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GIS-Based Spatial Analysis of Selected Water Quality Parameters in the Southern Part of Lake Sebu, South Cotabato, Philippines

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Abstract—This study used a Geographic Information System (GIS) to visualize water quality using Inverse Distance Weighted (IDW) Interpolation that assessed the water quality in the southern part of Lake Sebu, South Cotabato, in terms of pH, dissolved oxygen (DO), biochemical oxygen demand (BOD), total suspended solids (TSS), fecal coliform, temperature, and oil and grease. The maps illustrate the trends in water quality that are produced based on DENR's Water Quality Guidelines and Effluent Standards. The data from 2017 to 2022 revealed that pH, DO, temperature, and TSS stayed within acceptable levels throughout the year, and other parameters showed alarming tendencies such as the increasing amount of fecal coliform and oil and grease. Additionally, this study revealed that the increasing amount of fecal coliform and oil and grease resulted from anthropogenic activities. The indicators of declining water quality imply detrimental effects on the ecosystems of the lake.

Keywords—Geographic Information System (GIS), Inverse Distance Weighted (IDW), Water Quality, Lake Sebu

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I. INTRODUCTION

Tilapia production in Lake Sebu dates back to the early 1970s and serves as the cornerstone of the municipality's livelihood. However, the intensive cultivation of tilapia in floating fish cages, combined with high stocking densities and specific feeding practices, has led to a buildup of decaying organic debris from fish waste at the lake bottom. This accumulation is particularly harmful to the fish during lake overturns. Deep lakes such as Lake Sebu are negatively impacted when cage density exceeds their "carrying capacity"—the inherent ability to absorb and recycle external nutrients. This issue is further exacerbated by the lake's lack of natural exit points for waste removal [14].

A fish kill in Lake Sebu devastated the town's inland fishing sector, resulting in approximately ₱10 million in damages [13]. Fish kills serve as critical warning signs of water deterioration, typically driven by contamination from biological toxins, chemicals, and microbiological organisms [16]. Therefore, proper diagnosis of the lake is essential to improve water quality and prevent further ecological decline [2].

To alleviate water quality problems, various nations have enacted laws and regulations governing water resource management and pollution prevention, including mandates for monitoring operations [18]. In the Philippines, the Department of Environment and Natural Resources (DENR) implements Republic Act (RA) 9275, known as the Philippine Clean Water Act of 2004. It adopts Water Quality Guidelines (WQG) pursuant to Presidential Order 192 [3]. The primary objective of this Administrative Order is to establish standards for categorizing national water bodies, identifying temporal trends, and assessing stages of water quality degradation or improvement. Furthermore, it determines the need for actions to prevent, control, or mitigate water pollution and designates Water Quality Management Areas (WQMA).

Geospatial systems are highly effective for visualizing water quality parameters, particularly in understanding their spatial distribution for accurate assessment [19]. Water quality maps are generated using the Quantum Geographic Information System (QGIS), with Inverse Distance Weighted (IDW) interpolation utilized for map delineation. In the IDW method, sample points are weighted during interpolation, meaning the influence of a known point on an unknown point decreases as the distance between them increases [21].

This study assessed the southern part of Lake Sebu, in South Cotabato. The water quality parameters are pH level, dissolved oxygen (DO), biochemical oxygen demand (BOD), total suspended solids (TSS), fecal coliform, temperature, and oil and grease. The water quality was assessed through delineated maps in each parameter using QGIS specifically the IDW Interpolation. The baseline of the locations is adapted from Lake Sebu's designation of Water Quality Management Area (WQMA), and delineation of water quality in the southern part of Lake Sebu WQMA, and maps illustrating the trends of potentially degrading areas that are produced based on DENR's Water Quality Guidelines and Effluent Standards [4].

II. METHODOLOGY

Figure 1 shows the methodology, which is consists of a process started with defining the Lake Sebu Water Quality Management Area, identification of Southern Part of the study area, acquisition and preparation of DENR water quality assessment data, validation and organization of the dataset, and the creation of a spatial database in QGIS. The generated maps for the pH level, dissolved oxygen (DO), biochemical oxygen demand (BOD), total suspended solids (TSS), fecal coliform, temperature, and oil and grease are subsequently classified according to the DENR Water Quality Guidelines that assessed the condition of the lake's water.

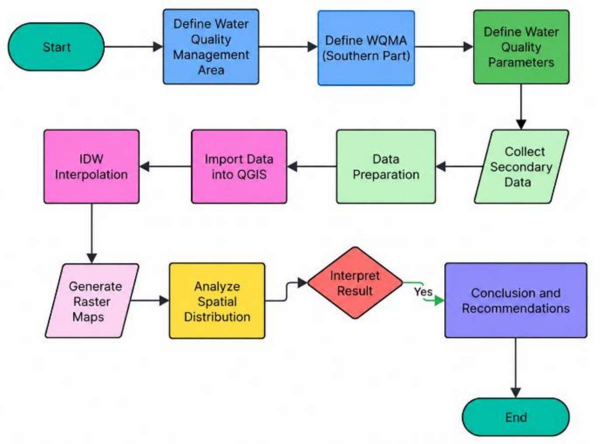

Fig. 1. Methodological Flow Chart.

A. Lake Sebu Water Quality Management Area

In the southern Philippines' SOCCSKSARGEN Region (Region XII), Lake Sebu is a first-class municipality situated in the province of South Cotabato (Figure 2). Located between 300 and 1,000 meters above sea level, it has a cool climate, undulating hills, dense forests, and a network of interconnected lakes that add to its rich cultural and ecological significance.

Lake Sebu comprises 335.43 hectares of water, and the portion of land is approximately 95 hectares, which adds up to a total area of 430.43 hectares, including the natural and man-made tributaries. Lake Sebu consists of 23 stations that are enclosed by three Barangays: Barangay Poblacion, Barangay Takunel, and Baranggay Bacdulong.

Fig. 2. Municipality of Lake Sebu, South Cotabato, Philippines

The WQMA is classified based on its intended beneficial use (Figure 3). Lake Sebu belongs to Class B or Recreational Water Class I, which is intended for recreational activities such as swimming and bathing, which are stations 7 to 10. Stations 1 to 6 were classified as Class C (Recreational Water Class II), which is intended for boating, fishing, and other recreational activities; the growth and propagation of aquatic resources; and agricultural uses, including irrigation and livestock watering.

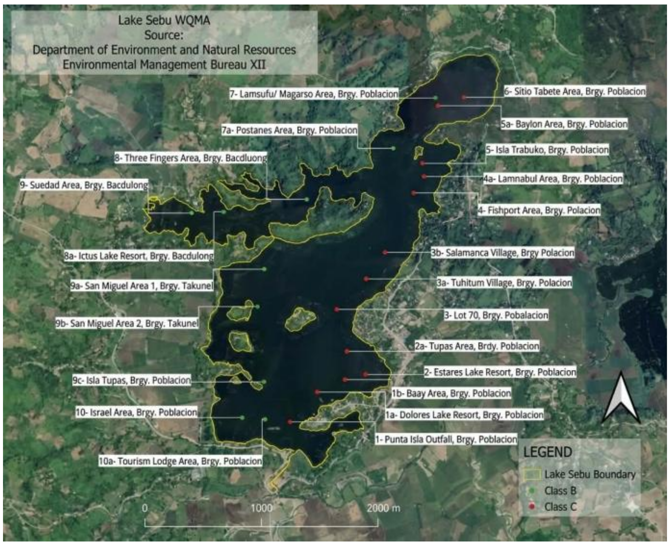

Fig. 3. Lake Sebu Water Quality Management Area and WQMA stations.

B. Lake Sebu WQMA (Southern Part)

The water quality was assessed through the geospatial distribution parameter of the southern part of Lake Sebu, which comprises approximately 180 hectares of the total water quality management area. The southern part of WQMA consists of 11 stations and encompasses Barangay Poblacion and Barangay Takunel (Figure 3).

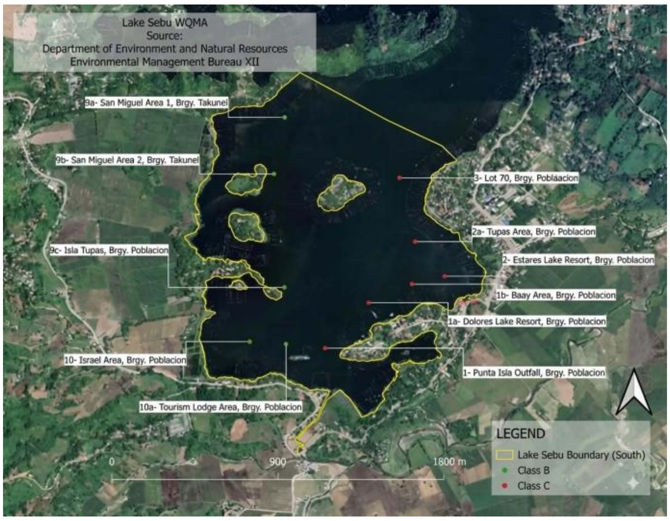

Fig. 4. Lake Sebu WQMA (Southern Part)

C. Water Quality Parameters

The water quality parameters were based on the DENR's Water Quality Guidelines and Effluent Standards. The body of water was based on the primary parameters, namely pH level, DO, BOD, temperature, TSS, and fecal coliform (Table 1), and the secondary parameter (Table 2), namely oil and grease. The body of water was then classified according to its intended use (Table 3).

TABLE I. GUIDELINES FOR WATER QUALITY AND THE PRIMARY PARAMETERS.

Parameters	Unit	Water Body Classification				
		AA	*A*	*B*	*C*	*D*
pH level		6.5-8.5	6.5-8.5	6.5-8.5	6.5-9.0	6.0-9.0
Dissolve d Oxygen (DO)	mg/L	5	5	5	5	2
Biochemical Oxygen Demand (BOD)	mg/L	1	3	5	7	15
Temperature	°C	26-30	26-30	26-30	25-31	25-32
Total Suspended Solids (TSS)	mg/L	25	50	65	80	110
Fecal Coliform	MPN/ 100 mL	<1.1	<1.1	100	200	400

TABLE II. GUIDELINES FOR WATER QUALITY AND THE SECONDARY PARAMETER-OGANICS.

Parameters	Unit	Water Body Classification				
		AA	*A*	*B*	*C*	*D*
Oil and grease	mg/L	<1	1	1	2	5

TABLE III. INTENDED BENEFICIAL USE AND THE WATER BODY CLASSIFICATION AND USAGE OF FRESHWATER

Classification	Intended Beneficial Use
Class AA	Public Water Supply Class I. Intended largely for watersheds that are deserted or otherwise designated as protected areas, and that simply need to be disinfected in accordance with established protocols to meet the most recent Philippine National Standard for Drinking Water (PNSDW).
Class A	Public Water Supply Class II. Intended to serve as sources of water that must undergo standard treatment (coagulation, sedimentation, filtration, and disinfection) in order to fulfill PNSDW.
Class B	Recreational Water Class I. Designed for main contact recreation (which includes swimming, bathing, etc.).
Class C	1) Water used in fishing for the growth and reproduction of fish and other aquatic resources; 2) Class II Recreational Water for Boating, Fishing, or Other Activities 3) For agriculture, irrigation, and livestock watering
Class D	Waters of the Philippines, including the territorial waters, are navigable. Region and inland rivers appropriate for water transportation)

D. Data Gathering

The secondary data of this study was gathered from DENR's Environmental Management Bureau (EMB) XII. This study has adapted the Water Quality Guidelines and Effluent Standards and its Implementation in the Philippines, and the DENR's standards for freshwater.

