DAO 23 1997*). However, BOD standard was not determined for Class SD (*DAO 34 1994*). BOD readings (**Table 3**) has an inverse relationship with DO readings (r= -0.61; p=0). Likewise, BOD reading was negatively correlated with class (source, transition, and repository area), (r= -0.42; p=0.005) and sampling periods (r=-0.48; p=0.001). The factors that explain the high variation of BOD in the different sampling sites were the organic matter present in the water, light intensity, water current, and kinds of living organisms present in the water body (*Lee et al. 2003; Voss et al. 2011*). The BOD reading per sampling period at different sampling sites ranged between 0-250 mg L^{-1}. Puka Beach (Site 2) at Yapak Village registered the lowest BOD of zero even during the October sampling period showing that less organic matter was being discharged in the area. It shows that the source (Site 1-mangrove swamp 1) adjacent to the Puka Beach was still effective in controlling the discharge of organic matter to the beach. The DO reading was high at 8.89 mg L^{-1} during the sampling period.

Site 4 -Dead Forest/Mangrove Swamp 6 (source) registered highest BOD at 250 mg L^{-1} during the April 27 sampling with DO=.07 mg L^{-1}. The BOD in the first three sampling periods (February, April and June) were comparatively high in all sampling sites and did not pass the BOD standard for Class SB and SC water. It can be explained that during these months there may be massive input of organic matter coupled with accelerated decomposition and relatively high intensity of light penetration (*Voss et al. 2011; Teal et al. 1978*).

Lower difference in BOD readings was registered between Puka Beach (Site 2) and Mangrove Swamp 1 (Site 1) in all sampling periods except in September (**Table 4**). However, during the rainy month of September, Puka Beach had higher BOD (9 mg L^{-1}) than mangrove swamp 1 (5 mg L^{-1}). This means that less organic matter was present in mangrove swamp probably due to the increase of its water level producing a dilution effect (*Valiela et al. 2013*). It could be possibly attributed also to the surface run off to the sea from other sources aside from Site 1 (10 masl), and underground percolation of organic matter (*Trousdale 1997*).

Lower BOD from September to December sampling periods were registered in all sites compared to previous sampling months. This happened because the preceding organic matter was already decomposed, or could be due to dissipation process as influenced by current and wave action as in the case of Puka Beach, Long Beach and Bulabog Beach (*Huggins and Anderson 2005*). However, Lugotan Cove (Site 6) being an embayment showed a relatively higher BOD compared to other sites except for Site 4 because of higher organic inputs and less dissipation of nutrients due to slow water movement.

Nitrate

Nitrate level ranged between 0-8 mg L^{-1} (**Table 4**). The lowest recorded nitrate level was in the Long Beach (Site 7) during the June 27 sampling period at 0 mg L^{-1}, while the highest was in Lugotan Cove (Site 6) during the April 27 and September 4 sampling periods at 8 mg L^{-1}.

The excess nitrate in water may be due to nutrients leaked from septic tanks and these had percolated in the ground into the sea. With June being a period of low tourist arrivals, it is being speculated that sewage did not exceed the septic tank level hence percolation into the coastal water was controlled. High nitrate level was observed during April and February sampling periods with high tourist arrivals (**Figure 6**). The association of increased nitrate level with high number of tourists during these periods was supported by the significant association of nitrate and tourist arrivals during the months of February to April 2012 (**Figure 6**). Nitrate increased due to tourism was also cited by *Patterson and McDonald* (*2004*) on their study of how clean and green tourism is in New Zealand.

