River flow pattern and heavy metals concentrations in Pasig River, Philippines as affected by varying seasons and astronomical tides

G R A Paronda¹, C P C David² and D C Apodaca¹³

¹School of Chemical, Biological and Materials Engineering and Sciences, MAPUA University, Muralla St. Intramuros, Manila Philippines 1002, Philippines
²National Institute of Geological Sciences (UP-NIGS), University of the Philippines, Diliman, Quezon City Philippines 1100, Philippines

Email: dcapodaca@yahoo.com

Abstract. This study explored the transport of metal pollutants in Pasig River, an important source of water for different uses in the National Capital Region of the Philippines. In particular, the study investigated the effect of varying seasons and varying levels of tides on the flow pattern and heavy metals concentrations in Pasig River. Pasig River is one of the main outlets which drain directly into the Manila Bay and Laguna de Bay. Four sampling sites were chosen along the 27 km-stretch of Pasig River which includes the following: Delpan, Lambingan, Guadalupe and Kalawaan sampling locations. Series of water samplings were conducted during the months of April, 2007 covering the dry season and November 2007 covering the wet season. Sampling design was primarily based on the height of tide at Manila Bay. Flow rate as computed from surface flow velocity was measured at each station. Concentration of heavy metals such as cadmium, copper, lead and nickel, were also measured. Results indicate that an observable backflow occurred during the dry season when the tide was high, that is, saline water from Manila Bay, intruding into the Pasig River. Further, this study established that the highest flow rate was noted during the wet season at low tide, particularly at the Kalawaan station. On the other hand, low flow rate was observed during the dry season when the tide was high. With regard to the levels of heavy metals, concentrations were found to be elevated during the dry season and also, when high tide occurs. Water samples collected from Delpan station yielded high metal concentrations with lead (Pb) as the dominant heavy metal among the four metals analysed in this study. Variability in the metal concentration due to seasonal changes, varying flow patterns and tide may indicate water quality problems not only in Pasig River but also to coastal areas such as Manila Bay.

1. Introduction
Sustainable water resource management remains a great challenge in megacities around the world [1], this despite the inclusion of clean water and sanitation in the United Nations Sustainable Development Goals to enable the availability of water with good quality for all by year 2030 [2]. For instance, in Manila, the capital city of the Philippines and a megacity with a total population of 12,877,253 based on the 2015 Census of Population [3], is threatened by water scarcity as well as by degradation of urban water environment. A large percentage of households in Manila are not connected to a wastewater treatment facility. Indiscriminate discharge of untreated domestic wastewater plus
struggling implementation of solid waste disposal have caused saturation of the absorptive capacity of the river system, resulting to serious pollution of the Pasig River [4].

Pasig River has since been subjected to environmental stress due to rapid urbanization, ballooning population, economic development and climate change in the National Capital Region (NCR) of the Philippines [5]. This river system was classified as one of the world's most polluted river systems and was considered biologically dead [6,7]. Pasig River is one of the major waterways in Manila, capital city of the Philippines, which directly connects to both Manila Bay and Laguna de Bay. The whole stretch of Pasig River has a total length of 27 kilometers, traversing at least six cities in the metropolis including Manila where the Malacañang Palace, official residence for the President of the Philippines, is located. A move to restore Pasig River to Class C water quality is currently being undertaken by the Philippine government [6,8]. Class C water quality, in accordance to Philippines’ Department Administrative Order 2016-08, specifies that a river system can be beneficially used for the following: 1) Fishery water for the propagation and growth of fish and other aquatic resources; 2) Recreational Water Class II- For boating, fishing or similar activities; and 3) For agriculture, irrigation, and livestock watering. Studies conducted by Environmental Management Bureau from 2006 to 2015 in fourteen (14) stations of Pasig River, showed that only one (1) station passed the Dissolved Oxygen (DO) water quality guideline of 5 mg/L for Class C waters while all of the stations failed to meet the Biological Oxygen Demand (BOD) guideline of 7 mg/L. While these are important indicators of the extent of water pollution, it tells little about the presence and effects of persistent toxins including metals [9,10].

With this current situation of the Pasig River, it is worthy to pursue studies in line with the transport of pollutants mainly heavy metals along the river [11,12]. Water movement is a significant means by which other material like pollutants, suspended and/or dissolved, are transported from place to place [13]. As previously reported, more than 90% of the total materials including metals from anthropogenic sources, introduced into the seas are transported via various river systems [14], which could result to serious environmental problems in coastal areas. In addition, the chemical composition of rivers has been reported to be influenced by varying river flow [14,15].