E. Water Quality Maps

The water quality maps are delineated through geospatial application the Quantum Geographic Information System (QGIS). The gathered data from Environmental and Management Bureau (EMB) XII for water quality is delineated by employing interpolation techniques in QGIS to generate water quality maps for Lake Sebu WQMA.
Interpolation is used for spatial analysis to generate maps.
The spatial interpolation is a process of using known points with values to estimate unknown points. The Inverse Distance Weighted (IDW) Interpolation was used in delineation for water quality maps. The sample points in the IDW interpolation method are weighted during interpolation; therefore, unknown points decrease the influence of one point in relation to another [22]. Since interpolation estimate water quality values at unsampled sites, this approach is beneficial especially in places with an absence of water quality monitoring stations. This approach is more comprehensive in understanding the spatial distribution of water quality in Lake Sebu WQMA.

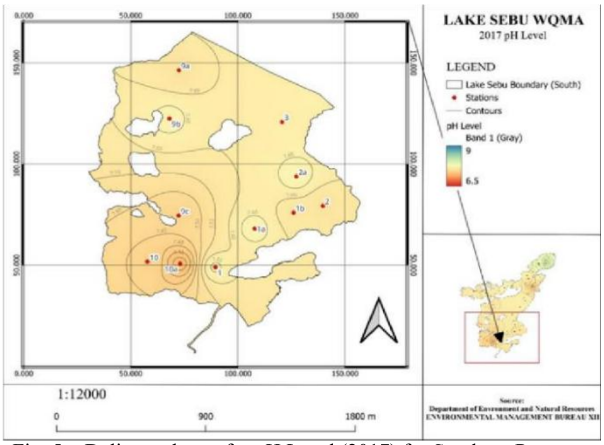

Fig. 5. Delineated map for pH Level (2017) for Southern Part Lake Sebu WQMA.

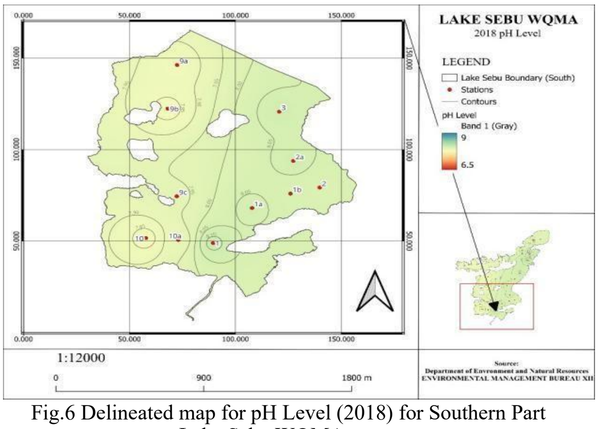

Fig.6 Delineated map for pH Level (2018) for Southern Part Lake Sebu WQMA.

III. RESULTS AND DISCUSSION

The purpose of this study was to assess the water quality in the southern part of Lake Sebu, South Cotabato. Specific goals of this study include the assessment of this water body through the delineation of important water quality indicators such as pH level, dissolved oxygen, biochemical oxygen demand, total suspended solids, fecal coliform, and temperature as the primary parameters, and oil and grease as the secondary parameters (organics). Delineation of water quality in the southern part of Lake Sebu, and maps illustrating trends.

A. pH Level

The resulting 2017 pH level (Figure 5) shows that the annual pH ranges from 7.25 to 7.70. The delineated map showed that the lowest pH level is along the stations for Class B, where pH level ranges from 7.25 to 7.65. The highest level is along the stations for Class C, where pH levels range from 7.55 to 7.70. According to the annual report from the Environmental Management Bureau (EMB) XII, the lowest level of pH level was in the first quarter, which was after the fish kill incident in the lake [5]. However, the pH level is within the DENR's standard.

Figure 6 shows the result in 2018: the pH level along the Class C stations is the highest, which ranges from 8.0 to 8.50. The lowest levels are along Class B, which range from 7.85 to 8.0. The resulting map shows that the annual pH level in 2018 is higher compared to 2017, which indicates that 2018 is more basic than 2017. The factor that contributed to the decrease in pH level is the uneaten feed from aquaculture cultivation. Aquaculture in Lake Sebu employs 30 or more bags of fish feeds which are consumed by fish farming for a 200 square meter fish cages with a duration of 6 months [21]. However, for the year 2018, the pH level is within the DENR's standard.

The map in Figure 7 shows that the pH level in 2019 is within the DENR's standard. The resulting map shows that the pH level is higher in Class C stations, which range from 8 to 8.15 due to aquaculture activities, and Class B stations, which range from 7.85 to 8.0. In Figure 8, the pH level in the year 2020 decreased compared to the year 2019. The highest amount of pH level is along the Class C stations, and the lowest level is along Class B. However, the pH level in 2020 is within the DENR's standard. In Figure 9, the pH level ranges from 7.10 to 7.50, which indicates that the pH level in 2021 is within the standard. However, the delineated whole map showed that the pH level outside the southern part is more acidic, which affects the resulting map. The map in Figure 10 shows that the pH level increased compared to the year 2021. The map shows that the pH is neutral, which indicates that the pH in the year 2022 is within the DENR's standard.

B. pH Level (2017-2022)

The delineated map shows the trend map for pH level (Figure 11). The map shows how the pH level in the southern part of Lake Sebu changes over time. In the year 2017 and 2021, the map shows that mostly yellow and orange hues are where the pH level at lowest or approaching to acidic stage. The year that there are severe fish kills in the lake. The map shows that pH levels were within the ideal range during 2018 and 2019, as reflected by the predominance of green areas. The fluctuating water quality in Lake Sebu suggests the management practices around the lake are not sustainable. These variations of resulted water quality highlight the need for more adaptive management. However, from the year 2017 to 2022, the pH level is within the DENR's standard

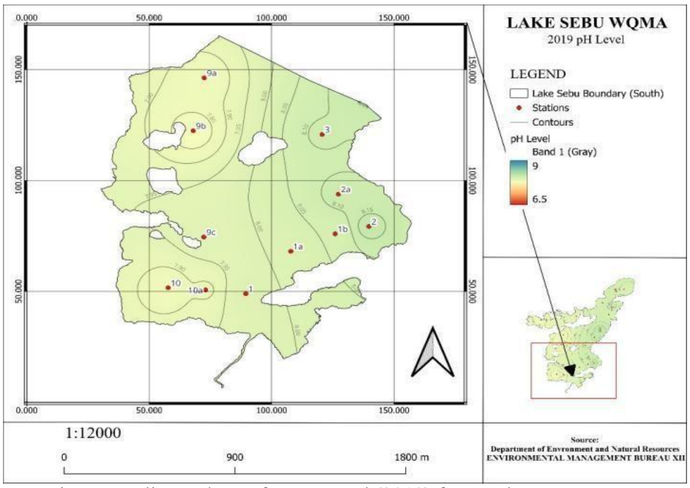

Fig. 7. Delineated map for pH Level (2019) for Southern Part Lake Sebu WQMA.

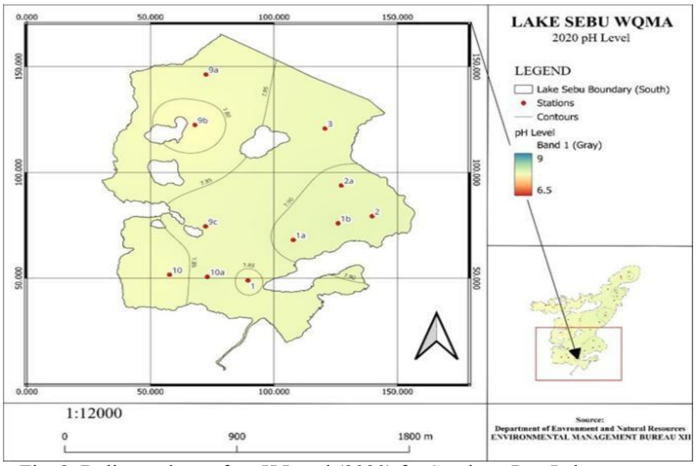

Fig. 8. Delineated map for pH Level (2020) for Southern Part Lake Sebu WQMA.

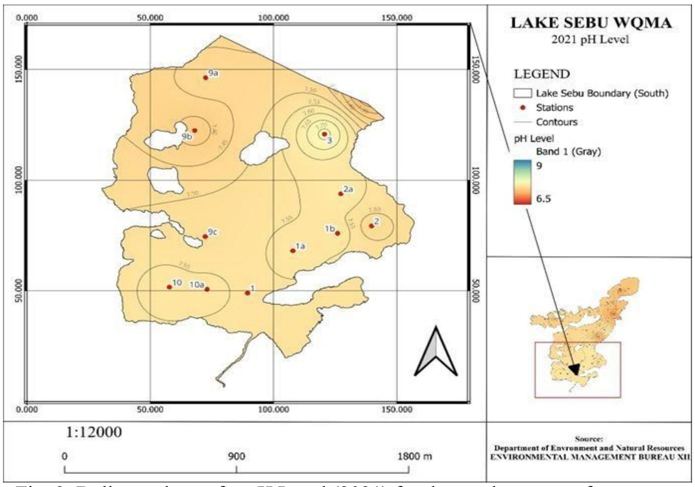

Fig. 9. Delineated map for pH Level (2021) for the southern part of Lake Sebu WQMA.

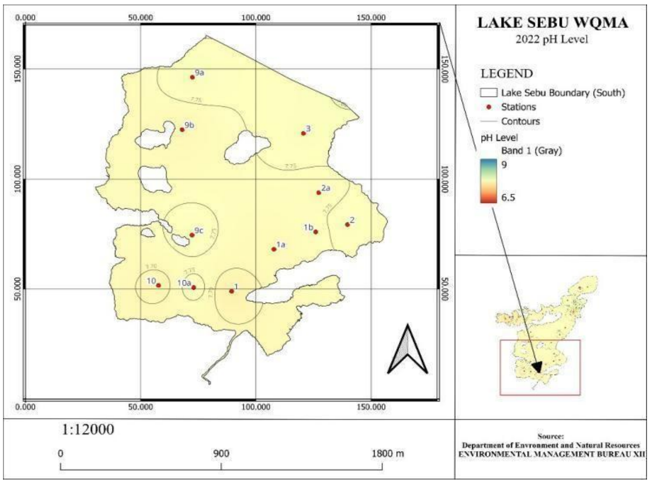

Fig. 10. Delineated map for pH Level (2022) for the southern part of Lake Sebu WQMA.

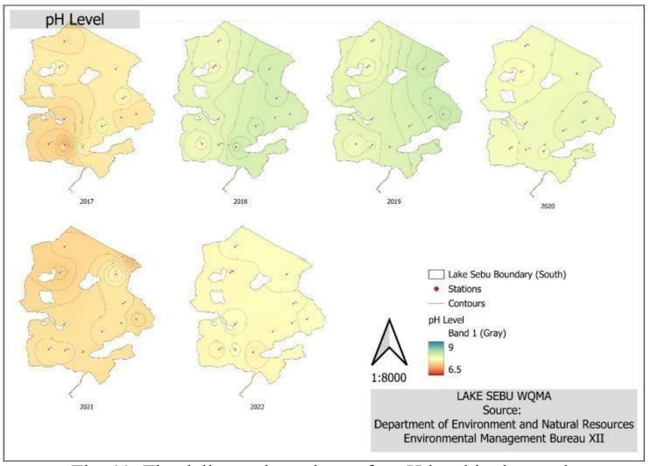

Fig. 11. The delineated trend map for pH level in the southern part of Lake Sebu WQMA.

C. Dissolved Oxygen

Figure 12 shows the resulting map of DO concentrations in Lake Sebu for 2017. The annual average DO concentrations ranged from 6 to 6.60 mg/L, which were within the water quality standard for Class B and Class C. Quarterly observations revealed that average DO concentrations ranged from 5.0 to 8.0 mg/L during the first quarter but declined to 2.0-3.5 mg/L in the southern part of Lake Sebu during the fourth quarter. The factors that contributed to the depletion of DO are heavy rainfall, which occurred in the first and fourth quarters of the year [9].

