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Effect of Water Turbidity on the Seasonal Variation of Modeled Mixed Layer Depth- A Case Study of Dumboor Reservoir, Tripura

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Abstract: **To solve complex environmental problems, modeling is very helpful for engineers and scientists with the aid of powerful computers and computational methods. During the last few years, interests in hydrological model design have been increasing for understanding the hydraulic features and also for the prediction of the regional health condition of lakes and reservoirs. In this paper, an attempt has been done for the prediction of vertical temperature structure along with the seasonal variation of mixed layer depth under different water turbidity in the case of the Dumboor reservoir, Tripura by using the Freshwater Lake model (Flake). Water turbidity is not only a good visible indicator of water quality but it also greatly affects the vertical temperature structure of this reservoir. As a preliminary investigation, this has been found from the output of such a modeling approach that water clarity puts its signature on the variability of seasonal mixed layer depth of this reservoir. A decrease in water transparency is an indicator of sustainability reduction of the aquatic habitats in this biome. Model results suggest that the change in water turbidity in this region can affect the seasonal patterns of mixed layer depth profile with an increasing trend of the layer depth for an increase in transparency of reservoir water.**

Index Terms: **turbidity, Flake model, vertical temperature structure, mixed layer depth, Dumboor reservoir.**

I. Introduction

Mixing is a dynamic science of lakes and reservoirs which is due to the consequence of several dynamic forcing events. Out of these dynamic events surface heat exchange, absorption of solar radiation with depth, wind magnitude, and direction, inflow magnitude, location, outflow magnitude, etc. are very crucial. The absorption of solar radiation by the water column is again greatly affected by the water turbidity level. Mixing has an important role in determining the thermal structure of any lake or reservoir. The observed temperature structure of a lake or reservoir puts a signature of past mixing events. Moreover, reservoir water quality is again greatly affected by reservoir mixing processes or mechanisms. In the case of any lake or reservoir density distribution is one of the important parameters that determine the thermal structure of the lake and reservoir. In the case of deep reservoirs, this has been observed that the density distribution is greatly modified by the effects of hydrostatic pressure (Farmer and Carmack, 1982). Surface waves, circulation currents, internal waves, seiches, turbulence, and Langmuir circulation like phenomena are mainly driven by wind flow over the water bodies and are very much responsible for causing the mixing process in any lake or reservoir. Again the water quality of any reservoir may be considered to depend on interactions among the dynamic mixing processes and of the chemical and biological responses to mixing in limnology at a certain depths of lakes or reservoir. A layer is formed having homogenized form of active turbulence and is termed as mixed layer formation. For the formation of such a layer, the required turbulences are mainly generated by winds, surface heat fluxes, and evaporation processes. The position of this layer determines

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the average level of sunlight that can observe any aquatic organisms. The dynamics of the surface mixed layer in lakes and reservoirs have already been explained by Monismith and Maclntyre (Monismith, S.G, and Maclntyre, S. 2009).

With the increase of turbidity, the concentration of suspended matter in the water column also increases. An increase in the turbidity will obviously increase in the light extinction coefficient of reservoir water. The absorption and attenuation of incident light by reservoir water is one of the crucial factors that control the thermal structure and also the food web of the reservoir. Intensity of light covering a distance z in water column shows exponential decay according to relation:

$$\boldsymbol{I} = \mathbf{I_0}\ \mathbf{e^{-E.Z}} \tag{1}$$

Where, E is the vertical attenuation coefficient for downward irradiance (Scheffer 1998).The value of 'E' increases with the increase of turbidity of liquid thereby reducing the intensity level at a shorter distance. The presence of clay particles causes scattering of light while dissolved organic substances can cause more absorption of light (Davies-Colley & Smith 2001).In case of clear waters, light can easily reach the bottom of shallow lakes, which allows the growth of phytoplankton in the water column and so the vertical domain of aquatic plants growth is restricted very much by light availability (Duarte 1991, Vant et.al.1986, Dennisin 1987, and Gallegos 1994). Moreover, this has been observed that morphological and physiological change of submerged plants can also occur due to reduced light condition (Barko and Smart 1981, Barko and Filbin 1983, Goldsborough and Kemp 1988, Dennison and Alberte 1982, Tanner et al. 1993). As the metabolism of bio-organisms is very much affected by the presence of light and so their growth in the aquatic environment is very much linked with the position of mixed layer depth. So information about the position of mixed layer depth is very helpful for analysis of phytoplankton growth and algal sequences of the reservoir. This has been identified that the depth of the mixed layer, determines the algal loss due to sinking (Reynolds, 1989; Howarth et al., 1993). If the turbulent friction velocities generated by a wind of 1 m/ s are larger than the highest sinking velocity, the slightest wind can allow the circulation of the algae in the mixed layer (Reynolds, 1989). In this paper, an attempt is made to investigate the effect of water turbidity on the seasonal fluctuation of modeled mixed layer depth of the Dumboor reservoir. This reservoir emerged as a result of construction of a dam over the river Gumti which was made for the purpose of the hydropower plant and is situated at the south Tripura district of India.

