An assessment of the water quality in major streams of the Madu Ganga catchment and pollution loads draining into the Madu Ganga from its own catchment

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Abstract

The Madu Ganga Lagoon is located in the Southern Coast, Northwest of the city of Galle within the Galle District. The aim of this study was to evaluate the pollution status of the lagoon and the contribution of the land base pollutants from the catchment of the Madu Ganga. Selected water quality parameters were measured at monthly intervals at twelve sampling locations in the catchment. Certain parameters such as salinity (2.2 ± 1.7 ppt), oil & grease (8.5 ± 6.5 mg/L), total suspended solids (16.1 ± 12.3 mg/L), and turbidity (20.1 ± 12.5 NTU) are found to be elevated levels when compared with water quality standards. The study revealed that the Lenagala Ela brought a high nutrient load (426.7 kg/day) into Madu Ganga and Arawavilla Ela, Magala Ela and Bogaha Ela also contributed significantly. The highest nutrient loads were found with the onset of the Northeast Monsoon during November to January. The increase in nutrient loads is attributed to the fertilizers added to the soil with the commencement of the major paddy cultivation season.

Keywords: Physico-chemical parameters, Madu Ganga, Water pollution, Nutrient load, Suspended sediment

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Introduction

One of the major environmental concerns at present is the contamination of fresh water bodies' discharge from various point and non-point sources. The characteristics of a stream and river environment can depend upon its geology, substrate, flow rate, volume, water chemistry, mode of primary production and inhabitants (Hynes, 1970). Rivers, estuaries and lagoon waters are used extensively for the disposal of various types of wastes. When agrochemicals are applied to farm lands, some are degraded but the remainder will flow with the runoff, ultimately flowing in to rivers and their flood plains. Also, while much public concern and debate has focussed on the disposal of wastes such as sewage sludge and industrial wastes, relatively less attention has been given to other lagoon disposal activities such as the discharge of industrial and municipal effluents, agricultural and urban runoff. Waste, effluent, agricultural and domestic disposals contribute pollutants directly to marine environments.

Fresh water systems such as lakes, rivers, and streams are the source of clean water for house hold, industrial and agricultural uses. They are also important as the living environments for the ecology of many species of animals and plants that inhabit them. Moreover, wetlands are one of the most productive ecosystems of the world and occupy about 6% of the earth's surface (Harikumar *et al.*, 2006). Estuarine lagoon environments are unique to that particular place or a region and productive wetlands (IUCN, 2000; Bambaradeniya *et al.*, 2002; CECB, 2003; Miththapala, 2013). Wetlands are also valuable in terms of hydrology, plant and animal productivity, and biodiversity since they carry out important functions in terms of sustaining the hydrological and chemical cycles. Effects of land-based pollution in to these resources is of particular concern and, therefore, an assessment of the pollution level of lagoons from catchment water and identifying the likely pollution agent is essential for the scientific management of particular lagoon systems.

Pollution of rivers and streams is one of the most visible threats to the ecosystem and to the survival of the biota (Allan & Flecker, 1993). Various factors have been identified as causes of water quality deterioration in fresh water resources in streams, rivers, reservoirs, estuaries and lagoons in the recent past (Amarathunga *et al.*, 2010-a;

Amarathunga *et al*., 2010-b; Azmy *et al.*, 2010; Azmy *et al.*, 2012-a; Azmy *et al.,* 2012-b; Hettige *et al.*, 2012; Shirantha *et al.*, 2010-a; Shirantha *et al.*, 2010-b; Sureshkumar *et al.*, 2007; Weerasekera *et al.*, 2010; Weerasekera *et al.*, 2012; Amarathunga *et al*., 2013-a; Amarathunga *et al.*, 2013-b) recorded a high nutrient enrichment in Madu Ganga lagoon from its catchment. It is important to understand the nutrient loading and impact of water quality behaviour from streams feeding in to the Madu Ganga lagoon (CEA/ Euroconsult, 1997; Bambaradeniya *et al.*, 2002; CECB, 2002; CECB, 2003; Amarathunga *et al*., 2010b). Hence the objective of this study was to determine the current situation with respect to the physico-chemical composition of the surface water of major streams that feed the Madu Ganga and assess the contribution from land-based pollutants.

Materials and Methods

Study Area

Sri Lanka's highland massif, located in the South Central part of the island is the most important geographic determinant of inland water resources. The radial drainage pattern that carries surface water down from the high watersheds includes 103 river basins that cover 90 percent of the island (Arumugam, 1969). The Madu Ganga lagoon is located in the wet zone of Sri Lanka, and spreads inland from the coast between latitude 60° 14' and 60° 22' N and longitude 80° 00' and 80° 08'E in the Balapitiya and Karandeniya Divisional Secretariat Divisions. The surface area of the lagoon covers 915.0 ha of which 770.3 ha is open water while 144.7 ha accounts for the total area of true islands (CEA/ Euroconsult, 1997; Bambaradeniya *et al.*, 2002; CECB, 2002; CECB, 2003; Amarathunga *et al.*, 2010b). The Southwestern group of crystalline rocks, which is one of the upper paleozoic rock formations and the dominant group in the entire Southwestern region of Sri Lanka, predominates in the study area. The coastal area is mainly covered by quaternary deposits with river alluvium and lagoon deposits such as clay, silt and sand, marine deposits such as beach sand, beach rock and coral debris. The stretches of land that extend to the interior have red yellow podzolic soils with soft or hard laterite while undulating terrain with bog and half bog soils dominate the study area. These are very poorly drained soils with a surface layer rich in dark brown to black organic matter (Panabokke, 1996; CEA/ Euroconsult, 1997; Mapa *et al*., 1999; CECB, 2002; CECB, 2003).

