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GEOSPATIAL ASSESSMENT OF WATER QUALITY OF PASIG RIVER USING PHYSICO-CHEMICAL PARAMETERS AND WATER QUALITY INDEX

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Acceptance Page:

This Special Problem titled: “Geospatial assessment of water quality of Pasig River using physico-chemical parameters and Water Quality Index” is hereby accepted by the Faculty of Management and Development Studies, U.P. Open University, in partial fulfillment of the requirements for the degree Master of Environment and Natural Resources Management.

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DECLARATION

This is to certify that:

I. The special problem comprises only my original work towards the MENRM except where indicated in the Preface

II. Due acknowledgment has been made in the text to all other material used

III. The special problem is fewer than 25,000 words in length, exclusive of tables, maps, bibliographies and appendices.

DIANA RIZA A. AFRICA

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Abstract

The Pasig River plays a crucial role in the economy of the city as it serves as means of transport, supplies water for households and industries, and offers recreational opportunities. Moreover, it connects the two major water bodies in Metro Manila: the Laguna de Bay and Manila Bay. Unfortunately, it also serves as a sink for industrial and domestic wastes in the metro. This paper attempts to characterize the Pasig River using Water Quality Index (WQI) and examine the spatial distribution of water quality parameters. Data used in computation of WQI are from analyses of physico-chemical parameters which include DO, BOD, fecal coliform, pH, temperature, TSS, phosphate, nitrate and ammonia from 2020 to 2022. Computed CCME-WQI values of Pasig River ranged from 30.3 to 38.9 with an average score of 33.9 which indicate that the water quality is “poor” across all stations. Findings suggest that the river's physico-chemical characteristics no longer comply with the river system's present waterbody classification, making it unsuitable for its intended purpose for fishery, recreational (Class II), agriculture, irrigation and livestock watering. Further, WQI scores show lowest values in the midstream to mid-downstream portions of the river, suggesting these sections as having the poorest water quality or areas of critical concern.

I. INTRODUCTION

The Pasig River plays a crucial role in the economy of the city as it serves as means of transport, supplies water for households and industries, and offers recreational opportunities. Moreover, it connects the two major water bodies in Metro Manila: the Laguna de Bay and Manila Bay. The Department of Environment and Natural Resources - Environmental Management Bureau (DENR-EMB) classified the Pasig River as Class C Water which is primarily intended for fishery, recreation (Class II), and water for irrigation, agriculture and livestock (DENR, 2016). However, the river was considered “biologically dead” during the 1990s due to its inability to support aquatic life (Philippine Daily Inquirer, 2023). Since then, the water quality of Pasig River has deteriorated further, indicating that the water quality standards for Class C water has not been met since 2003 (DENR-EMB, 2014; Gorme et al., 2010).

The assessment of inland surface waters in the country, including Pasig River, is based on compliance with the DENR Water Quality Guidelines (WQG) stated in the DENR Administrative Order No. 2016-08 and 2021-19. Water quality status and trends were generally described using individual water quality parameters. However, more often than not, not all required minimum physico-chemical parameters comply at the same time even in just one sampling event. Based on the Pasig River Unified Monitoring Stations (PRUMS) program report in 2020, most of the sampling stations failed to meet the Class C WQG for Biological Oxygen Demand (BOD), Dissolved Oxygen (DO), fecal coliform, temperature and nutrients (DENR, 2020). With this, adhering to water quality standards based on established classifications complicates the interpretation and analysis of assessment and monitoring, as the impact of each parameter is individually assessed and evaluated.

The Water Quality Index (WQI) is a metric used to evaluate and summarize the overall quality of water based on various physical, chemical, and biological parameters. It condenses complex water quality data into a single numerical value, providing a convenient way to assess and compare water quality (Sanchez et al., 2007; Akhtar et al., 2021) across different locations and time periods (Kaurish and Younos, 2007). Geospatial assessments, on the other hand, provide a spatial understanding of water quality patterns, which allows stakeholders to visualize and comprehend the distribution of water quality parameters as well as the overall status of water quality across a landscape. This spatial perspective helps identify hotspots of pollution, sources of contamination, and areas of concern that allows for effective monitoring and targeted management interventions.