The goal of the study was to quantify some metal pollutants in Pasig River and to establish the effect of varying seasons and astronomical tide to the transport of pollutants such as heavy metals. Specifically, this study evaluated the effects of seasonal changes [8] and varying astronomical tides (as determined by Philippines’ National Mapping and Resource Information Authority or NAMRIA) [16] on the concentration of heavy metals such as cadmium (Cd), copper (Cu), lead (Pb) and nickel (Ni) along Pasig River. The whole Pasig River area belongs to a geographical zone characterized by two pronounced seasons: dry season from December to April but sometimes reaches late May or early June and a wet or rainy season from May to November. Insights pertinent to the flux of some heavy metals along the Pasig River would be highly useful and relevant to the current government initiative of remediating and rehabilitating the Manila Bay. Understanding the pollution load contribution of Pasig River to Manila Bay would be essential to the design and eventual implementation of environmental management and monitoring practices for the revitalization of Manila Bay [17-19].

In addition, the study also sought to determine the occurrence of backflow along the stretch of the Pasig River by determining the mechanism for the occurrence of backflow. The Napindan Hydraulic Control Structure (NHCS) was built to regulate the passage of contaminated water of the Pasig River and saltwater from Manila Bay from intruding the Laguna de Bay. Laguna de Bay, which serves as host to thousands of private fish pens, is the largest freshwater lake in Southeast Asia. It is rationalized that there could possibly occurrences of backflow, significantly affecting the transport of metal pollutants as well as inducing potential impact of saline water to the immediate environment of Pasig River which may affect aquatic organisms thriving in the river.

2. Materials and methods

Reagents used in this study were all of analytical grade such as 70% Univar nitric acid, 1000 ppm Ajax Finechem Cadmium Nitrate Atomic Absorption Spectroscopy (AAS) Standard, 1000 ppm Ajax
Finechem Copper (II) Nitrate AAS Standard, 1000 ppm Ajax Finechem Lead Nitrate AAS Standard and 1000 ppm Ajax Finechem Nickel Nitrate AAS Standard. HACH HQ30D pH was used for in-situ monitoring of pH, while a laboratory thermometer was used to measure temperature of water samples collected. GARMIN e TREX H Global Positioning System was used to generate the locations of the samples collected.

2.1. Study site and sampling stations
Water samples were taken from four identified sampling locations along Pasig River, situated upstream, mid-stream and downstream of the river, are summarized in Table 1.

| Station | Description |
|---------|-------------|
| 1       | Downstream Pasig River, Delpan Station |
| 2       | Middle stream Pasig River, Lambingan Station |
| 3       | Middle stream Pasig River, Guadalupe Station |
| 4       | Upstream Pasig River (Downstream Marikina River), Kalawaan Station |

Sampling station 1 was located downstream of Pasig River near the Manila Bay, 14°35’47.18” North and 120°58’04.56” East. Water samples were taken from the riverside of the Pasig River, around 30 meters from the Delpan Bridge facing Manila Bay. Ocular observation of the site indicates several barges docked in the area. In addition, a large scale glass manufacturing plant is also located in the area.

Sampling station 2 was situated in middle stream of Pasig River, at Lambingan Station of the Pasig River Ferry Transport. The sample station was located at 14°35’13.25” North and 121°01’10.64” East. Sampling station 3, another middle stream portion of the Pasig River, was located near the mouth of Marikina River and the Napindan Hydraulic Control Structure, at 14°33’35.52” North and 121°03’57.84” East. Water samples were collected from the left side portion of the Guadalupe Station of the Pasig River Ferry Transport. The station is characterized as a highly industrialized area, marked by the presence of several large scale industries such as textile, galvanized iron sheets, food industries, chemicals industry, consumer products, detergents and many more.

Meanwhile, sampling station 4 was located in the upper stream between the mouth of Laguna de Bay and serves as the merging point with Marikina River. The chosen station, identified as Kalawaan Bridge, was specifically located at 14°33’12.97” North and 121°04’54.91” East. In Kalawaan area, two manufacturing industries are located in the vicinity of the sampling area, one chemical manufacturing plant and the other a glass manufacturing plant.