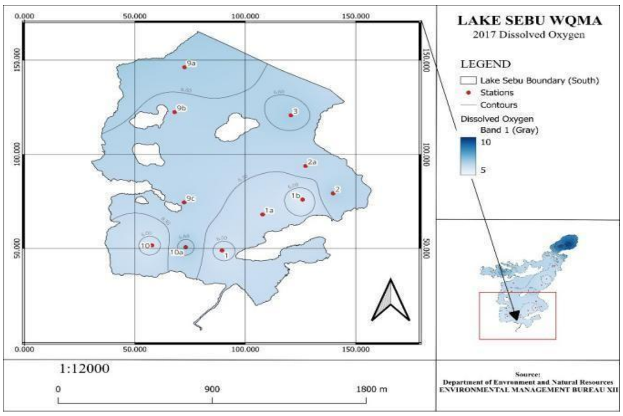

Fig. 12. Delineated map for DO (2017) for Southern Part Lake Sebu WQMA

The map in Figure 13 indicates that the DO in 2018 was within the water quality standard of DENR. However, stations in Barangay Poblacion, which were categorized as Class C, recorded an average DO concentration from 8 to 12 mg/L, which exceeded the DO level, and declined to 3-4 mg/L during the fourth quarter, falling below the minimum standard.

In terms of the amount of dissolved oxygen, in the year 2019 (Figure 14), the DO increased compared with the year 2018. The stations within Class B and Class C exceeded the amount which sustained the aquaculture cultivation in Class C stations, especially in the wet season. The resulting map showed that DO levels are within the DENR's standard.

The delineated map for the year 2020 (Figure 15) shows that the dissolved oxygen decreased compared in 2019. According to EMB XII, the depletion of DO was attributed to weather conditions in the month of December, January, and February that depleted the water DO [12]. The decrease in DO is also due to the 16% utilization of lake surface into aquaculture systems. However, the DO in the year 2020 is within the standard.

The DO in the year 2021 (Figure 16) decreased compared from the previous year, the year 2020. The depletion of the amount of DO are due to the fish kill incident. However, the resulted map showed that the DO is within the standard. The delineated map for DO in 2022 shows in Figure 17, DO can be seen to be within the standard and in some areas exceed the amount of DO which is required for the surface utilization in Lake Sebu increased by 18% [10].

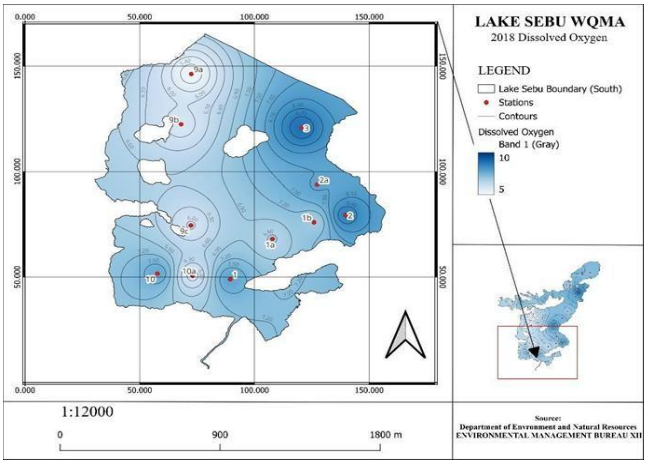

Fig. 13. Delineated map for DO (2018) for Southern Part Lake Sebu WQMA.

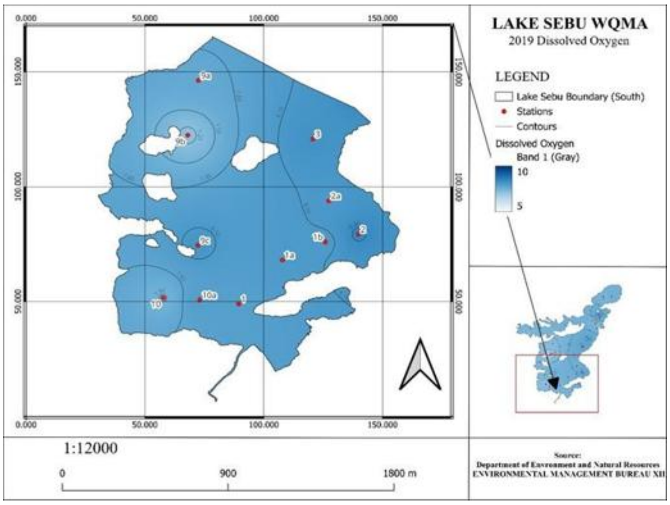

Fig. 14. Delineated map for DO (2019) for Southern Part Lake Sebu WQMA.

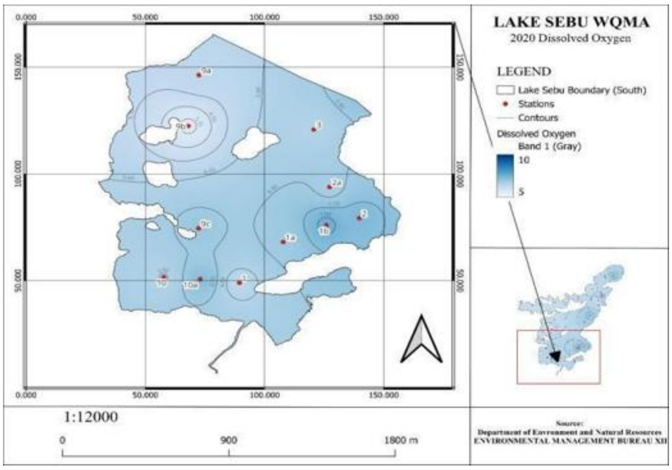

Fig. 15. Delineated map for DO (2020) for Southern Part Lake Sebu WQMA.

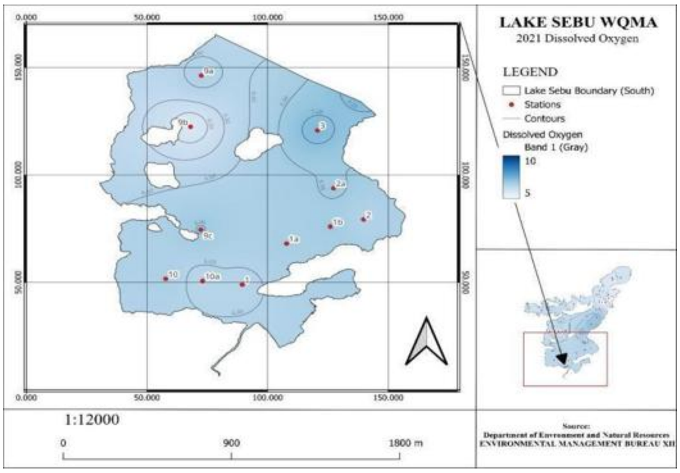

Fig. 16. Delineated map for DO (2021) for Southern Part Lake Sebu WQMA.

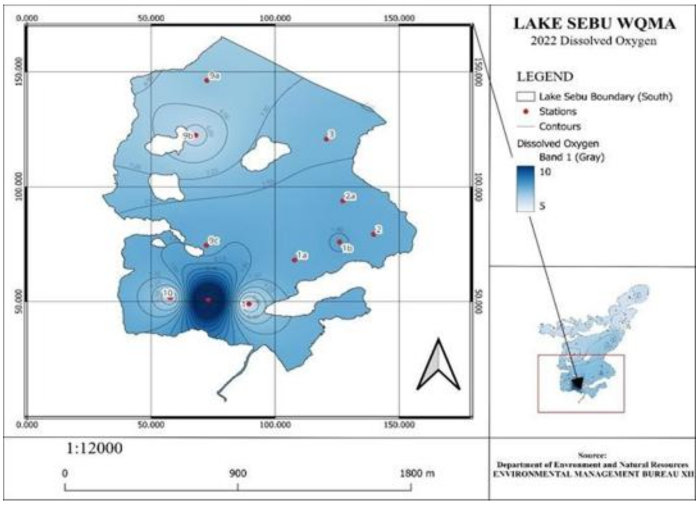

Fig. 17. Delineated map for DO (2022) for Southern Part Lake Sebu WQMA.

D. Dissolved Oxygen (2017-2022)

The delineated trend map in Figure 18, shows the trend of DO from the year 2017 to 2022. The lowest DO is in the year 2017 and 2021 where the fish kill incident happened or locally known as *"kamahong"* which are due to depletion of dissolve oxygen. Depletion of oxygen in lake's water is a natural phenomenon that usually occurs after heavy rainfall and due to low sunlight intensity [15]. According to EMB XII, the amount of DO is below acceptable value in rainy season [9], and from the annual report of EMB XII in the year 2021, overpopulated fish cages, and over utilization of lake's surface water are also the factors of decreased in DO [13].

The amount of annual DO in southern part of Lake Sebu is within the standards all throughout the years. However, the lake shall be seen exceedance when the utilization of its water surface exceeds the limit. This is particularly important during rainy season, when most fish kill events occur, as maintaining adequate water quality is essential for sustaining aquaculture activities. To maintain DO levels within the standard, regulations on fish cage operations are implemented in accordance with the Philippine Fisheries Code, which limits the utilization of the lake's water surface for aquaculture to 10% [12].

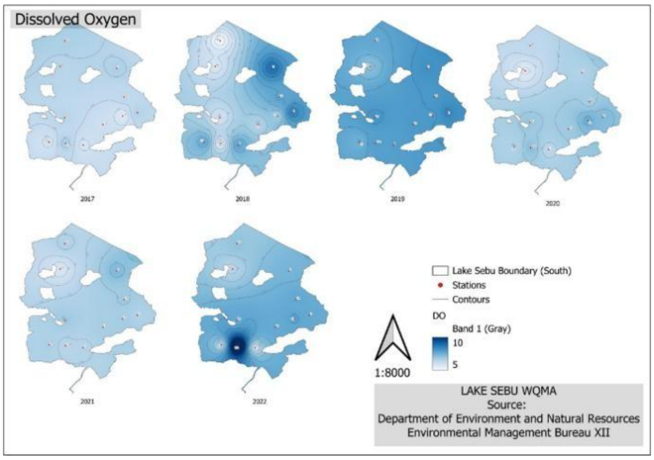

Fig. 18. The delineated trend map for DO in southern part of Lake Sebu WQMA.

E. Biological Oxygen Demand

BOD represents the amount of oxygen used by bacteria and other microorganisms for organic matter to break down in the presence of oxygen. High amount of BOD also one of the factors of DO depletion.

The affected area for the massive fish kills in 2017 is Barangay Takunel and Barangay Poblacion, which are in the southern part of Lake Sebu [20]. The delineated map shows in Figure 19, the BOD concentrations at Class B stations ranges from 6 to 7.5 mg/L, which exceed the DENR standard. For Class C, BOD concentrations at Stations 1, 1a, 1b, and 2 are within the prescribed standard, while Stations 2a and 3 exceed the standard. The highest BOD concentrations were recorded at Stations 10a and 9c for Class B, and at Stations 3 and 2a for Class C. Factor that contributed to the increased of BOD for these stations had the highest amount of phosphate that exceeded the DENR's standard [9]. The phosphates are the contamination from domestic and establishment sources, for sources of phosphates in water are natural from leachate from rock deposits, and anthropogenic activities such as the use of detergents, decomposition of organic waste, agricultural and domestic effluent. [2].

In 2018, the resulting map shows (Figure 20) the annual biochemical oxygen demand is within the standards for BOD. The map shows a darker hue in the areas where BOD concentrations are higher. During the first quarter, BOD exceeded the standard, particularly at stations in Barangay Poblacion, despite the relatively high DO levels recorded at these stations. The elevated BOD is attributed to inadequate waste management practices among household and establishments located around and within the islands of the lake [10]. Thus, the elevated BOD levels may be associated with pollution resulting from human activities, particularly the improper management and disposal of domestic and establishment-generated wastes [1].

The BOD in the year 2019 shows in Figure 21, the BOD concentration is higher in Barangay Poblacion where stations are classified as Class C which ranges from 2.50 to 3.50 mg/L, than in stations in Class B which ranges from 2.30 to 2.80 mg/L. One of the factors that contributed to the amount of BOD are the households near the lake that domestic wastes runoff to the lake's water, and the improper solid waste management [7]. However, due to the increase of DO in the year 2019, the resulting annual BOD is within the DENR's standard.