II. REVIEW OF RELATED LITERATURE

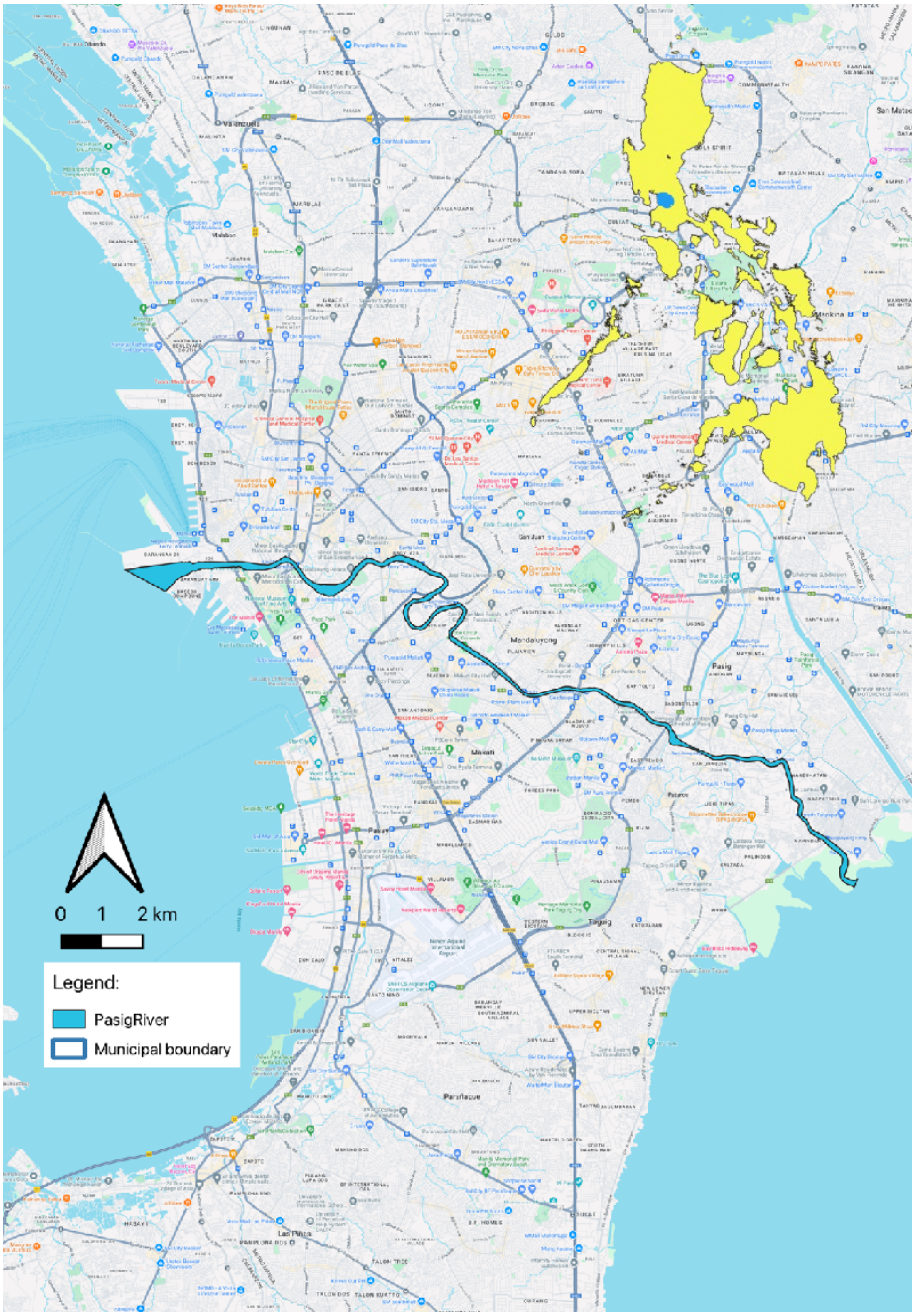
Pasig River System

The Pasig River is approximately 27 kilometers long, 91 meters (average) wide and about 0.5 to 5.5 meters deep. It originates from upstream section in Laguna de Bay and courses through urban areas via the Napindan Channel. It merges with the Marikina River and Pateros-Taguig River before it joins with the San Juan River. It finally empties into Manila Bay (Gorme et al., 2010). Pasig River passes through at least six cities within the metropolis, including Manila, where the official residence of the President of the Philippines, the Malacañang Palace, is situated. The location map of Pasig River is shown in *Figure 1*.

To some extent, the Pasig River transitions from freshwater characteristics to a marine-like environment depending on the prevailing flow pattern which is strongly associated to season and tide. Typically, water flows in the Pasig River from Laguna de Bay towards Manila Bay. However, during the late dry season, the water level in Laguna de Bay decreases significantly and during high tide, the level can drop below than that of Manila Bay. This leads to a reverse flow of salty water from Manila Bay into Laguna de Bay via the Pasig River (Paronda et al., 2019).

Since the Spanish colonization of the Philippines in the early 16th century, the Pasig River has served as a crucial artery for industry and trade, embodying our cultural heritage and history. It also served several purposes including bathing, fishing, drainage, sewage, and laundry area and means of transport and communication. Consequently, also as early as the Spanish era, the dwellers noticed that the river's water quality started to deteriorate with pollution coming from sewage and laundry washing (Gilles and Santos, n.d.).

Figure 1. Location map of Pasig River. Basemap data from Google, accessed via QGIS.



Following World War II, the city initiated a rebuilding phase by rapid urbanization and industrialization (Escoto et al., 2021). Urban development spread horizontally along the riverbanks, with buildings and informal settlements encroaching on easements (Gilles and Santos, n.d.). The gradual deterioration of the Pasig River commenced in the 1930s. During this time, fish migration from Laguna de Bay and ferryboat transport decreased (Escoto et al., 2021). By the 1950s, bathing and washing activities ceased. In the 1960s, the river emitted foul odors and turned dark in color. Pollution levels in the river had dropped below Class C standards in the 1970s. In the 1980s, river tourism declined and in 1985, all forms of fishing stopped (Gilles and Santos, n.d.). By 1990, the river was considered “biologically dead” (Philippine Daily Inquirer, 2023). Since then, the water quality of the river continues to deteriorate.

According to the PRUMS water quality monitoring report (DENR, 2020), all 19 sampling stations (including major tributaries and Manila Bay stations) failed to meet the DENR Class C standards for fecal coliform, phosphate and ammonia. Most of the sampling stations were also not compliant with the standards for BOD (17/19 stations), DO (16/19 stations), and temperature (9/19 stations). The data further revealed that the esteros and creeks exhibited the highest levels of BOD, particularly Buhangin and Maytunas creeks while the esteros or minor tributaries, notably Estero de San Lazaro, displayed the highest concentration of fecal coliform.

Water Quality Index (WQI)

Assessing freshwater ecosystems involves various methods and parameters depending on the intended purpose, sample type, and sampling area size (Boyacioglu, 2007; Sargaonkar and Deshpande, 2003). Internationally recognized standards have been established for water quality parameters, including physico-chemical and biological indicators, where exceeding defined limits can pose risks to human health. Traditional water quality assessment methods involved comparing parameter values against these standards. While this approach was well understood by technical experts in the water resources field, it lacked clarity and utility for policymakers and the general public (Tyagi et al., 2013). Moreover, it did not offer a comprehensive overview of the waterbody's condition (Boyacioglu, 2007; Debels et al., 2005).

The Water Quality Index (WQI) is a highly effective tool for assessing water quality, providing a single numeric score that reflects the water quality status at a specific location and time (Kaurish and Younos, 2007). It consolidates key physico-chemical and biological water parameters into a single value, simplifying complex data into an easily understandable format (Lumb, Halliwell & Sharma, 2006). This index is valuable for local planners, decision-makers, watershed managers, and the general public, as it offers a clear representation of water quality status (Reza and Singh, 2010; Nasirian, 2007).

Horton (1965) introduced the first WQI in the United States, comprising 10 commonly used water quality parameters such as dissolved oxygen (DO), coliforms, pH, conductivity, alkalinity, and chloride, among others. Each parameter was assigned a weight reflecting its relative importance and impact on a specific use (Said et al., 2004). Since then, numerous modifications to the WQI concept have been proposed by scientists and experts.

In 1971, Brown et al. developed a version of the WQI which was supported by the National Sanitation Foundation and therefore named as NSFWQI. This method was done by selecting variables rigorously, developing a common scale and assigning weights. It is based upon nine water quality parameters such as dissolved oxygen, biochemical oxygen demand, fecal coliform, temperature, pH, turbidity, total phosphates, nitrates and total solids.

The Canadian Council of Ministries of the Environment Water Quality Index (CCME-WQI) is one of the most commonly used WQI. It is a flexible tool for evaluating water quality, suitable for various types of water bodies and takes into consideration the local guidelines and standards where it is being used (Bilgin, 2018). There are no fixed parameters required though it is recommended that a minimum of four parameters be assessed at least four times a year. Nevertheless, a 2012 review suggests that more consistent and reliable results are achieved when at least eight parameters are considered (CCME, 2017).

Currently, the country is lagging behind its neighbor countries in the implementation and development of policies related to WQI. The Malaysian Department of Environment developed the DOE-WQI using six parameters. A weighted linear sum formula was used to calculate the WQI (DOE, n.d.). The Ministry of Natural Resources and Environment (MONRE) of Vietnam devised the MONRE-WQI which is based on the Weighted Arithmetic Water Quality Index (WAWQI) combined with River Status Index in order to describe the river condition more accurately (Pham et al., 2017). In 2017, the West Java Water Quality Index (WJWQI) was developed in Indonesia using nine water quality parameters. Sub-indices were derived for these nine parameters and weights were assigned based on expert judgments, employing the multiplicative aggregation method as the NSFWQI.

A case study on the water quality assessment in Metro Manila conducted by Regmi and Mishra in 2016 employed CCME-WQI. Data sets of four water quality parameters (pH, DO, BOD, total coliforms) collected in 14 stations in Pasig River and its tributaries from the first quarter of 2011 up to the 2nd quarter of 2014 were analyzed. Results showed low WQI levels indicating “poor” water quality which may be due to the lack of sewage systems and untreated domestic, industrial, and agricultural wastewater. Laguna de Bay was assessed in terms of CCME-WQI using six physico-chemical parameters (BOD, DO, pH, nitrate, phosphate and ammonia) from 2016 to 2019. Results revealed that the lake has WQI rank of marginal to excellent; however, WQI of its tributary rivers are mostly poor. Findings suggested that attention should be given to rehabilitation efforts not only in the lake but as well as its tributary rivers (Capili et al., 2021).

