

Draft Final Report

# WATER AVAILABILITY STUDIES OF SUKHNA LAKE, CHANDIGARH



Prepared by:  
**Dr. Suhas Khobragade,**  
Scientist E & Principal Investigator



**NATIONAL INSTITUTE OF HYDROLOGY  
ROORKEE- 247667 (UTTARAKHAND)**

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<b>Director</b>	<b>Sh. R. D. Singh</b>
<b>Division</b>	<b>Hydrological Investigations Division</b>
<b>Divisional Head</b>	<b>Mr. C. P. Kumar, Scientist-F</b>

**STUDY TEAM**

<b>Principal Investigator</b>	<b>Dr. Suhas Khobragade, Scientist-E</b>
<b>Other members of Study Team</b>	<b>C. P. Kumar, Sc- F &amp; Head, HID Sudhir Kumar, Sc-G, HID A. R. Senthil Kumar, Sc-D, HID P. K. Garg, Sc-B, HID V. K. Agarwal, SRA, HID Satyaprakash, MTS (T), HID</b>

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## 1.0 INTRODUCTION

Hydrologic characteristics of different lakes vary considerably because of differences in the depth, length, width, surface area, shape, basin material, climate, nature of inflows and outflows, and other factors. Lakes may have some common features but often exhibit strikingly different performance characteristics. This individuality has environmental values and as such, it presents the problem of having to understand variations due to local conditions in the backdrop of the general nature of the Lake System. This means that each lake requires its own investigation and evaluation as well as, its own hydrologic model.

Socio-economically, lakes are valuable natural resources. They are being used as natural centres of civilization and to cater the civilian needs, from time immemorial. They serve variety of purposes like domestic purposes, drinking water, irrigation, commercial purposes, aqua-culture, recreation, transport etc. However, this popularity of theirs often becomes the cause of their deterioration resulting into qualitative and quantitative degradation, reflected through problems like decreasing water availability, sedimentation or eutrophication, which could be due to natural or manmade reasons or both. In many cases the situation is further aggravated due to unscientific management. However, with ever increasing demand of freshwater for variety of purposes, conservation and management of lakes, both in terms of quantity and quality, has assumed great significance in India, particularly in the last couple of decades. Sincere efforts are now being made at various levels by the managing authorities to conserve the lake water resources for the socio-economic benefit of the society.

Sukhna Lake is a very significant lake of Chandigarh, because of being an important tourist attraction and centre of recreation. As such, the lake also has some contribution to the economy of the region. However, the lake is in limelight in recent times for intermittent water scarcity problems. During the year 2011-2012, the lake faced an acute problem of water availability. The water level in the lake continued to go down after the monsoon so much that the lake almost dried at the end of summer in 2012. Although the normal annual rainfall for Chandigarh is about 1120 mm, some of the years like year 2011 are deficit rainfall years. These deficit years get rainfall much lower than the normal. There are spatial variations also, as discussed earlier. During the year 2011, the total rainfall at the lake site during July to September, 2011 was 708.02 mm but average rainfall for the catchment, obtained from six rain gauge stations for the same period was 643.9 mm. As such, hardly any significant runoff contributed to the lake.

Although some scientific investigations on ecological aspects and siltation have been reported for the lake in past, there are only some scattered studies on other aspects. No systematic investigations on the various hydrological processes and hydrological behaviour of the lake have been reported for the lake till recently when a systematic and detailed scientific investigation was carried out by the National Institute of Hydrology, Roorkee during 2011-2013. However, as an outcome of the investigations it was thought necessary to further extend the study as phase to from the Internal Funding of the Institute, as some of the aspects needed further detailed investigations. The present study has therefore been proposed by the Institute.

## 2.0 REVIEW OF EARLIER WORKS

A number of studies have been reported on Sukhna Lake. Murthy and Shakaranarayana (1977) prepared the soil map of the Sukhna Lake catchment. Choudhary and Chandra (1982) studied the textural characteristics of the Sukhna Lake sediments. Some studies have been reported related to sedimentation in Sukhna Lake. These include studies by Bansal and Mishra (1982), Bansal and Grewal (1986), Bansal and Grewal (1990), CSWCR & TI (1993) etc. The Irrigation and Power Research Institute (IPRI), Amritsar has been carrying out regular bathymetric surveys of the lake and submitting a report to the Engineering Department, Chandigarh Administration. Shrimali et al. (2001) conducted studies for the delineation and prioritization of erosion-prone areas of Sukhna Lake catchment. Water quality of the lake has been reported by various investigators. The earliest reported study on water quality is by Jindal et al. (1995). Johal (2006) have studied the water quality of Sukhna Lake to investigate the relationship of biodiversity with the physico-chemical parameters of the lake. Central Pollution Control Board (2008) has reported the water quality of the Sukhna Lake for the year 2008. Sharma et al. (2010) studied the water quality of Sukhna Lake with emphasis on the bacteriological characteristics. Tyor and Chawla (2012) have reported the water quality of the lake for the study period of April 2009 to September 2009. CPCC, Chandigarh (2012) has also been carrying out regular monitoring of the water quality of the lake. Aspects of fisheries have also been studied and reported for the lake. Johal and Tandon (1983) determined the age of *catla* and *mrigal* fishes for prescribing an age-limit for their capture in the Sukhna Lake. Tandon and Johal (1983) studied the age and growth of minor carp *Puntius Sarana* (ham.) from Sukhna Lake. Tandon and Johal (1995) have reported their investigations on fisheries of Sukhna Lake. Jindal et al. (1995) have reported the studies on the birds of Sukhna Lake. Jindal et al. (1995) also studied the plankton of the Sukhna Lake. Johal (2006) have studied the aquatic biodiversity of Sukhna Lake. Tyor and Chawla (2012) have recently studied the phytoplankton composition of the lake. Singh (2002) has provided a chronology of the historical events/different activities carried out for checking the sedimentation of the lake till 1990. However, the review brings out that very few hydrological studies have been reported for Sukhna Lake, until comprehensive hydrological investigations were carried out by NIH under a consultancy project during 2011-13. Mishra et al. (1975) is known to have undertaken studies on water yields from the catchment, along with sediment yields, in the mid 1970's. Their work is presently not available with the authors for review or reference.

Shrimali (1999) (vide Grewal, 2009) conducted detailed studies on the rainfall-runoff modeling for Sukhna Lake catchment using RS and GIS. The runoff was estimated using SCS curve number method. Their results show that the lake catchment can generate runoff of about 20% of rainfall. He observed that the catchment can yield about 9.75 Mcum (975 ham) of water as runoff. He developed the following relationship for the event based rainfall-runoff:

$$Y = 0.0054 X^2 - 0.35 X + 5.7247 \quad (R^2 = 0.9413)$$

Where, Y = runoff from the catchment and X is rainfall

It has also been reported by Shrimali (1999) that 50 mm rainfall storms did not produce any runoff but a heavy storm of 180 mm produced 110 mm or 61% runoff. Shrimali

(1999, 2001) has also determined the runoff potential of the different sub-catchments of the lake catchment (Table 1). 74 % of the catchment area is reported to have moderate runoff potential.

**Table 1: Runoff Potential areas in the sub-catchment of Sukhna Lake**  
(after Shrimali et al., 2001)

Soil .N.	Runoff Potential	Area (Ha)				Total
		Subcatchments				
		Kansal	Nepli	Ghareri	Foothill villages	
1	Low	5	18	7	69	100
2	Moderate	1073	1323	507	269	3171
3	High	33	49	11	338	432
4	Very High	92	95	35	336	558
Total		1204	1485	560	1012	4261

**Grewal (2009)** has carried investigations on the impact of soil conservation measures taken in the lake catchment on ground water, soil and geology of the catchment. He observed that the lake catchment is floating on water with round the year flow in main drainage lines and just meter deep water tables in many old wells in the catchment. However, the water is not able to reach the outer periphery of the catchment. He suggested removal of congestion in drainage lines whenever it occurs, for continuous flow. He further observed that in case of emergent situation, possibilities of releasing a part of stored water in relatively bigger reservoirs to the lake, may be explored.

**Grewal (2012)** carried out studies on the carrying capacity of the water bodies (check dams) in the catchment. He observed that there are 150 functional water bodies in the catchment of the Sukhna Lake with a total capacity of 254.23 Ham. Further he observed that out of the 150 water bodies, 28 (18.6 %) are totally silted up. 38 (25.3 %) water bodies have limited storage capacity and are likely to be silted up in 2-4 years. 36 water bodies (24 %) have moderate storage capacities of 1- 2 Ham. These would silt up in next 6-8 years. 20 water bodies have good storage capacities of 2-3 Ham. Their aggregate capacity is 47.73 Ham. These are not likely to be silted up in next 20-25 years. Remaining 28 water bodies have very good storage capacities (above 3 Ham). Their total storage capacity is 131.97 Ham. These are not likely to be silted up for the next 25-30 years. They observed that around 19% of runoff producing rainfall ends up as runoff during normal rainfall years. They have observed the average runoff coefficient for flood producing rainfall years as 0.11 to 0.15 in UT Forest area and 0.15 to 0.20 in Haryana Forest area and accordingly total runoff from the catchment can go up to 410 Ham.

**Khobragade et al. (2012)** predicted the possible impact of deficit rainfall during monsoon of 2011 on the water availability of Sukhna Lake during summers of 2012. The work was carried out on the request of the Chandigarh Administration under the consultancy project on Sukhna Lake. The analysis was carried out using the data of water levels of the lake and bathymetry data of the lake. Bathymetric map prepared by IPRI, Amritsar after the monsoon season of 2010 was used. Further, it was assumed that there is no or negligible non-monsoon rainfall during the prediction period. Based on the

results, by the end of May, 2012 about 73 % percent area was predicted to be dry which was further expected to increase to more than 90 % by the end of June, 2012. Further, it was stated that even if an error of 25% is assumed on account of various assumptions including those of the bathymetric survey, more than 70% percent of the lake area will go dry by June, 2012 end and activities such as boating would be badly affected in the summer of 2012. Field verification during the summer has confirmed that the predictions have been more or less correct except for the end of June 2012. The errors of June end were obviously because desilting of the lake was carried out during post monsoon of 2010 after the preparation of bathymetric map and because of this, the depth – capacity curve did not truly represent the actual, causing errors particularly for the lower parts of the capacity curve.

**Khobragade et al. (2013)** predicted water availability in the lake for at the end of summer, 2013, on the request of Chandigarh Administration. The analysis was carried out using daily water level and bathymetric data. Since inflow during post monsoon is generally negligible during post monsoon months so a simple water balance equating change in storage to total losses from the lake was assumed. The results of the analysis (Table 2) indicated that the lake will have water in about 80% of its area by June, 2013 and more than 70% of the lake area will have water all through the summer till the onset of monsoon and as such, the lake will not face the type of water scarcity problem during 2013 summer as it did during 2012 summer.

**Table 2: A comparison of the predicted and actual observed water levels of lake**

Date/Month	Predicted lake water level (m)	Actual observed lake water level (m)	Error of prediction (in cm of lake water level)
1-Mar, 2013	352.84	352.87	3
1-Apr, 2013	352.60	352.67	7
1-May, 2013	352.33	352.39	6
1-Jun, 2013	352.02	352.14	12

As observed from the table above, most of the predictions up to June, 2013 were more or less correct.

**Khobragade et al. (2013)** carried out an extensive study on the hydrological aspects of the lake. The work was carried out under the consultancy project sponsored by the Chandigarh Administration. Detailed hydrological investigations including water quality and sedimentation were carried out. Water availability related work included detailed studies on lake evaporation, ground water recharge and ground water – lake interaction, water balance, water management etc. Some of the important results related to water availability analysis obtained in the study are summarized below:

- (i) There is no definite pattern in the distribution of isotopic values in different waters in and around the Sukhna Lake. Most of the water bodies (such as open wells in the catchment, the lake, and the nearby tube wells) do not seem to be interconnected (except probably the Nepli and Ghareri wells which appear to

have same source of water). All the tube wells, however, appear to be interconnected, but it seems that probably none of them has any inter-connection with the Lake. No open well in the catchment seem to have any hydraulic connection with the Sukhna Lake.

- (ii) Higher evaporation losses of water were reported for the warmer months of summer and lower losses were observed for the cooler months of winter. During the study period of period of July, 2011 to June, 2013 the losses were maximum in June, 2012 with a total loss of 34.13 Ham and lowest in the month of January, 2013 with a total loss of 9.64 Ham.
- (iii) 10 years monthly meteorological data for period of 2000-2009 indicates that there is a decreasing trend in evaporation for the study area. The pan evaporation data of Chandigarh also show a decreasing trend for the region.
- (iv) Evaporation is observed to play a significant role in deciding the total volume of water lost through the lake causing significant decline in the lake water levels particularly during deficit rainfall year. The share of evaporation in total losses is generally more than 80-90 % during summer months and during the period when the lake water level is below the critical mark.
- (v) Rainfall data of 1958-2012 shows that there is no definite pattern in rainfall at Chandigarh but there are large variations from year to year. Although, there is temporal variation in rainfall, trend line, however, does not indicate any general falling trend in rainfall for Chandigarh region. However, there are certainly variations from year to year without any specific cyclic or periodic pattern.
- (vi) In general, the average per day fall in lake water levels is higher in those years when the post monsoon water level of the lake was at higher elevation. The losses are particularly high if the post monsoon level was at 1160 ft or above. The lake appears to behave uniquely at certain level. In general, fall in per day water level appears to be least at 1156.3 ft elevation (2006-07) and more above this level. Although further detailed investigations are needed to establish the fact as well as this critical level, it certainly appears that there are possibilities of more seepage losses from the lake above this critical level (of above 1156.3 ft amsl).
- (vii) Average rainfall of 1-10 mm in the catchment does not have any effect on water levels of the lake initially in July and early August. Its only when the requirements of the catchment (soil moisture, check dam etc) are more or less fulfilled, that it has some effect towards end of August and in September, that too if the spatial variation consists of any significant rainfall at any of the stations.
- (viii) Inflow (runoff) to the lake was of the order of about 1000-1100 Ham during the first decade after its construction. The runoff started declining during the 1970's because of the beginning of the construction of check dams. As the number of check dams increased, the inflow got decreased. However, there is an increase in total inflow to the lake in recent years (2010 and 2012) due to the increased runoff.
- (ix) The runoff coefficient has in general significantly decreased over the years. The runoff coefficient was 0.26 to 0.27 during 1958 to 1978. It has come down to 0.1 or below presently. Even during 2010 and 2012, when the runoff was of the order of above 400 Ham, the runoff coefficient has been 0.12 and 0.11 only.
- (x) In general, the lake can get adequate water in the normal rainfall year. The real trouble is when the rainfall is below normal. Since such deficit rainfall years occur

frequently, the lake is vulnerable to water scarcity problems during the deficit rainfall years.

Based on the detailed scientific investigations which also include analysis of check dams on the lake water availability and preparation of a management plan, a number of recommendations have been made in the study. Since prevention of seepage losses appear to be the key to solving the water scarcity problem of the lake as per the study, it has been specifically recommended by them that detailed investigations on seepage from the lake be undertaken.

### **3.0 OBJECTIVES**

As mentioned above, the present study has been undertaken as phase –II of the Sukhna Lake study carried out by NIH under the consultancy, as the study indicated the need for detailed investigations of aspects such as water balance and seepage. The study has been undertaken with the following objectives:

1. To study inflow regime of the lake
2. To study seepage losses from the lake
3. To analyze long term trends in rainfall and evaporation
4. To study water availability aspect of the lake

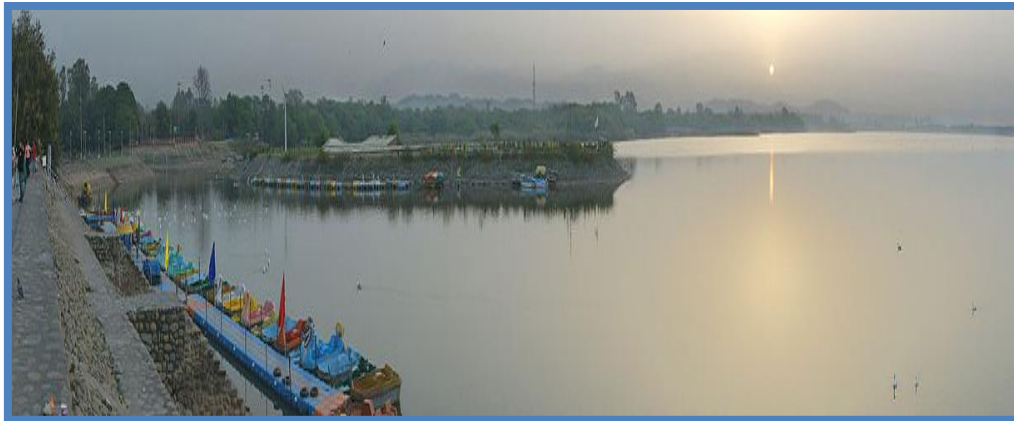
### **4.0 STUDY AREA**

Sukhna Lake is located in the Union Territory of Chandigarh in the foothills of Siwalik Hills. It is a manmade lake with its northern boundary adjoining the Siwalik Hills being natural and irregular. It was constructed in the year 1958 by constructing a 12.8 m high rock fill earthen dam across the Sukhna choe, which flows down from the Shivalik hills. According to IPRI (2011) the lake was constructed to meet the civic and aesthetic requirement of the city. The lake is surrounded by Kaimbwala village on the northern side, forest plantation and agricultural fields on the east and Boat club on the west. The dam is to the south. The three span spillway is located to the south eastern corner with crest at 349.91 m amsl. At the time of its construction the storage capacity of the lake was 10.74 MCM. As per the bathymetric survey carried out by IPRI after the flood season of 2010, the present storage capacity of the lake is 5.32 MCM (IPRI, 2013). After completion in 1958 the water spread area of the lake was 188 ha and the average depth was 4.69 m with deepest point at 343.2 m (1,126 ft) above msl (Singh, 2002). The surface area at the end of the flood season of 2012 was 166.235 Ha at 354.48 (1163 ft) elevation. The lake is rainfed. Two major ephemeral streams, Kansal and Saketri, locally called Choe, drain into the lake. The Nepli and Ghareri choe join to form the Saketri choe. The Kansal and Saketri join to form the Sukhna choe. The outflow from the lake is called the Sukhna choe.

