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Seasonal fluctuation of nutrients and primary productivity of the coastal waters of Culaman, Malita, Davao Occidental, Philippines

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ABSTRACT. The study was conducted to determine the nutrient and chlorophyll-a concentration of coastal water at Barangay Culaman, Malita, Davao Occidental, between two seasons. One shot sampling was done during the rainy season on November 19, 2017, and November 26, 2017. It was also done during the summer season on March 6, 2018, and March 11, 2018. Water samples were collected in the surface (5-10 cm depth) and subsurface (below 1m depth). Nutrients were analyzed in terms of their concentration expressed in mg/L, including ammonia, nitrate, nitrite, and phosphate. Chlorophyll-a was included being the most reliable index of primary productivity in seawater. Nitrate, nitrite, phosphate, and chlorophyll-a showed high concentrations during the rainy season, while ammonia exhibited a high concentration during the summer season. Further, nutrients were found in high concentrations from surface water compared to those from subsurface water. There were no significant differences in nutrient and chlorophyll-a concentrations between stations except for nitrate. In terms of its concentration between rainy and summer season and between surface and subsurface waters, there were no significant differences in ammonia, nitrate, and phosphate. However, significant differences in the concentrations of nitrite and chlorophyll-a between the rainy and summer season and between surface and subsurface water samples were observed. The prevailing levels of temperature, salinity, dissolved oxygen, and turbidity observed during sampling were found to be normal.

Keywords: *coal plant, chlorophyll-a, nutrient, phytoplankton, water quality*

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INTRODUCTION

Water quality plays a significant role in maintaining the health of biotic communities in aquatic ecosystems (Ganguly et al., 2015). However, due to the increasing human population inhabiting the coastal areas of the world, this aquatic and marine ecosystem is very susceptible to man-made disturbances, which could fluctuate the normal condition of its surrounding water (Harvey et al., 2015). The most common anthropogenic effect in the marine environment is the introduction of nitrates and phosphates as humans in agriculture, household, and industry were using these nutrients. Nutrients such as nitrates, nitrites, ammonia, and phosphate are vital in the marine ecosystem as they serve as limiting agents in the marine waters that influence primary production (Abdelmongy and El-Moselhy, 2015; Hardison et al., 2015). Further, these nutrients, if it is in excess, could be a source of contamination and may lead to eutrophication (Schraga and Cloern, 2017), an abnormal increase in nutrient loads as an effect of too much nutrients carried by runoffs during precipitations which is identified as major environmental problems by researchers (Huo et al., 2015). Therefore, nutrient enhancement was directly influenced by changes in season, as discussed by various literature (Abdelmongy and El-Moselhy, 2015; Baek et al., 2015; Steele et al., 2015; Stuhldreier et al., 2015).

Nutrients in the oceans are transported via biological and physical processes. This distribution helps in the growth of phytoplankton which is the main producer under the sea. Nutrient rich sea water is present on the surface brought by the upwelling and physical processes like the movement of seawater horizontally and are essential in nutrient distributions (Chen, 1997). According to Takeda (1998), seawater nutrient is found abundant in the surface water in which planktonic creatures are present because of the nutrients present and the sunlight. Nitrate, phosphate, and silicate, the major nutrient found in sea water and needed for phytoplankton growth, is found in seawater surface. Chlorophyll–a was considered the most reliable index of phytoplankton biomass (Senthilkumar et al., 2008). Also, Jamshidi and Abu Bakar (2011) said that increasing concentrations of chlorophyll-a in seawater, in reaction to the elevation of nutrient supply, can have severely damaging effects on the marine environment. Chlorophyll concentration is one of the key indices in the study of the health status of any natural marine ecosystem.

Seasonal fluctuations in nutrients and chlorophyll-a concentration were common (Vase et al., 2018). Normally, nutrient and chlorophyll-a concentrations were high during the wet season as it was influenced by effluents from runoffs and increased precipitations during rainy months (Blakey et al., 2015; Hitchcock and Mitrovic, 2015; Villanoy et al., 2011). However, there are instances when nutrients were low during the wet season as phytoplankton is utilized quickly under certain conditions like stratification (Baek et al., 2015). Eutrophication ends up in poor water conditions. Common observations in eutrophic waters were a hypoxic environment, decreasing vegetation, and harmful algal blooms (HABs), which negatively affect fisheries and tourism due to the decomposition of excess algae (Rajaee and Boroumand, 2015). Moreso, the continued influx of excess nutrients that leads to severe eutrophication may create an intrusion into ecosystem functioning and a change in trophic structure (Silva et al., 2015). As highlighted, it is important to study nutrient and chlorophyll-a concentrations in coastal waters especially in areas where human populations exist and contamination sources are observed, like in the case of Malita, Davao Occidental, Philippines.

The Philippines' coastal seas receive discharges from rivers, drainage, aquaculture, and mariculture parks, significantly affecting water quality degradation that would later affect biodiversity (Abreo et al., 2015; San Diego-McGlone et al., 2008; Taniguchi et al., 2008). The Philippines is an island nation that heavily depends on fishery resources, especially those living in the coastal areas like in the Davao region, where they harvest kinds of seafood like shellfish and small pelagic fishes (Bersaldo et al., 2023;

Bersaldo and Lacuna, 2022). Like in other countries, the Philippine fishery is dwindling due to anthropogenic stressors, including marine pollution like increased nutrients and other pollutants in the marine environment (Karydis and Kitsiou, 2013; Macusi et al., 2020). Given the negative impacts of nutrient enhancement on the marine environment and the possible shifts in environmental parameters which could affect the biological functioning of the water system (Karydis and Kitsiou, 2013), it is important to monitor the quality of water in the coastal areas for possible contamination due to increased nutrients that may inhibit eutrophication (Liu et al., 2011). With this, the current study was conducted to provide baseline information about the nutrient and chlorophyll–content of sea water in Barangay Culaman, Malita, Davao Occidental, during dry and wet seasons.

