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ASEAN-NORWEGIAN COOPERATION PROJECT ON LOCAL CAPACITY BUILDING FOR REDUCING PLASTIC POLLUTION IN THE ASEAN REGION (ASEANO) 2020 – 2021

SUBPROJECT 2:

SURVEY ON PLASTIC LITTERS ALONG IMUS RIVER, CAVITE, PHILIPPINES

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Partnerships in Environmental Management for the Seas of East Asia (PEMSEA)

Content

Acronyms/Abbreviations

BOD – Biological oxygen demand

CENRO – City Environment and Natural Resources Office

DENR – Department of Environment and Natural Resources

DLSU-D – De La Salle University-Dasmariñas

DO – Dissolved oxygen

HDPE – High Density Polyethylene

LDPE – Low Density Polyethylene

MENRO – Municipal Environment and Natural Resources Office

MISC – Miscellaneous Plastics

NIVA – Norwegian Institute for Water Research

PDV – Plastic Dominance Value

PET – Polyethylene terephthalate

PGENRO – Provincial Government Environment and Natural Resources Office

PP – Polypropylene

PS – Polystyrene

PVC – Polyvinyl chloride

SUP – Single-used plastics

TDS – Total dissolved solids

TSS – Total suspended solids

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Executive Summary

The persistence of plastics and its adverse effects to organisms and human health is a significant environmental challenge. Plastics are a non-biodegradable solid waste generated from different human activities. Plastic waste often ends up in aquatic ecosystems, threatening food safety and coastal tourism, affecting water quality, and increasing maintenance costs. Rivers serve as channels for plastic to flow into coastal and ocean waters. The path of plastic pollution from headwaters to the mouth of rivers is underexplored, and remains a gap in current understanding.

The Imus River, with a length of 38.4 km, is one of the six major rivers located in the province of Cavite. These rivers drain into Manila Bay, which a major pollution hotspot. Rapid urbanization and human settlements in Region IV-A (also known as CALABARZON), in which Cavite is included, have caused intensive changes. Pollution has increased in the rivers of the province. In this study, the extent of plastic pollution in the Imus River was assessed in terms of quantification and characterization, for both macroplastics and microplastics. The water quality of the river was also assessed based on its physicochemical characteristics against the standard of DENR for rivers is categorizes as Class C. The physicochemical parameters were also correlated to the quantities of collected plastic litter.

The data in this report were based on on-site observations and the collection of plastic litters during dry and wet months using. Both visual and active trawl sampling methods were used. Sampling sites were selected to represent the upstream, midstream and downstream of the entire stretch of the river located along five (5) municipalities/cities, i.e. Municipality of Silang, City of Dasmariñas, City of Imus, City of Bacoor, and Municipality of Kawit.

Findings highlighted in this report confirm that:

1. Plastic flux in the Imus River varies between stations and seasons. The movement of macroplastics downstream is influenced by urbanization, along with environmental factors such as elevation, tides, wind, flow velocity, and river curvature.

2. The most commonly found macroplastics (classified by utility) were packaging, bottles, and bags during dry months, and bags and miscellaneous plastics during wet months. HDPE, LDPE, and PP were common materials used in single-use plastics. HDPE, LDPE and PP are commonly used in single-use plastic such as packaging materials, bottles, and bags due to their flexibility and affordability.

   By weight, miscellaneous plastics and plastic bottles composed of PVC, PET, and PP were the most abundant form of microplastic during both dry and wet months. The most visible waste, determined by coverage of the river's surface, was plastic packaging composed of LDPE and HDPE during dry months, and plastic bags mainly composed of HDPE during wet months.

3. Microplastics show an increasing concentration going downstream in both dry and wet months. Microplastic fibers recorded the highest counts, followed by fragments, plus assorted microplastics and microbeads. Microplastics were characterized as PP, PET, HDPE, or miscellaneous through FTIR spectrophotometry.

4. The values of most sampled physico-chemical characteristics (temperature, TDS, pH, DO, BOD, salinity, and nitrates) are within the DENR standards. This confirms its Class C classification, which denotes use for fisheries, recreation, and agriculture. However, the values of phosphates and TSS exceeded critical limits, suggesting the need for close monitoring.

5. Physico-chemical parameters show no correlation with counts of microplastics and macroplastics except for total dissolved solids (TDS) and water temperature. TDS is positively correlated for both macroplastics and microplastics while water temperature is negatively correlated with microplastics.

This report gives the following recommendations:

1. Intensify the implementation of different laws and policies regarding solid waste management and the conservation and protection of freshwater

resources, such as RA 9003 (Solid Waste Management Act of 2000) and RA 9275 (Clean Water Act of 2004), by both the national government and local governments.

2. Implement a scheme that will promote recycling plastic to create a circular value chain for plastic wherein manufacturers and sellers of plastic products are encouraged to take discarded materials and remake them for resale, as practiced in Norway, among other countries.

3. Institute comprehensive national policy to ban the use of unnecessary plastics. The ban should prohibit the production, use and distribution of “oxo-degradable”, “biodegradable”, and “compostable” bags nationwide. A multi-sectoral consultation must be undertaken to look for other recyclable and reusable alternatives.

4. Governments must mandate that manufacturing industries develop alternative materials for plastics that will promote local and indigenous practices and resources. These innovations can be helpful in reviving affected packaging industries by absorbing potential job losses resulting from plastic bans.

5. Government agencies must involve all stakeholders through information and education campaigns regarding solid waste management and plastic pollution. Households should understand the different classification of wastes, be aware of pollution’s negative impacts, and practice proper waste segregation and minimization.

6. DENR must conduct regular monitoring of the physicochemical characteristics of river water to manage water quality. DENR should strictly implement the policy on requiring waste water management treatment facilities for industries and sewerage systems for households.

7. Conduct further research into microplastics in rivers, not only on presence in the water, but also in sediments, along with the effects on aquatic organisms. A socioeconomic valuation of the Imus River must also be conducted to assess the economic impact a lack of protection and conservation will have.

Introduction

Background of the Study

Status of Plastic Pollution in the World and in the Philippines

The persistence of plastics and its adverse effects to organisms and human health has become an international environmental concern. Plastic waste is non-biodegradable, and generated by a wide range of human activities. Rivers serve as natural channels for plastics to flow to the ocean, with waste often entering rivers both inadvertently and deliberately. The extent of plastic pollution within these channels, from headwaters to river mouths, remains underexplored. Plastic entering the water affects water quality, threatening food safety and coastal tourism.

Plastics constitute about 60% to 80% of marine debris, and may reach up to 95% in some areas. According to the International Union for the Conservation of Nature (IUCN), approximately eight million tons of plastic end up in our oceans every year (IUCN 2021). Minimum estimates of the number of marine plastics in the world's oceans are currently placed at 5.25 trillion pieces (Eriksen *et al*. 2014). Several marine species have been reported to have died due to ingestion of marine plastics (Kuhn *et al*. 2015) such as Deriniyagala's beaked whale *(Mesoplodon hotaula)* (Abreo *et al*. 2016).

Recent studies indicated that the Philippines is ranked third among the highest contributing countries of plastics in marine ecosystems (Jambeck *et al*. 2015; Lebreton *et al*. 2017). The country is said to contribute 0.28 - 0.75 million metric tons of marine plastic per year (Jambeck *et al*. 2015). This is substantiated by a study of Ecowaste Coalition, that found that Manila holds an estimated 9.4 billion pieces of plastic, with a total weight of more than 173,000 metric tons, across its 6,802 km^2 (Rubio *et al.* 2021). Likewise, a study of five Philippine river systems discovered a high bulk density value of plastic litter, ranging from 123 to 246 kg per m^3 (Tanchuling & Osorio 2020).

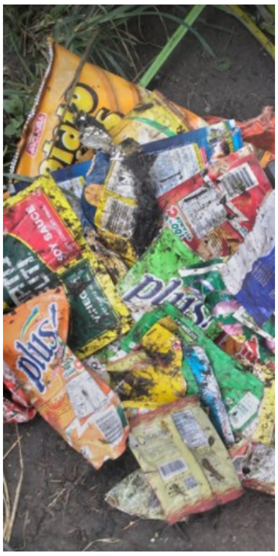
Plastics are non-biodegradable, but do break down. Pieces smaller than 5 mm down to the smallest and non-visible to the naked eyes are classified as microplastics. Most of the hundreds of millions of pieces of plastic in the oceans are microplastics. The effects of microplastics in the environment is not yet thoroughly explored (Issac & Kandasubramanian 2021).

Plastic Types in the Environment

Macroplastics can be classified based on resin material, i.e. Polyethylene Terephthalate (PET), High Density Polyethylene (HDPE), Polyvinyl Chloride (PVC), Low Density Polyethylene (LDPE), Polypropylene (PP), and Polystyrene (PS). The main sources of marine plastic litter are land-based – urban and storm runoff, sewer overflows, beach visitors, inadequate waste disposal and management, industrial activities, construction, and illegal dumping. A minority originates as ocean-based, mainly from the fishing industry, nautical activities, and aquaculture.

Microplastics are classified into primary and secondary microplastics. Pieces of plastic produced to be smaller than 5 mm are considered primary microplastics. Secondary microplastics are those created through the wear of larger plastic materials, such as fibers from synthetic clothing, flakes from car tires, beads from personal care products, and paint flakes (Issac & Kandasubramanian 2021).





Impact of Plastics in the Aquatic Ecosystem

Over the last 5-10 years, there has been growing public and political awareness of plastic pollution, alongside increasing concern regarding its impacts, especially in the ocean. A G7 Leaders declaration in 2015 identified marine plastic pollution as a major global problem. Images of seabirds and whales with stomachs full of marine debris are regularly reported across mainstream and social media. Interaction with plastic can cause significant injury to marine life, and in many cases, can lead to death through infection, starvation, and toxication. Direct harm from marine debris was reported for 663 species in 2012, with over 50% of instances involving entanglement in and/or ingestion of marine debris. Reports suggest that all known species of sea turtles, about half of all species of marine mammals, and one-fifth of all species of sea birds have been affected by entanglement or ingestion of marine debris (MCP 2018). Microplastics can also be ingested by aquatic organisms, even zooplankton.

Imus River

The Imus River is one of the six major rivers located in the province of Cavite. These major rivers of Cavite drain into Manila Bay, one of the Philippines' pollution hotspots (Rubio *et al.* 2021). Rapid urbanization and economic development in Region IV-A (also known as CALABARZON), in which Cavite is included, have had a substantial impact on levels of pollution in major rivers.

The Imus River has a length of 38.4 km, originating in the north of Tagaytay City, passing through the Municipality of Silang, City of Dasmariñas, and City of Imus, and draining from the City of Bacoor and the Municipality of Kawit into Bacoor Bay leading to Manila Bay. It has two major tributaries, one, which runs from Brgy. Bucal in Silang to Brgy. San Agustin in Dasmariñas, connects with the Imus River in Brgy. Pasong Bayog in Dasmariñas. Another, the Baluctot River, as its own dam (Baluctot dam) and joins the Imus River in Bacoor City (NIA 2017).

Objectives and Significance of the Study

With technical guidance/assistance from PRF, NIVA, and other partners, DLSU-D conducted a survey on plastic litters in the waters of the Imus River located in at least one barangay of five cities/municipalities (Municipality of Silang, City of Dasmariñas, City of Imus, City of Bacoor, and Municipality of Kawit) to:

1. determine the flux of macroplastics floating along Imus River;
2. classify and compare the macroplastics in the Imus River by intended use and resin materials during both dry and wet months, in terms of actual count, weight, and river surface covered;
3. determine the plastic dominance value (PDV) of macroplastics in the Imus River based on actual count, weight, and river surface covered;
4. quantify and characterize the microplastics from the Imus River during dry and wet months.
5. assess the water quality of the Imus River based on its physico-chemical characteristics;
6. correlate the densities of macroplastics and microplastics to the physico-chemical characteristics of water.