The main form of land-use in the catchments is agriculture with rice, coconut and cinnamon as the main crops interspersed with pepper, fruit trees and vegetables. Cinnamon is the most important cash crop grown in the area with considerable extents found around the lagoon (CEA/ Euroconsult, 1997; CECB, 2002; CECB, 2003; Amarathunga *et al.*, 2010b). The major streams feeding the Madu Ganga begin in the Magala South and Magala North areas. Magala South Ela joins with Magala North Ela at the upper stream of Lenagala Ela , while Parawathura Ela enters into the lower stream of the Lenagala Ela. In addition, Madu Ganga estuarine system is fed by Horandu Ela, Nelligoda Ela, Mudali Ela and Mahawela Ela (Fig. 1).

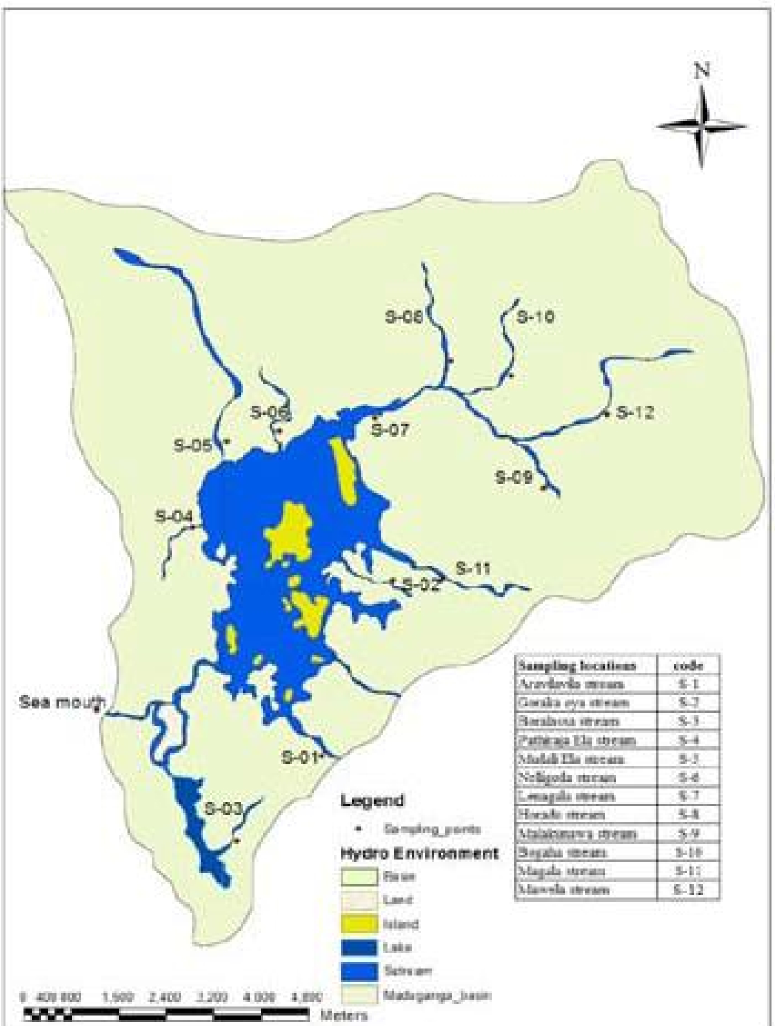

Fig. 1. Sampling locations in Madu Ganga basin

A major stream also connects with Halwathura Ganga which is fed by the Madampe Lake. When the outlet to the sea from the Madu Ganga lagoon is closed, the water flows from the Madu Ganga to the Halwatura Ganga but when it is open, the flow is in the opposite direction. The Randobe Lake also connects with the Madu Ganga estuarine system and both are unique systems; Randobe Lake is fed by the Boralessa Ela and Heen Ela. The entire Madu Ganga basin consists therefore, of several micro-catchments formed by the different streams (Bambaradeniya *et al.,* 2002; Survey Department of Sri Lanka, 2007) relating to the Madu Ganga basin.