II. Materials and Method

A. Study area

Dumboor reservoir is a charming water body located in the Amarpur Sub Division at about 120 km away from the state capital of Tripura. This is situated in South Tripura at the latitude of $23^{0}25'45''$ and longitude of $91^{0}49'20''$. The reservoir is the confluence of rivers Raima and Sarma and this is very much rich in natural and cultured fishes (debnath et al.2015).

The storage capacity of the Reservoir is 23,570 Hectare meter. Dead Storage at river level is 2590 Hectare meter and live storage is maintained at 20.980 Hectare meter. The submerged area at F.R.L of 92.05 m and M.W.L of 95.25m was found to be respectively 46.34 and 74.86 Sq.Km. The highest water level at the reservoir was found to be fluctuating between RL 87.90 and 93.97 meters in the last five years. The lowest water level varies between 81.38 and 87.35 meters in the same time frame. A hydrologic simulation model has been used using HEC-HMS software for estimating the quantity of water of this reservoir (Pal et al., 2019).

B. Hydrology

The reservoir has a catchment area 576sq.Km. From the record of the last ten years (2004-2013) annually, it receives 1.99 meters of rainfall at an average whereas peak rainfall remains at around 2.97 meters (2007) and a minimum rainfall was observed in 2008 which amounted to 1.35 meters of rainfall within that year. In the last ten years, average peak rainfall in the month varied from 358 to 403 mm whereby the month of June was found to have the highest rainfall. The minimum and maximum rainfall remains at an average of 2.103 m^3/sec and 91.77m^3/sec respectively. The annual Evaporation loss was found to be 0.86metres. Measurement of catchment area at the dam site of the river is found as 547 km^2. The turbidity of water is very high due to soil erosion on account of denudation of forests in the catchment area by shifting cultivators (*jhoom*).

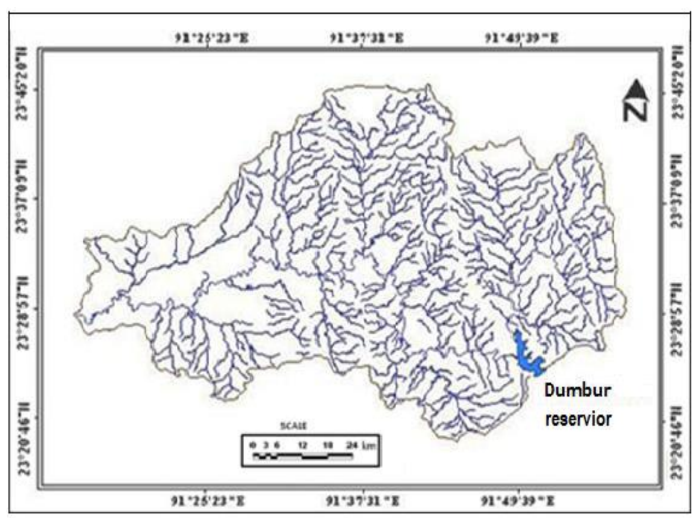

Fig 1: Dumboor basin area

C. Sampling details

The survey of the reservoir area for collection of samples and meteorological data was performed. The observation stations are selected considering the maximum water depth along the mid reach and considering the less human intervention of water of the lake, to study the temperature profile and also for studying seasonal variation of surface and bottom water temperature. The water temperature and turbidity has, however, been measured using multipurpose water quality analyzer device. Data are stored in memory cells of the device which are then transferred to the database of the computer. The laboratory methods (APHA, 1989) have been followed for calibrating the water quality instrument prior to the field work of every sampling day. The resolution of water temperature and turbidity measurement is 0.01^0C and 0.01 NTU respectively.

III. Theoretical Considerations

In order to predict the vertical temperature of any lake and mixing in lakes of various depths -one can take the help of Flake model which is also be very useful for numerical weather prediction. This model plays vital role of physical module in different aquatic ecosystem models and also different climate models can be monitored by using this . FLAKE model is based on the following quadratic equation of state for fresh water given by

$$\boldsymbol{\rho}_w = \boldsymbol{\rho}_T[1 - \frac{1}{2}a_T(\theta - \theta_T)^2] \quad (2)$$

Where, $\boldsymbol{\rho}_w$ is the water density $\boldsymbol{\rho}_T$ is the maximum density of fresh water at temperature θ_T=277.13 k which is taken as 1x 10^3 kg m^{-3} and a_T is empirical coefficient having value 1.6509 x 10^{-5} K^{-2}. (Farmer and Carmack 1981)