In addition to manufacturing firms situated along the river banks, there are several houses built along the river banks of Pasig River, which may account for the domestic wastes being disposed of into the river. A view of the sampling stations chosen along the 27 km stretch of Pasig River is shown on Figure 1.

Water sampling was done on two occasions, one during the dry season and the other during the rainy/wet season. As previously mentioned, astronomical tides from NAMRIA [16] were considered in the design and execution of sample collection.

Table 2 gives the sampling details including the prevailing Manila Bay’s height of astronomical tide at the time of sampling.
Figure 1. Sampling stations (screen shot from Google Maps).

Table 2. Sampling date and prevailing conditions.

| Date of Sampling | Time    | Astronomical Tide [16] | Manila Bay’s Height of Tide (meters) | Season     |
|------------------|---------|------------------------|-------------------------------------|------------|
| Apr 28, 2007     | 9:26 AM | High Tide              | 0.52                                | Rain showers |
| May 3, 2007      | 5:59 PM | Low Tide               | -0.12                               | Dry Season  |
| May 5, 2007      | 10:57 AM| High Tide              | 1.10                                | Dry Season  |
| Aug 11, 2007     | 5:11 PM | Low Tide               | -0.09                               | Wet Season  |

Initial sampling was conducted on 28\textsuperscript{th} of April 2007. Prior to sample collection, there were scattered rain showers recorded in the metropolis. The prevailing surface flow velocity of the river water including the direction of the flow was also measured. The surface flow velocity of the river was determined by measuring the duration for a floater such as any rubbish floating on the river (e.g. slipper, piece of wood, etc) to traverse a pre-determined distance. The distance divided by the time required for the floater to cover a specific distance corresponds to the surface velocity of the river. The distance was measured using a metric scale on the landside. However this improvised method was not performed especially when sampling was done over the bridge such as the one which transpired at Kalawaan Bridge. An alternative method was employed using a floating device. This device was made up of nylon string, 3 pieces of 6 liter-polyethylene (PET) bottles, and a concrete or stainless steel to function as an anchor. Meanwhile, PET bottles served as floaters and at the same time as markers for the two points along the river. With this device, surface flow velocity was calculated by dividing the distance between two points established on either side of the river with the time required for the float to cover the distance. The nylon string that was used for making markers was 20 meters in length with a polyethylene bottle attached at each end. One end had a 10 meter long nylon string with heavier concrete weight attached to it, to keep the floater in a fix location. A rubber slipper or a floating water hyacinth was used to indicate the direction of flow.

A total of 16 water samples were collected from these four sampling stations along the Pasig River. At the time of the fourth sampling conducted on August 11, 2007, it was noted that the Napindan Hydraulic Control Structure’s gates were closed. Only the navigational gate was left open for barges to pass. This was in response to the request of Philippines’ National Power Corporation (NAPOCOR), a government-controlled power generation company, to open the gate at high tide to induce the saline water into the lake for NAPOCOR’s usage in its facilities.
2.2. Preservation of water samples for subsequent chemical analysis

Approximately 2 ml of concentrated Univar 70% nitric acid was added to water samples in order to ensure that metals remain solubilize in the water sample. Water samples were placed in acid-washed Nalgene bottles and immediately after collection, samples were placed in ice chests containing Coleman® blue ice packs and transported to the laboratory. In the laboratory, the water samples were kept refrigerated at a temperature of 4°C prior to sample digestion. In situ measurements of pH and temperature were performed at each sampling site.

2.3. Acid digestion of Pasig River water samples

Laboratory wares were soaked in 14 % nitric acid bath for three (3) days and were rinsed thoroughly using distilled water to avoid contamination. Digestion of sample was carried out to reduce interference by organic matter and to convert metals associated with particulates to form (usually the free metal) that can be determined by Flame Atomic Absorption Spectrometry (AAS), following the analytical method given in the Standard Methods for the Examination of Water and Wastewater, American Public Health Association (APHA) [20].

A total of 89 samples were digested using concentrated Univar nitric acid. Duplicate analysis was performed for each sample, with two sample blanks (distilled water) for each batch (of digestion), three synthetic standard solutions were prepared by spiking with known concentrations of Pb, Cd, Cu and Ni, in ppm and one (1) 1643e trace elements in water (purchased from National Institute of Standards and Technology, USA) as standard reference material (SRM) were digested. Distilled water was used during the digestion process and in the preparation of standard solutions of metals for AAS analysis.