This study is important to produce baseline information on the types of macro- and microplastics in the Imus River, providing insight into potential origins and impacts. Such data can be used to educate stakeholders and inform policy development.

Methodology

Research Design

This study was designed to be descriptive and correlational, for both macro- and microplastics. The actual count, weight, surface covered, and density of the different types of macroplastics during dry and wet months were recorded, with relative values determined to rank them based on their plastic dominance values (Rubio *et al*. 2021). Microplastics were also quantified and characterized. These were correlated to the physico-chemical characteristics of the water.

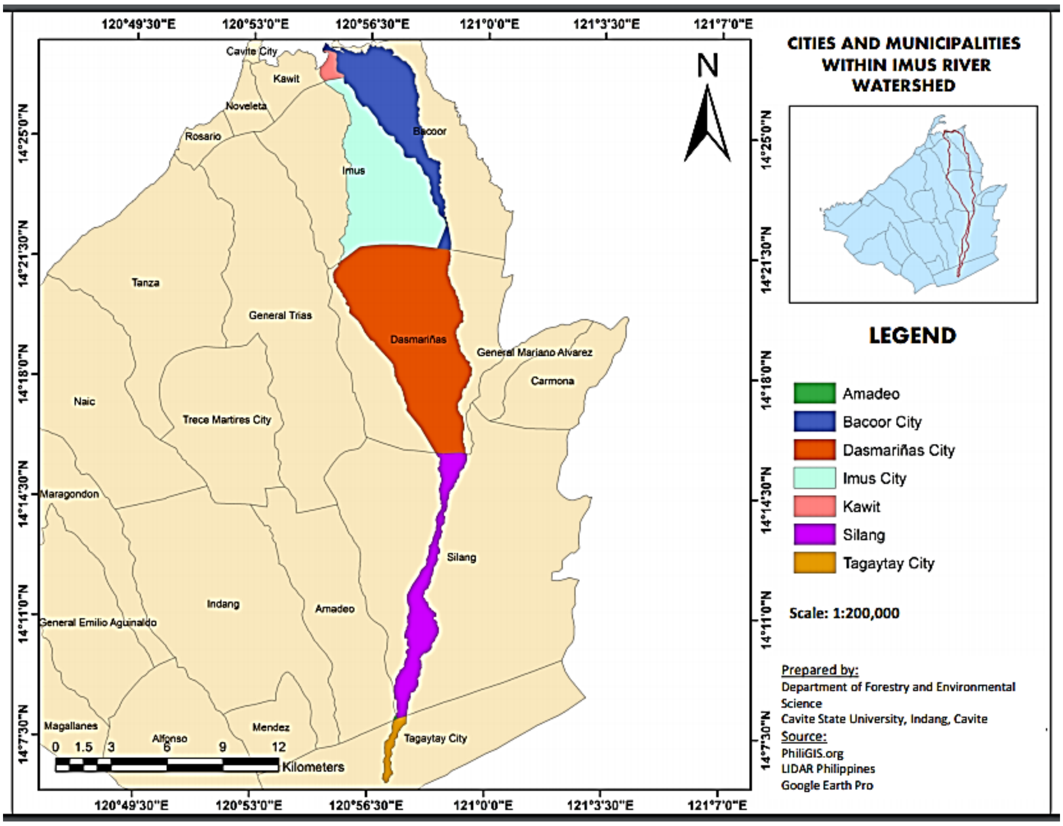


Figure 1. Map of Cavite province showing cities and municipalities within the Imus River Watershed (Department of Forestry and Environmental Science, CvSU)

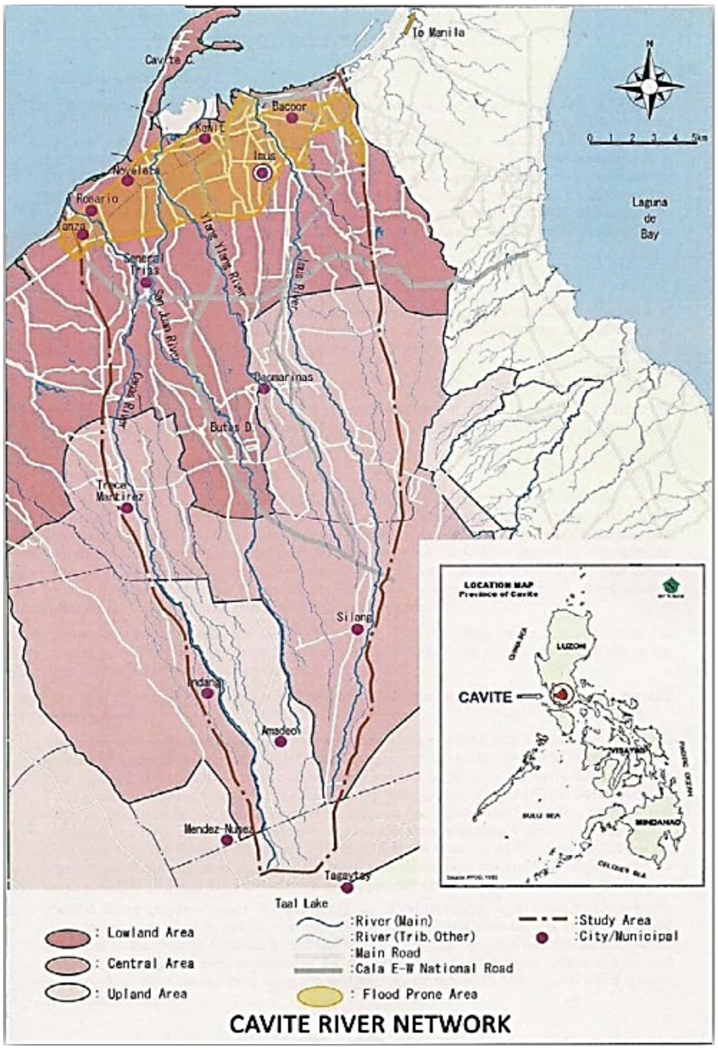


Figure 2. The Imus, Ylang-ylang, Rio Grande, and Cañas river systems (National Irrigation Administration 2017)

Sampling Stations

Sampling sites were selected to represent the upstream, midstream, and downstream stretches of the Imus River, spread among five (5) municipalities/cities, (Municipality of Silang, City of Dasmariñas, City of Imus, City of Bacoor, and Municipality of Kawit). The sampling stations were set in the middle and/or lower boundary of each municipality or city. Based on available maps (Figures 1 and 2) prepared by the Department of Forestry and Environmental Science of Cavite State University and the National Irrigation Administration, the following barangays were identified as the sampling station locations (**Table 1**).

Table 1. Different barangays where sampling stations were located, distributed among the upstream, midstream, and downstream stretches of the Imus River.

City/Municipality	Barangay (sampling stations)		
	Upstream	Midstream	Downstream
Municipality of Silang	Sabutan		
	Biga		
City of Dasmariñas	Sampaloc 2	Salitran I	
City of Imus		Tanzang Luma	
		Toclong 2B	
Bacoor City/ Municipality of Kawit			Mabolo 3/Binakayan
			Sineguelasan/Pulvorista

The sampling stations in upstream stretches (Brgy. Biga and Sabutan in Silang, and Brgy. Sampaloc 2 in the City of Dasmariñas) and one midstream sampling station (Salitran I in the City of Dasmariñas) are in areas where the Imus River is narrow with a strong current. The other midstream sampling stations (Brgy. Toclong 2B and Tanzang Luma in the City of Imus) and sampling stations in downstream stretches of the river (Brgy. Pulvorista and Binakayan in Kawit and Brgy. Mabolo 3 and Sineguelasan in the City of Bacoor) cover areas with a wide and slow-flowing river.

Collection and Classification of Macroplastics

Observation and collection of both macroplastics and the water samples needed for physico-chemical characterization and the quantification of microplastics were conducted first during the dry months of March and April with the assistance of community leaders. A second set of samples was undertaken during the wet months of July and August at the same locations.

Plastic Flux Measurements

A rapid assessment of macroplastics was done through a visual counting method. Visual counting of macroplastics is a simple and straightforward method to determine the plastic transport at various sections across the river width, needing little training and equipment. This method assessed the macroplastics fraction that is actively transported past the observation point during each measurement period (van Calcar & van Emmerik 2019).

Two researchers on a bridge assessed the plastic flux; one counted using binoculars the plastic litter passing within a 5-m predefined section of the river for a period of 5 min, with the second researcher serving as recorder for these observations. This was done three times with 15-min intervals starting at 8:00 in the morning. For sampling stations with wide cross sections, the river was divided into 2 or more 5-m sections to cover the entire river width. Each visible floating and superficially submerged plastic litter, with an estimated average minimum size of 1 cm, was counted. Floating litter that could not be identified was not counted as plastic (van Calcar & van Emmerik 2019; Vriend *et al*. 2020).

Plastic Composition

Plastic litter composition was determined after collection using an active sampling technique. Active sampling is one of the most practical techniques to study riverine plastic pollution (van Emmerik & Schwarz 2020). In this study, plastic was collected using belt transect line and trawl net sampling methods.

A belt transect line, measuring 100 m long and 5 m wide, was laid along each sides= of the river. In areas of narrow width, these lines sometimes overlapped. Where the river was wide, another belt transect line was set up in the middle of the tributary. All plastic litter within the upper 40 cm of the water column of each belt transect line was collected using trawl nets.

Trawls consisted of frames (70 cm high × 50 cm wide), with 2 m long nets attached with a mesh size of 2.5 cm were used. Horizontal buoys were attached on each side of the frame to increase buoyancy and stability (van Calcar & van Schwarz 2019). For stations with deep water, the trawl net sampler equipped with horizontal buoys were dragged by a slow-moving boat and for stations with shallow water, the trawl net sampler was dragged manually against the water current. Each trawling session lasted 30 min, and was accompanied by the determination of flow velocity. Collected plastic litter per volume of water was determined based on the cross-sectional area of the trawl net, velocity of water flow, and time.

The macroplastics that were trapped by the nets were collected, dried, sorted, counted, and weighed. These plastic litter were classified based on the dominant resin materials, i.e. Polyethylene Terephthalate (PET), High Density Polyethylene (HDPE), Polyvinyl Chloride (PVC), Low Density Polyethylene (LDPE), Polypropylene (PP), and Polystyrene (PS). The actual count, weight, and the expected surface area the items would cover of the classified plastics were recorded at each sampling station.

Collection and Characterization of Microplastics

Simultaneously, with the active sampling of macroplastics, water samples were collected for the quantification and characterization of microplastics. A 0.20 mm-mesh size plankton net with a diameter of 20 cm and a mouth area of 0.0314 m^2 was used. The plankton net was set against the water flow, near the surface. The flow rate and time of filtration were determined for the computation of the volume of water. Three water samples from the catch bucket of the plankton net were collected from each sampling station.







Water samples were stored in bottles with polytetrafluoroethylene coated screw cap and were subjected to preparation for microplastic analysis in the Biological Sciences Laboratory of De La Salle University – Dasmariñas (DLSU-D) in the City of Dasmariñas, Cavite. The water samples were analyzed quantitatively and qualitatively using a visual identification standard procedure provided by the Norwegian Institute for Water Research (NIVA) with some modifications.