Highest levels of nitrate 8 mg L^{-1} were observed in Lugotan Cove (Site 6) in April and September samplings (**Table 4**). It was possible that water from Mangrove Swamp 6- source (Site 4) flowed to Transition Area (Site 5) and to coastal area at Lugotan Cove- repository. With sufficient DO of 6 mg L^{-1} in the Transition Area (**Table 4**)

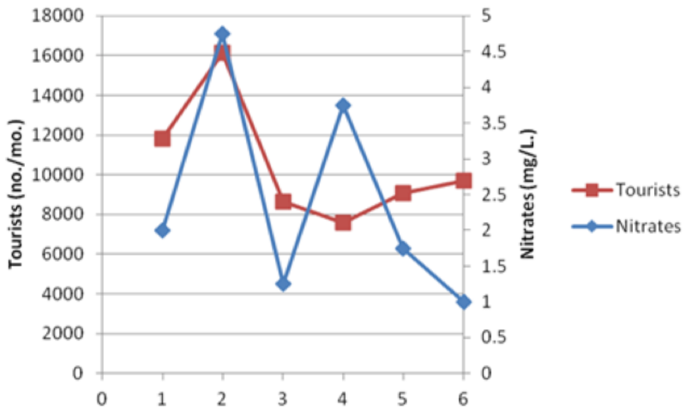

Figure 6. Relationship of tourist arrivals with nitrates level in water column (1- February 29, 2-April 27, 3-June 27, 4-September 4, 5-October 18, and 6-December 19).

during this period, biological and chemical processes could have facilitated the transformation of organic and inorganic nitrogen into dissolved nitrate (*Leonov and Toth 1981; Burt et al. 1993; Bode and Dortch 1996; Lordal et al. 2008*) and deposited it in Lugotan Cove causing nitrate level to increase. It can also be attributed to other sources of nutrients from the drainage canal that emptied into the Lugotan Cove as well as to the decomposition, of primary producers' biomass in the area. In the process of decomposition, the micro-organism used up dissolved oxygen which might had been quickly replenished by oxygen dissolved from air and those released by the seagrasses and phytoplankton such that DO level in Lugotan Cove remained high at 6.0 mg L^{-1} (*Huggins and Anderson 2005; Saffran and Anderson 1997*).

The lower level of nitrate in Bulabog Beach can be explained by the presence of vast area of seagrasses that utilized the dissolved nutrients in water for their growth and reproduction; consistent to the research study of *Chapin et al.* (*2004*), that the apparent decrease in nitrate during the low tide period could be attributed to denitrification in the sediments or uptake by photosynthetic and benthic organisms.

Mangrove swamp 6/Dead Forest-Site 4 (source) did not show higher nitrate compared to its adjacent coastal area (Lugotan Cove-Site 6) during the April water sampling despite the fact that there was high BOD of 250 mg L^{-1} (**Table 4**) and low DO of 0.7 mg L^{-1} (**Table 4**) indicating high organic matter content. This may be due to the high temperature of 31^{o}C which was recorded in the site (**Table 4**) during April which favors ammonia volatization. Hence, it is highly possible that low nitrate level in the site can be attributed to ammonia escape in April that inhibited the nitrification process (*Voss 2011; Poach et al. 2002*). However, Long Beach did not also show high nitrate level during this period, this may be attributed to wave dissipation process in the beach region.

Phosphates

The identified sources of phosphates in Boracay Island were from possible leak of water rich in phosphate that included the septic tanks, organic matter from surface run-off, and treated, partially treated and untreated sewage and waste water. Detergents from waste water are also primary source of phosphates. Phosphates are important nutrients for plant growth but excessive amount of phosphates in water can lead to algal bloom (*Hutchinson 1969; Correl 1998; Smith 1998*). In the issue of pollution, phosphates are one component of total dissolved solids (*Hochanadel 2010*).

Up to the present, there are no indicated water quality criteria for phosphate in marine waters in the Philippines. However, as discussed in the study of *Yang et al.* (*2008*), lakes to be considered uncontaminated should have a phosphate range of 0.01 - 0.03 mg L^{-1}, while phosphate level between 0.025 - 0.1 mg L^{-1} will stimulate plant growth, and 0.1 mg L^{-1} phosphate is the maximum acceptable level to avoid accelerated eutrophication, and phosphate of more than 0.1 mg L^{-1} will result to accelerated plant growth and subsequent ecological problems. Moreover, the US EPA, 1986 recommended that there should not be more than 0.1 mg L^{-1} total phosphorus for streams which do not empty into reservoirs; no more than 0.05 mg L^{-1} for streams discharging into reservoirs; and no more than 0.025 mg L^{-1} for reservoirs to be considered uncontaminated.