Digestion of the SRM (1643e trace elements in river water), blank, and synthetic spiked solutions was performed in the same manner as performed on the river water samples, to ensure that the metals were completely recovered during sample preparation as stipulated in WHO/UNEP (1996) [21].

2.4. Measurement of metal concentrations using Flame AAS

Metal analysis of the samples were performed using Perkin-Elmer Analyst 100 Flame AAS, equipped with deuterium arc background corrector, an air-acetylene burner and controlled by IBM personal computer. The hollow cathode lamp was operated at 15 mA. The analytical wavelength was set at 228.8 nm for cadmium (Cd) analysis, 324.8 nm for copper (Cu) analysis, 217 nm for lead (Pb) analysis and 341.5 nm for nickel (Ni) analysis.

3. Results and discussion

3.1. Variations in river depth as influenced by season and tide

Table 3 gives the experimentally determined depth (of the river) at each station. As indicated in Table 3, portion of the Pasig River specifically at Lambingan station was found to be the deepest. That area was assumed to have been dredged prior to the sampling since a ferry station was constructed in the area.

| River Depth | Delpan | Lambingan | Guadalupe | Kalawaan |
|-------------|--------|-----------|-----------|----------|
| DRY SEASON  |        |           |           |          |
| Low Tide    | 3.00   | 4.50      | 4.00      | 2.00     |
| High Tide - Backflow | 7.75 | 8.00 | 6.00 | 4.50 |
| WET SEASON  |        |           |           |          |
| Low Tide    | 8.50   | 9.00      | 7.00      | 6.00     |
| High Tide   | 4.50   | 6.00      | 5.00      | 3.00     |
Based on the results, a certain portion of the river was found to be relatively deeper at high tide during the dry season. As illustrated in Figures 2 and 3, deepest part was Lambingan station. However, during wet/rainy season, the river tends to be deeper during low tide as shown in Figure 5. At the time of sampling and when the tide is low, the volume of rainfall recorded was found to be higher than what was recorded during high tide, causing the level at Pasig River to slightly rise than its usual level. Further, at the time of the study, the Metro Manila Development Authority (MMDA), a government agency in charged with clearing of waterway during wet season, has already conducted dredging along the Pasig River which may have accounted for the noted changes in the river depth. Further, the observation that Pasig River tends to be shallower during wet season at high astronomical tide could also be attributed to a discrepancy between calculated height of astronomical tide at Manila Bay and the actual measurement conducted during sampling. At dry season, Pasig River has a depth of 3.1875 meters while at wet season, a depth of 3 meters was recorded.

Figures 2 and 3 reflect variation in water depth depending on the season and tide. Figures 2 and 3 show the graphical representation of the measured river depth during dry and wet seasons, respectively, which may reflect possible contributions to the overall flow pattern observed in Pasig River. As shown, there was occurrence of backflow. The normal flow pattern in Pasig River is from Laguna de Bay, which is located in the vicinity of Kalawaan station going to Manila Bay, downstream portion of the Pasig River, situated at Delpan station. But with backflow, water from Manila Bay drains through Pasig River, going to Laguna de Bay.

![Figure 2](image_url)

*Figure 2. Experimentally measured River Depth during the dry season.*
3.2. Mechanism of backflow along Pasig River

A river typically begins at a source and flows following elevation gradients down to its endpoint, called the mouth [22]. The source is the highest point in the waterway. The river follows a concave profile from the steeper upstream region where erosion usually takes place, going deeper down where particulates or suspended materials could be deposited as sea level is approached in the mouth. As it progresses downstream, the river tends to become larger and smoother. In the case of the Pasig River, Laguna de Bay serves as the source while Manila Bay would be the endpoint or mouth.

Normally, water flow along Pasig River takes the course from Laguna de Bay towards Manila Bay. According to Philippines’ Laguna Lake Development Authority (LLDA), towards the end of the dry season, the water level in Laguna de Bay reaches a minimum level of 10.5 meters. However, during the occurrence of high tide at dry season, the water level in the Laguna de Bay may drop below that of Manila Bay’s resulting into a backflow of saline water from the Manila Bay via the Pasig River into the Laguna de Bay. Such occurrence of backflow could result to an increase in pollution and salinity levels in Laguna de Bay during the dry season [4]. Laguna de Bay hosts several metric tons of fish, usually freshwater, to meet the demands in the metropolis. Intrusion of saline water from Manila Bay can be harmful to these freshwater aquatic organisms.

