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SIGNIFICANCE OF EVAPORATION IN WATER AVAILABILITY OF A SHALLOW SUB-TROPICAL LAKE IN INDIA

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Abstract: Knowledge of evaporation losses is important as it may be a deciding factor in the water availability of many of the water bodies in tropical and subtropical regions. In the present study evaporation losses and their relative significance in the overall water budget of Sukhna Lake in India have been studied. Evaporation has been estimated using Penman-Monteith method and its relative contribution has been studied using water balance of the lake. During the study period average monthly evaporation rate was found to vary between 2.03 mm/d for January to 10.21 mm/d during May. The total volume of water lost through the process of evaporation from the lake varied from low losses of 8.87 Ham in January 2012 to high losses of 40.93 Ham during May 2013. The volume of water loss was found to depend not only on the rate of evaporation but also on the water availability in the lake which determines the water spread area of the lake. The contribution of evaporation losses in total losses from the lake in different months was found to be different. The contribution depends on relative contribution from other losses. The losses were as high as about 95% during 2012 summer and were comparatively lower during 2013 summer. Comparative analysis of evaporation losses in total losses from the lake in monsoon and post-monsoon seasons indicates that evaporation losses could vary between 48-90%, depending upon the relative contribution from seepage, which is higher at higher lake water levels and negligible below the water level of 351.74 m above mean sea level. The study concludes that evaporation losses are a deciding factor in total water losses from the lake during deficit rainfall year. However, its relative significance is reduced due to seepage losses in a normal rainfall year.
Keywords: Evaporation; Penman-Monteith Method; Sukhna Lake; Water balance.
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INTRODUCTION

Owing to the warmer climatic conditions, most of the water bodies in tropical regions are subjected to heavy evaporation losses, especially in summer. As such, evaporation may be a deciding factor in the water availability of many of these water bodies. Delclaux *et al.,* 2007, for example, observed that annual evaporation is about 90% of the total output losses from the Lake Titicaca. Inspite of its significance, however, precise estimation of evaporation losses from water bodies still remains one of the challenging tasks for the hydrologists and water resources engineers the world over. This is because, evaporation is a very complex process involving complex interactions of various factors. Evaporation rates vary with region and also temporally within a region. The pattern of monthly evaporation is also not always consistent from year to year. Also, there are seasonal, intra-seasonal and interannual variations in evaporation. Ikebuchi *et al.,* 1988 observed that the annual variation of evaporation was greater in autumn and winter seasons, than in spring and summer seasons.

Sturrock *et al.,* 1992 observed that the pattern of monthly evaporation from the lake was not consistent from year to year. Rosenberry *et al.,* 1993 observed a variation ranging from 10 to 89% in the evaporation estimates. Lenters *et al.,* 2005 from their study on Sparkling Lake in northern Wisconsin, USA observed that seasonal changes have highest coefficient of variation (18%), followed by intra-seasonal (15%) and inter-annual timescales (12%).

The spatial and temporal variations in evaporation estimates are due to the variation in interrelationships and relative significance of the various controlling factors. Mohan and Arumugam, 1996 observed that relative humidity, temperature and wind speed are the factors with most influence in evapo-transpiration process, in that order while rainfall and sunshine duration have less influence. Lenters *et al.,* 2005 observed that while seasonal variations are largely driven by temperature and net radiation, the inter-annual changes in summer evaporation rates, are strongly associated with changes in net radiation. They further observed that the most important individual climatic influence on inter-seasonal variations in evaporation is relative humidity. Gianniou and Antonopoulos, 2007 from their study on Lake Vegoritis in Greece observed that evaporation rates are more sensitive to the values of long-wave radiation, followed by air and water surface temperatures. The controlling variables of evaporation are also known to vary with time scale (Xu and Singh, 1998; Lenters *et al.,* 2005). As far India is concerned, hardly any studies have been reported on the various aspects of evaporation from lakes.

No method exists for direct measurement of actual lake evaporation. It has to be determined indirectly. A number of studies have been reported on evaporation and a number of methods and models have been developed to indirectly estimate evaporation such as energy balance models, water balance models, mass transfer models, combination models, pan evaporation models, equilibrium temperature models and empirical models. The energy balance is considered to be the most accurate of all the available methods (Jensen *et al.,* 1990; Sturock *et al.,* 1992; Rosenberry *et al.,* 2007). However, extensive data and instrumentation requirements, associated costs and the requirement of precision in data, often limit their use. In such cases, the combination methods, typified by the Penman model, are used as the standard method for estimation of evaporation. The Penman combination method is a universally accepted method. It is based on the sound combination of the principles of mass and energy transfer. Estimates obtained from the Penman method have been found to agree closely with the energy budget values (Winter *et al.,* 1995; Rosenberry *et al.,* 2007). Moreover, the data requirement of the Penman method is also relatively easily met than the energy balance methods, as it uses the routinely observed meteorological data. Penman-Monteith (Allen *et al.,* 1998) method has been suggested by FAO as the standard method for reference evaporation and evapo-transpiration.

