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Assessing the impact of eutrophication and hourly discharge on dissolved oxygen fluctuation of urban water system linked to an estuary

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Abstract – *Eutrophication is a challenging problem which leads to increased biomass production disturbing the natural ecological balance. Imbalanced primary and secondary productivity and nutrient enrichment especially has been a threat to the health of coastal marine waters. The purpose is to identify water deterioration of urban canals and the Wellawatte outfall was selected to recommend eutrophication minimizing practices. Sampling was done at 4hr intervals for 24hrs and analyzed data informs on aquatic flora and fauna response to depleted oxygen conditions. Oxygen is high under a high level of Chl-a. Therefore, there is sufficient oxygen to decompose the organic waste. A huge algal bloom appears but as the sunlight is blocked reducing photosynthesis and decreases plant survival. With the maximum amount of dead bloom and plankton, microbes consume more oxygen as they decompose organic material. These causes DO levels to plummet even lower, creating hypoxic or even anoxic conditions. In absence of oxygen, all life undergoing aerobic respiration dies. Anaerobic organisms take over the decomposition of plant and animal matter. Since the anaerobic bacteria use nitrogen, phosphorous for their cell development causing the reduction of organic nitrogen to Ammonia. The anaerobic breakdown causes the release of carbon dioxide, methane, hydrogen sulfide and ammonia creating a horrible stench.*

Keywords: *Coastal waters, dissolve oxygen, eutrophication, hypoxia*

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1 INTRODUCTION

Eutrophication is a process in which the addition of nutrients (primarily nitrogen and phosphorous) to water bodies simulates algal growth (Lemley and Adams, 2018). This is a natural process, but it can be greatly accelerated by human activities. As the algae die and decompose, high levels of organic matter and the decomposing organisms deplete the water of available oxygen (Burcharth et al., 2007) . The occurrence of the phenomena will influence the biogeochemical cycles of elements and may have severe negative impacts on aquatic ecosystems, such as mortality of benthic fauna, fish kills, habitat loss, and physiological stress (Chu and Karr, 2017).

Water deterioration in urban reservoirs has happened because of many reasons(Wang et al., 2020). First, the pollution in around urban areas. Second, short-sighted urban planning, lack of infrastructure, unreasonable or outdated locations of factories, and poor villages situated in the city. Third, the environmental debts during the rapid industrialization and urbanization period cause the subsequent environmental problems to be more complicated and interdependent.

Urban sewages consist of mainly domestic sewage and underground water. Qualities of urban sewages depend on the customs of the inhabitants and the character of the city

(Jasim, 2020). Sanitary sewage mainly arises from cooking, bath, laundry, and faeces. In areas where sewer for sanitary sewage is not serviced yet, unopposed draining is led into the nearest marshes, lakes, and rivers. Runoff from streets carries oil, rubber, heavy metals, and other contaminants from automobiles. Untreated or poorly treated sewage can be low in dissolved oxygen and high in pollutants such as faecal coliform bacteria, nitrates, phosphorus, chemicals, and other bacteria (Chahal et al., 2016).

Dissolved oxygen (DO) is a measure of the number of free oxygen molecules in water. The concentration of DO is an important indicator of the health of an ecosystem because oxygen is essential for respiration and some chemical reactions (Croijmans et al., 2021). DO depression in urban water streams and rivers appears to be increasing in developing countries, which causes severe aquatic ecosystem stresses (Huang et al., 2017). One urban stream which suffers DO depression under low flow conditions and requires systematic research for effective mitigation strategies is the “Wellawatte outflow”. Wellawatte estuary is one of the major outfalls of the Diyawannawa canal network that has been threatened by the deterioration of water quality in metropolitan Colombo, Sri Lanka.

Measuring an estuary’s water quality and eutrophication is not an easy task. Estuaries are complex ecosystems made up of physical, chemical, and biological components in a constant state of action and interaction (Mateus et al., 2008). Nutrients are chemical elements that influence the productivity of all ecosystems. Excess nutrients in aquatic systems can stimulate the growth of plants and algae. In other words, these nutrients continue to serve as fertilizers once they reach the water. Nutrient-enriched aquatic systems sometimes become dominated by noxious species of algae that form floating surface scums called blooms (Smyth et al., 2022). Some of these algal species produce toxic substances that can negatively impact other plants and animals, including humans. In many estuaries and coastal waters, nitrogen fixation occurs at low rates, or not at all because of the saline environment. Thus, the algae respond primarily to nitrogen delivered by runoff from the land (Chapman, 2013). Blooms are often stimulated by excess nitrogen inputs related to human activities, such as fertilizer application and sewage runoff (Nwankwegu et al., 2019).