Surface water sampling and analysis

Surface water samples were collected monthly during the period May, 2006 to January, 2007 from twelve sampling locations. The sampling locations were selected according to a stratified random sample technique (Harikumar *et al*., 2006), so they were representative of all the major tributaries; such as, Aravilavila stream (S1), Goraka oya stream (S2), Boralassa stream (S3), Pathiraja Ela stream (S4), Mudali Ela stream (S5), Nelligoda stream (S6), Lenagala stream (S7), Horadu stream (S8), Malakunawa stream (S9), Bogaha stream (S10), Magala stream (S11), and Mawela stream (S12) in the Madu Ganga catchment (Fig. 1). Water samples were collected by an open water sampler at 0.5 m below the surface, where the total water depth is less than a meter. Wherever the water depth exceeded 1.5 m, Ruttner sampler was used to collect water samples with one meter depth (Greenburg *et al*., 1998). Two samples were collected from each site and each sample analyzed in triplicate; the mean value of the triplicates was adopted in the data analysis. The water samples were collected in pre-cleaned polypropylene sample bottles from each site and kept at 4 °C in the dark during the transportation. For certain parameters, data was collected in situ using calibrated portable instruments; water temperature and pH were measured by a pH meter (Orion 260A), electrical conductivity (EC) using a Hanna portable multi range conductivity meter (HI 8733), dissolved oxygen (DO) level was measured using a portable meter (Orion 830A), turbidity level was measured using portable meter (Hach 2100P) and flow rate with a portable flow meter (FP101).

Collected water samples were analyzed in the laboratory for nutrients (Ammonia-nitrogen, nitrate-nitrogen, nitrite-nitrogen and dissolved orthophosphate), five-day biochemical oxygen demand (BOD), total suspended solids (TSS), chlorophyll content (estimated spectrophotometrically and corrected for the presence of phaeophytin), hardness levels (calcium, magnesium, and total hardness), chloride, alkalinity and levels of oil & grease (analysis was carried out only at two sampling locations) in accordance with standard methods for examination of water and waste water (Greenburg *et al.*, 1998).

Data analysis

The data were analyzed by one-way ANOVA followed by Turkey test to determine the differences between sampling sites in water chemistry and pollution loads. Microsoft excel, SPSS version-20 and Minitab version-15 were used for the statistical analysis and means for each parameter compared for significance at the 0.05 level. Pollution loads were calculated using data for the entire period of eight months. Discharge was calculated using the Eq. 1.

$$Q = uA \qquad (Eq. 1)$$

$$L = F \times C \times Q \qquad (Eq. 2)$$

Where Q is discharge (m^3/s), A is the cross-sectional area of the portion of the channel occupied by the flow, u is the average flow velocity (m/s). The pollution load was calculated using Eq. 2, where L is load (kg/day), F is unit conversion factor, and C is concentration of pollutant (mg/L) (Buchanan and Somers, 1969). Cluster analysis was performed on the nutrients loading data sets at each sampling location to identify similar groups of pollutants at locations. Wards, hierarchical cluster method and squared euclidean distance of the data sets were followed for the cluster analysis (Aldenderfer and Blashfield, 1984). Updated land use data (Department of Surveys, 2005) were used to prepare land use maps using the software Arc GIS - version 10.1.

Results

The land use systems and the proportion of land allocated to different uses in the Madu Ganga catchment are shown in Table 1. and Fig. 2. Forty six percentage of the land was used by home-gardens in the basin while the other major land uses were for Paddy cultivation, coconut plantations, lagoon and river.

Table 1. Forms of Land use and their percentages in Madu Ganga basin

Land use type	Percentage
Build up areas	0.7
Coconut plantations	7.3
Home-gardens	46.0
Lake	0.6
Marsh	2.7
Other	16.3
Paddy cultivations	13.2
Rubber plantations	2.3
Sand areas	0.9
Scrub forest	1.3
River/stream/lagoon area	8.5
Tea	0.4

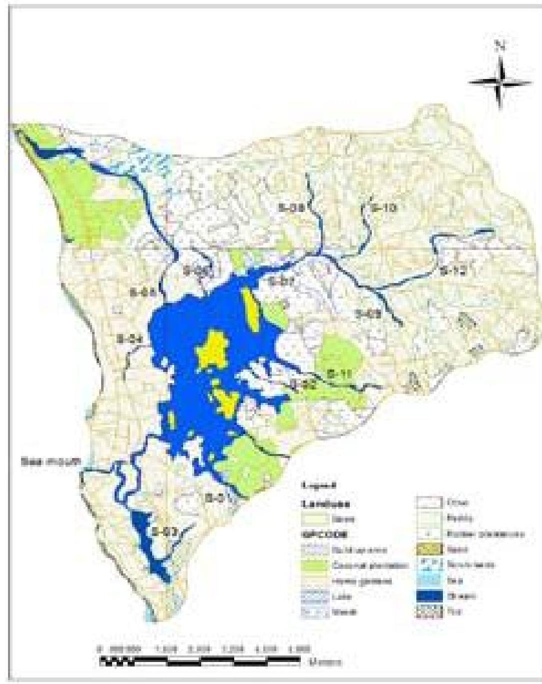

Fig. 2. Land use pattern in Madu Ganga basin

Lowest and highest ambient surface water temperature in the fresh water sources were 35.0°C and 26.9°C in January and June respectively. The pH of fresh water sources ranged from 5.00 to 7.57 and the differences between streams was highly significant ($P<0.01$). The lowest value for DO concentration was recorded from Pathiraja Ela in August and the highest from Mahawela Ela in November. There were significant differences in values for DO and pH between the different streams ($P<0.01$). The DO values from most sampling sites showed that the water was of inferior quality according to the standards. The mean and range for ammonia-nitrogen, nitrate-nitrogen and dissolved phosphate, are shown in Table 2 where it can be seen that the levels of these nutrients were high. The highest concentration of ammonia-nitrogen and nitrite-nitrogen were measured in the Pathiraja Ela while the highest concentrations of nitrate-nitrogen and dissolved phosphate were recorded in Magala Ela.

