Eco. Env. & Cons. 27 (February Suppl. Issue) : 2021; pp. (S267-S273)

ISSN 0971–765X

Quantification and classification of Groundwater - lake water exchange using conventional method

S. Mahenthiran*, Madhavi Ganesan*, L. Vignesh Rajkumar* and N. Sridhar***

***School of Civil Engineering, Vellore Institute of Technology, Vellore 632 014, T.N., India**
**** Centre for Water Resources, Anna University, Chennai 600 025, T.N., India**
*****Department of Civil Engineering, Rise Krishna Sai Prakasam Group of Institutions, Ongole 523 001, Andhra Pradesh, India***

(Received 8 August, 2020; Accepted 15 September, 2020)

ABSTRACT

The Water balance of Veeranam Lake is calculated by considering all inflow and outflow components of lake. Inflow components of Veeranam lake include direct rainfall, Vadavar River inflow, ungauged catchment inflow whereas outflow components of the lake include evaporation and discharge of water for various activities (CMWSSB pumping outflow, Irrigational outflow, Lalpet Weir outflow, VNSS outflow). Ungauged catchment runoff to Veeranam Lake is estimated by Soil Conservation Service-Curve Number (SCS-CN) method. About 42% of rainfall volume in the catchment is infiltrated into the ground and 58% of rainfall volume, flow as a direct surface runoff into the Veeranam Lake. Groundwater inflow and outflow to lake are commonly expressed as net groundwater exchange and it is estimated as 53% of total outflow components of the lake. Veeranam Lake is dominated by both the inflow and outflow components of the lake. The calculated net groundwater exchange is negative and this indicates that Veeranam Lake recharges the nearby aquifer zones.

Key words : *Water balance, Lakes, Conventional method, Net groundwater exchange*

Introduction

Lake impart impacts on hydrological cycle because it is a function of hydrological components such as surface water, groundwater and meteorological system (Dinka *et al.* 2014). Lakes are closely related to upstream catchment and downstream ayacut area. Irregular water management practices in the upstream catchment area of lake affect lake environment and in turn lake affect downstream command environment (Price and Maloney, 1994). Variations in lake water level also influence the groundwater table condition and land-use practices. Therefore effective water management should be adopted for the proper function of the lake system (Bocanegra *et al,.* 2013). For effective management of the lake system, individual water balance components of lake should be known. Estimation of lake water components provides a better understanding of groundwater level variations in terms of both seasonal and short term scale level. Determination of lake water balance is necessary to maintain lake volume constant and reason for the decrease in lake storage capacity is also assessed through it. Seepage meter is only point measurement and flow net provides information about the depth of groundwater flow and its area contributing to the lake system. The complete groundwater exchange around the lake area

(*Assistant Professor (Senior), **Professor, ***Associate Professor)

can be quantified through the lake water balance equation (Winter, 1981; Belanger and Kirkner, 1994; Labaugh, 1997; Li *et al.*, 2007; Surjeet Singh *et al.*, 2009; Biskop *et al.*, 2016; Lintang Fadlillah *et al.*, 2016; Saleem and Jeelani, 2017). In the previous research work carried out in Veeranam Lake (Pruthiviraj, 2013; Latha *et al.*, 2012; Senthilkumar and Sivakumar, 2018), the water balance of lake is not calculated. In this paper, hydrological components (inflow and outflow) that contributes to Veeranam Lake is calculated individually and net groundwater exchange between Veeranam Lake and aquifer is also calculated. Veeranam Lake classification is also determined in this research work by Szesztay diagram.

Study Area

The catchment of Veeranam Lake lies between 11˚08ˆ 28ˆ to 11˚24ˆ 59ˆNorth latitudes and 79˚33ˆ 05ˆ to 79˚11ˆ 19ˆEast longitudes. Veeranam Lake catchment area is divided into five zones on the basis of rain gauge stations and it is shown in