Chlorophyll-a is the pigment that makes plants and algae green. This pigment is what allows plants and algae to photosynthesize. In photosynthesis, plants use the sun’s energy to convert carbon dioxide and water into oxygen and cellular material. Chlorophyll-a is tested in reservoirs to determine how much algae is in the reservoir. Algae is important in lakes because it adds oxygen to the water as a by-product of photosynthesis (Chapman, 2013). On the other hand, if there are too many algae in the water it can produce a foul odour and be unpleasant for swimming. Chlorophyll-a concentration can tell you a lot about the reservoir’s water quality and trophic states.

Water clarity is a physical characteristic defined by how clear or transparent water is. Clarity is determined by the depth that sunlight penetrates in water. The further sunlight can reach, the higher the water clarity. The depth sunlight reaches are also known as the photic zone (Hudon et al., 2000). Water clarity is directly related to turbidity, as turbidity is a measure of water clarity. The transparency of water is affected by the amount of sunlight available, suspended particles in the water column, and dissolved solids such as coloured dissolved organic material present in the water (Hudon et al., 2000).

The past several decades has seen a massive increase in the eutrophication of estuaries globally, leading to widespread hypoxia and anoxia, habitat degradation, alteration of food web structure, loss of biodiversity, and increased frequency and harmful algal blooms (Malone and Newton, 2020). In aquatic ecosystems, hypoxia refers to a depletion of the concentration of dissolved oxygen in the water column. If hypoxic conditions are reached, these local, atypically low oxygen conditions can profoundly affect the health of an ecosystem and cause physiological stress, and even death, to associated aquatic organisms.

Over the past decades, the catchment areas of Metropolitan Colombo have been influenced by several anthropogenic impacts and unauthorized activities. Diyawannawa canal network (Fig. 1) has been threatened by the deterioration of water quality. Under these circumstances, harmful algae will be grown along the coastal area of Wellawatte making its nature very unpleasant. Hence, it affects the health of the ecosystem and causes physiological stress, and the foreign market can be badly affected.

Fig. 1. Downstream of Wellawatte canal

2 METHODOLOGY

2.1 Study Area

Wellawatte estuary is the place where the Kirulapone canal falls into the sea. It is situated in Wellawatte town, Colombo 6. The significance of the Kirulapone canal is that it is facilitated to prevent the possibility of flooding in the urban city of Colombo and conveys all the wastewater of the city towards the ocean through the canal.

Fig. 2. Estuary area

Wellawatte estuary is a partially enclosed body of water, and its surrounding coastal habitats, where saltwater from the ocean mixes with fresh water from Kirulapone canal (Fig 2). In freshwater, the concentration of salts, or salinity, is nearly zero. The salinity of water in the ocean averages about 35 parts per thousand (ppt). The mixture of seawater and fresh water in estuaries is called brackish water and its salinity can range from 0.5 to 35 ppt. The salinity of estuarine water varies from estuary to estuary and can change from one day to the next depending on the tides, weather, or other factors. First, it was important to identify the estuary region through the canal for research purposes.

2.2 Identification of estuary region

Water samples were taken 130m distance from the coastal bay along the canal. Salinity was measured using the conductivity meter. The salinity variation is shown in table 1.

1000mg/l = 1g/l = 1000ppm = 1ppt

Table 1-Salinity variation with the distance from coastal bay

Sample Number	Distance from the coastal bay (m)	Conductivity (µS/cm)	Salinity (ppt)
1	0	10320	4.5
2	10	3080	1.4
3	25	1771	0.9
4	40	1731	0.8
5	55	1036	0.7
6	70	451	0.5
7	85	420	0.5
8	100	405	0.5
9	115	404	0.4
10	130	373	0.4

Salinity varied from 4.5ppt to 0.5ppt, the estuary region was selected up to 100m distance from the coastal bay along the canal. Accordingly, the estuary region is situated between latitudes of 6^0 87866′N - 6^0 87899′N and longitudes of 79^0 85590′E - 79^0 85730′E.