Table 2. Summary of values for water quality parameters in fresh water streams in the Madu Ganga catchment (Mean ± SD, Minimum and Maximum values)

Parameter	Streams											
	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12
pH	5.87 ± 0.51 (5.38-7.95)	5.42 ± 0.33 (4.96-5.98)	6.45 ± 0.37 (6.02-7.85)	6.15 ± 0.37 (5.55-6.53)	6.85 ± 0.49 (5.25-7.46)	5.3 + 0.48 (4.33-5.76)	6.40 ± 0.79 (4.05-6.84)	5.12 ± 0.40 (4.39-5.57)	5.57 ± 0.43 (5.09-6.50)	6.68 ± 0.81 (5.13-7.57)	5.24 ± 0.40 (4.80-5.84)	5.14 ± 0.84 (3.54-6.4)
DO	2.43 ± 0.67 (1.52-3.3)	5.42 ± 1.17 (3.56-7.25)	2.94 ± 1.95 (1.61-7.67)	5.75 ± 0.66 (3.05-6.51)	4.93 ± 1.00 (1.33-5.26)	1.85 ± 0.76 (0.59-3.05)	6.38 ± 0.88 (3.18-7.09)	5.01 ± 0.69 (1.96-6.84)	5.32 ± 1.20 (3.72-7.66)	6.25 ± 0.83 (3.31-6.79)	5.82 ± 1.06 (3.57-6.86)	4.59 ± 1.66 (2.39-7.72)
BOD	10.83 ± 7.52 (3.2-22.4)	14.36 ± 20.07 (3.2-50.0)	8.45 ± 6.34 (3.1-20.0)	9.5 ± 5.38 (3.4-15.0)	9.97 ± 10.34 (3.2-30.0)	9.02 ± 7.77 (3.3-25.0)	10.33 ± 3.95 (5.0-15.0)	17.28 ±23.29 (3.2-67.2)	18.60 ± 18.89 (3.2-56)	12.22 ± 8.87 (3.2-26)	19.01 ± 15.84 (6.4-57.0)	10.35 ± 4.14 (3.2-16.0)
EC	1252.88 ± 2930.03 (89.0-8500.0)	50.57 ± 11.31 (38.0-73.0)	620.50 ± 419.73 (29-1620.0)	219.18 ± 42.71 (163.0-277.0)	952.75 ± 881.60 (117.0-2720.0)	273.26 ± 167.27 (80.0-614.0)	170.22 ± 185.25 (34.0-496.0)	185.37 ±158.76 (38.0-474.0)	69.37 ± 14.40 (50.0-94.0)	62.87 ± 10.07 (47.0-80.0)	51.51 ± 12.15 (38.0-75.1)	72.65 ± 41.00 (44-169.0)
Turbidity	18.23 ± 8.74 (8.2-32.1)	16.96 ± 22.04 (3.71-49.7)	19.95 ± 6.69 (10.5-31.2)	13.26 ± 6.91 (3.8-22.3)	18.11 ± 6.21 (12.3-30.7)	18.35 ± 7.93 (9.4-34.3)	21.85 ± 15.41 (9.2-45.7)	15.60 ± 6.81 (8.1-27.5)	22.89 ± 11.40 (7.1-42.4)	29.08 ± 14.15 (10.7-57.7)	30.62 ± 11.20 (12.6-49.0)	15.39 ± 10.98 (4.0-49.7)
Ammonia	0.11 ± 0.11 (0.02-0.33)	0.08 ± 0.09 (0.01-0.25)	0.18 ± 0.09 (0.02-0.30)	0.38 ± 0.48 (0.03-1.32)	0.09 ± 0.07 (0.02-0.26)	0.04 ± 0.01 (0.02-0.06)	0.12 ± 0.09 (0.04-0.31)	0.09 ± 0.02 (0.02-0.27)	0.16 ± 0.02 (0.02-0.62)	0.18 ± 0.19 (0.05-0.50)	0.13 ± 0.09 (0.03-0.34)	0.11 ± 0.1 (0.01-0.32)
Nitrite	ND	0.01 ± 0.01 (0.001-0.02)	0.02 ± 0.01 (0.004-0.02)	0.02 ± 0.01 (0.007-0.02)	ND	ND	ND	ND	0.01 ± 0.01 (0.001-0.02)	ND	ND	ND
Nitrate	0.22 ± 0.13 (0.05-0.38)	0.11 ± 0.09 (0.01-0.26)	0.20 ± 0.15 (0.01-0.48)	0.27 ± 0.09 (0.12-0.38)	0.13 ± 0.07 (0.04-0.27)	0.12 ± 0.07 (0.02-0.23)	0.26 ± 0.13 (0.13-0.50)	0.14 ±0.11 (0.03-0.41)	0.30 ± 0.02 (0.04-0.82)	0.37 ± 0.32 (0.06-1.01)	0.40 ± 0.21 (0.11--1.40)	0.16 ± 0.07 (0.11-0.40)
Phosphate	0.01 ± 0.01 (0.01-0.03)	0.01 ± 0.01 (0.01-0.04)	0.02 ± 0.01 (0.01-0.4)	0.02 ± 0.02 (0.01-0.04)	0.01 ± 0.01 (0.01-0.03)	0.01 ± 0.01 (0.01-0.03)	0.01 ± 0.01 (ND-0.4)	0.01 ± 0.01 (ND-0.03)	0.02 ± 0.01 (ND-0.04)	0.05 ± 0.01 (ND-0.3)	0.30 ± 0.06 (0.01-2.18)	0.01 ± 0.01 (0.01-0.04)

