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Temperature and dissolved oxygen stratification in the lake Rudrasagar: Preliminary investigations

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Abstract

Temperature drives the major physico-chemical and biological actions in inland water bodies. The higher the water temperature, the greater the biogeochemical activity influenced by the environmental intrinsic and extrinsic parameters. Temperature also controls the dynamics of sustainability of various aquatic organisms that live in lakes and reservoirs, though higher life forms, such as fish, insects, zooplankton, phytoplankton, and other aquatic species all have a recommended temperature variety. The increase in water temperature due to the increase in atmospheric air temperature results in lake water column stratification and the dissolved oxygen level variation in aquatic systems are greatly affected. The vertical distributions of dissolved oxygen in the water column are highly dependent due to change in vertical temperature gradient. In the present paper, an effort has been made to investigate the impact of temperature stratification on dissolved oxygen variability in the Rudrasagar, a natural lake in western Tripura. The changes in dissolved oxygen distribution in this natural lake will give us an idea of regional lake health condition and will also establish the need of further large scale research concerning the development of a biophysical-coupled model.

Keywords: Thermal stratification, Dissolved Oxygen, Thermocline, Rudrasagar Lake, Hypolimnion

Introduction

The thermal stratification which occurs in lake, is of direct importance in maintaining the water quality requirements, particularly for higher aquatic life (Ambrosetti and Barbanti, 2001; Samal et al.

2004; Samal et al. 2012; Samal et al. 2009; Bonnet et al. 2000; Dake and Harleman, 1969). Vertical profiles of temperature and Dissolved Oxygen (DO) provides sufficient information to define the state of turbulence and the potential of mixing and the depletion of oxygen in the hypolimnion (Barbanti et al. 1981; Samal et al. 2009, 2004b; Peeters et al. 2007; Joehnk and Umlauf, 2001; Livingstone and Imboden, 1996). The exchange of heat across the air water interface may be one of the key elements that regulate the temperature of a waterbody (Peeters et al. 2002). The progressive change in atmospheric air temperature has strong seasonal relationship with lake water temperature and other water quality parameters (Samal et al. 2004a, 2004b; Mazumdar et al. 2007). Measurements of thermal stratification cycles have been an integral part of basic limnological studies since the revolutionary work of Forel (Hutchinson, 1957). The interaction of heating, cooling and mixing processes and their opposing effects are qualitatively described by Brige (Ford et al. 1980). The existence of a surface layer of "warm water" (epilimnion), which is separated from the relatively cold water mass (hypolimnion) by a steep thermal gradient, is the essential physical aspects of lakes in certain periods of their yearly cycles. The thermocline represents a temperature and density barrier which consistently limits any exchanges between eplimentic and hypolimentic watermasses: the physical characteristics of these two layers are so different, particularly at the height of thermal stratification, that they may even be considered completely isolated.

Dissolved oxygen concentration is an important parameter that determines the spatial and temporal distribution of aquatic organisms as this is essential for their respiration (Wetzel, 1983; Samal and Mazumdar, 2005a; 2005b). Except the strong turbulence, diffusion of oxygen into natural water is a very slow process and hence photosynthesis by the aquatic plants is the major source of dissolved oxygen (Samal et al. 2008; MacIntyre et al. 2010; Goudsmit et al. 2002). As a result of thermal stratification it is evident that a very close relationship exists between temperature and oxygen concentration distributions along the water column in a lake (Samal et al. 2004a; 2004b; Samal et al. 2010): both are very useful in understanding lake hydrodynamics, and especially for evaluating the depth of mixed layer in the lake (Barbanti et al. 1996, Samal et al. 2008a). These in-lake physical processes are further triggered by the input of watershed inputs (Biswasroy et al. 2011; Klug et al. 2012) along with the external impact of meteorological forcing (Samal et al. 2008b). The water quality of the lakes is also affected by the large scale anthropogenic activities both in rural and urban areas in terms of human-ecosystem relationship (Biswasroy et al. 2010; 2012a; 2012b). The extent of water pollution by various direct and indirect drivers in lakes (Das et al. 2006) necessitates the need of lake dynamics study form hourly to weekly and weekly to monthly and on year to year time window to explore the detailed reasons of water quality degradation under different climatic conditions (Pierson et al. 2013; Samal et al 2013; Arai, 1981) and the influencing the socio-economic conditions of the lake users.