Geospatial assessment of water quality

GIS combined with remote sensing and mapping technologies are essential for various geographic and spatial aspects of water resource management. These tools offer robust visualization and analytical capabilities which allows for characterization, analysis and modeling of natural system processes and functions. GIS incorporates spatial analysis tools with various mathematical models to handle large water quality datasets effectively (Chabuk et al., 2020).

Given the technical and economic challenges associated with measuring environmental variables across an entire region or area, particularly due to the need for a substantial number of observations to understand spatial distribution, spatial interpolation methods have been developed. Spatial interpolation operates on Tobler's Law of Geography, which posits that spatially close points exhibit greater similarity in values than those farther apart. It employs spatial correlation principles to estimate environmental variable values at unsampled points using data from observed points within the same region (Katipoğlu, 2022).

Ordinary kriging is a geostatistical interpolation technique that leverages spatial autocorrelation to estimate values at unsampled locations. The process involves modeling the spatial variability of data through a variogram, which quantifies the degree of similarity between data points based on their spatial separation. Subsequently, kriging assigns weights to known data points based on their proximity to the prediction location, generating an interpolated value (Farooq et al., 2022).

Spatial assessment of the water quality of Laguna de Bay was conducted using ordinary kriging (Capili et al., 2021). Results revealed low WQI in the upper northwest portion of the lake, indicating poor water quality. This area includes rivers flowing from Metro Manila, Cavite and Rizal areas. Chen et al. (2012) efficiently evaluated river pollution index in tidal streams of Taiwan with the minimum amount of water quality data using ordinary kriging interpolation method.

III. STATEMENT OF THE STUDY

The WQI is a vital tool that simplifies large and complex water quality data into a simple numerical value or rating. It makes water quality assessment easily communicated with everyone, from researchers to policy makers and to the general public. It allows for rapid evaluation of water quality trends. Geospatial assessment, on the other hand, adds a crucial spatial dimension. It allows stakeholders to visualize and understand water quality data across a landscape. This perspective helps identify potential hotspots, sources of contamination and areas of concern.

This study intends to provide a comprehensive understanding of the spatial distribution, trends, and overall status of water quality of Pasig River. The results of the study may serve as a basis for developing policies and regulations related to water quality management of Pasig River as well as prioritization of efforts and effective allocation of resources. Ultimately, this study aims to support effective water resource management practices that will ensure sustainability and the health of ecosystems and communities that are dependent on Pasig River.

IV. OBJECTIVES

This study intends to provide a comprehensive understanding of water quality of Pasig River, specifically:

1. To assess trend of water quality of Pasig River from 2020-2022;
2. To determine WQI of Pasig River from 2020-2022;
3. To determine Pasig River's hotspots of poor water quality by visual examination using Geographic Information system (GIS).

V. SCOPE AND LIMITATIONS

The study used Pasig River water quality data from 2020 to 2022 as this period had the most comprehensive and complete datasets available as well as expanded monitoring network with the inclusion of additional sampling stations. Moreover, the analysis of water quality and computation of WQI was limited to the sampling stations within the main Pasig River and did not include those within the tributaries.

VI. STUDY AREA

Pasig River Unified Monitoring Stations (PRUMS)

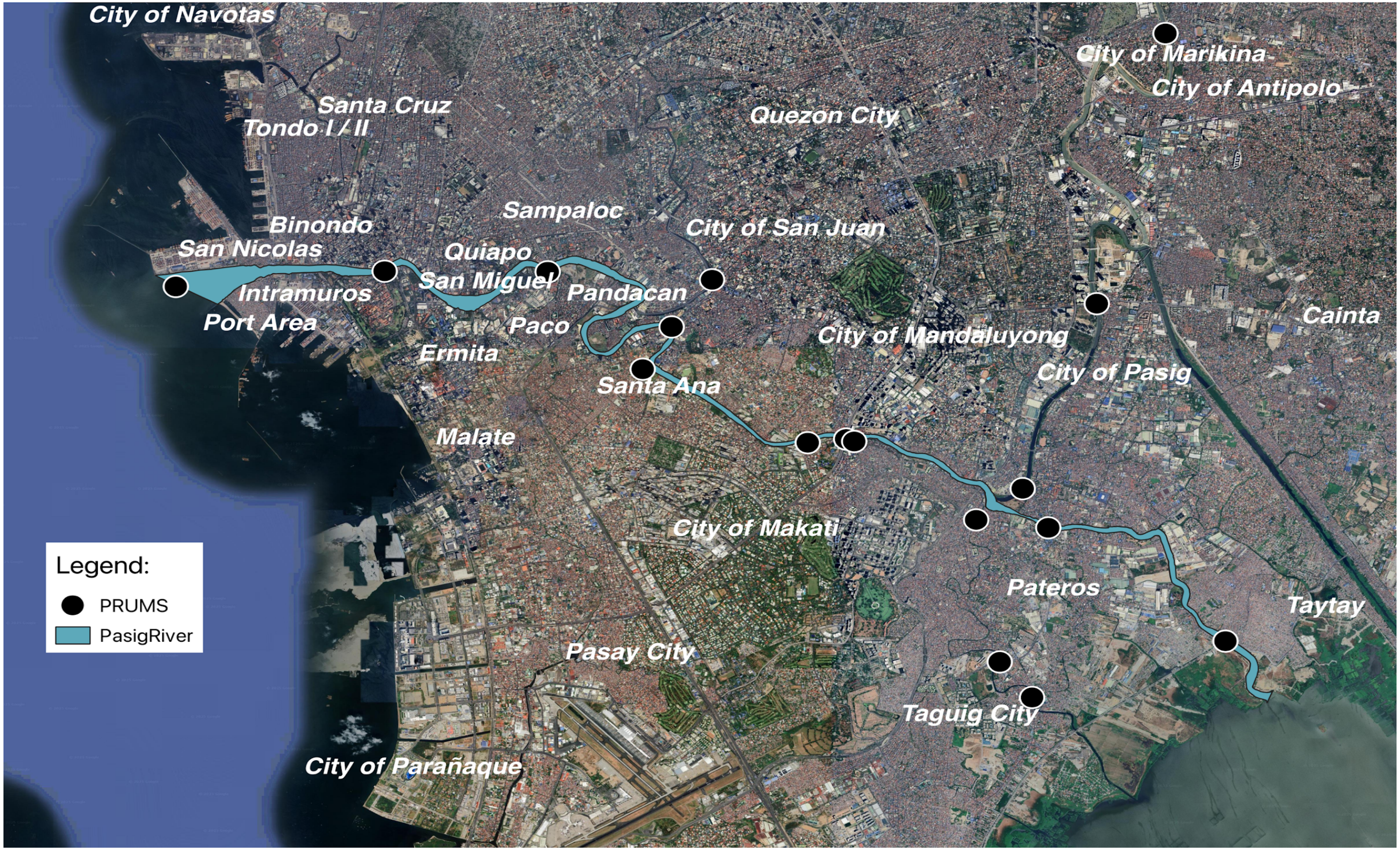
The PRUMS program is a collaborative effort among government agencies to standardize water quality assessment and monitoring in the Pasig River. It intends to produce comprehensive water quality reports for public information. A total of 19 sampling stations are assessed and monitored on a monthly basis (Table 1 and Figure 2).