MATERIALS AND METHODS

Description of Study Area

The study was conducted at Barangay Culaman, Malita, Davao Occidental, with a land area of 3,418 hectares and was among the coastal barangay of Municipality of Malita. The distance from Barangay Poblacion to this area is approximately 3.55 km. Its geographical coordinates are latitude 6˚ 23' 32.98'' N and longitude 125˚ 37' 12.13'' E, and it is where the Coal-Fired Power Plant is located, the biggest coal fired power plant in Mindanao. The coastline of Barangay Culaman is covered by Aquacor and Sitio Inaburan, as shown in Figure 1, and receives freshwater effluents from the Malita River, Culaman irrigation canal and powerplant waste water canal. Residential houses along its coast were also evident where fishing was their main source of livelihood.

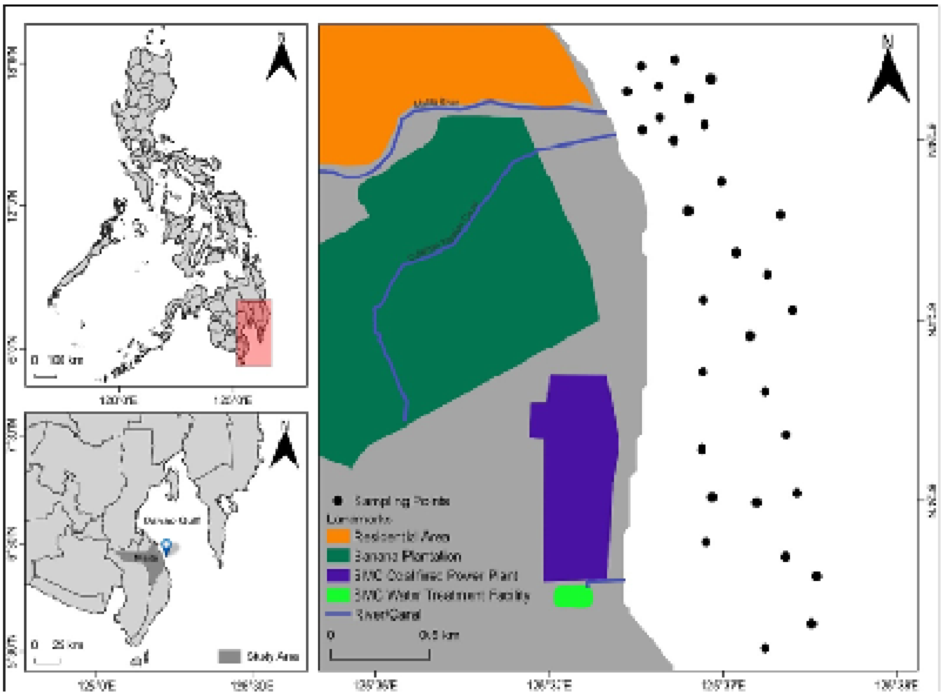

Figure 1. Map of Brgy. Culaman, Malita, Davao Occidental

Selection of sampling points

Preliminary observations were done to map out the three different sampling stations in the study area. The three sampling stations were located near the study area, 50 meters perpendicular to the shoreline. Water samples were collected on the sea surface with 5 to 10 centimeter depth and sub-surface at exactly 5 meters below surface water. The first station was established on the river mouth of Malita River, which this river network runs through agricultural land and residential areas of the municipality, second station was along the seas of Aquacor, in which less than 0.5 kiometer from the shoreline is a banana plantation. An irrigation canal flows from the banana plantation to the coast was observed. The third station was along the port of Malita Coal Fired Power Plant, in which there is a water treatment facility that releases water directly to the coastal sea, and numerous residential houses nearby were also noted. The sampling sites were identified based on the assumption that a possible nutrient point source could influence nutrient enhancement in the area.

Collection of Water Samples

The water samples were collected randomly in three different sampling stations in the study area and 50 meters perpendicular to the shoreline. Wherein in each sampling stations, there were five randomly cited sampling points that was tagged through GPS way points and had a 20 – 30 meters interval at each point. Samples were obtained vertically, in the sea surface and sub-surface at exactly one meter below the surface water, composed of ten collected water samples in each station. The water samples were collected with the use of D.O. bottles to collect water samples. The water samples were placed in a sterilized empty water bottle that was rinsed three times with water to be collected in the sampling area and labeled according to Stations, water columns, and replicates. The collected water samples were placed in an ice bucket with ice tubes to preserve and maintain the freshness of the samples prior to the laboratory analysis of the nutrients and chlorophyll–a. Sampling was done twice every season.

Sea Water Analysis

The nutrients like nitrate, nitrite, ammonia, and phosphate were subjected to water analysis using API saltwater master test kit marine and were analyzed on site. Water samples were brought to the SPAMAST General laboratory for extraction and analysis of chlorophyll-a using the spectrophotometric method. The SHIMADZU AA-7000 model spectrophotometer was used, and the wavelength was set at 645 and 663 nanometers. The chlorophyll content was determined by using the formula of Arnon (1949) equation:

$$\text{Total chlorophyll (mg/L)} = 20.2(A645) + 8.02(A663)$$

Where A=absorbance at respective wavelengths

Physico-chemical Parameters

The temperature of surface water was determined on site using a mercury thermometer. To obtain surface water temperature, the lower half of the thermometer was immersed into the upper few cm. of the water column for 1 minute. Obtained measurements were recorded. The salinity of water samples was determined using a handy ATAGO refractometer. One or two drops of the water samples were placed on the prism, and the salinity reading was obtained directly by looking at the scale through the eyepiece. The line separating the clear and blue spheres indicates the salinity level. Dissolved oxygen was determined on-site using a handy D.O. meter. Using a secchi disk, the transparency of the sampling area was determined by lowering the secchi disk in the water at each sampling station until it became invisible to the observer. At the point of disappearance, the string submerges were marked at the surface water level. The secchi disk was lifted, and the length of the string submerged from the surface to the secchi disk was measured with the use of a meter stick. The reading was recorded in centimeters.

