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Water quality assessment of the Guimaras Strait using comprehensive pollution index and geographic information system

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ABSTRACT

Assessing marine water quality involves evaluating water conditions and identifying areas that may require further attention. It is crucial to characterize water quality parameters and identify potential pollutants. A plethora of data sets resulting from multiple water quality parameters would be too complex to process individually. In this study, the water quality of the Guimaras Strait was assessed using the comprehensive pollution index and geographic information system. To realize this objective, water samples were collected from 11 sampling sites for 1 year in the coastal waters of Bago City and Pulupandan and were analyzed in terms of nine parameters, such as pH, dissolved oxygen (DO), temperature, color, chemical oxygen demand (COD), nitrates (NO_3 – N), phosphates (PO_4 – P), total suspended solids (TSS), and fecal coliform (FC). The comprehensive pollution index was adopted to discover the main water pollutants and to evaluate the water quality pollution levels. Geographic Information System (GIS) was used to visualize the spatial variation of the pollution characteristics and to identify the sources of spatial variation. The results showed that the general water quality in the Guimaras Strait was exposed to different pollutants but may be attributed to the presence of industrial wastewater in the area. The sources of the spatial variation are the industrial wastewater and domestic sewage. The average comprehensive pollution index value from April 2018 to March 2019 was 0.1653, indicating a sub-cleanliness pollution level. It is recommended to conduct regular coastal water monitoring and share data via GIS, in maintaining a healthy coastal environment.

KEYWORDS

coastal water, feature scaling, normalization, spatial variation, water pollution

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INTRODUCTION

The productivity and sustainability of marine, coastal, and estuarine ecosystems depend largely on the quality of coastal water (Jha et al., 2015). Continuous industrialization has contributed to the generation of increasing pollution that has resulted in numerous environmental problems and human health challenges (Liu et al., 2011). Impairment of water quality results from both anthropogenic inputs (e.g.,

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discharges of municipal and industrial wastewater, agricultural runoff) and natural processes (e.g., chemical weathering and soil erosion) (Holloway et al., 1998; Shin et al., 2013; Zia et al., 2013; Ji et al., 2015; Liu et al., 2018). The increase in pollution would degrade the quality of the water and would be lethal to the marine ecosystem.

Water pollution monitoring and assessment has become a very critical area of study due to the direct impact of water pollution on aquatic life and people (Manoj et al., 2012). Knowing the quality of coastal water is vital from the perspective of the use and management of coastal resources (Mishra et al., 2015). Measuring causes (pollutants) and effects (ecosystem impact) on the sea routinely evaluate the condition of the marine environment (Karydis & Kitsiou 2013). Various water quality indices and environmental indicators have been created over time, relying on physical, chemical, and microbiological properties (Medeiros et al., 2017). To simplify complex water quality assessments, researchers often use indices to combine multiple parameters into a single value. This approach facilitates interpretation and environmental management (Liu et al., 2010; Jha et al., 2015; Popovic et al., 2016). There is a lack of the use of a water quality index by regulatory agencies to qualify the water bodies in the Philippines; assessment and monitoring of water quality is still based on individual water quality parameters (Department of Environment and Natural Resources, 2016).

Guimaras Strait is located between the Panay and Negros islands and is considered to be one of the country's most productive fishing grounds. The area has been identified as having an average annual fish production of 50,000 tons and providing a significant percentage of the country's fishing demand. Combined with rapid economic development, the high concentration of people in the region's coastal areas has produced many economic benefits, including improved transport links, urban development, and revenue from tourism and food production. The same factors, however, threaten the ecosystems that are critical to these benefits. As a result, the region's coastal environments are under increasing anthropogenic pressure (Coastal Ecosystem Conservation and Adaptive Management under Local and Global Environmental Impacts in the Philippines, 2011).

The health indicators of the coastal environment are water quality variables such as pH, dissolved oxygen, biochemical oxygen demand, total suspended solids, ammonia, nitrate, total phosphorus, chlorophyll-a, and fecal coliform (Jha et al., 2015). In order to analyze the water quality parameters, it would be advantageous to have an accurate visual representation of the quality of coastal water. Visual maps are great tools in assessing possible causes and drivers of pollution in the area. This study aimed to assess the water quality of the Guimaras Strait using the Comprehensive Pollution Index and Geographic Information System. Also, the study determined the water quality in terms of pH, dissolved oxygen, temperature, color, chemical oxygen demand, nitrates, phosphates, total suspended solids, and fecal coliform, the pollution index for each of the water quality parameters, the comprehensive pollution index, the spatial variation of the comprehensive pollution index of the Guimaras Strait, and the possible causes of spatial variation of water quality in the Guimaras Strait.

MATERIALS AND METHODS

2.1 Water Quality Assessment

The Guimaras Strait is a body of water in the Western Visayas region of the Philippines, connecting the Visayan Sea with the Panay Gulf and Sulu Sea beyond. To the north and west are Panay and Guimaras Islands, while Negros Island is to the south and east. It serves as the traditional route for navigational shipping companies that ferry cargo and passengers from Iloilo to Negros Island (Environmental Management Bureau–Region 6, 2015). The sampling points for the coastal waters of Bago and Pulupandan were located on the western side of the province of Negros Occidental in Western Visayas. Bago City is located 21.5 km south of Bacolod City the capital of Negros Occidental. Bago City has moderately sloping rolling lands with slopes ranging from 0 to 3% covering 22,911.42 hectares, 3.1 to 8% covering 5,783.92 hectares, 8.1 to 18% covering 4,682.22 hectares, 18.1 to 30% covering 1,514.84 hectares, 30.1 to 50% steep hills and rolling lands covering 1,735.18 hectares and a very steep and mountainous 50% covering 3,528.28 hectares (Bago City Government, n.d.). Climate is wet from May to December and dry from

January to April with an average temperature level of 25.01°C. Average rainfall recorded is 6.04 mm for 70 rainy days within a year, and the average humidity level is 80.76%. Pulupandan is located 31 km south of Bacolod City and experiences a tropical climate, having an annual temperature of 27°C and an annual precipitation of 2759 mm.

Sampling was done in 11 sites in the coastal waters of Bago and Pulupandan. The sampling sites included sites 5, 11, 12, and 13 from coastal waters of Bago City, and sites 6, 7, 8, 10, 14, 15, and 16 in the coastal waters of the Municipality of Pulupandan as shown in Figure 1. The sites were chosen to have an adequate representation of the coastal waters of Bago City and the Municipality of Pulupandan. The sampling sites were chosen based on the sector where the Irrawaddy dolphins were frequently seen, proximity to industrial, residential, and recreational areas.

