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Journal of Environmental Sciences 2010, 22(6) 813–819

JOURNAL OF
ENVIRONMENTAL
SCIENCES
ISSN 1001-0742
CN 11-2629/X
www.jesc.ac.cn

Restoration of Koggala lagoon: Modelling approach in evaluating lagoon water budget and flow characteristics

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Received 31 October 2009; revised 07 December 2009; accepted 25 December 2009

Abstract

Groyne system modification is described related to restoration efforts to Koggala lagoon, Sri Lanka.The large-scale unplanned sand removal at the lagoon mouth shifted the formation of sand bar towards the lagoon and made adverse effects on its ecosystem. After the removal of the natural sand bar, groyne system was constructed to avoid sand deposition in the lagoon and to protect the highway bridge (across the lagoon outlet channel) from the wave attack. The existing groyne system resulted the lagoon mouth being permanently open to sea which in turn led to many environmental problems. Groyne system modification is proposed in this study to reduce the sea water intrusion.Water budget and two-dimensional depth averaged hydrodynamic model were developed for understanding the hydrologic and flow characteristics of the lagoon. Numerical experiments was performed at lagoon mouth area for two cases: (1) existing condition and (2) proposed rubble mound groyne system condition. Comparison of results was obtained for both cases to describe flow pattern at lagoon mouth. Results further showed, the width should be reduced to a maximum of 40 m. Proposed mouth width (40 m) pushed the salting factor towards 0.5 from 0.68. Salting factor reduction with the groyne modification may result a predominant influence of fresh water which may in turn lead lagoon to a fresh water ecosystem.

Key words: Koggala lagoon; hydrodynamic modelling; lagoon hydrology

DOI: 10.1016/S1001-0742(09)60182-0

Introduction

Coastal lagoons are inland water bodies, usually oriented parallel to the coast, separated from the ocean by a barrier, connected to the ocean by one or more restricted inlets which remain open at least intermittently, and have water depths which seldom exceed a few meters (Kjerfve, 1994). Coastal zones are currently experiencing intense and sustained environmental pressures from a range of natural, semi-natural and anthropogenic drivers (Mitsch and Gosselink, 2000).

At the lagoon mouth of Koggala there was a naturally built sand bar perpendicular to the lagoon mouth which controlled the seawater intrusion into the lagoon. With the opening of the lagoon mouth during the rainy season, rapid outflow of water begins. However, the flow of seawater into the lagoon during the monsoon and high tides ceases the formation of sand bar again in the dry season. This natural dynamic rhythm causes high seasonal variations in most of the physical and chemical properties of lagoon water. The natural sand barrier at the Pol-oya outlet was removed during coastal defense activities in early 1990's and this has been followed by unplanned removal of sand near the lagoon mouth. After the removal of the natural sand barrier, the formation of sand bar shifted towards the "Kathaluwa" bridge (highway bridge) by exposing the bridge to wave attack (Fig. 1). Breaching the sand bar became increasingly difficult and erosion close to the bridge posed a risk to the bridge. Subsequently in 1995, the Southern Provincial Council built a groyne system (old groyne) to protect the bridge from the wave attack. Another groyne (new groyne) was built in 2005 to control the erosion at the west side of the mouth due to prevailing groyne structure. Construction of the groyne provoked concern over local resource users and environmentalists as the lagoon hydrology and salinity showed drastic changes and variations. Increase in salinity levels (at present the average salinity is 25 ng/L) is a direct result of predominant seawater intrusion during high tides especially during the dry season (December to March).

Objectives of this study are to analyze quantitatively the adverse contribution of the existing groyne structure, caused by intensification of the seawater through the large mouth opening and to evaluate the restoration possibility.

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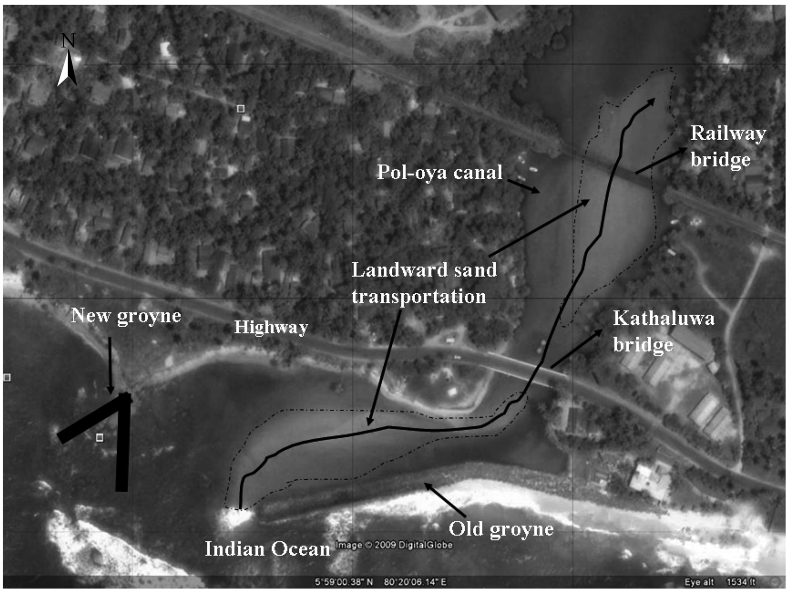