For water sample analysis, all glassware was rinsed with distilled water before use and all equipment was kept covered to prevent contamination. Each water sample was pre-filtered through a 5-mm sieve. Following this, it underwent a 24 hour digestion process through the addition of pre-filtered concentrated H_2O_2 to remove organic debris (Pfeiffer & Fischer 2020). Microplastics were separated from the water sample through vacuum-filtration with membrane filters with a pore size of 0.2 µm (Tagg *et al*. 2020).

For the quantitative analysis of microplastics, numerical concentrations were determined. The membrane filters with suspected microplastics were oven-dried at 40°C for 1-2 hours. The membrane filter with microplastics was examined under a scanning photomicroscope, with plastic items counted, and classified into fibers, fragments (irregular and polygonal), and microbeads (Woodward *et al*. 2020; HRWC 2021). Each membrane filter was examined in a traversal fashion (side to side), so that no particles were missed.

For the preparation for qualitative analysis or chemical characterization of microplastic, the device guide of NIVA for visual identification was used. Particles that were suspected of being plastics were isolated. Particles were moved with forceps to petri dishes containing plastics of similar type, leaving particles that appeared to be non-plastic or contaminated (Masura *et al*. 2015).

The isolated microplastics were analyzed using FTIR (Shimadzu®2018 model) in transmission mode. The material composition of the microplastic samples, such as polyethylene (PET), polystyrene (PS), or polypropylene (PP), were identified based on the FTIR spectrum of the sample. Their relative amounts as in % PET, % PS, and % PP, were taken from the ratio of their respective peak areas based on a standard sample (Käppler 2015).

Water Quality / Physico-chemical Analysis

The following physico-chemical parameters of water: surface temperature, pH, dissolved oxygen (DO), salinity, phosphates, nitrates, and total dissolved solids (TDS), were measured in-situ based on standard procedures using appropriate portable equipment. Measurements of biological oxygen demand (BOD) and total suspended solids (TSS) were done in the laboratory based on appropriate standard procedures using the water samples collected for microplastic characterization.

Data Analysis

The collected macroplastics were classified, counted, and weighed. Their individual sizes (maximum length and width) were measured to determine river surface cover. Relative values were computed for each type of collected macroplastic to determine plastic dominance value (PDV). PDV is used to determine the dominant type of plastic litter in each sampling station.

To compare the composition of collected plastic litter (both macro- and microplastics) during dry and wet months, a two-sample t-test, a two-way analysis of variance, and a Tukey’s test were used. For the water quality assessment, physico-chemical characteristics were compared to DENR standards for fresh water. A Pearson-r correlation coefficient was used to determine the association between the quantities of collected plastic litters, both macro- and microplastics, with the physico-chemical characteristics of water.

Results and Discussion

Macroplastic Flux in the Imus River: Visual and Trawl Methods

Direct visual observation recorded plastic flux varying between stations and seasons. The total plastic flux ranged from 1.58 to 10.49 items per meter width per hour (#/m width/h), with an average of 4.14 #/m/h (Figure 3).

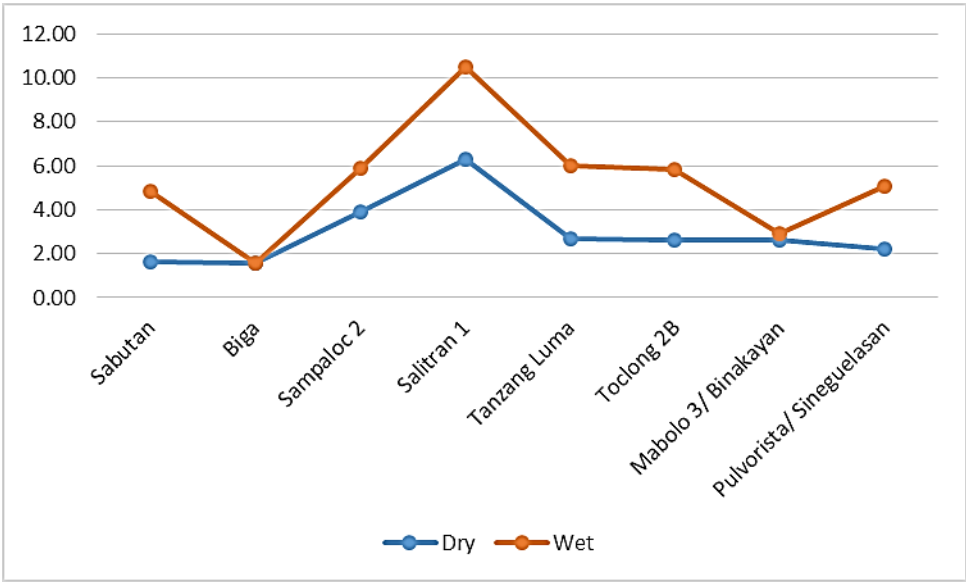


Figure 3. Mean plastic flux in items per meter width per hour (#/m width/hr) counted using the visual assessment method.

The floating macroplastics count was highest in Brgy. Salitran I in the City of Dasmariñas, both in dry and wet months. Floating macroplastics from upstream are temporarily concentrated in Brgy. Salitran due to its narrower width, which is known to influences the distribution of floating plastics (van Calcar *et al*. 2019). A more complex curvature and shape of a river affects its cross-sectional distribution, leading to a higher flow velocity in the outer bend that may lead to an increase in plastic litter transport (Van Calcar *et al*. 2019). The flow velocity of the sampling stations in more upstream areas, starting from Brgy. Sabutan in Silang, are lower that than of Brgy. Salitran I. Plastic litters also vary between barangays due to levels of urbanization – residential, agricultural, commercial and industrial, and due to the presence of dams.

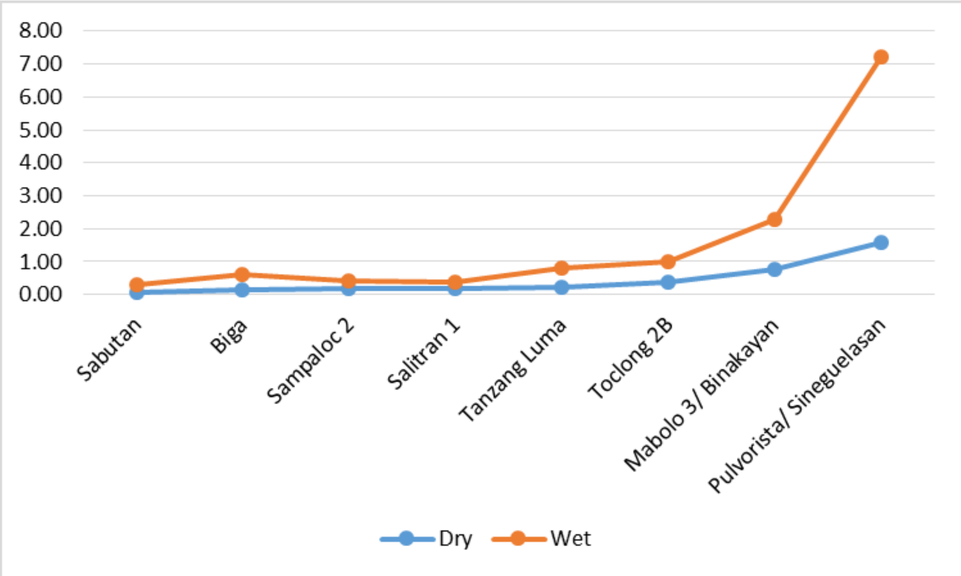


Figure 4. Mean plastic flux in items per meter width per hour (#/m width/hr) through trawl method

Trawl sampling shows an increasing amount of macroplastics going downstream both during the dry and wet months (Figure 4). Urbanization and population density increase going downstream as well, meaning this downstream increase is unlikely to be solely linear buildup (van Emmerik *et al*. 2020).

Table 2. Distribution of macroplastics classified by usage during dry and wet months

Classification Based on Usage	Visual (#/100m/hour)		Trawl Count (#/100 m³)	
	Dry	Wet	Dry	Wet
Plastic Bottles	1.38	9.74	0.00	1.08
Plastic Packaging	168.27	298.83	23.76	76.01
Plastic Bags	63.28	135.27	12.73	73.81
Disposable diapers	29.11	31.86	5.29	7.94
Other Plastics	32.80	57.22	2.21	4.06
Total	**294.83**	**532.93**	**43.99**	**162.91**

Plastic packaging was the most common use form of plastic found (Table 2), and plastic bottles the least found, in both visual and trawl sampling.

The weight of the material influences the height of macroplastics within the water column, and given the weight of plastic packaging is low compared with other plastic products, it easily floats to the surface. In addition, plastic packaging is widely used in the Philippines, because food items are available in small packaging. Plastic bottles likely have the lowest count because they are easily recycled.

Macroplastic litter along Imus River

The actual counts of collected macroplastics per 100 m^2 (#/100 m^2) classified by usage and resin materials show plastic packaging and plastic bags got the highest count during dry and wet months (Figure 5). The highest count of macroplastics is in Brgy. Pulvorista/Sineguelasan for both collection months.

Brgy. Pulvorista/Sineguelasan is where the mouth of the river is located, flowing out into Bacoor Bay (part of Manila Bay). This area has a delta plain, with flat land creating a sluggish fan-shaped river. It is likely that waste, which flows downstream to here, spreads out and perhaps settles in the delta plain (American Rivers 2021).

Classified by usage, plastic packaging and bags are the most abundant plastic litter types. They are popular, durable, cheap, and readily available materials for the transport of food and other materials. Plastic helps protect foods from damage, increasing food safety and extending food freshness (Mounts 2020). Their ubiquity leaves these rivers and coastal areas full of single-use plastics (SUPs) (Rubio *et al*. 2021).

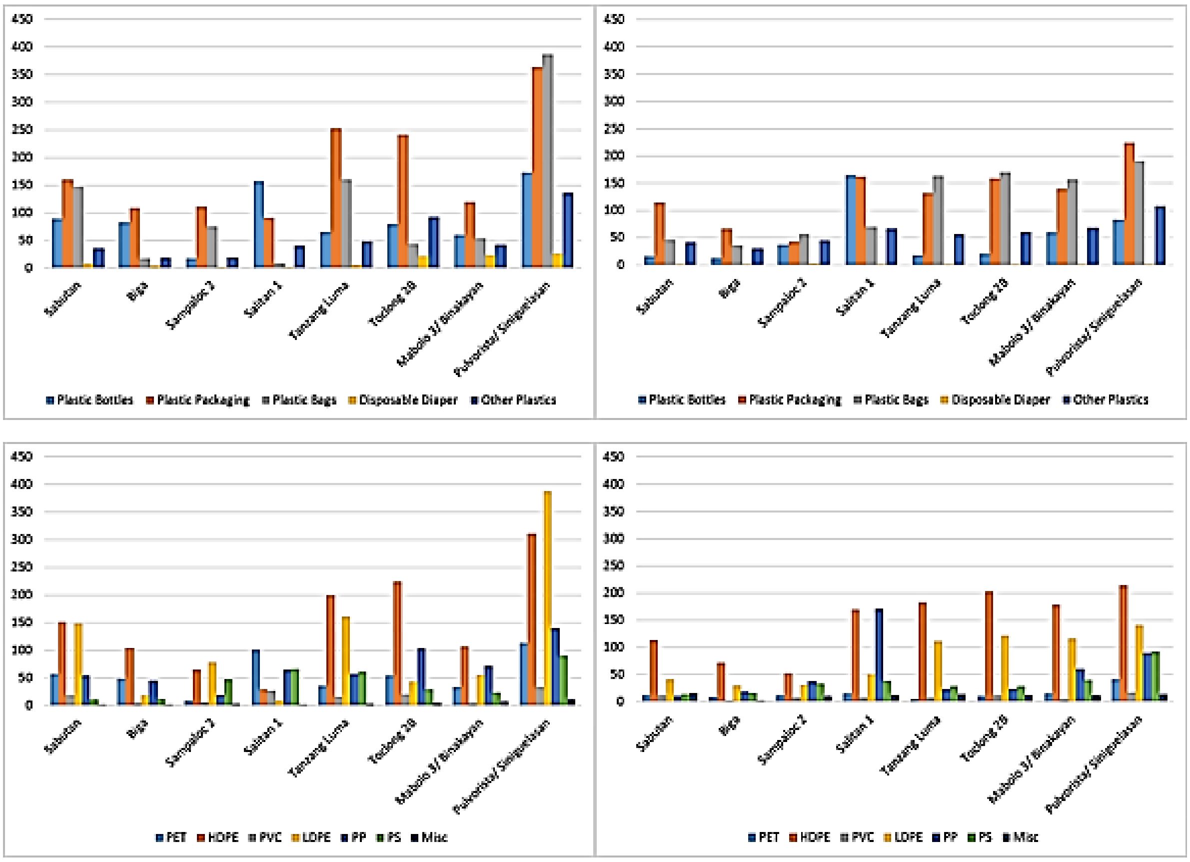


Figure 5. Actual counts (#/100 m^2) of collected macroplstics from the Imus River during dry (left) and wet (right) months classified by usage (top) and resin materials (bottom)