With a beautiful surrounding and facilities for water sport activities and boating, the lake has become an important source of recreation and tourism. The lake also serves as a sanctuary for a large number of birds. So far, about 150 different species of birds have been reported from Sukhna Wetland Bird Sanctuary. About 30 species are residents and

the rest are migratory, mainly the winter migrants. Kansal Khol comprises the wild life sanctuary, where large deer (grey and brown) with massive antlers, spotted deer, jackal, Indian mongoose and wild cat etc can often be seen (Yadwinder Singh, 2002). The lake was notified as wetland of National Importance by Chandigarh Administration; vide notification dated 6<sup>th</sup> July, 1988 as it attracts large number of migratory birds. The lake has been notified by the National Wetland Committee, Ministry of Environment, Govt. of India for Conservation (Dept of Env., UT, Chandigarh).

Fig. 1 presents a view of the lake and Table 3 present the salient features of the lake.



**Fig. 1: A view of Sukhna Lake**

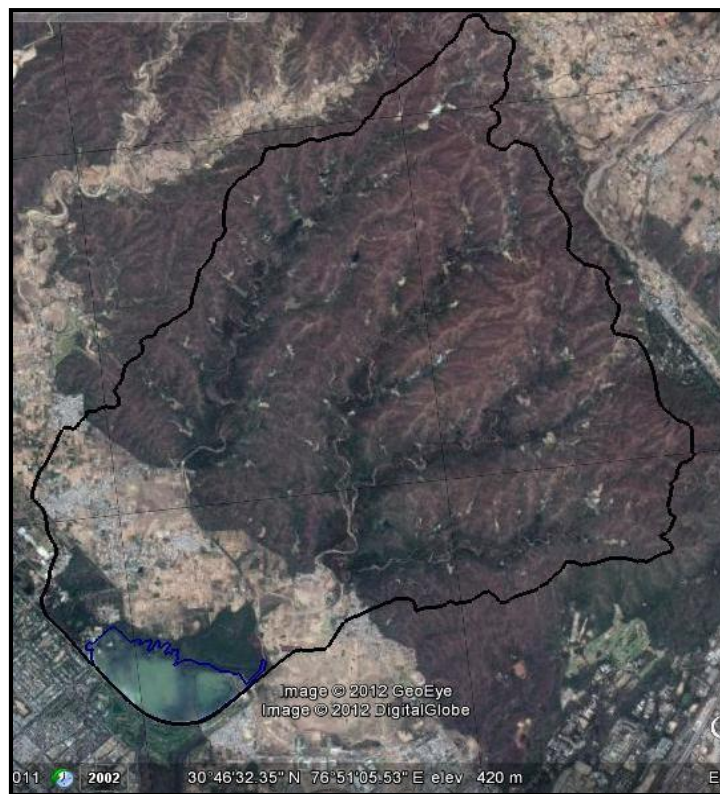
**Table 3: Salient features of Sukhna Lake, Chandigarh**

Parameter	Value
Latitude	30°44'8.5"N to 30°49'3.6"N
Longitude	76°48'16.8"E to 76°53'42.8"E
Altitude (m) amsl	349.15
Max. Surface Area (ha)	166.235
Max. Storage Capacity (ham)	532.083
Max. Depth (m)	5.33
Avg. depth (m)	3.2
Max. Lake Length (Km.)	2.32
Max. Lake Width (Km.)	1.06
Shore Line Length (Km.)	6.72
Water Use	Recreation, Tourism, Aquaculture

The catchment of the lake falls in the Ghaggar Basin. The catchment area is located in the foothills of the Shivalik hill ranges, which form part of the fragile Himalayan ecosystem, called Kandi (Bhabhar) region. The major land uses in the catchment area are forest and agriculture. The catchment area has rugged terrain with steep slopes. According to

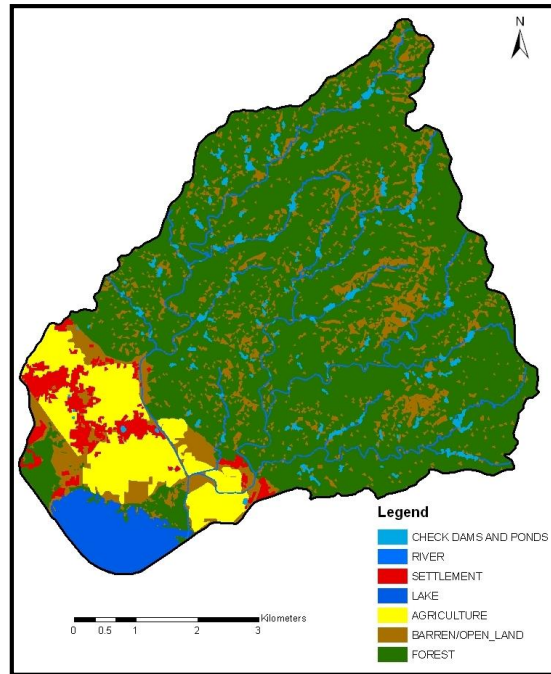
Yadwinder Singh (2002), out of the total catchment area, 76.4% lies in hilly forest catchment of Kansal, Nepali and Ghareri streams in the Siwaliks wherein the average slope is of  $30^{\circ}$ . The remaining 23.6% of Sukhna catchment (inclusive of the lake bed) extending from northern margin of the lake to the hills comprises of agricultural fields, the area under stream beds, pastures and forest area along with the lake on the slopes of the piedmont plain (Yadwinder Singh, 2002). The soils of the catchment are predominantly alluvial sandy embedded with layers of clay and are highly susceptible to soil erosion. The major rock types are clay stone, silt-stone, sand stone and conglomerate (Murthy and Shankaranarayana, 1977).

Fig. 2 presents a satellite view (Google earth) of the lake and its catchment.



**Fig. 2: A satellite view of the lake and its catchment**

The catchment area can be broadly classified into five major classes viz., forest, agriculture, barren/open land, check dams and ponds, and settlement. Fig. 3 presents the land use map of the study area. The major land use in the catchment area is Forest (32.32 sq. km area) which is about 76.44 % of the total catchment area followed by barren/open land and agriculture with 4.46 km<sup>2</sup> (10.58 %) and 3.6 km<sup>2</sup> (8.54%) area respectively.



**Fig. 3: Land Use/Land Cover map of the study area**

## 5.0 METHODOLOGY

For detailed analysis of the water availability problem of the lake, it is important to analyze the inflow (runoff) regime of the lake and rainfall-runoff relations for its catchment. Unfortunately, no discharge data are available for the lake except for a few references (for example, Grewal, 2009). The lake channel is highly erodible, so establishing a temporary discharge site is difficult. Moreover, even if a discharge site is established near the lake, the inflow channel gets filled with back water which makes it practically difficult to operate the site. If the site is located at a considerable distance upstream, then there are problems of safety. Because of these reasons, it was decided to estimate the runoff using the water balance method which is theoretically very sound, although there may be some errors involved. For lakes, which are not gauged, this is the soundest and practical approach. Using the water balance approach, runoff inflow of different years was estimated. The next section describes the water balance analysis for the lake.

### 5.1 General water balance of a lake

A simple water balance equation of a lake is:

$$\text{Inflow} - \text{Outflow} = \text{Change in lake storage}$$

The above water balance equation is based on the natural law of conservation of mass. It is applicable not only for any lake, but for any natural system. It is briefly explained here for easy understanding:

Assume that a certain amount of water is coming into the lake and a certain amount of water is going out of the lake during the same time period. Then, because of in-coming of water to the lake, the water level in the lake will increase and, because of the going out of water from the lake, the water level will come down. If during some specific period, say a day or a week or a month or a season or a year, the amount of water coming to the lake is equal to the amount of water going out of the lake, the net result will be “no change” in the lake water level or lake water storage. If the quantity of incoming water is more than the quantity of water going out, then the net result will be a rise in the lake level i.e. increase in storage of lake. Alternatively, if the quantity of water coming to the lake is less than the quantity of water going out of the lake, the lake water level will fall causing decrease in the lake water storage.

$$\text{Total Inflow} - \text{Total Outflow} = \text{Total change in storage}$$

The above water balance equation above involves three major terms:

- i) Inflow to the lake
- ii) Outflow from the lake
- iii) Change in storage of lake

The major factors which contribute to the lake inflow are runoff water from the catchment coming through the inflowing stream and the water which is falling directly on the lake as rainfall. There may be a third component which is the water coming as groundwater inflow, which is generally not very significant when compared to the first two components, unless a lake is a closed lake (i.e. without any inflowing river).

The major factors which contribute to the outflow are outflow through sluice gates or overflows from the lake, water being lost through the processes of evaporation/evapo-transpiration, water being pumped out of the lake, and seepage from the lake. The seepage could be through the sides or bottom of the lake or through the leakages in sluice gates.

In most situations, since within the areal extent of the lake, the geology may not change very significantly, it is assumed that the ground water inflow to the lake equals groundwater outflow from the lake and the net change due to groundwater is assumed as zero, which is a reasonable assumption. That leaves other components discussed above for consideration.

The net change in lake storage can be easily calculated from water levels of the lake if the depth-area-capacity curve called hypsographic curve, is available for the lake. Such a curve is prepared after a detailed bathymetric survey of the lake which determines the elevations at different locations in the lake. A contour map is first prepared from the survey and a hypsographic curve is then developed from the contour map. The hypsographic curve directly gives the volume of water in the lake corresponding to a water level. The change in volume of the lake can be calculated by finding out the difference in volumes of water at two different water levels in the lake.

The above explanation can be represented in a simple equation called the water balance equation for a specific period, as:

The water balance equation of a lake can be mathematically written as :

$$\Delta S = I_s + I_u + P_1 - Q_s - Q_u - E_1$$

where,

$\Delta S$  = change of lake storage

$I_s$  = surface inflow (including overland flow)

$I_u$  = underground inflow

$P_1$  =inflow due to direct precipitation over lake

$Q_s$  = surface outflow (including overflow,  $Q_o$ ; and withdrawal,  $Q_w$ )

$Q_u$  = underground outflow (including seepage losses)

$E_1$  = lake evaporation

## 5.2 Water balance components of Sukhna Lake

The components of water balance of Sukhna Lake are:

- i) The major water inflow components for Sukhna lake are inflow coming through the Sukhna Choe (inflow stream) and water falling directly over the lake as rainfall.
- ii) The outflow components include the water being lost through the process of evaporation, water being withdrawn from the lake for irrigating the gardens by the horticulture department and water being pumped for cleaning/washing of the floor around the boating area etc. by CITCO. According to the information provided by the Engineering Department, Chandigarh Administration, the pumping losses are negligibly small.
- iii) During the study period from July, 2011, the sluice gates were not opened hence the direct surface outflow from the lake was zero. Also, no overflow from the lake was observed during the study period. Similarly, no seepage through leakage from the sluice gates was observed.
- iv) Investigations on groundwater-lake interaction using isotope techniques and ground water table data, discussed previously, indicate either no interaction or very negligible interaction of the lake water with the ground water in the catchment. However, as has been discussed earlier, there are seepage losses from the higher elevations of the lake bed (upper periphery). Below this level, since the lake bed is heavily silted, the seepage from the lake bed can be assumed to be negligible.

Thus, the water balance equation for Sukhna lake can be written in a simplified form as:

$$(\text{Water received from direct inflow through river} + \text{Direct rainfall over lake}) - (\text{Total losses through evaporation and pumping}) = \text{Change in lake storage}$$

The above water balance equation has been used to determine the inflow to the lake, as explained below:

As per water balance equation,

$$\text{Total Inflow} - \text{total Outflow} = \text{Total change in storage}$$

Which implies that,

Total Inflow to lake = Total Change in lake Storage + Total Outflow (losses) from lake

Thus, if we have the values for change in storage and total losses from the lake, we can find out the net inflow to the lake. The same procedure has been applied in the present study. Water balance has been estimated for the years of 2011-12, , 2012-13 and 2010 (monsoon) .

The water balance equation for Sukhna Lake for the post monsoon period can be further simplified as:

$$\Delta S = P_1 - Q_w - Q_u - E_1$$

### 5.3 Evaporation Losses from the lake

Evaporation is one of the very significant components of the hydrologic systems. Knowledge of evaporation rates from a lake is essential to estimate water availability in the lake. Estimates of evaporation rates are also needed for various other purposes such as estimating energy balance, temperature modeling etc. In spite of its significance, however, precise estimation of evaporation 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 not so simple a process as it appears. It is a very complex process involving complex interactions of various factors such as radiation, temperature, humidity, wind, atmospheric pressure etc. 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 inter-annual variations in evaporation.

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 from the lakes. The various models of evaporation can be classified into different categories such as energy balance models, water balance models, mass transfer models, combination models, pan evaporation models, equilibrium temperature models and empirical models. Theoretically, the water balance appears to be the most realistic model. However, although the water balance equation looks simple, its practical application poses many difficulties causing errors in estimation of different components. The errors in lake water balance components are mainly due to errors of measurement and errors of regionalization. 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.

Pan method is one of the most popular methods because of the simplicity of measurement and also due to the element of actual observed evaporation in the data. The pan data are quite often taken to represent lake or reservoir evaporation. However, this is grossly erroneous because the thermodynamics of a pan is different than that of the water bodies like lakes and reservoirs. For example, heat transfer from sides and bottom of the pan is appreciable while for lakes and reservoirs, heat loss through the bottom is almost zero. Consequently, a coefficient has to be applied to pan data for converting it into the water surface evaporation like lake evaporation. This coefficient, called pan coefficient ( $K_p$ ) is the ratio between observed pan evaporation to the evaporation from water surface. From the studies carried out using data of water bodies from all over the world, it has been reported that annual pan coefficient values for US Class-A pan are scattered around 0.77. But this is true for only annual total evaporation. However, there is still a tendency to use a uniform coefficient of 0.7 for all time scales like daily, monthly or seasonal, which is erroneous. Studies have shown that Pan Coefficients are different for different regions and are also different for different time scales. The monthly pan coefficient has been observed to differ from the commonly used coefficient of 0.7 by more than 100%. The coefficient is dependent on local climate and physical conditions, and has to be determined locally from a standard method such as the Penman method. Alvarez et al. (2007), for example, derived pan coefficients for irrigation water reservoirs in south Eastern Spain. Monthly Pan coefficient ( $K_p$ ) values were observed to vary significantly throughout the year. The variation was found to be  $0.5 < K_p < 1.5$  for deep waters and  $0.8 < K_p < 1.2$  for shallow waters. Khobragade et al. (2010) determined the pan coefficients of USWB Class A pans for lakes of Udaipur region In Rajasthan, which has a semi-arid tropical climate. They observed that the monthly coefficient varied from 0.719 to 1.228 for the open pan while it ranged between 0.823 to 1.405 for mesh covered pans. Since the locally determined pan coefficients are not available for the study area, the method could not be used in the present study.

#### 5.4 Estimation of Evaporation losses

For the purpose of the present study, since data availability does not permit the use of energy balance method, so Penman combination method has been used for estimating evaporation rates from Sukhna Lake. The daily lake evaporation obtained by this method have been considered as the actual lake evaporation. The Penman combination equation as per Nokes (1995) is:

$$E = \frac{\frac{\Delta}{\Delta + \gamma} * (R_n - G) + \frac{\gamma}{\Delta + \gamma} * 6.43 * (1.0 + 0.53 * U_2) * (e_s - e_a)}{\lambda}$$

where,

- E = Lake evaporation [mmd<sup>-1</sup>];
- R<sub>n</sub> = net radiation [MJm<sup>-2</sup>d<sup>-1</sup>];
- G = heat flux density [MJm<sup>-2</sup>d<sup>-1</sup>];
- U<sub>2</sub> = wind speed measured at 2 m above the ground [ms<sup>-1</sup>];
- e<sub>s</sub> = saturated vapour pressure at air temperature [kPa];
- e<sub>a</sub> = actual vapour pressure at air temperature [kPa];
- Δ = slope of saturation vapour–pressure–temperature curve [kPa°C<sup>-1</sup>];

$\Upsilon$  = psychrometric constant [kPa<sup>0</sup>C<sup>-1</sup>]; and  
 $\lambda$  = latent heat of vapourization [M]kg<sup>-1</sup>

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 as follows:

Mean saturated vapour pressure is calculated from air temperature as per Allen et al. (1998) as:

$$e_s = \frac{[e_s(T_{\max}) + e_s(T_{\min})]}{2}$$

where,

$e_s$  = mean saturation vapour pressure at air temperature [kPa];  
 $e_s(T_{\max})$  = saturation vapour pressure at maximum temperature [kPa];  
 $e_s(T_{\min})$  = saturation vapour pressure at minimum temperature [kPa].

The saturation vapour pressure,  $e_s$ , which is a function of temperature, is given by (Shuttleworth, 1993, Allen et al., 1998) as:

$$e_s = 0.6108 \exp\left[\frac{17.27T}{T + 237.3}\right]$$

where,

$T$  = temperature [°C]  
 $e_s$  = saturation vapour pressure at temperature, T [kPa];

$e_s(T_{\max})$  and  $e_s(T_{\min})$  have been calculated from Equation for  $e_s$  as :

$$e_s(T_{\max}) = 0.6108 * \exp\left[\frac{17.27 * T_{\max}}{T_{\max} + 237.3}\right]$$

$$e_s(T_{\min}) = 0.6108 * \exp\left[\frac{17.27 * T_{\min}}{T_{\min} + 237.3}\right]$$

where,

$T_{\max}$  = maximum air temperature [°C]; and  
 $T_{\min}$  = minimum air temperature [°C]

Slope of the saturation vapour pressure curve ( $\Delta$ ) has been calculated from mean air temperature as per Allen et al. (1998) as:

$$\Delta = \frac{4098 * \left[0.6108 * \exp\left(\frac{17.27 * T}{T + 237.3}\right)\right]}{(T + 237.3)^2}$$

where,

$\Delta$  = slope of the saturation vapour pressure–temperature curve [kpa<sup>0</sup>c<sup>-1</sup>]; and  
 $t$  = mean air temperature [°c].

The psychrometric constant ( $\gamma$ ) has been calculated as per Nokes (1995) as:

$$\gamma = \frac{c_p * P}{0.622 * \lambda}$$

where,

- $\gamma$  = psychrometric constant [ $\text{kPa}^0\text{C}^{-1}$ ]; and
- $c_p$  = specific heat of water at constant pressure [=0.001013  $\text{kJ}/\text{kg}^{-1}\text{C}^{-1}$ ];
- $P$  = atmospheric pressure [ $\text{kPa}$ ]; and
- $\lambda$  = latent heat of vapourization [ $\text{MJ}/\text{kg}^{-1}$ ]

The latent heat of vapourization ( $\lambda$ ) has been calculated from the air temperature as per Nokes (1995) as:

$$\lambda = 2.501 - 2.361 * 10^{-3} * T$$

where,

- $\lambda$  = latent heat of vapourization [ $\text{MJ}/\text{kg}^{-1}$ ]; and
- $T$  = mean air temperature [ $^{\circ}\text{C}$ ].