Fig. 1 Satellite image of lagoon outlet with the existing groyne structures. Sand deposited areas are encircled by dotted lines (modified from Google earth, accessed January 2009).

An effort has taken to analyze water budget of the lagoon and flow characteristics at lagoon mouth area incorporating environmental variables.

1 Materials and methods

1.1 Study site description

Koggala lagoon is located (5°58′–6°20′N and 80°17′–80°22′E) on the southern coast of Sri Lanka (Fig. 2). The water-spread area of the Koggala lagoon, estimated as 7.27 km^2 measuring 4.8 km in length and 2 km in width (CEA, 1995). The water depth ranges from 1.0 to 3.7 m (IWMI, 2006). The lagoon is coastal lake essentially supplied by rain and a number of streams are connected to it. Warabokka-ela stream (Koggala-oya) that enters the lagoon from the north-west is the main freshwater supply. Kerena anicut was built combining the streams named as Mudiyansege-ela stream and Thithagalla-ela stream. Heen-ela stream contributes a minor to the freshwater inflow. Apart from those three streams, Kahanda-ela stream, Gurukanda-ela stream and Thelambu-ela stream were contributers for freshwater inflow but presently these three are abandoned and have become marsh lands with

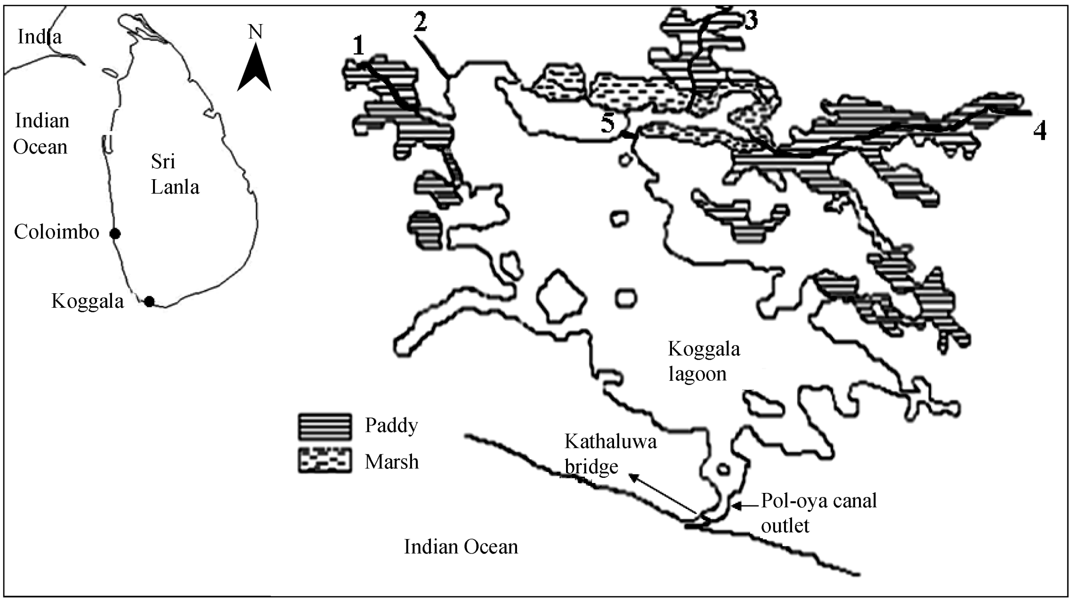

Fig. 2 Map of Koggala lagoon with the locations of outlet and major freshwater inflows. Suburb marsh and paddy field areas are shown in different shaded patterns (Modified from Gunawickrama and Chandana, 2006). (1) Warabokka-ela stream; (2) Heen-ela stream; (3) Thiththagalle-ela stream; (4) Mudiyansege-ela stream; (5) Kerena anicut.

almost zero water flow due to overgrown vegetation. The only outlet of the lagoon is Pol-oya located at the south-east corner; a narrow 300 m long canal connects the lagoon with the sea. Hydro-catchment of the lagoon outlet is about 55 km^2, of this amount about 15% consists of lagoon area. It is estimated to have further 15% of paddy fields or low lying areas (Priyadarshana et al., 2007).