The sampling sites were chosen as a representation of the coastal waters of Bago City and Pulupandan that have multiple sightings of Irrawaddy dolphins. Sampling sites 13, 14, and 15 were the Marine Protected Areas of Bago City and Pulupandan. Sites 5 and 16 have close proximity to the distilleries in the study area. Sites 5, 11, 12, and 10 were near the Calumangan River, Sibud River, Bago River, and Canjusa Creek outlets, respectively. Site 10 was near the Pulupandan municipal sewage outlet.

Figure 1. The sampling sites for the Guimaras Strait

2.2 Water Quality Sampling

Water quality assessment was done monthly for a period of one year covering April 2018 to March 2019 for seasonal trends to be fully represented. Based on the accounts of the fishers, the months of April to October 2018 were identified as the wet season (Southwest monsoon or Habagat), while the remaining months were associated with the dry season (Northeast monsoon or Amihan). Water samples were collected in the morning and during the neap tide of each month. Collection of water for sampling was done according to the Water Quality Monitoring Manual of the Department of Environment and Natural Resources–Environmental Management Bureau. Containers were rinsed with water being sampled prior to collecting each sample.

All samples were placed in an ice chest or cooler that was maintained at 4°C until it reached the laboratory for analysis (DENR EMB, 2008). For each sampling site, there were two sampling bottles used; a one-liter polyethylene bottle for the following parameters–pH, DO, temperature, color, COD, nitrates, phosphates, and TSS; and a 500 mL sterile glass bottle was used for testing fecal coliform. Dissolved oxygen and temperature were taken in situ prior to storage and transport using a MyronL® PT5 Ultrapen™. To test for fecal coliform bacteria in water, a specific volume of the water sample was filtered through a sterile membrane filter. This filter was then placed on a specialized culture medium that encourages the growth of fecal coliform bacteria. The filter was incubated at a specific temperature for a set period, allowing the bacteria to grow and form colonies. After incubation, the number of blue colonies on the filter was counted, representing the number of fecal coliform bacteria present in the sample. By calculating the number of colonies per 100 mL of water, the level of fecal contamination can be determined. This method provides a rapid and accurate assessment of water quality (Standard Methods Committee, 1992).

The parameters and the corresponding methods of analysis were based on the Department of Environment and Natural Resources (DENR) Administrative Order: Water Quality Guidelines and General Effluent Standards of 2016 (Department of Environment and Natural Resources, 2016), with the EMB Approved Methods of Analysis for Water and Wastewater (*DENR EMB*, 2016), based mostly on standard methods for examination of water and wastewater (Standard Methods Committee, 1992) and was done by Negros Prawn Producers Cooperative, Inc. (NPPCI), the only accredited laboratory by DENR as specified in Table 1.

Table 1. *Water Quality Parameters and their Methods of Analysis (DENR EMB, 2016)*

Parameter	Method of Analysis	Reference Standard
Temperature	Thermometer (on-site)	SMEWW 2550 B
pH	Glass Electrode Method	SMEWW 4500 – H^+ B
Dissolved Oxygen	Azide Modification (Winkler Method) or DO Meter	SMEWW 4500 – O G
Chemical Oxygen Demand	Closed Reflux Colorimetric or Open Reflux Method	SMEWW 5220
Color	Visual Comparison (Platinum Cobalt Scale)	SMEWW 2120 B
Fecal Coliform	Multiple Tube Fermentation or Membrane Filter	SMEWW 9221 B
Total Suspended Solids	Gravimetric Method	SMEWW 2540 D
Nitrates as Nitrogen	Specific Ion Electrode Method or Brucine Method	US EPA 352.1
Phosphate as Phosphorus	Stannous Chloride Method	SMEWW 4500-P D

2.3 Calculation of Pollution Index

The Pollution Index or Single Factor Pollution Index was calculated using the equation proposed by Liu et al. (2011):

For a reverse index, where the higher the value of the measured parameter, it would indicate poorer quality.

$$PI = \frac{M_i}{S_i} \tag{1}$$

For a positive index, such as DO, where the higher the value of the parameter, it would indicate better quality.

$$P_{DO} = \begin{cases} \dfrac{\left|C_{DOf} - M_i\right|}{C_{DOf} - S_i} & M_i \geq S_i \\ 10 - \dfrac{9M_i}{S_i} & M_i < S_i \end{cases} \quad (2)$$

$$C_{DOf} = \frac{468}{31.68 + T} \quad (3)$$

For the calculation of the pollution index, the average values of each parameter were divided by the corresponding standards of DAO 2016–08 for both Class SA and Class SB marine waters. For standards having a range of values (e.g., temperature and pH), the average of the minimum and the maximum values was used as the corresponding standard for the calculation of the pollution index (Yang et al., 2012, Ji et al., 2015).

A single factor pollution index, with its five levels outlined by Yan et al. (2015), can be used to assess pollution conditions. The calculated single factor pollution index was normalized using the Min-Max Scaling Eq. (4) to give the single factor pollution index values a range of 0 to 1 (Aksoy & Haralick, 2001). The min-max normalization transformed the minimum value to 0, the maximum value to 1, and all the other values were transformed into a decimal between 0 and 1. The data were scaled to a fixed range of 0 to 1; the resulting data ended up with smaller standard deviations, which suppressed the effect of outliers (Aksoy & Haralick, 2001).

$$x' = \frac{x - \min(x)}{\max(x) - \min(x)} \quad (4)$$

where *x'* is the transformed value, *x* is the single factor pollution index, *min(x)* is the minimum single factor pollution index in the data set, and *max(x)* is the maximum single factor pollution index in the data set.

The standard of the single factor pollution index also needed to be standardized to have the single factor pollution index fit the scale of the normalized data from 0 to 1. Standard values had been adjusted to indicate values from 0 to 1 instead of 0 to 5. This was done by dividing all the values by 5 to give the maximum single factor pollution index a value of 1.

2.4 Calculation of Comprehensive Pollution Index

The comprehensive pollution index (CPI) by Liu et al. (2010) was calculated using the PI according to the following formula.

$$CPI = \frac{1}{n}\sum_{i=1}^{n} PI \quad (5)$$

Ji et al. (2015) and Yan et al. (2015) presented similar classification standards for the comprehensive pollution index including water quality classification levels from I to Poor V as well as pollution levels from “cleanness” to “seriously polluted.”