The present investigations have been carried out for Sukhna Lake located in Chandigarh, India. It is a very popular destination in the region for tourism and recreation. It also has high ecological value due to its biodiversity. However, in recent years the lake is facing the problem of declining water availability. So, the study has been undertaken with the objective of estimating evaporation losses from the lake and to assess its significance in the total losses from the lake.

EXPERIMENTAL

Sukhna Lake is an important lake of Chandigarh region in India. It is situated between 30°44'53.76"N to 30°44'5.63"N latitudes and 76°48'36.53"E to 76°49'55.86"E longitudes at an elevation of 350 m amsl. It is a manmade lake constructed in the year 1958. The capacity of the lake is 537.84 Ham. The maximum water spread area is 160.84 Ha. The maximum depth of the lake is 5.5 m and the average depth is 3.3 m. The lake has a catchment area of 42.14 Sq. Km. The maximum length of the lake is 2.32 km and its maximum width is 1.06 km. Tourism and recreation are important activities associated with the lake. The lake also serves as a sanctuary for a large number of birds. As such, availability of water is an important aspect of the lake. The lake is rainfed. Two major ephemeral streams, locally called Choe, namely Kansal and Saketri, join to form the Sukhna choe which drains into the lake. Figure 1 presents the map of the study area.

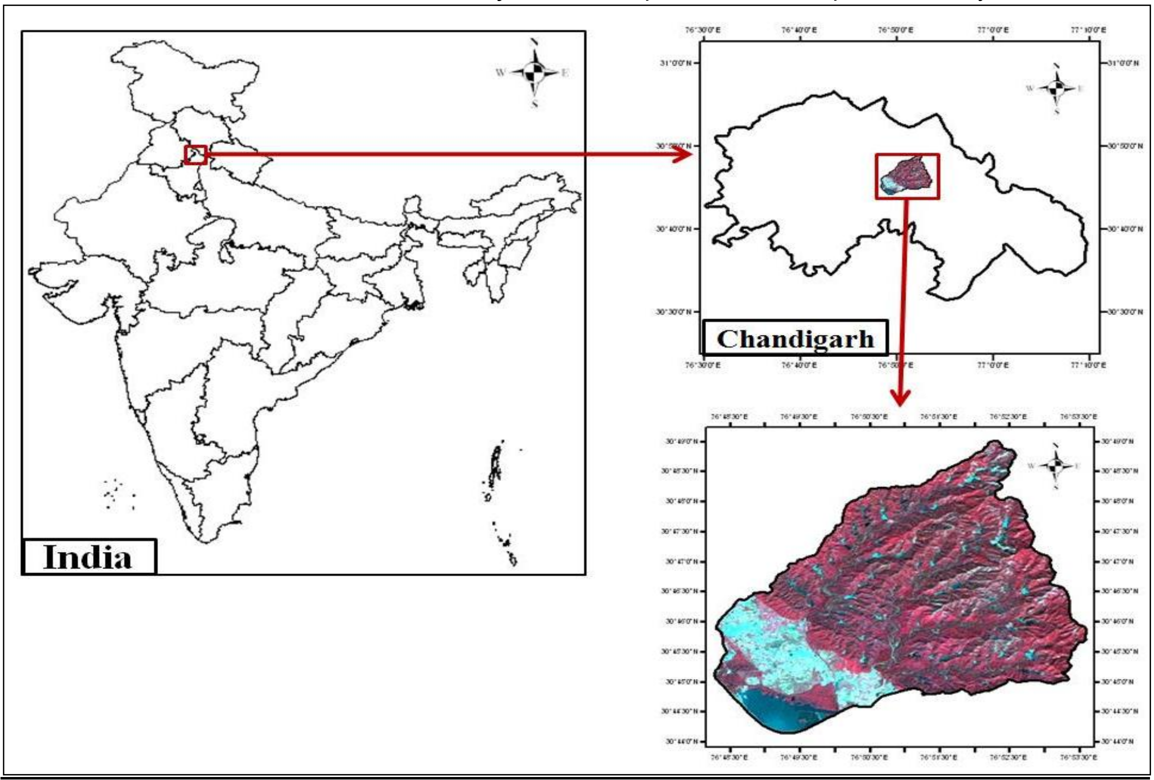

Figure 1. Map of the study area showing the Lake and its catchment

The study area has a humid subtropical climate with four distinct seasons. Summer is from about mid-March to mid-June which is followed by monsoon season that lasts upto mid-September. Mid-September to mid-November is the post monsoon autumn/transition season. The winter season is from mid-November to mid-March. Average annual rainfall is 1121.6 mm of which about 80% rainfall occurs in the three monsoon months of July to September (Agnihotri *et al.,* 2006). May and June are the hottest months of the year with temperatures going to about 40^0 C and above. January is the coldest month with minimum temperatures generally going down to about 3^0C and sometimes even below. Winds are generally light.