Chloride	1431.25 ± 1031.25 (400.0-3650.0)	1031.25 ± 877.10 (400.0-3100.0)	1322.00 ± 1162.45 (400.0-4025.0)	2575.00 ± 1041.01 (1250.0-4050.0)	1868.75 ± 1540.85 (350.0-5100.0)	1618.75 ± 589.75 (850.0-2450.0)	1850.00 ± 991.39 (1200.0-4100.0)	1425.00 ±891.63 (800.0-2850.0)	1831.25 ± 1889.81 (600.0-6350.0)	1968.75 ± 275.50 (600.0-6900.0)	1300 ± 68.76 (650.0-2650.0)	1675.00 ± 1196.12 (750.0-4000.0)
Alkalinity	56.87 ± 22.03 (15.0-90.0)	45.00 ± 22.83 (10.0-75.0)	85.63 ± 18.21 (60.0-110.0)	83.33 ± 21.60 (45.0-105.0)	68.12 ± 35.04 (40.0-150.0)	58.75 ± 16.64 (30.0-85.0)	63.12 ± 25.06 (30.0-100.0)	67.50 ± 13.63 (50.0-90.0)	55.00 ± 23.75 (20.0-100.0)	61.87 ± 17.91 (25.0-90.0)	76.87 ± 43.09 (10.0-155.0)	61.87 ± 21.86 (20.0-90.0)
Chlorophyll -a	10.73 ± 11.26 (1.3-31.2)	8.15 ± 9.92 (1.6-29.2)	9.86 ± 11.07 (0.8-25.7)	7.86 ± 14.98 (0.7-34.6)	4.16 ± 3.60 (0.1-10.8)	5.12 ± 3.88 (0.1-11.4)	7.86 ± 14.97 (0.5-12.6)	9.55 ± 1.38 (0.7-33.8)	6.27 ± 5.51 (1.0-16.8)	8.28 ± 14.97 (0.9-42.0)	6.90 ± 6.19 (1.0-20.5)	5.86 ± 3.83 (0.7-10.7)
WT	29.61 ± 1.04 (28.0-31.0)	31.90 ± 2.02 (28.0-34.3)	28.94 ± 1.51 (27.2-32.0)	28.87 ± 1.05 (27.4-30.1)	29.44 ± 1.67 (26.9-31.4)	30.32 ± 1.8 (27.5-32.6)	28.86 ± 1.05 (27.2-31.5)	30.28 ± 1.93 (27.4-32.5)	31.38 ± 2.21 (26.9-34.5)	31.45 ± 2.29 (27.3-35.0)	30.97 ± 1.36(29.1-32.4)	31.46 ± 1.34 (29.8-33.3)
TSS	13.83 ± 12.47 (3.3-43.0)	16.05 ± 24.28 (2.5-70.0)	17.96 ± 11.82 (4.6-36.0)	20.91 ± 15.64 (6.5-42.7)	13.90 ± 10.83 (1.5-30.0)	22.17 ± 9.90 (6.7-37.0)	20.91 ± 15.64 (3.0-23.5)	14.19 ± 8.27 (5.5-27.3)	15.53 ± 10.21 (0.1-30.0)	22.10 ± 12.25 (6.7-38.0)	17.97 ± 10.61 (3.3-34.7)	9.40 ± 8.77 (2.7-28.0)
Salinity	2.75 ± 3.18 (0.5-5.0)	ND	ND	ND	1.67 ± 0.57 (1.0-3.5)	ND	ND	ND	ND	ND	ND	ND
COD	NA	NA	NA	NA	6.92 ± 4.17 (4.1-52.0)	NA	23.26 ± 23.59 (4.0-64.0)	NA	NA	NA	NA	NA
Oil & Grease	NA	NA	NA	NA	6.92 ± 4.171.5-12.5)	NA	10.60 ± 8.70 (5.0-26.0)	NA	NA	NA	NA	NA

ND - Not detected
NT - Not analysed
WT - Water temperature
TSS - Total suspended solid

The p-value for the nitrate-nitrogen and ammonia-nitrogen were 0.049 and 0.063, respectively, showing that there is a significant difference of nitrate-nitrogen concentrations among the streams but no significant differences of ammonia-nitrogen concentrations among the sampling locations. It should be noted, however, that nitrite-nitrogen was measured only in Goraka Ela, Boralessa Ela, Pathiraja Ela and Malkunawa Ela. In addition, the mean test for dissolved phosphate p-value was 0.46 and it implies that there is no significant difference in levels of dissolved phosphate concentrations between the sampling locations. The spatial variation of nutrient loads from the basin in Fig.3. shows that four peaks flows of ammonia-nitrogen, nitrite-nitrogen nitrate-nitrogen and dissolves phosphate were observed from Arawavila Ela, Mudali Ela, Lenagala Ela and Magala Ela sampling locations.