1.2 Lagoon water budget

The natural water budget in the lagoon made up of contributions from precipitation (Q_{prc}) and surface evaporation (Q_{evp}), from runoff flow consist of stream discharge and surface runoff from catchment area (Q_{runoff}) from seawater inflow (Q_{inflow}) and from the outflow of water to the adjacent open sea area (Q_{outflow}). Assumption made in applying an annual water budget is that the total out flow of water (Q_{outflow}) from the watershed has been measured as stream flow. This implies that there is no loss from, or gain to, stream flow at the watershed outlet by deep seepage or ground water inflow associated with underground geological strata from adjacent watersheds (Gregersen et al., 2005). The identified major components of the water budget of the lagoon are given by Fig. 3. Inflows consist of precipitation, runoffs from streams and surface-catchment and seawater intrusion while outflows consist of evaporation and lagoon outflow to the adjacent sea.

Daily atmospheric precipitation data at Mapalana rain gauge station (located in the catchment area of the lagoon) from 1977 to 2007 were used to determine the precipitation contribution. A monthly constant evaporation with a pan coefficient of 0.8 (Priyadarshana et al., 2007) was used to evaluate the evaporation contribution. Freshwater inflows were determined by using surface velocities and cross sectional areas of the inflow streams. Velocities were measured by flow velocity meter (KENEK VP 1000, Japan). To estimate the cross sectional area, stream width was measured (Range finder, Laser 800-Nikon, Japan) and mean bottom depth was measured by a measuring pole along the section of the stream. Stream discharge can be expressed by Eq. (1).

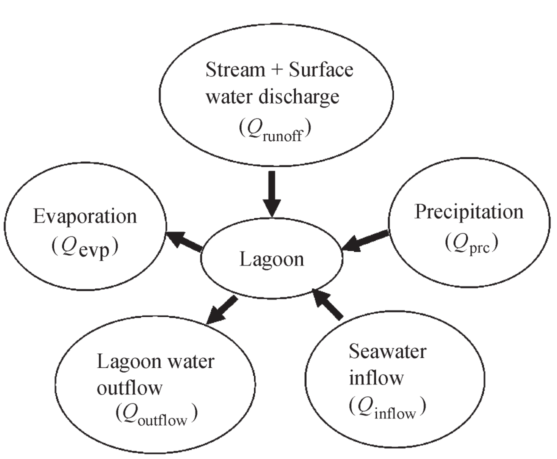

Fig. 3 Schematization of lagoon water budget with budget components for Koggala lagoon.

$$Q_{\mathrm{base}} = A_1 v \tag{1}$$

where, Q_{base} is the rate of stream inflow under zero precipitation conditions in catchment area and this was considered as the base flow; A_1 (m^2) is the mean cross sectional area of the stream; and v (m/sec) is the mean velocity. Surface water runoff from catchment area to the lagoon can be calculated using runoff model derived from storage function model as Eq. (2) (Sugiyama et al., 1997).

$$Q_{\mathrm{surface\text{-}runoff}} = \frac{1}{86.4} f_1 A q \tag{2}$$

where, $Q_{\mathrm{surface\text{-}runoff}}$ (m^3/sec) is the rate of surface water runoff to the lagoon from the catchment area due to precipitation, f_1 is the runoff coefficient (non dimensional), A (km^2) is the catchment area and q (mm/day) is average depth of runoff due to precipitation derived from storage function model.

Total runoff can be expressed by Eq. (3):

$$Q_{\mathrm{runoff}} = Q_{\mathrm{base}} + Q_{\mathrm{surface\text{-}runoff}} \tag{3}$$

Water level variations were used to calculate the corresponding ocean-lagoon fluxes (Göneç and Wolfin, 2005). As a first approximation, the time-dependent, spatially averaged lagoon levels were used. The spatially averaged and time-dependent lagoon levels ($h^{(t)}_{\mathrm{avg}}$) were obtained from averaging all levels measured at stations around the lagoon.

First, the level variation time series (Eq. (4)) were to be constructed from the spatially averaged level time series ($h^{(t)}_{\mathrm{avg}}$) over the entire period $T_{\mathrm{total}} = N{\cdot}\Delta t$ (Δt is sampling interval).

$$\Delta h^{(t+0.5\Delta t)}_{\mathrm{avg}} = h^{(t+\Delta t)}_{\mathrm{avg}} - h^{(t)}_{\mathrm{avg}} \tag{4}$$

For this field study N was 24 while the sampling interval was 1 hr. Then T_{total} was 24 hr. The terms of the ocean-lagoon exchange time series during any nth time step (n = 1 to N) can be obtained as Eq. (5).