For the purpose of the present study, since data availability does not permit the use of energy balance method, so Penman-Monteith method has been used for estimating evaporation rates from Sukhna Lake. The daily reference evaporation obtained by this method has been considered as the actual lake evaporation. The Penman-Monteith Penman combination equation as per Allen *et al.,* 1998 is:

$$ET_o = \frac{0.408\Delta(R_n - G) + \gamma \frac{900}{T_a + 273} U_2 (e_s - e_a)}{\Delta + \gamma(1 + 0.34U_2)}$$

Where,

ET_o = Lake evaporation [mm/d];
R_n = Net radiation [MJ/m²/d];
G = Heat flux density [MJ/m²/d];
U_2 = Wind speed measured at 2m above ground [m/s];
e_s = Saturated vapour pressure at air temperature [kPa];
e_a = Actual vapour pressure at air temperature [kPa];
Δ = Slope of Saturation vapour–pressure-temperature curve [kPa/^{0}C];
Υ = Psychrometric constant [kPa/^{0}C];

While calculating evaporation using the above equation, the term G has been neglected because it is negligibly small for a shorter time scale of a day or less. Other parameters required have been estimated using standard methods. Mean saturated vapour pressure is calculated as average of saturated vapour pressure from maximum and minimum temperatures, as per Allen *et al.,* 1998. The saturation vapour pressure (e_s, which is a function of temperature is estimated as per Shuttleworth, 1993. Slope of the saturation vapour pressure curve (Δ) has been calculated from mean air temperature as per Allen *et al.,* 1998. The psychometric constant (γ) has been calculated as per Nokes, 1995. The latent heat of vapourization (λ) has been calculated from the air temperature as per Nokes, 1995. Net radiation, R_n, is calculated as per Allen et al (1998) as:

$$R_n = R_{ns} - R_{nl}$$

Where,

R_n = Net radiation [MJ/m²/d];
R_{ns} = Net shortwave radiation [MJ/m²/d];
R_{nl} = Net long-wave radiation [MJ/m²/d]

The net shortwave radiation (R_{ns}) data have been obtained from the radiation sensors of the AWS. The net long-wave radiation (R_{nl}) has been calculated as per Allen *et al.,* 1998 as:

$$R_{nl} = \sigma * \left[\frac{T_{max,K}{}^4 + T_{min,K}{}^4}{2}\right] * \left(0.34 - 0.14\sqrt{e_a}\right) * \left(1.35 * \frac{R_s}{R_{so}} - 0.35\right)$$

Where,

R_{nl} = Net long-wave radiation [MJ/m²/d];
Σ = Stefan-Boltzmann constant [=4.903*10⁻⁹ MJ/K⁴/m²/d];
T_{max},k = Maximum absolute temperature during the 24hr [=⁰C+273.16];
T_{min},k = Minimum temperature during the 24-hour period [=⁰C+273.16];
e_a = Actual vapour pressure [kPa];
R_s = Solar radiation [MJ/m²/d];
R_{so}= Clear sky radiation [MJ/m²/d];
R_s/R_{so} = Relative shortwave radiation [limited to $\leq$ 1.0]
R_{so} has been calculated as per Allen *et al.,* 1998.

Evaporation rates have been obtained for daily data using the Penman-Monteith equation stated above and the monthly evaporation averages have been obtained by taking average of all the daily values of that month. The evaporation rates themselves do not give the volumes of water lost from the lake during a specific period. This can be obtained by multiplying the evaporation rate with the surface area (water spread area) of the lake. For the study, daily evaporation rates were applied to corresponding daily surface areas (derived from daily water levels in the lake) to get the daily volume of water lost from the lake. The daily water losses were added to get the total for a particular month. Relative contribution of evaporation losses in the total water loss from the lake has been studied based on the water balance of the lake. As far as water balance of Sukhna lake is concerned, the various losses from the lake include outflow or overflow from the lake, water being lost through the processes of evaporation and seepage and, water being withdrawn from the lake for irrigating the gardens by the horticulture department and for cleaning/washing of the floor around the boating area. During the study period the sluice gates were not opened so there was no outflow. Also, there was no overflow from the lake. According to the information provided by the Engineering Department, Chandigarh Administration, the pumping losses are negligibly small. Based on the water balance of the post-monsoon months, the average values of pumping losses were found to be about 2-3 Ham per month. Since water being used for cleaning the floors etc near the boating area is expected to be relatively less than the water being pumped for irrigating the gardens, it has been assumed that of the total average 2-3 Ham of water being pumped from the lake every month, about 0.5 Ham is being used for cleaning purpose and rest (1.5 to 2.5) is being used for irrigation.

Analysis of historical water levels and studies on water balance carried out by NIH (Khobragade *et al.,* 2013) indicates that there are significant seepage losses at higher water levels and negligibly small seepage losses below 351.74 m elevation level. Seepage rates at different water levels in the lake were determined based on the water balance of the post monsoon period. During this period, since there is no inflow to the lake, outflow equals the change in storage. The change in storage was determined from the storage capacity curve available for the lake which gives lake storage at different water levels. The depth area capacity curve prepared from bathymetric survey data of IARI (2010, 2012 and 2013) was used. As change in storage as well as other terms of outflow namely evaporation and withdrawal losses are known, so the only unknown to be determined is seepage losses.