In the year 1970 Kitaigorodskii and Miropolsky had described temperature profile by using the two layer parametric concept. The mean temperature of water column can be represented in terms of temperature of the upper mixed layer having depth h(t) and bottom temperature as

$$\bar{\theta} = D^{-1}\int \theta dz \quad (3)$$

and

$$\bar{\theta} = \theta_s - C_\theta\left(1 - \frac{h}{D}\right)(\theta_s - \theta_b) \quad (4)$$

Where, c_θ is the shape factor with respect to the temperature profile in the thermocline and is given by

$$c_\theta = \int_0^1 \phi_\theta(\zeta)\, d\zeta \quad (5)$$

The equation for the mean temperature of the water column considering z from 0 to D

$$D\frac{d\bar{\theta}}{dt} = \frac{1}{\rho_w c_w}[Q_s + I_s - Q_b - I(D)] \quad (6)$$

Where, C_w=4.2X10^3 $JKg^{-1}k^{-1}$ is the specific heat of water, Q_s and I_s are the values of the vertical heat flux Q and of the heat flux due to solar radiation respectively at the lake surface and Q_b is the heat flux through the lake bottom.

The equation of heat budget of the mixed layer is given by

$$h\frac{d\theta_s}{dt} = \frac{1}{\rho_w c_w}\left[Q_s + I_s - Q_h - I(h)\right] \quad (7)$$

Where, Q_h is the heat flux at the bottom of the mixed layer. The equilibrium mixed-layer depth h_e can be computed from

$$\left(\frac{fh_e}{c_{sn}u_s}\right)^2 + \frac{h_e}{C_{ss}L} + \frac{h_e n}{c_{si}u_s} = 1 \quad (8)$$

Where, f=2ΩsinΦ is the coriolis parameter, Ω is the angular velocity of the earth's rotation, Φ is the geographical latitude ,L is the Obukhov length, N is the bouncy frequency below the mixed layer and C_{sn}=0.5, C_{ss}=10 and C_{si} =20 are dimensionless constants.

The exponential approximation of the decay law for the flux of solar radiation is given by

$$I = I_s\sum_{k=1}^{n} a_k \exp\left[-\gamma_k\left(z + h_i\right)\right], \quad (9)$$

Where, I_s is the surface value of the incident solar radiation heat flux multiplied by 1-α, α being the albedo of the water surface with respect to solar radiation, n is the number of wavelength band, a_k are fractions of the total radiation flux for different wavelength bands, and γ_k are attenuation coefficients for different bands. The attenuation coefficients are taken as piece wise constant function of z.

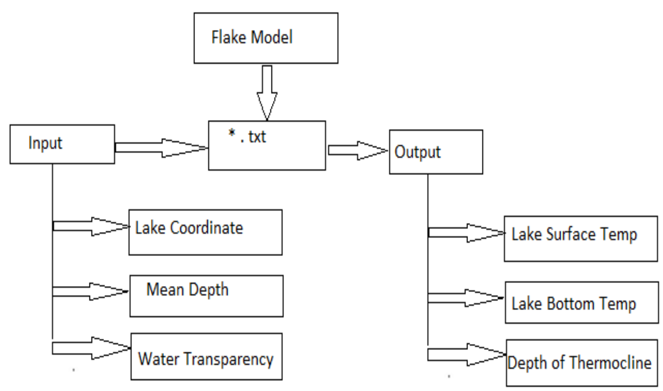

Fig 2: Schematic arrangement of the flow chart for the Model

IV. Results and discussion

A. *Experimental Results*

The mean value of turbidity of this reservoir as estimated from the recorded data of the multipurpose water quality analyzer device used is 4.87$\pm$0.6 NTU. The seasonal variation of surface and bottom water temperature of the reservoir as obtained according to experimental observation has been explored in fig.3.The observation record reveals that the difference in bottom and surface temperature exists up to the end of November.

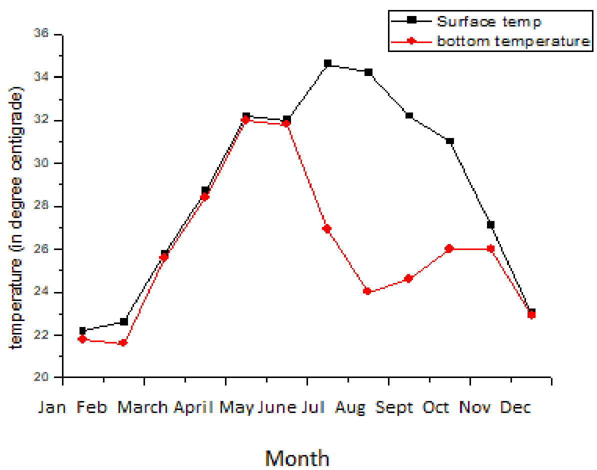

Fig 3: Seasonal variation of surface and bottom temperature

B. Model Results

1) Effect of increase in turbidity on depth wise seasonal temperature profile of the reservoir