$$\Delta h^{n}_{\mathrm{inflow}} = \Delta h^{n}_{\mathrm{avg}} - \Delta t (Q / S^{\mathrm{avg}}_{\mathrm{lag}})^{n} \tag{5}$$

where, $Q = Q_{\mathrm{riv}} + Q_{\mathrm{runoff}} - Q_{\mathrm{evp}}$ and $S^{\mathrm{avg}}_{\mathrm{lag}}$ is the lagoon surface area, which is time-dependent function of the level variation ($S^{\mathrm{avg}}_{\mathrm{lag}}(h^{(t)})$). The volume of inflow and flux are then can be easily calculated by summation of positive terms only as Eq. (6):

$$V_{\mathrm{inflow}} = S^{\mathrm{avg}}_{\mathrm{lag}} \sum \Delta h^{n}_{\mathrm{inflow}}(+) \qquad n = 1 \text{ to } N \tag{6}$$

and Q_{inflow} can be obtained by Eq. (7):

$$Q_{\mathrm{inflow}} = V_{\mathrm{inflow}} / T_{\mathrm{total}} \tag{7}$$

This water balance can be expressed by Eq. (8) (total inflow = total outflow).

$$Q_{\mathrm{runoff}} + Q_{\mathrm{prc}} + Q_{\mathrm{inflow}} = Q_{\mathrm{evp}} + Q_{\mathrm{outflow}} \tag{8}$$

1.3 Two-dimensional unsteady flow model

Flow patterns with the bathymetry are elaborated by the two-dimensional (2D) model. Bathymetry describes the lagoon's geometry and is the basis of the whole modelling. Model is constructed with a general expression ability of the flow channel geometry to the number of calculation lattices, which makes the calculation of lattice formation easier (specially, the former is confronted to the Cartesian coordinate system, and the latter to the orthogonal curvilinear coordinate system). It is assumed that the base type of the flow displayed in a general coordinate system is used, and explains the numerical analysis technique here.

Grid model with the bathymetry was generated at the first step of the hydrodynamic modelling. Boundary coordinates and the bathymetry data were used to generate the grid. Bathymetry was estimated using personal navigator (Etrex H – High Sensitivity, Garmin, USA) with a measuring pole during the field experiments in May 2009. Lagoon mouth water flow velocity was analyzed by a modified 2D unsteady model (Tanaka and Yagisawa, 2009) with the governing equations of continuity equation (Eq. (9)) and 2D depth-averaged Reynolds equations (Eqs. (10) and (11)).

$$\frac{\partial}{\partial t}\left(\frac{h}{J}\right)+\frac{\partial}{\partial \xi}\left(\frac{Uh}{J}\right)+\frac{\partial}{\partial \eta}\left(\frac{Vh}{J}\right)=0 \tag{9}$$

$$\begin{aligned}\frac{\partial}{\partial t}\left(\frac{Q_x}{J}\right)+\frac{\partial}{\partial \xi}\left(\frac{UQ_x}{J}\right)+\frac{\partial}{\partial \eta}\left(\frac{VQ_x}{J}\right)= \\ -gh\left(\frac{\xi_x}{J}\frac{\partial Z_s}{\partial \xi}+\frac{\eta_x}{J}\frac{\partial Z_s}{\partial \eta}\right)-\frac{\tau_x}{\rho J}-\frac{f_x}{\rho J}+ \\ \frac{\xi_x}{J}\frac{\partial}{\partial \xi}\left(-\overline{u'^2}h\right)+\frac{\xi_y}{J}\frac{\partial}{\partial \xi}\left(-\overline{u'v'}h\right)+ \\ \frac{\eta_x}{J}\frac{\partial}{\partial \eta}\left(-\overline{u'^2}h\right)+\frac{\eta_y}{J}\frac{\partial}{\partial \eta}\left(-\overline{u'v'}h\right)\end{aligned} \tag{10}$$

$$\begin{aligned}\frac{\partial}{\partial t}\left(\frac{Q_y}{J}\right)+\frac{\partial}{\partial \xi}\left(\frac{UQ_y}{J}\right)+\frac{\partial}{\partial \eta}\left(\frac{VQ_y}{J}\right)= \\ -gh\left(\frac{\xi_y}{J}\frac{\partial Z_s}{\partial \xi}+\frac{\eta_y}{J}\frac{\partial Z_s}{\partial \eta}\right)-\frac{\tau_y}{\rho J}-\frac{f_y}{\rho J}+ \\ \frac{\xi_x}{J}\frac{\partial}{\partial \xi}\left(-\overline{u'v'}h\right)+\frac{\xi_y}{J}\frac{\partial}{\partial \xi}\left(-\overline{v'^2}h\right)+ \\ \frac{\eta_x}{J}\frac{\partial}{\partial \eta}\left(-\overline{u'v'}h\right)+\frac{\eta_y}{J}\frac{\partial}{\partial \eta}\left(-\overline{v'^2}h\right)\end{aligned} \tag{11}$$