Net radiation,  $R_n$ , is calculated as per Allen et al (1998) as:

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

where,

- $R_n$  = net radiation [ $\text{MJ}/\text{m}^2\text{d}^{-1}$ ];
- $R_{ns}$  = net shortwave radiation [ $\text{MJ}/\text{m}^2\text{d}^{-1}$ ]; and
- $R_{nl}$  = net long-wave radiation [ $\text{MJ}/\text{m}^2\text{d}^{-1}$ ].

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:

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

where,

- $R_{nl}$  = net long-wave radiation [ $\text{MJ}/\text{m}^2\text{d}^{-1}$ ];
- $\sigma$  = Stefan-Boltzmann constant [= 4.903\*10<sup>-9</sup>  $\text{MJ}/\text{K}^4\text{m}^2\text{d}^{-1}$ ];
- $T_{\max,k}$  = maximum absolute temperature during the 24-hour period [=0C+273.16];
- $T_{\min,k}$  = minimum temperature during the 24-hour period [=0C+273.16];
- $e_a$  = actual vapour pressure [ $\text{kPa}$ ];
- $R_s$  = solar radiation [ $\text{MJ}/\text{m}^2\text{d}^{-1}$ ];
- $R_{so}$  = clear sky radiation [ $\text{MJ}/\text{m}^2\text{d}^{-1}$ ];
- $R_s/R_{so}$  = relative shortwave radiation [limited to  $\leq 1.0$ ]

$R_{so}$  has been calculated as per Allen et al. (1998).

## 6.0 RESULTS AND DISCUSSIONS

### 6.1 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 variation in the meteorological parameters. Figs. 4 to 13 show the daily temporal variations in the various meteorological parameters for the study area for the period of 1 July, 2011 to 15 March, 2013.

During the study period of 1<sup>st</sup> July, 2011 to 15 March, 2013, the maximum temperature ( $T_{\max}$ ) ranged from 6.8 °C to 46.0 °C. Highest value of maximum temperature was observed during May, 2012 while lowest value of 6.8°C was observed on 8<sup>th</sup> January, 2013. Minimum temperature ( $T_{\min}$ ), varied from -0.66 °C to 29.8 °C. Highest value of minimum temperature (29.8 °C) was observed during July, 2012 and lowest value of -0.66°C was observed on 4<sup>th</sup> January, 2013 in the catchment. The average daily temperature varied from 3.77 °C on 8<sup>th</sup> January, 2013 to 36.75 °C in June, 2012.

Relative humidity was generally high during the monsoon months and low during the warmer months. The maximum relative humidity ( $RH_{\max}$ ) values during the study period varied from as high as 100 % during July and December, 2012, to a low of 23 % on 2<sup>nd</sup> June, 2012. The minimum relative humidity values ( $RH_{\min}$ ), on the other hand, varied from as low as 8 % in May 2012 to a high value of 98 % during July month. The average relative humidity ranged from 18 % on 2<sup>nd</sup> June, 2012 to 97 % on 15<sup>th</sup> September, 2011. The wind was observed to vary within the range of 0 m/s to 9.5 m/s. The high value of 9.5 was observed on 5<sup>th</sup> July, 2012. In general wind velocity was higher during the monsoon months of 2012. The daily atmospheric pressure values ranged between a minimum of 96.3 KPa to 98.9 KPa. During the study period, the actual vapour pressure was observed to be highest at 4.03 KPa and minimum at 0.49 KPa. The vapour pressure deficit, which represents the evaporative demand of the air, varied from minimum of 0.05 KPa to a maximum of 5.49 KPa.

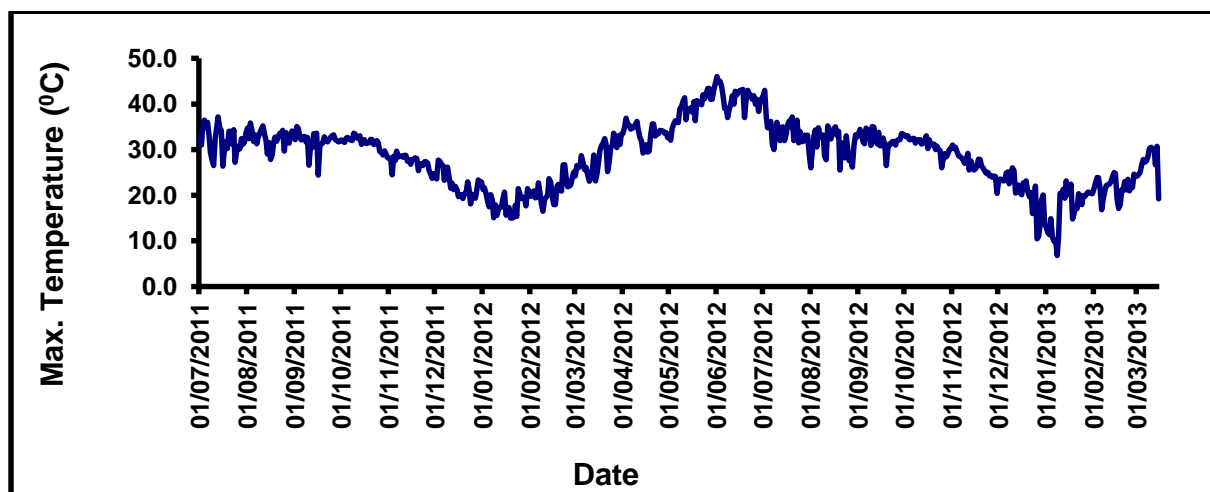


Fig.4: Variation of maximum temperature during the study period

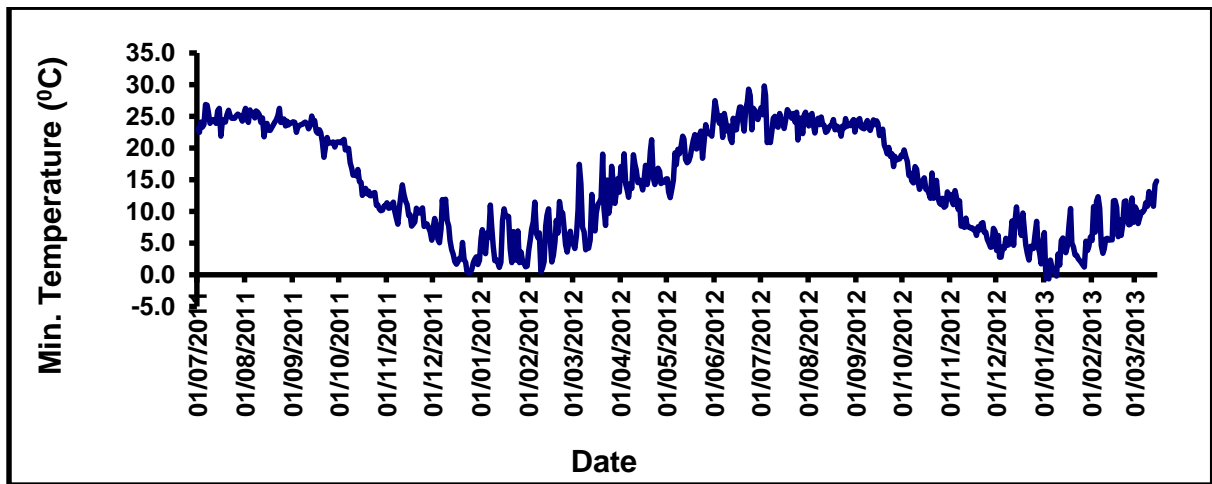


Fig.5: Variation of minimum temperature during the study period

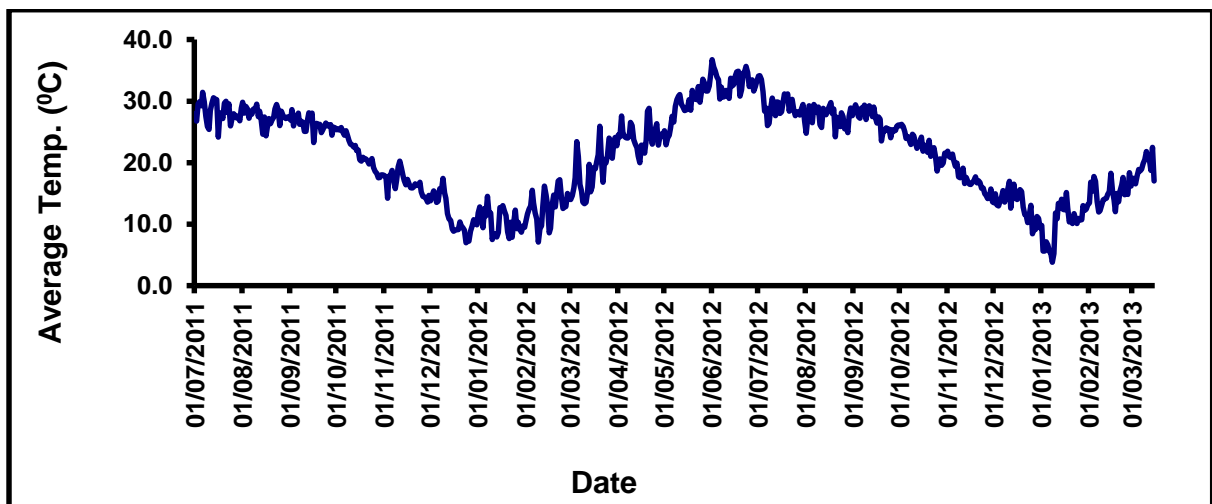


Fig.6: Variation of average daily temperature during the study period

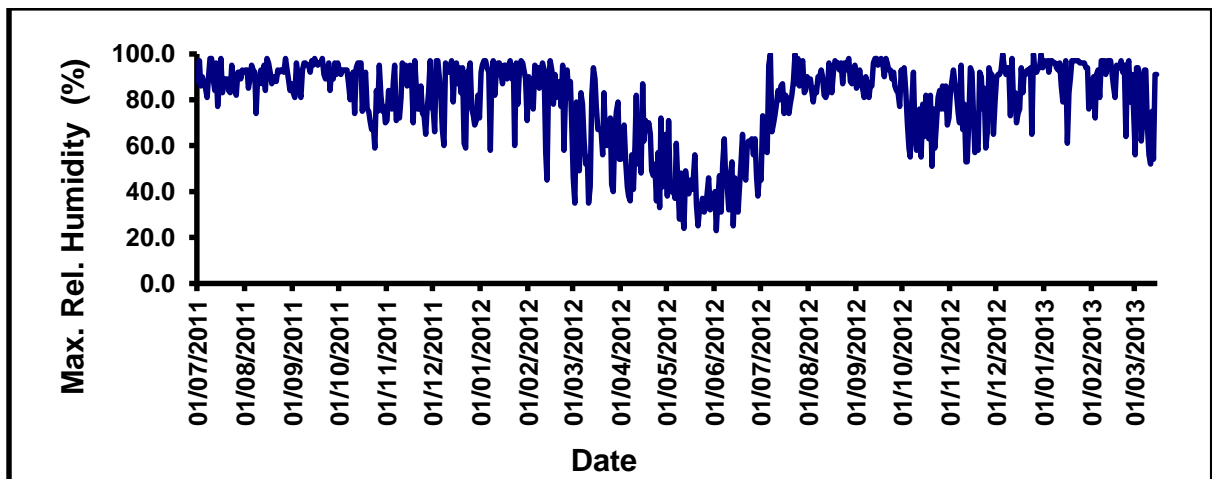
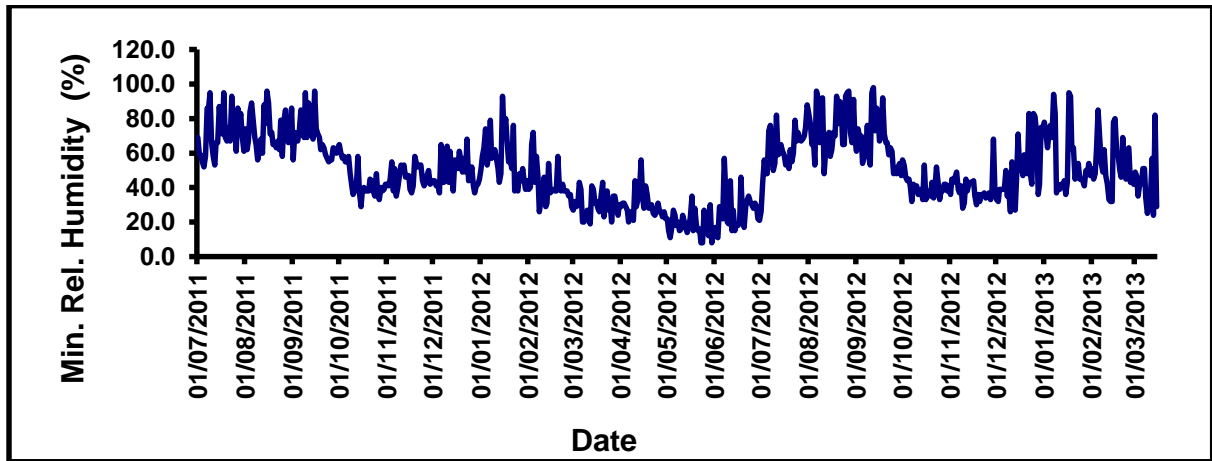
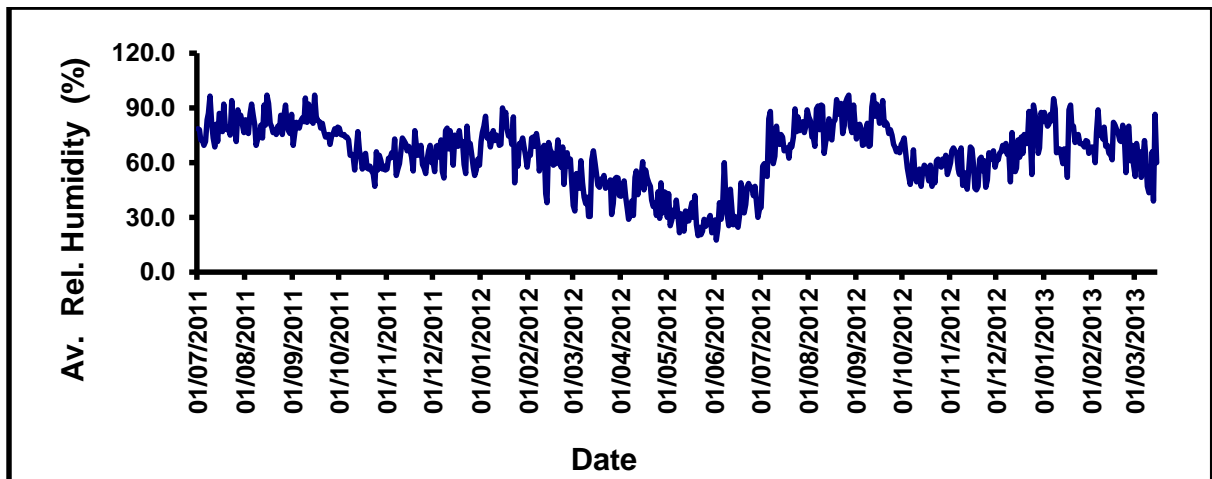


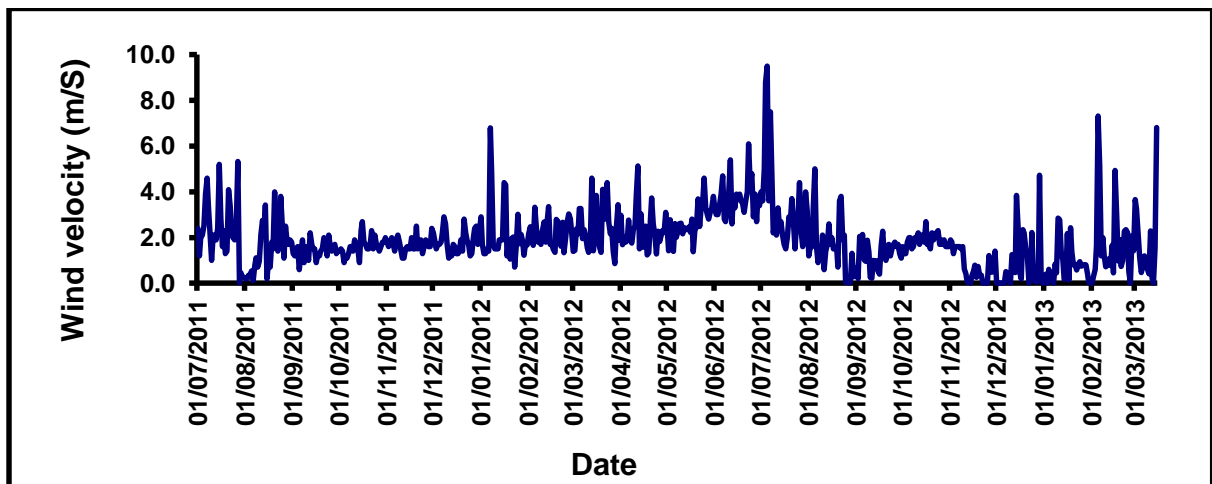
Fig.7: Variation of maximum relative humidity during the study period