The color maps obtained as model output under different transparency condition of reservoir water display the typical annual temperature cycle in time-depth coordinates. Fig 4, fig 5, fig 6 and fig.7- all are representing depth wise modeled temp distribution profile of reservoir under different transparency conditions. Depth wise annual temperature variation is insignificant in case of well transparent water column. Whereas for higher turbid water having transparency less than 0.5m , there exists a distinct temperature difference between surface and bottom water layer during the period from June to October as found in these seasonal temperature distribution profiles.

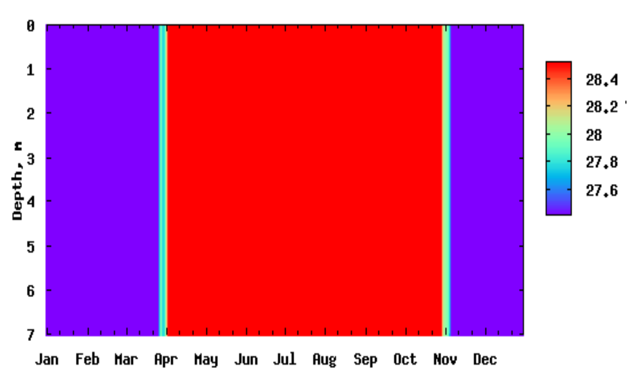

Fig4: Depth wise modeled seasonal temp distribution (for transparency >5m)

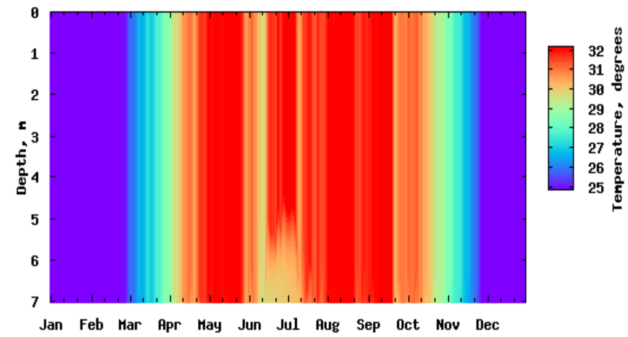

Fig 5: Depth wise modeled seasonal temp distribution (for transparency 2m)

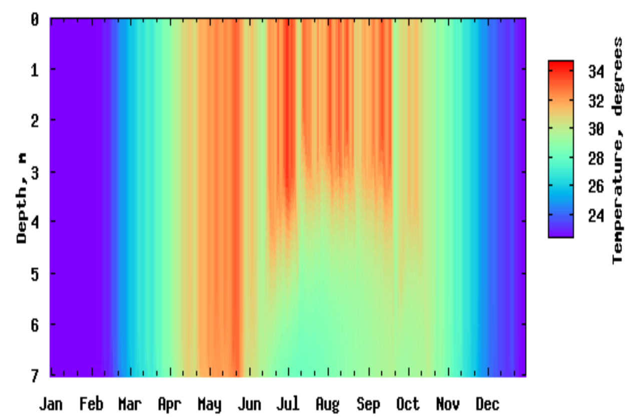

Fig 6: Depth wise modeled seasonal temp Distribution (Transparency1m)

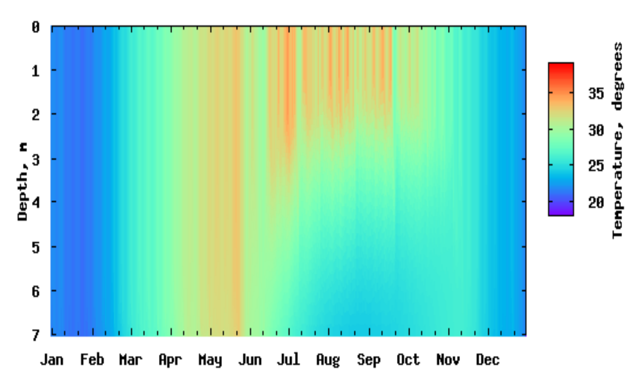

Fig 7: Depth wise modeled seasonal temp distribution (Transparency < 0.5m)

2) Effect of turbidity on seasonal variation of bottom temperature profile of the reservoir

For transparent water, seasonal variation of bottom water temperature exactly follows the similar type of variation as observed in reservoir surface water. From the modeling approach seasonal variation in bottom water temperature starts to deviate from seasonal pattern of surface water temperature with the increase in turbidity of reservoir water. Modeled surface water and bottom water temperature profiles of the reservoir under different transparency conditions has been displayed in figure 8 to figure 11.

