# Assessment of Spatial Variation in Water Quality: A Case Study at Three Surface Water Bodies in Galle Municipal Council Area

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***Abstract:*** *This study was conducted in two phases. In the first phase, a water quality analysis was conducted on Moragoda Ela, Kepu Ela and Mahamodara Lake. The results revealed that the water quality of the three water bodies was lower than the demanded quality of water for many usages. Moragoda Ela was identified to be the most polluted one. In the second phase, a detailed water quality analysis was carried out on Moragoda Ela. Mean values of COD and $BOD_5$ were 127.5mg/L and 14.8 mg/L, respectively. Mean values of fecal and total coliforms were 47 and 23471 colonies/100 mL, respectively. Prevailing $BOD_5$, COD and the total and fecal coliform content exceed the ambient water quality standards for inland waters in Sri Lanka. It is concluded that the water quality deterioration of all three water bodies may be attributed to the large number of industries, institutions and commercial establishments, high population density and the illegal community activities.*

***Keywords:*** *Water quality parameters, standards, effluent discharge.*

## 1. INTRODUCTION

The apparent water quality of the surface water bodies such as Moragoda Ela, Kepu Ela and Mahamodara lake in Galle Municipal Council (GMC) area is not satisfactory. Most of them receive wastewater discharges from different sources. Rapid urbanization and industrialization have accelerated the water quality deterioration of these water bodies. GMC possesses industries and institutions number of which is enough to cause surface water deterioration. These wastes contain different organic and inorganic pollutants and various pathogenic microbes. The industrial discharges cause euthrophication that leads water bodies to become dead. This may lead to a chain of adverse effects on the aquatic environment and the human beings. Kepu Ela and Mahamodara lake are located in the heart of the GMC area and are at high risk of receiving various types of waste discharges. The catchment of Moragoda Ela covers an area of 6.5 $km^2$ serviced by a mixed sewer system. The stream receives the effluent discharged by about 50 000 population equivalent. It is surrounded by a number of industries, institutions, commercial and residential establishments, and cultivated areas. These sources pose immense water quality deterioration. In addition urbanization is very rapid in the area.

A vital tool for assessing the extent of contamination in water is water quality monitoring in that the level of pollutants present in water is determined. Water quality monitoring is imperative because the results of such a study can determine the degree of usability of surface water bodies. Ultimately the results would help take preventive actions against the existing water pollution.

The aim of this study was to evaluate the water quality in three urban streams, namely Moragoda Ela, Kepu Ela and Mahamodara Lake in the GMC area with respect to several physical, chemical and biological water quality parameters. The objectives included investigating the variation of water quality parameters along these streams according to land use pattern, general hydraulic conditions such as flow pattern, direction and apparent velocities, the locations of sewer outfalls and abandoned waste disposal sites along the streams.

## 2. METHODOLOGY

### 2.1. Phase 1: Water Quality Analysis of Three Water Bodies

Moragoda Ela, Kepu Ela and Mahamodara Lake were selected for the study. Industrial, institutional, commercial, domestic and agricultural areas at the sites of the selected water bodies were identified and marked on a map of the Galle town. Then the selected streams were divided into several segments anticipating that the water quality of each segment would be different. One sampling point was selected from each segment. There were 5, 3 and 2 sampling points in Moragoda Ela, Kepu Ela and Mahamodara Lake, respectively. Sampling points were established within about 3.65 km and 2.25 km from the outfall of Moragoda Ela and Kepu Ela, respectively. The area of the Mahamodara Lake is about 0.125km$^2$. Water samples were analysed for several water quality parameters, namely temperature, pH, turbidity, solids (Total Suspended Solids, Total Solids, Fixed Suspended Solids) dissolved oxygen (DO), chloride ($Cl^-$), nitrate nitrogen ($NO_3^-$-N), total nitrogen (TN), sulphate ($SO_4^{2-}$), alkalinity, Biochemical Oxygen Demand ($BOD_5$), Chemical Oxygen Demand (COD) and coliform organisms.

### 2.2. Phase 2: Detailed Water Quality Analysis of Moragoda Ela

In the second phase a detailed water quality analysis was carried out on Moragoda Ela. Based on a site survey 14 sampling points (SP1, SP2, ..., SP14) of different potentials for getting polluted were identified. Figure 1 shows the selected sampling points along Moragoda Ela. Table 1 gives a description of the selected sampling locations.