The map in Figure 22 shows that the BOD levels in 2020 were generally within the DENR standard. However, the delineated map indicates an increase in BOD level compared with the previous year. In 2021, the map in Figure 23 shows further increase in BOD levels. This increase may have been influenced by fish kill incident and other sources of pollution entering the lake through surface runoff. Domestic and livestock wastes are sources of organic pollutants and are among the major contributors to increased BOD Concentrations [24]. According to EMB XII, one of the major environmental concerns in Lake Sebu is inadequate solid waste management, particularly on the islands within the lake, where solid wastes may be left uncollected [13]. For Class B, only the San Miguel Area 1 (Station 9a) met the standard, while the remaining stations exceeded the prescribed standard. The stations classified as Class C also showed an increase in BOD level. However, the BOD levels at the Class C stations remained within the DENR standard.

The delineated map for 2022 (Figure 24) shows that the BOD level decreased compared with 2021. Although relatively higher BOD level was still observed at some Class C stations, the overall levels indicate an improvement with the previous year. The BOD levels remained within the standard.

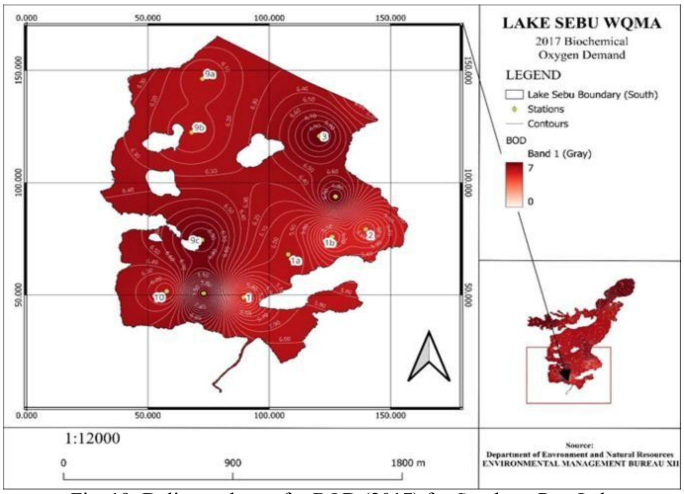

Fig. 19. Delineated map for BOD (2017) for Southern Part Lake Sebu WQMA.

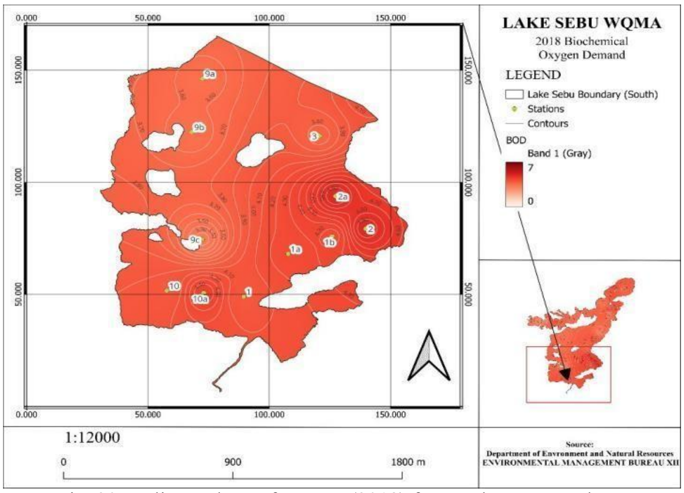

Fig. 20. Delineated map for BOD (2018) for Southern Part Lake Sebu WQMA.

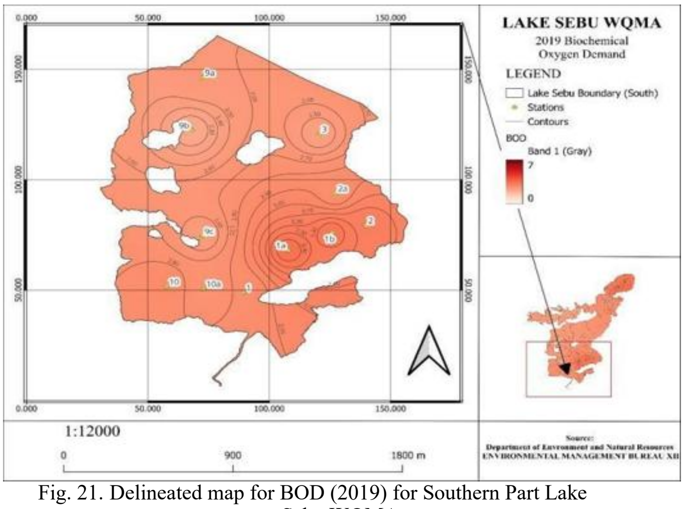

Fig. 21. Delineated map for BOD (2019) for Southern Part Lake Sebu WQMA.

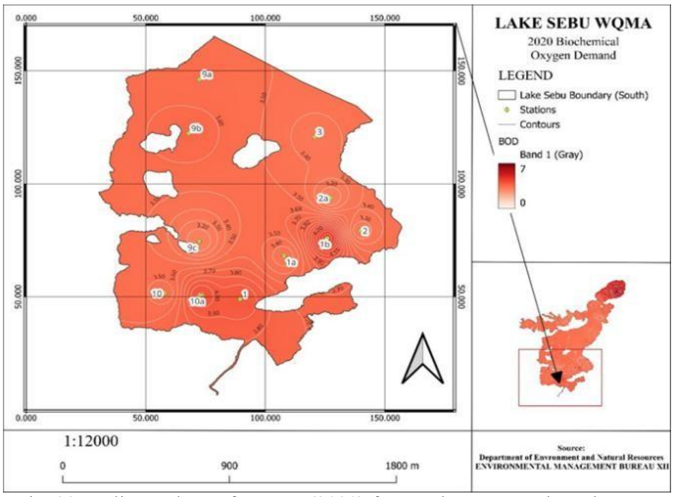

Fig. 22. Delineated map for BOD (2020) for Southern Part Lake Sebu WQMA.

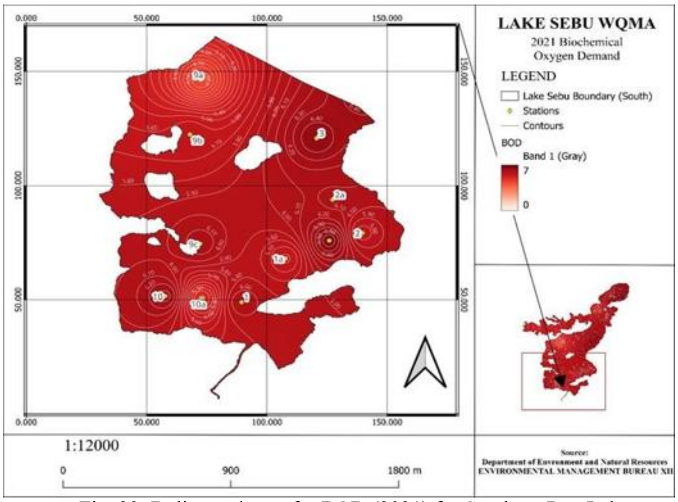

Fig. 23. Delineated map for BOD (2021) for Southern Part Lake Sebu WQMA.

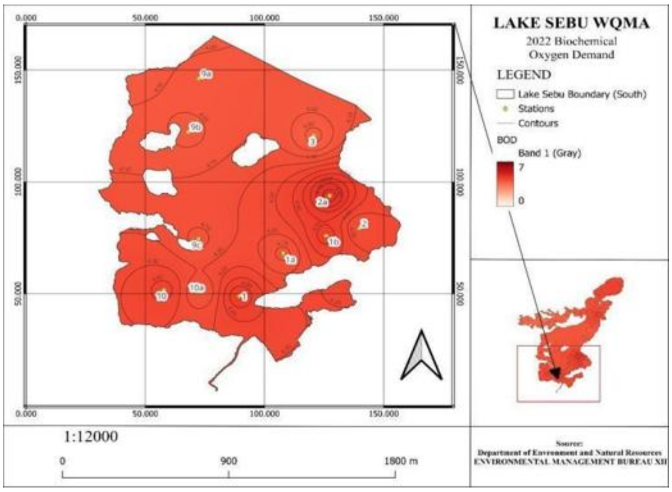

Fig. 24. Delineated map for BOD (2022) for Southern Part Lake Sebu WQMA.

F. Biological Oxygen Demand (2017-2022)

BOD is a surrogate parameter used to quantify the amount of dissolved oxygen consumed by microorganism during decomposition of organic matter [24]. The delineated map in Figure 25 shows that the highest BOD level is represented by the areas with darkest red shade. The highest BOD levels were observed in 2017 and 2021, which correspond to periods associated with depleted DO levels and major fish kill incidents. Fish kill events may be associated with nutrient pollution and oxygen depletion. Following a massive fish kill, the decomposition adds organic matter to the water, which can increase microbial activity and consequently raise BOD levels [23].

High concentration of BOD indicates a greater demand for oxygen due to the presence of organic matter and negatively affect aquaculture by increasing competition for available DO. Conversely, the lowest BOD level was recorded in 2019, which also had the highest DO level. The BOD levels in 2018, 2019, 2020, and 2022 were within the standard.

To mitigate increasing BOD concentration, regular environmental assessment should be conducted to identify and monitor sources of organic pollution, particularly effluent from household, commercial establishments, and other activities surrounding the lake.

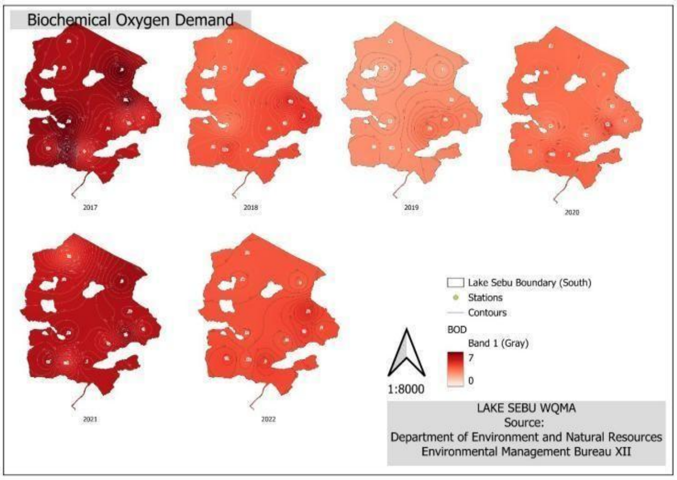

Fig. 25. The delineated trend map for BOD in southern part of Lake Sebu WQMA.

G. Total Suspended Solids

Figure 26 shows the total suspended solid (TSS) in 2017. The delineated map indicates that TSS concentrations in the southern portion of the WQMA were within the standard. According to EMB XII, Lake Sebu's Governing Board conducted clean up drive activities such as cleaning the water hyacinths and lilies and collecting discarded materials that are used for fish cages [9].

The map Figure 27 shows that the TSS concentration in 2018 remained within the DENR standard. The continued implementation cleanup activities and community efforts helped maintain TSS at relatively low. Similarly, Figure 28 shows that TSS in 2019 remained within the DENR standard. TSS concentration around Class B ranges from 5.20 to 8.80 mg/L, and stations around Class C ranges from 8.0 to 10.0 mg/L. The continuing minimum concentration of TSS are due to clean up drives and community efforts [7].

Figure 29 shows that TSS concentrations were at their lowest level in 2020. During this period, regular cleanup activities were implemented in the lake. The activity includes removal of lilies and water hyacinth in the lake, dismantling illegal structures, demolition of fish cages with no permits excess fish cages and abandoned structures [12]. The amount of TSS (Figure 30) in 2021 in Class B ranges from 5.20 to 8.80 mg/L, and Class C ranges from 5.50 to 8.80 mg/L. The map shows in 2022 (Figure 31), the TSS has higher amount within stations in Class C. Factors that affect to this result is the discarded materials that are used for fish cages, and other aquaculture activities. Overall, the resulting maps for TSS from 2020 to 2022 show that the recorded concentrations remained the DENR standard.