**Fig.8: Variation of minimum relative humidity during the study period**



**Fig.9: Variation of average daily relative humidity during the study period**



**Fig.10: Variation of wind velocity in the lake catchment during the study period**

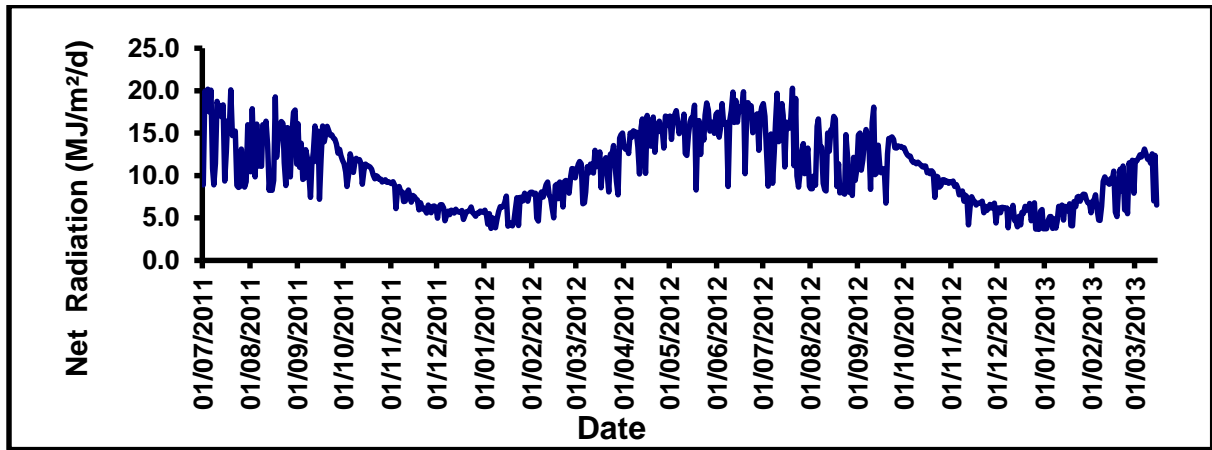


Fig.11: Variation of net radiation during the study period

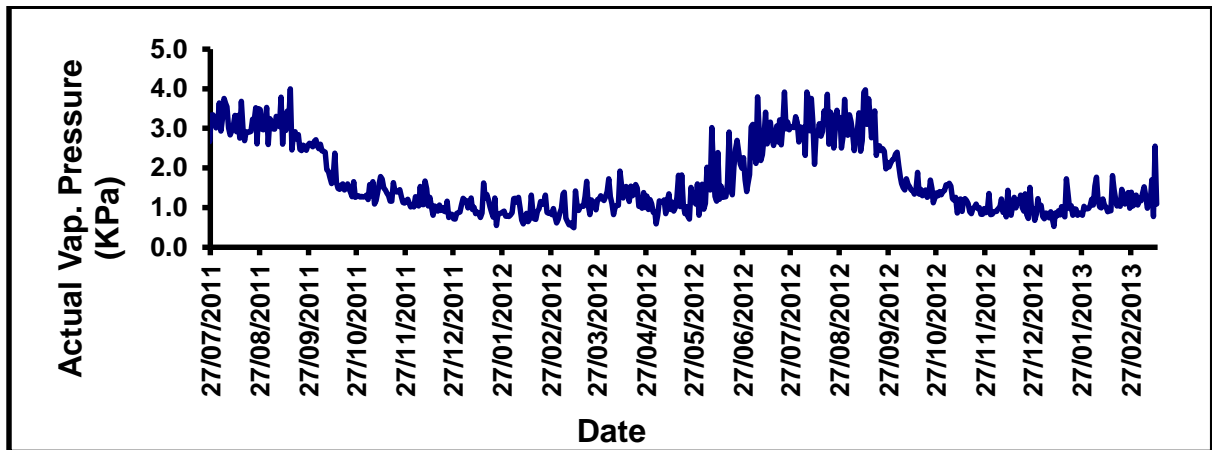


Fig.12: Variation of actual vapour pressure during the study period

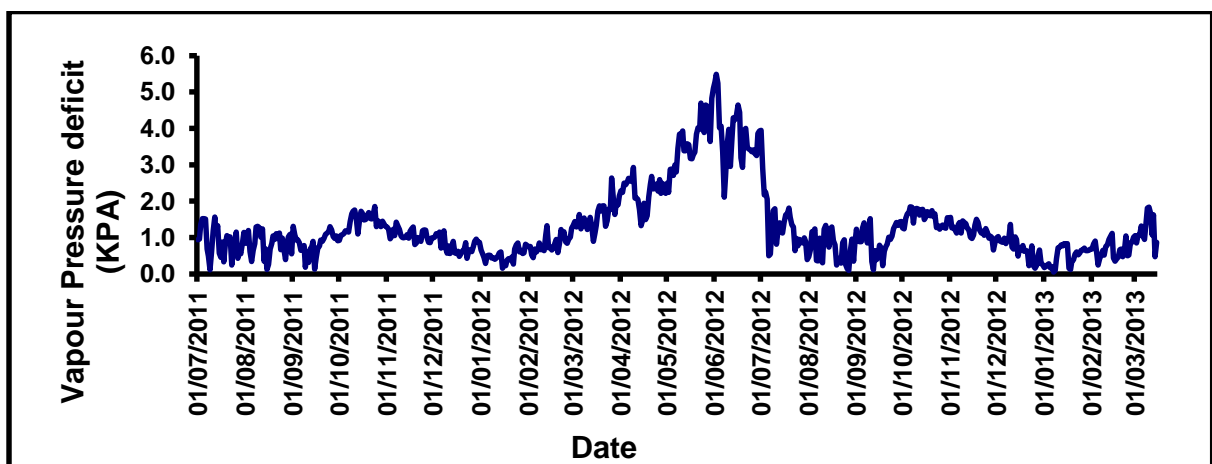


Fig.13: Variation of vapor pressure deficit during the study period

To get the feel of the average climatic conditions during the study period, the average monthly meteorological data of the study area are presented in Table 4. The radiation

balance of the study area for the study period is presented in Fig. 14. The data in Table 7.1 indicates that during the study period average maximum temperature was highest for the month of January, 2012 with a value of 41.1 °C and minimum during January (17.2 °C). The minimum temperature, on an average was highest during June, 2012 (24.8°C) and minimum during January, 2013 (3.3°C). On an average, maximum relative humidity was highest during September, 2011 and minimum during the month of May, 2012 while average minimum relative humidity was highest during August, 2012 and minimum during the month of May, 2012. The atmospheric pressure on an average was highest during January, 2013 and lowest during August, 2011. The wind velocity on an average around 1.9 m/s during the entire study with an average maximum of 3.67 m/s during June, 2012 and an average minimum of 0.77 m/s during November, 2012. Net radiation, which reflects the amount of energy available for evaporation, is in general, higher during the warmer months and lower during the cooler months. The average was found to be highest for the month of June, 2012 (16.62 MJ/m<sup>2</sup>/d) and lowest for the month of December, 2012 (5.37 MJ/m<sup>2</sup>/d).

**Table 4: Avg. monthly meteorological data of Sukhna Lake catchment during the study period**

Month	Max Temp (°C)	Min Temp (°C)	Max Humidity (%)	Min Humidity (%)	Atm. Press. (Kpa)	Wind Speed (m/s)	Net Radiation (MJ/m <sup>2</sup> /d)
Jul-2011	32.1	24.7	89	71	97.09	2.28	14.31
Aug-2011	32.6	24.4	90	72	96.76	1.53	13.27
Sep-2011	32.0	22.5	92	69	97.04	1.46	12.87
Oct-2011	31.5	14.9	83	44	97.69	1.62	10.43
Nov-2011	27.3	9.8	82	46	98.04	1.68	7.15
Dec-2011	22.5	4.4	83	49	98.27	1.83	5.69
Jan-2012	18.3	4.8	90	56	98.32	2.13	5.84
Feb-2012	21.3	6.3	84	41	98.11	2.22	8.05
Mar-2012	28.2	10.3	64	30	97.70	2.41	11.06
Apr-2012	33.6	15.6	57	30	97.40	2.33	14.48
May-2012	39.2	19.5	40	18	97.07	2.63	15.68
Jun-2012	41.4	24.8	47	26	97.18	3.67	16.62
Jul-2012	34.3	24.5	80	62	97.18	3.42	13.96
Aug-2012	31.4	23.7	90	76	97.14	1.59	11.29
Sep-2012	32.3	21.7	90	66	97.09	1.23	12.88
Oct-2012	31.0	14.3	73	40	97.18	1.85	10.63
Nov-2012	26.7	8.1	77	39	98.01	0.77	7.03
Dec-2012	20.7	5.5	89	50	98.45	0.85	5.37
Jan-2013	17.2	3.3	92	57	98.63	0.80	5.85
Feb-2013	21.9	8.2	90	54	98.48	1.73	8.21

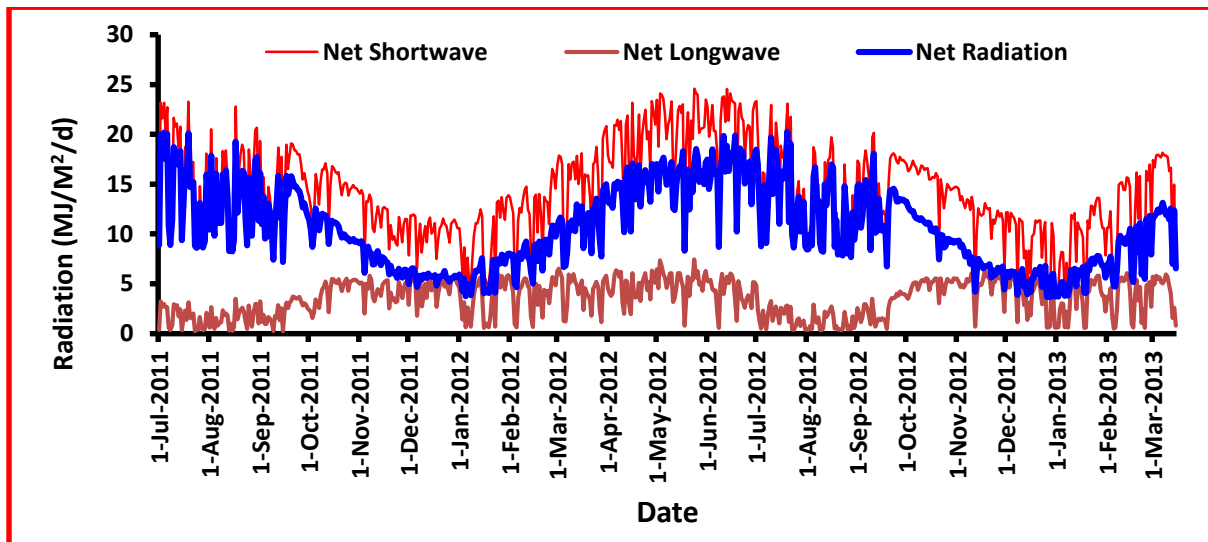


Fig. 14: Radiation balance of the study area for the study period

## 6.2 Spatial Variation in Rainfall

In order to generate the required rainfall data for the lake catchment, raingauges have been installed at different locations in the lake catchment. Accordingly, ordinary raingauges have been installed at Lake site, Kansal Log Hut and Nepli Rest House and automatic raingauges have been installed at Watch Tower near Kansal and Kansal village. The AWS installed at Kansal Rest House also has an automatic rain gauge. Besides these raingauges, the ordinary raingauge already existing at Kansal Rest House has also been made operational. Since the raingauges have been made operational at different points of time during the study period, the data availability varies from station to station. Past data of rainfall, available with the Forest Department, for the stations of Nepli and Kansal Rest House, have also been collected and used. Fig. 15 presents views of some of the raingauges installed in the study area.



ARG at Kansal Watch Tower



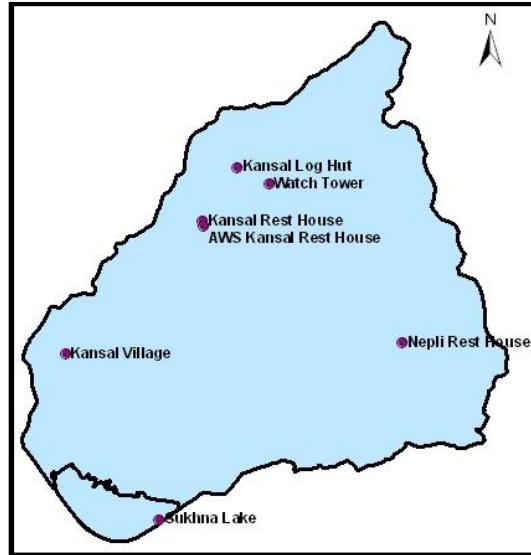
ARG at Kansal Village



ORG at Sukhna Lake

Fig. 15: Views of some of the raingauges installed in the study area

Fig. 16 shows the location of the various raingauge stations. Table 8.1 present details of the various raingauge stations.



**Fig. 16: Locations of rain gauge stations**

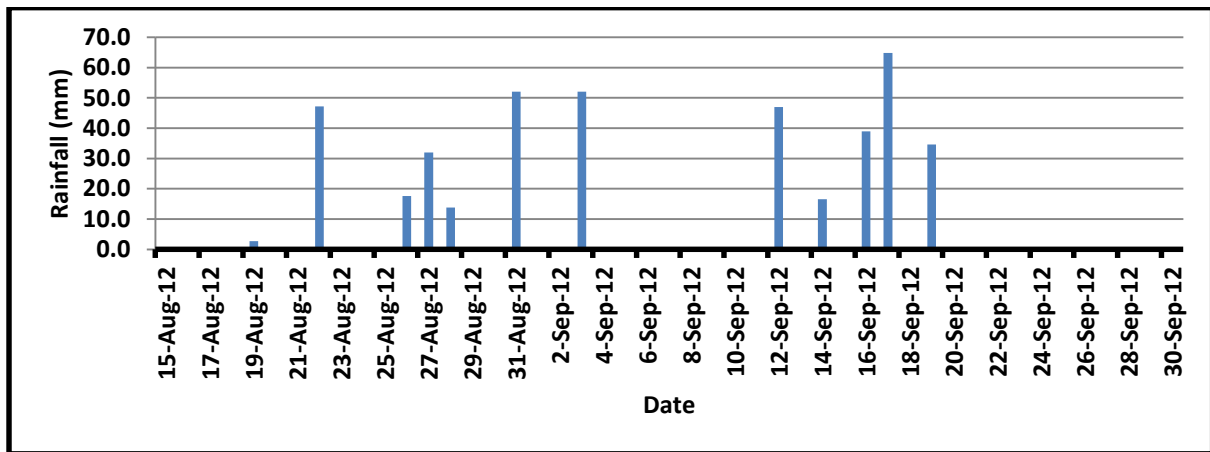
**Table 5: Details of rain gauge stations**

Name	Latitude	Longitude	Elevation
Kansal Rest House	30 <sup>o</sup> 47'09.0"	76 <sup>o</sup> 50'17.4"	399
AWS Kansal Rest House	30 <sup>o</sup> 47'09.0"	76 <sup>o</sup> 50'17.4"	399
Kansal log Hut	30 <sup>o</sup> 47'38.9"	76 <sup>o</sup> 50'41.4"	420
Kansal Village	30 <sup>o</sup> 45'55.3"	76 <sup>o</sup> 48'47.3"	370
Nepli Rest House	30 <sup>o</sup> 45'58.4"	76 <sup>o</sup> 52'27.9"	399
Watch Tower	30 <sup>o</sup> 47'29.9"	76 <sup>o</sup> 51'02.5"	489
Sukhna Lake Site	30 <sup>o</sup> 44'20.5"	76 <sup>o</sup> 49'47.5"	346

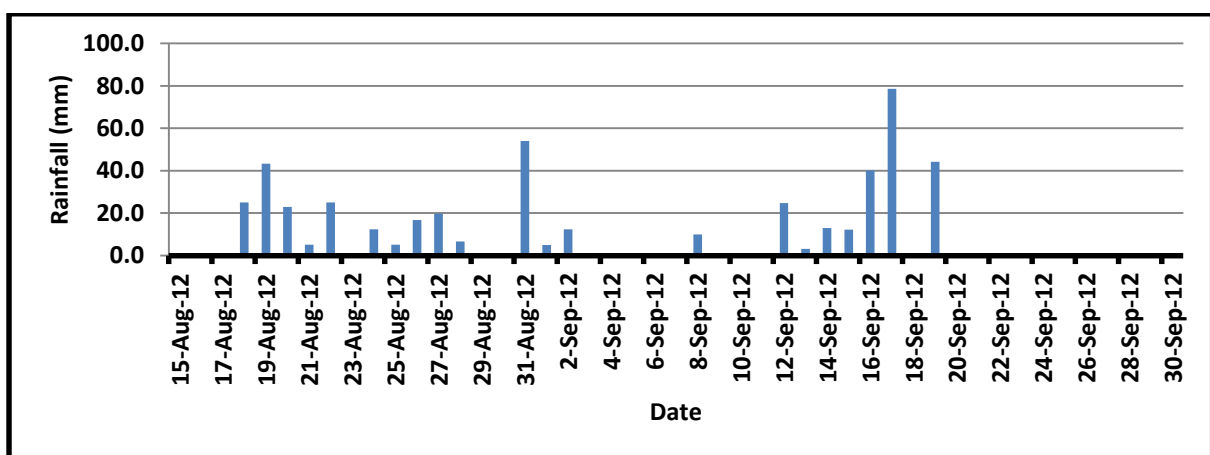
The rainfall pattern in the study area is erratic and shows large variations, both temporal and spatial. This is illustrated in Table 6 which presents the variation in rainfall characteristics of different rain-gauge stations for the period of 15<sup>th</sup> August, 2012 to 30<sup>th</sup> September, 2012. Fig. 17(a) to 17(f) present the rainfall data of the various rain gauge stations for the period of 15<sup>th</sup> August, 2012 to 30<sup>th</sup> September, 2012. It can be observed from Table 6 as well as Fig. 17, that there is significant temporal and spatial variation in rainfall in the study area.