Table 1

List of the Pasig River Unified Monitoring Stations (PRUMS)

SN	STATION NAME	LAT (N)	LONG (E
1	Napindan (C6) Bridge	14.5351	121.1022
2	Bambang Bridge	14.5536	121.0759
3	Guadalupe Ferry	14.5681	121.0459
4	Lambingan Bridge	14.5864	121.0200
5	Nagtahan Bridge	14.5954	121.0016
6	Jones Bridge	14.5955	120.9774
7	Guadalupe Nuevo	14.5677	121.0471
8	Guadalupe Viejo	14.5675	121.0402
9	Havana Bridge	14.5795	121.0157
10	Manila Bay	14.5930	120.9464

Figure 2. Location map of the Pasig River Unified Monitoring Stations (PRUMS). Basemap data from Google, accessed via QGIS.



VII. MATERIALS AND METHODS

Data Collection

The 2020-2022 water quality data of Pasig River was requested from the DENR NCR -Pasig River Coordinating and Management Office (PRCMO). Parameters include DO, BOD, fecal coliform, pH, temperature, TSS, phosphate, nitrate and ammonia. Water quality data were compared with the DENR WQG based on DAO No. 2016-08 and DAO No. 2021-19. According to the DENR-EMB, Pasig River is classified under Class C which is intended for fishery, recreational (Class II), agriculture, irrigation and livestock watering.

Calculation of WQI

WQI was computed using the Canadian Council of Ministries of the Environment - Water Quality Index (CCME-WQI). Among the different WQI methods, the study used the CCME-WQI since it is one of the most commonly used and considered as one of the “stricter” methods in a comparative assessment study conducted by Zotou et al. (2018). Further, CCME-WQI is one of the most flexible methods and can be adapted to different guidelines and usage of water. Unlike other methods which are using reference standards of pure or drinking water, CCME-WQI can be used in specific classification of water which in this study is Class C.

There are three factors on which the equation for calculating the CCME-WQI is based upon: 1. Scope – pertaining to the number of parameters with unmet guidelines; 2. Frequency – referring to how often the guidelines are unmet; and 3. Amplitude – the amount by which the guidelines are not met. The CCME-WQI can be calculated using the following equation:

$$CCMEWQI = 100 - \left(\frac{\sqrt{{F_1}^2 + {F_2}^2 + {F_3}^2}}{1.732}\right)$$

Where,

CCMEWQI is the calculated water quality index value (0-100),

F_1 is the scope,

F_2 is the frequency,

F_3 is the amplitude; and

1.732 is the normalizing constant

The scope (F_1) is the percentage of the number parameters that did not comply with guidelines at least once during the time span being considered over the total number of parameters. The equation below is used to calculate the scope:

$$F_1 = \left(\frac{no. of\ failed\ parameters}{total\ no. of\ parameters}\right)x100$$

The frequency (F_2) is the number of non-compliant individual tests over the total number of tests in percentage, as shown in the equation below:

$$F_2 = \left(\frac{no. of\ failed\ tests}{total\ no. of\ tests}\right)x100$$

The amplitude (F_3) or the amount by which the failed tests do not meet their guidelines can be obtained after multiple calculation steps. First, the excursion value must be calculated. Excursion is the number of times an individual failed test value is less than or greater than the standard. When test value must not exceed the standard, the equation below was used:

$$excursion_i = \left(\frac{FailedTestValue_i}{Objective_j}\right) - 1$$

On the other hand, when the test value must not fall below the standard, the equation below was used:

$$excursion_i = \left(\frac{Objective_j}{FailedTestValue_i}\right) - 1$$

After calculating the excursions of the individual tests, the sum of all the excursions were calculated and then divided by the total number of tests (compliant and not compliant with guidelines). This value indicates the normalized sum of excursions (nse) and was computed as follow:

$$nse = \frac{\sum_{i=1}^{n} \quad excursion_i}{total\, no.of\ tests}$$

After determining the *nse*, the amplitude value was calculated using the formula: $F_3 = \left(\frac{nse}{0.01nse+0.01}\right)$

The CCME-WQI value was described based on the interpretation shown in *Table 2.*

Table 2

Description of the CCME-WQI value (CCME, 2017)

CCME-WQI Value	General Description	Specific Description
95-100	Excellent	Water quality is protected with a virtual absence of threat or impairment; conditions very close to natural or pristine levels.
80-94	Good	Water quality is protected with only a minor degree of threat or impairment; conditions rarely depart from natural or desirable levels.
65-79	Fair	Water quality is usually protected but occasionally threatened or impaired; conditions sometimes depart from natural or desirable levels.

45-64	Marginal	Water quality is frequently threatened or impaired; conditions often depart from natural or desirable levels.
0-44	Poor	Water quality is almost always threatened or impaired; conditions usually depart from natural or desirable levels.

Statistical analysis

Water quality data and WQI scores were subjected to descriptive and ANOVA analyses to be able to determine the following:

- If there are significant differences in individual WQ parameters across sampling stations;
- If there are significant differences in individual WQ parameters across sampling periods;
- If there are significant differences in calculated WQI across sampling stations; and
- If there are significant differences in calculated WQI across sampling periods.

Geostatistical analysis of physico-chemical parameters and WQI

The delineation and image processing of the study were done using ArcGIS software. The ordinary kriging (OK) interpolation of selected physico-chemical parameters and WQI were carried out using the basic equation (Farooq et al., 2022) shown as:

$$z\hat{}(s)o = \sum_{i=0}^{n} \lambda i.Z(s)i$$

Where:

zˆ(s)o = the estimated value at the unsampled point (s)o,

Z(s)i = the measured value at (s)i,

λi = the weighting coefficient, and

n = the number of points considered in the searching domain.

The variogram models were assessed using the criteria of coefficient of determination (R^2) and root mean square error (RMSE). R^2 determines how well the independent variables in a regression model explains the variation in the dependent variable while RMSE measures the differences between predicted and observed values. Thus, accurate prediction model should have high R^2 and small values of RMSE. The basic equations for R^2 and RMSE are shown as (Farooq et al., 2022):

$$R^2 = \lfloor \frac{\sum_{i=1}^{n} \quad (O_i - O_{avg})\,(P_i - P_{avg})}{\sum_{i=1}^{n} \quad (O_i - O_{avg})^2\,(P_i - P_{avg})^2} \rfloor^2$$

$$RMSE = \sqrt{\frac{\sum_{i=1}^{n} \quad (O_i - P_i)^2}{n}}$$

Where:

P_i = the predicted values at the ith point;

P_{avg} = the average predicted values at the ith point;

O_i = the measured values at the ith point;

O_{avg} = the average measured values at the ith point;

n = the total no. of data points

VIII. RESULTS AND DISCUSSIONS

Water quality assessment using individual physico-chemical parameters

Biological Oxygen Demand (BOD)

BOD is a measure of the organic pollution in water. It indicates the amount of oxygen needed by microorganisms to decompose organic matter (Penn et al, 2009). High BOD levels indicate a high degree of pollution, which can deplete oxygen levels in water bodies, harming aquatic life (Ukpaka, 2016).

Results revealed that BOD levels ranged from 4.33 to as high as 155 mg/L (Table 3) and approximately 88% of total BOD observations within the 3-year period failed to meet the DENR WQG for Class C (7 mg/L). Spatial interpolation of BOD in 2020 shows elevated concentrations in the midstream to mid-downstream portions of Pasig River (Figure 3). Both 2021 and 2022 data, on the other hand, show elevated BOD levels in the midstream portions only (Figure 4 and Figure 5). While BOD levels varied significantly among monitoring stations, there was no substantial change in overall BOD concentrations over the three-year period (Table 4).