HDPE and LDPE were the most common materials in terms of item count in both sampling months (Figure 5). Both materials are common in plastic packaging and bags. Much of this is in the form of food, beverage, detergent, shampoo, and toothpaste sachets. Plastic bags are made up of LDPE and represented by thin filmed sando bags and containers (Mounts 2020). Plastic packaging and bags, which are made up of HDPE and LDPE, are usually single use (Rubio *et al*. 2021).

Table 3. Average actual count (#) of macroplastics classified by usage and resin materials in the Imus River during dry and wet months.

Use	Resin Material	Average Actual Counts (#/100m^2)			Estimated Total Count
		Dry	Wet	Average	
Plastic Bottles	Soda/Water bottles (PET)	55.71	14.71	35.21	13,520
	Bottle caps (PP)	30.25	34.71	32.48	12,472
	Shampoo/condiment bottles (PP)	3.92	1.54	2.73	1,048
Plastic Packaging	Sachets/candy wrappers (HDPE)	148.00	115.25	131.63	50,544
	Styrofoam (PS)	31.25	12.83	22.04	8,464
	Bubble wrap (LDPE)	1.50	1.58	1.54	592
Plastic Bags	Thin-filmed bags (LDPE)	110.58	78.29	94.44	36,264
	Grocery bags (HDPE)	0.79	32.50	16.65	6,392
Disposable Diaper	Plastic diapers (PP)	11.25	1.29	6.27	2,408
Other Plastics	Disposable coffee cups (PS)	6.50	13.79	10.15	3,896
	Disposable cups and plates (PP)	13.08	11.17	12.13	4,656
	Disposable spoons and forks (PP)	7.75	0.96	4.35	1,672
	Drinking straw (PP)	2.96	4.33	3.65	1,400
	Shoes/slippers (PVC)	15.67	8.25	11.96	4,592
	Brittle toys/plastic ware (PS)	4.42	9.38	6.90	2,648
	Facemask/shield (MISC)	3.50	11.46	7.48	2,872
	Total	**447.13**	**352.04**	**399.58**	**153,440**

Plastic packaging and bag litter made of HDPE was the most abundant waste type during dry and wet collection months (Table 3). The entire Imus River (not including tributaries), with a total length of 38,400 m, is estimated to contain 153,440 macroplastic items.

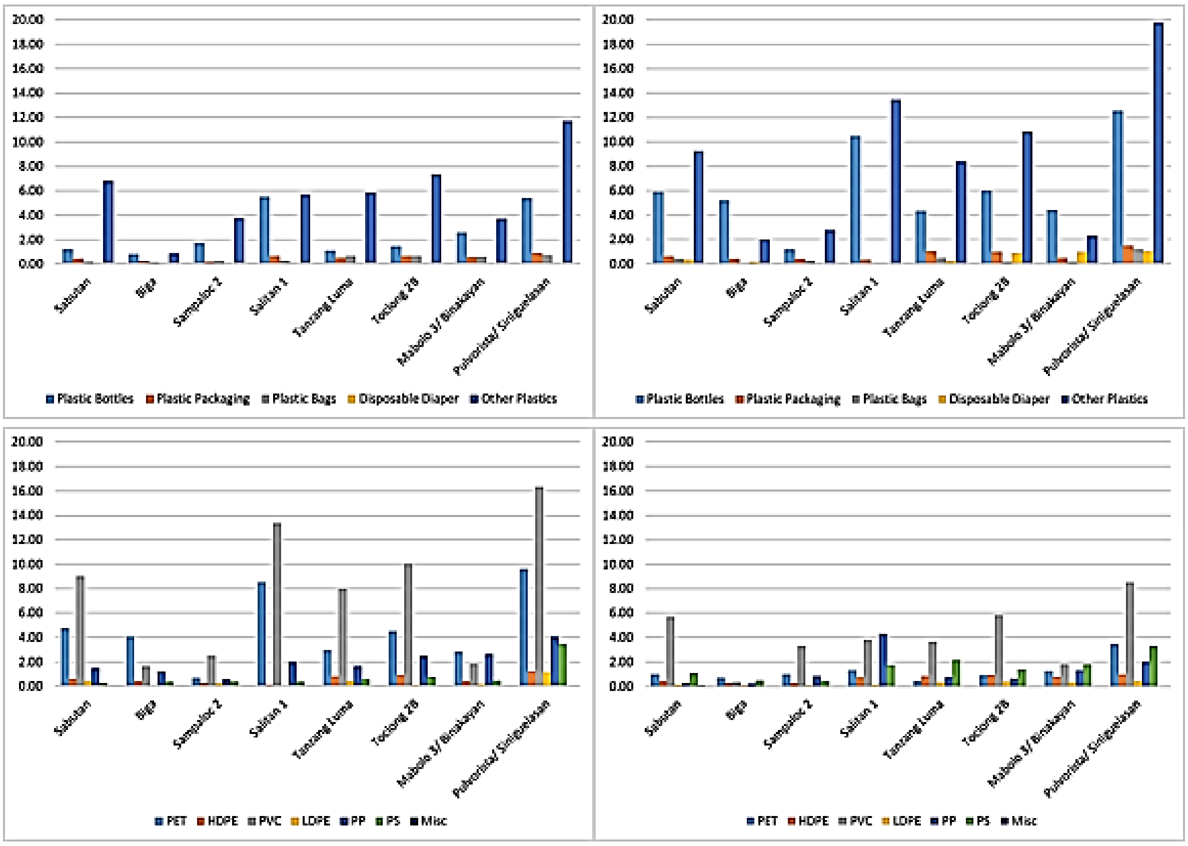


Figure 6. Actual weights (kg/100m^2) of collected macroplstics from the Imus River during dry (left) and wet (right) months classified by usage (top) and resin materials (bottom)

In both collection months, Brgy. Pulvorista/Sineguelasan had the most plastic by weight, likely due to it being at the mouth of the Imus River. The items included in "Other plastics" include slippers, shoes, toys, sewage pipes, and often uses heavier plastic materials than those listed separately. More plastic was collected during the wet season sampling than the dry season sampling. By weight, PVC was the most collected material during both sampling months.

Table 4. Average actual weight (kg) of macroplastics taken by both trawl and transect sampling classified by usage and resin materials in the Imus River during dry and wet months

Use	Resin Material	Average Actual Weight (kg/100m^2)			Estimated Total Weight
		Dry	Wet	Average	
Plastic Bottles	Soda/Water bottles (PET)	4.74	1.25	2.99	1,149.20
	Bottle caps (PP)	0.82	0.94	0.88	336.74
	Shampoo/condiment bottles (PP)	0.71	0.28	0.49	188.64
Plastic Packaging	Sachets/candy wrappers (HDPE)	0.59	0.46	0.53	202.18
	Styrofoam (PS)	0.13	0.05	0.09	33.86
	Bubble wrap (LDPE)	0.01	0.01	0.01	3.55
Plastic Bags	Thin-filmed bags (LDPE)	0.33	0.23	0.28	108.79
	Grocery bags (HDPE)	0.00	0.20	0.10	38.35
Disposable Diaper	Plastic diapers (PP)	0.45	0.05	0.25	96.32
Other Plastics	Disposable coffee cups (PS)	0.05	0.10	0.08	28.83
	Disposable cups and plates (PP)	0.03	0.02	0.02	9.31
	Disposable spoons and forks (PP)	0.02	0.00	0.01	3.34
	Drinking straw (PP)	0.00	0.00	0.00	0.59
	Shoes/slippers (PVC)	7.83	4.13	5.98	2,296.00
	Brittle toys/plastic ware (PS)	0.66	1.41	1.03	397.20
	Facemask/shield (MISC)	0.02	0.06	0.04	14.36
	Total	**16.37**	**9.18**	**12.78**	**4,907.27**

The heaviest waste (jointly classified by use and material) came from items such as shoes and slippers made up of PVC (Table 4). PVC was one of the first type of plastics created, and is one of the top three most common synthetic pollutants. PVC products include pipes, window frames, toys, bottles, blister packs, shoes, credit cards, drawer slides, and more (Osmanski 2020). The total weight of all plastic collected through both methods was estimated to be 4,907.27 kg.

In terms of surface area covered (the space occupied by plastic items if they were plotted onto the surface of the ground) plastic bags were the most prolific item during both dry and wet months (Figure 7). Plastic bags included thin film sando bags and plastic grocery bags, which are large in size as well as being numerous. Most sampling stations were dominated by plastic bags, including Brgy. Pulvorista/ Sineguelasan at the mouth of river (Figure 7).

