Engineered Wetland System for Enhancing Aquatic Environment of Urban Canals for Transportation: Case Study on Kirulapone Canal in Colombo, Sri Lanka

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Abstract: *Kirulapone canal is a foremost branch of Diyawanna canal system which is highly polluted due to the anthropogenic haphazard wastewater disposal. As a migratory measure for the traffic congestion in Colombo Metropolitan City, it is expected to relaunch a boat service along Kirulapone. Therefore a feasibility study was carried out to comprehend the behavior of canal bed and to propose engineered wetlands at tributaries to upgrade urban water quality of Kirulapone canal. SLLRD*
A simultaneous water quality study and changes of canal bed was studied with the integration of "Surfer" mappings. According to the pollutant concentration, geotechnical properties and topography, a horizontal subsurface wetland was introduced as a sustainable purification system to remediate disrupting complexes. Possibility of flash flooding during storm events due to the construction of the engineered wetland was analyzed using "HEC – RAS".
The interpolated contour figures revealed that the canal bed was accumulated with sediments intensified by waste disposing, and soil erosion. Constructed wetland to withstand against seasonal influences was designed with biochar to increase the treatment efficiency of tributary to remediate the disastrous nutrient enrichment in surface waters. The hydraulic analysis based on channel survey data with the steady flow conditions showed that upstream is free from flood inundation.

Keywords: *Kirulapone canal, Canal Transportation, Water quality, bathymetry survey, engineered wetland, "HEC- RAS" flood modelling.*

1. INTRODUCTION

Diyawanna Lake which covers a large area of the metro Colombo region, owns a royal merit of the great history in Sri Lanka with its natural panoramic view. At the Dutch era, the Diyawanna water system was constructed as a network of waterways in Colombo to fulfil the purpose of flood control and stormwater drainage. Kirulapone canal is a foremost branch of Diyawanna water system which is located at the downstream (Fig 1). It is one of the most polluted urban canals in Colombo. Over the past decades, the catchment areas of Metropolitan Colombo have been influenced by rapid urbanization, industrialization and unauthorized activities (Ministry of the Environment, 2006). Recently the Kirulapone canal is under attention to re-launch a boat passenger service. But the severe deteriorated water quality and variation of canal bed levels have become a dominant challenges to fulfil the current governmental ambition. The immediate mitigatory measures, renovations and maintenance of the canal network for boat passenger service would be beneficial to provide a reliable, time saving and safe mode of public transportation system.

The Canal bed varies due to hydrodynamics and especially due to sedimentation which is a very dynamic procedure. Dynamics of river bed depends on various unpredictable factors (Tigrek & Aras, 2011: 86) and estimation is important for sustainable transportation. Therefore, this study was aimed on assessing the canal bed behavior of Kirulapone canal by visualizing the bed level variation for establishing canal transportation and proposing an engineered solution for urban water quality improvement. In addition, the benefit of constructed wetland system was discussed in the context of the global trend for introducing sustainable environmental management.

1.1. Study Area

The bed level study was carried out along the selected canal stretch of Kirulapone canal starting from Nawala-Nugegoda Bridge to Wellawatta outfall in Diyawanna water system. The selected canal extent was approximately 2.5 km.

A tributary of Kirulapone canal flows across the OUSL premises was selected to improve the water quality by proposing an engineering constructed wetland. The OUSL canal length is about 450m and it is surrounded by residential community. The type of pollutants and level of contamination, space availability and accessibility were considered when selecting this tributary to introduce an engineering solution.

Figure 1 Study Area of the selected urban Canal

2. METHODOLOGY

Methodology of the research contains assessing the canal floor behaviour and proposing an engineered wetland for the urban water improvement.

2.1. Bathymetric Survey of Kirulapone Canal

The data obtained by previous bed level surveys carried out by Sri Lanka Land Reclamation and Development Cooperation (SLLRDC) were gathered and used to visualize the existed bed level of the canal. Lateral and longitudinal levels of the canal bed were measured manually using a survey staff along the Kirulapone canal were used as input data. Recorded levels in 2012 and 2016 were plotted using a free software namely "Surfer". In addition height to the bridge deck and water depth were noted to estimate clear height between bridge and water surface during rainy seasons to select the appropriate boat type.