**Table 1 Sampling points of Moragoda Ela**

| Sampling Points | Land usage and geological features | Bank condition | Flow pattern |
|---|---|---|---|
| SP1 | Galle Harbour (outfall) | Both sides covered by gabions | Both upward and downward due to tidal effects |
| SP2 | Bend | Both sides covered by gabions | Both upward and downward due to tidal effects |
| SP3 | Highly residential area | Both sides covered by gabions | Both upward and downward due to tidal effects |
| SP4 | School and Coir factory | One side covered by gabions | Slower flow due to the SP4 located in a bend |
| SP5 | Coir factory | One side covered by gabions | Both upward and downward due to tidal effects |
| SP6 | Residential area | One side covered with gabions and other side covered with vegetation | Resultant flow to the down ward |
| SP7 | Slaughter house | One side covered by gabions | Resultant flow to the down ward |
| SP8 | Pulp and paper industry | Both side covered by gabions. | Resultant flow to the down ward |
| SP9 | Ginger cultivation | No proper bank protection | Resultant flow to the down ward |
| SP10 | Highly residential area | No proper bank protection | Slower flow due to SP6 located in a bend. |
| SP11 | Highly residential area | One side covered with gabions | Resultant flow to the down ward |
| SP12 | Water surface is covered with aquatic plants | No proper bank protection | Resultant flow to the down ward |
| SP13 | Residential area | Gabion wall up to some distance | Resultant flow to the down ward |
| SP14 | Residential area, Cement block industry, Car wash center | No proper bank protection | Resultant flow to the down ward |

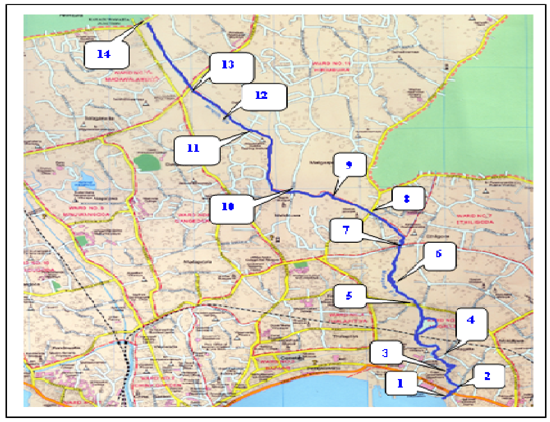


**Figure 1 Sampling points {SP1 (at the mouth) ……SP14 (furthest point upstream)}**

The following criteria were considered in identifying the sampling points: land usage such as industrial, institutional, commercial, residential and agricultural areas, general hydraulic conditions such as flow patterns, directions (Direction may change due to effect of sea wave) and apparent velocities, the locations of sewer outfalls along the stream, sanitary bypasses and the locations of solid waste deposits with a high content of organic silt and matter. Water samples collected from all the sampling points were analysed for several water quality parameters. Statistical and graphical analyses of the values of water quality parameters were used to quantify the extent of pollution of the stream. Principal Component Analysis (PCA) was used to identify the multi-variation of the water quality and obtain the correlation matrix of all the parameters. The same sampling protocol was used for all the parameters in order to maintain the consistency of sampling and to make all the results accurately comparable.

## 3. RESULTS AND DISCUSSION

### 3.1. Water Quality Analysis of Three Water Bodies

Discharges of sewage or industrial waste and the presence of large numbers of microorganisms cause high turbidity. Turbidity in Moragoda Ela and Mahamodara Lake was lower than Kepu Ela. According to David H. Liu et. al. (1997), the three water bodies are not suitable to be used as a source for drinking water and recreational purposes when considering the turbidity level. The prevailing turbidity level may also be harmful to the wildlife propagation.

There is a noticeable increment of total solids in Moragoda Ela. The allowable optimum and maximum limits of TS (Total Solids) for domestic purposes are 500 mg/L and 1500 mg/L, respectively and both Kepu Ela and Mahamodara Lake can be used for domestic purposes, bathing and swimming in terms of solids concentration (David H. Liu. et. al., 1997). The solids concentration of these two water bodies is also within the tolerance limit to be suitable for boating and fishing purposes. pH value changes within 6.2-7.5 and it does not show a significant varation. Alkalinity is higher in Moragoda Ela. In Moragoda Ela, upstream water may not be suitable for drinking and recreational purposes as the pH level is not within the acceptable range (David H. Liu et. al., 1997). Mahamodara Lake satisfies the permissible range of pH.