Data Analysis

Data analyses on different nutrients and chlorophyll-a in the three stations were done using the Analysis of Variance (ANOVA) at a 0.05 level of significance. Tukey's test was further used to establish significant differences between sampling stations. Moreover, paired sample t-test was also used to determine significant differences in the different nutrients and chlorophyll-a between surface and sub-surface water and rainy and summer seasons. Analyses were carried out with IBM SPSS V.20 and Microsoft Excel 365.

RESULTS AND DISCUSSION

Nutrients and chlorophyll-a (Chl-a) concentration during rainy and summer season

The study on nutrients and primary production of the coastal water in barangay Culaman was conducted in two seasons (rainy and summer) and two water depths (surface and subsurface). This study was done twice every season. During the rainy season, the study was conducted on November 19, 2017, and November 26, 2017, while during the summer season, sampling was done on March 6, 2018, and March 11, 2018, respectively. Nutrient concentrations were determined qualitatively, including ammonia, nitrate, nitrite, and phosphate, because according to Rajakumar et al. (2008), nutrients that are commonly found in the marine environment are nitrogen base compounds. Accordingly, Grasshoff (1976) added that in marine ecosystem analysis and budgets, phosphorus, and nitrogen are inevitably the most important, and Huang et al. (2017) claim that it can be introduced to the aquatic environment via runoffs coming from agricultural lands which use fertilizers to their crops. Further, chlorophyll-a was also included in the study since chlorophyll concentration is one of the key indices in the study of the condition of any natural marine ecosystem (Abu Bakar, 2011).

The data in the concentration of each nutrient and chlorophyll-a in the study area during rainy and summer seasons from surface (5-10cm deep) and sub-surface (5m deep) water samples are presented in table 1. During the rainy season, results revealed surface water concentration of ammonia ranged from 1.13-1.28 mg/L, nitrates from 5.50-8.00 mg/L, nitrites range from 2.50- 2.60 mg/L while phosphates ranged from 3.20 mg/L to 4.10 mg/L. Chlorophyll-a ranged from 5.00 mg/L to 5.56 mg/L. On the other hand, the sub-surface water samples showed a concentration ranging from 1.15-1.30 mg/L for ammonia, nitrates 5.50-8.00 mg/L, nitrites 1.65-2.05 mg/L, phosphates ranged 3.15-3.70 mg/L, and chlorophyll-a concentration was 3.99-4.40 mg/L.

During the summer season, surface nutrients concentrations in ammonia ranged from 2.85-3.00 mg/L, nitrates from 1.50-3.00 mg/L, nitrites 1.33-1.45 mg/L while phosphates ranged from 1.40-1.85 mg/L and chlorophyll-a concentration ranged from 2.16-2.36 mg/L. In terms of nutrient and chlorophyll concentrations in subsurface water during the summer season, the concentration of ammonia was from 2.75-2.80 mg/L, nitrates ranged from 1.50-3.00 mg/L while nitrites ranged from 1.13-1.20 mg/L, phosphates ranged from 1.28 -1.40 mg/L and chlorophyll-a concentration was from 1.26-1.45 mg/L. Based on statistics, no significant difference was observed between stations for surface and sub-surface water ($p>0.05$). Further, analysis for nitrite and chlorophyll-a analysis between seasons and between water depths showed significant differences ($p<0.05$). These results were comparable to that of Senthilkumar et al. (2008), who stated that the concentration of chlorophyll-a is high during the wet season due to monsoonal runoff. Also, the concentration of nutrients and chlorophyll-a between surface and subsurface water was perhaps dictated by the upwelling and physical processes (Chen, 1997)(Cervantes-Duarte et al., 2015). Whereas nitrate showed a significant difference in between stations ($p<0.05$), these results were supported by the statement of Page et al. (1995) that nitrate-nitrogen concentration decreased with increasing salinity.

Table 1. Concentration of nutrient and chlorophyll-a of seawater in the study area (mg/L).

	Station	Rainy Season			Summer Season		
		1	2	3	1	2	3
Surface	NH_3	1.2±0.12^b	1.13±0.12^b	1.28±0.12^b	2.85±0.14^b	3±0.14^b	2.95±0.14^b
	NO_2	2.5±0.29^b	2.6±0.29^b	2.5±0.29^b	1.33±0.14^b	1.38±0.14^b	1.45±0.14^b