In this study, the phosphate concentrations (**Table 4**) were highest in the Long Beach (Site 7) during the April and June sampling at 99.1 mg L^{-1} and 88.6 mg L^{-1}, respectively. Zero phosphate was recorded in the Transition Area (Site 5) of mangrove swamp 6 (Site 4) during the September 4 sampling. Sampling sites with lower phosphates were Puka Beach (Site 2) at Yapak Village (0.8 mg L^{-1}) in February, Bulabog Beach (Site 3) with 1.1 mg L^{-1} during the October sampling, Lugotan (2.8 mg L^{-1}) October sampling, and Dead Forest/Mangrove Swamp 6 – source (Site 4) with phosphate level of 3.7 mg L^{-1}) April sampling.

Generally, phosphate level was higher in February, April, June and December sampling periods. It could be that higher volume of sewage was discharged to the coastal water due to high influx of tourists (**Figure 7**) from late December to April as can be supported by data from DOT. The relatively high phosphate level in June can be attributed to the discharge of surface soils containing accumulated inorganic and organic matter laden with phosphates into

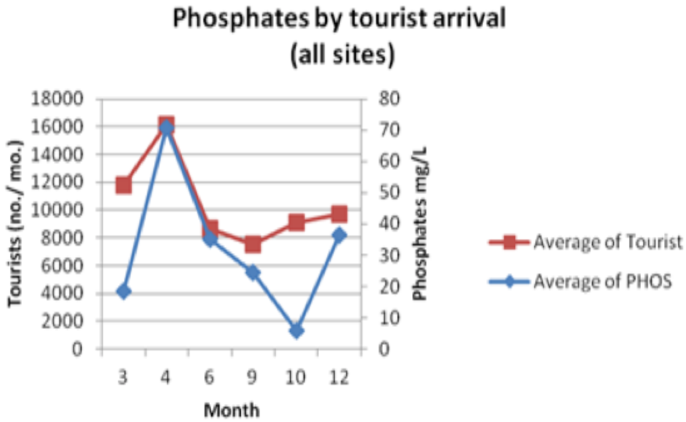

Figure 7. Relationship of tourist arrivals with phosphates level in water column (1- February 29, 2-April 27, 3-June 27, 4-September 4, 5-October 18, and 6-December 19).

the study sites by storm waters that started during the month of May. In shallow water, the increased frequency of disturbance enabled the release of P from the sediment; especially the high temperature which may explain the high phosphate level in areas where water was flowing (*Cai et al. 2007; Sharpley et al. 1996*)

There was rapid dissipation of phosphorous from higher concentration at the pollution source (Site 4) to Transition (Site 5) and ultimately to the coastal area (Site 6). The phosphate was then gradually released into dissolved form during the mineralization process of the sea (*Owilli 2003*). High levels of phosphorus can facilitate blooms and growth of autotrophs in general. This leads to an overall decrease in DO, as the algae after death were decomposed by aerobic bacteria.

pH

The "pH" measures the H+ ion concentration of substances and gives the results on a scale from 0 to 14. It affects biological processes, and influence reaction rates (*Ulrich 1976*). Sudden changes in pH can indicate nutrient or chemical runoff (*Heiland 2009*). In Boracay Island, the pH reading was positively correlated with site (r=0.317; p=0.041) and sampling period (r=0.46; p=0.002). Thus pH increased from source (Site 4 and Site 1) to coastal area (Site 6 and Site 2) and from the first to the 6th sampling periods.