**Table 6: Variation in rainfall characteristics of different rain-gauge stations during the period of 15<sup>th</sup> August, 2012 to 30<sup>th</sup> September, 2012**

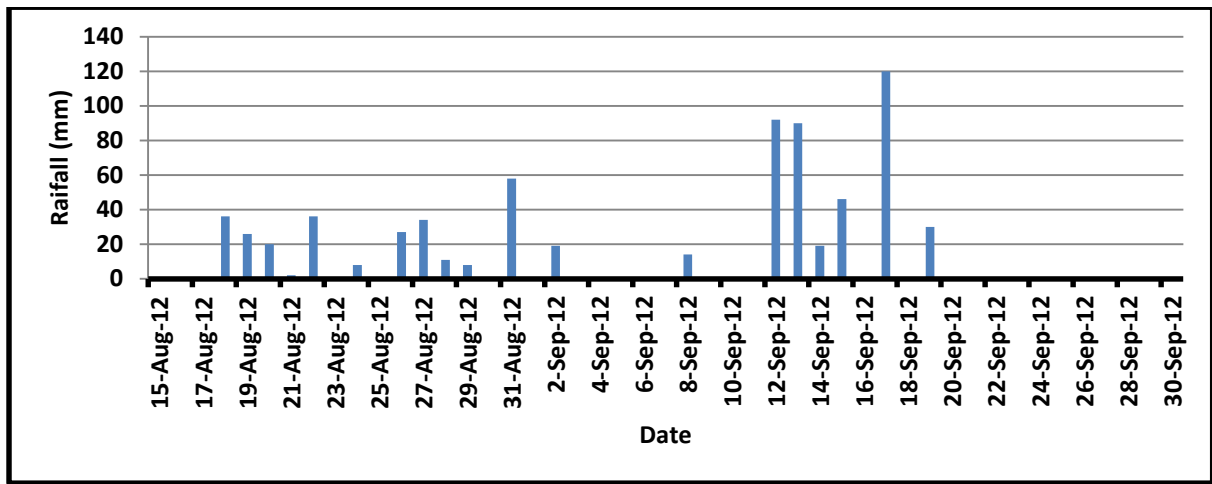
Station	Lake	Kansal Rest House	Kansal Log Hut	Kansal Watch Tower	Kanal Village	Nepli
No. of rainy days	12	21	21	23	20	19
Max daily rainfall (mm)	64.8	78.6	154	113	83.8	120
No. of days with more than 50 mm rainfall	3	2	4	1	4	4
No. of days with more than 40 mm rainfall	5	5	6	2	5	5
Total Rain(mm)	<b>419.3</b>	<b>480</b>	<b>717</b>	<b>531.6</b>	<b>526</b>	<b>696</b>



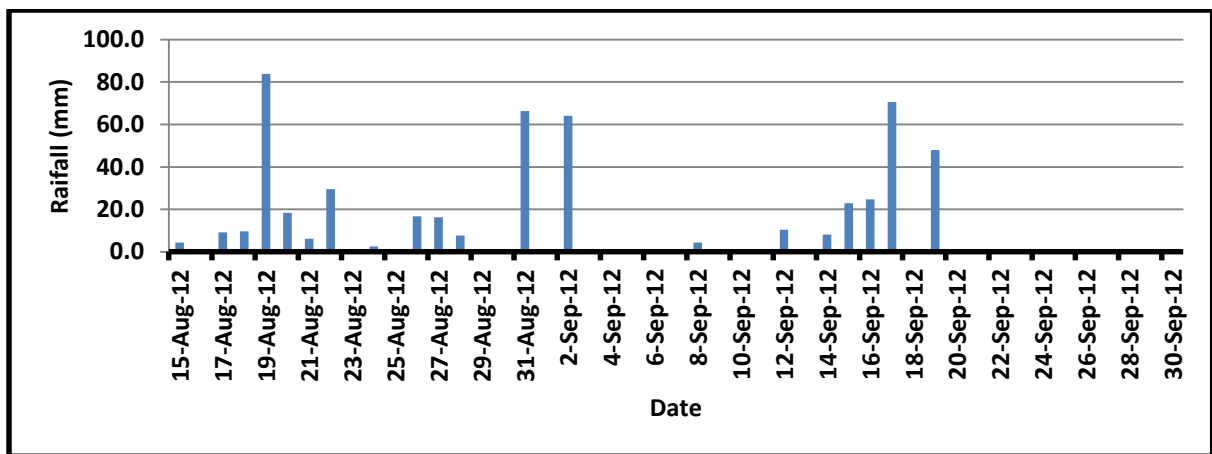
**(a) Rainfall at Lake Site**



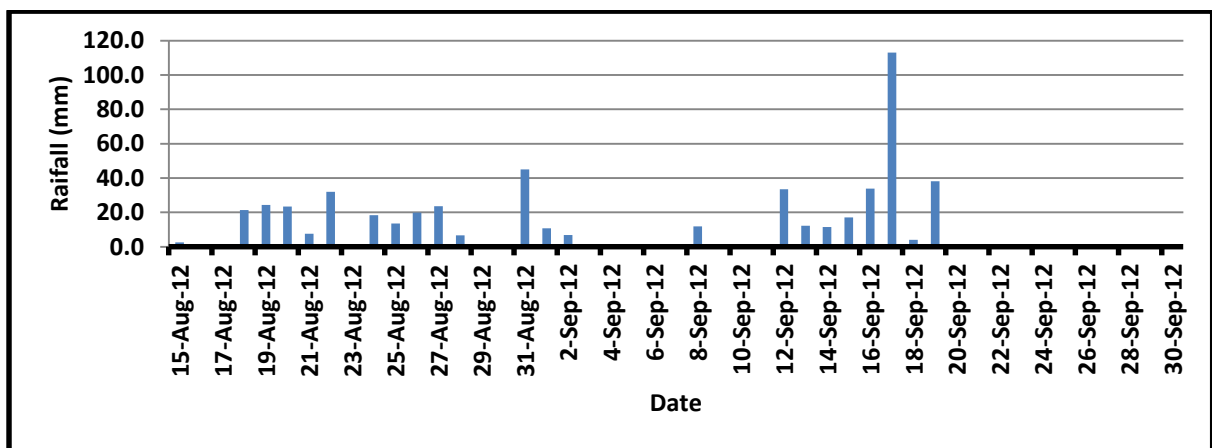
**(b) Rainfall at Kansal Rest House**



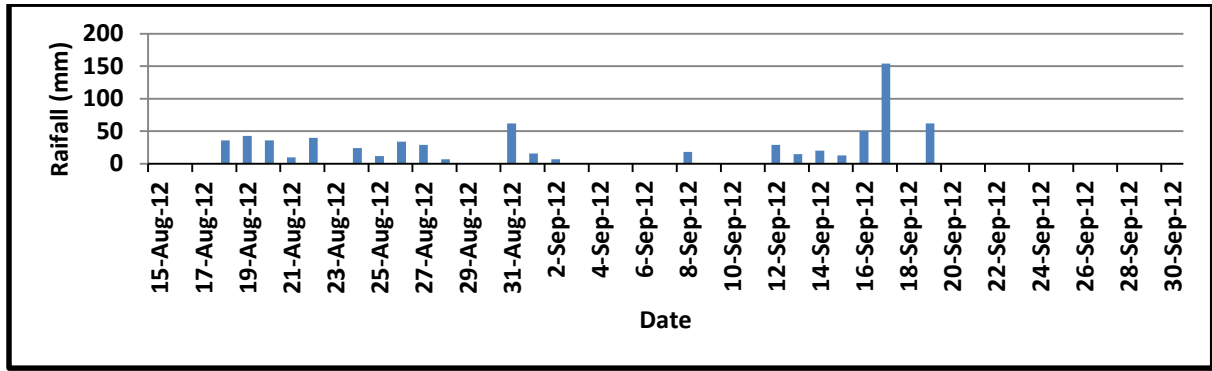
(c) Rainfall at Nepli Rest House



(d) Rainfall at Kansal Village



(e) Rainfall at Kansal Watch Tower



(f) Rainfall at Kansal Log Hut

Fig. 17: Variation of rainfall at different stations

In view of significant spatial and temporal variation in rainfall characteristics at different locations in the catchment, it is not fair to use rainfall data of one particular station as representative rainfall of the lake catchment. So, average rainfall data for the lake catchment has been used. For different periods, weighted average rainfall has been computed for the lake catchment depending upon the availability of the rainfall data at various stations during different periods. The weighted average was obtained using the Thiessen Polygon method, which is the most popular method for the purpose. It is given as:

$$\bar{h} = \frac{\sum_{i=1}^n A_i h_i}{\sum_{i=1}^n A_i};$$

where,  $\bar{h}$  = spatial average of precipitation

$A_i$  = area of the part of the sub-catchment that belongs to the rain gauge  $i$

$h_i$  = rain gauge precipitation value at rain gauge  $i$

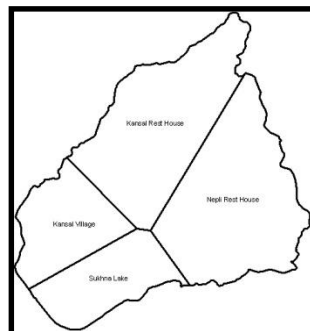
$n$  = total number of rain gauges

$A = \sum_{i=1}^n A_i$  total area of the sub-catchment

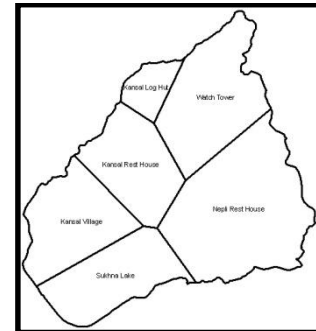
Fig. 18 shows some examples of the Thiessen Polygon constructed for some periods. Thus, during 9<sup>th</sup> July to 27<sup>th</sup> July 2011 data of three stations was available while during 11<sup>th</sup> September 2011 to 22<sup>nd</sup> May 2012 data of 6 stations was available and used.



9th July to 27th July 2011



28th July 10th Sep 2011

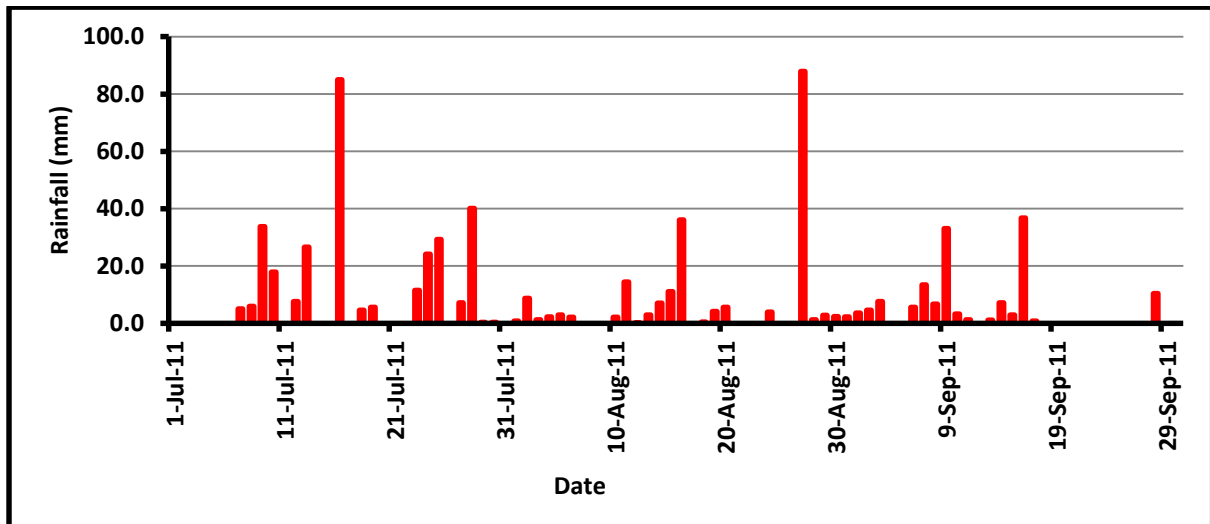


11<sup>th</sup> Sep 2011 to 22<sup>nd</sup> May 2012

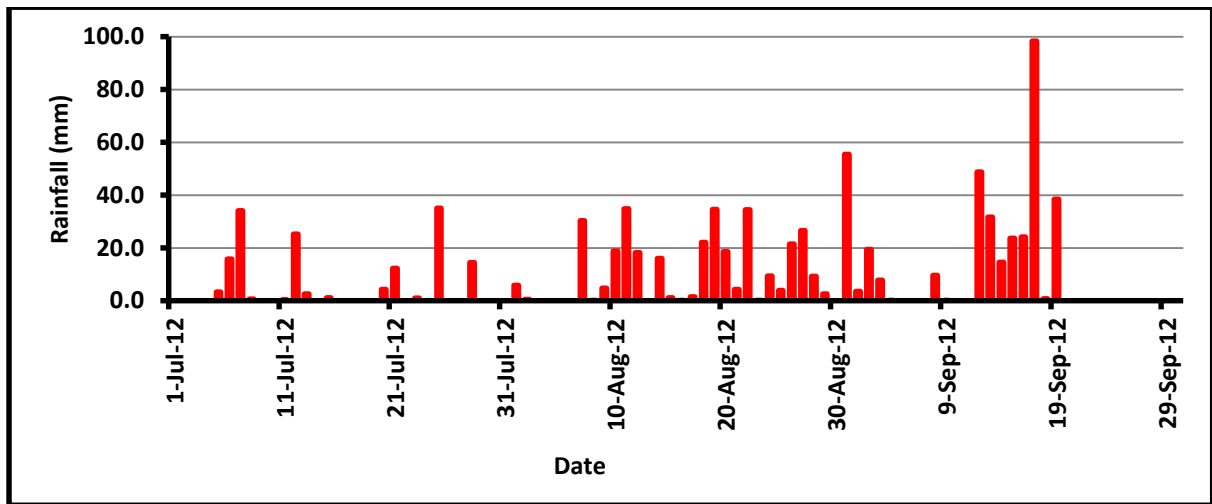
Fig. 18: Thiessen Polygons for different periods

Fig. 19 and 20 presents the average rainfall estimated for the lake catchment during 2011 and 2012 monsoon respectively. While the average rainfall in the catchment during monsoon 2011 (1<sup>st</sup> July-30<sup>th</sup> September, 2011) was 643.9, it was 845.8 during the same period in 2012.

The normal monsoon rainfall at Chandigarh is 850 mm. Thus, while 2011 was a deficit rainfall year, 2012 was a normal rainfall year. As such, it is interesting to compare the characteristics of rainfall in these two years. The number of rainy days observed during monsoon 2011 was 42 while it was 39 during monsoon 2012, as per the average rainfall data. Thus, although 2011 was a deficit rainfall year, there were actually more number of rainy days during 2011 monsoon than in 2012 monsoon. This means that the already lesser amount of rainfall received during monsoon 2011 as compared to monsoon 2012 was distributed in more number of rainfall events, indicating that there were mostly less intensity rainfall events during 2011, causing less runoff from the catchment and subsequently less inflows to the lake. Interestingly, the rainfall events with more than 50 mm of rainfall were observed to be 2 in monsoon of both the years. Similarly, the number of events with more than 40 mm rainfall was observed to be same as 3, for monsoon of both the years. However, the number of events with more than 30 mm rainfall was observed to be 6 during 2011 and 10 during 2012 monsoon. The number of events with more than 20 mm rainfall was 20 for monsoon of 2011 and 17 for monsoon of 2012. Thus, it can be said that the rainfall characteristic of 2011 monsoon was more erratic and variable compared to 2012 monsoon.

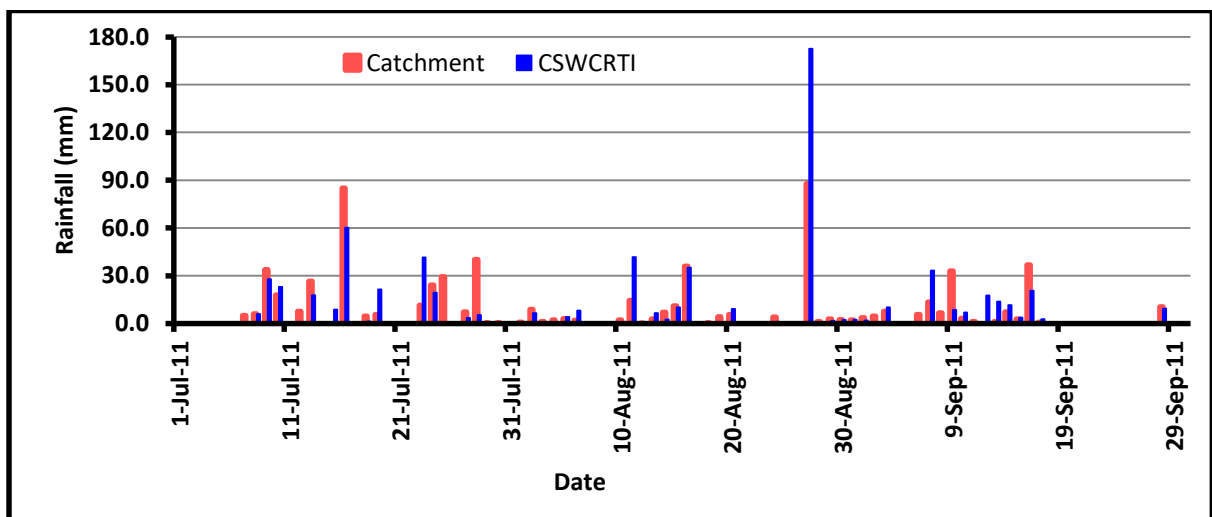


**Fig. 19: Estimated weighted average rainfall for lake catchment during monsoon 2011**

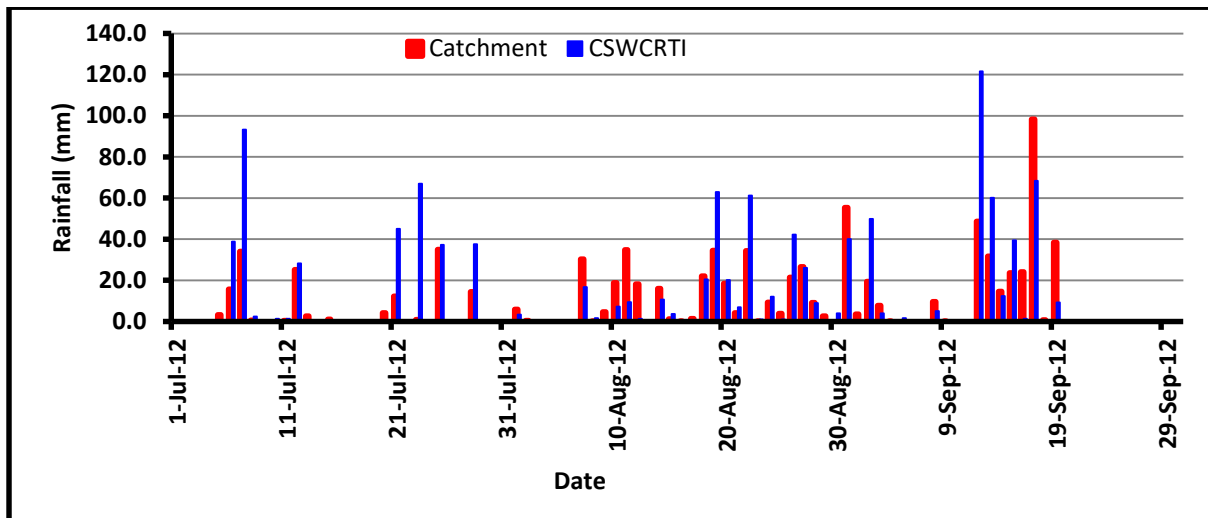


**Fig. 20: Estimated weighted average rainfall for lake catchment during monsoon 2012**

No long-term historical data of rainfall are available for lake catchment. So, for the historical data analysis, one has to depend on the rainfall data available with Central Soil and Water Conservation Research and Training Institute, Chandigarh (CSWCR&TI). So, it is not out of place to discuss the variation in rainfall characteristics (average rainfall) of lake catchment as well as that of the CSWCR&TI, Chandigarh data. Fig. 21 (a and b) presents a comparison of data of the two stations for the monsoon of 2011 and 2012. It can be easily observed that there is a significant variation in the rainfall data of the two stations. The total rainfall during 1<sup>st</sup> July -30<sup>th</sup> September, 2011 at CSWCR&TI station was 678.6 mm while the average rainfall of the catchment was 643.9 mm for the same period. The variation during 2012 was much more significant. The total rainfall during 1<sup>st</sup> July -30<sup>th</sup> September, 2012 at CSWCR&TI station was 1088.9 mm while the value was 845.8 mm for the average rainfall of the catchment. This variation needs to be kept in mind while using the historical data for analysis of Lake Hydrology, particularly for analysis of rainfall-runoff relationships or lake water level variation with historical data of rainfall.