2.3 Sampling

The fieldwork for this study was done in November 2019 at 4hr time intervals throughout a 24hr period. Sampling profiles were selected to obtain the best area coverage possible. Three (3) sampling stations were plotted by considering the estuary range at the outfall namely 5m, 55m, and 105m from the estuary mouth with another sampling station selected at 3 km away from the estuary. This sampling station was selected to measure and identify the difference between saline water and water without any salinity intrusion.

Water samples were collected at 1.0m deep from the surface water by using a deep-water sampler. Each water sample was prepared according to the requirement of each laboratory test.

2.3.1 In situ measurements

In situ measurements for DO were taken using a calibrated probe using the HITECH DO600 DO meter. The temperature was measured using the help of a thermometer and a DO meter. The thermometer was held for a one-minute time in the water sample before the reading was taken. CyberScan pH 300 meter was used to take the in-situ pH values of the water.

2.3.2 Sampling of water for DO & BOD_5

Collected water samples by deep water sampler were slowly filtered into the sample bottles to measure DO at the laboratory using Winkler's method. Then Alkaline potassium iodide solution and Manganous sulfate (1.5ml) were added to the water samples to fix DO in the bottles. The bottle was caped and stored at 4^0C or less.

Additional samples were prepared in the above manner and were stored in an incubator for 5 days at 20^0C for the BOD_5.

2.3.3 Water clarity measurements

Water clarity was measured using a Secchi disk. Secchi depth measurement variability by the Wisconsin Department of Natural Resources LED devices was found to be the most suitable light source for night-time measurements and Secchi depth was measured using an artificial light system.

2.4 Water quality measurements

The laboratory tests were performed on water quality parameters such as Nitrate, Ammonia, Phosphate, Chlorophyll-a, and dissolved oxygen (DO). DO was measured using Winkler's method. Water samples were filtered using 0.45µm filter papers to measure nitrate, ammonia nitrogen, and phosphate using calibrating methods in ion chromatography.

2.4.1 Chlorophyll-a

Before spectrophotometric analysis, all microalgae were extracted using centrifugation for 10 min at 4000 rpm in a centrifuge machine. The absorbance of microalgae was measured using the spectrophotometer model Varian (Canny) UV-Visible spectrophotometer with selected wavelengths at 66nm, 647nm, and 630nm. 90% acetone was used as a blank in the spectrophotometer. The spectrophotometer selected a range of the above three wavelengths and obtained the absorbance values for each of the 0.4ml sample water to 3.6ml of acetone.

3 RESULTS AND DISCUSSION

Water samples from sample station 4 were checked to compare the results between brackish water and freshwater. According to fig. 3(a), there is a gradual increase in the nitrogen concentration in the period of 21hr to 9hr of all stations in the estuary region and outside station. By the late afternoon and evening, the nitrogen content was gradually decreasing. However, the nitrogen content of the 4th sample station is always significantly higher than the other station's values. The maximum concentration in the 4th sample station is 11, 615mg/l respectively.

As shown in fig. 3(b), TP concentration is ranging from 0.05mg/l-0.217mg/l during the 24hr period. The phosphorous concentration of the sample obtained at the first station at 17hr was relatively high. It was caused by a substance that was flowing with water at the time. At the second sample station, concentration varied between 0.064mg/l-1.092mg/l and at the third sample station it was ranging from 0.104mg/l-0.188mg/l. At the fourth sample station TP concentration is varied from 0.05mg/l-0.281mg/l. When considering the variance of data, there is no significant difference of water in and out of the estuary region.

The second sample station receives the highest concentration of ammonia in the 1hr. After one o'clock in the morning, the ammonia concentration in all three stations decreases markedly. The variation in ammonia concentration at the fourth sample station is significantly different from the other three sample stations as shown in fig. 3(c).

According to the New Zealand standards, the water quality is classified with chlorophyll concentration as follows. These are eutrophic level (5mg/l-12mg/l), super trophic level (12mg/l-31mg/l) and hypertrophic level (>31mg/l) respectively.

The chlorophyll values in sample station 2 changes up to 14.1 mg/l. According to the data available for the second sample station, the water appears to be in a similar state, not just eutrophic conditions but also hypertrophic. At the third sample station, where there is very little chlorophyll concentration, the peak value has changed to 14.1 mg/l. The station then migrates to a hypertrophic state. Both stations 2 and 3 have the highest selective concentrations by the 9hr. Although the concentration of chlorophyll in the estuary region has been clearly reduced over time, the chlorophyll concentration has increased gradually since 1hr at the 4th sample station. According to data obtained, the water quality has dropped from eutrophic to the next super trophic level.