COD and $BOD_5$ are two of the most common generic indices used to assess aquatic organic pollution. According to Figure 2, $BOD_5$ concentration is extremely high in all three water bodies. Figure 2 shows that COD concentration in Kepu Ela has a significant increment due to the presence of high organic waste. This may be an evidence of illegal untreated wastewater discharge from the Mahamodara teaching hospital. COD and $BOD_5$ values of all three water bodies are higher than the critical values which are 0.5-30 mg/L for $BOD_5$ and 20-30 mg/L for COD. Therefore the degree of pollution of these water bodies is extremely higher when compared with the permissible concentrations in a surface water body. Minimum DO range that should be in a water body for its water to be used for domestic purposes, recreation and wildlife propagation is 2 mg/L (David H. Liu. et. al., 1997).

The relative low DO values are indicated in Moragoda Ela and it can happen due to the utilization of oxygen for the degradation of organic matters present in the stream. In Mahamodara Lake, DO concentration is relatively high.

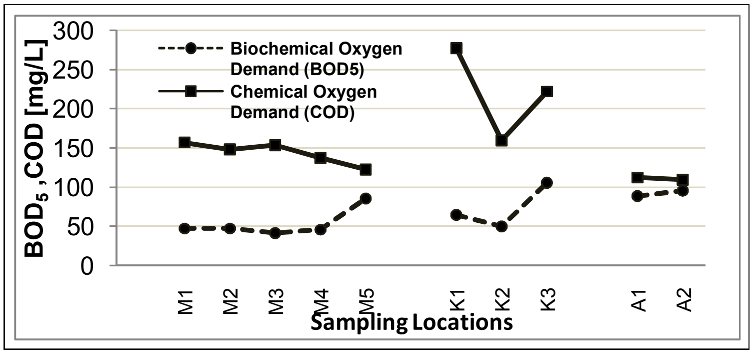


**Figure 2 Spatial Variation of $BOD_5$ and COD at three water bodies (M-Moragoda Ela, K-Kepu Ela and A-Mahamodara Lake)**

Chloride enters waterways through erosion and leaching from soil. Other sources of chloride include seawater intrusion, human and animal wastes, industrial wastes and fertilizers. Chloride is responsible for sewage pollution because of the chloride content in urine. At the upstream area of Moragoda Ela Chloride concentration is in the allowable limit for domestic purposes and wildlife propagation according to David H. Liu. et. al.(1997). Chloride concentration of Kepu Ela and Mahamodara lake have reached an alarming level as the allowable range is 750-2500 mg/L for domestic purposes and wildlife propagation.$SO_4^{2-}$ concentration at the sampling location where the cement block industry is nearby is the highest. It may be due to the illegal discharge of effluent from the cement block industry. The presence of shells and sea water may also cause concentration of $SO_4^{2-}$ to increase.

TN and $NO_3^-$ -N are important parameters since biological reactions can only proceed in the presence of sufficient nitrogen. $NO_3^-$ is an essential nutrient for plants. Excess $NO_3^-$ into waterways may lead to eutrophication, which is the excess growth of algae and aquatic plants. $NO_3^-$-*N* and TN concentrations are higher in Moragoda Ela due to the presence of cultivated areas around the lake. According to the WHO guidelines, the maximum permissible $NO_3^-$ -*N* concentration that should be in potable water is 10 mg/L. Since $NO_3^-$ -*N* concentrations in all segments of Moragoda Ela and two segments of Kepu Ela are less than 10 mg/L, the quality of this water in terms of $NO_3^-$ -N concentration is satisfactory.

The presence of fecal and total coliform organisms in a water sample indicates that water might be harmful to the human health. Very high levels of fecal and total coliform can give water a cloudy appearance, cause unpleasant odors and increase oxygen demand. According to David H. Liu. et. al. (1997), maximum coliform limits are 50, 100 and 10 000 colonies/100ml for domestic purposes, bathing and swimming, and for boating, fishing and aquatic life propagation, respectively. In accordance with Figure 3, the highest coliform concentration exists at the sampling location M4, which is at a slaughter house and a very less concentration of coliforms is shown at the sampling location M3, which is near a ginger cultivation.