Accordingly, seepage rates were determined for different water levels in the lake. Using the seepage rates at different water levels so obtained, total seepage losses from the lake during a specific month were estimated based on the water levels of the lake. Daily water levels of the lake were monitored.

For estimating evaporation from the lake using Penman-Monteith equation above, various meteorological data are required. Since no meteorological data were available for the lake catchment, an automatic weather station was installed in the catchment and daily data on maximum temperature, minimum temperature, maximum relative humidity, minimum relative humidity, wind velocity, atmospheric pressure and radiation were generated. The periods during which any sensor was not working and there were data gaps, the same were filled with data obtained from the meteorological observatory of the Central Soil Conservation Research and Training Institute, Chandigarh located at a distance of about 2 km from the lake. To reduce the variability in the data of the two stations, the data used for filling the gaps was suitably modified based on the comparative analysis of the two datasets and applying a suitable coefficient which was derived using a one parameter optimization model. Daily data of different parameters were collected for the period from July, 2011 to October, 2013.

RESULTS AND DISCUSSION

Climatic variation during the study period

In order to understand variations in evaporation rates in different months and seasons, it is necessary to understand the corresponding variations in the meteorological parameters. During the study period (July 2011-October, 2013), the average maximum temperature was highest for May with a value of 39.3^{0}C and average minimum was observed during January (17.7^{0}C). The minimum temperature, on an average was highest during July (23.6^{0}C) and minimum during January (3.7^{0}C). Average maximum relative humidity was highest during January (91.21%) and minimum during the month of May (41.97%) while average minimum relative humidity was highest during August (73.68%) and minimum during the month of May (23.05%). The average maximum sunshine hours was highest for May with 8.57 hours and average minimum was observed during August (4.13 hours).The average wind velocity was 2.42 m/s during the whole study period of July 2011 to October 2013 with average maximum in the month of June (3.65 m/s) and average minimum during September (1.49 m/s). Net radiation, which reflects the amount of energy available for evaporation, was in general, higher during the warmer months and lower during the cooler months. The average was found to be highest for the month of May (15.26 MJ/m^2/d) and lowest for the month of December (4.87 MJ/m^2/d).

Evaporation Losses from the Lake

The total daily variation in lake evaporation rates for the study period of July, 2011 to October, 2013 is shown in Figure 2. It can be seen that during 2011 after the monsoon is over by September, the evaporation rates start increasing from 1st of October to about mid of October. A similar increasing trend is, however, not observed during 2013. During 2012 the increase is only during the first week of October. A steady decline in the lake evaporation hereafter is observed till end of January in all the years. Evaporation then starts increasing from February and continues to increase till May end. During the monsoon period of July to September the daily evaporation rates remain highly variable on day to day basis due to corresponding variations in the other meteorological parameters such as net radiation and vapour pressure deficit. As far as the increase in evaporation during the first half of October during 2011 and 2012 is concerned, this is mainly due to the increased values of vapour pressure deficit in this period compared to the values during September. The steady fall in evaporation rates from mid-October to January end can be mainly attributed to the decreasing values of radiation, temperatures as well as vapour pressure deficit. Rise in their values from February onwards causes a steady increase in the lake evaporation till May and June. Correlation analysis between daily evaporation and daily values of different meteorological parameters indicates that evaporation has a highest correlation with vapour pressure deficit (r=0.91) followed by net shortwave radiation (r=0.82), and, net radiation and maximum temperature (r=0.79). A high correlation is also observed with maximum humidity. However, the correlation is negative (r=-0.77). Other parameters such as minimum temperature (r=0.45), minimum humidity (r=-0.57), wind speed (r=0.52), sunshine hours (r=0.49) and net longwave radiation (r= 0.39) show a relatively lower correlation. The average monthly rates of evaporation for different months are shown in Figure 3. As can be seen from the figure, highest evaporation rates are generally observed in the summer months of May and June while lower rates are observed in cooler months of winter. During the study period highest average evaporation rate of 10.21 mm/d was recorded for the month of June, 2012. During the year 2013 it was recorded for May (9.41 mm/d).