Similar to the single factor pollution index, the comprehensive pollution index standard also needed to be normalized to have a scale from 0 to 1. This was done by dividing the maximum value of 2.0 by 2 to obtain a value of 1.0.

2.5 Spatial Analysis

The calculated comprehensive pollution indices were imported to QGIS 3.4.1, a free and open-source software for geographic information systems. The comprehensive pollution index data was added to the specific sampling point location identification to match the data with its specific identifier. The selected comprehensive pollution index was interpolated through the Inverse Distance Weighted (IDW) method using QGIS 3.4.1 to generate spatial distribution maps of the comprehensive pollution index in the Guimaras Strait. For inverse distance weighted interpolation, it is assumed that things that are close to one another are more alike than those farther apart. In order to predict a value for any unmeasured location, IDW used the measured values nearest to the predicted location. The minimum and maximum values used in the IDW interpolation methods were the lowest and highest comprehensive pollution indices. The search radius for the IDW interpolation method was within 7,920 meters of the study area. The generated spatial distribution map was adjusted to show the gradient transition of the color from blue indicating a low value, to red indicating a high value with a range of values from low to high.

The generated map with the spatial distribution of the comprehensive pollution index was assessed by comparing the differences in colors of the generated maps and checking which areas would show the polluted or seriously polluted parts of the Guimaras Strait. The map shows where the pollution is coming from and how the comprehensive pollution index varies spatially in the Guimaras Strait. The generated map was also used to find out possible point sources or non-point sources of variations in the comprehensive pollution index.

RESULTS AND DISCUSSION

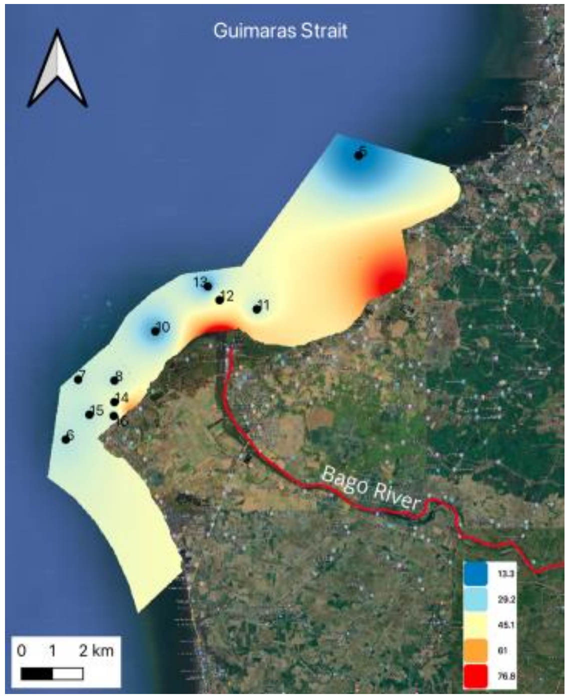
3.1 Water Quality Assessment

The samples for all sites were taken from April 2018 to March 2019. The parameters were determined and compared to the standards set by DENR. The result of the water quality parameters (dissolved oxygen, temperature, total suspended solids, pH, color, chemical oxygen demand, nitrates as nitrogen, phosphates as phosphorus, and fecal coliform) in terms of the two seasons are as follows:

3.1.1 Dissolved Oxygen (DO). The values of DO ranged from 6.57 ppm to 11.7 ppm (SD = 1.49) and 7.301 ppm to 9.737 ppm (SD = 0.69) during the northeast and southwest monsoon seasons, respectively. Higher levels were observed during the northeast monsoon season, and this is due to the mixing of the water by the strong waves during this time.

3.1.2 Temperature. The temperature was not significantly affected by seasonal changes and location. No trend was seen with respect to the type of water since coastal waters and river waters exhibited almost similar values. Temperature values in the study area are within the standards set by DENR, ranging from 27.13°C to 29.2°C (SD = 0.54) and 27.31°C to 28.97°C (SD = 0.57) for the northeast and southwest monsoon seasons, respectively. It was also observed that we have cooler seas during the northeast monsoon season and cooler rivers during the southwest monsoon.

3.1.3. Total Suspended Solids (TSS). Total suspended solids ranged from 5.9 ppm to 85.2 ppm (SD = 23.95) during the northeast monsoon season and 13.3 to 76.8 ppm (SD = 25.80) during the southwest monsoon season. Higher TSS values were seen in the rivers, which indicates that sediments are being transported to the sea from upland activities. This is further verified by a higher TSS average value (44.44 ppm) and a shorter range of values during the southwest monsoon season, which is the rainy season. Rains bring about run-off, which can transport soil and waste through the river into the coastal waters. It was observed that dredging activities were present in the area, and this can highly contribute to the increase of sediments in the sampling sites.



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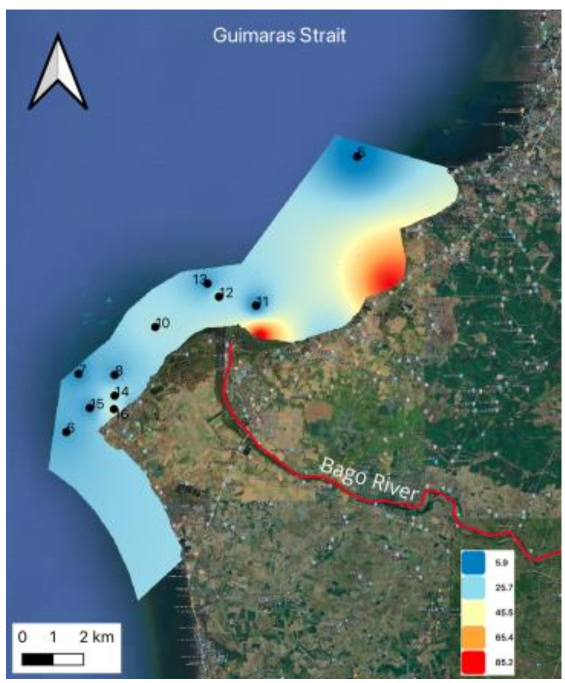
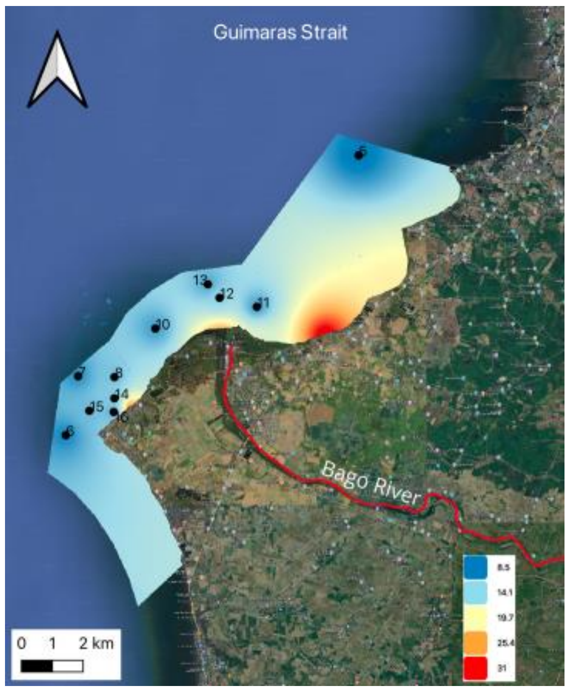