2.2. Water Quality and Proposing Engineered Solution

Measurements of physical, chemical water quality parameters were measured to identify the critical parameters. TDS, pH and DO were measured in-situ using "Multi Parameter Water Quality Monitor" at the field while conducting the laboratory tests for determining BOD, COD, Phosphate and Nitrate. The average stream discharge was estimated by the float method and using a 'v-notch' weir. A levelling survey was carried out to find the gradient of the stream and the topographical features of the area where the treatment unit to be introduced.

2.1.1. Design of constructed wetland

The constructed wetland was designed by using the design concept of Horizontal Subsurface flow (HSSF) constructed wetlands. The design criteria given in the Constructed wetland manual by United Nations Human Settlements in 2008 Programme was followed in the designing process. The suitable plants for HSSF constructed wetland identified considering the local availability, physical and chemical characteristics of the stream, space availability and efficiency of pollutant removal.

2.1.2. Flood modelling

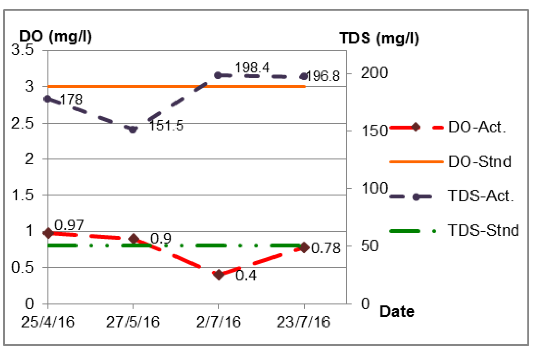
Due to the installation of proposed dam for wetland across the OUSL tributary, the upstream might be subjected to flood in maximum discharge. Therefore, it was necessary to carry out a flood modelling using HEC – RAS. The following parameters were calculated to obtain input data. Maximum discharge was estimated by using rational formula

The area which rainfall flows into the drainage canal is determined by drawing the catchment boundary which is a line drawn along the highest points of the land surrounding the canal, on a contour plan of the area by using contour plan of the SLLRDC and topographic features are inspected and area was measured using Google Earth. Runoff coefficient was determined by considering the catchment slope and land use pattern. The slope was determined as the difference in level between the highest and lowest point of the longest stream and runoff coefficient computed based on tabulated values. (Ponrajah, 1986) After a field survey and using Google Earth the land use of catchment area was identified and the runoff coefficient was computed based on Recommended Runoff Coefficient for Various Land Uses. When computing the peak discharge, the rainfall intensity was assumed to be constant and it was calculated by using IDF equation which was developed by D.G.L.Ranathunga (Ranathunga, 2001).

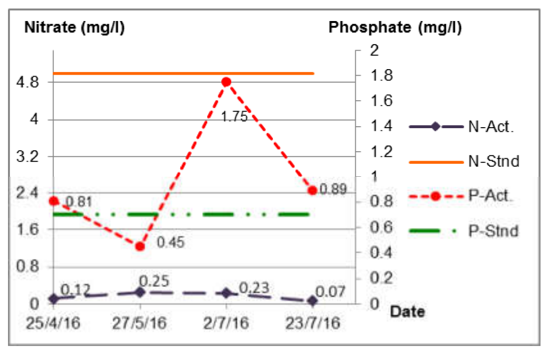
3. RESULTS

3.1. Water Quality of OUSL Canal

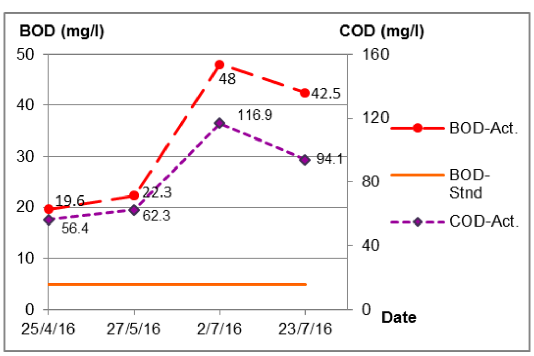
Water quality analysis was carried out to assess the pollutant status of the canal before designing the engineered wetland to upgrade the water quality for recreational status such as applicable for transportation through boats. pH values and Nitrate values were fallen within the standards stipulated by Central Environmental Authority for recreational purpose of inland waters. Figure 2 show the variation of selected water quality parameters during the study period. High Phosphate, BOD, TDS and low DO values were recognized as the most critical issue.