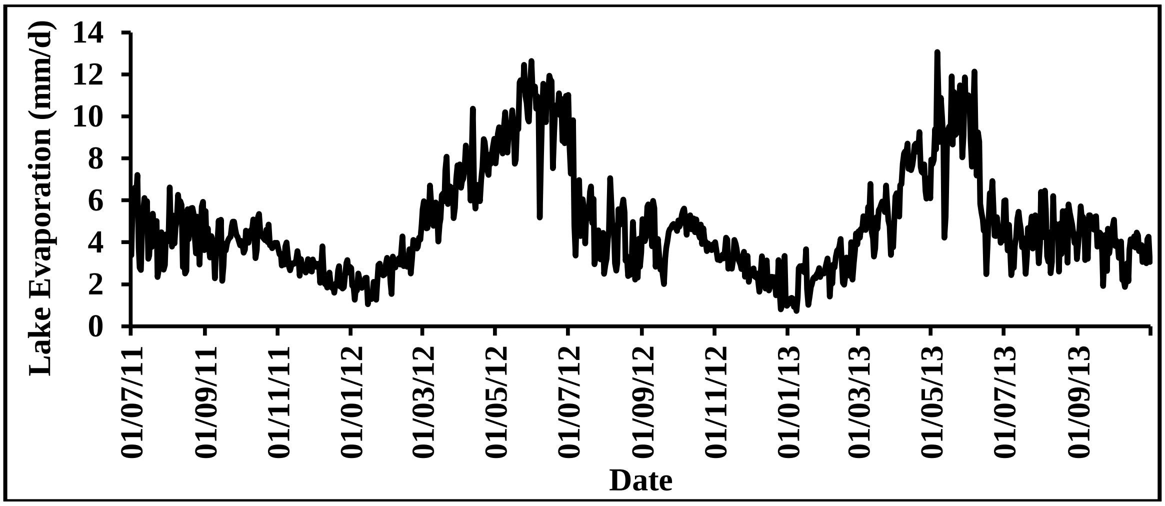

Figure 2. Variation of Daily Evaporation from Sukhna Lake during Study Period

The lowest rate was observed for the month of January. It was 2.03mm/d for 2013 and 2.10 mm/d for 2012. The month of December also exhibited lower evaporation rates. It was 2.15 and 2.41 mm/d for the year 2012 and 2011 respectively. The monsoon months showed significant variations during different years. Variation in evaporation rates of different months during a year as well as between the same months of the different years from 2011 to 2013 was obviously due to corresponding variation in other meteorological parameters as mentioned earlier. The total volume of water lost through the process of evaporation from the lake during different months of the study period is presented in Figure 4. It varied from low losses of 8.87 Ham in January 2012 to high losses of 40.93 Ham during May 2013. Higher losses of water were reported for the warmer months of summer and lower losses were observed for the cooler months of winter. The volume of water loss not only depends on the rate of evaporation but also on the water availability in the lake which determines the water spread area of the lake from which the evaporation occurs. It is for this reason that the losses are significantly different in the various months of the three years. The water availability in the lake during a particular period depends not only on the inflow of water received by the lake during that period but also on the water level of the lake (already available water) in the lake. The water availability in the lake was different at the end of the summer and onset of monsoon in each year. This was affected by the amount of rainfall and subsequent inflow to the lake during the month of June. The amount of rain received during June was different in different years. It was 96.9 mm, 0 mm and 354.7 mm respectively during 2011, 2012 and 2013. Thus, the lake water level was at 351.75 m elevation on 1stJuly, 2011, 350.82 m elevation on 1stJuly, 2012 and 352.81 m elevation on 1stJuly, 2013. The rainfall received in the lake catchment during 1stJuly-30th September during 2011, 2012 and 2013 was 644.2 mm, 849.1 mm and 541.7 mm respectively. The lake water level reached at the end of September (30th September) was, therefore, different in different years. It was at 352.46 m elevation during 2011, 354.04 m elevation during 2012 and 353.83 m elevation during 2013. The combined effect of variation in water spread area and evaporation rate in different months caused variation in the amount of water lost through evaporation in different months. Thus, for example, the evaporation loss for June was similar for the two years of 2012 and 2013 at 25.61 ham and 26.30 ham respectively, although the evaporation rates for these months were significantly different at 10.21 mm/d and 6.42 mm/d respectively. This is because the average water level of June was much higher for 2013 (352.46 m amsl) compared to 2012 (350.95 m amsl). During 2012 the evaporation rate for the month of April was 7.53 mm/d and the evaporation loss was 29.49 Ham. This loss was less compared to the loss of 31.65 Ham for the same month during 2013 though the evaporation rate was higher compared to the rate of April 2013 which was 7.42 mm/d. This is because the average water level during April, 2013 was higher (352.53 m amsl) than April, 2012 (351.45).

Relative Contribution of Evaporation in Total Losses

Contribution of evaporation in total water losses from the lake has been analysed. The results are presented in Figure 5. It can be seen from Figure 5 that the contribution of evaporation losses to total losses in different months is comparatively much higher during July 2011 to June, 2012 than the corresponding months of the period of July 2012 to June, 2013. This is because the total rainfall received during July,2011-June, 2012 was 727.6 mm which was very much deficit compared to the higher rainfall of 1276.3 mm received during July, 2012 to June, 2013 which was more than normal. This caused lesser inflow of water to the lake during 2011-12 compared to 2012-13. During 2011-12 the water level was above the critical mark of 351.74 m amsl for a relatively shorter duration than in 2012-13. So the contribution of seepage was much higher in 2012-13 than in 2011-12 where losses mostly were contributed by evaporation.