(b)

Figure 2. Average Total Suspended Solids concentration (ppm) of Sampling Points during (a) Southwest monsoon and (b) Northeast monsoon Season

3.1.4 pH. As expected, coastal waters were more alkaline than rivers since salinity brings about ions that could interact with ions in the soil or water to produce basic substances. River water showed values approaching 7, which is the pH for freshwater. pH was also higher during the dry season (northeast monsoon). pH ranged from 7.458 to 8.636 (SD = 0.451) and 7.364 to 7.856 (SD = 0.178) during the northeast monsoon and southwest monsoon seasons, respectively.

3.1.5 Color. The highest values for color were seen in rivers, while the lowest values were seen in the sites that were farthest from the shore. Color values ranged from 9.19 TCU to 26.4 TCU (SD =5.48) and 8.5 TCU to 31 TCU (SD = 7.58) during the northeast and southwest monsoon seasons, respectively. This indicates that color in the coastal waters was coming from the river and may be due to domestic discharges or sediment transport in the water.



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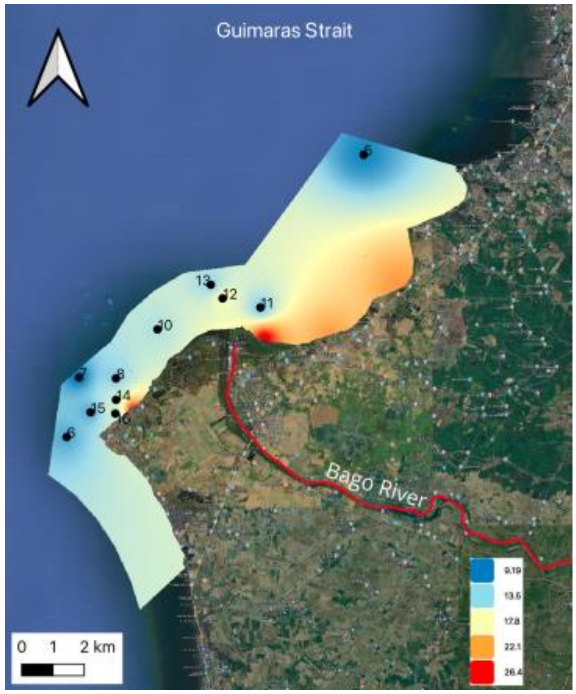
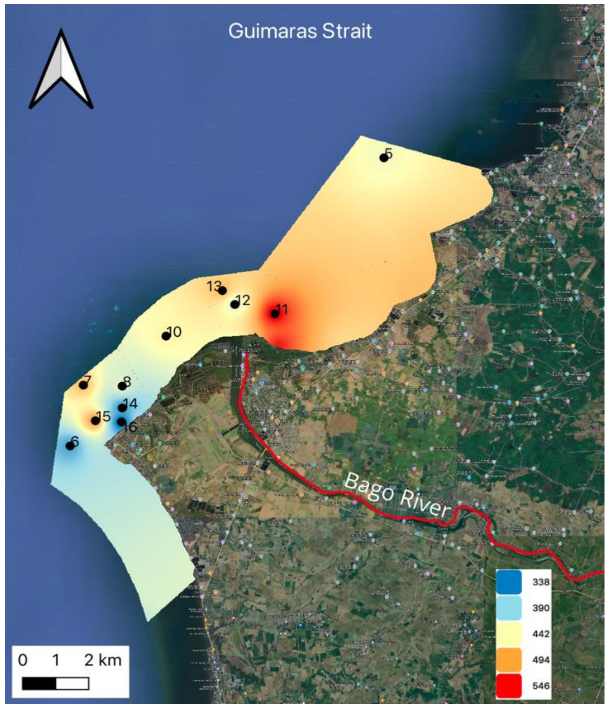


(b)

Figure 3. Average Color (TCU) of Sampling Points during (a) Southwest Monsoon and (b) Northeast Monsoon Season

3.1.6 Chemical Oxygen Demand (COD). COD values ranged from 338 ppm to 546 ppm (SD = 62.63) and 314 ppm to 814 ppm (SD = 157.63) during the northeast and southwest monsoon seasons, respectively (Figure 4). The COD value of the water is an indication of organic pollution in the water, and results show that the lowest value was that of the sewer line in Pulupandan (sampling point 16). This stipulates that domestic wastewater was not contributing to the COD of the coastal waters. However, post hoc tests in COD values show that sampling points of the MPA, its vicinity, and the industrial sources are clustered together. This specifies that industrial plants were possible sources of contamination in the area. From the ocular survey, there were two (2) distilleries in the area, and distillery waste is known to have a very high organic content. It should be noted that DENR did not set any standard for COD for coastal waters, but DAO 2016-08 set effluent standards for Class SA (protected waters and fishery water class 1) as zones of no discharge allowed.