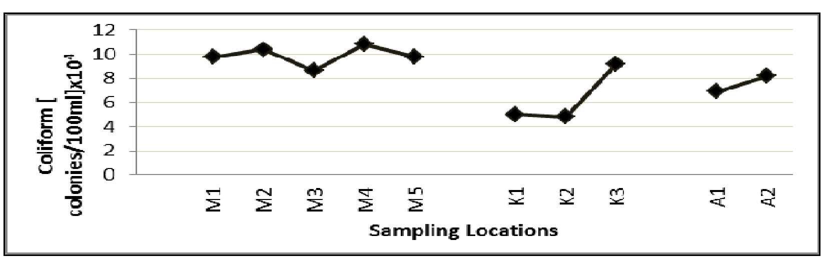


**Figure 3 Spatial Variation of Total Coliform Concentrations at three water bodies (M-Moragoda Ela, K-Kepu Ela and A-Mahamodara Lake)**

Overall Moragoda Ela was identified to have got more deteriorated than the others when measured water quality data were compared with the ambient water quality demanded for various usages.

## 3.2. Detailed Water Quality Analysis of Moragoda Ela

Table 2 shows the mean and standard deviation values for several measured parameters and the compliance status of Moragoda Ela in each parameter with the ambient water quality standards demanded for different usages. The ambient water quality standards enacted by Central Environmental Authority (CEA) were obtained from Priyanka *et al*. 2007.The PCA plot in which the angle between two variables is inversely proportional to the correlation coefficient between those variables indicates that all water quality parameters of SP4, SP6, SP12 are scattered. It implies that those three locations have a relatively similar pattern of water quality variation.

**Table 2 Mean and standard deviation (SD) values and compliance status of Moragoda Ela in each parameter with the ambient water quality standards demanded for different usages**

| Parameter | Mean value | SD | Drinking water with simple treatment | Bathing | Fish and aquatic life | Drinking water, conventional treatment | Irrigation and agricultural | Minimum quality other uses |
|---|---|---|---|---|---|---|---|---|
| Turbidity (NTU) | 34.5 | 10.11 | √ | - | - | - | - | - |
| Conductivity(µs) | 888.3 | 875.7 | - | - | - | - | × | - |
| pH | 7.2 | 0.5 | √ | √ | √ | √ | √ | √ |
| Minimum DO(mg/L) | 5.7 | 1.4 | × | √ | √ | √ | √ | √ |
| $SO_4^{2-}$ (mg/L) | 404.3 | 282.7 | × | - | - | × | √ | - |
| $Cl^-$ (mg/L) | 2248.4 | 4186.3 | × | - | - | × | × | - |
| Total Hardness(mg/L) | 875.7 | 1515.0 | × | - | - | - | - | - |
| $BOD_5$(mg/L) | 14.8 | 3.6 | × | × | × | × | × | × |
| COD(mg/L) | 127.3 | 49.3 | × | × | × | × | - | × |

√ - Satisfy the standard quality × - Not satisfy the standard quality

Temperature along the stream lies within a range of 25.9-29.6 $^0$C.Temperature does not vary significantly along the stream. According to the PCA analysis, Temperature negatively correlates with $BOD_5$, COD, salinity, alkalinity and pH, while it positively correlates with turbidity. Pradhan et al. (2003) and Das .(2000) showed a positive correlation between temperature and each of turbidity and DO.

The electrical conductivity values of first two sampling points which are close to the sea are over twofold higher than those of other locations. There is a notable correlation between conductivity and salinity with a correlation coefficient (R) of 0.95 (Figure 4). R between the conductivity and chloride, and salinity and chloride are 0.913and 0.903, respectively. The PCA analysis shows that conductivity is positively correlated with TS,TSS, alkalinity, Ca hardness, total hardness, chloride, sulphate with R of more than 0.8. Kataria and Jain (1995) stated that the conductivity positively correlates with the parameters that directly or indirectly add up to available ions in water. Singh and Kalra (1975) and Lystrom et.al. (1978) used conductivity either generally or specifically to estimate salinity in natural water. Measuring salinity of water is important to irrigation (Metcalf and Eddy 2003).