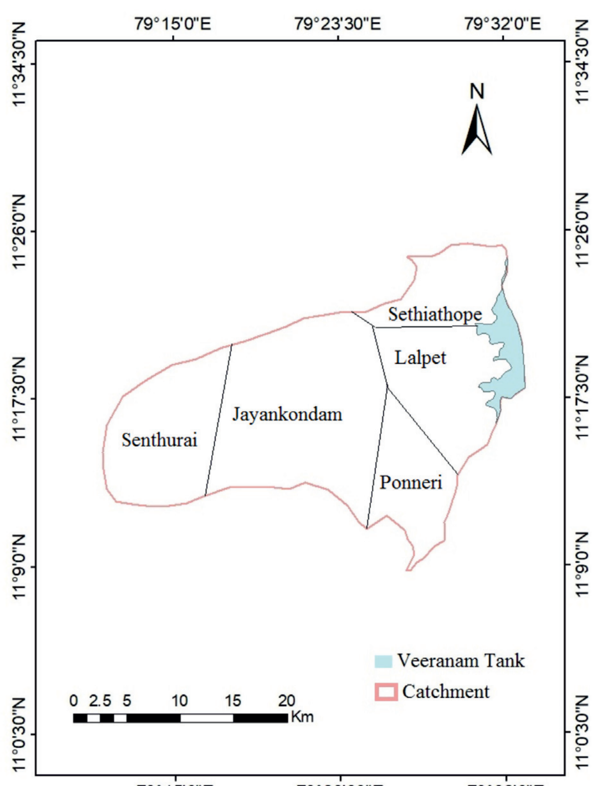

Fig. 1. Computed catchment area on the basis of rain gauge stations

Fig. 1. The dominant soil type prevails in the study area is black soil and alluvial soil (CGWB, 2009). In this study, land use pattern is grouped into five categories as agriculture, plantation, forest, scrubland and water bodies. The study area receives high rainfall in the northeast monsoon and moderate rainfall in the southwest monsoon. The climate is semi-arid, which is hot during summer and moderately cool during winter. Veeranam Lake receives water from its catchment through 8 major and 37 minor inlets during monsoon seasons (PWD, 2000).

Methodology

The water balance of Veeranam Lake is based upon the principle, change in water storage of lake (C_{TS}) is equal to the difference between the inflow and outflow water components of lake. The annual water balance of Veeranam Lake is calculated for the water years 2005-2015. In order to avoid the separation of the flood season, the water year (April – March) is considered in the water balance equation. Inflow components of the Veeranam Lake include direct rainfall (R_f), Vadavar River inflow (R_{IF}), ungauged catchment inflow (UC_{IF}) and groundwater inflow (GW_{IF}). The outflow components of Veeranam Lake include evaporation (E), groundwater outflow (GW_{OF}) and discharge of water for various activities (D). D comprises of CMWSSB pumping outflow (M_{OF}), Irrigational outflow (C_{OF}), Lalpet Weir Outflow (W_{OF}), VNSS outflow (V_{OF}). The runoff contribution to Veeranam Lake from the catchment is ungauged and runoff in this ungauged catchment is estimated by Soil Conservation Service-Curve Number (SCS-CN) method. To estimate runoff in the catchment, SCS-CN incorporates HSG (Hydrological Soil Group), land-use practices and Antecedent Moisture Conditions (AMC). The groundwater inflow and groundwater outflow are commonly expressed as net groundwater exchange (GW_E) in the water balance equation. Calculated net groundwater exchange is the unknown residual term, where all other components are known terms in the water balance equation.

The general water balance equation of lake system is,

Inflow-Outflow = Change in storage. .. (1)

The water balance equation of Veeranam Lake is expressed as below by considering the inflow and outflow components of the lake.

$R_F+R_{IF}+UC_{IF}+GW_{IF} = E+ D+GW_{OF}+ C_{TS}$ .. (2)

Where $D = M_{OF} + C_{OF} + W_{OF} + V_{OF}$ .. (3)

After rearranging equation (2)

$$C_{TS} = R_F + R_{IF} + UC_{IF} + GW_{IF} - E - D - GW_{OF} \quad .. (4)$$

Groundwater inflow and outflow is commonly expressed as net groundwater exchange (Blanco-Coronas *et al.* 2020).

$$\text{Hence } GW_E = (GW_{IF} - GW_{OF}) \quad .. (5)$$

Substituting equation (5) in equation (4) gives

$$C_{TS} = R_F + R_{IF} + UC_{IF} - E - D + GW_E \quad .. (6)$$

Rearranging equation (6),

$$GW_E = C_{TS} - R_F - R_{IF} - UC_{IF} + E + D \quad .. (7)$$

Net groundwater exchange with Veeranam Lake is calculated in volumetric scale from water balance equation (7).