For the four stations, there is a gradual increase in concentration of dissolved oxygen from the first day 17hr to the second day 13hr. This may be due to photosynthesis by algae present in the water along with the sunlight. After the 13hr of the second day, there was a rapid decrease in the concentration at 17hr. This is because the demand for oxygen by the bacteria is high and they are taking that oxygen from the oxygen dissolved in the water. When looking at the data in fig. 3(e), the DO concentration of the fourth sample station water is always higher than the DO concentration in the estuary water. This may be attributed to the lower salinity concentration, higher nitrate concentration and higher chlorophyll concentration of algae at the 4th sample station.

Biological Oxygen Demand (BOD) is the measure of the oxygen used by microorganisms to decompose this waste. If there is a large quantity of organic waste in the water supply, there will also be a lot of bacteria presents working to decompose this waste. In this case, the demand for oxygen will be high so the BOD level will be high. As the waste is consumed or dispersed through the water, BOD levels begin to decline. According to fig. 3(f), the highest BOD value was obtained during the periods of 9hr-13hr, whereby the oxygen demand with large quantities of organic waste was highest.

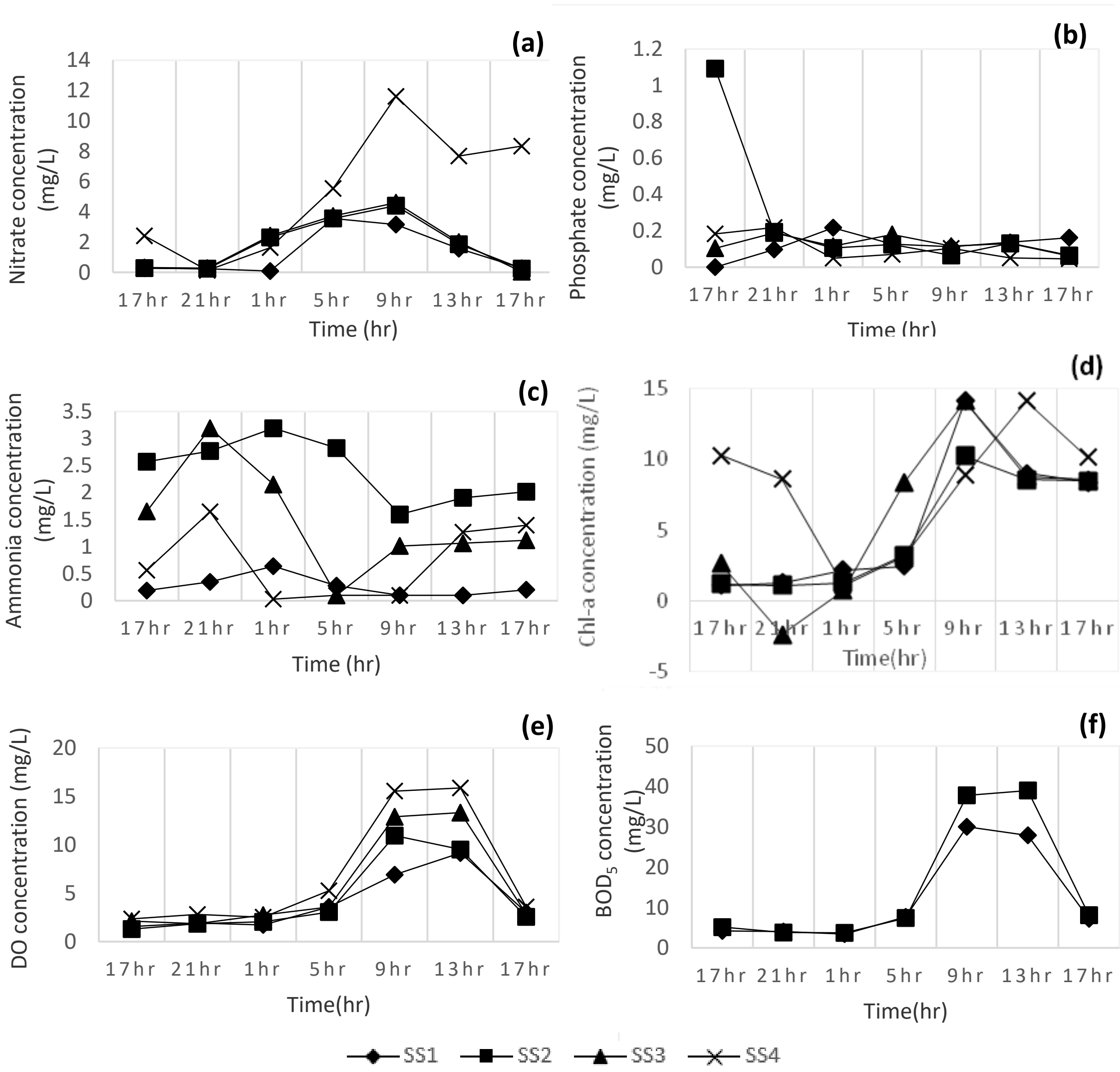

Fig. 3. (a)Variation of Nitrate concentration with time; (b) Variation of Phosphate concentration with time; (c) Variation of Ammonia concentration with time; (d) Variation of Chl-a concentration with time; (e) Variation of DO concentration with time; (f) Variation of BOD_5 concentration with time.

Nitrates and phosphates in a body of water can contribute to high BOD levels. Nitrates and phosphates are plant nutrients and can cause plant life and algae to grow quickly. When plants grow quickly, they also die quickly. This contributes to the organic waste in the water, which is then decomposed by bacteria resulting in high BOD levels.

Salinity is one of the main causes of eutrophication. When looking at the data variation of fig. 4, there's high nutrient concentrations for low salinity values in the sample stations of estuary region. Accordingly, the third sample station which is far from the estuary mouth contains the highest nutrient concentration among all sample stations in the estuary. Salinity decreased with increasing temperature. That means nutrient concentration decreases with the increment of temperature respectively. That is under these conditions there is an increase in water enrichment, and it shows that there is a negative relationship between nutrient concentration and salinity as shown in fig. 4.