Dissolved Oxygen was positively correlated with pH (r=0.36; p=0.0211), (**Table 3**). It means that with higher pH there is also higher level of DO. If the soil is Karstic which is rich in calcium carbonate ($CaCO_3$) or limestone, water bodies tend to have higher pH because water acidity reduces as affected by limestone weathering in the upper epikarst because acidity reduces as affected by the limestone weathering in the upper epikarst and subsequent dissolution (*Maree and du Plessis 1994; Faimon 2005*) as in the case of Boracay Island. The pH readings in all sampling areas ranged from 6.82-8.48 and were within the criteria of Class SB and Class SC water. The normal pH value can be attributed to the Karstic soil of Boracay Island containing high $CaCO_3$ that helped buffer pH changes even with the inputs of pollution in the mangrove swamps and coastal water that may reduce or increase the pH level. The photosynthetic activity of seagrass and algae may have also aided in the increase of pH by consuming the CO_2 present in the water (*Heber et al., 1976*). Photosynthesis of these autotrophs also liberates O_2 in the coastal water leading to high DO reading.

Total Suspended Solids (TSS)

The TSS reading was found positively correlated with temperature (r=0.411; p=.007) (**Table 3**). This means that higher TSS readings where registered at sampling periods where the temperature of the coastal water was also high. The TSS readings (**Table 4**) ranged between 25-799 mg L^{-1}. The high readings in most sampling periods may be explained by the fact that water samples were taken along the shore during sampling months at low tide level for consistency. These were also the times when most tourists were active in the coastal zone. However, the TSS of 25 mg L^{-1} in Bulabog Beach during September 4 sampling could be explained by the wind direction and current which was South-Southwest (SSW) monsoon with calming effect at the back beach or Bulabog Beach (Site 3) located in the eastern portion of the Island. The wide seagrass bed cover in Bulabog performed its functions in binding the sediments creating clearer water. On the other hand, the high TSS readings in Bulabog for the rest of the sampling periods were due to the sewage outfalls from the drainage that were confined by current during the North-East (NE) and East-Northeast (ENE) wind direction, and also owing to the docking of pump boats along the shore and wind surfing activity. The high level of TSS at the Long Beach (Site 7) could be attributed to the swimming activities of the tourists. Puka Beach at Yapak Village (Site 2), also located in the eastern portion of the Island, had a comparatively lower TSS reading. The rest of the sampling periods that gave Puka Beach (Site 2) a higher TSS may be due to the effect of sea turbulence when the wind direction was North-East (NE).

The sewage outflow to the Dead Forest/mangrove swamp 6 (Site 4) contributed to the high TSS level. High TSS readings were also recorded in Transition Area (Site

5) and Lugotan Cove-Repository Area (Site 6). Movement of water in the Transition Area going to the coast and additional input of sediments from the drainage canal adjacent the Mangrove Swamp 6 (Site 4) and emptying into the Lugotan Cove (Site 6) influenced the TSS levels. The high TSS level in Wetland 1-Source (Site 1) could be due to the very low water level wherein sediment was disturbed during water sampling.

Comparison of Water Quality Results Between Study Sites

Comparative analysis of water quality parameters by sampling Sites using 2-way Analysis of Variance (ANOVA) at 5% significant level and Tukey's test based on log-transformed data, showed no significant differences among sampling points in terms of TSS, phosphates, nitrates, and water temperature parameters. However, Site 4 or Mangrove Swamp 6 was slightly higher in pH and much higher BOD than Site 1 or Mangrove Swamp 1, Site 2 (Puka Beach) and Site 7 (Long Beach). Site 6 (coastal part of wetland 6 or the Lugotan Cove) has the highest *E. coli* and total coliform populations. The rest of the sites had the same levels.

The difference in volume and degree of pollution load between mangrove swamp 1 (Site 1) and mangrove swamp 6 (Site 4) was very distinct. Higher pollution load was estimated in mangrove swamp 6 than mangrove swamp 1. The water quality results between the two mangrove swamps and between the two coastal sites adjacent to the mangrove swamps: Puka Beach (Mangrove Swamp 1) and Lugotan Cove (Mangrove Swamp 6) proved the importance of mangrove swamp as it assimilates the nutrients from the organic matters discharged through biological and chemical processes before it is being discharged to the adjacent coastal waters (*Gearheart 1993; Primavera 2004*). Moreover, Mangrove Swamp 1 was densely vegetated compared to Mangrove Swamp 6 (*DENR VI, PAWCZMS Wetland Assessment Report, 2009*).