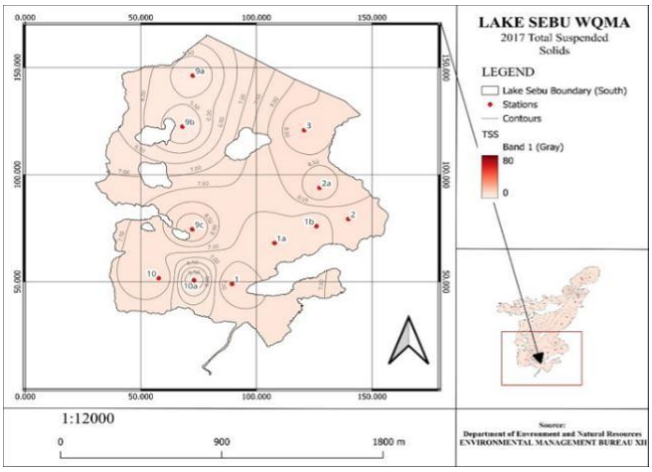

Fig. 26. Delineated map for TSS (2017) for Southern Part Lake Sebu WQMA.

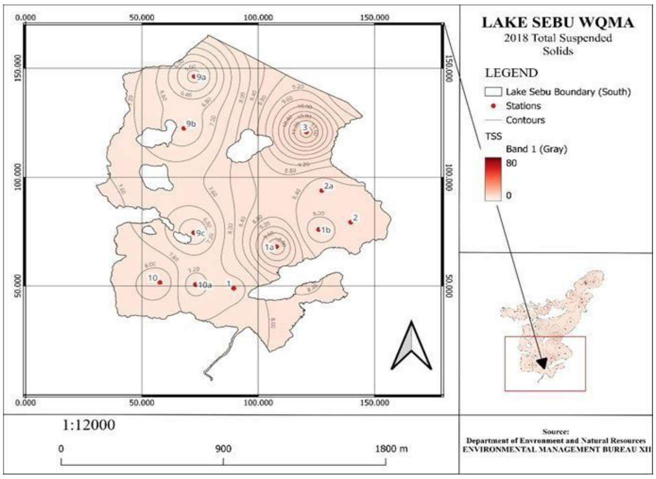

Fig. 27. Delineated map for TSS (2018) for Southern Part Lake Sebu WQMA.

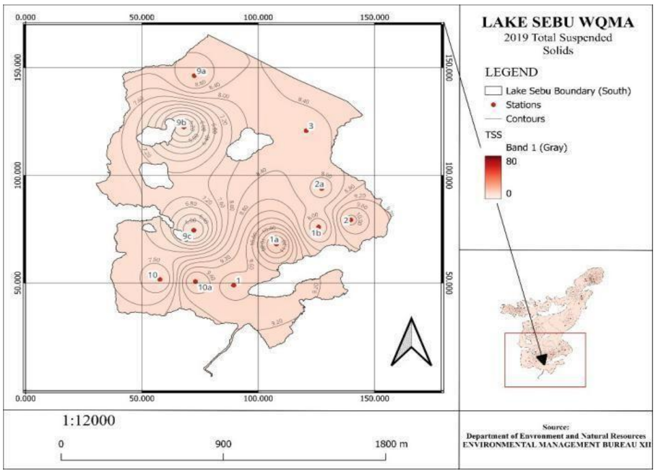

Fig. 28. Delineated map for TSS (2019) for Southern Part Lake Sebu WQMA.

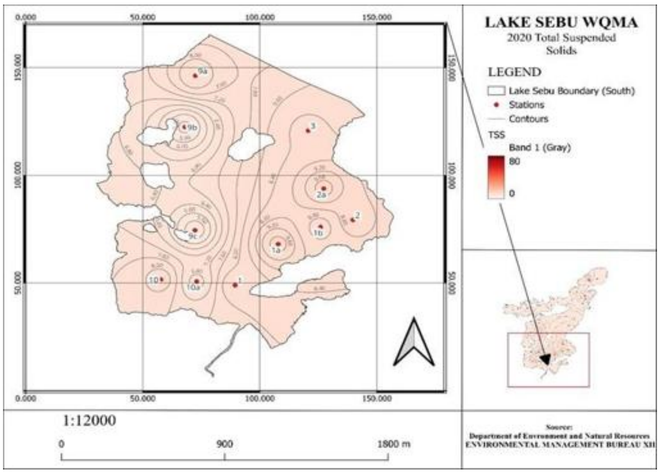

Fig. 29. Delineated map for TSS (2020) for Southern Part Lake Sebu WQMA.

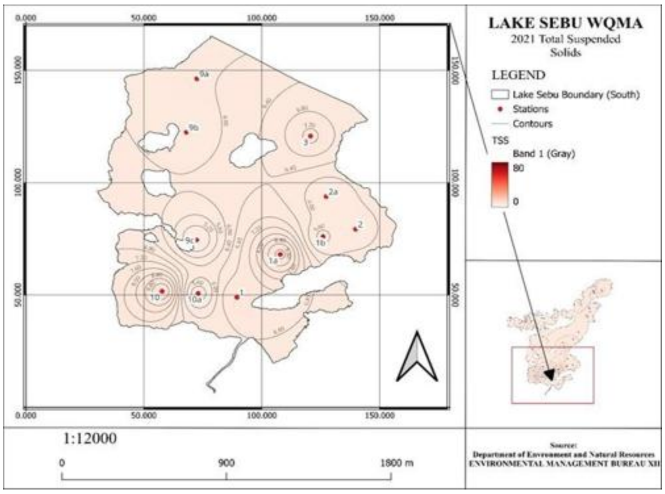

Fig. 30. Delineated map for TSS (2021) for Southern Part Lake Sebu WQMA

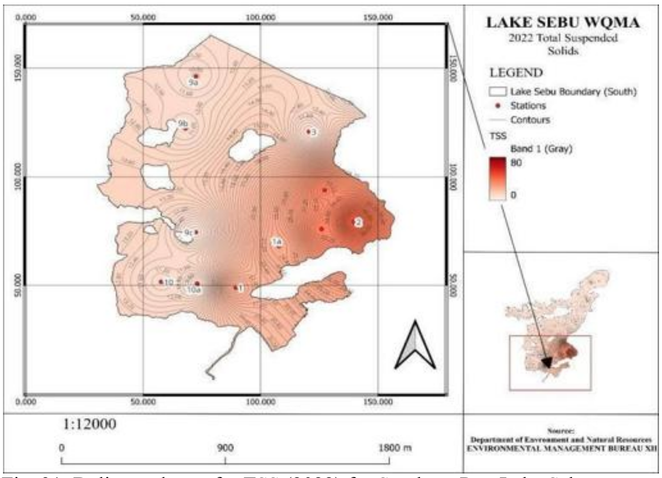

Fig. 31. Delineated map for TSS (2022) for Southern Part Lake Sebu WQMA.

H. Total Suspended Solids (2017-2022)

The TSS throughout the years showed to be at minimum (Figure 32). Factors affecting the amount of TSS are the wastes and rotten fish cages materials, water lilies and water hyacinth. Through community efforts, the minimal amount of TSS is maintained. In 2022, the delineated map showed higher concentration of TSS at stations located Class C. Continued aquaculture activities and the accumulation of discarded materials may contribute to increase in TSS. Overall, the delineated maps show that the TSS concentration from 2017 to 2022 remained within DENR standard.

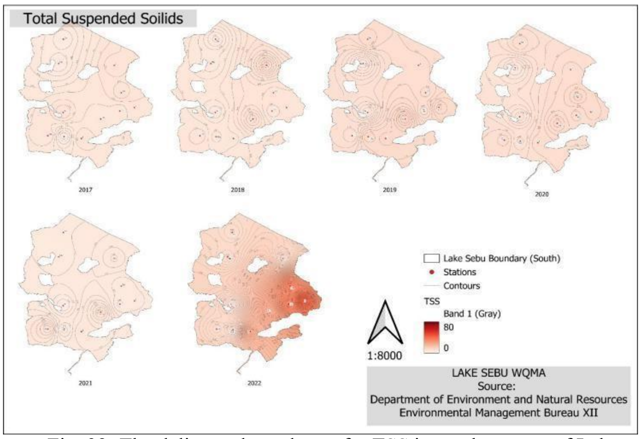

Fig. 32. The delineated trend map for TSS in southern part of Lake Sebu WQMA.

I. Fecal Coliform

The fecal coliform that is shown in Figure 33, the resulting map shows that the amount of fecal coliform ranges between 10 to 85 MPN/100mL, which indicate that the parameter is within the DENR standard in the year 2017.

Delineated map in 2018 shows in Figure 34, the fecal coliform in all parts of Lake Sebu in southern exceeded the DENR standard especially in Class B which are intended for recreational activities. According to EMB XII, one of the possible causes of increasing fecal coliform are the lack of household toilets and septic tanks [6]. Levels of fecal coliform from various point source and non-point sources are prone to health risk. Point sources came from effluents into the water bodies that can be directly identified, while non- point sources are due to diffusion of waste into the environment [17].

Figure 35 shows that the fecal coliform concentration was lowest in 2019. In contrast, fecal coliform levels exceeded the prescribed standard in 2018, indicating contamination from fecal sources. The Local Government Unit (LGU) conducted surveys for households and provided toilet bowls. These interventions may have contributed to the reduction in fecal coliform by improving sanitation practices and reducing the potential discharge of domestic wastewater into the lake [7].

Figure 36 shows the fecal coliform in 2020 which the concentration exceeded the standard. The resulting map shows that the highest level of fecal coliform is in San Miguel, Area 2 or at Station 9b, Barangay Takunel where it is classified as Class B. The factor that exceeds the concentration of fecal coliform are the septic tanks noticed to be near the lake's water [8]. This specific station did not pass the standard and the rest of the stations are within the standard for fecal coliform.

The delineated map shows in Figure 37, the fecal coliform in 2021 exceeded the standard, for the delineated map shows the fecal coliform ranges from 0 to 200 MPN/100mL which exceeds the maximum amount of 100 MPN/100mL for Class B and 200 MPN/100mL for Class C. According to EMB XII, continued proliferation of fecal coliform is associated with households and establishments, open defecation around the lake and the main sources of coliform bacteria came from household discharges, human and animal wastes, and coliforms that are naturally present in the soil that leached off by rainwater [9].

The delineated map shows in Figure 38, the concentration of fecal coliform in 2022 decreased compared in 2021. However, map shows that the fecal coliform exceeded the DENR standard, for Class B ranges from 200 to 580 MPN/100mL. Class C which ranges from 120 to 300 MPN/100 mL, thus, station 3 only pass the standard amount of fecal coliform in terms of class. According to EMB, educating the people around the lake to minimize the effect of anthropogenic activities in water quality. However, continued practice of mitigating problems can degrade water quality in the future [10].

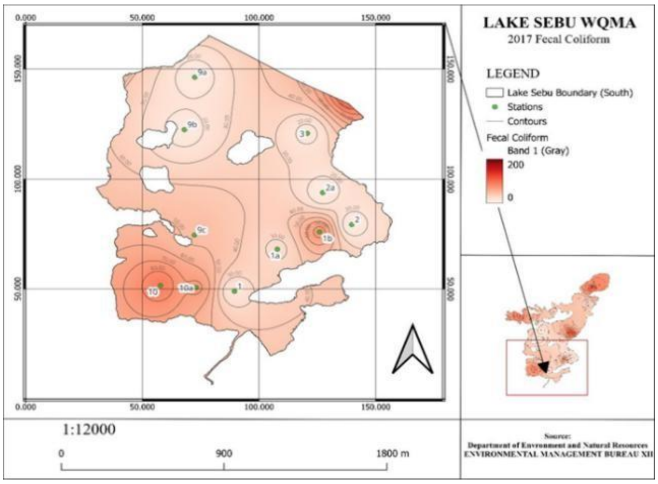

Fig. 33. Delineated map for Fecal Coliform (2017) for Southern Part Lake Sebu WQMA.