Table 3

Results of descriptive analysis of physico-chemical parameters

Variables	BOD	DO	FC	Phosphate	Nitrate	Ammonia	Temperature	pH	TSS
N	108	120	120	120	120	120	120	120	120
Mean	36.9	4.16	3.82E+06	0.96	0.398	9	28.8	7.56	77.2
Std. error mean	3.56	0.218	607653	0.0901	0.0527	1.01	0.149	0.0372	4.07
Median	19	4.33	800000	0.5	0.24	4.06	28.9	7.55	66.2
Standard deviation	37	2.39	6.66E+06	0.987	0.577	11.1	1.63	0.408	44.6
Minimum	4.33	0.01	6000	0.124	0.011	0.14	23.1	6.77	21.3
Maximum	155	11.7	3.86E+07	4.27	2.9	71.5	32.4	8.59	253
Shapiro-Wilk p	< .001	0.044	< .001	< .001	< .001	< .001	0.256	< .001	< .001

Figure 3. Spatial distribution map for BOD in 2020. Basemap data from Google, accessed via QGIS.

Figure 4. Spatial distribution map for BOD in 2021. Basemap data from Google, accessed via QGIS.

Figure 5. Spatial distribution map for BOD in 2022. Basemap data from Google, accessed via QGIS.

Table 4

Results of statistical analyses of physico-chemical parameters

Variables	Statistical analysis		df	p
BOD - Stations	Kruskal-Wallis	$\chi^2 = 62.8$	8	<.001***
BOD - Sampling period	Kruskal-Wallis	$\chi^2 = 0.805$	2	0.669
DO - Stations	Kruskal-Wallis	$\chi^2 = 49.5$	9	<.001***
DO - Sampling period	One-Way ANOVA	f = 4.80	2	0.011*
Fecal coliform - Stations	Kruskal-Wallis	$\chi^2 = 80.1$	9	<.001***
Fecal coliform - Sampling period	Kruskal-Wallis	$\chi^2 = 0.914$	2	0.907
Phosphate - Stations	Kruskal-Wallis	$\chi^2 = 65.9$	9	<.001***
Phosphate - Sampling period	Kruskal-Wallis	$\chi^2 = 1.69$	2	0.430
Nitrate - Stations	Kruskal-Wallis	$\chi^2 = 20.4$	9	0.016*
Nitrate - Sampling period	Kruskal-Wallis	$\chi^2 = 2.86$	2	0.239
Ammonia - Stations	Kruskal-Wallis	$\chi^2 = 66.1$	9	<.001***
Ammonia - Sampling period	Kruskal-Wallis	$\chi^2 = 12.4$	2	0.002**
Temperature - Stations	One-Way ANOVA	f = 0.208	9	0.992
Temperature - Sampling period	One-Way ANOVA	f = 0.0923	2	0.912
pH - Stations	Kruskal-Wallis	$\chi^2 = 24.0$	9	0.004**
pH - Sampling period	Kruskal-Wallis	$\chi^2 = 15.4$	2	<.001***
TSS - Stations	Kruskal-Wallis	$\chi^2 = 24.0$	9	0.004**
TSS - Sampling period	Kruskal-Wallis	$\chi^2 = 15.4$	2	<.001***

Note: * p < .05, ** p < .01, *** p < .001
Dissolved Oxygen (DO)

DO is crucial for aquatic life and reflects overall river health (US EPA, 2021). DO concentrations below 5 mg/L can harm aquatic ecosystems (Carter 2005), and levels below 2 mg/L are often lethal for fish (Hobbs & McDonald 2010). Analysis revealed that levels ranged from 0.01 to 11.7 mg/L (Table 3) and approximately sixty-two percent (62%) out of the total DO observations within the 3-year period did not comply with the DENR WQG for Class C (5 mg/L) and Class SB (6 mg/L). Maps show that DO concentrations were consistently lowest in the middle section of the river throughout the study period (Figure 6, Figure 7, and Figure 8). Levels varied significantly among different stations. Results also showed significant difference in DO levels in sampling periods indicating improvement in overall oxygen levels from 2020 to 2022 (Table 4).

Fecal coliform

Fecal coliform bacteria are harmful microorganisms found in the intestines of warm-blooded animals (Seo et al, 2019). Their presence in water indicates contamination from human or animal waste and poses serious health risks (Avigliano and Schenone, 2015). High levels of fecal coliform can cause water pollution, including cloudy water and foul odors, as well as deplete oxygen levels needed for aquatic life. Fecal coliform levels in the Pasig river ranged from 6,000 to as high as 38.6M MPN/100ml. They consistently exceeded way above the standard limits for both Class C (200 MPN/100ml) and Class SB (200 MPN/100ml) water bodies throughout the three-year monitoring period. The three-year distribution maps showed elevated levels of fecal coliform in the midstream to downstream portions of the river. Analysis showed significant difference in fecal coliform concentrations among stations. However, levels did not significantly vary from 2020-2022 (Figure 9, Figure 10, and Figure 11).

Figure 6. Spatial distribution map for DO in 2020. Basemap data from Google, accessed via QGIS.

Figure 7. Spatial distribution map for DO in 2021. Basemap data from Google, accessed via QGIS.

Figure 8. Spatial distribution map for DO in 2022. Basemap data from Google, accessed via QGIS.

Figure 9. Spatial distribution map for fecal coliform in 2020. Basemap data from Google, accessed via QGIS.

Figure 10. Spatial distribution map for fecal coliform in 2021. Basemap data from Google, accessed via QGIS.

Figure 11. Spatial distribution map for fecal coliform in 2022. Basemap data from Google, accessed via QGIS.

Phosphates

Phosphates, while essential nutrients for plant growth, can negatively affect freshwater ecosystems in excessive amounts. Elevated phosphate levels, often stemming from human activities such as agriculture and industrial processes, can trigger harmful algal blooms. These blooms deplete oxygen in the water, jeopardizing fish and other aquatic life (Schaum, 2018).

Phosphate levels in Pasig river ranged from 0.124 to 4.27 mg/L (average: 0.96 mg/L). All monitoring stations failed to meet phosphate standard levels for DENR Class C (0.025 mg/L) and Class SB (0.2 mg/L) throughout the study period. The results revealed significant difference in phosphate levels among stations. Levels were observed to be highest in the midstream to mid-downstream portions of the river (Figure 12, Figure 13, and Figure 14). No significant difference in levels were observed within the study period.

Nitrates

Similar with phosphate, nitrate is an essential nutrient required by plants for growth and development but excessive amounts may cause negative effects to water quality. Nitrates, together with phosphates, in high concentrations are pollutants that can trigger harmful algal blooms in water bodies. These nutrients often originate from agricultural runoff, industrial waste, and sewage (Rao et al, 2017).

Nitrate levels in all monitoring stations of Pasig River range from 0.011 to 2.9 mg/L. These levels passed the DENR standards in Class C (7 mg/L). The upstream portion of the river had the highest nitrate concentrations in 2020 (Figure 1), while the lower sections showed higher levels in 2021 and 2022 (Figure 16 and Figure 17). Nitrate levels varied significantly among the monitoring stations, however, no significant changes were observed over the three-year period.

Figure 12. Spatial distribution map for phosphates in 2020. Basemap data from Google, accessed via QGIS.

Figure 13. Spatial distribution map for phosphates in 2021. Basemap data from Google, accessed via QGIS.