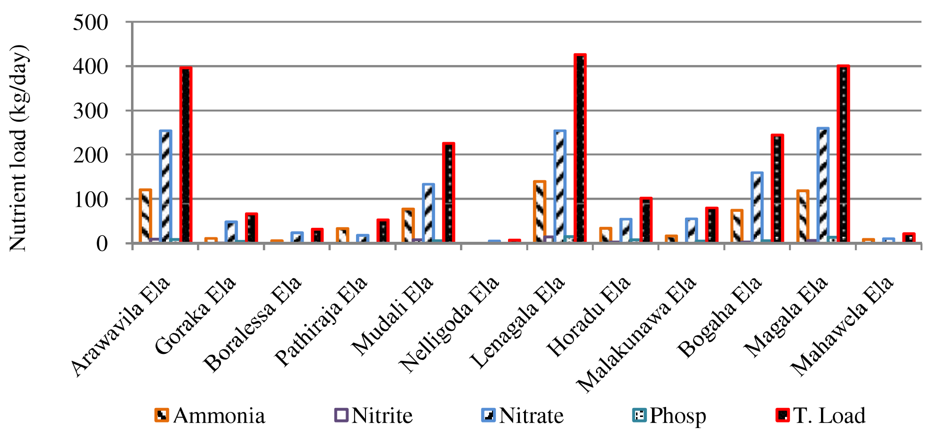

Fig.3. Total nutrient loads draining in to Madu Ganga Lagoon from streams

The temporal variation of nutrient loading from the basin is shown in Fig 4.

Phosphate and nitrate-nitrogen were high in May-June and December-January period, while ammonia-nitrogen and nitrite nitrogen were increased in the period from December to January. Highest total nitrate, total phosphate, and total ammonia loads are drained through the Lenagala Ela. The total nitrate load released to the lagoon is 1285.94 kg/day, Total nitrite load released 53.37 kg/day, total ammonia load released 650.42 kg/day, and total phosphate load released to lagoon is 75.0 kg/day. Fig. 5. illustrates the classification of different streams based on the pollutant load draining in to the lagoon.

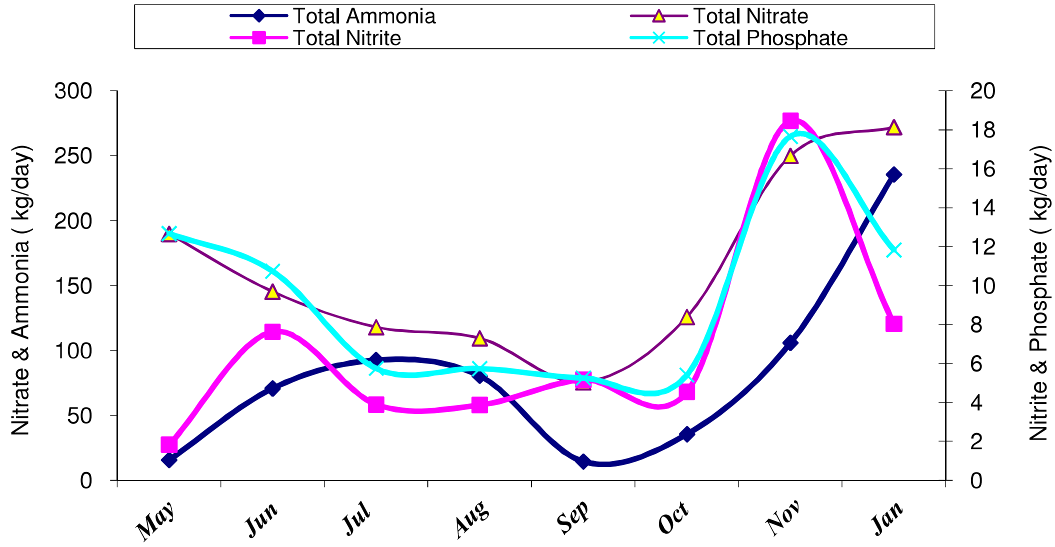

Fig 4. Total nutrient loads draining in to Madu Ganga Lagoon in different months

The highest TSS value was recorded in Gorakadanda sample location in the month of November. Two peaks in turbidity levels were recorded in May - June period and in January from the streams of the basin. The P value for means of TSS tested by ANOVA was 0.64. Fig. 6. illustrates the means TSS, and turbidity variation with rainfall in the basin.