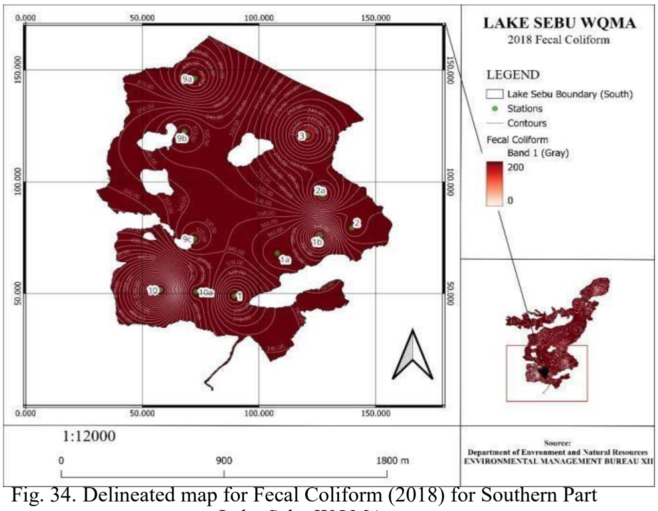

Fig. 34. Delineated map for Fecal Coliform (2018) for Southern Part Lake Sebu WQMA.

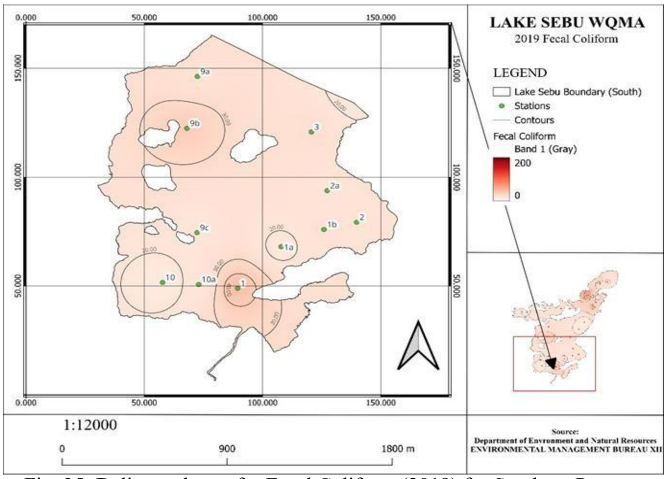

Fig. 35. Delineated map for Fecal Coliform (2019) for Southern Part Lake Sebu WQMA.

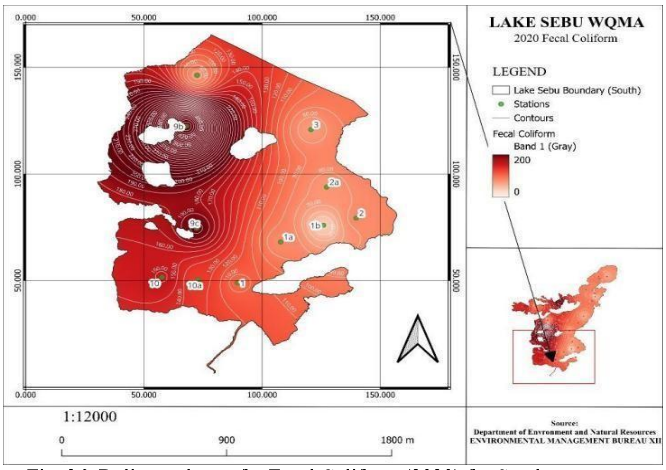

Fig. 36. Delineated map for Fecal Coliform (2020) for Southern Part Lake Sebu WQMA.

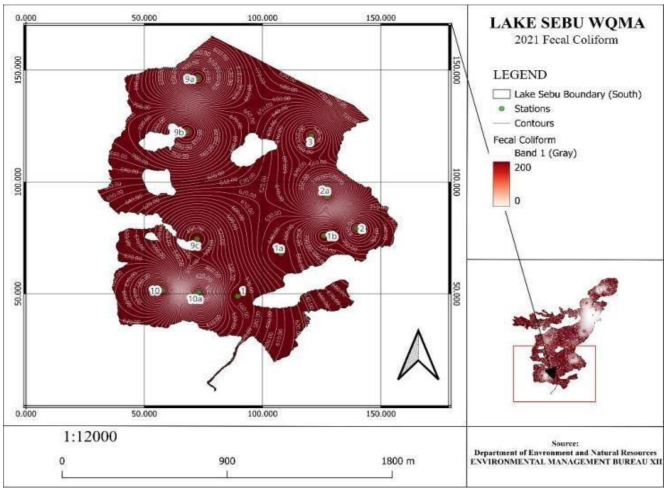

Fig. 37. Delineated map for Fecal Coliform (2021) for Southern Part Lake Sebu WQMA.

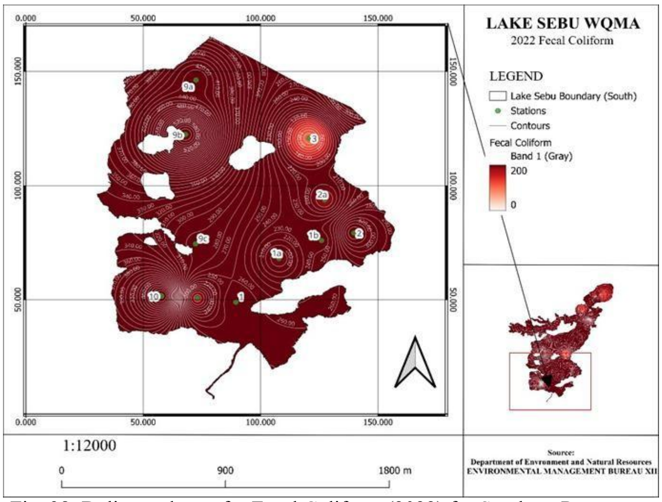

Fig. 38. Delineated map for Fecal Coliform (2022) for Southern Part Lake Sebu WQMA.

J. Fecal Coliform (2017-2022)

The fecal coliform is used to determine the bacteria that are commonly found in the human feces and other warm-blooded animals such as livestock, and fecal coliform indicate potential presence of other bacterial and viral pathogens that are in the water. The resulting map (Figure 29) shows that year 2017 and 2019 are the only year to have a minimal concentration of fecal coliform and the year 2018, 2020, 2021, and 2022, exceeded the standard.

The exceeded amount of fecal coliform indicate that the lake is susceptible in diseases that are caused by the presence of these microorganisms. Lake Sebu had parts that are designated for recreational purposes, the higher risk of waterborne disease if the contaminated water is ingested or came in contact. The effects of fecal coliforms in aquaculture and aquatic ecosystems for high concentration can lead to nutrient pollution that depleted dissolved oxygen. The possible mitigation are inspection and maintenance of septic tanks, animal waste disposal, education for proper hygiene, and regulation enforcement.

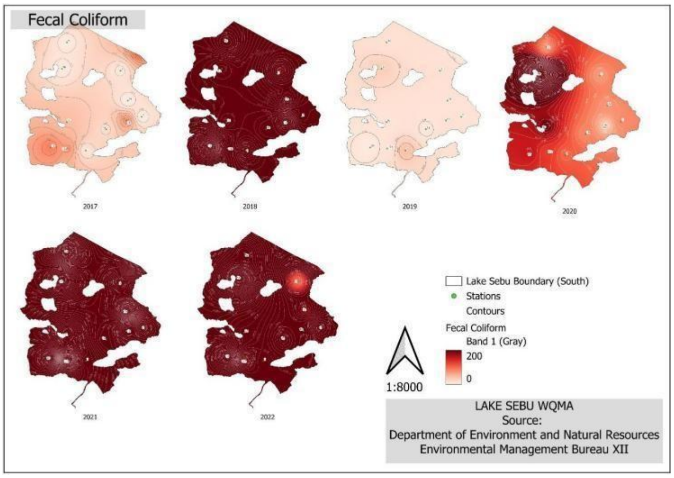

Fig. 39. The delineated trend map for fecal coliform in southern part of Lake Sebu WQMA.

K. Temperature

Temperature parameter started to be monitored in the year 2019. The resulting map shows in Figure 40, the temperature is within the standard. According to EMB XII, the water temperature affects the water characteristics, such as, it affects the amount of DO, photosynthesis of aquatic plants, and metabolic rate of aquatic species [7]. One of the factors that contributed to the resulted water temperature is, Lake Sebu has a ranging ambient temperature from 21° to 30°C due to its elevation which is approximately 702 meters above sea level.

Figure 41 shows the resulting map in 2020, in which water temperature increased compared with 2019. The explanation for this increase is the change in monitoring method. In 2020, temperature measurements were conducted in situ, providing a more direct representation of the actual temperature conditions of the lake compared with the previous monitoring approach [8].

In terms of water temperature, Figure 42 shows that the temperature in 2021 decreased compared with 2020. In 2022, as shown in Figure 43, the recorded temperature remained relatively similar to that of 2021. The delineated maps indicate that the southern portion of the lake remained within the prescribed temperature standard in both years.

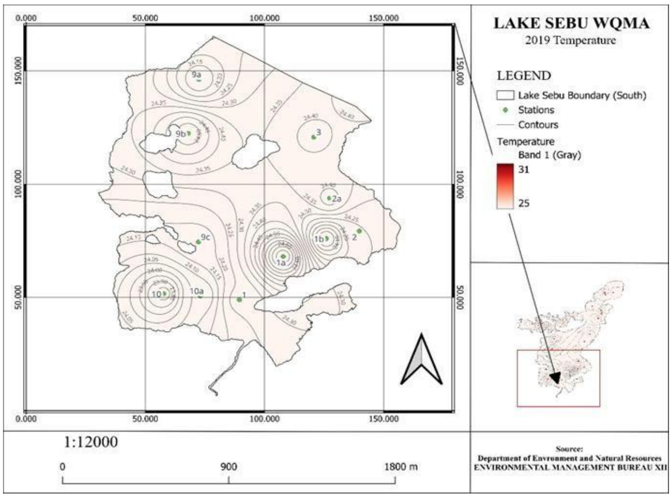

Fig. 40. Delineated map for Temperature (2019) for Southern Part Lake Sebu WQMA.

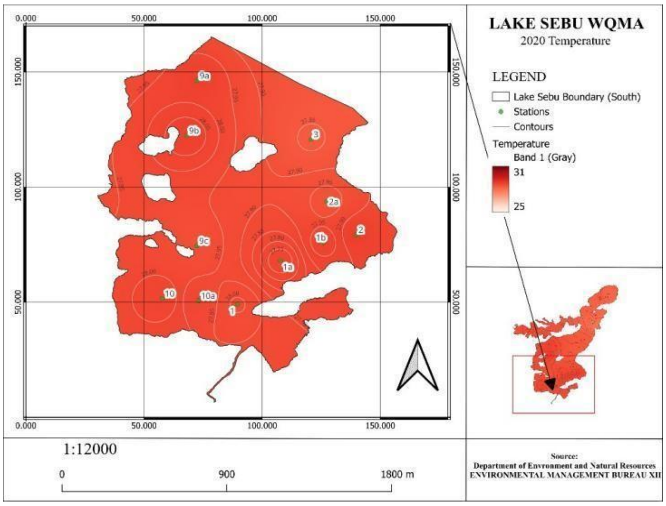

Fig. 41. Delineated map for Temperature (2020) for Southern Part Lake Sebu WQMA.