It may, however, be noted here that the contribution depends on other corresponding contribution from other losses. The losses are as high as about 95% during 2012 summer with values of 94.26 %, 95.16% and 93.95% respectively for March, April and May. The contribution during the summer of 2013 is, though high, is comparatively lower with values of 74.35%, 79.66% and 91.92 % respectively for March, April and May, 2013. This is because contribution of seepage was higher in these months during 2013 than in 2012. While the seepage was 6.2 Ham for March, 6.6 Ham for April and 1.1 Ham during, 2013, there were no seepage losses in these months during 2011-12, as the water levels in the lake were much below the critical level above which seepage occurs. Relative losses of evaporation volumes during monsoon and post-monsoon months have been compared and are presented in Figures 6 and 7 respectively. It can be seen that evaporation losses were in the range of 81-88% during monsoon of 2011 and 2012 where as during the monsoon of 2013 the losses were 48% of the total losses from the lake (Figure 6). The higher contribution of evaporation losses in total losses during the year 2011 and 2012 compared to the year 2013 can be explained based on the water levels reached by the lake during the monsoon seasons of the three years, as explained previously. As far as post monsoon season is concerned, the data are available for 2011-12 and 2012-13 (Figure 7). It can be seen from Figure 7 that the total evaporation losses were 83% of the total losses and they were about 55% of the total losses during 2012-13. This is because at the end of monsoon 2011 i.e. on 1st October 2011, the lake water level reached was 352.46 m amsl. At this level the seepage rates are lower (0.22 ham/d) so the amount of water lost through seepage are also lower. Therefore, the losses during the post monsoon season of 2011-12 were dominated by evaporation with little share of 10 % from seepage. As far as 2012-13 is concerned, the water level reached at the end of monsoon was much higher compared to

2011-12. It was 354.04 m amsl on 1st October, 2012. At this level the seepage rates are higher (1.84 ham/d) so the amount of water lost through seepage are also higher (41%) compared to 2011-12, reducing the relative contribution of evaporation in the total losses from the lake to about 55%.

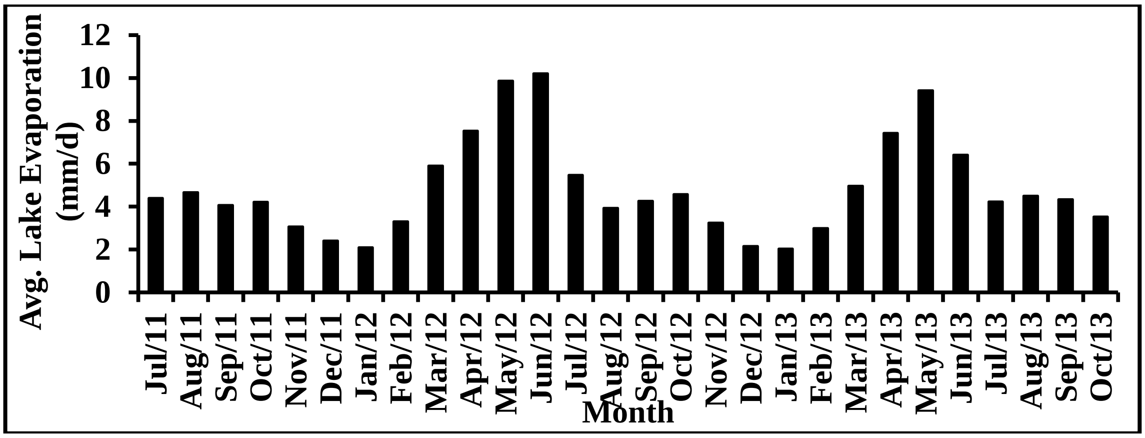

Figure 3. Average Monthly Rates of Lake Evaporation During Study Period

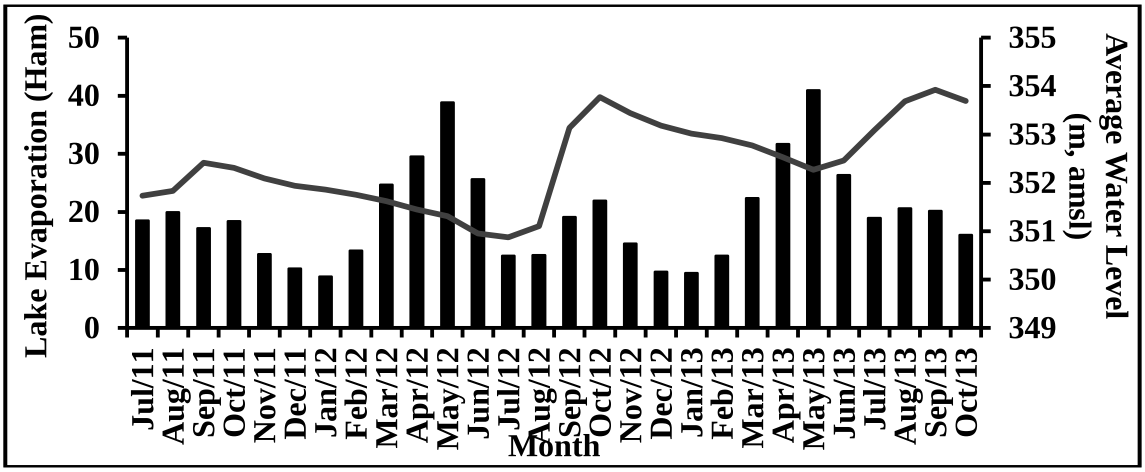

Figure 4. Volume of Water lost through Evaporation from the Lake during Study Period