Figure 14. Spatial distribution map for phosphates in 2022. Basemap data from Google, accessed via QGIS.

Figure 15. Spatial distribution map for nitrates in 2020. Basemap data from Google, accessed via QGIS.

Figure 16. Spatial distribution map for nitrates in 2021. Basemap data from Google, accessed via QGIS.

Figure 17. Spatial distribution map for nitrates in 2022. Basemap data from Google, accessed via QGIS.

Ammonia

Ammonia is a byproduct of organic matter decomposition. It contaminates water bodies through similar sources as nitrates and phosphates, including agricultural runoff, industrial waste, and sewage. It is a highly toxic pollutant that can harm aquatic life and influenced by factors like water temperature, pH, and duration of exposure. Warmer, more alkaline conditions increase ammonia's toxicity (Levit, 2010).

Ammonia levels (0.14 to 71.5 mg/L) in all monitoring stations consistently failed to meet the DENR WQG of 0.06 mg/L for both Class C and SB waters. Significant changes were observed across sampling stations with concentrations particularly high in the midstream portion of the river. Ammonia levels fluctuated significantly over the three years, showing a general improvement from 2020 to 2022 (Figure 18, Figure 19, and Figure 20).

Temperature

Temperature significantly influence aquatic ecosystem processes. It modulates rates of chemical and biological processes, impacting overall ecosystem function. Additionally, it directly affects the physiology and behavior of aquatic organisms, influencing growth rates, reproduction, and species distribution. Abrupt temperature fluctuations can induce physiological stress and disrupt ecological interactions within the aquatic environment (Whitehead et al., 2009). All monitoring stations of Pasig River passed the standard levels for Class C (25-31^{o}C) and SB (26-30 ^{o}C) water bodies throughout the 3-year study period. Results also revealed that no significant changes in temperature levels were observed among stations and sampling periods (Figure 21, Figure 22, and Figure 23).

Figure 18. Spatial distribution map for ammonia in 2020. Basemap data from Google, accessed via QGIS.

Figure 19. Spatial distribution map for ammonia in 2021. Basemap data from Google, accessed via QGIS.

Figure 20. Spatial distribution map for ammonia in 2022. Basemap data from Google, accessed via QGIS.

Figure 21. Spatial distribution map for temperature in 2020. Basemap data from Google, accessed via QGIS.

Figure 22. Spatial distribution map for temperature in 2021. Basemap data from Google, accessed via QGIS.

Figure 23. Spatial distribution map for temperature in 2022. Basemap data from Google, accessed via QGIS.


CITY OF NAVOTAS
CALOOCAN CITY
CITY OF MARIKINA
CITY OF ANTIPOLO
QUEZON CITY
Legend
Temperature
Band 1 (Gray)
28.955309
27.829241
2022
BINONDO, CITY OF MANILA
CITY OF SAN JUAN
CITY OF MANDALUYONG
CITY OF PASIG
MANILA BAY
CITY OF MAKATI
PATEROS
TAYTAY
PASAY CITY
TAGUIG CITY
CITY OF PARAÑAQUE
LAGUNA LAKE

pH

pH is a critical factor influencing aquatic ecosystem health. Extreme pH conditions, both acidic and alkaline, pose significant threats to aquatic life (Tolkkinen et al, 2014). Low pH levels, or acidity, can impair fish reproduction, increase the toxicity of heavy metals, and reduce species diversity (Fondriest Environmental, Inc., 2013). Conversely, prolonged exposure to high pH levels, can cause tissue damage to fish and ultimately lead to mortality (US EPA, 2017). Despite fluctuations in pH levels across different monitoring sites over the three-year period (Figure 24, Figure 25, and Figure 26), all stations consistently met the pH standards for Class C (6.5-9.0) and SB (7.0-8.5) waters.

Total suspended solids (TSS)

TSS comprise particulate matter suspended in the water column. These particles can be inorganic, such as clay, silt, or sand, or organic, originating from decaying plants and animals, or living organisms like algae and bacteria. TSS significantly impacts water clarity, as higher concentrations attenuate light penetration, impeding photosynthetic processes essential for aquatic primary production. Moreover, sedimentation associated with high TSS can smother benthic organisms, disrupt spawning grounds, and reduce habitat complexity. The suspended particles can also act as carriers for various pollutants, exacerbating water quality degradation (Fondriest Environmental, Inc., 2014). The assessment revealed that TSS levels ranged from 21.3 to 253 mg/L. Further, approximately 32% of all TSS observations throughout the three-year monitoring period failed to comply with the DENR standard limits for Class C (80mg/L) and SB (50mg/L). TSS levels varied significantly across all monitoring stations throughout the study period (Figure 27, Figure 28, and Figure 29).

Figure 24. Spatial distribution map for pH in 2020. Basemap data from Google, accessed via QGIS.

Figure 25. Spatial distribution map for pH in 2021. Basemap data from Google, accessed via QGIS.

Figure 26. Spatial distribution map for pH in 2022. Basemap data from Google, accessed via QGIS.

Figure 27. Spatial distribution map for total suspended solids in 2020. Basemap data from Google, accessed via QGIS.

Figure 28. Spatial distribution map for total suspended solids in 2021. Basemap data from Google, accessed via QGIS.

Figure 29. Spatial distribution map for total suspended solids in 2022. Basemap data from Google, accessed via QGIS.

Water Quality Index

Computed CCME-WQI values in Pasig River ranged from 30.3 to 38.9 with an average score of 33.9 (Table 5). These values indicate that the water quality in all stations is “poor” or impaired such that the conditions depart from the natural or desirable levels. Findings suggest that the river's physico-chemical characteristics no longer comply with the river system's present waterbody classification, making it unsuitable for its intended purpose for fishery, recreational (Class II), agriculture, irrigation and livestock watering. Spatial distribution map of the WQI scores show lowest values in the midstream to mid-downstream portions of the river (Figure 30, Figure 31, and Figure 32). These results coincide with the results of individual physico-chemical parameters as most of the observations failed in the middle section of the river. While WQI scores varied significantly among monitoring stations, there was no substantial change in WQI over the three-year study period (Table 6).

The Pasig River exhibits a pronounced spatial disparity in water quality, with the midstream and mid-downstream sections demonstrating significantly poorer conditions compared to the upstream reaches. This deterioration is primarily attributed to a confluence of anthropogenic pressures. A high density of residential, commercial, and industrial establishments in these lower river segments results in elevated pollutant loads from domestic sewage, industrial effluents, and agricultural runoff. Moreover, numerous *esteros* or minor tributaries drain in these portions of the river. The influx of fecal coliform-contaminated waters from these *esteros* further exacerbates the situation. The river's reduced capacity to dilute pollutants due to decreased flow rates in the lower reaches compounds these issues. These interrelated factors have led to persistent exceedances of water quality standards, underscoring the critical need for comprehensive pollution control measures.