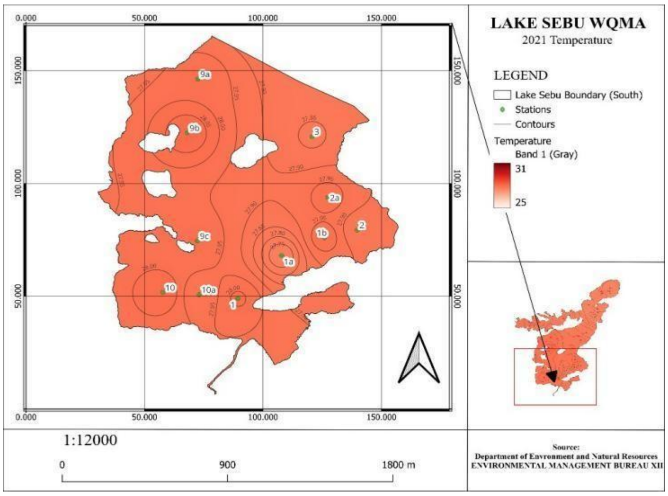

Fig. 42. Delineated map for Temperature (2021) for Southern Part Lake Sebu WQMA.

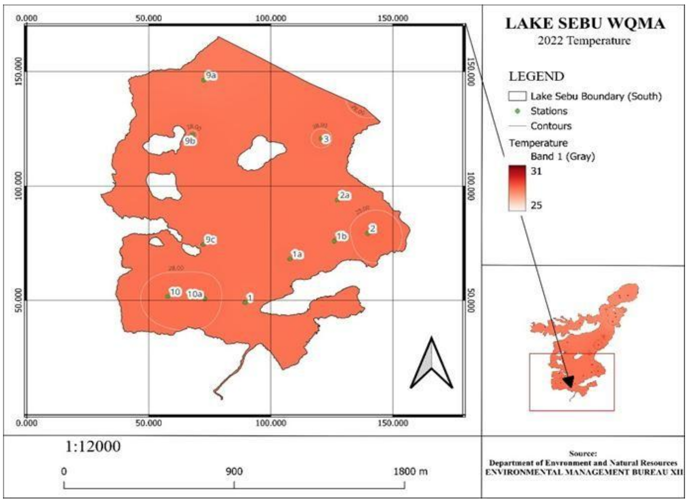

Fig. 43. Delineated map for Temperature (2022) for Southern Part Lake Sebu WQMA.

L. Temperature (2019-2022)

The delineated map (Figure 44) shows the annual temperature from 2019 to 2022. Temperature changes over time; in 2019, the temperature is at its minimum, and highest in 2020. Factors affecting the annual results of temperature is the climate of Lake Sebu, and the elevation. The delineated maps show a noticeable difference in water temperature between the monitoring years. From 2020 to 2022, the maps exhibit darker red shading compared with 2019. From 2020 to 2022, the data are in situ compared to 2019, providing a more direct representation of the actual temperature of the lake.

Temperature affects the reproduction of aquatic species in the lake and the overall development. According to EMB XII, temperature in December, January, and February is also the factors that affects the lake overturns or *kamahong* [8]. Lake Sebu are colder in these months that contributed to fish kill incidents. The measures that are performed by EMB XII to maintain standard temperature, is by clean up drives, and maintaining the cleanliness of the lake's water. However, temperature is due to the climate and weather of the place.

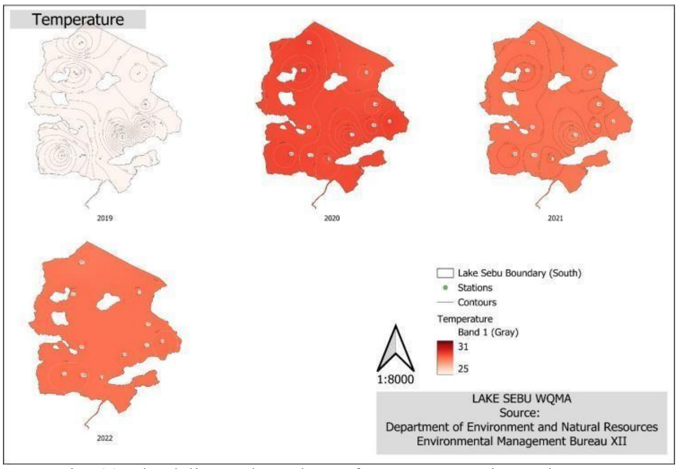

Fig. 44. The delineated trend map for temperature in southern part of Lake Sebu WQMA.

M. Oil and Grease

Oil and grease are indicators of the presence of substances that are not mixed with water that are commonly used in households and industries, such as motor oils, lubrication oils, fuels, animal fats, and cooking oils. Oil and grease parameters were started to be monitored in 2019. The resulting map shows (Figure 45) that stations in Class C are within the standard. Some stations in Class B exceeded the standard concentration, which is 1 mg/L. Factors that affect the result are associated with leaks of petroleum oil from motorboats, as well as the disposal of cooking oils from households and recreational establishments around these stations [7].

In 2020, the delineated map shows in Figure 46 that the parameter increased compared to 2019. Station in Isla Tupas, Barangay Poblacion or Station 9c which is classified as Class B are within the standard for oil and grease, while the rest of the stations under Class B exceeded the DENR standard. However, Stations 1, 1b, 2a, and 3, which is classified as Class C are within the standard and the rest of the stations exceeded. Oil and grease are highest in stations near Barangay Poblacion. Factors influencing these results are the households and establishments that direct kitchen wastes into the lake, motor engine oils that are used for transportation, and other lubrication oil for engines [8].

In 2021, the delineated map shown in Figure 47 shows that the oil and grease in Lake Sebu exceeded the standard; the maximum concentration for Class B is 1 mg/L and for Class C is 2mg/L. The delineated map shows exceedance; the highest amounts are found in Barangay Poblacion, which range from 3.60 to 6.60 mg/L, where most households are situated. Oil and grease is also the cause of a decrease in dissolved oxygen, as it has a negative effect on the amount of DO in the lake's water [9].

Figure 48, the delineated map, shows that in 2022 which exceeded the standard. The map shows that oil and grease increases annually, where Class B ranges from 4.60 to 5.20 mg/L, which indicates that the oil and grease failed the DENR standard. The highest amount can be seen in stations along Barangay Poblacion that were classified as Class C, which ranges from 3.80 to 7. The amount of oil and grease far exceeds the standard amount for water quality.

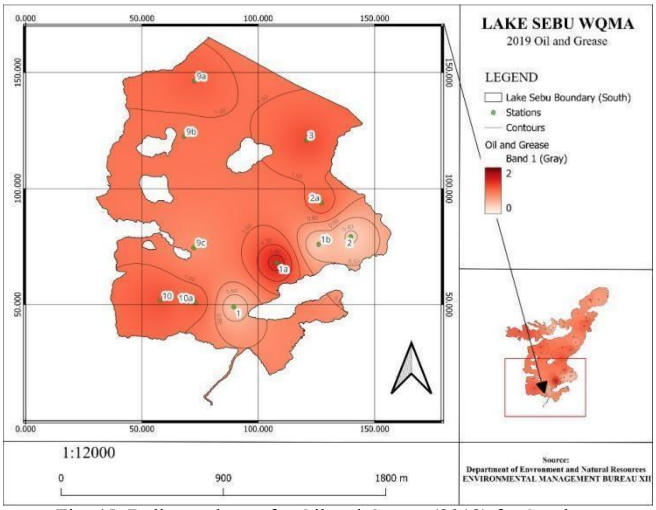

Fig. 45. Delineated map for Oil and Grease (2019) for Southern Part Lake Sebu WQMA.

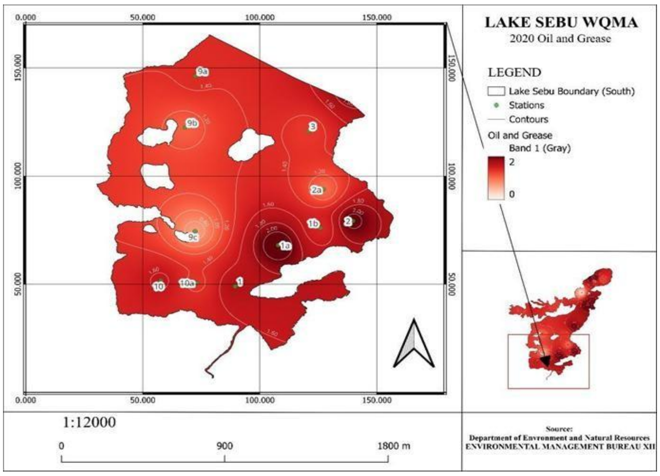

Fig. 46. Delineated map for Oil and Grease (2020) for Southern Part Lake Sebu WQMA.

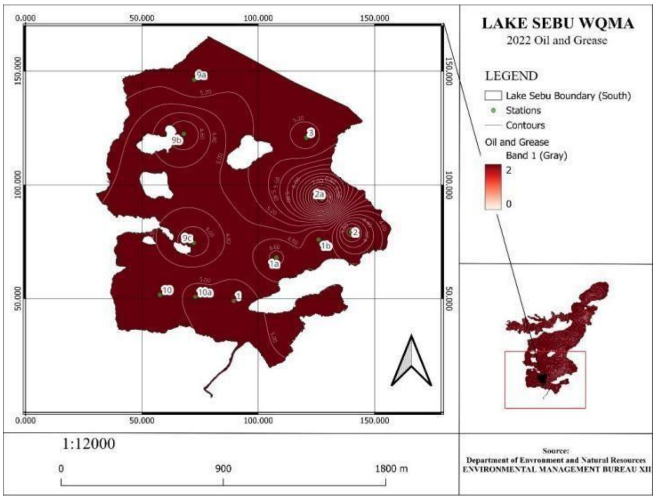

Fig. 47. Delineated map for Oil and Grease (2021) for Southern Part Lake Sebu WQMA.

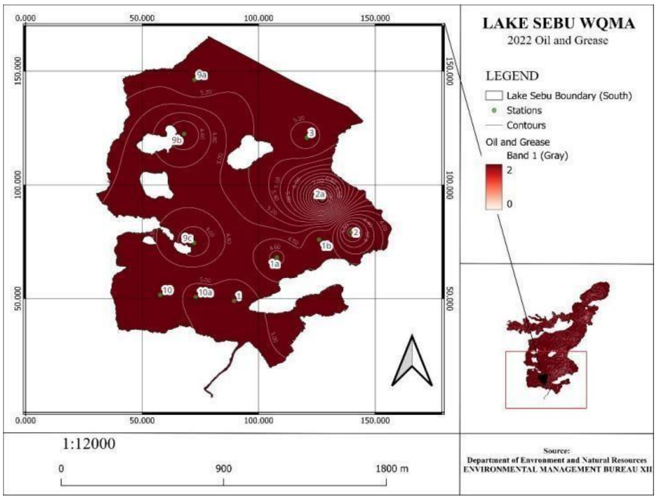

Fig. 48. Delineated map for Oil and Grease (2022) for the southern part of Lake Sebu WQMA.

N. Oil and Grease (2019-2022)

The oil and grease parameter is monitored to determine the amount of substances that are not mixed with water. The amount of oil and grease is an indicator of pollution from households and establishments that run off into the lake, and engine oils that contaminate the lake's water. The resulting map shows (Figure 49) that the only year that some stations pass the standard is the year 2019, and the rest of the years are otherwise. The delineated map shows that over the years, the amount of oil and grease increases. Oil and grease have low biodegradability, and dissolved oxygen is one of the most affected water quality parameters if oil and grease increase [11].

The effect of oil and grease on aquatic life in lakes can be detrimental, as contamination by oil and grease creates a film that blocks the exchange of oxygen from the atmosphere to the water. For recreational purposes, oil and grease have foul odors that are unappealing during recreational activities. Possible mitigation is proper waste disposal, public education, establishment of household regulations, and implementation of rules and regulations.