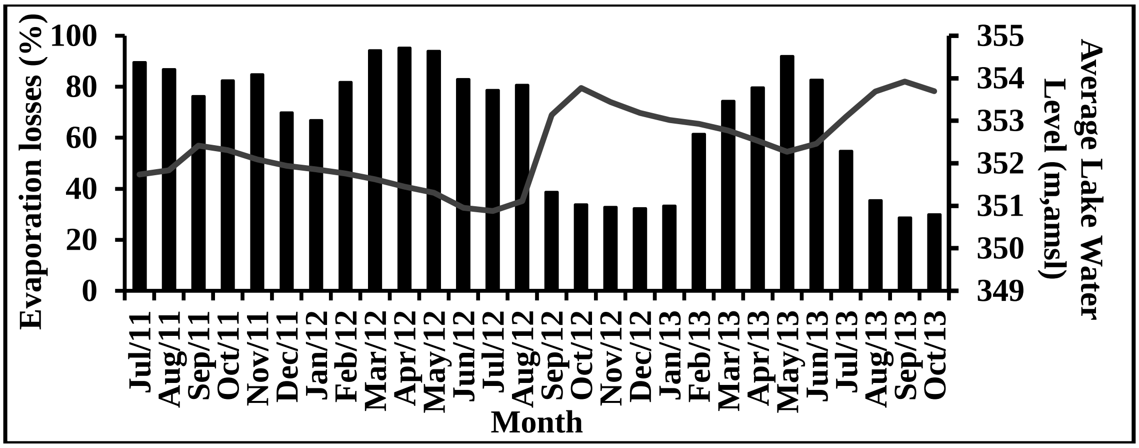

Figure 5. Evaporation Losses as Percentage of Total Losses from the Lake

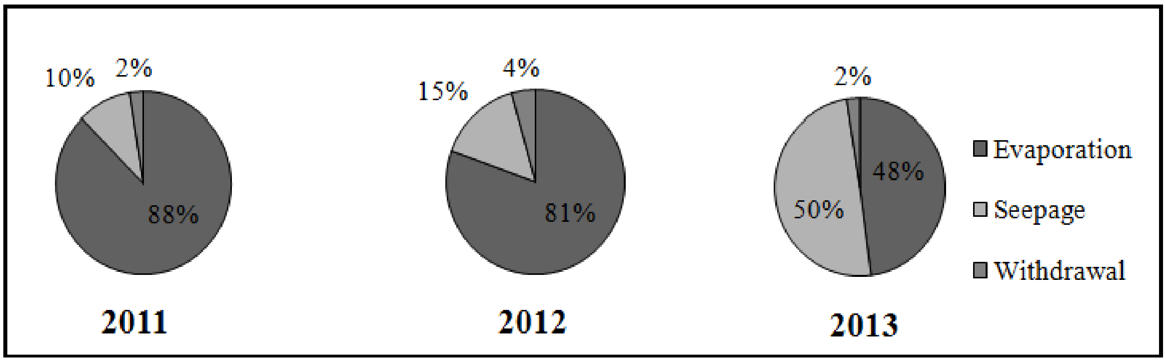

Figure 6. Relative Contribution of Various Losses during Monsoon Season

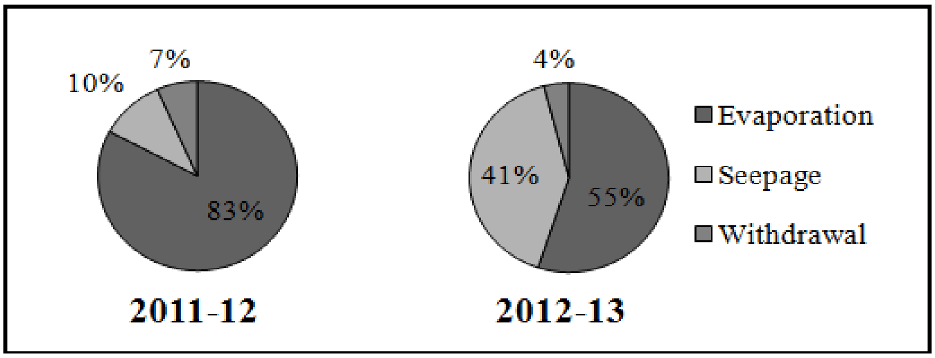

Figure 7. Relative Contribution of Various Losses during Post-monsoon Season

Comparison with other studies

No evaporation studies have been reported for Sukhna lake previously. A number of studies on different lakes of the world have, however, been reported. However, most of these studies deal with development or validation of the various evaporation models or their inter-comparison. A few studies discuss the relative contribution of evaporation in overall water budget of the lake. Since different lakes have different climatic and hydro-geologic setting as well as morphometry, the relative contribution of evaporation in different lakes is bound to be different. Nachiappan and Kumar, 2002 observed evaporation losses to be 11.1 to 12.5% of the total losses from Lake Nainital in India. Sahoo *et al.,* 2013 gave a figure of 70% for Lake Tahoe in USA. Schwerdtfeger *et al.,* 2014 from their studies on six lakes in Pantnal, Brazil observed the evaporation losses to be in the range of 23.1% to 36.6% of the total losses while they were in the range of 11.6% to 42.8% for the 17 lakes in China, as reported by Qian *et al.,* 2014. The relatively low contribution of evaporation in total losses from Nainital Lake compared to the other lakes above is obviously because a significant portion of total losses amounting to about 50% is being lost through seepage and ground water outflow and about 35% is being lost through withdrawal, as reported by Nachiappan and Kumar, 2002.

Evaporation losses from tropical lakes are generally higher. Ressule and Johnson, 2006 observed that the losses were 54% for Lake Edward in Uganda-Congo. Deganovski and Brook, 2008 from their studies on four lakes in Ethiopia observed the evaporation losses to vary from 58.5%-100% of the total losses. Delclaux *et al.,* 2007 gave a figure of 90% for Lake Titicaca in Africa. Earlier, Coulomb *et al.,* 2001 observed that the evaporation contribution in total losses from Lake Ziway in Ethopia was 89.7%. In the present studies evaporation contribution of about 90% or more in total water losses were observed for the summer months of 2012 and May, 2013, when the climatic conditions are very warm and dry. It may be observed that evaporation losses in Tana lake and Lake Edward are much lower Compared to the Lake Ziway and Titicaca, although they are located in similar climatic settings. This is obviously because a significant amount in Lake Tana is also being lost through ground water outflow and withdrawal, like in Lake Nainital. For the same reason, evaporation losses from the lake Tahoe, Brazil lakes and China lakes are also lower. In Sukhna Lake also when the seepage losses are significant, the evaporation contribution is drastically reduced, for example, during monsoon 2013 and post monsoon period of 2012-13, as discussed earlier. Furthermore, in Sukhna lake highest evaporation rates were observed in the deficit rainfall year of 2011-12 compared to the normal rainfall year of 2012-13. A similar observation has also been made by Gibson and Reid, 2014. Qian *et al.,* 2014 have also observed that evaporation is extreme under dry conditions