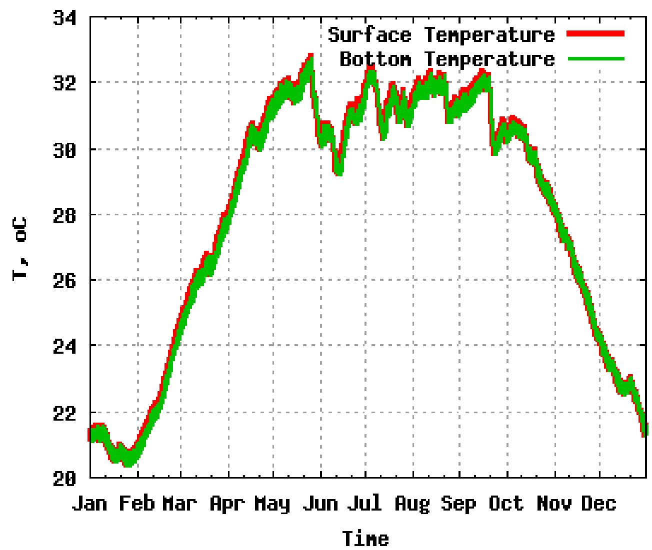

Fig 8: Modeled surface water & bottom water temp (for transparency >5m)

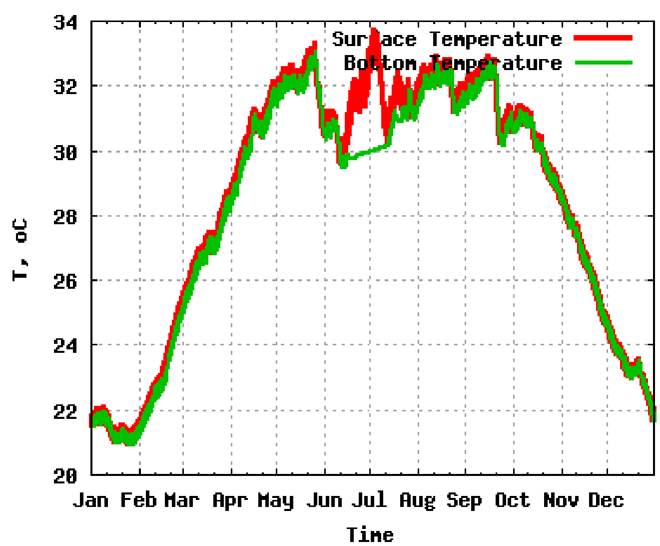

Fig 9: Modeled surface water & bottom Water temp (for transparency 2m)

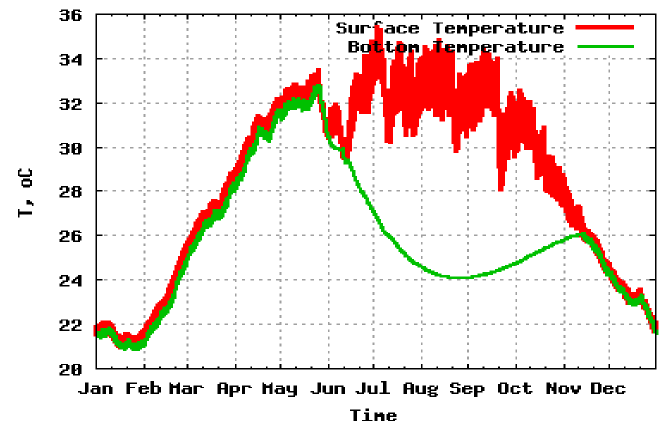

Fig 10: Modeled surface water & bottom Water temperature (for transparency 1m)

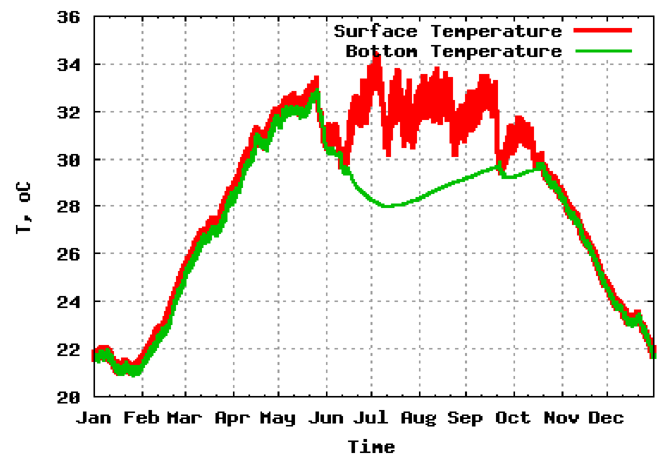

Fig 11: Modeled surface water & bottom Water temperature (for transparency< 0 .5m)

From all these figures this can be interestingly noted that the highest temperature difference between surface and bottom modeled water temperature moves towards the right of the seasonal temperature profile with the increase of turbidity of reservoir water.

