Current characteristics of salinity stratification of two coastal lagoons in southern area of Sri Lanka after different human interventions

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Abstract: Field investigations were conducted to estimate the present state of density stratification of Koggala Lagoon and Rekawa Lagoon, Sri Lanka. The variation of salinity, water temperature and dissolved oxygen were measured vertically at different tidal conditions and rainy seasons. For both lagoons, salinity stratification occurred in not only lagoon but also inflow stream and lagoon mouth. Furthermore, the stratification was measured in mainly rainy season for both lagoons. On the other hand several temporal and spatial characteristics, such as salinity level, area of strong stratification and the reason of the seasonal difference of stratification, were contrastive for each lagoon. These depend on the inherent difference of hydrological characteristics of each lagoon, recently intensified by human intervention conducted in mouth area for both lagoons. Conceptual model has been constructed for the hydraulic characteristics of each lagoon related to the salinity stratification as the basis for the future quantitative analysis.

Keywords: seasonal difference, tidal effects, inflow stream, conceptual model.

1. INTRODUCTION

Water environment in Sri Lanka is recently under pressure with the rapid development activities and more concern is needed with respect to environmental resources preservation. Coastal lagoons play an important role not only by offering various “natural resources” for regional community but also by providing “natural infrastructure” for hazard protection and/or mitigation, which is commonly called “bio-shield” (Tanaka 2009). Appropriate preservation of natural systems and mitigation of such impacts will be strongly required in future due to development activities by various functions. Thus, it is important to know sufficiently about the various processes occurred in and around such systems.

Coastal lagoon system consists of various processes, such as physical, chemical, biological and ecological phenomena and is established on finely-balanced various relationships among these factors (Hume et al. 2007). On the other hand, anthropogenic interventions effects lead diverse responses of the system. Salinity stratification and vertical mixing is such an important process that plays a central role. Further, salinity stratification is an interesting area considered under density current hydraulics. Many studies have been conducted on estuary hydraulics in the past (Uncles 2002). Coastal lagoon is one type of water body considered under various types of estuaries such as river mouth, fjord and bay (Kierfve and Magill 1989). In particular, narrow channel at downstream area of estuary water body is the inherent nature of coastal lagoons. There are little information about the relationship between lagoon mouth characteristics and salinity stratification in the past research.

The effects of mouth characteristics should be clarified for understanding the salinity stratification processes of coastal lagoons. Furthermore, regional or local endemism is important for such complex system of coastal lagoon. During past decade, Koggala Lagoon and Rekawa Lagoon suffered the effects
of different human intervention around the mouth area. These lead some environmental social problems. Base on the backgrounds, field surveys were conducted about the present states of salinity stratification of both lagoons from 2011 as a preliminarily study. There are some other information on water temperature, water quality and biological/ecological situation of those two lagoons (Priyadarshana et al. 2007, IMMI 2006). However, salinity stratification behavior is not clear. Firstly, current situation of salinity stratification has been estimated. This paper shows the comparison of the salinity stratification characteristics of these two lagoons and discuss about the effects of human interventions on salinity stratification qualitatively.

2. MATERIALS AND METHODS

2.1 Site description

Koggala Lagoon and Rekawa Lagoon are located in the southern area of Sri Lanka (Fig. 1). These two lagoons have converse characteristics of not only lagoon mouth topography but also human interventions conducted last decade (Priyadarshana et al. 2007, Gunaratne et al. 2010a). Koggala Lagoon is situated in the southern coast of Sri Lanka (Fig. 1) about 130 km south of the capital Colombo between 5º 59' - 6º 02' N and 80º 18' - 80º 21' E (Priyadarshana et al. 2007). The water body at present is a saline coastal lagoon, with a surface area of 574 ha and a catchment area of 55km². The water depth ranges from 1.0 to 3.2 m. The natural seasonally opening protective sand bar at the Koggala Lagoon mouth was removed for development activities and a groyne system has been constructed as a remedial action to minimize erosion. So the mouth is opened to sea throughout the year creating a high saline aquatic environment. That has caused various unexpected impacts on the lagoon (Priyadarshana et al. 2007, Gunaratne et al. 2010b). Rekawa Lagoon is a choked shallow lagoon located in the Southern Province of Sri Lanka. The average depth and the widest point of the lagoon are around 1.4 m and 2.5km, respectively (Gunaratne et al. 2010a). The water body at present is relatively low salinity brackish lagoon, with a surface area of 2.4 km² and a catchment area of 225 km². The main water body of the lagoon is connected with the sea by a narrow, meandering 3km long channel. A causeway constructed across this channel approximately 0.7km from the lagoon mouth to the inland has narrowed the width of the water flow of the channel to about 6m. Kirama-Oya River, the main fresh water inflow connects to the lagoon outlet channel at the sea ward end 0.2km from the lagoon mouth to inland. The lagoon mouth keeps closed for most of the year and is intermittently opened naturally in rainy season or manually by local community to prevent flooding when high rainfall is received.