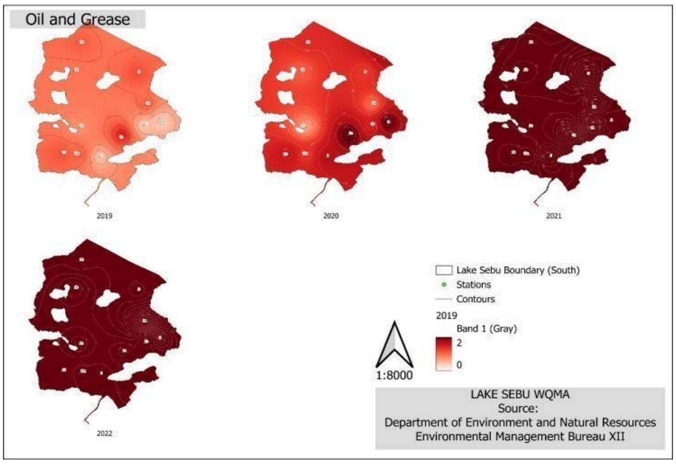

Fig.49. The delineated trend map for oil and grease in the southern part of Lake Sebu WQMA.

O. Water Quality Trend

The data from the year 2017 to 2022 showed fluctuations in terms of water quality. The pH in Figure 50 shows the year where pH level decreased and increased, especially in the year with fish kill incident. Dissolved oxygen (Figure 51) had minimal fluctuation and decreased as the pH level approached the acidic stage, and BOD (Figure 52) shows a period with a higher level that decreases the amount of DO. The spike in BOD shows the effects on DO, especially in the years 2017 and 2021, when BOD had a higher concentration while DO decreased. Temperature (Figure 55) is more stable through the years; however, in the year 2019 had a lower value due to the monitoring method. TSS (Figure 53) shows an increasing level in 2022, which indicates the number of particulates in that area. The fecal coliform shown in Figure 54 represents the significant level of contamination that spikes the amount of BOD in Figure 52. It shows that a high concentration of fecal coliform increases BOD, suggesting a sanitation issue. The continuous increase in oil and grease contamination shown in Figure 56 suggests issues in household and establishment effluents, and engine oils that are directed to the lake's water.

Overall, trends show areas with poor water quality, which are the areas around Stations 9b and 10, which are classified as Class B. Station 9b had a low pH level, low amount of DO, and moderate BOD throughout the years and had a significant contamination spike of fecal coliform. The area around Station 10 shows poor water quality, as it had a moderate pH level, low DO and highest amount of BOD. The high amount of fecal coliform indicates the pollution and other anthropogenic activities around Station 10. These targeted areas are suggested for management and intervention to improve the water quality around these stations.

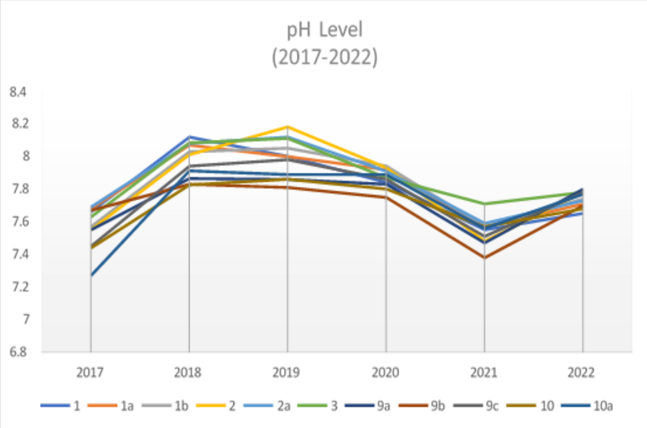

Fig. 50. The trend in terms of pH level in southern part of WQMA

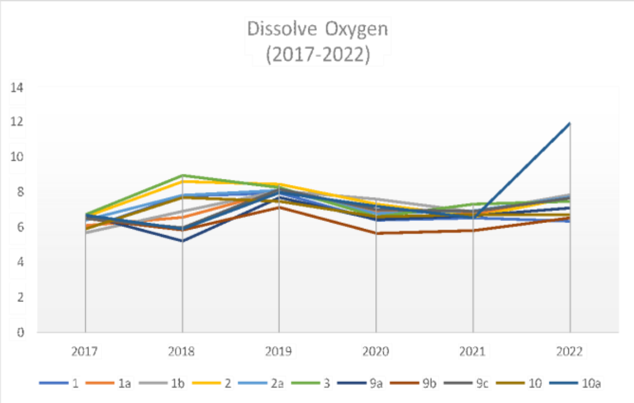

Fig. 51. The trend in terms of DO in southern part of WQMA

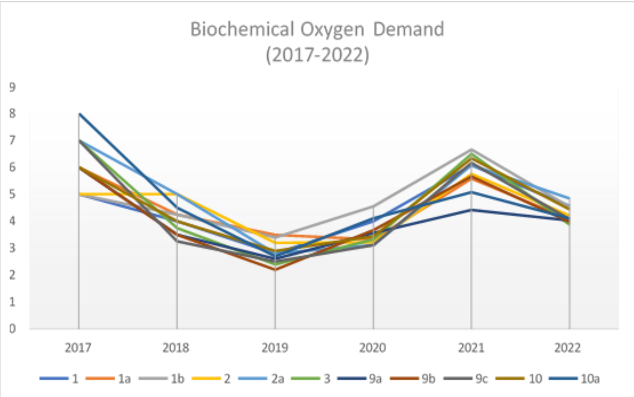

Fig. 52. The trend in terms of BOD in southern part of WQMA

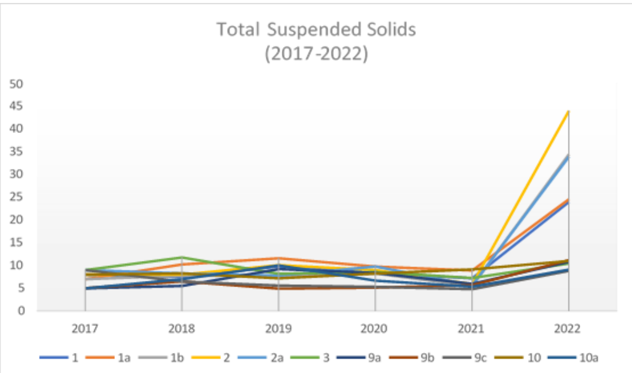

Fig. 53. The trend in terms of TSS in the southern part of WQMA

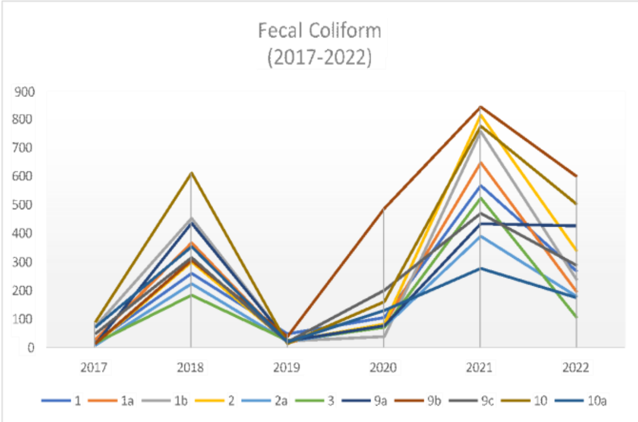

Fig. 54. The trend in terms of fecal coliform in the southern part of WQMA

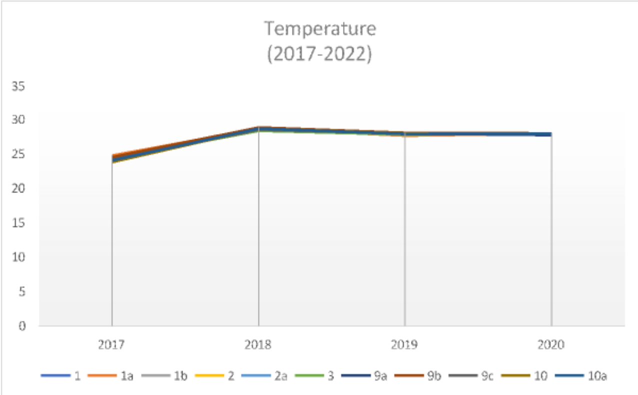

Fig. 55. The trend in terms of temperature in southern part of WQMA

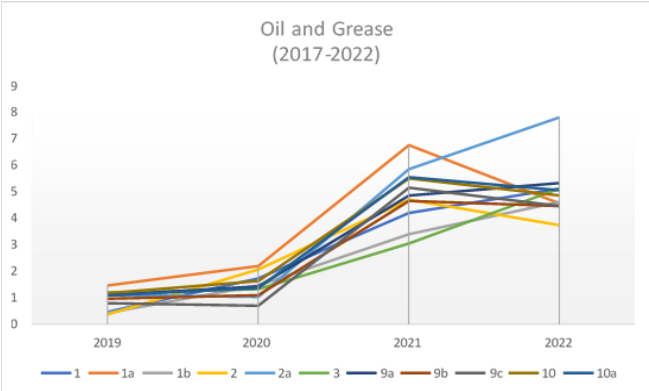

Fig. 56. The trend in terms of oil and grease in southern part of WQMA

IV. SUMMARY, CONCLUSION, AND RECOMMENDATIONS

The results of this study highlight Sustainable Development Goal 6 (SDG 6): Clean Water and Sanitation, which emphasizes universal access to safe water and adequate sanitation. The delineated maps illustrate the spatial distribution of key water quality parameters, including pH, dissolved oxygen (DO), biochemical oxygen demand (BOD), temperature, total suspended solids (TSS), fecal coliform, and oil and grease. These parameters were assessed based on the DENR Water Quality Guidelines and General Effluent Standards.

The pH, dissolved oxygen, temperature, and total suspended solids levels remained within the prescribed standards from 2017 to 2022, indicating that the water quality of Lake Sebu generally remained suitable for aquaculture cultivation during the period covered by the study. BOD levels were within the standard in 2018, 2019, 2020, and 2022, but exceeded the allowable level in 2017 and 2021. Fecal coliform levels were within the DENR standard in 2017 and 2019 but exceeded the permissible limit in 2018, 2020, 2021, and 2022. Oil and grease concentrations were within the standard in 2019 but showed an increasing trend in the succeeding years.

The deterioration of water quality has negatively affected the aquatic ecosystem and may contribute to the decline of aquatic populations. Increasing levels of BOD and oil and grease can reduce the amount of dissolved oxygen in the lake. This condition, combined with the depletion of DO below acceptable levels during the rainy season and the intensive utilization of the lake, increases the likelihood of fish kill incidents, particularly in the southern portion of Lake Sebu. Similarly, elevated levels of oil and grease and fecal coliform pose potential risks to recreational activities, such as swimming and bathing, and may compromise the safety of individuals using the lake.

Several mitigation practices can be implemented to maintain water quality within acceptable standards. These include regular cleanup drives, proper and enforced solid waste management, and the establishment and maintenance of appropriate wastewater treatment systems. The regulation of fish cage operations in accordance with the prescribed 10% utilization standard should also be strengthened. Providing alternative livelihood opportunities for communities surrounding the lake may further reduce their dependence on lake resources and minimize activities that contribute to water quality deterioration. The Environmental Management Bureau Region XII (EMB XII) has also conducted Information, Education, and Communication (IEC) campaigns to raise awareness among communities around Lake Sebu regarding human activities that contribute to water pollution and the importance of protecting the lake's water resources.

The resulting maps indicate that 2019 had the best overall water quality, with the monitored parameters generally within the prescribed standards. The spatial maps also identified areas associated with major fish kill incidents and revealed temporal and spatial trends in water quality deterioration. In particular, the southern portion of Lake Sebu showed a gradual decline in water quality, with most of the observed deterioration associated with anthropogenic activities.

Future studies should employ quantitative approaches, such as the Water Quality Index (WQI), to provide an integrated assessment of the overall water quality of Lake Sebu. On-site assessments are also recommended to determine the specific human activities surrounding the lake that contribute to water quality deterioration. Future researchers should consider collecting monthly water quality data to establish more detailed temporal trends, particularly during the wet season when changes in water quality may be more pronounced. Further studies should also examine water-surface utilization and fish stocking density, as well as identify specific point and non-point sources contributing to increasing levels of pollutants in the lake. These approaches can provide a stronger scientific basis for developing sustainable water resource management strategies and protecting the ecological integrity of Lake Sebu.

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