where, J is the Jacobian coordinate transformation, $J = 1\big/\left(x_\xi y_\eta - x_\eta y_\xi\right)$; t (sec), x (m), y (m) are time-space coordinates. ξ_x, η_x, ξ_y, η_y are definded with Jacobian conversion matrices relating x_ξ, x_η, y_ε, y_η, where, ξ and η affixing characters with the subscripts of x and y show the partial differentials (for instance, ξ_x is $\partial\xi/\partial x$). u (m/sec) and v (m/sec) are the depth-averaged velocities in x and y directions, respectively; U (m/sec) and V (m/sec) are the contra-variant velocity components of u and v, respectively; Q_x (m^2/sec)and Q_y (m^2/sec) are the unit discharge flows in x and y directions, respectively; τ_x (N/m^2) and τ_y (N/m^2) are the bed shear stress in x and y directions, respectively; f_x (N/m^2) and f_y (N/m^2) are the drag forces per unit area in x and y directions, respectively (in this simulation, f_x and $f_y = 0$, as there is no mangrove in the calculated region); $-\overline{u'^2}$, $-\overline{u'v'}$, $-\overline{v'^2}$ and are depth-averaged Reynolds stresses (these terms were calculated by the same method with Hosoda (2002)); g (m/sec^2) is the gravitational acceleration, h (m) is the water depth, ρ (kg/m^3) is the fluid density; and Z_s (m) is the water level. Required discharge and water level data were collected from the field measurements in May 2009.

2 Results and discussion

2.1 Lagoon water budget

Koggala is located in the wet zone and annual rainfall varies between 2000 and 2500 mm with the heaviest rainfall in May (300 mm) and October (340 mm) (IWMI, 2006). It gets fairly high rainfall from South west monsoon from May to Septemebr and fairly less rainfall during the northwest monsoon from October to February (Suppiah and Yoshino, 1984). Mean annual precipitation volume was calculated using mean annual precipitation as shown in Table 1.

The temperature in the area ranges between 15 and 28°C (IWMI, 2006). The evaporation rate depends on the temperature and therefore has seasonal variations. Mean annual evaporation was calculated (Table 2) using monthly constant pan evaporation value of 120 mm (Priyadarshana et al., 2007).

Total runoff from streams and surface-catchment are tabulated in Table 3. Runoff volume has a great dependency on monthly fluctuations of rainfall. Sea water inflow values, obtained from numerical simulations are shown in Table 4. Lagoon out flow then can be calculated by Eq. (8). Total mean annual outflow of the lagoon was calculated as 9.83×10^8 m^3/yr.

The annual water budget of the Koggala lagoon can be elaborated with a pie chart (Fig. 4). The highest inflow contributor is seawater inflow while the highest outflow contributor is the lagoon outflow to the sea. Even though the budget contributors can be expressed by absolute values it has fluctuations throughout the year mainly due to the change of freshwater inflow. Freshwater inflow directly

Table 1 Mean annual precipitation of Koggala lagoon (from 1977 to 2007)

Description	Value
Mean annual precipitation (mm)	2314.5
Mean precipitation rate (m^3/sec)	0.54
Mean annual precipitation volume (Q_{prc}) (m^3/yr)	1.68×10^7

Table 2 Mean annual evaporation of Koggala lagoon

Description	Value
Monthly constant pan evaporation* (mm)	120
Pan coefficient	0.8
Monthly evaporation volume from pan (m^3/month)	0.10
Monthly evaporation water loss from lagoon (m^3/month)	4.85×10^5
Rate of evaporation from lagoon (m^3/sec)	0.186
Annual evaporation water loss from lagoon (Q_{evp}) (m^3/yr)	5.81×10^6

* Priyadarshana et al., 2007.

Table 3 Mean annual runoff from inflow streams and surface catchment of Koggala lagoon

Name of the stream	Description	Value
Warabokka-ela stream	Mean flow velocity (m/sec)	0.22
	Average cross sectional area (m^2)	32.68
	Mean water flow rate (m^3/sec)	7.19
Kerena Anicut (Mudiyansege-ela stream + Thiththagalle-ela stream)	Mean flow velocity (m/sec)	0.065
	Average cross sectional area (m^2)	15.6
	Mean water flow rate (m^3/sec)	1.01
Heen-ela stream	Mean flow velocity (m/sec)	0.024
	Average cross sectional area (m^2)	3.1
	Mean water flow rate (m^3/sec)	0.074
Total stream water inflow (m^3/sec)		8.08
Mean annual stream water inflow (Q_{base}) (m^3/yr)		2.54×10^8
Total surface water inflow from catchment area (m^3/sec)		1.40
Mean annual surface stream water inflow ($Q_{\text{surface-runoff}}$) ($m^3$/yr)		4.42×10^7
Mean annual runoff to the lagoon (Q_{runoff}) (m^3/yr)		2.99×10^8