On account of the third sampling conducted on 5th of May 2007 which was covered by dry season in the Philippines, and at a time that a high tide prevailed (with a predicted Manila Bay’s height of tide of 1.10 meters), there was an observable backflow occurring in Pasig River. The backflow can be observed from the first station (Delpan) to the last station in Kalawaan station, near the Laguna de Bay. This observation affirms that the Pasig River could serve as an estuary depending upon the water level difference between Manila Bay and Laguna de Bay. During the dry season, the water level in Laguna de Bay is assumed to be low and the flow direction of the Pasig River would be dependent on the prevailing astronomical tide. Meanwhile, during the wet season, when the water level of Laguna de Bay is high, flow is normally from Laguna de Bay towards Manila Bay [4].

In view of the above mentioned observations, characteristic of Pasig River transitions to some extent from a river to a marine-like environment. The prevailing flow pattern shall dictate the chemical composition of river and can be strongly associated to varying season and tide. Water movement is a significant means by which other materials like pollutants are transported from one point to another. Variations in terms of flow can be problematic, as in the case of Pasig River. In the same way that Manila Bay could affect aquatic organisms thriving in Laguna de Bay, pollution in Laguna de Bay as to the presence of antibiotics, high phosphate content, including heavy metals can also be transported and released from Laguna de Bay into Pasig River and nearby environment. Some of these pollutants even exhibit tendencies to persist indefinitely, circulate and eventually accumulate throughout the ecological food chain, becoming a serious threat to the Pasig River environment [19].
3.3. Flow rate as computed from surface flow velocity

This study also calculated the flow rate of the river based from the surface flow velocity. Table 4 summarizes the calculated flow rate at each station.

| Table 4. Flow Rate Measurement of Each Station (in meters/seconds). |
|---------------------------------------------------------------|
| Flow Rate                                              | Delpan | Lambingan | Guadalupe | Kalawaan |
| Low Tide - Dry Season                                      | 0.267±0.139 | 0.362±0.007 | 0.399±0.098 | 0.549±0.001 |
| High Tide - Dry Season (Backflow)                          | 0.154±0.010 | 0.226±0.031 | 0.257±0.011 | 0.264±0.029 |
| Low Tide - Wet Season                                       | 0.396±0.088 | 0.462±0.004 | 0.642±0.044 | 1.048±0.007 |
| High Tide - Wet Season                                      | 0.088±0.009 | 0.096±0.022 | 0.249±0.052 | 0.341±0.011 |

As can be gleaned from the table, Kalawaan station yielded the fastest flow rate. The low tide during wet season resulted to a higher flow rate due to the increase water level flowing from Laguna de Bay towards Manila Bay. Figures 4 and 5 show the graphical representation of the flow rate during the dry season and wet season.

![Figure 4](image1.png)

**Figure 4.** Experimentally calculated flow rate in Pasig River during dry season.

![Figure 5](image2.png)

**Figure 5.** Experimentally calculated flow rate in Pasig River during wet season.
Figures 4 and 5 illustrate the characteristic flow rate in Pasig River as affected by varying seasons and tides. Figure 4 shows a relatively insignificant difference in flow rate during high and low tide during the dry season, suggesting an almost constant/stagnant flow pattern. Low flow rate can be problematic as inorganic wastes like heavy metals could settle in the sludge on rivers, which may result to clouding of the water and consequently, coating the riverbed. Inorganic wastes can smother the riverbed in a blanket of toxic residue and cloud the water [7]. This clouding blocks the penetration of sunlight into the water and therefore obstructs photosynthesis and inhibits plant growth, similar to what can be observed during eutrophication.

On the other hand, a clearly distinct flow pattern was observed during the wet season at different tides. Relatively faster flow rate was observed during low tide. At high flow rate, contaminants will be washed out straight towards the Manila Bay.