Table 5

Results of the CCME-WQI calculation in Pasig River

SN	STATION NAME	2020	Rating	2021	Rating	2022	Rating
1	Napindan (C6) Bridge	36.10	Poor	38.90	Poor	37.57	Poor
2	Bambang Bridge	34.83	Poor	34.82	Poor	35.15	Poor
3	Guadalupe Ferry	33.86	Poor	33.10	Poor	34.03	Poor
4	Lambingan Bridge	31.33	Poor	33.07	Poor	33.07	Poor
5	Nagtahan Bridge	31.20	Poor	32.16	Poor	30.33	Poor
6	Jones Bridge	33.86	Poor	33.94	Poor	34.73	Poor
7	Guadalupe Nuevo	32.07	Poor	32.95	Poor	33.81	Poor
8	Guadalupe Viejo	33.82	Poor	32.97	Poor	34.63	Poor
9	Havana Bridge	32.96	Poor	32.96	Poor	33.81	Poor
10	Manila Bay	32.03	Poor	35.72	Poor	36.59	Poor

Table 6

Results of statistical analyses of WQI values

Variables	Statistical analysis		df	p
WQI - Stations	One-Way ANOVA	f = 7.87	9	0.004**
WQI - Sampling period	One-Way ANOVA	f = 1.17	2	0.334

Note: * *p* < .05, ** *p* < .01, *** *p* < .001

Figure 30. Spatial distribution map for WQI for 2020. Basemap data from Google, accessed via QGIS.

Figure 31. Spatial distribution map for WQI for 2021. Basemap data from Google, accessed via QGIS.

Figure 32. Spatial distribution map for WQI for 2022. Basemap data from Google, accessed via QGIS.

IX. CONCLUSIONS AND RECOMMENDATIONS

The study revealed a critical state of water quality in the Pasig River. Parameters indicative of fecal contamination and nutrient pollution consistently exceeded standard levels set by the DENR. While BOD and DO levels also showed significant exceedances, they were less pervasive compared to the former parameters. Conversely, temperature, pH, and nitrate concentrations remained within acceptable limits.

WQI transforming the complex water quality data revealed that all stations of Pasig River to be of poor water quality with lowest scores observed in the middle to mid-down sections of the river. The spatial variation in water quality, with the most critical conditions in the midstream and mid-downstream sections, points to the cumulative impact of pollution sources in these areas. This highlights the need for targeted interventions to address the specific challenges faced by these river segments.

This also impacts water quality of Laguna Lake. Normally, water flows in the Pasig River from Laguna de Bay towards Manila Bay. However, during the late dry season, there is a reverse flow of salty water from Manila Bay into Laguna de Bay via the Pasig River (Paronda et al., 2019). Consequently, the Pasig River carries pollutants to Laguna Lake. Pollutants from Pasig River significantly impact the water quality of Laguna Lake. Excess nutrients from the Pasig River may lead to algal blooms, which can deplete oxygen levels and harm aquatic life. Fecal coliform contamination poses a serious threat to public health, particularly for those who consume untreated water or engage in fishing or recreational activities in Laguna Lake.

The findings emphasize the importance of a comprehensive approach to river management. While individual parameters provide valuable insights, the WQI offers a holistic perspective on water quality. The persistent low WQI values across the river emphasize the urgency for sustained and concerted efforts to restore the river's ecological health.

The persistent failure of the Pasig River to meet the water quality standards highlights the need for a comprehensive and multi-faceted approach that addresses both immediate and long-term challenges. Continuous and regular monitoring under the PRUMS program is essential to track water quality trends, identify emerging issues, and enable timely responses to pollution incidents. Additional sampling stations is imperative to enhance data resolution and precision. This approach allows for identification of more refined localized pollution hotspots and areas requiring immediate attention. Ultimately, this will lead to more targeted and effective management and mitigation strategies.

Concurrently, modern wastewater treatment infrastructures should be developed to intercept and treat domestic and industrial effluents effectively. This may include technologies such as nanobubbles, nanofiltration, use of anaerobic baffled reactors, and constructed wetlands. To address the critical issue of fecal coliform contamination, a comprehensive strategy encompassing the rehabilitation of the *esteros*, the expansion of sewerage networks, and the promotion of proper sanitation practices is essential. Furthermore, riverbank stabilization and restoration may enhance the river's self-purification and can contribute to improved water quality.

Further research and development are essential to refine and standardize the WQI methodology and incorporate with the DENR water quality guidelines. The effectiveness of WQI in assessing the overall health of the Pasig River highlights the need for its wider application in water body management. Its capacity to easily and effectively communicate complex water quality data to diverse stakeholders underscores its value as a public engagement tool. Possible utilization of the WQI as a performance indicator for relevant agencies can enhance accountability and transparency in water resource governance.

X. REFERENCES

Akhtar, N., Ishak, M. I. S., Ahmad, M. I., Umar, K., Md Yusuff, M. S., Anees, M. T., ... & Ali Almanasir, Y. K. (2021). Modification of the water quality index (WQI) process for simple calculation using the multi-criteria decision-making (MCDM) method: a review. Water, 13(7), 905.

Avigliano, E., & Schenone, N. F. (2015). Human health risk assessment and environmental distribution of trace elements, glyphosate, fecal coliform and total coliform in Atlantic Rainforest mountain rivers (South America). Microchemical Journal, 122, 149-158.

Boyacioglu, H. (2007). Development of a water quality index based on a European Classification Scheme. *Water S.A.*, 33: 101-106.

Brown, R. M., McClelland, N. I., Deininger, R. A., O'Connor, M. (1971). A water quality index—crashing the psychological barrier. Presented at 138th meeting of the American association for the advancement of science, Philadelphia, Pennsylvania

Canadian Council of Ministers of the Environment (CCME). 2017. Canadian Water Quality Guidelines for the Protection of Aquatic Life: CCME Water Quality Index User's Manual 2017 Update. Retrieved March 17, 2022, from https://ccme.ca/en/res/wqimanualen.pdf

Capili, N. I. F., Marilla, J. F., Montes, K. M. S., & Villasenor, F. C. (2021, February). Spatial variability model for water quality assessment of the physicochemical parameters and the water quality index of Laguna Lake and its tributaries. In Journal of Physics: Conference Series (Vol. 1803, No. 1, p. 012006). IOP Publishing.

Carter, K. (2005). The effects of dissolved oxygen on steelhead trout, coho salmon, and chinook salmon biology and function by life stage. California Regional Water Quality Control Board, North Coast Region, 10.

Chabuk, A., Al-Madhlom, Q., Al-Maliki, A., Al-Ansari, N., Hussain, H. M., & Laue, J. (2020). Water quality assessment along Tigris River (Iraq) using water quality index (WQI) and GIS software. Arabian Journal of Geosciences, 13, 1-23.

Chen, Y. C., Yeh, H. C., & Wei, C. (2012). Estimation of river pollution index in a tidal stream using kriging analysis. International journal of environmental research and public health, 9(9), 3085-3100.

Department of Environment and Natural Resources (DENR). (2016). DENR Administrative Order 2016-08: Water Quality Guidelines and General Effluent Standards of 2016. Retrieved February 20, 2024 from https://pab.emb.gov.ph/wp-content/uploads/2017/07/DAO-2016-08-WQG-and-GES.pdf

Department of Environment and Natural Resources (DENR). (2020). DENR 2020 Annual Report. Retrieved February 20, 2024 from https://www.denr.gov.ph/images/DENR_Accomplishment_Report/Pasig_River_Rehabilitation_Program_opt.pdf

Department of Environment and Natural Resources (DENR). (2021). DENR Administrative Order 2021-19: Updated Water Quality Guidelines and General Effluent Standards for Selected Paramters. Retrieved February 20, 2023 from https://emb.gov.ph/wp-content/uploads/2021/07/DAO-2021-19-UPDATED-WQG-AND-GES-FOR-SELECTED-PARAM.pdf

Department of Environment and Natural Resources – Environmental Management Bureau (DENR-EMB). (2014). National Water Quality Status Report 2006-2013.