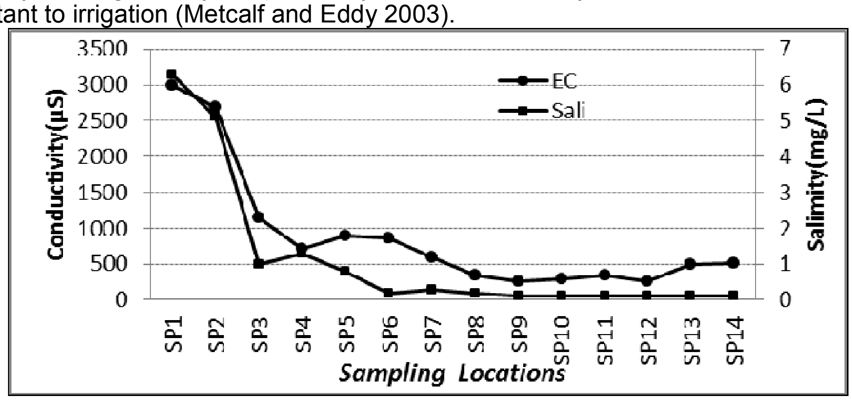


**Figure 4 Spatial Variations of Conductivity and Salinity**

Turbidity in water is caused by suspended matter such as clay, silt, and organic matter and by plankton and other microscopic organisms that interfere with the passage of light through the water (American Public Health Association, 1998). Turbidity is closely related to total suspended solids (TSS), but also includes plankton and other organisms. Figure 5 shows the variation of turbidity and TSS along the stream. Except three sampling locations (SP4, SP6 and SP7) there is the same variation pattern between turbidity and TSS. Hence turbidity can be used as a surrogate parameter for TSS analysis for Moragoda Ela. Samples were collected from SP3 and SP6 after a heavy rainfall. However the high rainfall has not affected much on the turbidity of the stream because there are sampling points with more turbidity than those two locations. The solid content in a stream largely depends on how frequently the water body gets affected by soil erosion and floods, and the amount of receiving decayed plants and animals. SP4 and SP13 have significant lower values of solids compared to the other sampling points. This is probably due to the fact that gabions have been placed in the stream banks and the area has a good vegetation cover.

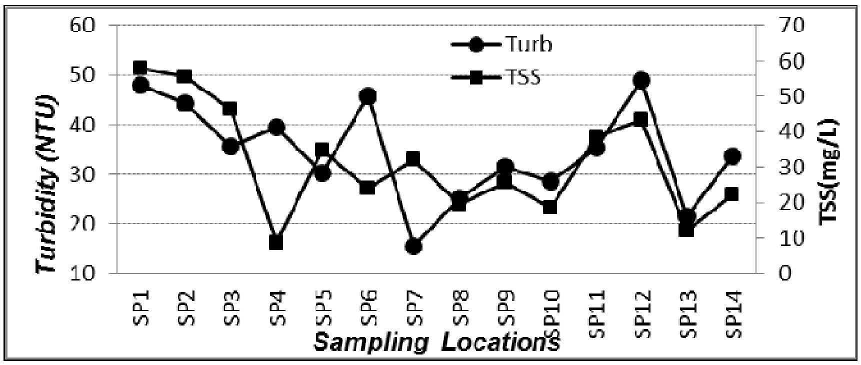


**Figure 5 Spatial Variations of Turbidity and Total Suspended Solids**

pH changes within 6.5-8.3 along the stream and it does not show a significant variation with the type of surrounding area. Alkalinity level lies within 90-365 mg/L. The highest value of pH is 8.30. Water with a pH of less than 4.8 or greater than 9.2 can be harmful to aquatic life, and alkalinity of 100-200 mg/L will sufficiently stabilize the pH in a stream (Mitchel, M.,2003). The alkalinity value of Moragoda Ela lies within this range and then scaling or corrosion potential of water is low. The drinking water standard for pH and the range of pH demanded by irrigation water lies within 6-8.5. Significantly high values of alkalinity were observed throughout the investigation period at sampling point 1 and 2. Das and Pandey (1978) stated that high alkalinity indicates pollution.