Evaporation can also be estimated as percentage of total inflow to the lake. Nachiappan and Kumar, 2002, observed evaporation losses to be 10.99% to 12.62% of total inflow to Lake Nainital. Sahoo *et al.,* 2013 gave a figure of 70% for Lake Tahoe in USA. Deganovski and Brook, 2008 found it to vary from 58.5%-93.9%. Gibson and Reid, 2014 from their studies on a chain of tundra lakes in Canada, gave a range of 26-32% of the total inflow to the lakes, and 72-100% for the ponds. Schwerdtfeger *et al.,* 2014, observed the evaporation losses to be in the range of 30% to 57.1% that of the total inflow to the lake. Dessie *et al.,* 2015 observed the evaporation contribution to be 51.7% of the total inflow of water for Lake Tana in Ethiopia. The variation in relative contribution of evaporation in total inflow for the different lakes is obviously because of the variation in the amount of runoff received from the lake catchments which is different for different lakes owing to the variation in the size of lake catchments. It also depends upon the precipitation directly falling on the lake surface and the surface area of the lake. As far as present study is concerned, the evaporation losses were observed to be 28.5% of the total inflow during 2012-13 and 29.8% during July-October, 2013. However, they were as high as 90.6% during 2011-12, obviously because 2011-12 was a deficit rainfall year and the total inflow to the lake was very less compared to 2012-13.

CONCLUSION

In the present study, evaporation losses and their relative significance in the overall water budget of Sukhna Lake at Chandigarh in India have been studied for the period of July 2011 to October, 2013. The average monthly evaporation rate as well as the volume of water lost through evaporation is found to vary from month to month and is also found to be different for the same months during different years. The evaporation rate is higher in warmer months of summer and lower in cooler winter months. Evaporation rate is found to have highest correlation with vapour pressure deficit followed by net shortwave radiation, net radiation, maximum temperature, and maximum humidity. The evaporation volume is found to depend not only on the rate of evaporation but also on the water availability in the lake which determines the water spread area of the lake. The relative contribution of evaporation losses in total losses from the lake in different months is found to be different. It depends on the relative contribution from other losses, mainly seepage, which depends on the water availability in the lake above the critical mark of 351.74 m above mean sea level, below which the seepage losses are negligibly small. The evaporation losses could be as high as about 95% in summer months of deficit rainfall years or could be 55%, if there is adequate water available in the lake. In general, the study concludes that evaporation losses are significant in a deficit rainfall year and is a deciding factor in total water losses from the lake during such deficit year. However, its relative contribution is significantly reduced due to seepage losses in a normal rainfall year.

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