Further, the shallow lake and the deep lake have different variability in ecosystem processes and also change in hydrodynamics and the water quality (Gorham and Boyce, 1989; Samal, 2004). Observations from lakes in several different regions of both temperate and tropical zone of the world show that whether a lake stratifies depends on both the maximum depth and the surface area of the lake, whereas the depth of the thermocline depends primarily on the surface area (Gorham and Boyce, 1989). Thus, the variability of physico-chemical and biological characteristics of water in lakes and waterbodies are highly dependent on their latitude, wind fetch and morphometry of lake (Mazumdar et al. 2007; Samal et al. 2010; Samal et al. 2011), affecting particularly, the degrees of relationship between the gradient of temperature and dissolved oxygen in the water column. Considering the dynamical change in water quality of the lake, an investigation is proposed to study and understand the physical mechanisms responsible for evolution of lake temperature stratification at diurnal scale at two sampling points in the mid-reach of the natural lake, Rudrasagar. Also it is attempted to evaluate the effect of thermal stratification on dissolved oxygen using simple regression model. Though various one dimensional (vertical) water quality models are developed and also are under testing for predicting the major driving parameters in lakes, most simplified hydrothermal models are the prerequisite in water quality modeling investigations considering the changes in hydrology under the impact of climate change (Yao et al 2014).

Material and Methods

Study area: the Rudrasagar Lake (23˚29′ N and 90˚01′ E) is geographically located in the Melaghar Block under Sonamura Sub-Division in the West Tripura District and at a distance of about 50 km from the state capital of Tripura. Hydromorphologically, Rudrasagar Lake is a natural sedimentation reservoir, which has three evergreen sources of inflow namely, Noacherra, Durlavnaraya cherra and Kemtali cherra (Figure 1.). The sediment particles transported along with the flow settles in the reservoir over the time and the clear water discharges into the river Gomati through a connective channel namely Kachigang as an outflow. The silts and sediments are deposited on the bed of the lake influencing a change in lake depth. As such no rock formation is found with 50m is silt (Clay loam) and below formation is sandy. Surrounding hillocks are of soft sedimentary formation. The soil in lake area is silt clay loam to clay loam.

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Lake water is fresh with insignificant pollution with a depth varies from 2 m to 8m. The water basin area of the lake was found as 1.2 square km during the period of observation.