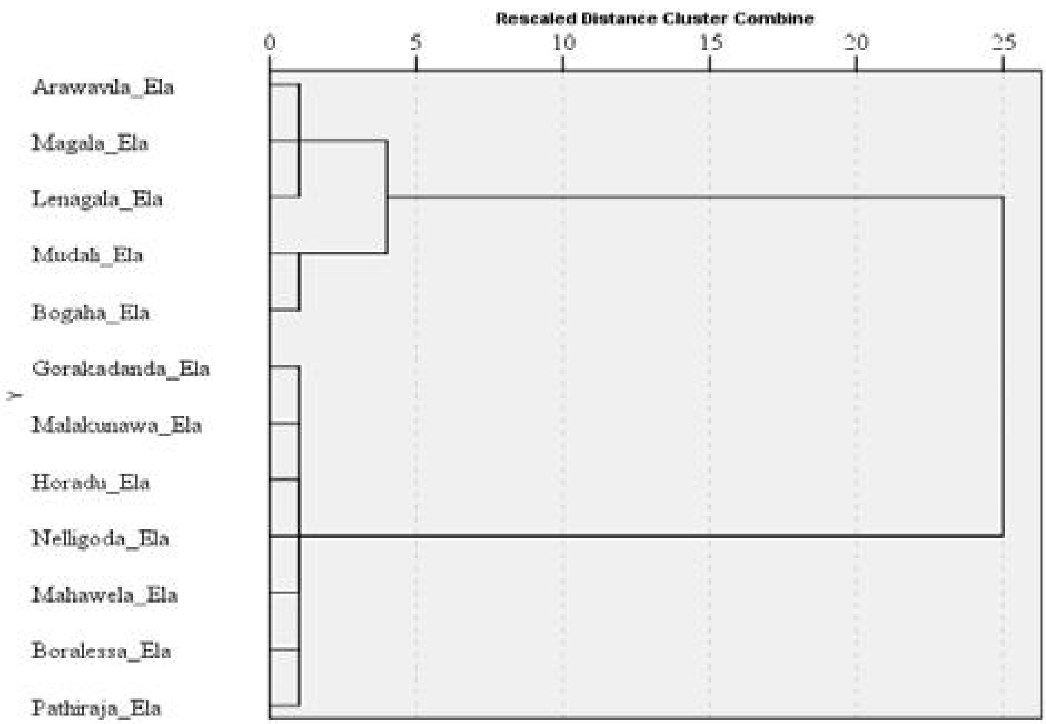

Fig. 5. Classification of streams based on stream pollutant load

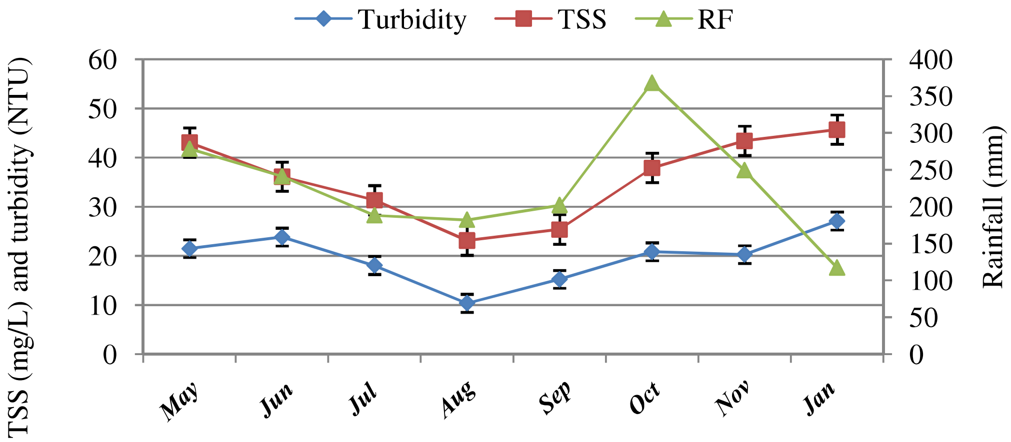

Fig. 6. Mean total suspended solids and turbidity variation with rainfall in the fresh water streams (mean rainfall from 2004 to 2009- source: Meteorological Department, Colombo)

High turbidity was recorded in Bogaha Ela in June and lowest turbidity value was observed in Gorakadanda sampling location in November. Many streams recorded BOD of more than 20.0 mg/L except Pathiraja Ela, Lenagala Ela and Mawela Ela during the study period. The highest BOD was recorded from Horandu Ela in January. Highest chlorophyll-a concentration was recorded from Bogaha Ela sampling location in September and lowest chlorophyll-a concentration from Nelligoda Ela in June. Some sites showed higher Electrical Conductivities (EC) than found in normal fresh water, while 1.0 to 5.0 ppt salinity was recorded from Arawavila Ela and Mudali Ela because of brackish water contamination from the lagoon. The highest and lowest EC values were recorded from Arawavilla Ela and Lenagala Ela sampling locations in November and October, respectively. Chloride content was higher in streams that showed mixing with brackish water. The chlorophyll content of the streams ranged from 0.01 mg/m^3 to 42.02 mg/m^3.

Discussion

Land-use patterns, variability in climate, soil erosion, and other environment factors all interact to affect natural resources by altering the structure and function of the ecosystems in the area. The slightly acidic pH recorded in this study sites would be a favourable condition for the growth of aquatic flora and fauna. There were significant seasonal fluctuations of DO levels in all streams. DO values below critical value of 4.0

mg/L were recorded at certain locations, which may cause detrimental effects on most aquatic organisms. Hence frequent fish mortality incidents can be expected to occur due to unfavourable conditions for fish. Moreover, in several sites BOD exceeded 30.0 mg/L and these elevated levels of BOD exceed the water quality standard value (BCS, 1983; Gazette, 1980; and Gazette, 2008) and lead to possible pollution of the environment in the lagoon.