Department of Environment and Natural Resources – Environmental Management Bureau (DENR-EMB). (n.d.) NCR, List of Waterbodies. Retrieved February 20, 2024 from https://water.emb.gov.ph/?page_id=809

Department of Environment Ministry of Natural Resources and Environmental Sustainability (DOE). (n.d.). National Water Quality Standards and Water Quality Index. Retrieved February 28, 2024 from https://www.doe.gov.my/en/national-river-water-quality-standards-and-river-water-quality-index/

Escoto, J. E., Blanco, A. C., Argamosa, R. J., & Medina, J. M. (2021). Pasig River Water Quality Estimation Using an Empirical Ordinary Least Squares Regression Model of Sentinel-2 Satellite Images. The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences, 46, 161-168.

Farooq, I., Bangroo, S. A., Bashir, O., Shah, T. I., Malik, A. A., Iqbal, A. M., ... & Biswas, A. (2022). Comparison of Random Forest and Kriging Models for Soil Organic Carbon Mapping in the Himalayan Region of Kashmir. Land, 11(12), 2180.

Fondriest Environmental, Inc. (2013). “pH of Water.” Fundamentals of Environmental Measurements. Accessed from: https://www.fondriest.com/environmental-measurements/parameters/water-quality/ph/

Fondriest Environmental, Inc. (2014). “Turbidity, Total Suspended Solids and Water Clarity.” Fundamentals of Environmental Measurements. Accessed from: https://www.fondriest.com/environmental-measurements/parameters/water-quality/turbidity-total-suspended-solids-water-clarity

Gilles, M.S.N. and Santos, R. B. (n.d.). Revitalization of Pasig River Through the Years: Bringing a Dying Ecosystem Back To Life. Retrieved February 28, 2024 from https://www.academia.edu/5765195/Revitalization_of_the_Pasig_River_Through_the_Years_Bringing_a_Dying_Ecosystem_Back_to_Life

Gorme, J. B., Maniquiz, M. C., Song, P., & Kim, L. H. (2010). The water quality of the Pasig River in the City of Manila, Philippines: Current status, management and future recovery. Environmental Engineering Research, 15(3), 173-179.

Hobbs, J. P., & McDonald, C. A. (2010). Increased seawater temperature and decreased dissolved oxygen triggers fish kill at the Cocos (Keeling) Islands, Indian Ocean. Journal of Fish Biology, 77(6), 1219-1229.

Kachroud, M.; Trolard, F.; Kefi, M.; Jebari, S.; Bourrié, G. (2019). Water Quality Indices: Challenges and Application Limits in the Literature. *Water*, *11*, 361.

Katipoğlu, O. M. (2022). Spatial analysis of seasonal precipitation using various interpolation methods in the Euphrates basin, Turkey. Acta Geophysica, 70(2), 859-878.

Kaurish, F.W. and Younos, T. (2007). Developing a standardized water quality index for evaluating surface water quality. Journal of the American Water Resources Association 43 (2), 533–545.

Levit, S. M. (2010). A literature review of effects of ammonia on fish. Montana.

Lumb, A., Halliwell, D., & Sharma, T. (2006). Application of the CCME water quality index to monitor water quality: A case study of the Mackenzie River Basin, Canada. *Environmental Monitoring and Assessment, 113*, 411–429.

Nasirian. M. (2007). A new water quality index for environmental contamination contributed by mineral processing: A case study of Amang (tin tailing) processing activity, *J. Appli. Sci.,* 7(20). 2977-2987.

Paronda, G. R. A., David, C. P. C., & Apodaca, D. C. (2019). River flow pattern and heavy metals concentrations in Pasig River, Philippines as affected by varying seasons and astronomical tides. In IOP conference series: Earth and environmental science (Vol. 344, No. 1, p. 012049). IOP Publishing.

Penn, M. R., Pauer, J. J., & Mihelcic, J. R. 2009. Biochemical oxygen demand. Environmental and ecological chemistry, 2, 278-297.

Pham, H., Rahman, M. M., Nguyen, N. C., Le Vo, P., Le Van, T., & Ngo, H. (2017). Assessment of surface water quality using the water quality index and multivariate statistical techniques–A case study: the upper part of Dong Nai river basin, Vietnam. Journal of water sustainability, 7(4), 225-245.

Philippine Daily Inquirer. (2023). Reviving the Pasig River, again. Retrieved February 20, 2023 from https://opinion.inquirer.net/165277/reviving-the-pasig-river-again

Rao, E. P., Puttanna, K., Sooryanarayana, K. R., Biswas, A. K., & Arunkumar, J. S. 2017. Assessment of nitrate threat to water quality in India. In The Indian nitrogen assessment (pp. 323-333). Elsevier.

Reza, R & Singh, G. (2010). Heavy metal contamination and its indexing approach for river water. International Journal of Environmental Science and Technology. 7. 10.1007/BF03326187.

Said, A. & Stevens, D. & Sehlke, G. (2004). An Innovative Index for Evaluating Water Quality in Streams. *Environmental management. 34.* 406-14. 10.1007/s00267-004-0210-y.

Sanchez, E., Colmenarejo, M. F., Vicente, J., Rubio, A., Garcia, M. G., Travieso, L. and Borja R.. 2007. Use of the water quality index and dissolved oxygen deficit as simple indicators of watersheds pollution. Ecological Indicators. 7(2): 315-328, April.

Sargaonkar, A., and Deshpande, V. (2003). Development of an overall index of pollution for surface water based on a general classification scheme in Indian context. *Environ. Monit. Assess.*, 89: 43-67.

Schaum, C. (Ed.). (2018). Phosphorus: Polluter and Resource of the Future: Motivations, Technologies and Assessment of the Elimination and Recovery of Phosphorus from Wastewater. IWA Publishing.

Seo, M., Lee, H., & Kim, Y. 2019. Relationship between coliform bacteria and water quality factors at weir stations in the Nakdong River, South Korea. Water, 11(6), 1171.

Tolkkinen, M., Marttila, H., Saukkoriipi, J., Martinmäki, K., Tammela, S., Tertsunen, J., ... & Klöve, B. (2014). pH-levels in intensively drained and peatland-dominated river basin: Paleolimnological approach to detect impacts of past land use. Ecological engineering, 64, 367-376.

Ukpaka, C. P. (2016). The Concept of Examination of Biochemical and Chemical Oxygen Demand in Stagnant Water System. Chemistry Research Journal, 1(1), 35-43.

U.S. Environmental Protection Agency (US EPA). (2017). Causal Analysis/Diagnosis Decision Information System (CADDIS): About Stressors: pH. Retrieved February 28, 2022, from: https://www.epa.gov/caddis-vol2/caddis-volume-2-sources-stressors-responses-ph

U.S. Environmental Protection Agency (US EPA). (2021). Dissolved Oxygen Parameter Factsheet. Accessed from: https://www.epa.gov/system/files/documents/2021-07/parameter-factsheet_do.pdf

Whitehead, P. G., Wilby, R. L., Battarbee, R. W., Kernan, M., & Wade, A. J. (2009). A review of the potential impacts of climate change on surface water quality. Hydrological sciences journal, 54(1), 101-123.

Zotou, I., Tsihrintzis, V. A., & Gikas, G. D. (2018, August). Comparative assessment of various water quality indices (WQIs) in Polyphytos Reservoir-Aliakmon River, Greece. In Proceedings (Vol. 2, No. 11, p. 611). MDPI.