Surface	NO^3	8 ± 0.48^{a}	6 ± 0.46^{a}	5.5 ± 0.48^{a}	3 ± 0.41^{f}	1.5 ± 0.41^{f}	2 ± 0.41^{f}
	PO^4	3.3 ± 0.41^{b}	4.1 ± 0.41^{b}	3.2 ± 0.41^{b}	1.63 ± 0.41^{b}	2.36 ± 0.41^{b}	2.16 ± 0.41^{b}
	Chl-a	5.56 ± 0.07^{c}	5.41 ± 0.07^{c}	5 ± 0.07^{c}	2.32 ± 0.05^{g}	2.36 ± 0.05^{g}	2.16 ± 0.05^{g}
Sub-surface	NH^3	1.3 ± 0.12^{b}	1.15 ± 0.12^{b}	1.23 ± 0.12^{b}	2.75 ± 0.14^{b}	2.8 ± 0.14^{b}	2.8 ± 0.14^{b}
	NO^2	1.65 ± 0.29^{b}	2 ± 0.29^{b}	2.05 ± 0.29^{b}	1.13 ± 0.14^{b}	1.2 ± 0.14^{b}	1.13 ± 0.14^{b}
	NO^3	8 ± 0.48^{d}	5.5 ± 0.48^{d}	5.5 ± 0.48^{d}	3 ± 0.41^{h}	2.5 ± 0.41^{h}	1.5 ± 0.41^{h}
	PO^4	3.15 ± 0.41^{b}	3.7 ± 0.41^{b}	3.25 ± 0.41^{b}	1.3 ± 0.41^{b}	1.4 ± 0.41^{b}	1.28 ± 0.41^{b}
	Chl-a	4.34 ± 0.07^{e}	4.4 ± 0.07^{e}	3.99 ± 0.07^{e}	2.32 ± 0.05^{i}	1.43 ± 0.05^{i}	1.26 ± 0.05^{i}

Note: Different superscript denotes significant difference

The comparison of the concentration of nutrients and chlorophyll-a in the study area is shown in Figure 2-6. The data revealed that there was a high concentration level of nutrients and chlorophyll-a in surface water samples. Results conform to the study of Chen (1997), who stated that nutrient rich seawater is present on the surface brought by upwelling processes and physical processes like the movement of seawater horizontally and are essential in nutrient distribution. Additionally, figure 2-6 also serves as the graphical presentation of nutrients and chlorophyll-a during rainy and summer seasons. It was evident that during the rainy season, there was a high concentration of nutrients, especially nitrate, nitrite, and phosphate, as well as Chlorophyll-a. This was due to nutrient influx that came from industrial, agricultural, and residential runoff (Jamshidi and Abu Bakar, 2011). Chlorophyll-a was also noted higher during rainy season than in the summer season. Findings of the present study was like that reported by Jamshidi and Abu Bakar (2011) and Senthilkumar et al. (2008), which revealed that increased concentration of chlorophyll-a in seawater was in reaction to the elevation of nutrient load due to monsoonal runoff. The increase in the concentration of ammonia during the dry season is exactly the opposite as observed in other nutrients and chlorophyll-a. This observation coincided with the result reported by Senthilkumar et al. (2008).

Based on the Department of Environment and Natural Resources classes of coastal and marine waters revised by DENR administrative ordinance number 23, series of 1997, the coastal waters of barangay Culaman were under in class S.D. Coastal and marine water class S.D. was identified as (1) industrial and water supply II (ex. Cooling, etc.) and (2) other coastal and marine waters by their quality belong to this classification. Water quality guidelines and effluents standards of the Department of Environment and Natural Resources (DENR) was the basis for identifying if the results were still on the normal level of concentrations.

The data obtained in the study showed that major nutrients in seawater, such as nitrate (5.5 mg/L to 8 mg/L), nitrite (2.5 mg/L to 2.6 mg/L), phosphate (3.2 mg/L to 4.1 mg/L) and chlorophyll-a (5 mg/L to 5.56 mg/L) was high during rainy season compared to the readings during summer season like nitrate (1.5 mg/L to 3 mg/L), nitrite (1.33 mg/L to 1.45 mg/L), phosphate (1.63 mg/L to 2.36 mg/L) and chlorophyll-a (2.16 mg/L to 2.32 mg/L). This was an indication of nutrient influx that came from industrial, agricultural, and residential runoff (Jamshidi and Abu Bakar, 2011). Chlorophyll-a was also noted higher during the rainy season than summer season. Findings of the present study was in consonance with the report of Jamshidi and Abu Bakar (2011) and Senthilkumar et al. (2008), who reported that increased concentration of chlorophyll-a in seawater was in reaction to the elevation of nutrient load due to monsoonal runoff. However, ammonia concentration was high during summer season, and the same result was also observed in the study of Senthilkumar et al. (2008).

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Nutrients and chlorophyll-a were also noted higher in the surface water than the subsurface water, and this is due to the upwelling and downwelling process at the shelf break and the shoreline (Mihailov et al., 2010). Based on the primary parameters and effluent standards set by the Department of Environment and Natural Resources, the results of the nutrients (nitrates and phosphates) were in normal range since the standard concentration of nitrates and phosphates based on the set parameters by the DENR was, nitrates 15 mg/L and phosphates 5 mg/ L in class S.D. of the water classification of coastal and marine waters (Gonazales and Cleofas, 2008).