Results and Discussion

Direct Rainfall

Rainfall is measured at Lalpet and Sethiathoppe rain gauge stations, which are located at the northern and southern end of Veeranam Lake respectively. The average rainfall of these two stations is taken as daily rainfall because the major axis of the lake is in the north-south direction. Direct rainfall contribution to Veeranam Lake is obtained on the volumetric scale by multiplying rainfall with lake surface area. Annual minimum direct rainfall contribution to Veeranam Lake is 17 Mm^3 and the maximum is 42 Mm^3. Annual average direct rainfalls over Veeranam Lake is 31 Mm^3 and it contributes 4 % of total inflow components of the Lake. High intensity of rainfall not only influences lake water storage, it also enhances the flow of water in the Vadavar River and Veeranam Lake catchment area.

Vadavar River Inflow

Vadavar River contributes major amount of water to Veeranam Lake and its flow plays a significant role in water balance components of Veeranam Lake. Vadavar River receives water from Mettur dam and gauges regulate this water at Grand anaicut and Lower anaicut. Almost throughout the year, Vadavar River supplies water to Veeranam Lake. Vadavar River inflow to Veeranam Lake is measured daily by gauge located at the head of Veeranam Lake. The minimum annual Vadavar River inflow is 100 Mm^3 and maximum inflow is 621 Mm^3. Annual average Vadavar River inflow to Veeranam Lake is 329 Mm^3 and it contributes 48% of total inflow components of the lake. An increase in rainfall enhances Vadavar River flow because a large amount of water is released from Mettur dam, Grand anaicut and Lower anaicut during monsoon seasons. Thus Vadavar River inflow to Veeranam Lake is based on the intensity of rainfall in its catchment area.

Ungauged Catchment Inflow

Runoff estimation in Veeranam Lake ungauged catchment is essential for the determination of lake water balance. Runoff in the catchment is influenced by both rainfall and runoff characteristics. Daily rainfall data of five rain gauge stations, namely Senthurai, Jayankondam, Ponneri, Lalpet and Sethiathoppe are considered as a polygon to estimate runoff in the ungauged catchment. Direct runoff for each polygon is calculated for each rainfall event after calculation of curve number, potential maximum soil retention, initial abstraction and AMC. Soil in Veeranam catchment is classified according to HSG classification (USDA-SCS, 1985). HSG D is dominant in catchment area and it covers 92.6% of total catchment area 4.16%, 2.62% and 0.55% of catchment area comprises of HSG C, HSG B and HSG A respectively. Infiltration and runoff varies from one land use pattern to another (Anbazhagan *et al.*, 2005). Thus land use also possesses significant effect on catchment runoff. 62% of catchment area occupies agricultural land and 29.4% area covers plantation land. 8%, 0.64% and 0.015% catchment area comprises of scrubland, water bodies and forest respectively. If HSG or land use pattern is not homogenous in catchment, then composite curve number is used (Anbazhagan *et al.*, 2005). In order to standardize curve number in each polygon, it is calculated for individual HSG and land use pattern. The weighted curve number ranges from 78 (Senthurai) to 94 (Ponneri). The calculated curve number (CN_{II}) is for antecedent soil moisture under normal conditions. Curve number also varies based on antecedent soil moisture conditions (water content present in soil during rainfall event). The adjusted curve number for dry soil condition (CN_I) varies from 60.52 to 88.09 and wet soil condition (CN_{III}) varies from 89.11 to 97.5. Before the computation of surface runoff in catchment, initial abstraction is calculated for each polygon. Initial abstraction comprises of water loss, infiltration, interception and surface storage which occurs prior to surface water runoff (USDA-SCS, 1985). It is assumed that, if rainfall event is less than initial abstraction, then no surface runoff occurs in the catchment. Hence rainfall events which are greater than initial abstraction are taken into account for runoff estimation.

Direct runoff in Veeranam catchment is calculated for each polygon after calculation of curve number, potential maximum soil retention, initial abstraction and AMC. Since direct surface runoff in the catchment flows to the lake through 8 major and 37 minor drainage inlets, it is very difficult to predict the drainage in the inlets individually. Therefore in the present study it is assumed that runoff in the catchment completely contributes to Veeranam Lake. Average annual runoff in Veeranam catchment during study period is 330 Mm^3 and it contributes 48% of Veeranam Lake inflow components. Average monthly runoff volume is high (124.35 Mm^3) during November and low (1.03 Mm^3) during February. The average monthly rainfall volume (direct rainfall) is high (9.84 Mm^3) during November and less during February (0.23 Mm^3). This shows that surface runoff in the catchment is directly proportional to rainfall. 42% of rainfall volume in catchment is infiltrated into ground and 58% of rainfall volume flows as direct runoff in catchment and flow into Veeranam Lake.