**(a) Monsoon 2011**



(b) Monsoon 2012

Fig. 21: Comparison of rainfall data of lake catchment and CSWCRTI station

### 6.3 Temporal Variation in Rainfall at Chandigarh

For understanding the decreasing water availability in the lake as well as for knowing the possible future prospects of water availability for the Sukhna lake, trend analysis of long term data of rainfall is needed. Although a few raingauge stations have been established by the Forest Department in the lake catchment, systematic and authentic long term records of rainfall are not available for the catchment, as mentioned above. Long term rainfall data for Chandigarh are, however, available with the Central Soil Conservation Research and Training Institute, Chandigarh (CSWCRTI), as the Institute has a meteorological observatory established for the purpose, located only a few kilometers from the lake catchment. Rainfall data of Chandigarh for the years 1958-2012 have been obtained from CSWCRTI. The annual rainfall data for the period 1958-2012 are plotted in Fig. 22.

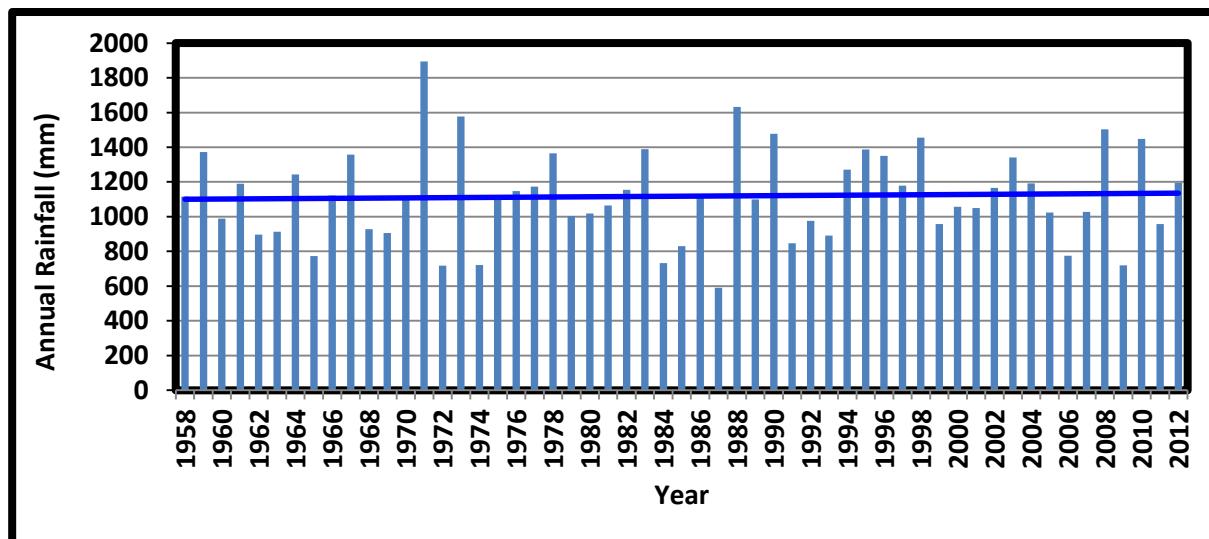
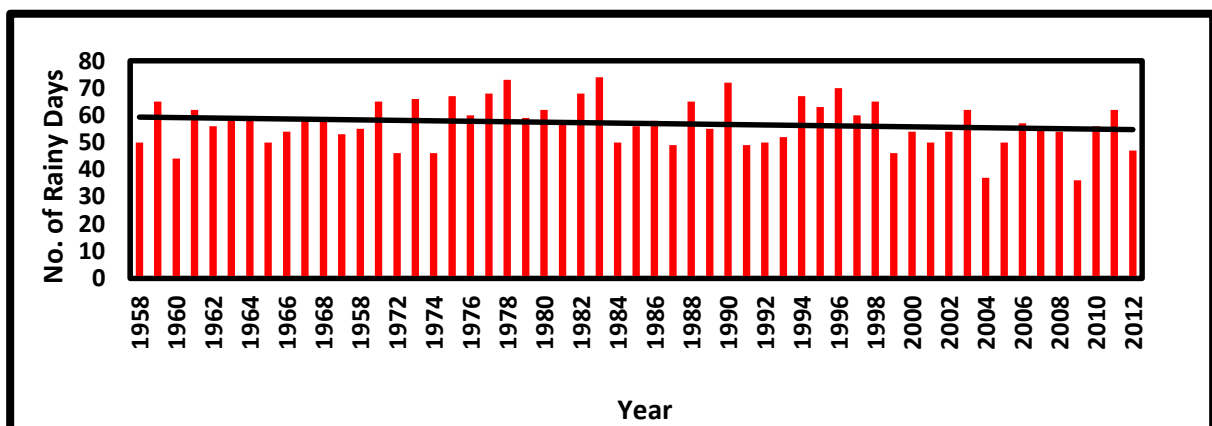


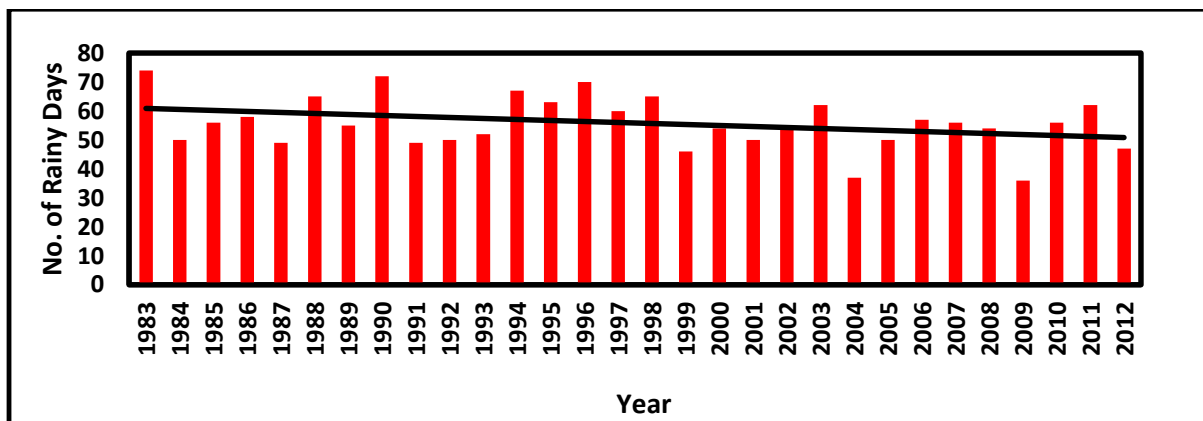
Fig. 22: Rainfall variation at Chandigarh (1958-2012)

The average annual rainfall for Chandigarh is 1121 mm. However, as can be seen from Fig. 8.8, rainfall data shows a large variation from year to year. The maximum rainfall in a year during the period 1958-2012 was recorded in 1971 when the rainfall was as high as 1894 mm. The minimum in a year was recorded during 1987 which recorded a total rainfall of only 591 mm. The data also shows that there is no definite pattern in rainfall at Chandigarh. But there are large variations from year to year. Year 2011 was a deficit rainfall year. Year 2012 was a normal rainfall year and the present year 2013 is also predicted to be a normal rainfall year. Fig. 8.8 also shows that, although there is temporal variation in rainfall, trend line, however, does not indicate any general falling trend in rainfall for Chandigarh region. On the contrary it shows a very marginally increasing trend which is not statistically significant. In general, it can be said that there is no increasing or decreasing trend in rainfall at Chandigarh. However, there are certainly variations from year to year without any specific cyclic or periodic pattern.

Fig. 8.9 shows a plot of annual number of rainy days for Chandigarh for the period of 1958-2012. The average number of rainy days during the period is 57. The number, however, varies from year to year. The maximum number of rainy days was recorded in the year 1983 which had 74 numbers of rainy days while the minimum was recorded during 2009 with only 36 rainy days. Trend line indicates a marginal fall in the number of rainy days per year during the period 1958-2012 (Fig. 23), which is statistically not very significant or more or less indicates no trend. However, a fall in number of rainy days from 1983 onwards is clearly visible as can be seen in Fig. 24.



**Fig. 23: Annual variation of number of rainy days at Chandigarh (1958-2012)**

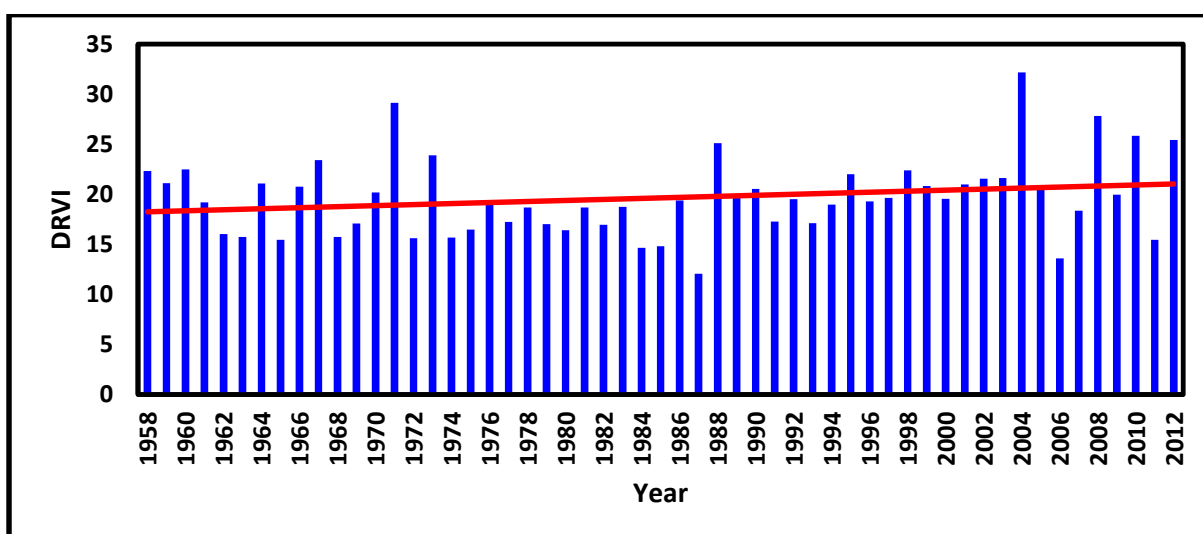


**Fig. 24: Annual variation of number of rainy days during 1983-2012**

It is a general trend that characteristics of rainfall are changing all over India. These include changes in patterns of rainfall magnitude, duration and intensity. For the study area, the rainfall duration and intensity data are not available with the investigators. So, analysis of trends in rainfall intensity has been carried out indirectly. An index called Daily Rainfall Variability Index (DRVI) has been considered for the purpose which has been defined as:

$$\text{DRV Index} = \text{Amount of rainfall in a year} / \text{Number of rainy days in that year}$$

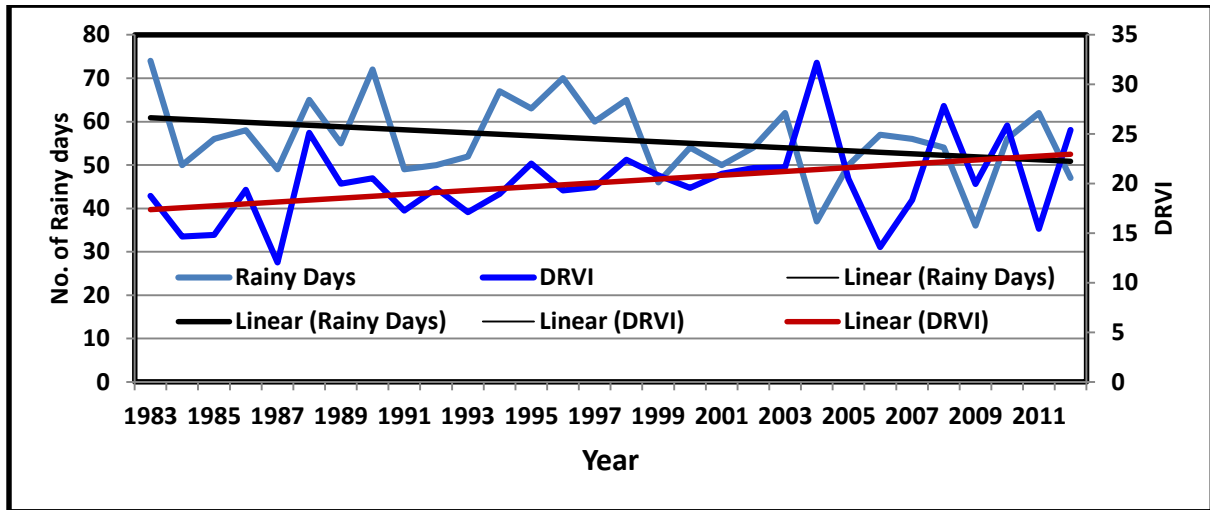
The DVRI gives the amount of rainfall received in a year per rainy day and as such, indirectly indicates the effect of rainfall intensity and duration. A higher DRV index indicates a higher amount of rainfall received per rainy day in that year which could be due to increased intensity or duration within a 24 hour span. Fig. 25 shows the variation of annual DRV Index for Chandigarh region for the period of 1958-2012.



**Fig. 25: Annual variation of DRV Index at Chandigarh (1958-2012)**

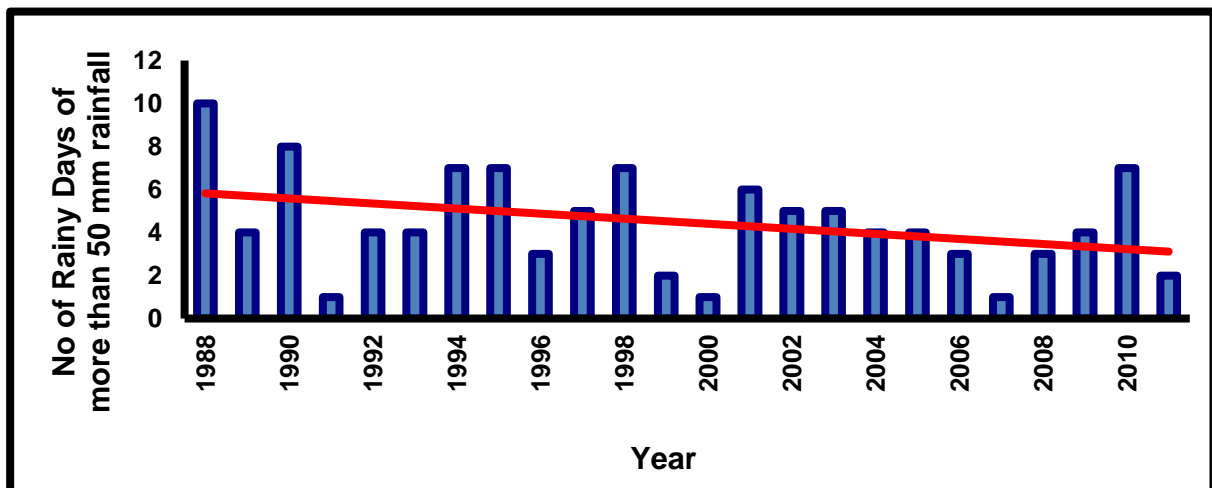
A clear cut change (increase) in the DRV Index can be seen which indicates the change of pattern of rainfall at Chandigarh. Thus, for an average rainy day, the amount of rainfall is increasing which indirectly indicates an increase in rainfall intensity. This is clear from

Fig. 26 which shows a comparison of annual DRVI and annual number of rainy days for the period of 1983 to 2012. This Figure clearly shows that while the number of rainy days during 1983-2012 is showing a decreasing trend, the DRVI exhibits an increasing trend. As far as Sukhna lake is concerned, since its catchment, being located in the Siwalik Hills, is very fragile with highly erodible soils, this may mean increased runoff potential with a danger of increase in erosion and consequently, an increase in the lake sedimentation rates in future in response to higher rainfall intensities.



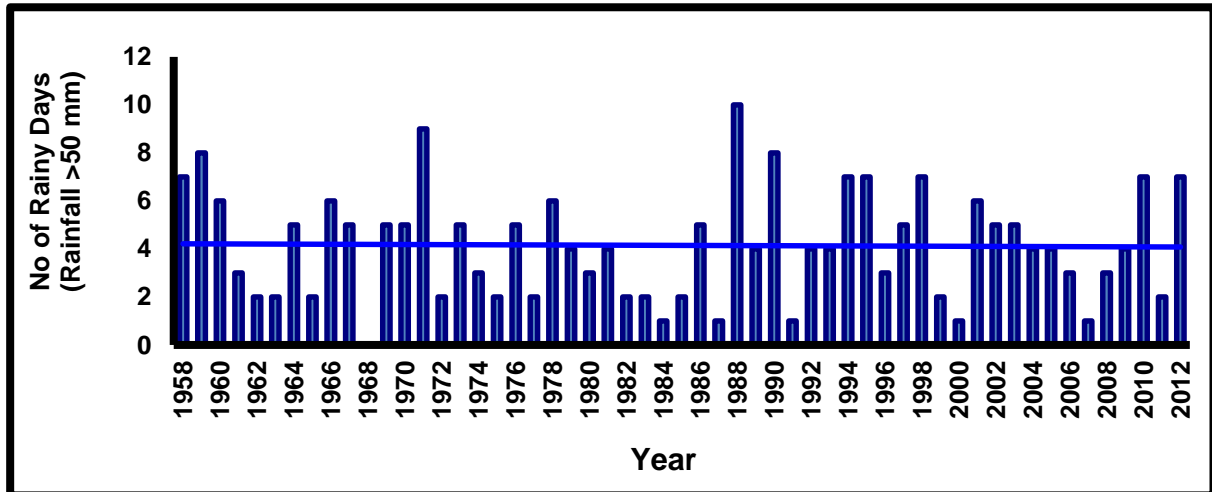
**Fig. 26: A comparison of number of rainy days with DRV Index (1983-2012)**

All rain events do not produce runoff. Some rainfall events of specific magnitude or specific intensity or duration (or different combinations of it) may produce runoff. Since decrease in number of rainy days with high intensity/magnitude rainfall can be one of the possible reasons for declining water availability for the lake, so an analysis of occurrence of high magnitude rainfall events was carried out. Fig. 27 presents the data on number of rainfall events with more than 50 mm rainfall. It can be seen that from 1988 to 2011 there has been a continuous and significant decline in such number of rainy days of more than 50 mm.



**Fig. 27: Variation in number of rainy days with rainfall of 50 mm or above during 1988--2011**

However, years 2010 and 2012 show that there is no such general and long term trend of declining number of rainy days as far as heavy rainfall events are concerned. The long term data (1958-2012) does not show any such declining trend as can be seen in Fig. 28. However, there appears to be no definite periodic pattern in the number of such days, as has been seen for the rainfall also. Year, 2011 received only a few such heavy rainfall events which helped in causing reduction in inflow to the lake.