Figure 8 Map of Koggala and Rekawa Lagoon
2.2 Field observation

Field observation for two lagoons have been conducted during about one-half year for several stations in each lagoons including mouth area and typical inflow streams (Fig. 1). A water quality measuring equipment (multi probe) YSI Model 55 was used to measure temperature, salinity, and dissolved oxygen (DO) (approx. 0.5 m intervals). Vertical profiles of these parameters were measured longitudinally from inflow streams to the lagoon mouth through the lagoon water body (Fig. 1). From Nov. 2011 to Feb. 2012 several times survey were conducted for each lagoons. The days of field survey are shown in Fig. 2 as circles with the temporal variation in tidal change and rainfall related areas. For selecting the survey timing, the some different factor effecting on the mixing and stratification were focused. Generally, several factors, such as rainfall seasonal changes and tidal conditions, should be considered for discussing the salinity stratification in coastal lagoons (Uncles 2002). For the representativeness of field survey, some factors were classified for selecting the analysis of field survey results. Table 1 shows the classified factors related to the time scale of it. Qualitatively, longer time scale of the factor means large effects of the balance between saline water intrusion from the sea and freshwater inflow from catchments.

### Table 1 Factors focused on in the preliminary survey for Koggala and Rekawa Lagoon

<table>
<thead>
<tr>
<th>Time scale</th>
<th>Koggala Lagoon</th>
<th>Rekawa Lagoon</th>
</tr>
</thead>
<tbody>
<tr>
<td>Several months</td>
<td>Rainy or Dry season</td>
<td>Opened or Closed mouth</td>
</tr>
<tr>
<td>Weeks</td>
<td>Spring or Neap tide</td>
<td>Ebb and Flood</td>
</tr>
</tbody>
</table>

3. RESULTS

3.1 Longitudinal salinity distribution for both lagoons

Fig. 3 shows the longitudinal variation of surface and bottom salinity of both lagoons. For understanding the comprehensive states, temporal averaged data for each station were used. Although almost of all station for both lagoons exhibit different salinity level between surface and bottom, different characteristics of longitudinal salinity distribution can be confirmed between the two lagoons. Firstly, the salinity level of Koggala Lagoon was higher than that of Rekawa Lagoon. Secondly, the significant difference in salinity level between surface
and bottom occurred in converse area. In Koggala Lagoon, upstream inflow region exhibit the remarkable vertical difference in salinity compared to Rekawa Lagoon in which downstream region exhibit it. These characteristics are related to not only the mouth conditions but also the position of freshwater inflow streams. Whereas in Koggala Lagoon, upstream end of lagoon water body is main freshwater inflow region, freshwater inflow from down stream end of lagoon body (3.2km) and mouth area (0.3km) in Rekawa Lagoon.

3.2. Koggala Lagoon

3.2.1. The effects of seasonality related rainfall

Fig. 4 shows the comparison between each measured parameters of selected stations of Koggala Lagoon during the monsoon rainy and dry season. For avoiding the tidal effects, neap and ebb condition data are selected. The parameters exhibit differences depending on the season. In the rainy season, partially mixing of the mouth area and strong density stratification of both the lagoon and inflow stream were measured. On the other hand, the results of survey in the dry season indicated that such mixing states of Koggala Lagoon differ remarkably depending on the season.

3.2.2. The effects of weekly tide (spring and neap)

Fig 5 shows the comparison of vertical salinity and DO profiles of Koggala Lagoon in spring and neap conditions. These surveys were conducted in rainy season. Because of large quantity of freshwater inflow, salinity stratification in both tidal conditions can be found. Although surface salinity level exhibits relatively small difference, the effects of the tidal condition such as spring and neap, is smaller than that of seasonal rainy conditions. In both tidal conditions, bottom layer of lagoon (L-1) exhibits the decrease in DO. Regardless of the weekly tidal conditions, there exist high salinity and low DO in bottom layer because of the salinity stratification.