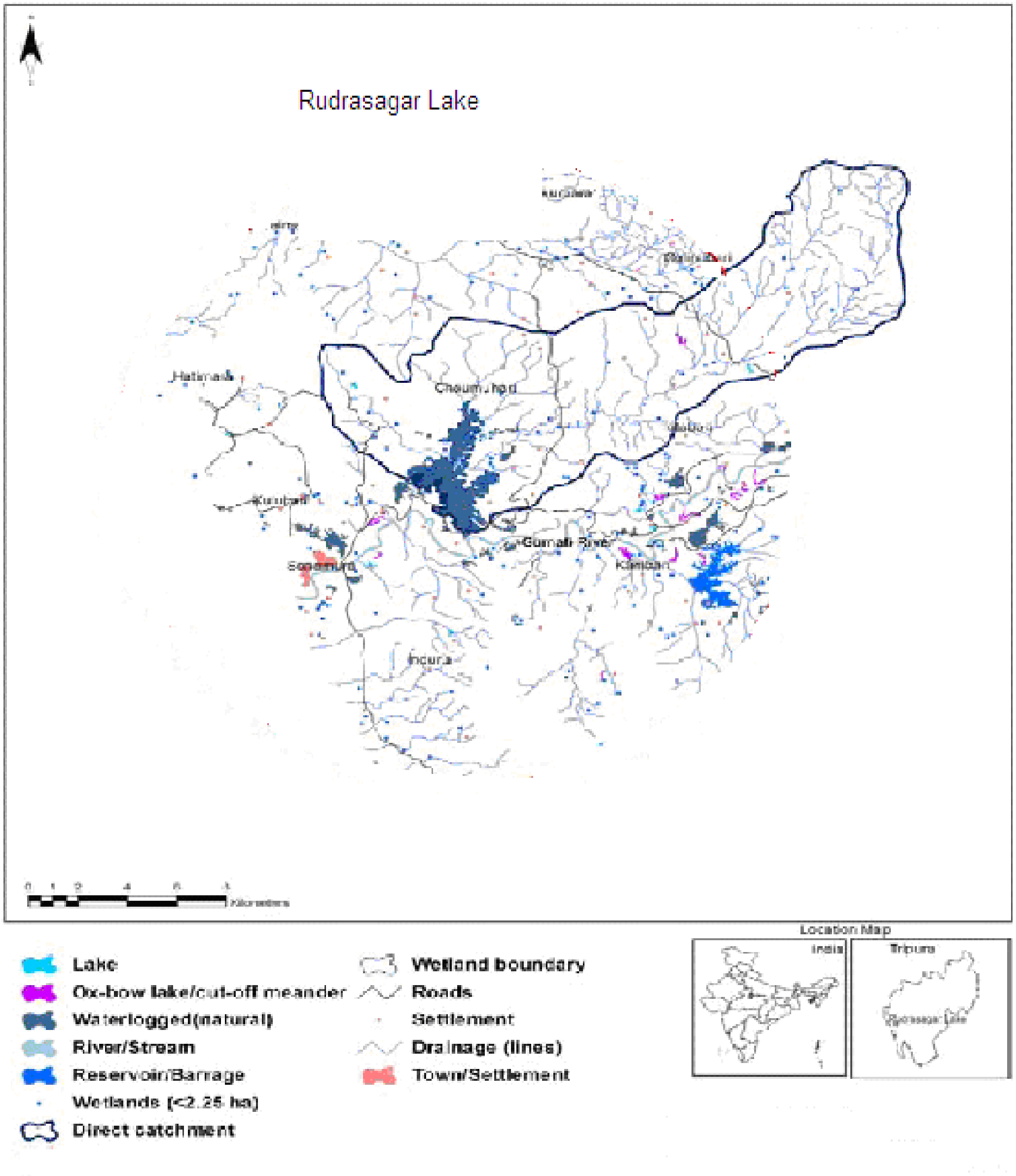
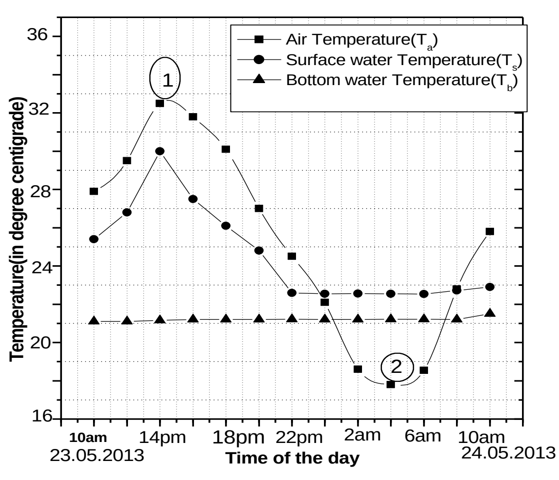


Figure 1. Map for Study Site of Rudrasagar Lake based on Resourcesat-1 LISS-III (Source: ISRO)

Sampling details and instrumentation: The observation stations are selected considering the maximum water depth along the mid reach (Station I & II) and considering the less human intervention of water of the lake, to study the temperature stratification. The water temperature and dissolved oxygen (DO) have, however, been measured using two multipurpose water quality analyzer device along the depth at an interval of 0.5 m below the water surface simultaneously in both the station. Data are stored in memory cells of the device which are then transferred to the database of the computer. The water quality instrument is usually calibrated before the field work in every sampling day following the laboratory methods (APHA, 1989). The resolution of water temperature and dissolved oxygen measurement are 0.01^{0}C and 0.01 mg/L respectively.

Results and discussion

The diurnal variation of temperature and dissolve oxygen over a 24 hour window in Rudrasagar lake is illustrated in Figure 2. It is observed that that the diurnal variation of dissolved oxygen (DO) in the lake surface exactly follows the similar trend of variation with the air temperature over the lake through the day during the period of observation, the day has been relatively calm and clear sky. The diurnal oxygen cycle follows nearly a sinusoidal pattern with a maximum concentration late hours in the day and minimum in the early morning. The peak value is denoted by (1) and the lowest value by (2) respectively in Figure 2. The dissolved oxygen concentration is found to be high towards the end of the day and since algae and aquatic plant populations are actively photosynthesizing and producing more oxygen than is being consumed. This usually occurs in the mid to late afternoon. The peak level is attained roughly an hour later than the time of occurrence of the peak in air temperature. The oxygen flux at the air-water interface may be controlled by the atmospheric effects over the lake.