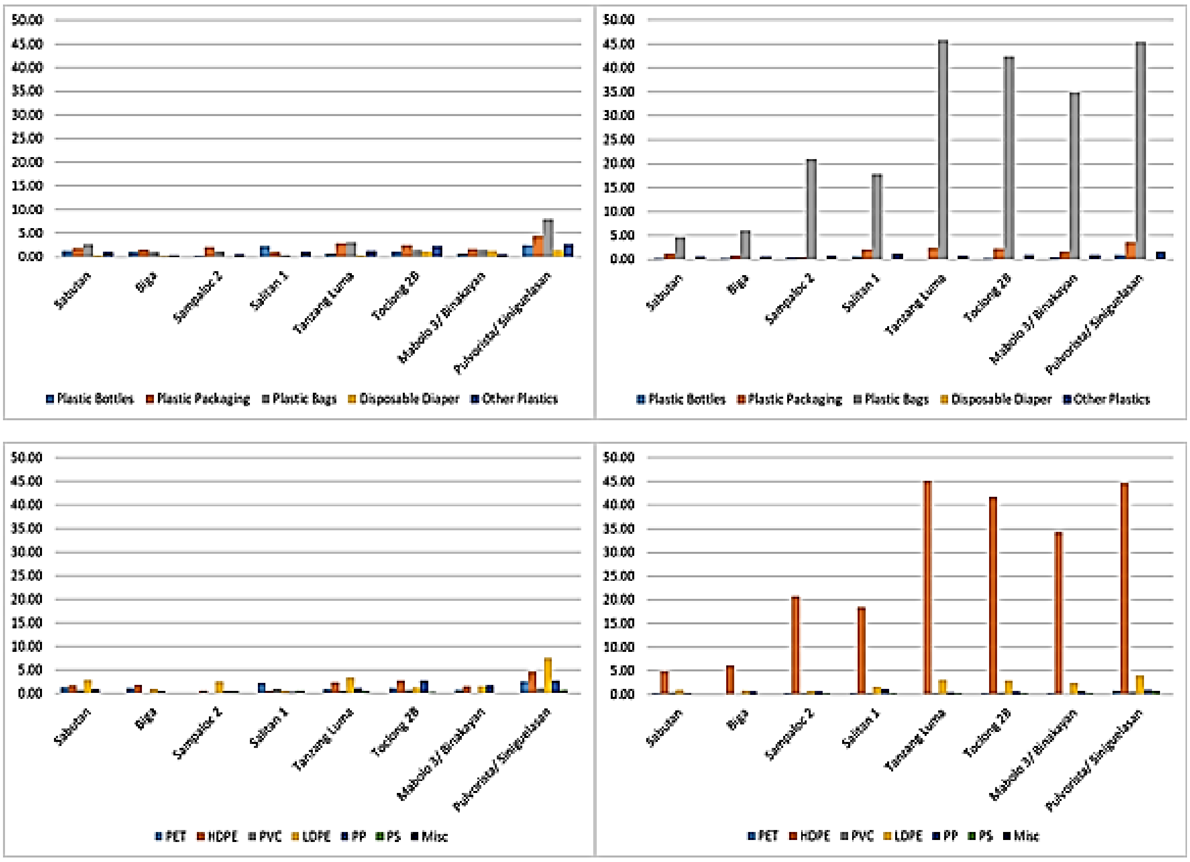


Figure 7. Actual cover (%/100m^2) of macroplstics collected from the Imus River through trawl and transect sampling during dry (left) and wet (right) months classified by usage (top) and resin materials (bottom)

LDPE products appear more visible during dry months, while HDPE dominates the surface during wet months (Figure 7). HDPE and LDPE are both common in plastic packaging and bags, among other items. They are the most common types of polyethylene, one of the world's most widely used thermoplastics (Mounts 2020).

Taking into account both utility and material, plastic bags consisting mostly of thin film bags (LDPE) covered the widest area during both dry and wet months (Table 5). The total potential cover of all plastic items was estimated to be 7792.63 m^2.

Table 5. Actual cover (%/100m^2) of macroplastics classified by usage and resin materials in the Imus River during dry and wet months

Use	Resin Material	Actual Cover (%100m²)			Estimated Total Cover
		Dry	Wet	Average	
Plastic Bottles	Soda/Water bottles (PET)	1.17	0.31	0.74	283.92
	Bottle caps (PP)	0.04	0.05	0.05	17.59
	Shampoo/condiment bottles (PP)	0.02	0.01	0.01	4.19
Plastic Packaging	Sachets/candy wrappers (HDPE)	1.28	1.00	1.14	437.21
	Styrofoam (PS)	0.23	0.09	0.16	60.94
	Bubble wrap (LDPE)	0.75	0.79	0.77	296.00
Plastic Bags	Thin-filmed bags (LDPE)	1.77	1.25	1.51	580.22
	Grocery bags (HDPE)	0.63	26.00	13.32	5113.60
Disposable Diaper	Plastic diapers (PP)	2.40	0.07	1.24	474.33
Other Plastics	Disposable coffee cups (PS)	0.59	0.10	0.34	132.47
	Disposable cups and plates (PP)	0.05	0.46	0.26	97.94
	Disposable spoons and forks (PP)	0.54	0.00	0.27	105.00
	Drinking straw (PP)	0.03	0.00	0.02	6.58
	Shoes/slippers (PVC)	0.00	0.27	0.14	52.50
	Brittle toys/plastic ware (PS)	0.52	0.09	0.31	117.26
	Facemask/shield (MISC)	0.04	0.02	0.03	12.88
	Total	**10.06**	**30.52**	**20.29**	**7792.63**

LDPE is clear or translucent plastic that exhibits flexibility, chemical resistance, and waterproofing capabilities, and a melting point of around 115°C. It is more transparent than HDPE. LDPE is included in a wide range of products, such as grocery bags, plastic wrap and film, flexible packaging material, and injection molded parts. HDPE has a more crystalline structure, and is usually translucent to opaque. It displays greater chemical resistance and rigidity, and more durability than LDPE. Products made from HDPE include rigid packaging containers, toys, outdoor furniture and structures, kitchen equipment, and plumbing pipes. HDPE has higher melting point than LDPE at 135°C. These characteristics make it more likely to be used as a durable packaging material, whereas LDPE is common for single-use items. LDPE is usually more difficult to recycle, being softer and liable to get caught in recycling machinery. HDPE is easier both to transport and to run through recycling equipment (Mounts 2020).

Plastic Dominance Value

In order to determine the most dominant plastic litter based on their counts, weights, and area covered, plastic dominance values (PDV) were calculated. Relative values of each classified type of plastic in terms of weight, count, and area covered are ranked to generate these values. Higher values may indicate a higher overall impact compared to other types of plastic litter.

Table 6. Plastic dominance value of collected macroplastics from the Imus River during dry and wet months classified by use

Use	PDV			Rank
	Dry	Wet	Average	
Plastic Bottles	26.83	14.12	20.47	4
Plastic Packaging	26.40	17.33	21.86	3
Plastic Bags	17.08	40.39	28.74	1
Disposable Diaper	4.29	0.54	2.42	5
Other Plastics	25.41	27.61	26.51	2

Table 7. Plastic dominance value of collected macroplastics from the Imus River during dry and wet months classified by resin material

Resen Materials	PDV			Rank
	Dry	Wet	Average	
PET	20.029	6.926	13.48	4
HDPE	20.748	45.510	33.13	1
PVC	18.507	15.437	16.97	2
LDPE	18.454	10.869	14.66	3
PP	15.248	10.197	12.72	5
PS	6.680	9.630	8.15	6
Misc	0.334	1.431	0.88	7

Classed by usage (Table 6), plastic bottles and packaging had the highest PDV values during dry months, with plastic bags were the highest in wet months. Plastic bottles were high due to their substantial weight, and was closely followed by plastic packaging, which was high due to the large number of individual items. Plastic bags ranked first due to their large surface cover during wet months.

Classed by resin material (Table 7), HDPE was the dominant waste during both dry and wet months. This is likely due to its common use in plastic packaging and bags, which are numerous year-round.

Counts and Types of Microplastics

Microplastics are synthetic solid particles or polymer matrixes of regular or irregular form with size ranging from 1 µm to 5 mm, of primary or secondary origin. They are insoluble in water (Frias & Nash 2019). Rivers are major pathways through which plastic, including microplastic items, enters the oceans (Carr *et al*. 2016; Jambeck *et al*. 2015; Lebreton *et al*. 2017; Lima *et al*. 2014). Secondary microplastics occur in rivers due to the fragmentation of macroplastics brought about by photo-oxidative degradation, as well as by physical damage due to human activities (Andrady 2011). Such fragmentation can occur on riverbanks and in flood plains, where plastic may be repeatedly washed into and out of the river (Andrady 2011; Keshaw & Rochman 2016). Plastic fragments generated on land also drain into rivers.

Quantification of Microplastics

Microplastics were classified based on types (Woodward *et al*. 2020; HRWC 2021) from all sampling stations along the Imus River (Figure 8).

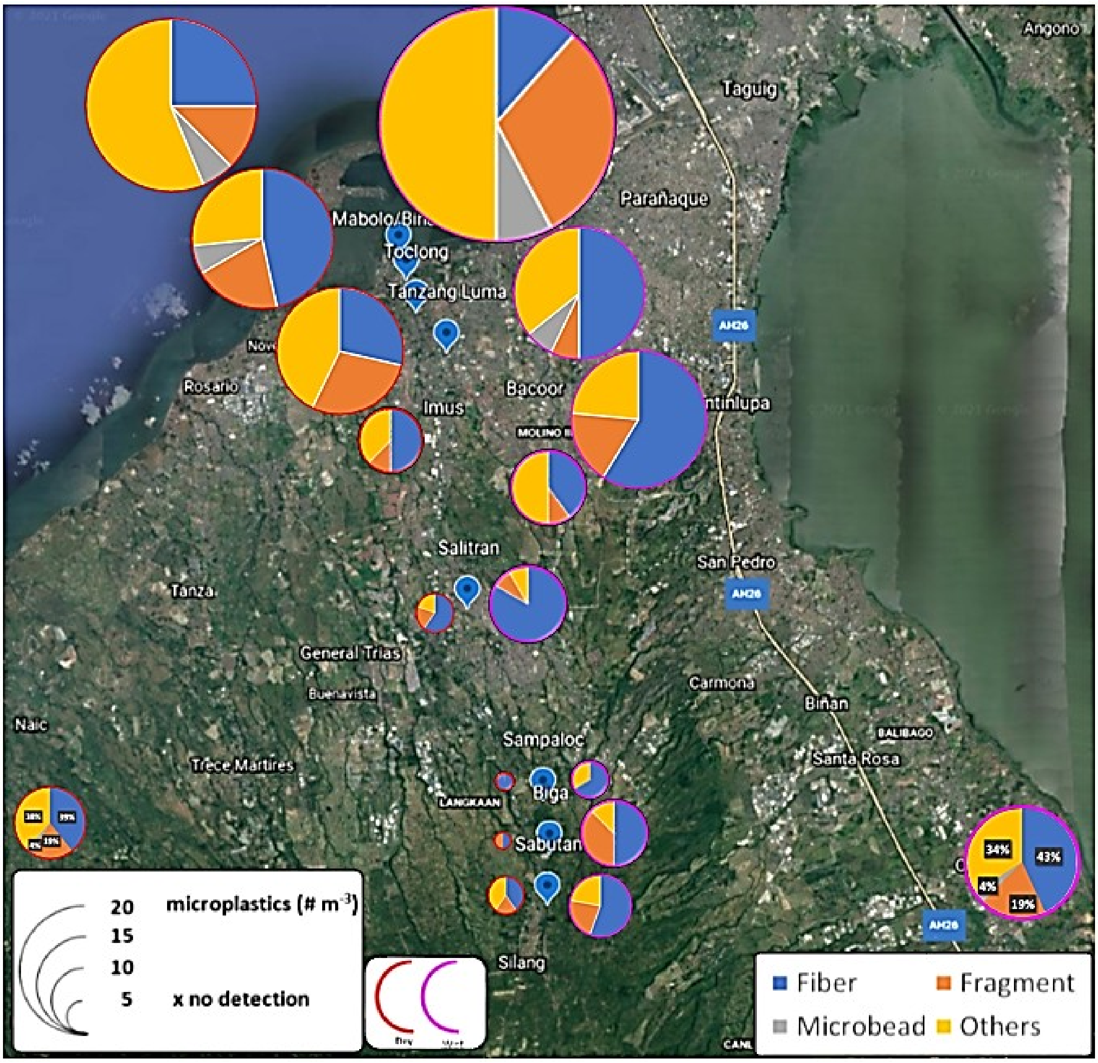


Figure 8. Microplastics classified by types along the 8 sampling stations of the Imus River. Each station has a circle for the dry season (outlined in red) and a circle for the wet season (outlined in purple).