Evaporation

Evaporation is measured by pan evaporation and it is the simple reliable method because Veeranam Lake water storage is at shallow level. Evaporation data is converted to volumetric scale by multiplying evaporation data with lake surface area. The calculated annual maximum and minimum evaporation is 46 Mm^3 and 34 Mm^3 respectively. The average annual evaporation in Veeranam Lake (surface area) is 41 Mm^3 and evaporation contributes 6% of total outflow components of Veeranam Lake. Evaporation component is greater than rainfall component in the Veeranam Lake water balance equation. The rainfall is minimum and evaporation is maximum during water year 2012-2013 which clearly implies that inverse relationship exists between these two components.

Discharge of Water for Various Activities

Veeranam Lake water is released through channels to supply water for irrigational activities in its own ayacut area. Veeranam New Supply Sluice (VNSS) discharges lake water into Vellar River during flood seasons and it also supplies water to irrigation practices. Quantity of water released is not equal in all the channels and it varies because the channel ayacut area is not uniform and also varies with respect to seasons. For drinking water to Chennai residents daily 180 MLD of water is pumped from Veeranam Lake by CMWSSB (Chennai Metropolitan Water Supply and Sewage Board) through intake tower located at northern end of lake. Lalpet Weir along with its bye wash is the surplus arrangement to discharge huge amount of water from lake during flood seasons. The discharge of water for various activities varies from 61.84 Mm^3 to 586.70 Mm^3. Annual average discharge through channels, CMWSSB pumping, Lalpet Weir and VNSS is 281 Mm^3 and it contributes 41% of lake total outflow components.

Net Groundwater Exchange

Groundwater inflow and outflow to lake is commonly expressed as net groundwater exchange in lake water balance equation. Water exchange between lake and aquifer depends on land use practices, climate, hydrogeology conditions and also the head difference between lake and aquifer (Congdon, 1985). Positive net groundwater exchange implies that groundwater inflow to lake occurs whereas negative net groundwater exchange implies that groundwater outflow from lake occurs. The calculated net groundwater exchange varies from -515 Mm^3 (2005-2006) to -169 Mm^3 (2012-2013). Since the calculated net groundwater exchange is negative, it is considered as an outflow component. Groundwater inflow to lake is high during monsoon and declines in summer season (increased evaporation). The negative net groundwater exchange implies, groundwater outflow is more than groundwater inflow in Veeranam Lake system and it recharges the nearby aquifer zones. The average annual Veeranam Lake water balance components is shown in Fig. 2.

Change in Storage

Change in storage of lake is generally influenced by both nature and human activities. Natural phenomenon includes rainfall, river flow, evaporation and human activities includes regulation of inflow and outflow of the lake. Positive change in storage is due

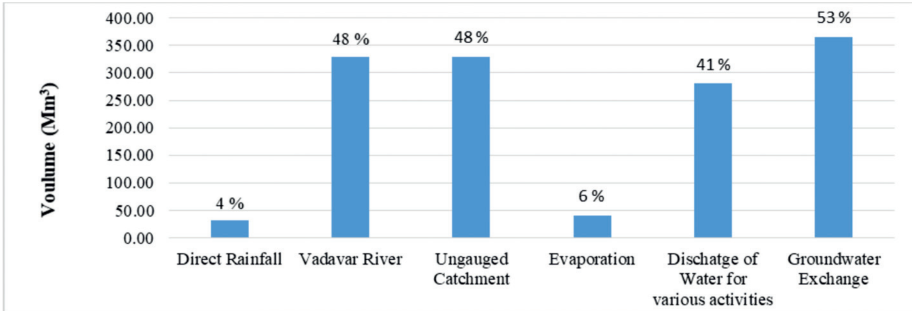

Fig. 2. Average annual Veeranam Lake water balance components

to increase in storage of lake whereas negative change in storage is due to decrease in storage of the lake. Positive change in storage is observed in the months of April, May, June, July and September. The average annual change in storage is 0.89 Mm^3.