When the lagoon outlet to the sea is closed by a sand bar, water flows from Madu Ganga to the Madampe Lake through the Halwature Ela, When the outlet is open, however, salinity in the lagoon increases and spreads into other streams as well. Introduction of fresh water fish could, therefore, lead to a risk for such fish in their earlier life stages due to fluctuations in conductivity and salinity in the fresh water streams. The presence of suspended sediment or solids in river water is an important physical characteristic. Such sediment can have a direct effect on aquatic life through damage to organisms and their habitats (Muncy *et al*., 1979) and an indirect effect through its influence on turbidity and light penetration. The faster flowing water erodes the stream banks and the suspended sediments and turbidity levels are high in such streams. Statistically, there were no significant differences in TSS between streams. Even though higher total suspended solid concentrations of 70 mg/L drain through Goraka Ela, actual highest loads were observed in Lenagala Ela because of the larger volumes of its discharge.

A significant proportion of the fertilizers used in agriculture end up in ground and surface waters and ultimately in the sea unless there is degradation. Nitrate is highly soluble and the concentration increases as the water flow increases, and there is no apparent dilution (Hill *et al.,* 1999). Farmers cultivate paddy land in two seasons, at the onset of Southwest monsoon (*Yala*) and Northeast monsoon (*Maha*) and during these times, the runoff carries relatively large quantities of nitrate from the catchments. A high total nitrate nitrogen load was measured during the period November to January from the basin (Fig. 4.) coinciding with the commencement of the major paddy cultivation season (*Maha*) and high rainfall received in the study area (Fig. 6). The highest ammonia value was recorded in January in Pathiraja Ela and lowest value from Gorakadanda Ela sampling location in August. De-nitrification was observed from Pathiraja Ela and it may be a result of anaerobic ammonium oxidation, because of high ammonia-nitrogen, nitrite-nitrogen and much sewage contamination from the urban areas (Knowles, 1982; Seitzinger, 1988). Fertilizer, sewage, and surface runoff are the main sources of phosphorus (ortho-phosphate) in freshwater system (Khan and Ansari, 2005; Paytan and McLaughlin, 2011). However, the sources of phosphate in Madu Ganga are surface runoff and erosion of rivers banks and lagoon perimeter. Statistically, there were no significant differences of ortho-phosphate concentration between the sampling locations. The ortho-phosphate concentration in the streams did not exceed 0.05 mg/L; phosphate exceeding this level can cause algal blooms that can choke out other plants and completely take over the lagoon water (Gamito *et al*., 2005). Magala Ela showed high phosphate concentration during rainy season but values in other sites did not exceed the tolerable limit. As with phosphorus, excessive nitrogen also leads to eutrophication in the lagoon. The cluster analysis according to pollutant loads draining to streams revealed two major clusters (Fig. 5). The first cluster was formed by Arawavila Ela, Magala Ela, Lenagala Ela, Mudali Ela and Bogaha Ela are the highest nutrient loading streams and second cluster include rest of the other streams. The sampling locations represent each case on the Y axis and the X axis is a rescaled distance coefficient for nutrient load. Aldenderfer and Blashfield, (1984) stated that, the length of the branch shows how apart each case is from the other cases within its cluster and cases with low distance/high similarity are close together.

These streams had mean values for biological oxygen demand ranging from 3.21 mg/L to 67.2 mg/L and it appears that the untreated waste and nutrient from the catchment area are largely responsible for the degradation of aquatic resources. The residents living in the lagoon reservation also contribute to the pollution of water. The chlorophyll content was high due to accumulation of nutrients in the lagoon providing favourable conditions for growth of *Najas marina* (Amarathunga *et al*., 2010b) and other aquatic plants. This situation arises due to increasing discharge of sewage and other waste material from households as well as dumping of garbage and saw dust. Since the tidal amplitude in lagoons and estuaries in Sri Lanka is low and the water flow is gentle, there is a tendency for the accumulation of nutrients and chemical residuals in these coastal areas (Bambaradeniya *et al.,* 2002). Oil & grease at concentrations over 1.0 mg/L were found in the streams from two sampling locations at every sampling. Levels in Mudali Ela exceeded the limit of 10.0 mg/L in October while Lenagala Ela recorded 26.0 mg/L in

July; both exceed the general standard for discharge of effluents in to inland surface water (BCS, 1983; Gazette, 1980; Gazette, 2008). These are indications of heavy contamination of oil & grease in water due to poor management of the motorized boats in Madu Ganga lagoon.

Conclusions

Land based pollutants affect the water quality in Madu Ganga basin. While the parameters of water quality is within acceptable limits for potable water, some water quality parameters exceeded the standard levels which indicated deterioration in water quality. The results of the study showed that BOD was high at some locations. In addition, levels of 10.0 mg/L oil & grease concentration were recorded throughout the study period in Lenagala Ela and 6.9 mg/L in Mudali Ela. Higher rainfall increased the nutrient load in the lagoon relative to periods of low rainfall because of runoff from paddy fields and other agricultural activities. The study revealed that the Lenagala Ela contributed a high nutrient load to Madu Ganga and Arawavilla Ela, Magala Ela and Bogaha Ela also brought significant nutrient loads into Madu Ganga lagoon. A particularly high nutrient load was brought into the Madu Ganga basin with the onset of the Northeast monsoon during the period from November-January and commencement of the *Maha* paddy cultivation season.

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