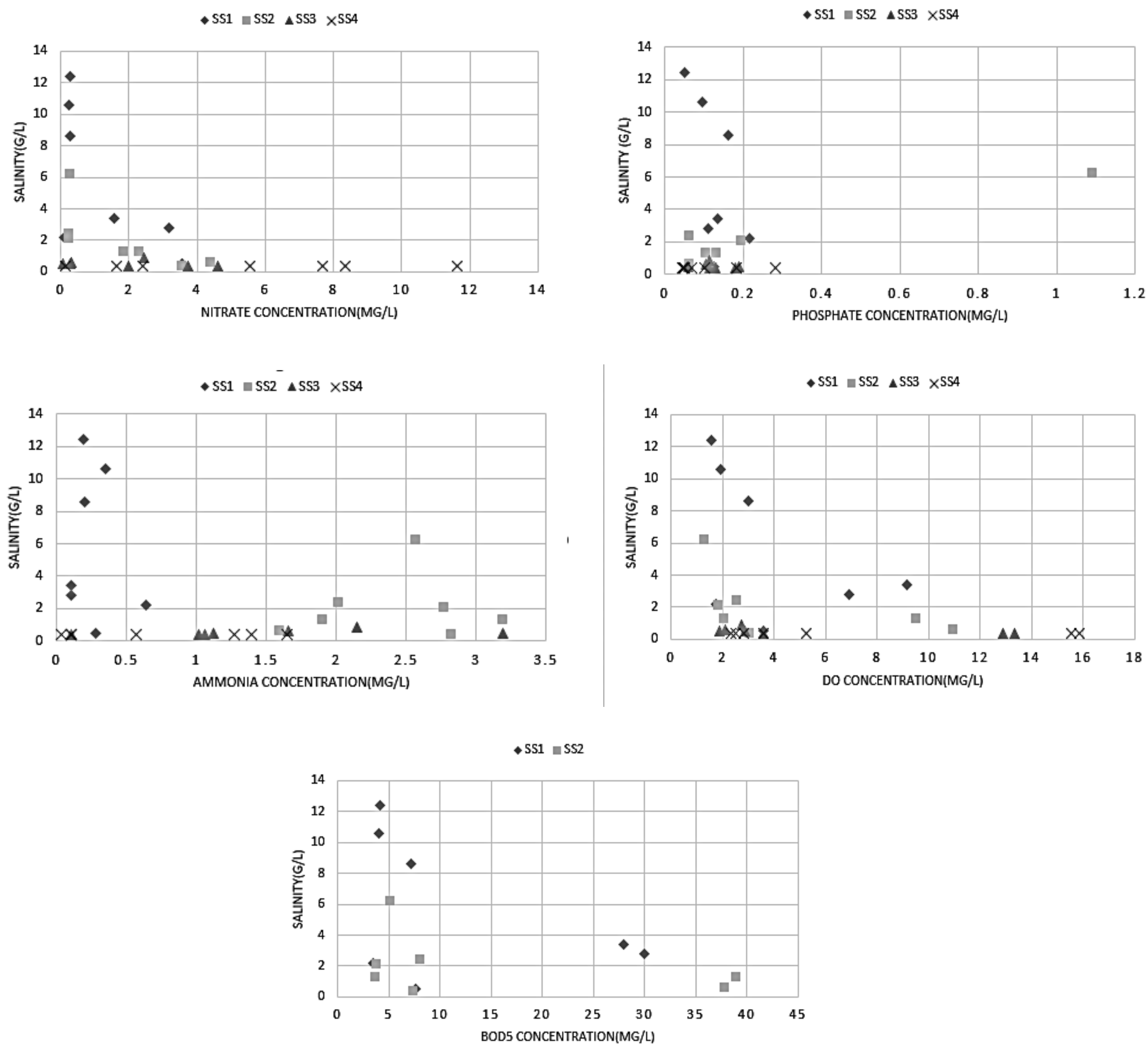

Fig. 4. (a)Variation of Nitrate concentration with salinity; (b) Variation of Phosphate concentration with salinity; (c) Variation of Ammonia concentration with salinity; (d) Variation of DO concentration with salinity; (e) Variation of BOD_5 concentration with salinity.

As shown in fig. 4(d), dissolved oxygen concentration increases with the salinity decreases. The highest concentration of oxygen in the estuary is at the third sample station which contains low salinity concentration. The reason for the increase of dissolved oxygen concentration is the increase of chlorophyll concentration in the water with salinity. However, this higher DO concentration occurs during the period of high salinity concentration and low temperature.

According to fig. 5 & 6 there can be seen a clear correlation between the first and second sample stations. That means BOD concentration is correspondingly high at the higher DO concentrations. That means, the amount of oxygen that is used to decompose the waste in the sample water by the algae that contributes to the production of algae is increased with the number of algae contains in water.

Considering the variations in data, some adjoining data for each station show that the nutrients like phosphorus and ammonia increase while dissolved oxygen concentration declines. Algae consumes mainly nitrate and phosphate present in the water. As a result of that algal blooms created in the water. When algal bloom appears, it blocks sunlight from reaching any submerged vegetation, killing those plants, and decreasing the amount of dissolved oxygen produced.