**Fig. 28: Long term trend in number of rainy days with rainfall of 50 mm or above**

The above analysis of rainfall and number of rainy days shows that on a long term basis, there is no falling trend in the magnitude of rainfall as well as number of days with heavy magnitude rainfall events. Moreover, there is no specific periodic pattern both in rainfall and number of such heavy rainfall days. There is of-course a significant variation from year to year.

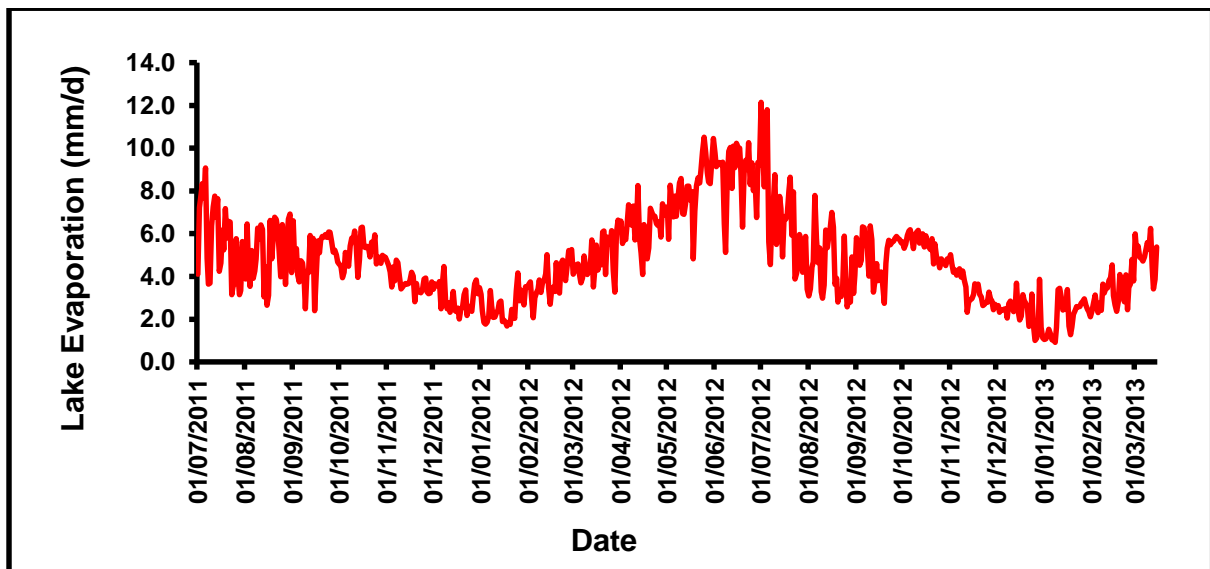
However, as far as the water scarcity problem of the lake is concerned, this variation cannot be said as the only or most significant reason, because during 2007 which was also a deficit rainfall year with monsoon rainfall of 460.6 mm, the number of such high rainfall events were significantly less as compared to the deficit rainfall year 2011, but there was significantly more runoff in 2007 as compared to year 2011. Furthermore, it should be remembered that this variation has existed ever since the lake was created in 1958, and there were many years with very few high rainfall events (Fig. 27), but the lake received significant runoff during the initial two decades after its creation (1958-78) which led to heavy siltation of the lake.

#### **6.4 Evaporation Losses from Sukhna Lake**

The total daily variation in lake evaporation rates for the entire study period of 1 July, 2011 to 15<sup>th</sup> March, 2013 is shown in Fig. 29. It can be seen that after the monsoon was over by September, 2011, evaporation rates increased briefly during October, 2011. The evaporation rates then started decreasing till about the end of January, 2012. Evaporation rates then started increasing from February, 2012 and continued to increase till June

2012 end. During June and July, 2012 the daily evaporation rates remained highly variable on day to day basis due to corresponding variations in the other meteorological parameters such as net radiation and vapour pressure deficit. A steady fall in evaporation rates from October, 2012 to January, 2013 was observed after which it started to steadily increase again till 15<sup>th</sup> March, 2013. The fall in evaporation during post monsoon months till January can be mainly attributed to the decreasing radiation, temperatures as well as vapour pressure deficit. Rise in these values from February onwards causes a steady increase in the lake evaporation from February onwards.

Maximum daily evaporation rate observed during the study period was 12.2 mm/d on 1<sup>st</sup> July 2012 while the minimum observed was 0.9 on 8<sup>th</sup> January, 2013.



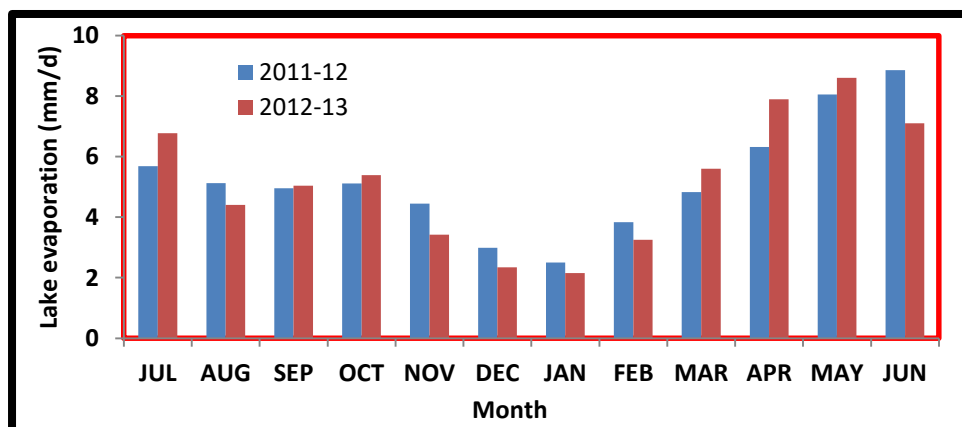
**Fig. 29: Variation of daily evaporation rates from Sukhna Lake during study period**

The average monthly rates of evaporation derived from the daily data for different months during the study period are tabulated in Table 7. The lowest average evaporation rate of 2.15 mm/d was observed for the month of January, 2013 while the highest was observed in June, 2012 (8.86 mm/d).

A comparison of the evaporation rates of years 2011-12 and 2012-13 is shown in Fig. 30. It can be easily seen that except for the winter months of November to February, in all the other months evaporation rates were higher during 2012-13 compared to 2011-12. Higher rates in October 2012 compared to 2011 may also be one of the reasons for higher fall in daily lake water levels observed in October 2012 as compared to October, 2011.

**Table 7: Average monthly rates of evaporation from Sukhna Lake during July, 2011- June, 2013**

Month	Average Lake Evaporation (mm/day)
Jul-2011	5.69
Aug-2011	5.12
Sep-2011	4.96
Oct-2011	5.11
Nov-2011	4.45
Dec-2011	2.99
Jan-2012	2.50
Feb-2012	3.83
Mar-2012	4.83
Apr-2012	6.32
May-2012	8.05
Jun-2012	8.86
Jul-2012	6.78
Aug-2012	4.41
Sep-2012	5.04
Oct-2012	5.39
Nov-2012	3.42
Dec-2012	2.34
Jan-2013	2.15
Feb-2013	3.25
Mar-2013	5.6
Apr, 2013	7.9
May, 2013	8.6
Jun, 2013	7.1



**Fig. 30: Comparison of the evaporation rates of 2011-12 and 2012-13**

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. The total volume of water lost through the process of evaporation from the lake during different months of the study period is presented in Table 8. Higher losses of water were reported for the warmer months of summer and lower losses were observed for the cooler months of winter. During the period of July, 2011 to June, 2013, the losses were maximum in June, 2012 with a total loss of 34.13 Ham and lowest in the month of January, 2013 with a total loss of 9.64 Ham. During June, 2012 the water level in the lake was very low as the lake was almost on drying condition and therefore, the available water spread area for evaporation was very less. Still the losses are high because the evaporation rates during this month are higher. As a matter of fact they were the highest of all the rates observed for all the months during the study period.

**Table 8: Volume of water lost through Sukhna Lake due to evaporation**

Month	The total volume of water lost through the process of lake evaporation
July-2011	23.84
August-2011	22.45
September-2011	23.67
October-2011	27.10
November-2011	23.03
December-2011	16.34
January- 2012	11.89
February- 2012	14.86
March-2012	19.67
April- 2012	23.81
May-2012	30.91
June-2012	34.13
July-2012	16.48
August-2012	15.41
September-2012	22.24
October-2012	25.99
Novemeber-2012	15.04
December-2012	10.66
January-2013	9.64
February-2013	13.49
March, 2013	25.11
April,2013	33.38
May, 2013	36.95
June, 2013	30.14

## 6.5 Variation in Lake Water Levels

Variation in water levels of a lake is an indication of the dynamics of the lake system and its hydrological behaviour. It is an indication of the response of the lake and its catchment to changes in climatic variables (such as rainfall, evaporation etc). Also, it reflects the interaction of the lake with its catchment particularly its hydro-geological and hydro-meteorological characteristics. Variations in lake levels are determined by the rainfall and other meteorological factors. While the rainfall characteristics like amount and intensity decide the inflow to the lake, the meteorological factors decide the losses like evaporation from lakes. The changes in land use also affect the runoff rate from the catchment in different years thereby contributing to lake level variations. Since all these factors vary from year to year, and season to season within a year, the variations in lake levels from year to year, and season to season also are not the same. Analysis of variation in the lake levels is very important for understanding the water budget of the lake as well as to understand the individual contribution of various factors responsible for rise or fall in the volume and water spread area of a lake.

Systematic and adequate historical data on water levels of the Sukhna lake are not available. So, for the purpose of the present study, systematic daily lake water level data have been generated. The data have been collected from 1<sup>st</sup> July, 2011. An Automatic water level recorder (AWLR), also called Digital Water Level Recorder (DWLR) was installed in the lake for the purpose (Fig. 31). Daily water levels have also been monitored manually from the gauge site located near the pumping station tower.



**Fig. 31: Automatic water level recorder installed at the lake**

Variations in lake levels have been analyzed for the study period of July, 2011 to February, 2013. Variations for the monsoon and post-monsoon periods have been analyzed separately for better understanding of the lake behavior. These are discussed below.

### 6.5.1 Variations during Monsoon 2011

Variations of lake water level during the monsoon months of 2011 are shown in Fig. 32. The first major increase in the water level was recorded on 27<sup>th</sup> August, 2011 which showed an increase of 0.27 m in the lake water level. This was mainly due to the heavy rainfall event of 26<sup>th</sup> August, 2011. A rainfall of 87.9 mm was recorded in the catchment on this day while a rainfall of 82 mm was recorded at the lake site. The maximum water level reached by the lake was 352.56 m (amsl) during the third week of September. The monsoon was more or less over by this period. This highest level was reached after few significant rainfall events during the third week of September. A rainfall of 56 mm was recorded at Lake site on 13 September while an average rainfall of 36.7 mm was recorded for catchment on 15<sup>th</sup> September. A rainfall of 10.4 mm recorded thereafter in the catchment on 27 September, 2011 did not cause any change in the lake level. The water level of the lake on 1<sup>st</sup> July 2011 was 351.75 m and the water level observed on 30 September, 2011 (end of monsoon) was 352.46. Thus, a net change of 0.71 m was observed during the monsoon period of 1<sup>st</sup> July, 2011 to 30 September, 2011. This caused a net change of 98.85 ham of volume of water in the lake (988445 cubic meters or 0.099 Mcum). The average change of water level during 1<sup>st</sup> July-30<sup>th</sup> September, 2011 was 7.72 mm/day. This change is the net result of the increase in lake levels due to inflow of water and decrease due to losses such as evaporation etc.

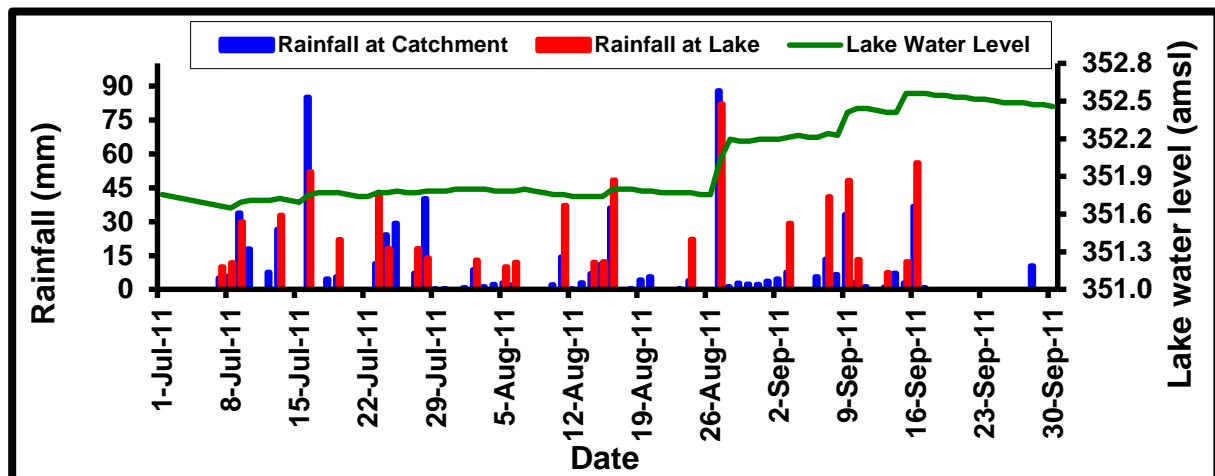
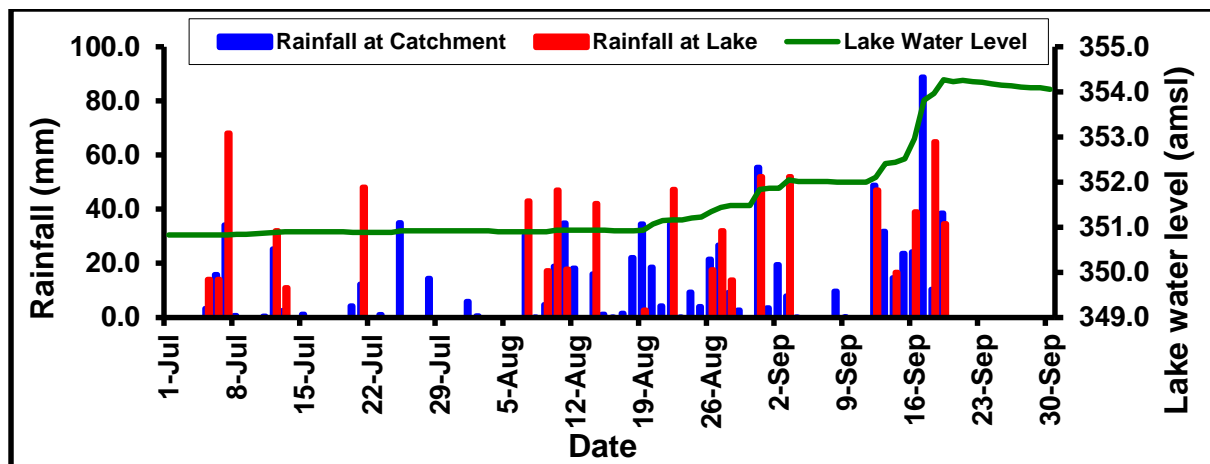


Fig. 32: Variations of lake water level during Monsoon months of 2011

### 6.5.2 Variations during Monsoon 2012

Variations of lake water level during the monsoon months of 2012 are shown in Fig. 33. During the monsoon of 2012, the maximum water level reached by the lake was 354.27 m (amsl) on 19<sup>th</sup> September, 2012. The monsoon was more or less over after this rainfall. This highest level was reached after few significant rainfall events during 12-19 September. An average rainfall of 88.8 mm was recorded in the catchment on 17<sup>th</sup> September while a rainfall of 64.8 mm was recorded at the lake on 18<sup>th</sup> September. The water level of the lake on 1<sup>st</sup> July 2012 was 350.82 m and the water level observed on 30 September, 2012 (end of monsoon) was 354.06. Thus, a net change of 3.24 m was observed during the monsoon period of 1<sup>st</sup> July, 2012 to 30 September, 2012. The average

change (increase) of water level during 1<sup>st</sup> July-30<sup>th</sup> September, 2012 was 3.52 cm/day which was significantly much higher than the observed rate of 7.72 mm/day during the monsoon of 2011.



**Fig. 33: Variation of lake water levels during monsoon months of 2012**

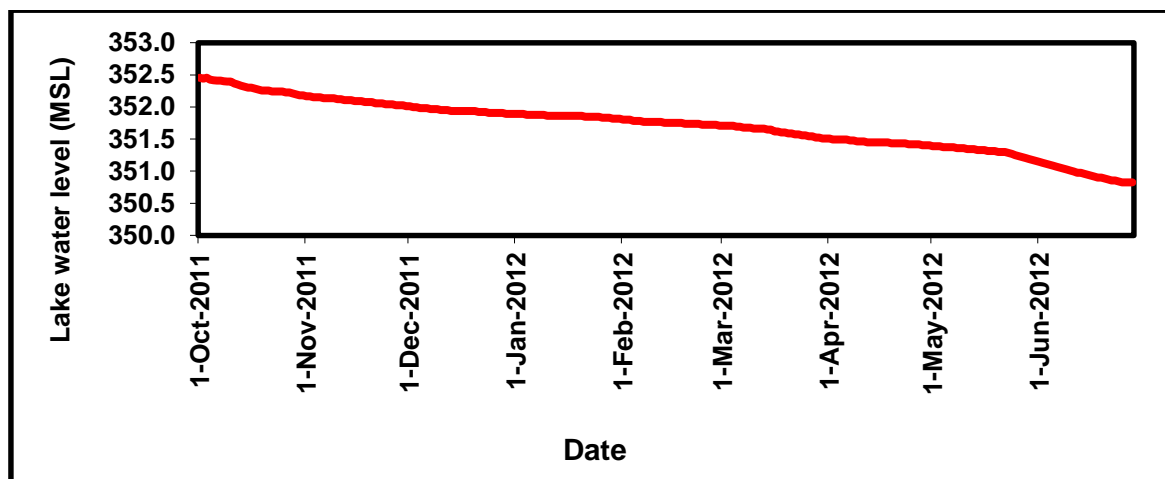
The highest water level reached by the lake, net change in lake water levels, and average rates of lake water level change during different months of the study period are presented in Table 9. As can be seen from the table, of all the three monsoon months of July to September, the highest variations are observed during the month of September, 2012 while lowest in the month of July, 2011. However, it does not mean that there were no increases or decreases in the month of July, 2011. Actually, the rates of increase were compensated by the rates of decreases thereby giving a net change of only 0.05 m only. As far as August, 2011 is concerned on most days a decrease in water levels can be seen. But a single major event of rise in water level has compensated for these decreases, giving a net change of 0.40 m rise in the lake level in the month. During the month of September, 2011, two significant rises in the lake were observed, but decreases on most of the other days gave a result of net change of 0.26 m in the lake level for this month. As far as average rates of change in water levels are concerned, the rate is highest for the month of August (12.78 mm/day) in 2011. However, it can be clearly observed that this rate is basically affected by one single major event of lake level rise. For the similar reason, the average daily change in water level is higher for the month of September, 2011 also as compared to the month of July, 2011. The rate for the month of July, 2011, however, portray a much fairer picture, as the average is not adversely affect by any single major event. As far as 2012 is concerned, for the reasons similar to those for 2011, the rates of change are low. Much more consistent rainfall events of 40 mm during August, 2012 and above added significant water to the lake giving a high rate of 29.5 mm/d change in water level. Few significant rainfall events of second and third week of September, 2012 causing significant increase in lake water level gave a very high average rate of water level change for the month.