3.4. Variations in the heavy metal concentrations along Pasig River

This study also attempted to establish the concentrations of at least four (4) heavy metals in water samples collected from Pasig River. Concentrations of cadmium (Cd), copper (Cu), nickel (Ni) and lead (Pb) were analyzed by flame AAS. Data are tabulated in Tables 5 and 6.

| Table 5. Heavy metals concentrations during dry season at different tide levels. |
|---------------------------------------------------------------|
| **Dry Season** | **Lead** (mg/L) | **Copper** (mg/L) | **Nickel** (mg/L) | **Cadmium** (mg/L) |
| HIGH TIDE | | | | |
| Delpan | 0.628 ± 0.003 | 0.063 ± 0.000 | 0.249 ± 0.007 | 0.051 ± 0.001 |
| Lambingan | 0.537 ± 0.016 | 0.056 ± 0.000 | 0.191 ± 0.009 | 0.041 ± 0.000 |
| Guadalupe | 0.545 ± 0.053 | 0.053 ± 0.004 | 0.164 ± 0.002 | 0.038 ± 0.001 |
| Kalawaan | 0.465 ± 0.001 | 0.044 ± 0.002 | 0.148 ± 0.011 | 0.034 ± 0.000 |
| LOW TIDE | | | | |
| Delpan | 0.420 ± 0.006 | 0.038 ± 0.001 | 0.095 ± 0.034 | 0.028 ± 0.000 |
| Lambingan | 0.397 ± 0.009 | 0.035 ± 0.003 | 0.092 ± 0.037 | 0.027 ± 0.000 |
| Guadalupe | 0.330 ± 0.019 | 0.032 ± 0.004 | 0.063 ± 0.049 | 0.022 ± 0.001 |
| Kalawaan | 0.278 ± 0.018 | 0.032 ± 0.002 | 0.088 ± 0.011 | 0.018 ± 0.000 |

| Table 6. Heavy metals concentrations during wet season at different tide levels. |
|---------------------------------------------------------------|
| **Wet Season** | **Lead** (mg/L) | **Copper** (mg/L) | **Nickel** (mg/L) | **Cadmium** (mg/L) |
| High Tide | | | | |
| Delpan | 0.312 ± 0.031 | 0.038 ± 0.003 | 0.105 ± 0.000 | 0.030 ± 0.000 |
| Lambingan | 0.264 ± 0.023 | 0.034 ± 0.007 | 0.080 ± 0.022 | 0.026 ± 0.000 |
| Guadalupe | 0.233 ± 0.034 | 0.043 ± 0.013 | 0.059 ± 0.016 | 0.021 ± 0.001 |
| Kalawaan | 0.209 ± 0.017 | 0.026 ± 0.003 | 0.039 ± 0.009 | 0.019 ± 0.001 |
| Low Tide | | | | |
| Delpan | BDL | 0.003 ± 0.004 | BDL | BDL |
| Lambingan | BDL | 0.032 ± 0.025 | BDL | BDL |
| Guadalupe | BDL | BDL | BDL | BDL |
| Kalawaan | BDL | BDL | BDL | BDL |

BDL: Below the Detection Limit
Results suggest the presence of those heavy metals along the Pasig River. Among the metals determined, lead yielded the highest concentration, specifically at Delpan station. Occurrence of lead can be due to point sources such as industrial wastes, vehicular emissions, etc. The highest concentration of lead measured at Delpan station during the dry season at high tide was 0.629 mg/L. This level was found to be higher than the water quality standard of the Philippines’ DENR for Class C River, that is, 0.05 mg/L. On the other hand, copper measured in water sample collected from Delpan station was found to be 0.063 mg/L, way above the threshold guideline of 0.05 mg/L. Likewise, cadmium in river water samples was also found to exceed the threshold level of 0.01 mg/L. 0.249 mg/L nickel was obtained in water collected from Delpan station.

3.4.1 Comparison of heavy metals concentration at different types of season and height of tide. The heavy metals concentrations during dry season at different tide levels are shown in Figures 6-9 while the heavy metals concentration during wet season at high tide is shown in Figures10-13.

![Figure 6. Levels of lead in Pasig River water during dry season.](image)

![Figure 7. Levels of nickel in Pasig River water during dry season.](image)
Figures 6-9 illustrate the variations in the level of heavy metals measured as a function of varying astronomical tides, during the dry season. As shown, the concentration of the metals was found to be lower during low tide.