Table 4 Estimated seawater inflow to the Koggala lagoon

Description	Value
Seawater inflow (from the values of model) (m^3/day)	1.84×10^6
Mean Seawater influx rate (from the values of model) (m^3/sec)	21.33
Annual seawater influx (m^3/yr)	6.73×10^8

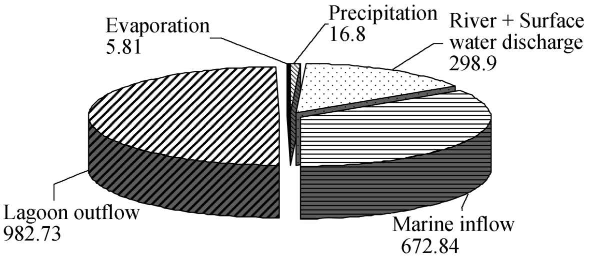

Fig. 4 Mean annual water budget components for Koggala lagoon. All values are in $\times 10^6$ m^3/yr.

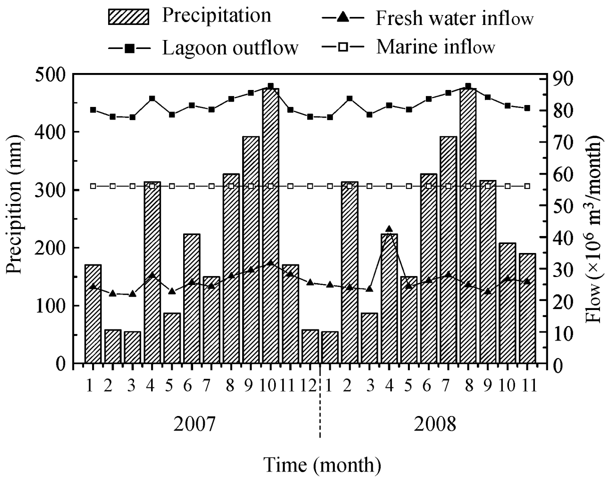

Fig. 5 Mean monthly precipitation, mean monthly estimated freshwater flow, mean monthly estimated seawater flow and mean monthly estimated outflow of Koggala lagoon from January 2007 to November 2008. Numbers from 1 to 12 in *X*-axis denote the months from January to December.

depends on atmospheric precipitation. Once the precipitation increases the freshwater inflow also increases.

Figure 5 shows the precipitation, estimated mean freshwater inflow, seawater inflow and mean lagoon outflow of the lagoon during January 2007 to November 2008.

Seawater inflow is higher than freshwater inflow through out the studied time period. Lagoon has a salting factor of 0.68. Salting factor (F_s) is the ratio of seawater inflow (Q_{inflow}) and total inflow which can be expressed as follows (Eq. (12)) (Göneç and Wolfin, 2005).

$$F_s = \frac{Q_{\text{inflow}}}{(Q_{\text{inflow}} + Q)} \tag{12}$$

where,

$$Q = Q_{\text{runoff}} + Q_{\text{prc}} - Q_{\text{evp}} \tag{13}$$

If $F_s \leqslant 0.5$, it predominantly influenced by freshwater inflow; while $0.5 < F_s \leqslant 1$, it is predominantly influenced by seawater like present situation of Koggala lagoon. If $F_s > 1$, it shows the hyper-saline situation where lagoon salinity is greater than seawater salinity. Before the sand bar removal Koggala used to be a freshwater lagoon. The one essential drawback of this water budget calculation, is neglecting the groundwater seepage due to impossibility of proper calculation. By providing a proper solution for reducing seawater inflow, Koggala lagoon ecosystem can be restored which in turn starts to be influenced by freshwater predominantly.

2.2 Two-dimensional unsteady flow model

As given by Eq. (12), in order to be predominantly influenced by freshwater, seawater inflow should be equal to the freshwater influx in the sea-lagoon interface in the mouth. From the water budget results, estimated flow rates at lagoon mouth can be expressed in Table 5.