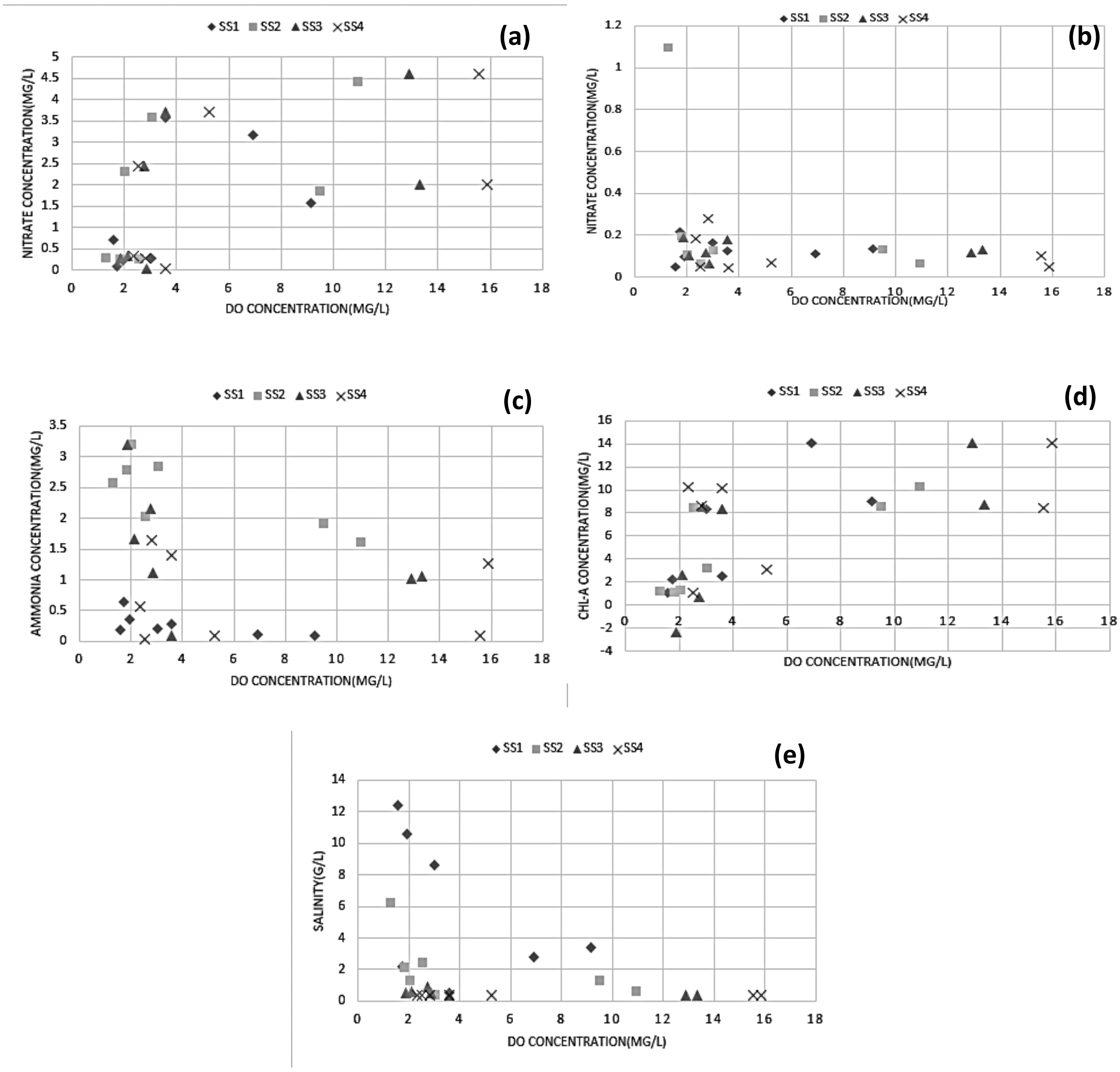

Fig. 5. (a)Variation of Nitrate concentration with DO; (b) Variation of Phosphate concentration with DO; (c) Variation of Ammonia concentration with DO; (d) Variation of Chl-a concentration with DO; (e) Variation of salinity with DO

The nutrient concentration of brackish water increases as the sample stations move away from the estuary mouth. That is, the third sample station has the most amount of nutrient and it has the lowest amount of dissolved oxygen. Comparing nitrate and phosphate content of fresh water with brackish water, the fourth sample station increases its nitrate and phosphate content. But oxygen depletion in brackish water in estuary is higher than the oxygen depletion in fresh water. The above explanations show that salt concentration and temperature are influenced by this. However, estuary regions contain the maximum ammonia concentration. So that the minimum oxygen concentration is in estuary region and the outside DO concentration does not fluctuate to a that much lesser degree.