Lake Classification

Szesztay (1974) classified lakes into nine types based on its water balance components. Szesztay diagram consists of nine quadrants as shown in Fig. 3. X and Y axis of the diagram is outflow factor and inflow factor of lake respectively. Inflow factor of Veeranam Lake is determined by the following equation (8),

$$i = \frac{(R_{IF} + UC_{IF} + GW_{IF})}{(R_{IF} + UC_{IF} + GW_{IF} + R_F)} \quad (8)$$

Outflow factor of Veeranam Lake is determined by the following equation (9)

$$O = \frac{(W_{OF} + V_{OF} + C_{OF} + M_{OF} + GW_{OF})}{(W_{OF} + V_{OF} + C_{OF} + M_{OF} + GW_{OF} + E)} \quad .. (9)$$

Since groundwater outflow is dominant than groundwater inflow in Veeranam Lake system, the computed net groundwater exchange is considered as outflow factor of Veeranam Lake and substituted in the equation (9). In Szesztay, Veeranam Lake falls in (I-O) quadrant. Lake in this quadrant is dominated by both inflow and outflow water balance components. Almost equilibrium exists between the climatic components rainfall and evaporation. Major amount of water is contributed to Veeranam Lake by Vadavar River and also by its own catchment during monsoon seasons. At the same time, water is withdrawn from lake for drinking, irrigation activities and also recharged into aquifer. Large amount of water is also discharged through surplus arrangements during monsoon seasons. Thus Veeranam Lake is characterized as flow through type and water balance of this lake is also highly unstable due to both natural and artificial factors.

Limitations of the Study and Scope for Future Work

Lake water balance calculation may also involve uncertainities due to errors in measuring and estimating the inflow and outflow components of the lake (Winter *et al.*, 1981). Runofff in the catchment is contributed to the Veeranam Lake through 8 major and 37 minor drainage inlets. In this study, it is assumed that catchment surface runoff directly contributes to the lake and these drainage inlets are not considered. Veeranam Lake possess 34 sluices and only major sluices under operation is considered in this study. Lake water balance should be calculated on daily and monthly basis with the aid modelling coupled with conventional method to better understand the seasonal variation of groundwater recharge and discharge around the lake.

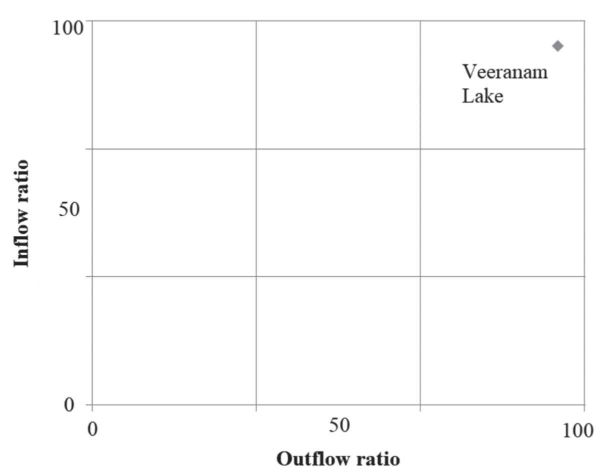

Fig. 3. Classification of veeranam lake by Szesztay diagram

Conclusion

Major amount of inflow to Veeranam Lake is contributed by Vadavar River flow and ungauged catchment flow. Change in water storage of lake (rise and fall) is almost constant except during flood seasons. Increase in lake storage is influenced by Vadavar River inflow, direct rainfall over lake and ungauged catchment inflow to the lake. Decrease in lake storage is due to discharge of water from lake for various activities and also due to recharge of lake water to the aquifer. 42% of rainfall in the catchment area is infiltrated into ground and 58% of rainfall contributes to Veeranam Lake as direct runoff. Groundwater exchange (interaction) between lake and aquifer is estimated as 53% of the total lake outflow components. The calculated average net groundwater exchange is negative and this implies that Veeranam Lake recharges the nearby downstream aquifer zones. It is inferred from water balance analysis that, increase in lake storage is influenced by Vadavar River inflow, direct rainfall over lake and ungauged catchment inflow whereas decrease in lake storage is due to evaporation, discharge of water from lake and recharge of lake water to the aquifer.

Acknowledgemet

The authors are thankful to Water Resources Organisation, Public Works Department, Tamil Nadu and Chennai Metropolitan Water Supply and Sewarage Board, Tamil Nadu to make use of the data essential for this research.

References

Anbazhagan, S., Ramasamy, S.M. and Das Gupta, S. 2005. Remote sensing and GIS for artificial recharge study, runoff estimation and planning in Ayyar basin, Tamil Nadu, India. *Environmental Geology.* 48(2) : 158-170.

Belanger, T.V. and Kirkner, R.A. 1994. Groundwater/surface water interaction in a florida augmentation lake. *Lake and Reservoir Management*. 8(2) : 165–174.