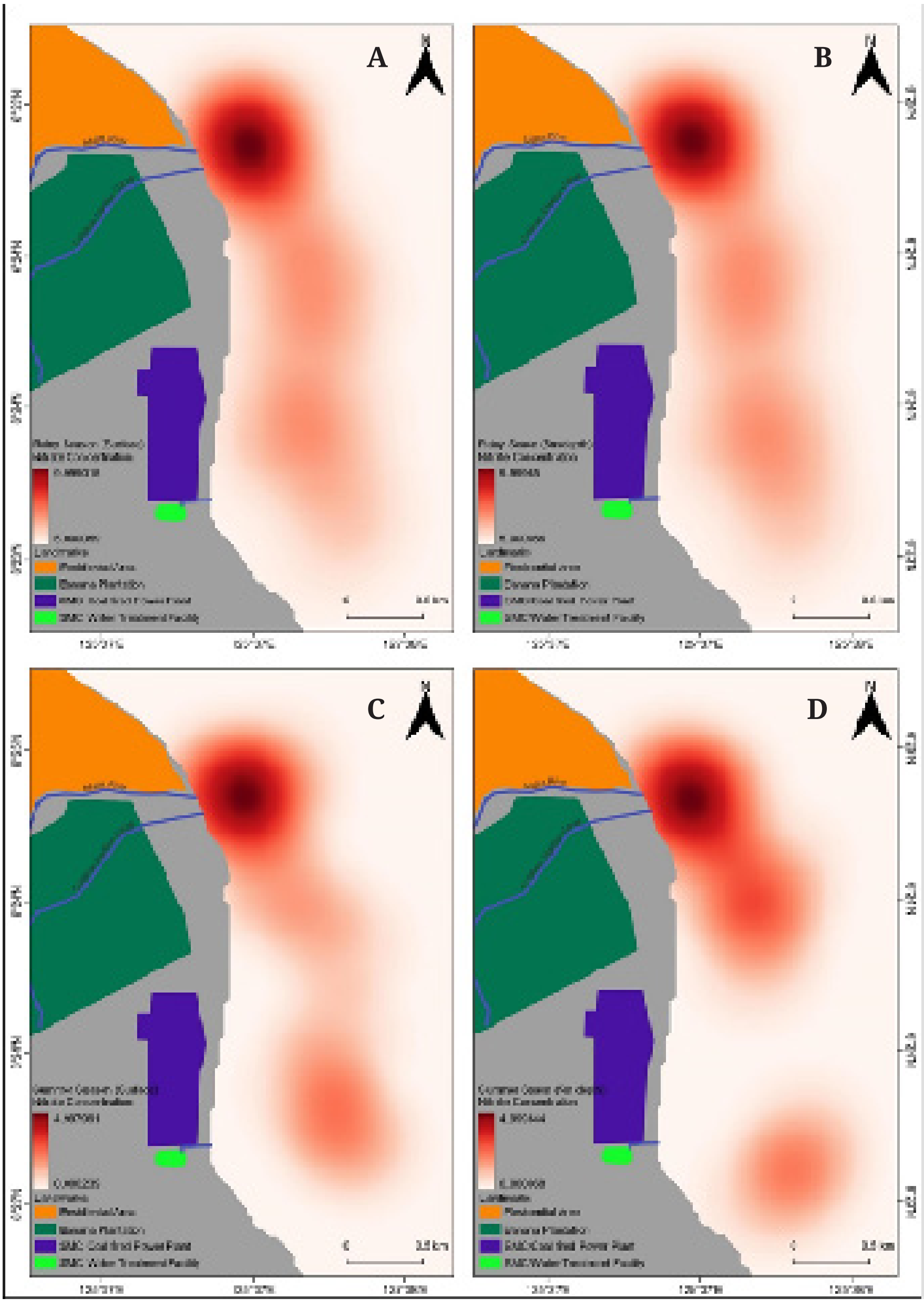

Figure 2. Nitrates concentration in (A) surface water and (B) subsurface water during rainy season and (C)surface water and (D) subsurface water during summer season.