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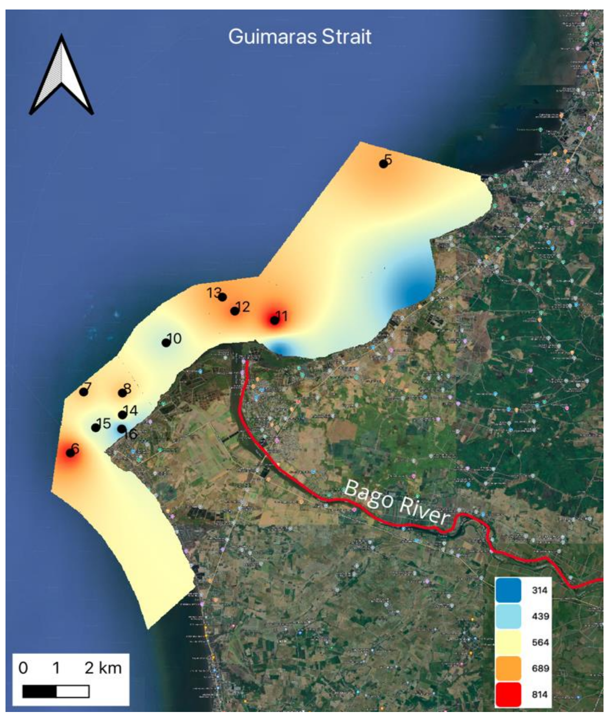


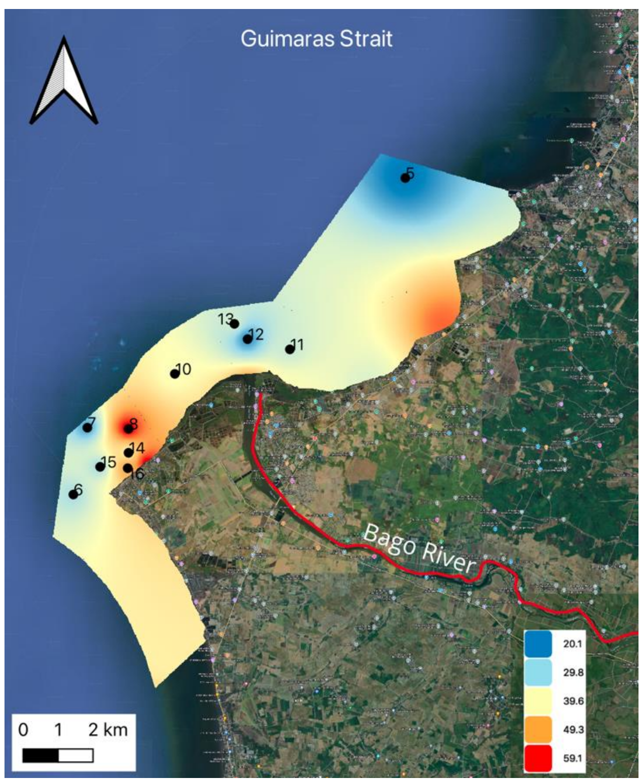
(b)

Figure 4. Average Chemical Oxygen Concentration (ppm) of Sampling Points during (a) Southwest Monsoon and (b) Northeast Monsoon Season

3.1.7 Nitrates. Just like color, nitrate content was highest in the rivers and lowest in the farthest sampling site, which could show that agricultural runoff was affecting the coastal waters. Nitrate content ranged from 0.0146 ppm to 0.494 ppm (SD = 0.117) and 0.0264 ppm to 0.402 ppm (SD = 0.126) during the northeast and southwest monsoon seasons, respectively. Since the values are far below the standard set by DENR, this effect is very minimal. Bago City sites showed higher values than Pulupandan, which is understandabl e since the former have agricultural lands unlike the latter.

3.1.8 Phosphates. The range of phosphate concentrations were 0.0182 ppm to 0.734 ppm (SD = 0.180) and 0.00755 ppm to 0.23 ppm (SD = 0.064) during the northeast and southwest monsoon seasons, respectively. Elevated values were seen in the river sites, with Sampinit River exhibiting elevated values (Figure 11). Since the nitrate values were very small, these may not be attributed to agricultural runoff. These show that the phosphates were probably coming from domestic wastewater, specifically detergents and cleaning agents. It was observed that there were a lot of human settlements in Sampinit River and most of them directly threw their wastes into the river.

3.1.9 Fecal Coliform. Similar spatial trends were observed in fecal coliform counts. Fecal coliform values ranged from 48.9 MPN/100 mL to 204 MPN/100 mL (SD = 42.59) and 20.1 MPN/100 mL to 59.1 MPN/100 mL (SD = 12.84) during northeast and southwest monsoon seasons, respectively. Coliform content was highest in the sites with river discharge (Sampinit, Canjusa, and Calumangan Rivers) and sewer line in Pulupandan and lowest in the farthest sites from the shore. It can be deduced from this pattern that the source of the coliform was domestic wastewater. For seasonal changes, coliform counts were higher during the northeast monsoon season, and this may be due to the release of coliform in the sediments due to the strong waves during that time.



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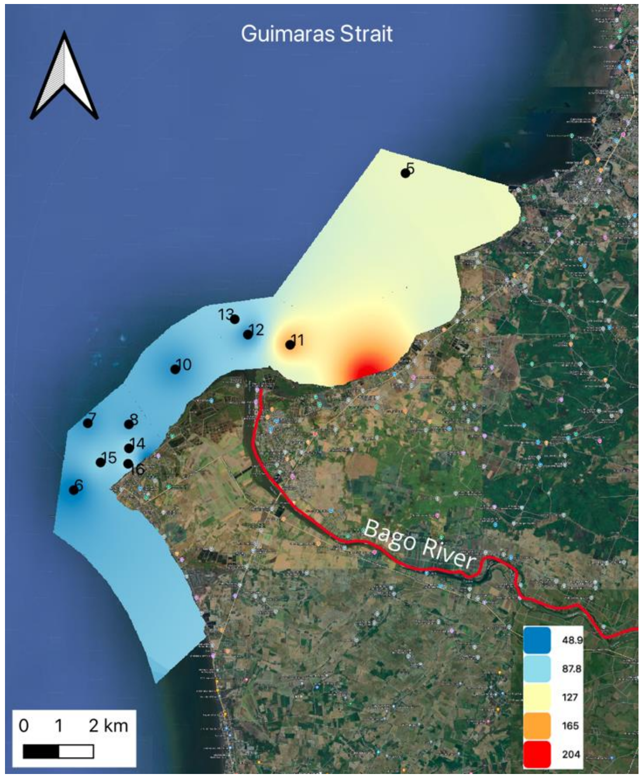


(b)

Figure 5. Average Fecal Coliform Concentration (MPN/100mL) of Sampling Points during (a) Southwest Monsoon and (b) Northeast Monsoon Season

3.2 Calculation of Pollution Index

The calculation of the pollution index of each parameter except for dissolved oxygen per sampling site was done by using Eq. (1). For positive indices like dissolved oxygen, Eq. (3) was used to calculate the saturated dissolved oxygen concentration for the given temperature value, while Eq. (2) was used to calculate the single factor pollution index of dissolved oxygen.