In both sampling months, microplastics show a mostly increasing concentration going downstream. Most of the sampling sites contained microplastic fibers and unclassified (other) microplastics in varying proportions. Fibrous microplastics are present in all stations, and fragments were detected in every station except Brgy. Sampaloc.

During the dry months, the most contaminated sites were located in the downstream stretches of the river, from Brgy. Toclong to Brgy. Pulvorista/Sineguelasan, where recorded concentrations ranged from 8 to 42 microplastic particles per cubic meter of water. The lowest concentrations were recorded upstream, ranging from two to six microplastic particles per cubic meter of water. Overall, microplastic particles were 38% fibers, 19% fragments, 3% microbeads, and 39% others in the dry month samples.

Almost the same trend was observed for the wet months. Upstream segments of the river recorded concentrations ranging from 6 to 13 microplastic particles/m^3 of water while downstream segments recorded 21 to 43 microplastic particles/m^3 of water. The exception to a general trend of increasing microplastics going downstream is the first sampling station in Brgy. Sabutan. This station was near an urban settlement, and had microplastics concentrations of 5 to 10 particles/m^3 of water. Overall, in the wet month samples, microplastic particles were 43% fibers, 19% fragments, 4% microbeads, and 34% others.

Table 8. Mean concentrations of microplastics (classified by type) in the Imus River.

Types	Microplastics (#/m^3)	
	Dry	Wet
Fiber	4.87 ±3.257	7.51 ±3.624
Fragment	2.38 ±2.065 S	3.36 ±4.172
Microbeads	0.41 ±0.767	0.61 ±1.214
Others	4.76 ±5.239	5.97 ±6.717
Total	**12.41 ±10.035**	**17.45 ±11.757**

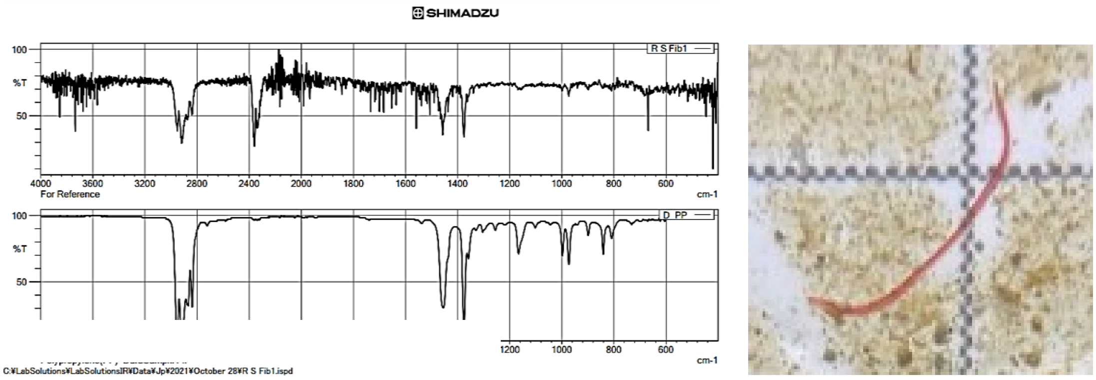
Microplastics were found in all water samples (amounting to 12 m^3 from all sampling stations for both dry and wet months) with a mean (±SD) concentration of 12.41 (±10.035) and 17.45 (±11.757) #/m^3, for dry and wet months respectively. Microplastic concentrations was significantly higher in the wet months ($p<0.01$).

Classified by type, fibrous microplastics are the most common in both dry and wet seasons, with concentrations of 4.87 #/m^3 and 7.51 #/m^3, respectively (Table 8). Unclassified (other) microplastics had concentrations of 4.76 #/m^3 for the dry season and 5.97 #/m^3 for the wet season. Microbead concentrations were only 0.41 #/m^3 for the dry season and 0.61 #/m3 for the wet season.

The microplastic concentrations of 46,334 #/m^3 and 210 #/m^3 found in Soya Island and Nakdong River in South Korea, respectively (Kim *et al*. 2015; Kang *et al*. 2015), as well as in Oujiang, Jiaojiang, and Minjiang estuaries in China, which were 680 to 1,245 #/m^3 (Zhao *et al*. 2015), are all higher than those found in this study.

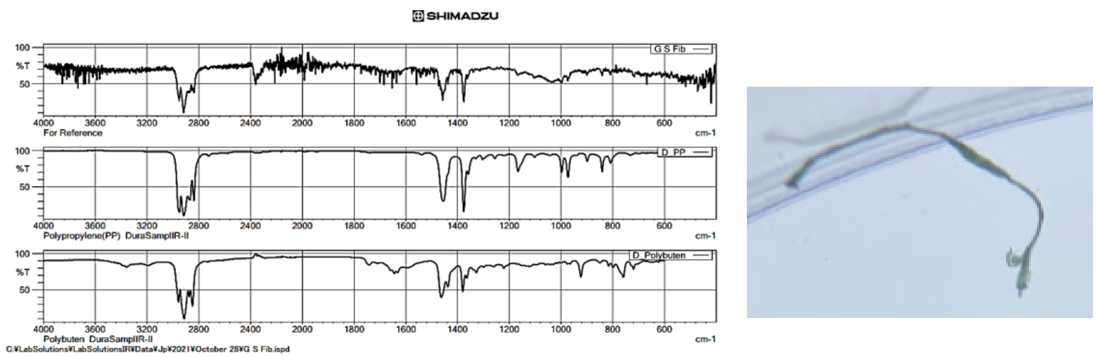
Characterization of Microplastics

Isolated samples of microplastics were analyzed by FTIR spectroscopy, and the resulting spectrum was matched using reference libraries of known materials (examples shown in Figures 9-13).



	Score	Library	Name	Comment
1	737	24 - ATR-Polymer2	D_PP	Polypropylene(PP) DuraSampIIR-II

Figure 9. Optical image and the FTIR results of a red fiber. The spectrum of the red fiber is consistent with that of polypropylene (PP).



	Score	Library	Name	Comment
1	843	24 - ATR-Polymer2	D_PP	Polypropylene(PP) DuraSampIIR-II
2	842	156 - ATR-Polymer2	D_PP_Isotactic	Polypropylene, Isotactic DuraSampIIR-II

Figure 10. Optical image and the FTIR results of a green fiber. The spectrum of the green fiber is consistent with that of polypropylene (PP)

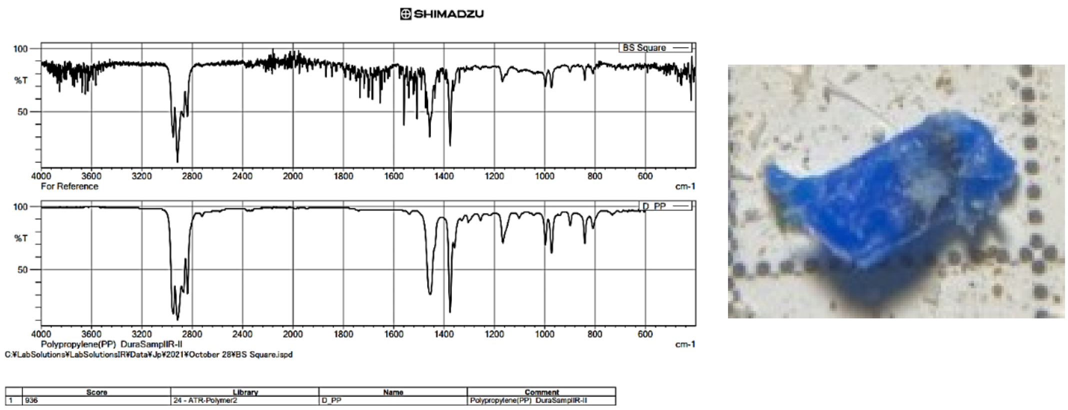


Figure 11. Optical image and the FTIR results of a blue fragment. The spectrum of the blue fragment is consistent with that of polypropylene (PP)

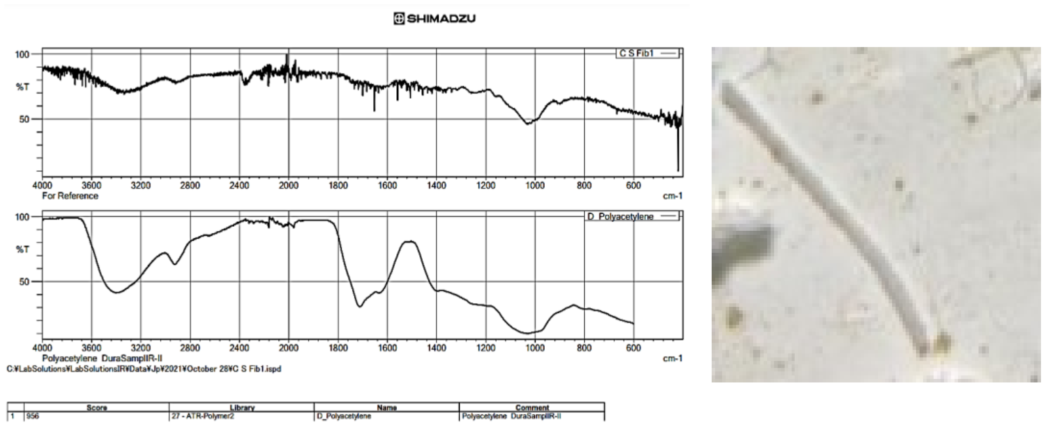


Figure 12. Optical image and the FTIR results of a transparent fiber. The spectrum of the transparent fiber is consistent with that of polyacetylene (PA)

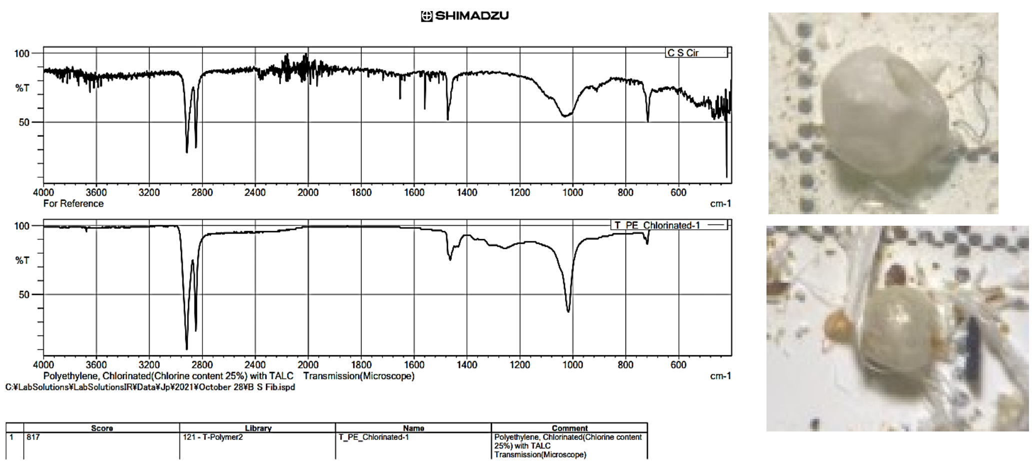


Figure 13. Optical image and the FTIR results of a white microbead. The spectrum of the white microbead is consistent with that of polyacetylene (PE)