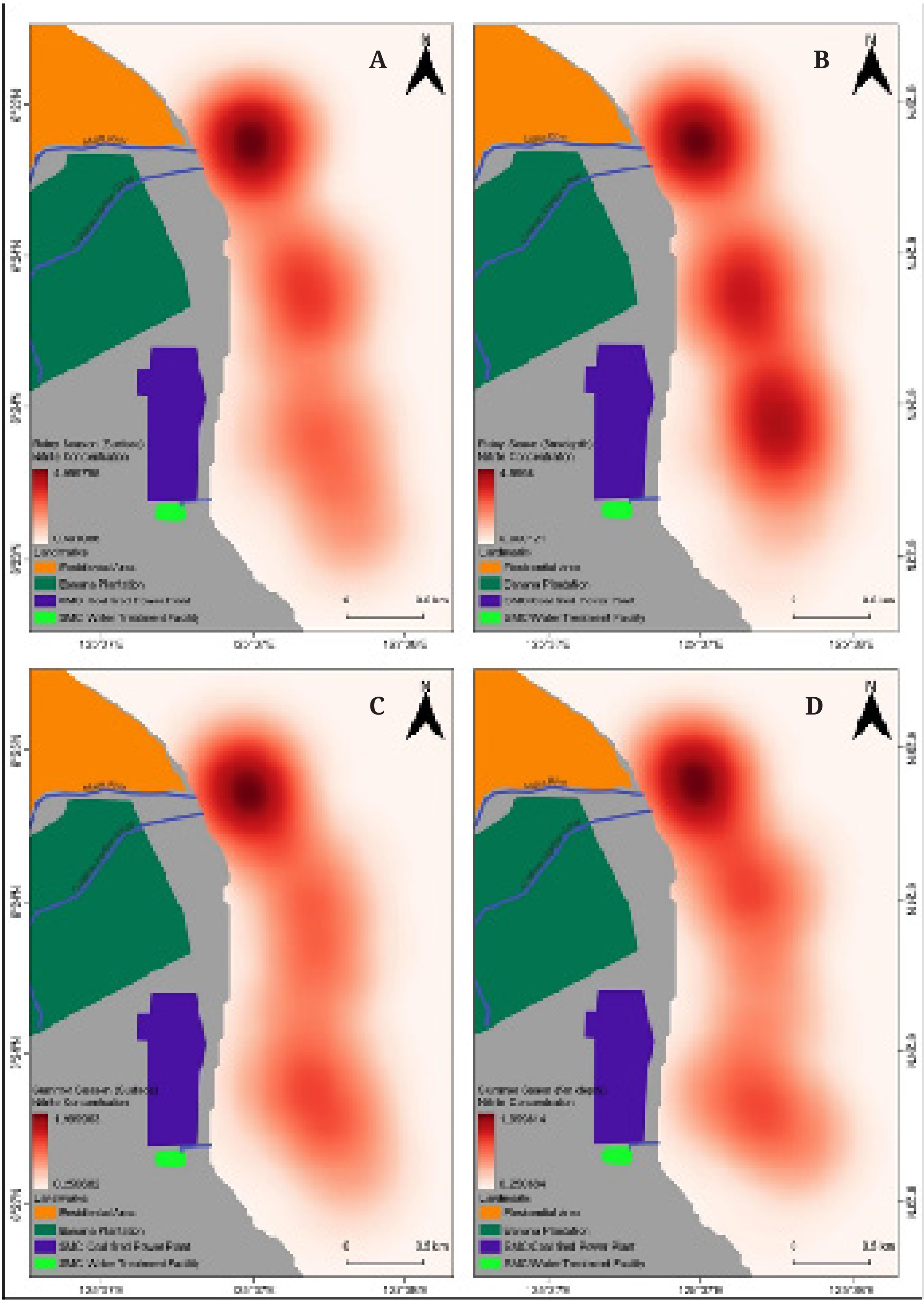

Figure 3. Nitrites concentration in (A) surface water and (B) subsurface water during rainy season and (C) surface water and (D) subsurface water during summer season.

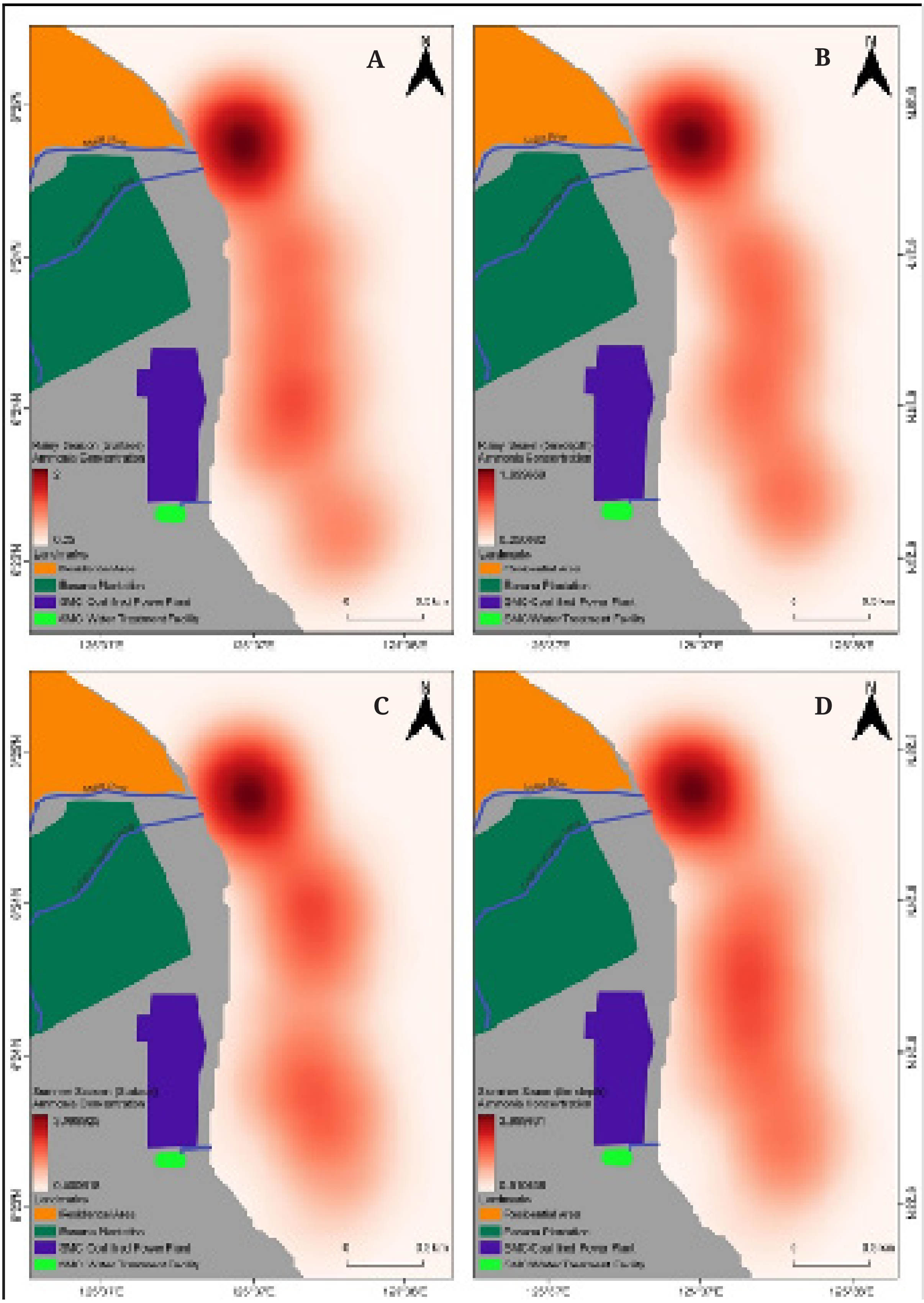

Figure 4. Ammonia concentration in (A) surface water and (B) subsurface water during rainy season and (C) surface water and (D) subsurface water during summer season.