The pollution index of each parameter per sampling site had a range of extreme values. The evaluation factor, or the single factor pollution index, in practice does not have an equal contribution to the overall water quality. The comprehensive score would be increased in situations where the index value for one parameter is much higher than the rest of the pollution index. The higher index value would tend to offset the comprehensive score due to being an outlier in the set of data (Ji et al., 2015).

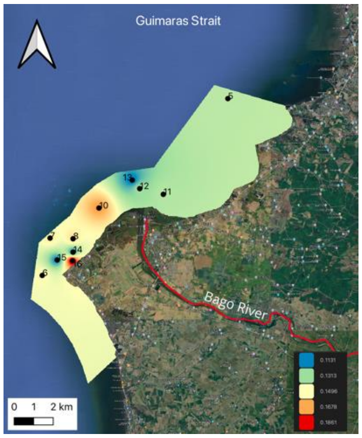
3.3 Calculation of Comprehensive Pollution Index

The calculation of the comprehensive pollution was done by using Eq. (5) taking the average of the entire pollution index per sampling site. The comprehensive pollution indices from April 2018 to March 2019 are shown in Figure 6.

For the normalized CPI values, the study area was generally classified as level II in terms of sub-cleanness. The results showed that different parameters had different single-factor index values, while the CPI was grade II at seven stations and grade III for all stations. The study area may not be completely clean, but it was certainly not polluted according to the CPI values.

3.4. Spatial Variation of the Comprehensive Pollution Index

Comprehensive pollution indices of the normalized CPI were spatially interpolated with the Inverse Distance Weighted (IDW) method in QGIS 3.4.1.


Guimaras Strait
Bago River
0 1 2 km

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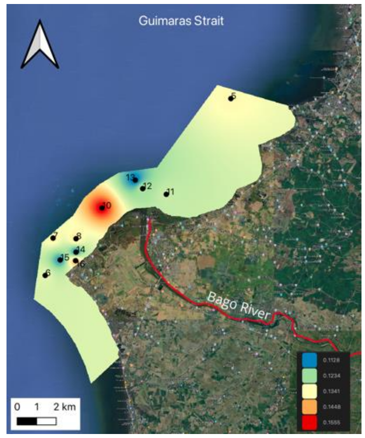
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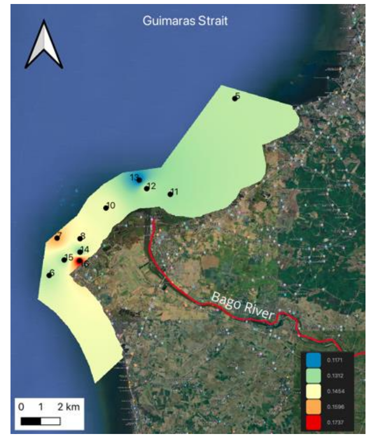
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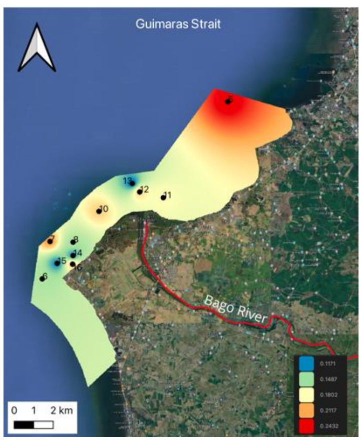
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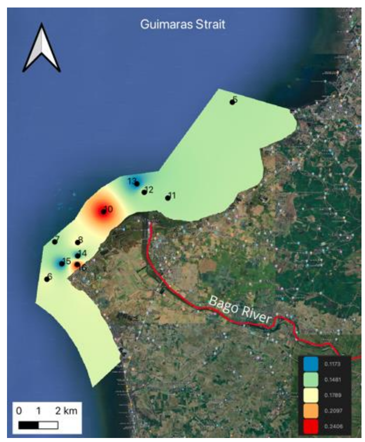
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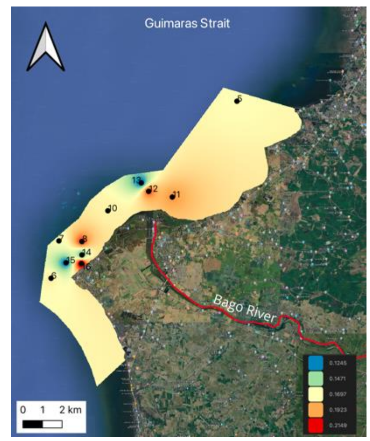
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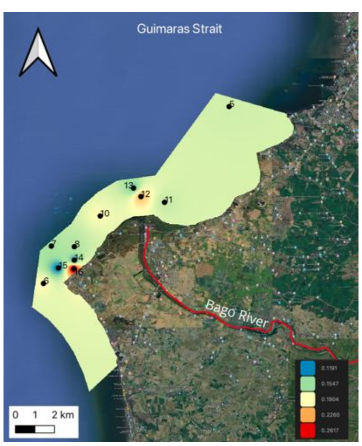
Guimaras Strait
Bago River
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Guimaras Strait
Bago River
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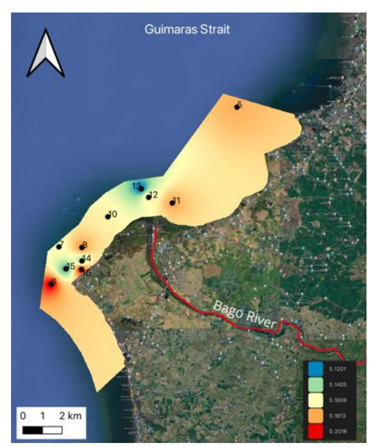
(h)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Bago River
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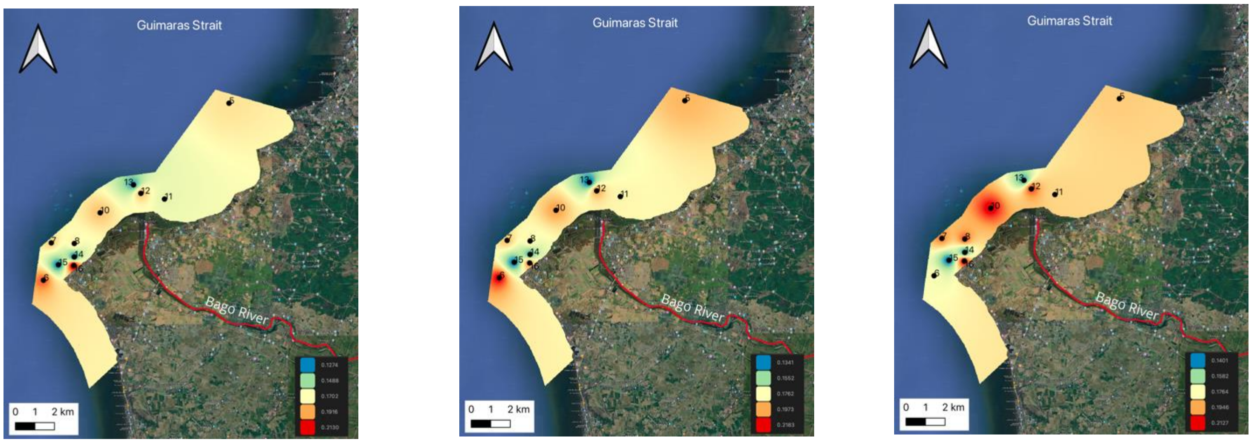
(i)