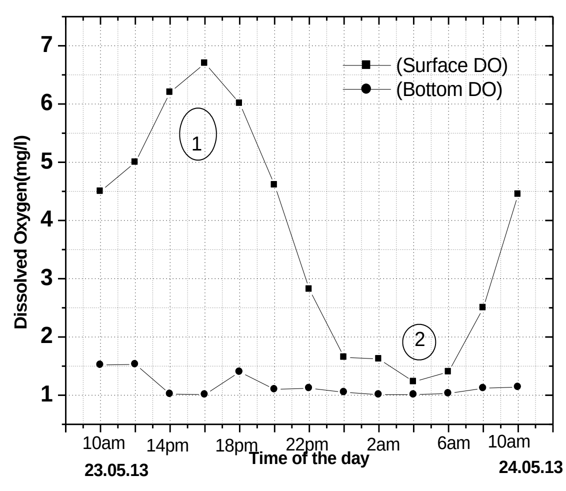
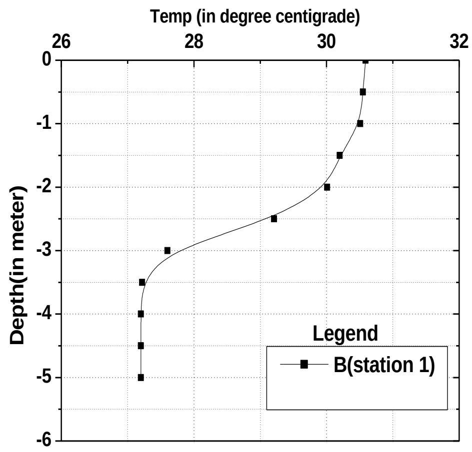


Figure 2. Diurnal Temperature Curve and oxygen curve



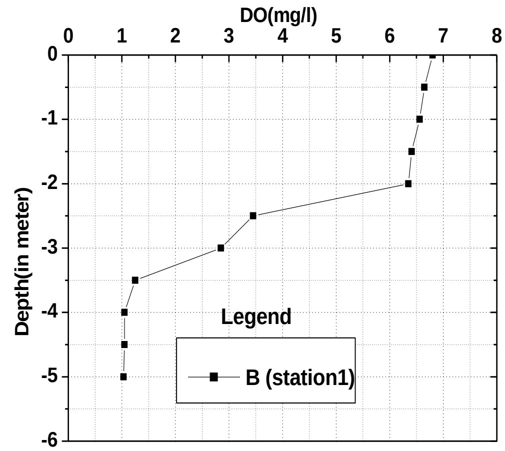
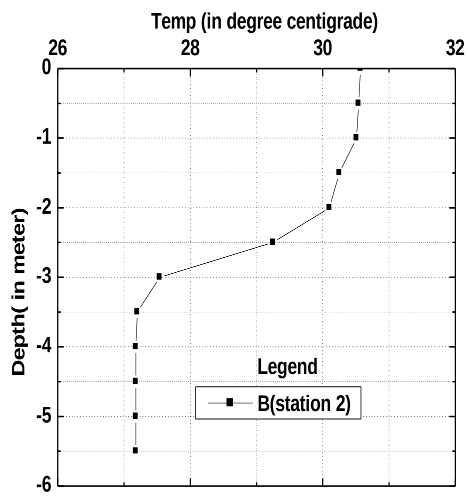
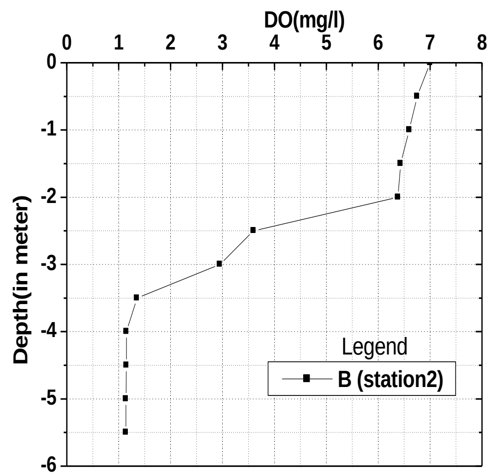


Figure 3. Vertical distribution of temperature and dissolved oxygen.





. Figure 4. Vertical distribution of temperature and dissolved oxygen.

It is also cleared that the DO concentrations falls gradually below saturation level as there is not enough wind to mix the water column. This may be explained by the plant or animal populations in water column consume more oxygen than produced during the night time. That's why the lowest DO level often occurs during the pre-dawn hours. The DO in bottom layer is less influenced by the atmospheric gas exchange phenomena.