3) Effect of turbidity on variation of modeled vertical temperature profile

The Flake model was run on the reservoir to follow the vertical temperature profile of reservoir water under several modeled turbidity conditions on a specific day. The specific day chosen was 10th July, 2018. For following the turbidity dependency on such modeled profile, only the transparency condition has been varied while all other input conditions of the model remaining same. For transparent water there exists no temperature variation throughout the entire liquid column, whereas interface between two adjacent layers of different temperature gradient gradually shifts upward with the increase in turbidity of liquid. Modeled temperature- depth profiles of the reservoir water under different transparency conditions have been displayed from figures 12 to figure 15.

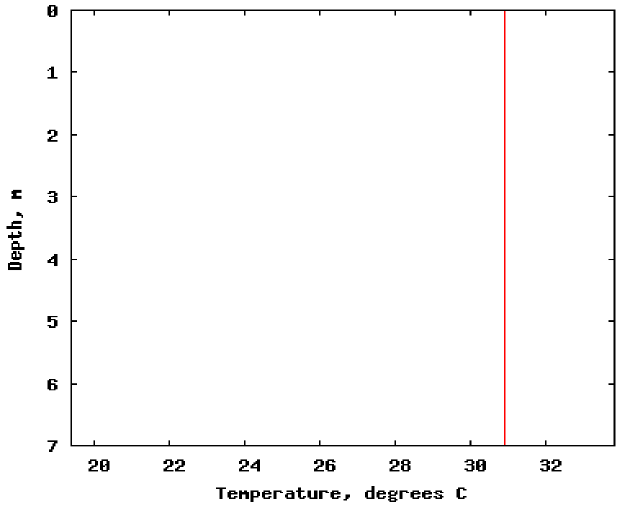

Fig 12: Modeled Temperature-depth profile of reservoir water (for transparency >5m)

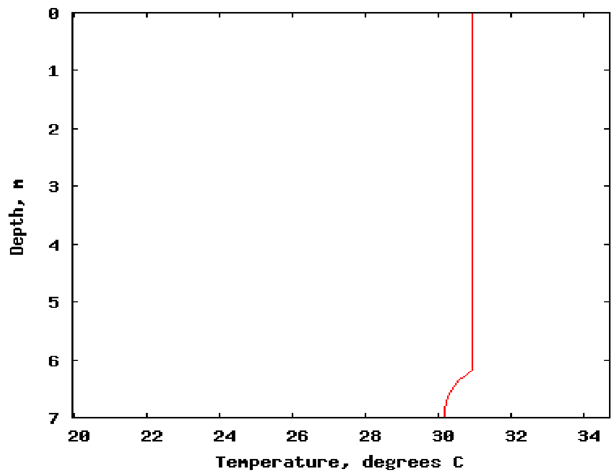

Fig 13: Modeled Temperature-depth profile of reservoir water (for transparency 2m)

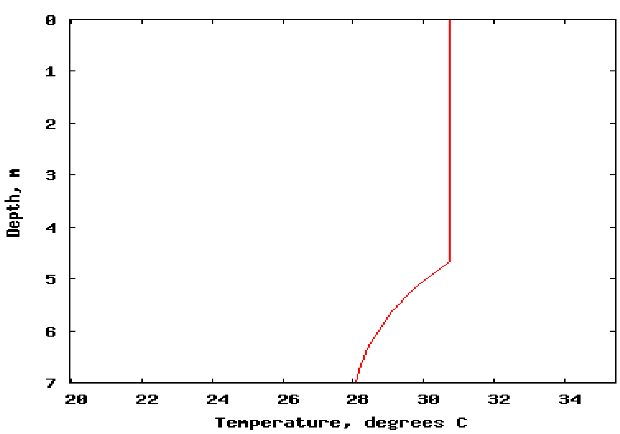

Fig 14: Modeled Temperature-depth profile of reservoir water (for transparency 1m)