(j) (k) (l)

Figure 6. Spatial Variation of the 11 sampling sites (a) April 2018, (b) May 2018, (c) June 2018, (d) July 2018, (e) August 2018, (f) September 2018, (g) October 2018, (h) November 2018, (i) December 2018, (j) January 2019, (k) February 2019, and (l) March 2019

The pollution level of sampling site 16 was highest in April and may be attributed to its proximity to the distillery. The MPA sampling sites recorded the lowest pollution levels. Overall, the month of April is classified under "sub-cleanness" according to (Ji et al., 2015 & Yan et al., 2015). The MPA sampling sites continued to record the lowest pollution levels, while sampling site 8 stood out in terms of the pollution levels. The month of May retained the "Sub-cleanness" levels. The MPA sampling sites remained to have the lowest recorded pollution levels for the month of June, while sampling 16 obtained the highest pollution levels. The "Sub-cleanness" pollution levels remained for the month of June. Sampling site 5, with close proximity to the distillery, got the highest pollution level for the month of July. The same observations were made for the MPA sampling sites. Sampling sites 5, 7, and 16 were classified under "slightly polluted" levels, while the rest were "sub-cleanness" levels. Sampling sites 10 and 16 had very high pollution levels compared with the rest for the month of August. These sampling sites were very near point sources, a nearby municipal sewage line outlet and distillery, respectively. Sampling sites 10 and 16 were also classified under "slightly polluted" levels; overall the level was "sub-cleanness" for August. Sampling sites 8, 12, and 16 were classified under "slightly polluted" levels; the rest were "sub-cleanness" levels. Sampling 12 and 16 were near point sources of pollution, near the outlet of a river and distilleries, respectively. The MPA sampling maintained their low pollution levels for the month of September. Sampling site 16 continued to record the highest pollution levels for the month of October, having "slightly polluted" levels together with sampling site 12. For the month of November, sampling site 16 still exhibited the highest pollution levels in the Guimaras Strait, along with sampling sites 5 and 12 reaching "slightly polluted" levels. High pollution levels are still attributed to the point sources near the sampling sites. Sampling sites 6 and 16 showed high pollution levels as compared with the rest of the sites for the month of December. The Guimaras Strait was observed to be at "sub-cleanness" pollution levels for December. The same trend was observed for the month of January, wherein sampling sites 6 and 16 continued to obtain the highest pollution levels among the sites. For the month of February, a similar trend was obtained, where sampling sites 6 and 16 recorded the highest levels. Pollution levels were still at "sub-cleanness". The month of March had the most sampling sites reach the "slightly polluted" levels, sites 8, 10, 12, and 16. The MPA sampling sites 13, 14, and 15 remained to have the lowest pollution levels.

3.5 Causes of Spatial Variations

Spatial variation of the study area occurred in sampling sites with point source and nonpoint source pollutions. The main contributors of pollution to the higher CPI values were chemical oxygen demand, dissolved oxygen, pH, temperature, and fecal coliform. The four sampling sites, 5, 12, 10, and 16, showed that they may have received pollution from industrial wastewater, and domestic sewage may have been due to the presence of distillery industries, near residential estuarine rivers, and the municipal sewage discharge in the proximity of the sampling sites. Sampling site 16 got the highest pollution level for 9 of the 12 sampling months, the effects of the distillery industry may have contributed to a higher pollution index. This is with respect to the list of pollution contributors from the normalized pollution index. The average comprehensive pollution index value for the Guimaras Strait from April 2018 to March 2019 was 0.1653 and is classified as “sub-cleanness” pollution levels according to the standards of Ji et al. (2015) and Yan et al. (2016). Compared to the studies of Ji et al. (2015), Jha et al. (2015), and Oladipo et al. (2021), pollution levels for the Guimaras Strait are lower than the water body pollution levels exhibited by similar studies with a range of “heavily polluted” to “seriously polluted.” The spatial variation of the study area occurred with point source and nonpoint source pollutions. The main contributors of pollution to the higher CPI values were chemical oxygen demand, dissolved oxygen, pH, temperature, and fecal coliform. The sources of the variation of the comprehensive pollution index may be from pollution due to industrial wastewater and domestic sewage.

CONCLUSIONS

This study has made an assessment of the Guimaras Strait using the comprehensive pollution index and the geographic information system and found that the status of the Guimaras Strait is classified as “sub-cleanness” pollution levels based on the standards from the study of Ji et al. (2015) and Yan et al. (2015).

These consistent results could be very useful and valuable in formulating future pollution control strategies, as well as in the establishment of monitoring and management systems of coastal waters. The use of indices would lessen the burden of analyzing a plethora of water quality data. The results of the study would also be helpful to future research on water quality assessment and further exploration of the different water quality indices that would come up with better water quality assessment. It is recommended that periodic monitoring of coastal waters, delineation of point and nonpoint pollution sources, dissemination of environmental awareness, and data sharing through GIS interfaces are essential for safeguarding coastal ecosystems. The seasonal variation of the water quality parameters may also be considered.

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ETHICAL CONSIDERATION

All research has been conducted in accordance with the ethical principles and guidelines. There were no animal or human engagements in the conduct of the study.

CONFLICT OF INTEREST

The authors declare no conflict of interest regarding the publication of this manuscript. Commission on Higher Education through its DARE TO (Discovery-Applied Research and Extension for Trans/Inter-disciplinary Opportunities) Research Grant fully funded the study and had no role in the study's design, data collection, analysis, or interpretation.