As previously discussed, Pasig River experiences backflow which could occur during the dry season. As such, it can be assumed that the salinity of the river may have also increased. A salt wedge could have been developed from the river mouth which blocks the flow of freshwater resulting to high concentrations of heavy metals measured at Delpan station [23]. Suggesting that the condition in the area, may have caused solubilization or desorption of heavy metals from the particulate matter into the water column and that this phenomenon particularly occurs during the dry season [24].

On another note, Figures 10-13 give a comparison of the heavy metal concentration measured at high and low tide during the rainy season.
**Figure 10.** Measured levels of lead in Pasig River water during wet season.

**Figure 11.** Levels of nickel in Pasig River water during wet season.

**Figure 12.** Levels of copper in Pasig River water during wet season.
Heavy metals concentrations of water samples taken during wet season were found to be relatively lower than the heavy metals concentrations measured from samples obtained during dry season. In addition, heavy metals concentration during low tide was also found to be generally lower than the concentration of heavy metals during high tide. This is probably due to dilution/dispersion effect in which heavy metals in water were washed out towards Manila Bay due to high flow rate during the wet season.

4. Conclusions and recommendations
The flow pattern and the levels of some heavy metals in Pasig River, as influenced by varying seasons and astronomical tides were investigated in this study. Highest flow rate was established during the wet season at low tide, particularly at the Kalawaan station. On the other hand, low flow rate prevailed during the dry season at high tides. As the river water flows from Laguna de Bay to Manila Bay, it is assumed that contaminants from the Pasig River could be washed out straight towards the Manila Bay especially at high flow rate. Manila Bay becomes the repository of these contaminants such as heavy metals coming from Pasig River. This suggests that the transport of heavy metal pollutants along Pasig River can be influenced by varying flow pattern, seasons and astronomical tides. During the dry season, it is also rationalized that a salt wedge could have developed from the river mouth which blocks the flow of fresh water, which may have resulted to higher concentrations of heavy metals found at Delpan station. In addition, desorption of heavy metals from the particulate matter into the water column could have occurred particularly during dry season.

This study was also able to establish the presence of cadmium, nickel, copper and lead in Pasig River. Furthermore, it was found that heavy metals concentrations were relatively higher during dry season at high tide. High heavy metals concentration may have come from specific sources located along the river banks of the Pasig River system and other sources such as road dust, vehicular emissions and burned fossil fuels. Among the heavy metals measured, lead gave the highest concentration. Moreover, high levels of heavy metals were measured from water samples collected at Delpan station. It was assumed that lead could have come from anti-corrosive coatings of barges and tugboat berthing/anchoring along the riverside of Delpan station.

In addition, this study also investigated if a backflow can possibly occur along Pasig River, that is, saline water from Manila Bay flows into the Pasig River. Normally, flow of river water in Pasig River flows from Laguna de Bay towards Manila Bay. However, towards the end of the dry season, the water level in Laguna de Bay reaches its minimum level. At high tide, the water level in Laguna de Bay tends to drop below the water level of Manila Bay, resulting to a backflow of saline water from the Manila Bay via the Pasig River into the Laguna de Bay. As such, Pasig River was shown to exhibit
characteristics of an estuary, intermediate that of the river and marine environments, depending on the prevailing season and tide.

Acknowledgments
The authors would like to acknowledge funding from the Commission on Higher Education (CHED) Zonal Research grant. GRAP gratefully acknowledges MAPUA University’s School of Graduate Studies for financial support for her MS thesis. We also acknowledge assistance from the following people: Mr. Allan Mendoza, station manager of Pasig River Ferry Boat Lambingan Station and to the guards of the station, Mr. Gerardo R. Turla and Mr. Marlon A. Sacro; Mr. Ariel Matatquin, station manager of Pasig River Ferry Boat Guadalupe; Engr. Jaime Dinioso and Mr. Nilo Aklan, manager and engineer of MMDA Napindan Hydraulic Control Structure.

Declaration of no competing interests
We declare we have no competing interests and/or no non-financial competing interests, or other interests that might be perceived to influence the interpretation of this article.