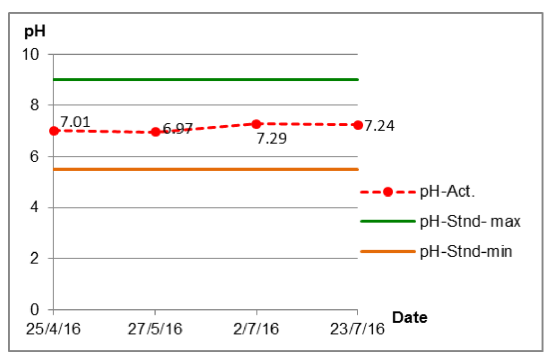
(a) DO and TDS



(b) Nitrate and Phosphate



(c) BOD and COD



(d) pH

Figure 2 Variation of selected water quality parameters during the study period
(a) DO and TDS (b) Nitrate and Phosphate (c) BOD and COD (d) pH

3.2. Canal Bed Measurements

According to the previous survey data gathered by the SLLRDC due to the implementation project of the Wellawatta outfall in 2012 the bed level appearance was generated using “Surfer” while generating the current bed level by the input data obtained after a level survey along the same canal stretch. The existed bed level of Wallawatta to Polhengoda Bridge was considered when mapping (Fig 3a-3b). Longitudinal sections at right, left bank and centre of the selected canal length were plotted (Fig 4a-4c).