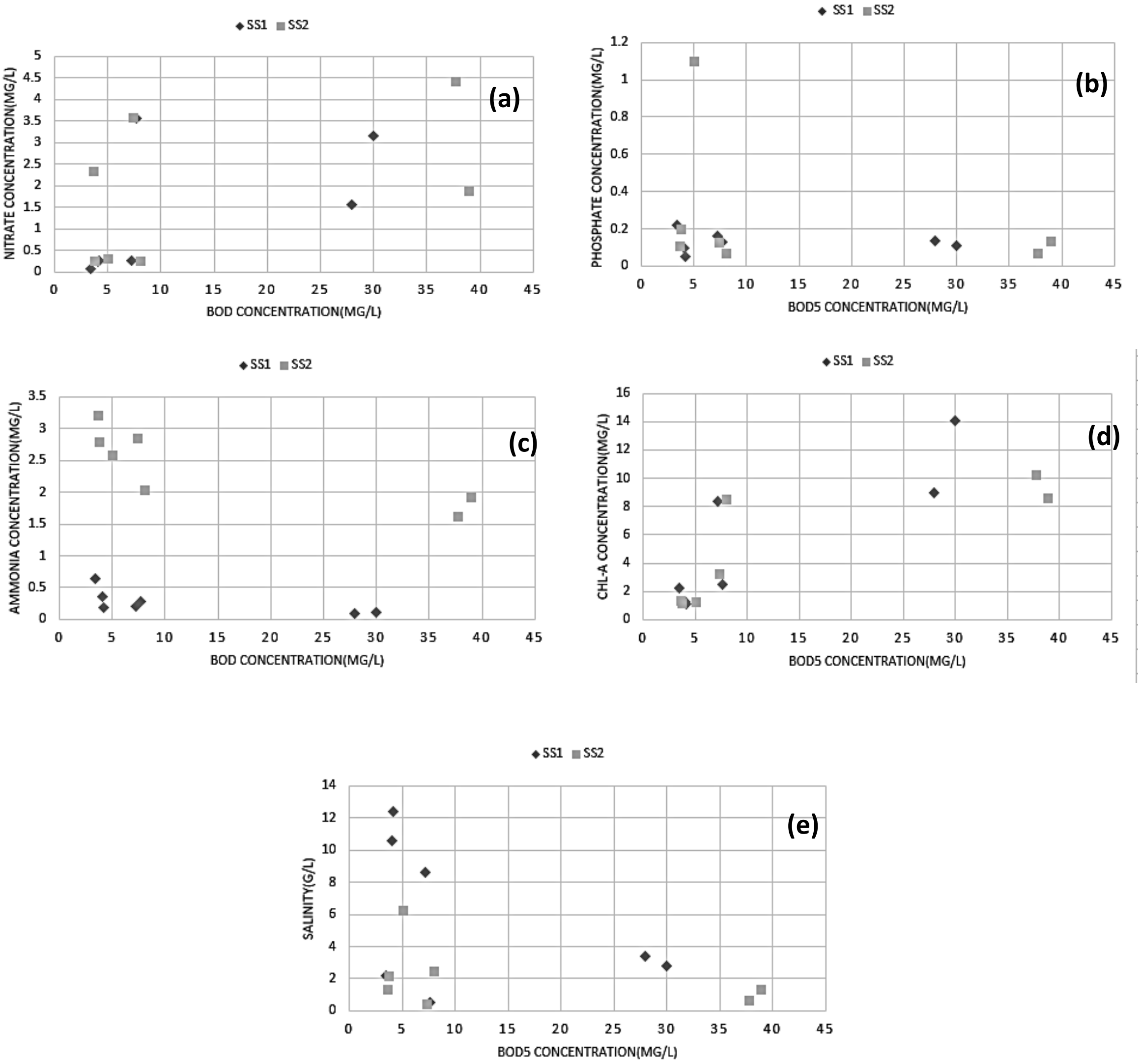

Fig 6: (a)Variation of Nitrate concentration with BOD_5; (b) Variation of Phosphate concentration with BOD_5; (c) Variation of Ammonia concentration with BOD_5; (d) Variation of Chl-a concentration with BOD_5; (e) Variation of salinity with BOD_5

4 CONCLUSION

According to the data distribution, the second and third stations have a much higher nutrient concentration as they move away from the estuary mouth. There is an abundance of nitrate additives for every sample station in the estuary ranging from 5hr-9hr. According to the above explanations, this time interval of oxygen concentration is high in the estuary under high level of Chl-a concentrations. As a result of that, the region has sufficient oxygen in the morning or afternoon to decompose the organic waste in the estuary. But with the algal bloom of nominees, sunlight is blocking the network. It reduces photosynthesis and it decreases plant survival.

This situation is aggravated by low temperatures and high salinity concentrations from the 17hr-1hr. Both sunlight and algae are required for photosynthesis. The dissolved oxygen concentration in the water is low. With the maximum amount of died bloom and planktons, microbes consume more oxygen as they decompose the organic material. This causes DO levels to plummet even lower, creating hypoxic (low DO) or even anoxic (no DO) conditions. So that, BOD values reach low concentrations from 17hr-1hr period. With the absence of oxygen all life undergoing aerobic respiration dies. Anaerobic organisms take over the decomposition of plant and animal matter.

It is important to control eutrophication to get out of these situations. Dissolved oxygen concentration increases with the decrease of phosphorous concentration, so it is recognized to be the limiting factor for eutrophication. Controlling the phosphorous concentration in a low level in the Wellawatte estuary by a chemical precipitation method can be considered. Another method is using algicide by covering the canal as algicide can cause harmful toxins. But this method is impractical with the cost.

The maximum Chl-a concentration at first sample station in the estuary between 9hr-13hr period. Thus, algal bloom at that time is huge. So that it is advisable to control salinity concentration below this level. The reduction of water salinity can be performed by freshwater replenishment and saline water discharge.

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