REFERENCES

Aksoy, S., & Haralick, R. M. (2001). Feature normalization and likelihood-based similarity measures for image retrieval. Pattern Recognition Letters, 22(5), 563-582. doi:10.1016/s0167-8655(00)00112-4

Coastal Ecosystem Conservation and Adaptive Management under Local and Global Environmental Impacts in the Philippines. (2011). Study Sites. Retrieved October 1, 2024, from https://sites.google.com/view/cecam-project/home/study-sites

DENR EMB. (2008, February). Water Quality Monitoring Manual Volume 1 Manual on Ambient Water Quality Monitoring. Environmental Management Bureau. https://water.emb.gov.ph/wp-content/uploads/2017/09/Water-Quality-Monitoring-Manual-Vol.-1-ambient_14aug08.pdf

DENR EMB. (2016, November 21). EMB APPROVED METHODS OF ANALYSIS FOR WATER AND WASTEWATER. Environmental Management Bureau. https://emb.gov.ph/wp-content/uploads/2022/08/ERLSD_EMB-MC-2016-012.pdf

Holloway, J. M., Dahlgren, R. A., Hansen, B., & Casey, W. H. (1998). Contribution of bedrock nitrogen to high nitrate concentrations in stream water. Nature, 395(6704), 785-788. doi:10.1038/27410

Jha, D. K., Devi, M. P., Vidyalakshmi, R., Brindha, B., Vinithkumar, N. V., & Kirubagaran, R. (2015). Water quality assessment using water quality index and geographical information system methods in the coastal waters of Andaman Sea, India. Marine Pollution Bulletin, 100(1), 555-561. doi:10.1016/j.marpolbul.2015.08.032

Ji, X., Dahlgren, R. A., & Zhang, M. (2015). Comparison of seven water quality assessment methods for the characterization and management of highly impaired river systems. Environmental Monitoring and Assessment, 188(1). doi:10.1007/s10661-015-5016-2

Karydis, M., & Kitsiou, D. (2013). Marine water quality monitoring: A review. Marine Pollution Bulletin, 77(1-2), 23-36. doi:10.1016/j.marpolbul.2013.09.012

Liu, S., Lou, S., Kuang, C., Huang, W., Chen, W., Zhang, J., & Zhong, G. (2011). Water quality assessment by pollution-index method in the coastal waters of Hebei Province in western Bohai Sea, China. Marine Pollution Bulletin, 62(10), 2220-2229. doi:10.1016/j.marpolbul.2011.06.021

Liu, S., Ryu, D., Webb, J., Lintern, A., Waters, D., Guo, D., & Western, A. (2018). Characterisation of spatial variability in water quality in the Great Barrier Reef catchments using multivariate statistical analysis. Marine Pollution Bulletin, 137, 137-151. doi:10.1016/j.marpolbul.2018.10.019

Liu, X., Li, G., Liu, Z., Guo, W., & Gao, N. (2010). Water Pollution Characteristics and Assessment of Lower Reaches in Haihe River Basin. Procedia Environmental Sciences, 2, 199-206. doi:10.1016/j.proenv.2010.10.024

Manoj, K., Kumar, P., Chaudhury, S., 2012. Study of heavy metal contamination of the river water through index analysis approach and environ metrics. Bull. Environ. Pharmacol. Life Sci. 1 (10), 7–15.

Medeiros, A. C., Faial, K. R., Do Carmo Freitas Faial, K., Da Silva Lopes, I. D., De Oliveira Lima, M., Guimarães, R. M., & Mendonça, N. M. (2017). Quality index of the surface water of Amazonian rivers in industrial areas in Pará, Brazil. Marine Pollution Bulletin, 123(1-2), 156-164. doi:10.1016/j.marpolbul.2017.09.002

Mishra, P., Panda, U. S., Pradhan, U., Kumar, C. S., Naik, S., Begum, M., & Ishwarya, J. (2015). Coastal Water Quality Monitoring and Modelling Off Chennai City. Procedia Engineering, 116, 955-962. doi:10.1016/j.proeng.2015.08.386

Oladipo, J. O., Akinwumiju, A. S., Aboyeji, O., & Adelodun, A. A. (2021). Comparison between fuzzy logic and water quality index methods: A case of water quality assessment in Ikare community, southwestern Nigeria. Environmental Challenges, 3, 100038. https://doi.org/10.1016/j.envc.2021.100038

Popovic, N., Duknic, J., Canak Atlagic, J., Rakovic, M., Marinkovic, N., Tubic, B., & Paunovic, M. (2016). Application of the Water Pollution Index in the Assessment of the Ecological Status of Rivers: a Case Study of the Sava River, Serbia. Acta Zoologica Bulgarica, 68(1), 97-102. Retrieved from http://www.acta-zoologica-bulgarica.eu/downloads/acta-zoologica-bulgarica/2016/68-1-97-102.pdf

Shin, J. Y., Artigas, F., Hobble, C., & Lee, Y. (2012). Assessment of anthropogenic influences on surface water quality in urban estuary, northern New Jersey: multivariate approach. Environmental Monitoring and Assessment, 185(3), 2777-2794. doi:10.1007/s10661-012-2748-0

Standard Methods Committee of the American Public Health Association, American Water Works Association, & Water Environment Federation. (1992). 9221 multiple-tube fermentation technique for members of the coliform group. In W. C. Lipps, T. E. Baxter, & E. Braun-Howland (Eds.), Standard Methods for the Examination of Water and Wastewater. APHA Press. https://doi.org/10.2105/SMWW.2882.192

Yan, C., Zhang, W., Zhang, Z., Liu, Y., Deng, C., & Nie, N. (2015). Assessment of Water Quality and Identification of Polluted Risky Regions Based on Field Observations & GIS in the Honghe River Watershed, China. PLOS ONE, 10(3), e0119130. doi:10.1371/journal.pone.0119130

Yang, D., Zheng, L., Song, W., Chen, S., & Zhang, Y. (2012). Evaluation Indexes and Methods for Water Quality in Ocean Dumping Areas. Procedia Environmental Sciences, 16, 112-117. doi:10.1016/j.proenv.2012.10.015

Zia, H., Harris, N. R., Merrett, G. V., Rivers, M., & Coles, N. (2013). The impact of agricultural activities on water quality: A case for collaborative catchment-scale management using integrated wireless sensor networks. Computers and Electronics in Agriculture, 96, 126-138. doi:10.1016/j.compag.2013.05.001