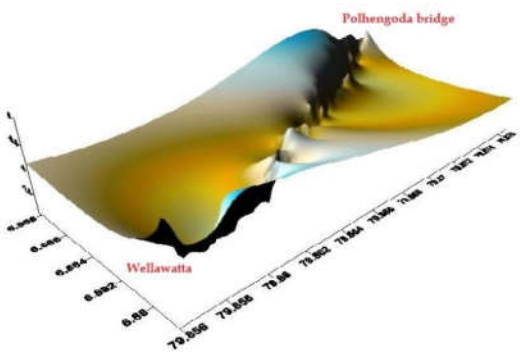


Figure 3(a) Existed canal bed in 2012

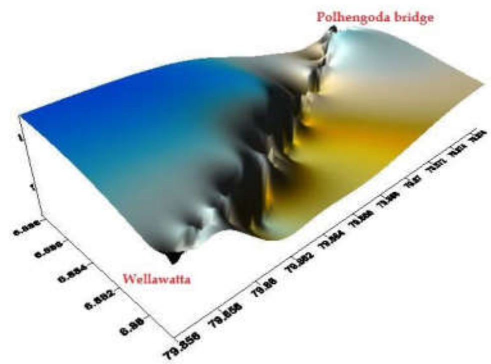


Figure 3(b) Current bed level in 2016

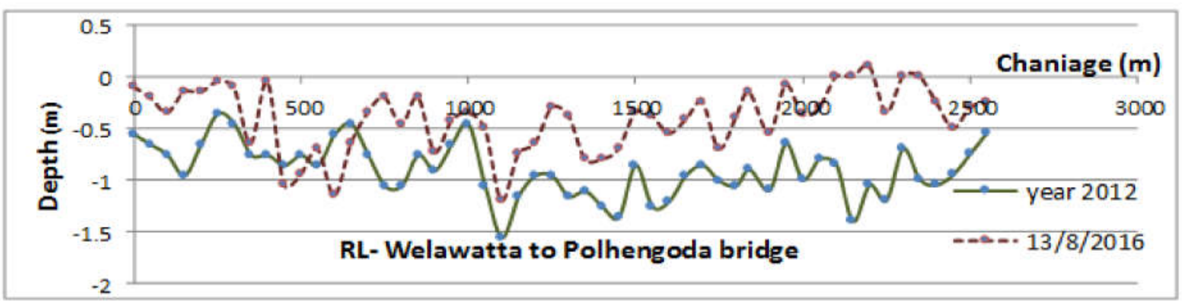


Figure 4(a) Longitudinal section at right bank

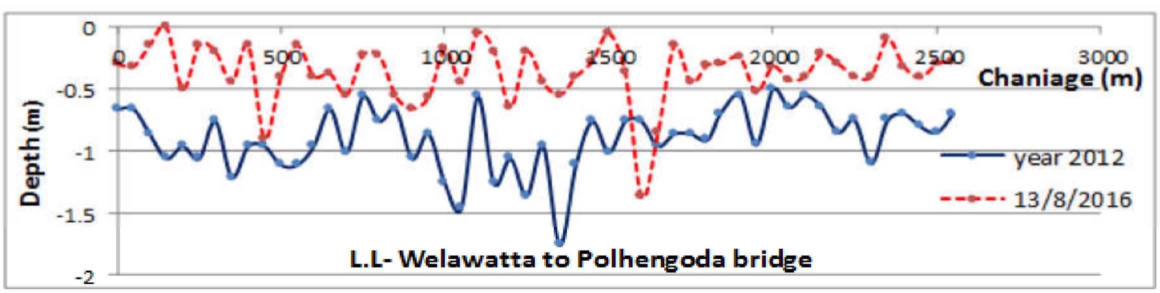


Figure 4(b) Longitudinal section at Left bank

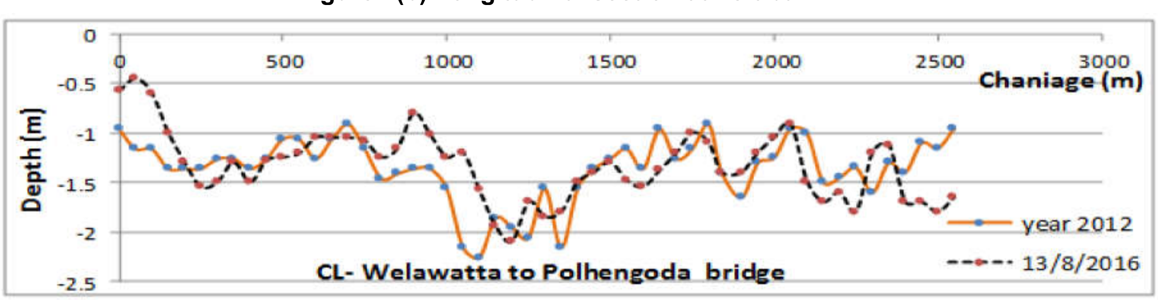


Figure 4(c) Longitudinal section at centre

3.3. Constructed Wetland (HSFF)

High BOD, Phosphate and TDS and low DO were observed along the Kirulapone canal and its tributaries. Hence the constructed wetland was designed based on the BOD for the average discharge $0.02 m^3s^{-1}$ to OUSL tributary. The discharge of the tributary was fluctuated and peak discharges were observed at morning and evening (Figure 5) that directly related to the water consumption pattern of urban cities.

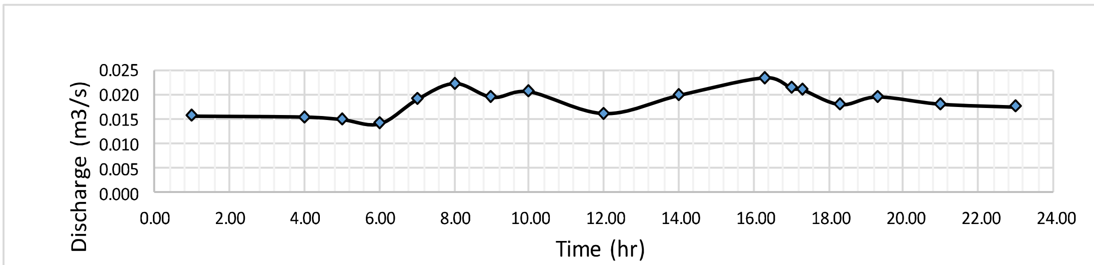


Figure 5 Discharge pattern of canal tributary at the OUSL

The constructed wetland was conceptually designed for 10 wetland cells at each bank with 14 m x 2 m x 0.5 m in dimension and 560 m^2 of total area. 50 mm thick filter with biochar was decided to install at the two sides of both channels which supply water to the wetland to increase the efficiency of nutrient removal. The media of the HSSF wetland also supposed to mix with biochar because of its ability of act as an absorbent.

3.4. HEC-RAS Flood Forecasting Model

The flood profiles at any given cross section of canal was plotted for different flood intensities with different return periods. Flooding water level at the maximum discharge was given in Figure 6. During the simulation of flood forecasting model, the dam height was taken as 0.5 m and flood forecasting model was run in HEC –RAS and the maximum flood level was obtained. The result showed that the flood level was safely fallen within the canal bank. Therefore it is proven that, a flood condition won't be occurred due to the construction of dam.