Seawater inflow should be reduced up to present freshwater influx (0.0389 m/sec). Dimensions of the lagoon mouth should be redesigned to reduce the seawater influx. Calculation can be done as follows:

Table 5 Seawater and freshwater influxes at sea-lagoon interface

Description	Value
Mean cross sectional area of sea-lagoon interface (m^2)	256.5
Present freshwater influx (m/sec)	0.0389
Present seawater influx (m/sec)	0.0832

In order to get a salting factor of 0.5, $Q_{\text{inflow}} = Q$ (by Eq. (12)), therefore,

$$Q_{\text{influx}} = Q/d_1 h_1 \tag{14}$$

where, d_1 (m) is the width of the redesigned mouth cross section, and h_1 (m) is the depth of the redesigned mouth cross section.

0.832 (m/sec) $= 9.964$ (m^3/sec)$/d_1 h_1$,

$d_1 h_1 = 119.76$ m^2; $d_1 \approx 40$ m, $h_1 \approx 3$ m.

Existing width of lagoon 85.5 m should be reduced up to 40 m while having the depth of 3 m at lagoon entrance. The 40 m should be the maximum width of the opening and this can be reduced further under comprehensive investigations. Groyne should be redesigned to reduce the width of the mouth and the proposed rubble mound structures would be placed as Priyadarshana et al. (2007) suggested to minimize the seawater intrusion while reducing inland sediment transportation. Figure 6 shows the lagoon mouth with proposed rubble mound structures with respect to existing groyne structures.

Orthogonal numerical grid elaborated the velocity profile at lagoon mouth in the 2D unsteady flow model. The stream lines may help to locate the highly eroded and sand accumulated areas. Seawater intrusion occurs substantially in high tides and only that scenario was considered in numerical simulation. Figure 7a shows the simulated flow velocity profile with respective stream lines at high tide for south-west monsoon rainy season. Numerical simulation shows that the flow has a maximum velocity of 1.9 m/sec. Main flow is close to the right bank beyond the Kathaluwa bridge towards the lagoon.

Numerical simulation was conducted according to proposed structural interventions, placing rubble mound structures. Figure 7b shows the simulated velocity profile with respective streamlines at high tide. Numerical simulation shows a maximum velocity close to the narrow opening, 2.2 m/sec. Seawater flow makes a vortex close to the opening and mitigates the flow towards the lagoon drastically.

Priyadarshana et al. (2007) showed, according to the lagoon water level hydrograph for 10-years return period of flood, the restricted outlet opening with 20 m heads up the lagoon to 0.63 m mean sea level (MSL). This is 0.4 m above the spring-high tide level of the lagoon under existing conditions. No significant impact is expected due to an inundation height of 0.4 m (maximum) at low lying areas around the periphery of the lagoon. At its peak, the inundation height is more than 0.3 m above the high tide level lasts about 12 hours and this occurs only once in 10 years. Flood level can be further reduced if the bed level of the sand bar erodes beyond the assumed –0.5 m MSL. According to the corresponding discharge at restricted mouth, flow velocity is around 2.2 m/sec. With these high velocities, sand bar breach has high possibility to be eroded and actual inundation levels should therefore be lower than the above predictions.

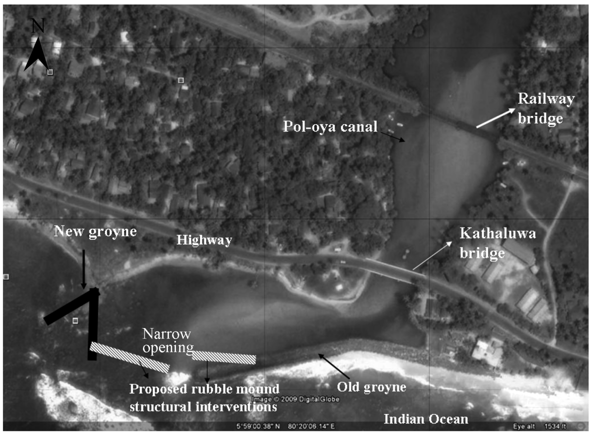

Fig. 6 Satellite image of lagoon mouth with proposed structural intervention with respect to existing structures.