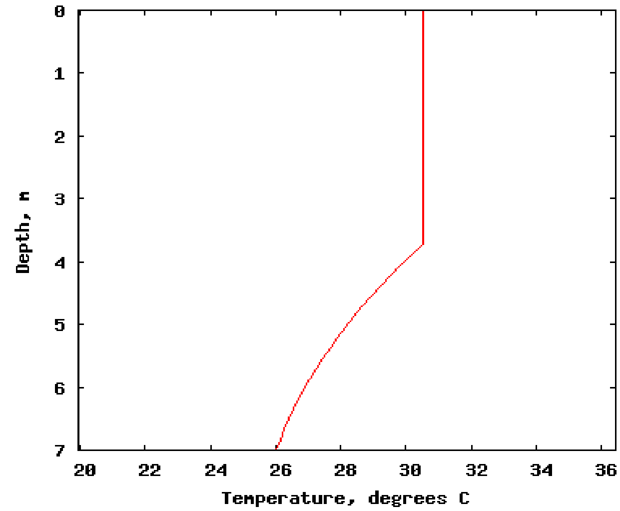

Fig 15: Modeled Temperature-depth profile of reservoir water (for transparency < .5m)

4) Effect of turbidity on seasonal variation of mixed layer depth position of the reservoir

From figure 16 to figure 19 one can easily follow the Seasonal variation of modeled mixed layer depth variation under different turbidity conditions of the reservoir water. From modeled results this can be followed that mixed layer depth positions in different seasons are greatly affected by water turbidity condition of this reservoir .The average depth of modeled mixed layer decreases with the decrease of transparency level of reservoir water. Moreover with the fall of transparency level, spreading for lowest depth of mixed layer over a complete season increases.

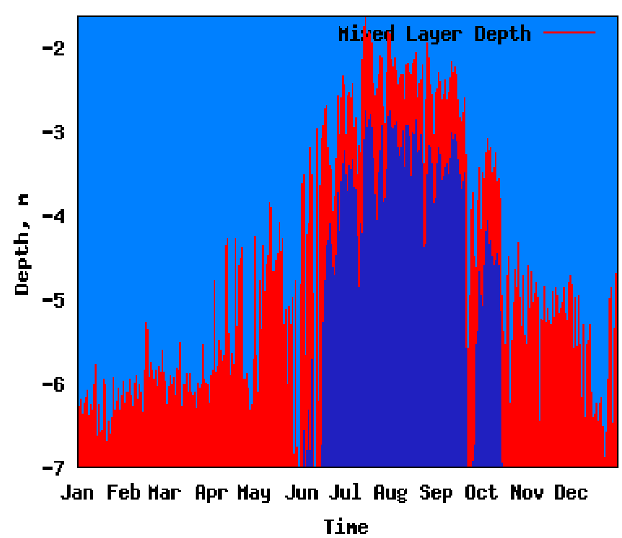

Fig 16: Seasonal variation of modeled mixed layer depth (for transparency>5m)

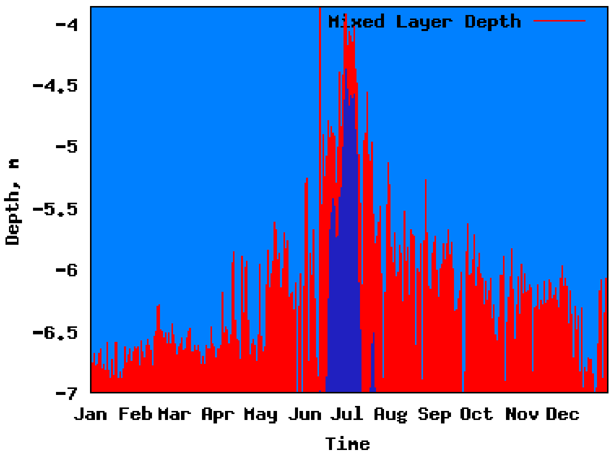

Fig 17: Seasonal variation of modeled mixed layer depth (for transparency 2m)

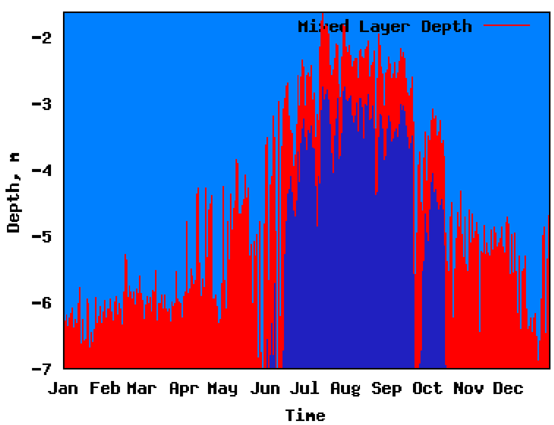

Fig 18: Seasonal variation of modeled mixed layer depth (for transparency 1m)