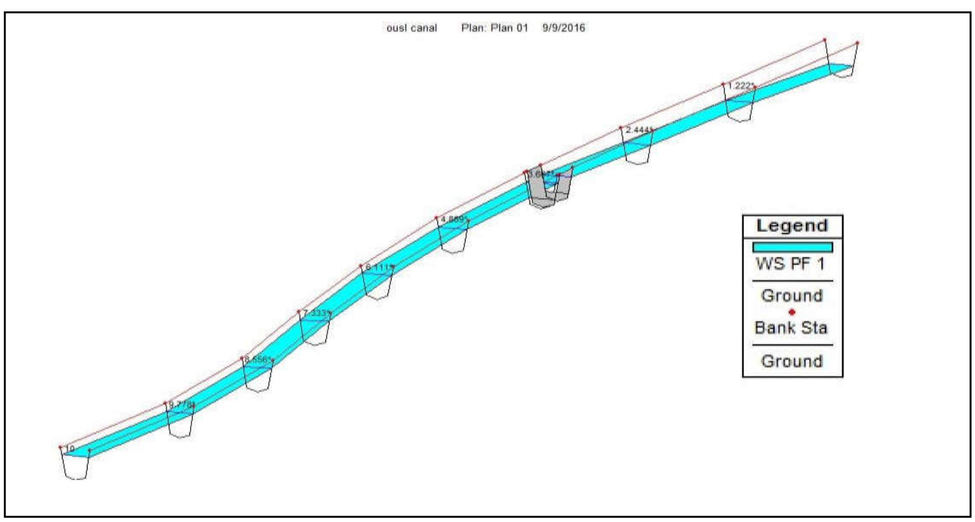


Figure 6 *x-y-z* perspective plot of flooding water Level

4. DISCUSSION

The results showed that, the siltation of canal bed has increased with time (near to the canal banks). Comparatively bed height is lower at the center of canal. Such hydrological variations generated due to the daily travel of Navy boats, and dredging activities carried out by SLLRDC for canal maintenance.

The changes of canal bed can be occurred due to waste disposal of habitants and sediment erosion at canal banks and sediments transported through Hume pipes directed to the canal. Further, higher loads on ground applied through multi-storey constructions adjacent to the canal bank a pressure exerted on the ground. Due to such external loads, the subsurface peat may come out as a paste (eg. tooth paste action) causing the canal bed to rise upward. Therefore, the dredging will encourage the accretion of bed level due to the decrement of surcharge load applied by the top soil. Hence, continuous dredging is not a reliable solution.

During the canal bed survey it was observed that the bridge heights were significantly low and thereby it will be difficult to use high roof boat for passenger transportation. Therefore, it is better to focus on low height vessel systems to use for preventing future posers.

In 2013, a canal boat service in Colombo was launched from Nawala to Wellawatte during the peak hours of traffic as a remediation for the traffic congestion at office hours by Navy. “Padda boats“ specially made with fibre which can be used to transport 12 to 15 passengers and lagoon crafts specially designed by Sri Lankan Navy which could accommodate 35 passengers were also used for this purpose. But, nowadays boats with flatbed which can be accommodated number of passengers at once are universally available. It can be facilitated with air conditioning and other tertiary requirements if needed. It will be useful if attention is paid on such kind of boats for passenger service to provide more efficient, reliable, and comfortable service. Further it will improve the aesthetic value of metro Colombo region.

4.1. Engineered Wetland System for Improving Water Quality of Canal

The necessity of water quality improvement in the canal is justifiable for urban canal transportation without impact on human health. According to the cost efficiency, labourer skill requirements, affordability and space availability constructed wetland was identified as the most feasible treatment system to ameliorate the water quality of a stream in a developing country like Sri Lanka. When considering the possibility of breeding insects, odour nuisance, maintenance ability and treating capacity HSSF constructed wetland was recognized as the most suitable wetland system for OUSL.

Athapattu et al, (2016) have been introduced a purification system to the tributaries to bring the water quality status to an adequate level for recreational purpose without obstructing the main canal. Hence application of constructed wetlands in urban water recycling is effective for such polluted stream for a low income country such as Sri Lanka. Flood risk due to dam construction was analysed in maximum discharge and found that there is no flood risk. Native aquatic plants, terrestrial and edible plants are proposed to use for increasing the treatment efficiency and aesthetic appeal of the wetland.

The wetland was designed at the canal embankment without intercepting the tributary. A dam rises water to the embankment so that water can be evenly distributed throughout the total wetland area. During the flood extra water above the wetland capacity will overflow from the dam and will be driven to the main canal system without damaging the wetland area. Therefore, cost of spill way has been eliminated through this proposed design. The effect of increment of water level construction was analysed using HEC RAS hydraulics modelling and found that no flood condition will be occurred during the maximum discharge of the stream in a steady condition. The short-term variations in wastewater flows were observed at canal water discharge. A first peak of flow was occurred in the late morning, and a second peak flow usually was occurred in the evening. The peak flow observed in the evening was higher than the morning peak. It is recognized that the pattern of discharge is equivalent to the water consumption pattern and the plotted discharge curve was fallen parallel to curve of water demand.