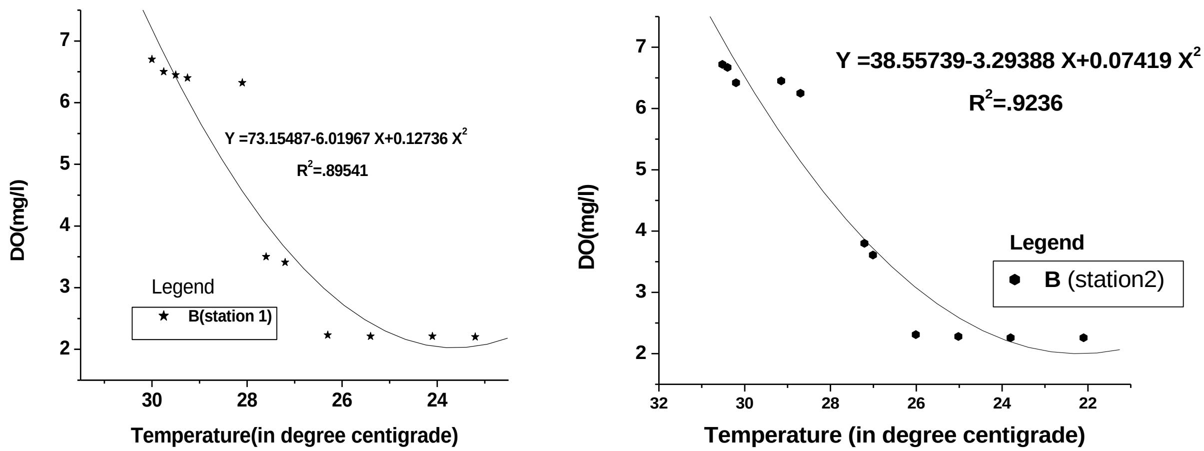


Figure 5. Graph and equation showing relationship of dissolved oxygen and temperature.

The effect of wind was relatively less in Rudrasagar lake during observation period since it's average value was measured as 0.65km/h only. So the strong surface heat flux in Rudrasagar lake accompanied with relatively lower wind action displays pronounced effect on the diurnal pattern of change in the DO level in the watermass. The vertical distribution of temperature from surface to the bottom in lake also implies the stability of the water column and the nature of the profile can be explained by the buoyancy frequency. In the present study the vertical profile of the temperature and dissolved oxygen along the depth at stations I and II in the Rudrasagar lake is presented in Figures 3-4. These data show the timing of onset of thermal stratification in the lake. The pattern of thermal stratification is observed to be clear and indicates the position of thermocline from 2m to 3m at station I (maximum depth 5.5 m). The surface water temperature and bottom water temperature is found to be maximum of 30.5^{0}C and minimum of 21^{0}C at station I. The water temperature and DO at both the stations are related along the depth through a linear regression expressed in Figures 5. The dissolved oxygen curve for the Rudrasagar lake give an indication of the inherent relationship between DO and temperature and is known as the clinograde curve. It is well reflected from these curves (Figure 5) that the rate of oxygen consumption is rapid in the thermocline zone due to strong temperature gradient. This contributes to the development of minimum DO at a depth of 4.5m from free surface of the lake at both the stations. Low value of DO can not enhance other bio-chemical processes in the fringe of hypolimnion, resulting in rapid release of toxic substances at the sediment-water interface.

Though, considerable works have already been done on various lakes and reservoirs of India, no such work have been done on the lake Rudrasagar. The observations made in this paper stress the need for more studies linking the physical and chemical dynamics of the lake Rudrasagar. The regression model developed from temperature and dissolved oxygen profiles for this lake show a strong relationship between the two dynamic limnological parameters. The sinusoidal nature of the diurnal curve will further be tested at different locations/stations for other lakes in the next phase of investigation. The diurnal nature of the temperature and dissolved oxygen variation will strongly support the gap of information at the interface of sudden change in heating and cooling of the water column. The nature of the modeled variation at the point of sudden change in warming and cooling of water column will potentially be useful for the growth of phytoplankton and zooplankton and species functional groups. Also extensive studies are required for adopting the mechanisms to reduce the magnitude and quantum of thermal stratification. The exchange of heat energy with the atmosphere is very active of controlling the hydrodynamics of the lake and the resulting thermal structure which affects the physical, chemical and biological cycles within the waterbody. In order to sustain the aquatic life in a thermally stratified lake, an attempt should be made to estimate the period and quantum of oxygenation required by artificial and mechanical means. The effect of increased air temperature under the future climate emission scenarios will be attempted in next phase of investigation.

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