3.2.3. The effects of semi-diurnal tide (ebb and flood)

Fig. 6 shows the comparison of salinity between ebb and flood condition in same day (30, Nov. 2012, rainy and spring tidal condition). Basically, only mouth region exhibits the difference by the semi-diurnal tide. For estimating the lagoon water body, the effects of short period factor, that is to say semi-diurnal tide, can be neglected except for discussing the hydraulic phenomenon in mouth region.
3.3. **Rekawa Lagoon**

For Rekawa Lagoon, as shown in Table 1, the mouth opened conditions regulated by the existence of natural sand bar at the end of lagoon mouth is focused. The sand bar of Rekawa Lagoon tends to be formed in mainly dry season.

3.3.1. **The effects of mouth open condition**

Fig. 7 shows the comparison of salinity and DO vertical profiles between different mouth open condition. Salinity stratification in mouth area is prominent compared to the lagoon water body. It formed in both mouth opened and closed conditions. On the other hand, in lagoon area, stratification can be measured in only mouth opened and flood condition occurred in rainy season as small vertical difference in salinity. This seasonal tendency is similar to the tendency of Koggala Lagoon. However, the salinity level of mixed condition in dry season is significantly lower than the level in Koggala Lagoon. One of the reasons of the mixed state occurring despite of continuous freshwater supply even in dry season is the mixing caused by external factors such as wind. Actually, we got an information from fishermen living at Rekawa village that the transparency of lagoon was low during relatively strong wind season. This phenomenon suggests the effects of wind in dry season on the mixing of lagoon water body as re-suspension of bottom mud.

3.3.2. **The effects of semi-diurnal tide (ebb and flood)**

Fig. 7 also shows the comparison between semi-diurnal tide on 21 Oct. 2012, rainy and neap tide condition. The effect of semi-diurnal tide was not significant in mouth and lagoon water bodies. This agrees with the mouth topographic condition of Rekawa Lagoon that is narrow, meadow and long characteristics preventing the sea water intrusion into the mouth channel.

4. **DISCUSSION**

Based on the preliminary field surveys, the current states of salinity stratification with temporal and spatial
Figure 15 Conceptual model of the effects of rainy season for Koggala and Rekawa Lagoon variation and related factors of both lagoons where different human interventions were done during last...
decade were understood. Fig. 8 shows the conceptual figures of salinity stratification for both lagoons. Based on the prominent factors for determining the stratification, two seasonal conditions are presented. Firstly, common temporal and spatial characteristics of salinity stratification for both lagoons exist. As spatially, salinity stratification occurred in not only lagoon water body but also inflow stream and lagoon mouth is common property. Generally, in Rekawa Lagoon mouth is opened in rainy season. As seasonal characteristics for both lagoons, salinity stratification is formed in mainly rainy season. Temporal characteristics for the stratification were also common. On the other hand, several temporal and spatial differences between two lagoons, such as salinity level, area of strong stratification and the reason of the seasonal difference of stratification, were contrastive as described below. The inherent difference of hydrological characteristics of each lagoon, recently intensified by human intervention conducted in mouth area, is considered to be main reason of the difference.

Koggala Lagoon exhibits an entirely different mixing state depending on the season. In the rainy and monsoon seasons, the lagoon was brackish and a salinity stratified water body. On the other hand, in the dry season, the lagoon was high saline concentration and strongly mixed. In this season, only in the inflow stream, brackish and salinity stratification could be confirmed. The reason of this seasonal difference is to be the difference of inflow stream discharge caused by the seasonal rainfall variations. As Gunaratne et al. (2010) reported the balance of inflow quantity from the catchment and lagoon differs from the monsoon season. The hydraulic characteristics affect not only salinity level but also mixing state of the Koggala Lagoon.

Similar to Koggala Lagoon, salinity stratification can be found in almost all survey stations in Rekawa Lagoon. In particular, the field survey results indicate that vertical salinity stratification tendency is greater at lagoon outlet channel compared to the main water body of the lagoon. The hydrological characteristics of Rekawa Lagoon, such as depth of mouth being greater than lagoon and the small amount of saline water inflow into the lagoon, lead the tendency. As temporal characteristics, salinity stratification of lagoon water body occur in opened mouth conditions. In such situation, not only increase in freshwater inflow from streams but also high salinity water inflow from ocean through opened mouth will act as the cause of it. The key factor determining the degree of vertical mixing in Rekawa Lagoon is mouth opened conditions as well as inflow of freshwater stream.

5. ACKNOWLEDGMENTS

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6. REFERENCES