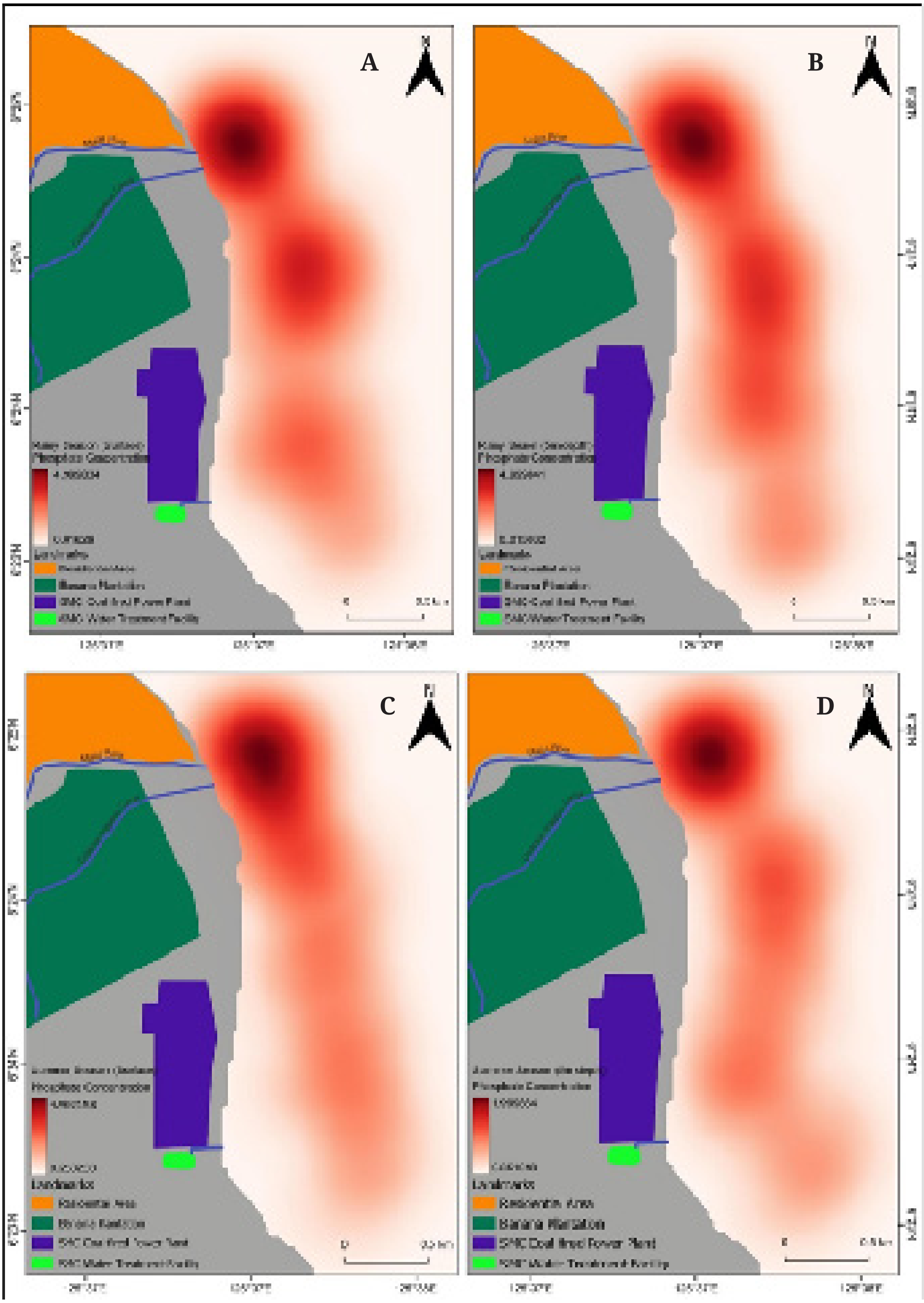

Figure 5. Phosphate concentration in (A) surface water and (B) subsurface water during rainy season and (C) surface water and (D) subsurface water during summer season.