Effect of Season on Water Quality

The t-test conducted comparing the wet and dry samplings periods showed that only air temperature and *E. coli* colony counts had significant differences at 1% level between seasons. Other parameters were not significantly affected by seasonal variation. Air temperature was significantly higher in dry season than in the wet season (27.05C vs. 25.79, t=4.84, p<0.0010), but air temperature had no significant effect on the autotrophs since they are not exposed to air. It can be deduced that one of the factors that affected the lower concentration of nitrate was dilution effect of precipitation. The rainy season was also a lean season of tourist arrivals in Boracay Island, which means that there were also lesser inputs of nitrate from anthropogenic activities.

On the other hand, coastal *E. coli* was higher in dry season than in the wet season (105.94 vs. 28.12, t=3.16, p=0.01) as there could be less dilution and dissipation of polluted water during this time. Specifically, highest recorded *E. coli* was observed in the month of April, the month with the highest tourist arrival. As mentioned above, septic tanks may have overflowed as well the flow of the untreated sewage from residential houses and business establishments not connected with the sewerage system may have increased during this period, both of which were possible sources of *E.coli* contamination. However, during wet season, high amount of precipitation may have diluted the pollutant in the swamp and coastal areas. It was also possible that the pollutants were washed away by rain and dissipated into the open sea.

CONCLUSION AND RECOMMENDATIONS

The coastal water quality in Boracay Island was influenced by natural and anthropogenic sources of nutrients, coastal sea water dynamics, geological characteristics of the area and weather and climate. The major sources of pollution affecting the water quality are waste water from households and commercial establishments not connected to the sewerage system. Influx of tourists during peak season contributed heavily to nutrient loading. On the other hand, the coastal water in Boracay Island undergoes natural cleansing mechanisms through biogeochemical processes in the mangrove swamps and through activities of the autotrophs present in the coastal zone of the island. The process of cleansing the water of excess nutrients was described in the dynamic interaction of phytoplankton, sea grass and macro algae in utilizing available N and P in the coastal water of the Island discussed in the parallel work by the same authors in a recent paper (*Limates et al. 2016*).

The capacity of the mangrove swamps to purify water was affected by the extent of mangrove cover and the amount of waste discharged into it. Basically, the physical and water chemistry of mangrove swamp was influenced by the relative amount of solid and liquid waste discharged into the swamp and waste waters from anthropogenic and natural sources. Coastal water surrounding areas with higher anthropogenic activities where establishments not connected to sewerage system are adjacent to mangrove swamp impoverished of mangrove trees showed poor water quality, while coastal water adjacent to mangrove swamp with relatively good mangrove cover and with lesser anthropogenic activities proved to have good water quality. Likewise, good water quality was recorded in coastal areas with commercial establishments connected to the sewerage system as in the case of Long Beach (Site 7), the most populated and visited area in Boracay Island.

Pollution reduction and proactive measures should be put in-place to sustain the tourism industry in the Island. Based on the results of this study the following are recommended actions that need to be done: Rehabilitation of the mangrove swamps by relocating all informal settlers and increasing the mangrove cover; Establishment of waste water treatment facility at the outfall of drainage canals before discharging into the coastal water; Strictly implementing the policy that all residential and commercial establishments should be connected to the Island's sewerage system; Protection and rehabilitation of seagrass beds because of its role in nutrient recycling, water purification, as habitat of marine organisms and provision of other vital ecological services; Effective implementation of a collaborative and comprehensive monitoring system as one important proactive strategy to prevent further degradation of the coastal water of Boracay Island; and Inclusion of analysis of phosphates and nitrates levels in the conduct of regular water quality monitoring by concerned government agencies.

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