The permissible concentration of chloride for drinking water with simple treatment is 200mg/L and that for agricultural irrigation is 100mg/L (Priyanka *et al*. 2007). Hence the water in the reaches from SP6 to SP14 is suitable for agricultural irrigation in terms of chloride concentration (Figure 6).Sulphates of Moragoda Ela vary between 160-970mg/L (Figure 6). The maximum standard value of sulphate in drinking water with simple treatment is 250mg/L and for agricultural irrigation is 1000mg/L (Priyanka *et al*. 2007).The high sulphate concentration at the upstream of Moragoda Ela may be due to the discharge of detergent-laden sanitary water directly into the stream by the surrounding residential areas.

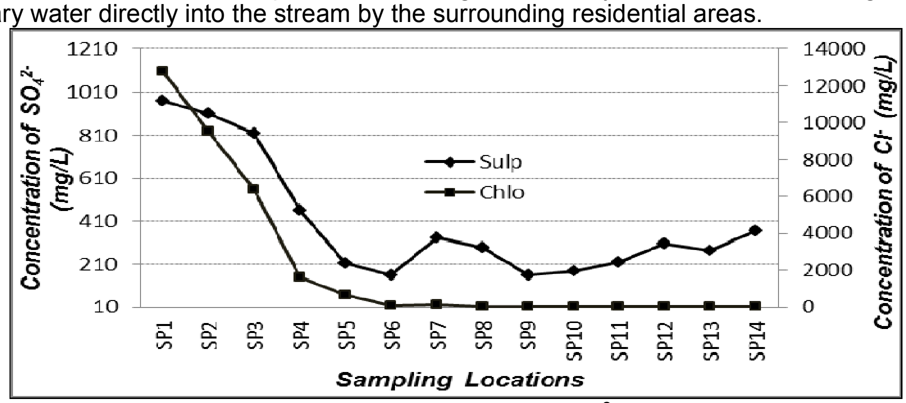


**Figure 6 Spatial Variations of $SO_4^{2-}$ and $Cl^-$**

Minimum DO range that should be in a water body for its water to be used for domestic purposes, recreation and wildlife propagation is 2 mg/L (David H. Liu. et. al., 1997). $BOD_5$ is often used to evaluate the biodegradable fraction, and COD is the total organic pollution load of waters contaminated by reductive pollutants. DO concentration varies from 8.55 mg/L to 3.49 mg/L. SP7 experienced the lowest DO concentration. The same sampling location has the second highest $BOD_5$ concentration (Figure 7). Hence the low DO level may be attributed to the illegal discharge of slaughter house wastewater which is rich in biodegradable organic matter and suspended solids.