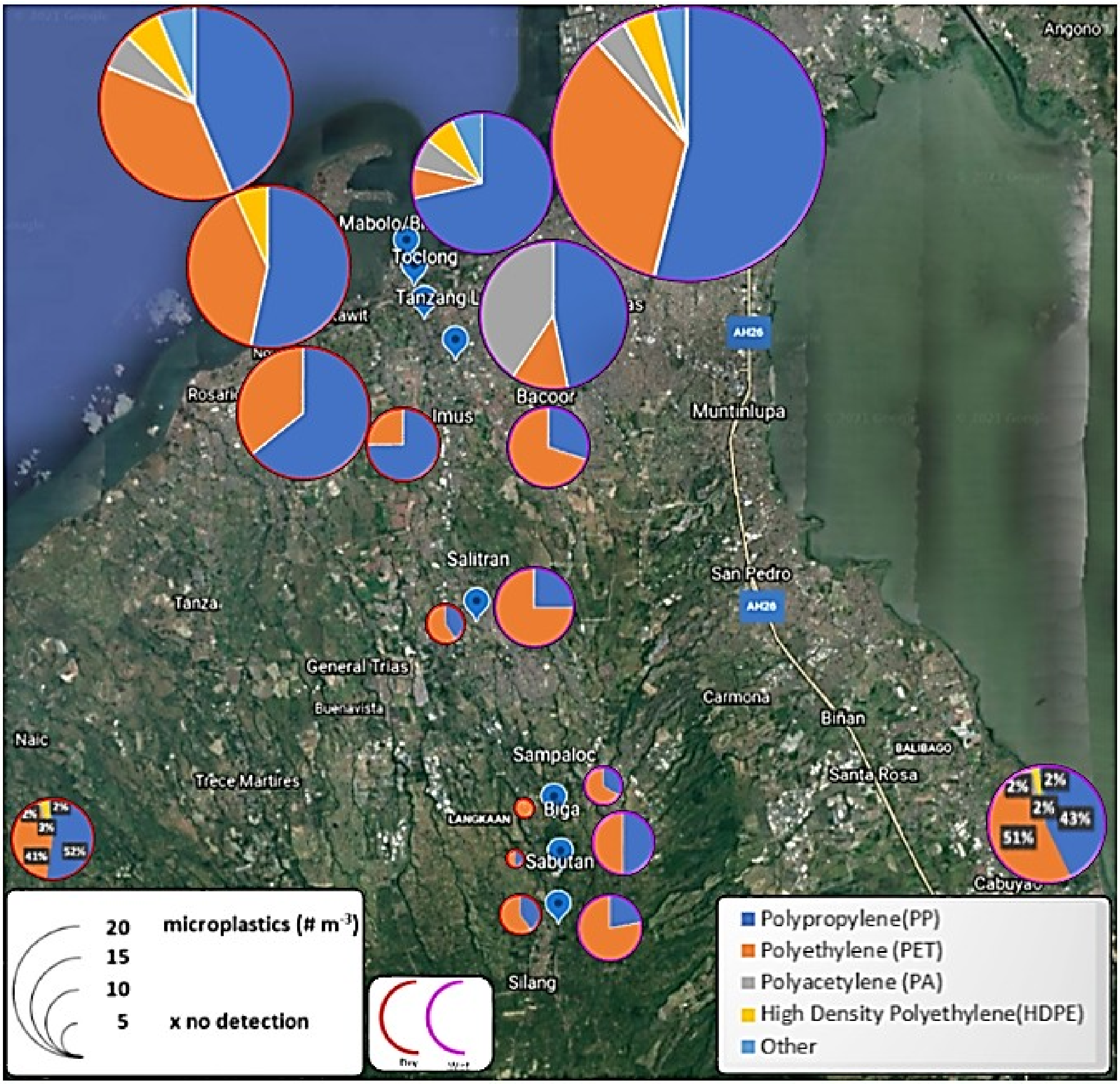


Figure 14. Patterns of microplastics composition classified by resin materials along the 8 sampling stations of the Imus River. Each station has a circle for the dry season (outlined in red) and a circle for the wet season (outlined in purple).

Classification by resin materials among all sampling stations (Figure 14) shows that microplastics in the Imus River are mostly PP and PET, with small amounts of polyacetylene (PA), HDPE, and others. In the dry month samples, PET microplastics were recorded in all sampling stations, ranging from 2-11 microplastic particles per cubic meter of water, while PP ranged from 1 to 10 microplastic particles per cubic meter of water. HDPE was recorded in the downstream stations of Brgy. Mabolo/Binakayan and Brgy. Pulvorista/Sineguelasan, while PA was found only in the latter. Altogether, microplastic particles were 52% PP, 41% PET, 2% PA, 3% HDPE, and 2% others in the dry month samples.

In the wet month samples, PP concentrations increased to 4-26 microplastic particles per cubic meter of water and were recorded in all sampling stations. PET, also present in all stations, ranged from 2-15 particles per cubic meter of water. PA, HDPE, and other microplastics were present only in Brgy. Mabolo/Binakayan and Brgy. Pulvoritsa/ Sineguelasan. Microplastic particles in these samples were 43% PP, 50% PE, 2% PA, 2% HDPE, and 2% others. The wet season samples show more PP and PE microplastics than the dry season samples.

These findings are similar to the types of microplastics, i.e. PP, PET, and PA, found in the Yangtze and Hanjiang Rivers in China (Wang *et al*. 2017).

Table 9. Mean concentrations of microplastics (classified by resin materials) in the water of the Imus River.

Resin Material	Microplastics (#/m3)	
	Dry	Wet
Polypropylene (PP)	6.50 ±5.620	7.54±7.616
Polyethylene (PET)	5.07 ±3.466	8.71 ±5.391
Polyacetylene (PA)	0.21 ±0.597	0.40 ±0.742
High Density Polyethylene (HDPE)	0.41 ±0.767	0.40 ±0.742
Others	0.21 ±0.597	0.40 ±0.742
Total	**12.41 ±10.035**	**17.45 ±11.757**

Classified by resin materials, PP microplastics are highly concentrated during both the dry (6.50 #/m^3) and wet (7.54 #/m^3) seasons (Table 9). In these seasonal samples PET had concentrations of 5.07 #/m^3 and 8.71 #/m^3, respectively. PA, HDPE, and others are also present in minimal concentrations for both sets of samples.

Water Quality Based on Physico-chemical Characteristics

The Imus River has been classified by the Department of Environment and Natural Resources – Environmental Management Board (DENR-EMB) of the Philippines as a Class C freshwater body, suitable for the purposes of fishery, recreation, agriculture, irrigation, and livestock watering. Physical characteristic assess for this characterization include surface temperature, while chemical characteristics include pH, dissolved oxygen (DO), biological oxygen demand (BOD), salinity, phosphates, nitrates, total dissolved solids (TDS) and total suspended solids (TSS).

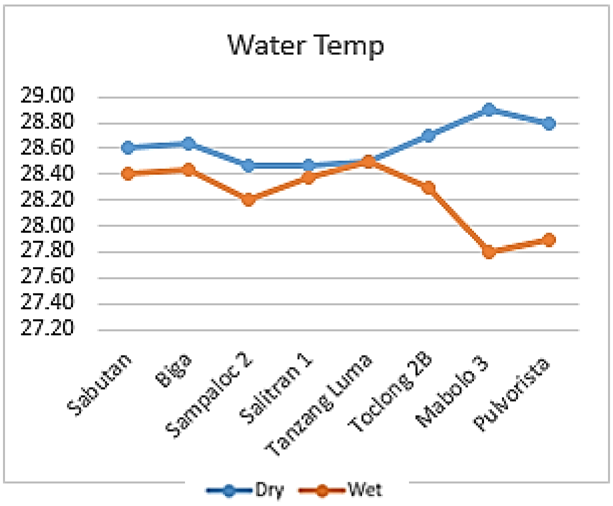


Figure 15. Water temperature in different stations of the Imus River during dry and wet months

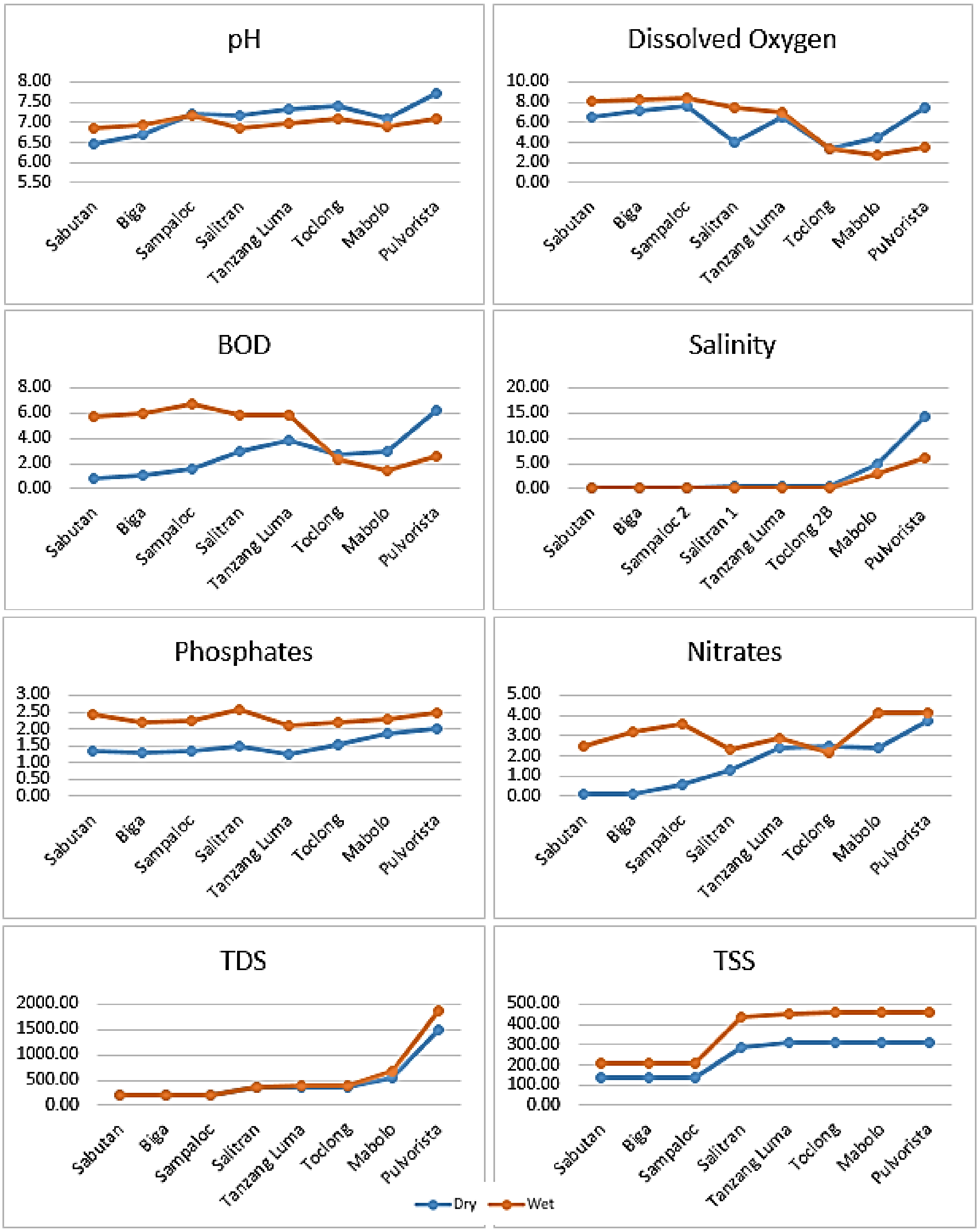


Figure 16. Chemical characteristics of water in different stations of the Imus River during dry and wet months

Table 10. Physico-chemical characteristics of surface waters of the Imus River during dry and wet months

Physico-chemical Characteristics	Dry	Wet	Average	Standard Values (DAO 2016-08)
Surface Temp (°C)	28.63 A	28.24 B	28.44	26.0 – 30.0
pH	7.14 A	6.99 A	7.07	6.5-9.0
DO (mg/L)	5.89 A	6.12 A	6.01	5.00 (min)
BOD (mg/L)	2.77 A	4.58 B	3.67	7.0 (max)
Salinity (ppt)	2.60 A	1.23 A	1.91	not specified
Phosphates (mg/L)	1.51 A	2.32 B	1.92	0.5
Nitrates (mg/L)	1.65 A	3.12 B	2.38	7
TDS (mg/L)	463.37 A	539.56 A	501.46	not specified
TSS (mg/L)	241.65 A	362.56 B	302.11	80

**Different letters indicate significant difference ($p<0.05$) between sampling months*

The surface water temperature is significantly lower during wet months as compared to dry months (Figure 15), likely due to rainfall. pH, DO, salinity, and TDS registered equal values during dry and wet months, while BOD, phosphates, nitrates and TSS were significantly higher during wet months (Figure 16).