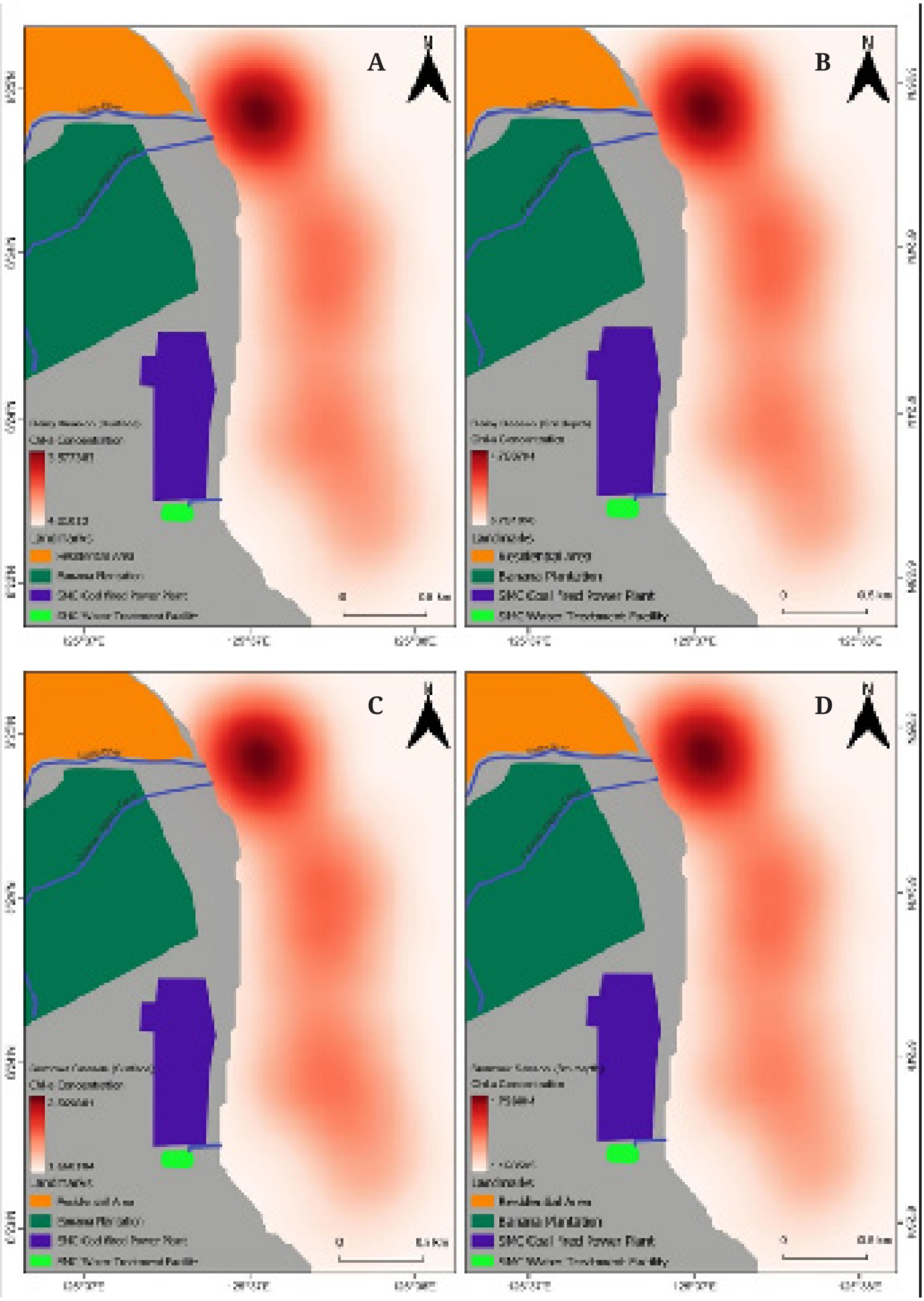

Figure 6. Chlorophyll-a concentration in (A) surface water and (B) subsurface water during rainy season and (C) surface water and (D) subsurface water during summer season.

Physico-chemical Parameters

The physico-chemical parameters monitored in the study area during the rainy and summer season are presented in Table 2. During rainy season the temperature ranges from 28^{O}C to 29^{O}C in the study area, salinity ranged from 30.5 ppt to 33.5 ppt, dissolved oxygen was 7.16 ml/L to 8.15 ml/L, and turbidity was in the range of 268 cm to 472 cm in summer season, the result were as follows: temperature 29^{O}C to 30.5^{O}C, salinity 32 ppt to 34.5 ppt, dissolved oxygen 5.58 mg/L to 6.02 mg/L and turbidity ranges from 489 cm to 634 cm. Results revealed that variation between rainy and summer seasons was observed as temperature and salinity were highest during dry season while dissolved oxygen was high and turbidity was shallower during the rainy season. Normally sea surface temperature is influenced heavily by the availability of sunlight and is commonly high during summer when the solar insolation was greatest (Chen, 2019). Further, temperature and salinity were directly proportional to each other as warmer seawater temperature influences an increase in salinity due to less precipitation and freshwater tributaries and an increased evaporation rate that makes the seawater more saline (Whitehouse et al., 1996). Moreover, dissolved oxygen was normally high during summer season as less sedimentation were mostly observed during this time (Fitri et al., 2021). However, the current study showed that dissolved oxygen was higher during rainy season than summer season though both seasons were above the optimum D.O. level of 4 mg/L. The variability of dissolved oxygen between different seasons might be due to the changed concentration of nutrients between two different time scales (Lu and Gan, 2015; Ning et al., 2004). Water turbidity is also one of the parameters to consider when investigating water quality, as it can affect the productivity of a specific seawater. Depending on the season, the magnitude of turbid water changes since, usually during rainy season, it is very common observation that seawater was very turbid especially if there is a presence of a nearby river (Onabule et al., 2020; Starkey and Karr, 1984). The result of the current study in seawater turbidity where in consonance with other published study which observed high turbidity during wet season due to the influx of sediments from upstream via river runoffs (Elmanama et al., 2006; Takada et al., 2005).

Table 2. The physico-chemical parameters monitored during rainy and summer season.

	Station 1	**Station 2**	**Station 3**
Temperature (Rainy)	28.5^{O}C	28^{O}C	29^{O}C
Temperature (Summer)	29.5^{O}C	29^{O}C	30.5^{O}C
Salinity (Rainy)	30.5 ppt	33.5 ppt	33 ppt
Salinity (Summer)	32 ppt	34.5 ppt	34 ppt
D.O. (Rainy)	8.15 mg/L	7.62 mg/L	7.16 mg/L
D.O. (Summer)	5.83 mg/L	5.58 mg/L	6.02 mg/L
Turbidity (Rainy)	268 cm	472 cm	439 cm
Turbidity (Summer)	489 cm	634 cm	578 cm

CONCLUSION

Water quality monitoring is important in coastal marine environments, especially in areas that are constantly exposed to possible sources of pollution like rivers, drainage, and domestic sewage networks that could inhibit eutrophication. Barangay Culaman, Malita, Davao Occidental coastal waters are no exemption with the above-mentioned drivers of marine pollution. Rainy and summer season along with surface variability

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and sub-surface) observation of nutrients and chlorophyll-a was done, and variations were noted. Most nutrients like nitrates, nitrites, ammonia, and phosphates including chlorophyll-a were noted to have higher values during rainy season and only ammonia havehigher values during summer season. The seasonal differences of nutrients and chlorophyll-a between dry and wet season are influenced by the concentration of nutrients added to the seawater during wet season. In terms of nutrient and chlorophyll-a concentration between surface and sub-surface levels, it was observed that surface concentrations were higher. The different concentration observed in surface and sub-surface water were driven by coastal upwelling and downwelling processes. Accordingly, it is important to have continued monitoring of the quality of water in the coastal area of barangay Culaman, Malita, Davao Occidental to detect potential eutrophic water condition which can greatly affect the water system's health and therefore, wastewater treatment should be a top priority to maintain the quality of the coastal water of Malita, Davao Occidental.

CONFLICT OF INTEREST

The authors declared no conflict of interest.

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