References
[1] Namany S, Al-Ansari T and Govindan R 2019 Sustainable energy, water and food nexus systems: A focused review of decision-making tools for efficient resource management and governance J. Cleaner Prod. 225 610-26
[2] Gutierrez A 2018 The Sustainable Development Goals Report (Available at: https://unstats.un.org/sdgs/report/2018, date accessed: July 6, 2019)
[3] Census of Population 2015 (Available at: https://psa.gov.ph/tags/2015-census population, date accessed: July 8, 2019)
[4] Asian Development Bank 2000 Report and Recommendation of the President to the Board of Directors on Proposed Loans and A Technical Assistance Grant to the Republic of the Philippines for the Pasig River Environmental Management and Rehabilitation Sector Development Program, 1-40
[5] Kumar P, Masago Y, Mishra B K and Fukushi K 2018 Evaluating future stress due to combined effect of climate change and rapid urbanization for Pasig-Marikina River, Manila Groundwater Sustain. Develop. 6 227-34
[6] Manila Water Company, Inc. 2005 Environmental Impact Statement for Manila Third Sewerage Project vol 1 pp 1-10
[7] Australian Agency for International Development 2000 The Pasig River: Life After Death (Australia: Australian Government) 1-11
[8] Special Assistance for Project Formation Team 1998 Pasig-Marikina River Channel Improvement Project Final Report, Japan International Cooperation Agency (JICA) and Department of Public Works and Highways DPWH
[9] Greenpeace Southeast Asia 1999 Backgrounder 1-3
[10] Juan-Tio B D 2003 Ecotoxicological Assessment of Water Samples from Pasig River, Philippines by Whole Effluent Toxicity (WET) Test (Philippines: University of the Philippines) PhD dissertation
[11] Garcia T P, Urase T and Suzuki Y 2003 Comparison of Heavy Metal Pattern Between Water and Sediments in Pasig River System, Philippines Report of Japan-Philippines Exchange Program, JSPS, Vol 1 pp 1-7
[12] Li L, Jiang M, Liu Y and Shen X 2019 Heavy metals inter-annual variability and distribution in the Yangtze River estuary sediment, China Marine Poll. Bull. 141 514-20
[13] Ming L, Dejiang F, Naishuang B, Xueshi S and Yuan T 2019 Impact of water-sediment regulation on the transport of heavy metals from the Yellow River to the sea in 2015 Sci. Tot. Envi. 658 268-79
[14] Meybeck M and Vorosmarty C 2005 Fluvial filtering of land to ocean fluxes: from natural Holocene variations to Anthropocene C. R. Geoscience 337 107-23
[15] Dsikowitzky L, van der Wulp S A, Dwiyitno, Ariyani F, Hesse K J, Damar A and Schwarzbauer J 2018 Transport of pollution from the megacity of Jakarta into the ocean: Insights from organic pollutant mass fluxes along the Ciliwung River Estuar. Coast. Shelf S. 215 219-28
[16] National Mapping and Resource Information Authority 2007 Tide and Current Tables (San Nicolas, Manila, Philippines: Oceanographic Survey Department)
[17] Cruz RT, Helmer P, and Hespanhol I 1997 Water Pollution Control – A Guide to the Use of Water Quality Management Principles: The Pasig River, Philippines United Nations Environment Programme (UNEP), the Water Supply and Sanitation Collaborative Council and the World Health Organization (WHO), London (UK)
[18] Osmond D L, Line, D E, Gale J A, Gannon R W, Knott C B, Bartenhagen K A, Turner M H, Coffey S W, Spooner J, Wells J, Walker J C., Hargrove L L, Foster M A, Robillard P D and Lehning D W 1995 WATERSHEDSS: Water, Soil and Hydro-Environmental Decision Support System, North Carolina State University Water Quality Group
[19] Partnerships in Environmental Management for the Seas of East Asia 2001 Manila Bay: Initial Risk Assessment. PEMSEA Technical Information Report No. 2001/01 p 112 (Quezon City, Philippines)
[20] Garbarino J R and Hoffman G L 1999 Methods of Analysis by the U.S. Geological Survey National Water Quality Laboratory—Comparison of a Nitric Acid In-Bottle Digestion Procedure to Other Whole-Water Digestion Procedures U.S. Geological Survey, Open-File Report 99–094
[21] Clesceri L et al 1998 Standard Methods for the Examination of Water and Wastewater 20th edition (USA: American Public Health Association)
[22] Herbert P and Kundell J 2007 River Cleveland C. J. The Encyclopedia of Earth (Washington D.C.)
[23] Clean Colorado River Alliance 2006 Recommendations to Address Colorado River Water Quality 34
[24] Zeng Y and Huai W 2014 Estimating longitudinal dispersion coefficient in rivers J. Hydro-Environ. Res. 8 2-8