Biskop, S., Maussion, F., Krause, P. and Fink, M. 2016. Differences in the water-balance components of four lakes in the southern-central Tibetan Plateau. *Hydrology and Earth System Sciences.* 20 : 209–225.

Blanco-Coronas, A.M., Lopez-Chicano, M., Calvache, M.L., Benavente, Jose, and Duque, C. 2020. Groundwater-Surface Water Interactions in "La Charca de Suárez" Wetlands, Spain. *Water.* 12(2) : 344.

Bocanegra, E., Quivoz Londono, O.M., Matinez, D.E. and Romanelli, A. 2013. Quantification of the water balance and hydrological processes of ground water - Lake interaction in the Pampa Plain, Argentina. *Environmental Earth Sciences.* 68 : 2347-2357.

CGWB (Central Ground Water Board). 2009. District Groundwater Brochure Perambalur District, Tamil Nadu. Ministry of Water Resources, Government of India.

Congdon, R.A. 1985. The water balance of Lake Joondalup. *Bulletin no. 183,* Department of Conservation and Environment, Perth, Western Australia.

Dinka, M.O., Loiskandl, W. and Dan Ndambuki, J.M. 2014. Hydrologic Modelling for Laka Basaka: Development and application of a conceptual water budget model. *Environmental Monitoring and Assessment.* 186(9) : 5363-5379.

Labaugh, J.W., Winter. T.C., Rosenberry, D.O., Schuster, P.F., Reddy, M.M. and Aiken, G.R. 1997. Hydrological and chemical estimates of the water balance of a closed-basin lake in north central Minnesota. *Water Resources Research.* 33 (12) : 2799–2812.

Latha, M., Rajendran, M. and Murugappan, A. 2012. Comparison of GIS based SCS-CN and strange table method of rainfall-runoff models of Veeranam tank, Tamil Nadu, India. *International Journal of Scientific and Engineering Research.* 3(10) : 1-5.

Li, X.Y., Xu, H.Y., Sun, Y.L., Zhang, D.S. and Yang, Z.P. 2007. Lake-level change and water balance analysis at lake Qinghai, West China during recent decades. *Water Resources Management.* 21 : 1505–1516.

Lintang Fadlillah, N. and Wiyastuti, M. 2016. Water balance and irrigation water pumping of Lake Merdada for potato farming in Dieng Highland, Indonesia. *Environmental Monitoring and Assessment.* 188(8) : 448 (1-8).

Price, J.S. and Maloney, D.A. 1994. Hydrology of a patterned Bog-Fen complex in Southeastern Labrador, Canada. *Nordic Hydrology.* 25 : 313-330.

Pruthiviraj, T. 2013. *Study on geochemical characteristics of Veeranam lake sediments, Cuddalore district, Tamil Nadu, South India-Geospatial and temporal variations.* Ph.D Thesis. Department of Earth Sciences, Annamalai University, Tamil Nadu, India.

PWD (Public Works Department). 2000. Groundwater perspectives a profile of Cuddalore district, Tamilnadu. State ground and surface water resources data centre, Water Resources Organization, Government of Tamilnadu, India.

Saleem, M. and Jeelani, G. 2017. Geochemical, isotopic and hydrological mass balance approaches to constrain the lake water–groundwater interaction in Dal Lake, Kashmir Valley. *Environmental Earth Sciences.* 76: 533.

Senthilkumar, R. and Sivakumar, K. 2008. Studies on phytoplankton diversity in response to abiotic factors in Veeranam lake in the Cuddalore district of Tamilnadu. *Journal of Environmetal Biology.* 29 (5) : 747-752.

Surjeet Singh, Bhishm Kumar, Thakural, L.N. and Ravi, Galkate. 2009. A Comprehensive Study on water balance, sedimentation and physico-chemical characteristics of Sagar Lake in India. *Environmental Monitoring and Assessment.* 148 (1) : 265-276.

Szesztay, K. 1974. Water balance and water level fluctuations of lakes. *Hydrological Sciences Bulletin.* 19 : 73–84.

USDA-SCS (United States Department of Agriculture-Soil Conservation Service). 1985. *National Engineering Handbook, Section 4, Hydrology,* USDS-SCS, Washington DC.

Winter, T.C. 1981. Uncertainties in Estimating the Water Balance of Lakes. *Journal of the American Water Resources Association.* 17 (1) : 82–115.