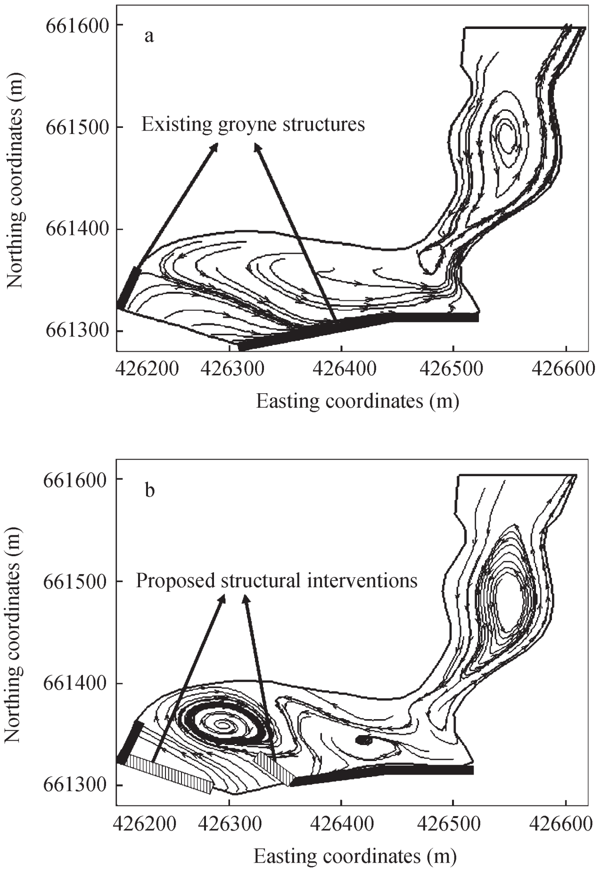

Fig. 7 Simulated flow at high tide with the existing groyne structures (a) and the proposed structural intervention (b) (sleamline elaboration) – May, 2009.

3 Conclusions

Koggala lagoon has experienced different states in the past with regard to its connection to the Indian Ocean and the associated water exchange. After the construction of the groyne the sand accumulation pattern changed seizing the periodical formation of the sand bars across the lagoon mouth. Lagoon has become more saline lagoon with a salting factor of 0.63. Water budget shows that lagoon presently influenced by seawater largely. Numerical simulation of 2D unsteady flow model reveal, narrowing the mouth while reducing mouth width up to 40 m, maintaining the salting factor (F_s) of 0.5 may result a lagoon, predominantly influenced by freshwater. Besides proposed mouth opening (40 m) at the sea ward end of the outlet channel would be sufficient to discharge a flood with 10 years return period smoothly. Simulated results supported the proposed rubble mound structures at mouth in the lagoon restoration.

Acknowledgments

This study is partially funded by Sumitomo Foundation, Japan. The authors would like to acknowledge the assistance of Dr. Nimal Wijeratne, from Faculty of Engineering, University of Ruhuna, Sri Lanka and Dr. Junji Yagisawa from Graduate school of Science and Engineering, Saitama University, Japan in simulations of numerical modelling discussed in this paper.

References

CEA (Central Environmental Authority), 1995. Wetland site report and conservation management plan. Koggala lagoon under wetland conservation project. Sri Lanka Euroconsult, Sri Lanka.

Gregersen H M, Ffolliott P F, Brooks K N, 2005. Integrated watershed management: Connecting people to their land and water, CABI, Oxfordshire, UK.

Gunawickrama K B S, Chandana E P S, 2006. Some hydrographic aspects of Koggala lagoon with preliminary results on distribution of the marine bivalve Saccostrea forskalli: pretsunami status. *Ruhuna Journal of Science*, 1: 16–23.

Göneç I E, Wolfin J P, 2005. Coastal Lagoons, Ecosystem Process and Modeling for Sustainable Use and Development. CRC Press, Washigton DC.

Hosoda T, 2002. River flow analysis by generalized coordinate system. In: Programme Library for Hydraulic Engineering. CD-ROM (ISBN 4-8106-0203-6).

IWMI (International Water Management Institute), 2006. Sri Lanka Wetlands Database. http://dw.iwmi.org/ wetland/wetlands_info_options.aspx?wetland_name=Koggala %20Lagoon&wetland/(accessed January 10, 2009).

Kjerfve B, 1994. Coastal Lagoon Processes. Elsevier Science, Amsterdam, the Netherlands.

Mitsch W J, Gosselink J G, 2000. Wetlands. Willey, New York.

Priyadarshana T, Manatunge J, Wijeratne N, 2007. Report, Impacts and Consequences of Removal of the Sand Bar at the Koggala Lagoon Mouth & Rehabilitation of the Lagoon Mouth to Restore Natural Formation of the Sand Bar, Practical Action, Sri Lanka.

Sugiyama H, Kadoyab M, Nagaic A, Lauseyds K, 1997. Evaluation of the storage function model parameter characteristics. *Journal of Hydrology*, 191: 332–348.

Suppiah R, Yoshino M M, 1984. Rainfall Variations of Sri Lanka, Part 1: Spatial and Temporal Patterns. Archieves of Meterology, Geophysics and Bioclimatology Series, B34: 329–340.

Tanaka N, Yagisawa J, 2009. Indices for evaluating the breaking and wash-out condition of trees on gravel bar at flood events. In: Proceedings of 33rd the International Association of Hydro-Environment Engineering and Research (IAHR) Biennial Congress, Canada. August 9–14, CD-ROM (ISBN 978-90-78046-08-0).