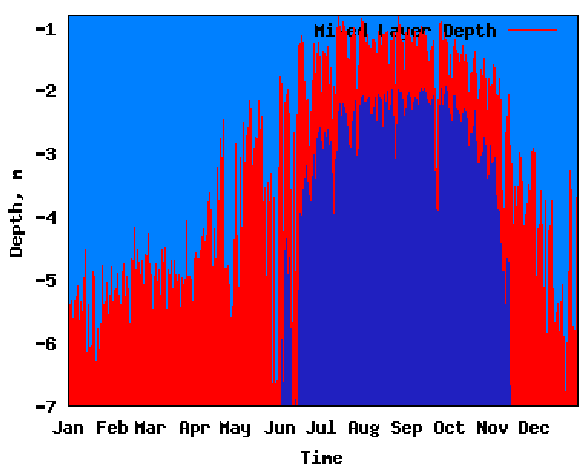

Fig 19: Seasonal variation of modeled mixed layer depth (for transparency < .5m)

CONCLUSIONS

Dumboor reservoir is the largest artificial lake in Tripura and is due to the consequence of the construction of a hydroelectric dam in 1974. As the reservoir is very much enriched by macrophytes community and varieties species of fishes, monitoring of its aquatic ecosystem is very much essential for its sustainability. The transparency level of this reservoir water has a great role in controlling the mixed layer depth of the reservoir; which has been identified from the modeled output. Moreover information about fluctuation of the depth of such layer is also very crucial for monitoring the sustainability of aquatic organisms. The transparency level of this reservoir water may be considered as a good indicator for finding the position of mixed layer depth. In order to boost up the aquatic environment by implementing proper management strategies, such types of information explored in this paper will be very helpful.

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REFERENCES

APHA, AWWA, WPCF. 1989. Standard methods for the examination of water and waste water, 7th Edn., Washington, D.C.

Barko,J.W. and R.M.Smart (1981) Comparative influences of light and temperature on the growth of metabolism of selected submersed fresh water macrophytes. Ecol.Mona gr,51:pp 219-235

Barko, J.W. and G.J.Filbin (1983) Influences of light and temperature on chlorophyll composition in submersed freshwater macrophytes.Aquat.Bot, 15:pp 249-255.

Davies-Colley, R.J., and Smith, D.J., "Turbidity, Suspended Sediment, and Water Clarity", Journal of the American Water resources Association, vol 37, pp 1085-1101.

Debnath .B,Ananthan.P.S,Debnath .B,Sharma .A, and Sharma .R,(2015), Fisheries of Gumti (Dumboor) Reservoir in Tripura: production, performance and management, Indian J. Fish., 62(3) , pp 14-20.

Dennison,W.C and R.S.Alberte (1982) Photosynthesis responses of Zostera marina L,(Elgrass) to in situ manipulations of light intensity, Ecologia(Berl) 55,pp 137-144.

Dennison,W.C,(1987)Effects of light on seagrass photosynthesis,growth and depth distribution. Aquat Bot 27: pp 15-26.

Duarte,C.M(1991) Seagrass depth limits,Aquat.Bot 40:pp 363-377.

Farmer, D. M., and Carmack, E. 1982. "Wind-Mixing and Re stratification in a Lake near the Temperature of Maximum Density," Journal of Physical Oceanography, Vol 11, pp 1516-1533.

Gallegos, C.L.(1994) Refining habitat requirements of submersed aquatic vegetation: role of optical models. Estuaries 17: pp187-199.

Goldsborough,W.J and M,kemp(1988), Light responses of a submersed macrophyte: implications for survival in turbid tidal water.Ecology69:pp 1775-1786.

Howarth, R.W., Butler. T . and Lunde K., (1993) Turbulence and plank tonic nitrogen fixation : a mesocosm experiment . Limnol. Oceanogr, 38, pp1696-1711.

Monismith,S.G and Maclntyre,S. (2009), The Surface Mixed Layer in Lakes and Reservoirs. Encyclopedia of Inland Waters, pp 636-650

Pal M, Biswas Roy M, Roy PK,.(2019). Use of HEC-HMS Software for Quantitative Assessment of Water of Dumboor Reservoir, Tripura, India. International Journal for Research in Applied Science & Engineering Technology (IJRASET) Volume 7 Issue XII, pp 495-500.

Reynolds.C.S.(1989) Physical determinants of phytoplankton succession. In Sommer. U. (ed.), Plankton Ecology: Succession in Plankton Communities. Springer-Verlag, Berlin, Heidelberg, New York.

Scheffer, M., Ecology of Shallow lakes, Springer-Science & Business media, B.V, 1998,p 21.

Tanner,C,C,.J.S. Clayton,R.D.S.Wells,(1993) Effects of suspended solids on the establishment and growth of Egeria dend=sa.Aqat.Bot.45:pp 299-310.

Vant.W.N., R.J.Davies-Colley, J.S.Clayton and B.T. Coffey,(1986), Macrophyte depth limits in North Island(New Zealand) lakes of differing clarity, Hydrobiologia 137 : pp55-60.

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