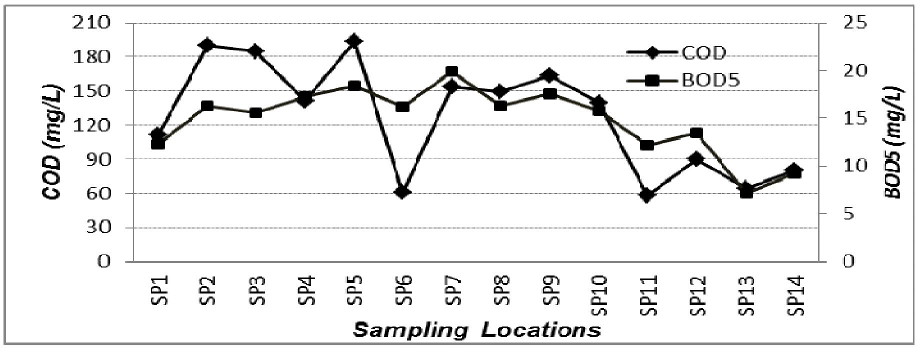


**Figure 7 Spatial Variations of Biochemical Oxygen Demand and Chemical Oxygen Demand**

The COD and $BOD_5$ values of all sampling points except few are higher than the critical values which are 10 mg/L for $BOD_5$ and 20 mg/L for COD. Therefore the degree of pollution of this stream is high when compared with the permissible concentrations in a stream. Mean value of COD and $BOD_5$ are 127.5mg/L and 14.8mg/L, respectively. Prevailing $BOD_5$ and COD in Moragoda Ela exceed the ambient water quality standard for inland waters in Sri Lanka. According to Figure 7, COD concentration varies from 193.84 mg/L to 58.38 mg/L. SP2 shows the highest COD value. This point is at a bend of the river. It can reasonably be argued that this may be due to the accumulation of organic suspended solids at the bend. Both $BOD_5$ and COD are in a trend of decreasing toward the upstream. The lower COD value at SP14 implies that the illegal discharges from the cement industry may not have caused much effect on the increase of organic load into the stream. SP8 which is close to the pulp and paper industry has relatively high $BOD_5$ and COD values compared to the locations of its upstream area. The pulp and paper industry discharges wastewater rich in COD and deficient in $BOD_5$. Therefore there may be another source of biodegradable organic matter at that point such as the discharge of domestic sewage. High values of COD due to accumulation of domestic sewage were reported by Mohan et al. (2007) ranging between 88 - 535 mg/L. Sharma and Gupta (2004) also found that the municipal waste water is responsible for maximum organic pollution, resulting in an increased $BOD_5$. There is an inverse relation between DO and oxygen utilization in terms of $BOD_5$ and COD (Das, 2000). BOD gives a complete picture of the nature and extent of pollution and about the water quality (Kumar and Sharma, 2002).

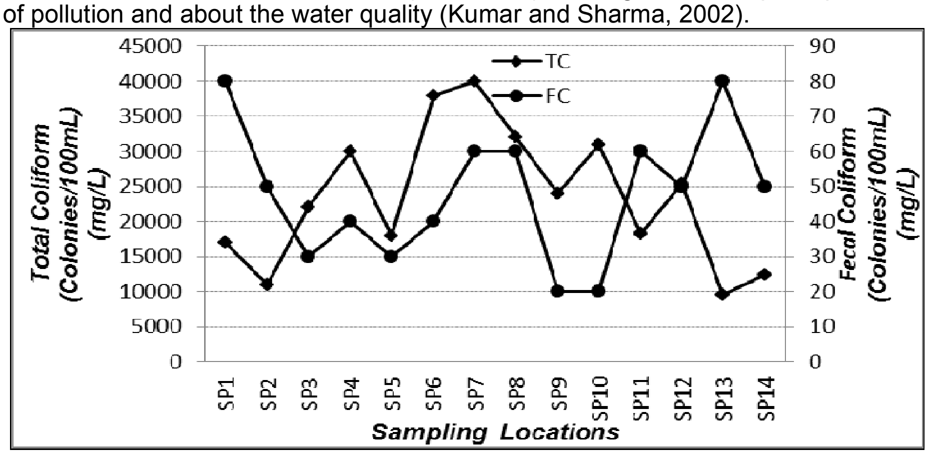


**Figure 8 Spatial Variations of Total and Fecal Coliform Concentrations**

Figure 8 shows the variation of total coliform organisms. Mean values of fecal and total coliforms are 47 colonies/100mL and 23471 colonies/100mL, respectively. Prevailing total coliforms in Moragoda Ela exceed the ambient water quality standard for inland waters in Sri Lanka Priyanka *et al*. 2007).The mean fecal coliform value does not satisfy the ambient water quality standards for activities other than irrigation and agricultural purposes. The highest total coliforms content is seen at SP7 which is closer to the slaughter house.

## 4. CONCLUSIONS

It can be concluded that the water quality of Moragoda Ela, Kepu Ela and Mahamodara Lake is lower than the demanded quality of water that is used for domestic purposes, bathing and recreational activities. They are also not suitable to be used as water sources for water treatment plants. The study revealed that Moragoda Ela has relatively a high pollution level. The degree of pollution decreases along the river from downstream to upstream. Different segments of Moragoda Ela have got polluted to different degrees. The level of pollution is highly dependent on the parameter of concern. Especially first three sampling locations which are near the sea experience most of water quality parameters exceeding the demanded quality of water that is used for many activities. Those 3 locations posses elevated values for chloride and sulphate concentrations, conductivity, salinity, alkalinity and hardness. There is a notable correlation between conductivity and salinity with a correlation coefficient (R) of 0.95. Conductivity is also positively correlated with TS, TSS, alkalinity, Ca hardness, total hardness, chloride, sulphate with R of more than 0.8. Turbidity can be used as a surrogate parameter for TSS analysis for Moragoda Ela because there is a good correlation between the two parameters except at three sampling locations.The stream receives a high organic loading from the surrounding industries and residential and commercial establishments. This may be the major source of pollution in the stream.The poor implementation of rules and regulations on wastewater discharge and less contribution by the government to maintain and clean those water bodies may also contribute to the existing pollution.

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