4.2. Biochar Application in Engineered Wetland

Biochar casing was proposed to apply at the sides of open channel and as a mixture of soil material used in wetland bed to facilitate phosphate adsorption. Constructed wetland to withstand against seasonal influences was designed with the addition of biochar obtained by "*pyrolyzed Gliricidia sepium*". Gravel, course aggregate and sand are the most frequently used bed materials for constructed wetlands. (Arcielvala & Asolekar 2006). Gravel bed was proposed for the constructed wetland as the porous media. Recently, biochar has won the attention as an adsorbed due to its valuable activeness against nutrient removal and action of soil amendment. (Ahmad et al, 2013). Hence, a 2" thick membrane of biochar was proposed to be installed at the two side walls of the open channels and also as a mixture of bed soil.

4.3. Aquatic Environment through Wetland and Biotope for Transportation

The most frequently used applied aquatic plants for CW in Mediterranean countries are *canna, Iris, Typha, Cyperus, Juncus, Pragmites, Poceae* and *Paspalum*. There is high potential of purifying domestic and industrial waste water, tannery wastewater, dye rich and food processing waste water using *P. australis* and *T. latiforlia* in CW as revealed by previous researches. (Cristina et al, 2007). Hence *Canna Iridiflora, T. angustifolia* and *Heliconia* was proposed to use as flowery wetland plants due to its high propagation ability in Sri Lankan climate. In purification of Kandy lake floating wetlands with *Canna Iridiflora* and *Typha angustifolia* have been identified as a possibly, economical and efficient flowery plants for CW (Weragoda et al., 2012) Most popular plants species used in constructed wetlands include macrophytes such as Cattails, Bulrush, etc. (Jayasekara, 2008) Therefore locally available plants such as Gal ehi pan, Thunhiriya pan with Diya Habarala which are common in Sri Lanka can be used for the Bio Geo Filter in CW (Priyanthi et al, 2015). The constructed wetland was designed at the embankment. Hence, some of suitable flowery plants species for biotope such as Kelani Tissa (*Tecoma stans*), and Bowitiya are proposed at the edge of the wetland (Rizwan and Athapattu, 2015). The use of some other edible plants for horizontal subsurface wetlands with gravel bed introduced to apply in CW. (Pathiraja et al, 2013). This will be additionally advantageous in increasing of the aesthetic value, controlling odour and increasing the nutrient removal efficiency from waste water to produce a convenient aquatic environment for passenger transportation through boats.

5. CONCLUSION AND RECOMMENDATIONS

It is revealed that Diyawanna canal network is significantly polluted at the downstream and could be subjected to further degradation in future, if mitigatory measures are not undertaken. Proposed engineered constructed wetland design in urban water recycling is effective for such polluted stream for a low income country such as Sri Lanka to bring the water quality status for recreational purpose. Constructed wetland was designed with the addition of biochar membrane at the sides of open channel and mixture of soil used in wetland bed facilitates adsorption of pollutants. Flood risk due to dam construction was analysed in maximum discharge and found that there is no flood risk and withstand against seasonal influences. Hence the proposed engineered construction wetland is promising solution to improve canal water quality for restoration of urban canal transportation.

It is recommended that appropriate measures for water quality management should be placed in solid waste disposal and sewage disposal. Awareness programmes to educate local people about disposal of waste for sustainable utilization illegal wastewater disposal is of utmost need. Firm rules, regulations and policies are required to be introduced against illegal wastewater disposal in to urban canals. Silt traps and filter nets are recommended to be provided at the exit of hume pipe which carries storm water. Canal bed is recommended to be maintained at least 1m depth by dredging as it is sufficient for transportation. Care should be taken on the height of bridge deck when constructing or renovating bridges along Kirulapone canal. Future study should also be focused on bed changes due to mushrooming high rise buildings at the canal bank.

6. ACKNOWLEDGMENT

This work was conducted in collaboration with the Wetland Department of Sri Lanka Land Reclamation and Development Cooperation. We are grateful to Dr. Nalin Wikramanayaka of Open University of Sri Lanka, for his immense guidance and valuable instructions.

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