The pH of water is an important parameter concerning water quality (Gupta *et al*. 2013). Pollution can change the water's pH. Excessively low and high pH can be damaging for aquatic organisms (USGS 2020). During both dry and wet months, the recorded pH with an average value of 7.07 indicates slight basicity, falling within the standards set by DENR Administrative Order in 2016.

DO is needed by fish and zooplankton to survive (USGS 2020). The measured DO with average value of 6.01 for both dry and wet months exceeded the minimum value for Class C water set by DENR, indicating the water is suitable for fishery and aquaculture purposes.

The addition of organic matter usually increases the respiratory demand of oxygen by aerobic bacteria, lowering DO. Domestic, industrial, and agricultural wastes pollute both ground water and surface water bodies through surface run-off (Basavaraddi *et al*. 2012; Mocuba 2010). The measured BOD during the wet season month is significantly higher that of the dry season month. However, both values met the DENR standard for Class C water by not exceeding a maximum value of 7.0.

The values of salinity in Imus River ranges from 0.12 ppt to 14.35 ppt. The sampling stations located in the upstream and midstream portions of the river do not exceed the maximum limit of 0.5 ppt set by US-EPA (1994). The downstream sampling stations located in Brgy. Mabolo/Binakayan and Brgy. Pulvorista/Sineguelasan are considered estuarine, consisting of brackish water.

Nitrates and phosphates, despite being important nutrients for aquatic organisms, are pollutants if their concentrations exceed a critical limit (Ngatia *et al*. 2019). Phosphate sources include untreated or partially-treated domestic sewage containing phosphate-rich detergents, as well as runoff from agricultural land and urban areas (PEMSEA 2006). Sources of nitrates include anthropogenic, regular use of chemical fertilizers, sewage and landfill and domestic wastes (Shrimali & Singh 2001). Both nutrients showed significantly higher concentration in the wet month samples than the dry month samples. This is likely due to the transport of pollutants from land by rainfall (Dans *et al*. 2010; Gong *et al*. 2016). The higher level of nitrates during rainy season observed in this study is similar to the findings of Singh and Choudhary (2013) in the Ganga (Ganges) river.

Any particle that is smaller than 2 um is considered dissolved solid (Sawyer 1994; Butler & Ford 2018). TDS concentrations in natural waters often result from industrial effluent, changes to the water balance (limited inflow, increased water use, or increased precipitation), or salt-water intrusion (Weber-Scunner & Duffy 2007). The TDS values from the upstream up to Brgy. Mabolo/Binakayan in both dry and wet months that ranged from 185.2 mg/L to 640.00 mg/L did not exceed the maximum standard set by US-EPA (1994). Only the sampling station located in Brgy/ Pulvorista/ Sineguelasan recorded a TDS value exceeding the maximum limit of 1,000 mg/L.

TSS may include sand, silt, clay, mineral precipitates, and biological matter. It can be generated through soil erosion, from dissolved organic matter, and from the precipitation of inorganic solids (Hudson-Edwards 2003). High TSS in surface water blocks sunlight for photosynthesis, decreasing DO levels (Campbell 2021). Recorded TSS values in this study are significantly higher in the wet month sample, though both values exceed the DENR standard for Class C waters.

The higher levels of BOD, phosphates, nitrates, and TSS found during the wet month are likely related to higher wastes levels. Plastics and organic wastes are brought by the presence of residential, industrial, commercial, and agricultural. During rainfall events, storm water tends to carry pollutants such as organic compounds, heavy metals, and other suspended solids including plastic (Rossi 2005).

Correlation between the Quantity of Plastic Litter and Water Quality

Table 11. Correlation of physico-chemical parameters with the counts of macroplastics along the Imus River

Physico-chemical Characteristics	Average Values	r Values	Verbal Interpretation
Surface Temp (°C)	28.44	-0.58	Moderate negative correlation
pH	7.07	0.11	No correlation
Initial DO (mg/L)	6.01	-0.44	Low negative correlation
BOD (mg/L)	3.67	-0.11	No correlation
Salinity (ppt)	1.91	0.46	Low positive correlation
Phosphates (mg/L)	1.92	0.46	Low positive correlation

Nitrates (mg/L)	2.38	0.56	Low positive correlation
TDS (mg/L)	501.46	0.86	High positive correlation
TSS (mg/L)	302.11	0.52	Moderate positive correlation

All physico-chemical characteristics show no correlation with the counts of macroplastic litters except for TDS, which exhibits a high positive correlation (Table 11).

Table 12. Correlation of physico-chemical parameters with the counts of microplastics along Imus River

Physico-chemical Characteristics	Average Values	r Values	Verbal Interpretation
Surface Temp (°C)	28.44	-0.74	High negative correlation
pH	7.07	-0.05	No correlation
Initial DO (mg/L)	6.01	-0.42	Low correlation
BOD (mg/L)	3.67	-0.13	No correlation
Salinity (ppt)	1.91	0.26	Low correlation
Phosphates (mg/L)	1.92	0.52	Moderate positive correlation
Nitrates (mg/L)	2.38	0.54	Moderate positive correlation
TDS (mg/L)	501.46	0.72	High positive correlation
TSS (mg/L)	302.11	0.49	Low correlation

Almost all physico-chemical characteristics also show no correlation with microplastic count. The exceptions are water surface temperature and TDS, which exhibit a negative correlation and a positive correlation, respectively. This conforms to the findings of Mani *et al*. (2014) in the Rhine River, where microplastic concentrations also increase going downstream. Kataoka *et al*. (2019) found that microplastic concentrations are significantly correlated with urbanization and population density, likely a factor here as downstream areas of the Imus River are more urbanized than areas upstream.

With regards to temperature, this is likely an effect of cooling rainfall also bringing microplastics to the river. A relationship between rainfall and microplastic concentration was found by Xia *et al*. (2020).

Conclusions and Recommendations

Conclusions

To determine the flux of macroplastics floating along the Imus River

The macroplastic flux in the Imus River varies between stations and seasons, with visual observation results ranging from 1.58 to 10.49 pieces per meter width per hour (#/m width/h). An average of 4.14 #/m/h was estimated using a rapid visual method. The visual method found an increasing flux of floating plastics beginning in Brgy. Sabutan, reaching its highest count in Brgy. Salitran, before lowering towards Brgy. Pulvorista, in both the dry and wet months. The spatial and seasonal variation of floating plastic may be influenced by wind, flow velocity, river shape and curvature, and urbanization.

The trawl method finds a generally increasing flux of macroplastics going downstream, highest in Brgy. Pulvorista/ Sineguelasan in the Municipality of Kawit and in the City of Bacoor. This was true in both the dry and wet season samples.

To classify and compare the macroplastics in the Imus River classified by usage and resin materials during dry and wet months in terms of actual count, weight, and surface area covered

Classified by usage, the highest counts of macroplastics were plastic packaging for both collection months, followed by plastic bottles and bags during the dry month, and plastic bags and miscellaneous plastics during the wet month. Classified by material, the highest counts were HDPE followed by LDPE and PP during both sampling months. These materials HDPE, LDPE and PP are commonly used in single-used plastic, such as packaging materials, bottles, and bags.

In terms of weight, during dry and wet months, based on usage, the items with the most weight were miscellaneous plastics and plastic bottles. While based on resin material, PVC, PET, and PP recorded the highest weight. The highest surface cover was taken up by plastic packaging composed of LDPE and HDPE during the dry month, and plastic bags mainly composed of HDPE during the wet month.

To determine the plastic dominance value (PDV) of macroplastics in the Imus River based on actual count, weight, and cover

Macroplastic litter was dominated by plastic bags, miscellaneous plastics, and plastic packaging. These plastics were mainly composed HDPE, LDPE, and PVC.

To quantify and characterize the microplastics from collected water of the Imus River during dry and wet months

Different microplastics show an increasing concentration going downstream in both the dry and wet months. Microplastic fibers were the most common form of microplastic, followed by fragments, unclassified (other), and microbeads.

To assess the water quality of the Imus River based on its physico-chemical characteristics

The values of the following most physico-chemical characteristics are within the DENR standards for Class C classification. However, the values of phosphates and TSS exceeded critical limits.

To correlate the densities of macroplastics and microplastics to the physico-chemical characteristics of water.

All physico-chemical parameters show no correlation with the counts of microplastics and macroplastics except for TDS and water temperature. TDS is positively correlated for both macroplastics and microplastics while water temperature is negatively correlated with microplastics.

Recommendations

Based on the findings, this report gives the following recommendations:

1. Intensify the implementation of different laws and policies regarding solid waste management and the conservation and protection of freshwater resources such as RA 9003 (Solid Waste Management Act of 2000) and RA 9275 (Clean Water Act of 2004), by both the national government and local government units.

2. Implement a scheme that will promote recycling plastic to create a circular value chain for plastic wherein manufacturers and sellers of plastic products are encouraged to take discarded materials and remake them for resale, as practiced in Norway, among other countries.

3. Institute a comprehensive national policy that will ban the use of unnecessary plastics. The ban should prohibit the production, use and distribution of "oxo-degradable", "biodegradable", and "compostable" bags nationwide. A multi-sectoral consultation must be undertaken to look for other recyclable and reusable alternatives.

4. Governments must mandate that manufacturing industries develop alternative materials for plastics that will promote local and indigenous practices and resources. These innovations can be helpful in reviving affected packaging industries by absorbing potential job losses resulting from plastic bans.

5. Government agencies must involve all stakeholders through information and education campaigns regarding solid waste management and plastic pollution. Households should understand the different classification of wastes, be aware of pollution's negative impacts, and practice proper waste segregation and minimization.

6. DENR must conduct regular monitoring of the physicochemical characteristics of river water to manage water quality. DENR should strictly implement the policy on requiring waste water management treatment facilities for industries and sewerage systems for households.

7. Conduct further research into microplastics in rivers, not only on presence in the water, but also in sediments, along with the effects on aquatic organisms. A socioeconomic valuation of the Imus River must also be conducted to assess the economic impact a lack of protection and conservation will have.

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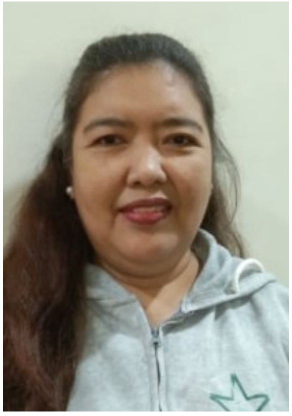

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