**Table 9: Observed water level changes in different monsoon months of 2011 and 2012**

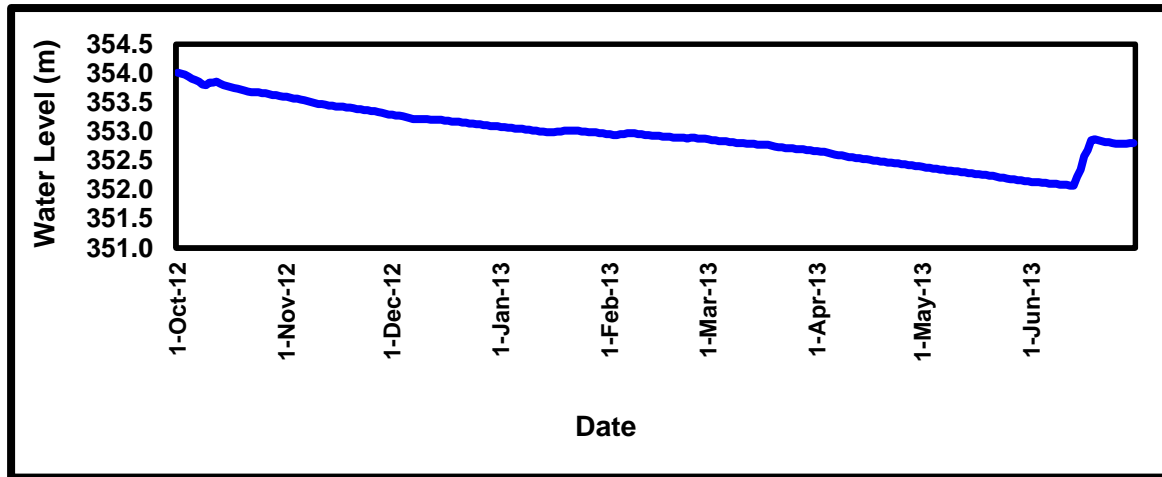
Month	Highest water level reached by the lake (m, amsl)	Net change in lake water level during the month (m)	Average daily change in lake water level (mm/d)
July, 2011	351.8	0.05	1.48
August, 2011	352.2	0.40	12.78
September, 2011	352.56	0.26	8.64
July, 2012	350.92	0.09	2.95
August, 2012	351.83	0.91	29.5
September, 2012	354.27	2.19	70.79

**6.5.3 Variation during Post Monsoon Period**

As far as water level variation in post monsoon months are concerned, the rates of change are not affected by compensation due to increase or decrease, as the water levels generally show only steady decrease. As such, the average value indicates relatively a much realistic figure of daily change in lake water level due to losses only, for these months. Variation of lake water level during post monsoon period of 2011 are shown in Figure 34 while those for the post monsoon of 2012 are presented in Fig. 35.



**Fig. 34: Variation of lake water level during post monsoon period of 2011 (1<sup>st</sup> October, 2011 to 30<sup>th</sup> June, 2012)**



**Fig. 35: Variation of lake water level during post monsoon period of 2012 (1<sup>st</sup> October, 2012 to 30<sup>th</sup> June, 2013)**

Table 10 presents the water level data of the lake for the year 2011-12 for the post monsoon season of October, 2011 to June, 2012 while Table 11 presents the observed per day change in lake water level during different months of the period. Negative sign in the table indicates fall in the water level.

It can be observed from Table 8.4 and 8.5 that the post monsoon lake water level was at 352.46 m (1156.35 ft) (amsl) on 1<sup>st</sup> October, 2011 and 350.82 m on 1<sup>st</sup> July, 2012. From Table 8.5, it can be seen that higher changes in lake water during the post monsoon season were observed in the months of October, 2011 and summer months of May and June, 2012. Although evaporation rates are higher for April, the change in lake level was not high. This was due actually to the addition of water through rainfall falling directly over the lake during this month. The average daily changes for December, January and February were lower owing mainly to low evaporation rates. Evaporation analysis for the lake for the year 2011-12 (reported earlier in Chapter 7) has already indicated that significant part of the losses from the lake were due to evaporation.

**Table 10: Water level data of year 2011-12 (Post- Monsoon Period)**

Date	Water level (amsl) (ft)	Water level (amsl) (m)
1 Oct, 2011	1156.35	352.46
1 Nov, 2011	1155.4	352.17
1 Dec, 2011	1154.9	352.01
1 Jan, 2012	1154.5	351.89
1Feb, 2012	1154.2	351.80
1 Mar, 2012	1153.9	351.71
1 Apr, 2012	1153.25	351.51
1 May, 2012	1152.85	351.39
1 June, 2012	1152.05	351.14
1 July, 2012	1151	350.82

**Table 11: Average per day decline in water level during different months of 2011-12 (Post-Monsoon Period)**

Month	Change in Water level during first and last day of the month (mt)	Per day change in water level (mm/d)
<b>Oct, 2011</b>	-0.274	-8.85
<b>Nov, 2011</b>	-0.152	-5.08
<b>Dec, 2011</b>	-0.122	-3.93
<b>Jan, 2012</b>	-0.076	-2.46
<b>Feb, 2012</b>	-0.091	-3.15
<b>Mar, 2012</b>	-0.198	-6.39
<b>April, 2012</b>	-0.107	-3.56
<b>May, 2012</b>	-0.229	-7.37
<b>June, 2012</b>	-0.320	-10.67

Table 12 presents the water level data of the lake for the year 2012-13 for the post monsoon season of October, 2012 to June, 2013 while Table 13 presents the average observed per day fall in lake water level during different months of the period. Table 14 presents a comparison of the average per day water level change during the post monsoon seasons of 2011-12 and 2012-13.

**Table 12: Water level data of year 2012-13 (Post- Monsoon Period)**

Date	Water level (amsl) (ft)	Water level (amsl) (m)
<b>1 Oct, 2012</b>	1161.55	354.04
<b>1 Nov, 2012</b>	1160.1	353.60
<b>1 Dec, 2012</b>	1159.1	353.29
<b>1 Jan, 2013</b>	1158.45	353.10
<b>1Feb, 2013</b>	1158.0	352.96
<b>1 Mar, 2013</b>	1157.4	352.78
<b>1 April, 2013</b>	1157.05	352.67
<b>1 May, 2013</b>	1156.15	352.39
<b>1 June, 2013</b>	1155.30	352.14
<b>1 July, 2013</b>	1157.50	352.81

**Table 13: Average per day decline in lake water level during different months of 2012-13 (Post-Monsoon Period)**

Month	Change in Water level during first and last day of the month (m)	Per day change in water level (mm/d)
Oct, 2012	-0.427	-13.77
Nov, 2012	-0.290	-9.65
Dec, 2012	-0.198	-6.39
Jan, 2013	-0.122	-3.93
Feb, 2013	-0.09	-3.15
Mar, 2013	-0.004	-3.55
Apr, 2013	-0.009	-9.33
May, 2013	-0.008	-8.06
Jun, 2013	0.022	22.33

**Table 14: Comparison of average per day change in water level during different months of 2011-12 and 2012-13**

Month	Per day water level change during 2011-12 (mm/d)	Per day water level change during 2012-13 (mm/d)
October	-8.85	-13.77
November	-5.08	-9.65
December	-3.93	-6.39
January	-2.46	-3.93
February	-3.15	-3.15
March	-6.39	-3.55
April	-3.56	-9.33
May	-7.37	-8.06
June	-10.67	22.33

It can be observed from Tables 12, 13 and 14 above that the lake water level decline in different post monsoon months is much higher in 2012-13 as compared to 2011-12. The evaporation losses for October are slightly higher in the year 2012 (5.39 mm/d) as compared to 2011 (5.11 mm/d), but the amount of fall in lake water level during the months of October, 2012 appear to be much higher and do not seem to be mainly due to increased evaporation rates. This is further proved by the fact that evaporation rates for the months of November to January are lower in 2012-13 than in 2011-12, still the water level decline in these months during the year 2012-13 are higher compared to 2011-12. As a reminder, the evaporation rates of the two years are compared again in Table 15 below.

**Table 15: Comparison of evaporation rates**

Month	Lake evaporation rate (mm/d)	
	2011-12	2012-13
October	5.11	5.39
November	4.45	3.42
December	2.99	2.34
January	2.50	2.15
February	3.83	3.25
March	4.83	5.6
April	6.32	7.9
May	8.05	8.6
June	8.86	7.1

Although no records are available on the amount of water being pumped from the lake for gardening and cleaning of floors by the horticulture department and CITCO, however, based on the information collected from the Engineering Department, it is understood that these withdrawals are not very significant so as to cause such high changes in lake water levels. This is also substantiated by the water balance of the lake discussed subsequently. This leaves another possibility that there may be variation in seepage losses from the lake during the two years. However, a close look at the data in Tables 8.8 and 8.9 do not indicate significant seepage losses during the months of January and February (particularly February) because the rate of fall of lake water in these months represent more or less equivalent to the evaporation rates. Thus, there does not seem to be any additional seepage losses for this period in 2013 compared to year 2012. However, the differences in the fall of lake water level for October to December in years 2011 and 2012 are significant. The higher rates of fall in October, November and December, 2012 compared to year 2011 as well as compared to other post monsoon months of 2012, may be due to differential rates of seepage losses during these months. To understand this unique behaviour of the lake, further analysis of the past data has been carried out as discussed below.

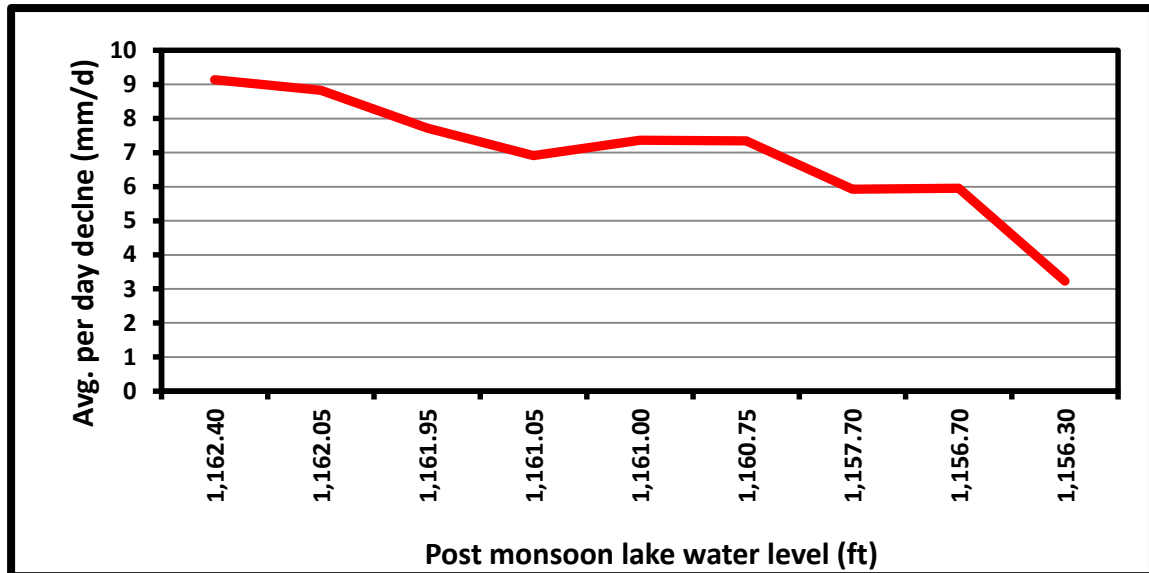
The present study had been initiated from July, 2011 and systematic daily lake water level data are being collected under the study from 1<sup>st</sup> July, 2011. Unfortunately, no systematic water level records are available for the past, except for some data in 2010-11. The lake water level data are being maintained by the Engineering Department. However, for want of any specific objective, no systematic daily data have been collected by the Department in the past. Only some scanty observations, that too only during the monsoon (mostly after rainfall events), have been recorded. Thus, a water level record is available since 1983 giving some water levels during the monsoon months. The first and last data of water level appear to be related to first rainfall and last rainfall event respectively. Assuming the changes in lake water level between the last recorded water level of a monsoon season and the first recorded water level of the next season as representing the water level regime of the post monsoon season, some analysis has been carried out and the results of the per day fall in post monsoon season of different years (since 2001) have been obtained. These are presented in the Table 16.

**Table 16: Water Level changes in lake during post monsoon of 2001 to 2012**

Date	Water level (amsl)		Date	Water level (amsl)		Net change in lake level (m)	Average per day change in water level	
	(ft)	(m)		(ft)	(m)		m/d	mm/d
23-Aug-01	1161.95	354.16	9-Jul-02	1153.85	351.69	-2.469	-0.008	-7.72
18-Sep-02	1161	353.87	5-Jul-03	1154	351.74	-2.134	-0.007	-7.36
12-Sep-03	1160.75	353.80	1-Aug-04	1153	351.43	-2.362	-0.007	-7.34
27-Aug-04	1161.65	354.07	4-Jul-05	1154.6	351.92	-2.149	-0.007	-6.91
24-Sep-05	1162.4	354.30	1-Jul-06	1154	351.74	-2.560	-0.009	-9.14
3-Sep-06	1156.3	352.44	2-Jul-07	1153.1	351.46	-0.975	-0.003	-3.23
12-Sep-07	1157.6	352.84	<b>Data Not Available</b>					
<b>Data Not Available</b>			1-Jul-09	1153.90	351.71			
13-Sep-09	1157.70	352.87	3-Jul-10	1152.00	351.13	-1.737	-0.006	-5.93
24-Sep-10	1162.05	354.19	11-Jul-11	1153.65	351.63	-2.560	-0.009	-8.83
15-Sep-11	1156.7	352.56	4-Jul-12	1151.00	350.82	-1.737	-0.006	-5.95

A close look at the data of Table 16 brings out that the average per day fall in lake water levels are in general higher in those years when the post monsoon water level of the lake was at higher elevation (above 1157.7 ft). During the years 2006-07, 2009-10 and 2011-12 when the post monsoon level was at or below 1157.7 ft, the per day loss in water level was relatively lesser. The losses were particularly high if the post monsoon level was at 1160 ft or above. This means that the lake behaves uniquely at certain level. In general, fall in per day water level was least at 1156.3 ft elevation (2006-07) and more above this level. Although further detailed investigations are needed to establish the fact as well as this critical level, it certainly appears that there are possibilities of more seepage losses from the lake above this critical level (of above 1156.3 ft amsl).

The data of Table 16 is also shown graphically in Fig. 36. It can be observed from the Fig. 36 that there is a definite correlation between the average daily fall in lake water level during post-monsoon months and the lake water at the end of monsoon. The correlation coefficient is as high as 0.9. The higher is the lake water level at the end of the monsoon season, more is the change in lake water level during post monsoon months. However, the decline is very high as the lake water level comes down from 1162.4 to 1161.05. The change in water level between 1161.05 ft to 1160.75 ft is not very steep. However, after 1160.75 the average decline in lake water levels falls sharply. After the lake water level of 1156.7 is reached, the fall reduces significantly to a very low range of about 3 mm/d at 1156.3 ft and below.



**Fig. 36: Average daily decline in the lake water level during post monsoon months at different levels of post monsoon lake water levels**

#### 6.5.4 Analysis of lake water level variation year for 2010-11

Fortunately, some post monsoon water level data have been recorded by the Engineering Department during 2010-11 and are available for analysis. The data are presented in Table 17.

**Table 17: Lake water level data for year 2010-11**

Date	Water level amsl(ft)	Water level amsl ( m )
29-Sep-10	1162.00	354.18
27-Nov-10	1159.20	353.32
3-Dec-10	1158.80	353.20
15-Dec-10	1158.50	353.11
24-Dec-10	1158.20	353.02
30-Dec-10	1158.00	352.96
4-Jan-11	1158.00	352.96
15-Jan-11	1157.80	352.90
1-Feb-11	1157.50	352.81
15-Feb-11	1156.20	352.41

Since the water level at the end of the monsoon season during the year 2010 was 1162 ft, it more or less represents the scenario similar to the year 2012 where the post monsoon water level recorded was 1162.25 on 21<sup>st</sup> September, 2012. The water level was observed to be at 1156.2 ft on 15<sup>th</sup> Feb 2011 and on 15<sup>th</sup> Feb 2013 it was 1157.9 ft. The slightly higher water level during 2013 is due to combined effect of the difference in rainfall received and variation in evaporation rate. From the Table 18 below, it can be seen that

average per day change during different months in post monsoon of 2010-11 are much higher compared to 2011-12 and even more than 2012-13.

**Table 18: Water Level changes in Lake during post monsoon of 2010-11**

Date	Water level		Date	Water Level		Net change in lake level	Per day change in lake water level	
	ft	m		Ft	m		m	m/d
29-Sep-10	1162.00	354.18	27-Nov-10	1159.20	353.32	-0.85	-0.014	-14.22
27-Nov-10	1159.20	353.32	15-Dec-10	1158.50	353.11	-0.21	-0.011	-11.22
15-Dec-10	1158.50	353.11	15-Jan-11	1157.80	352.90	-0.21	-0.007	-6.88
15-Jan-11	1157.80	352.90	15-Feb-11	1156.20	352.41	-0.49	-0.016	-15.73

From the analysis of the lake water level data of different years from 2001 to 2013 and detailed analysis of the data for the years 2010-11, 2011-12 and 2012-13, it is evident that the fall of lake water level observed during the post monsoon season of 2013 is normal and within the normal annual variability range. Irrespective of the higher evaporation rates of October month, it should be noted that, in comparison to the post monsoon seasons where the lake water levels is about 1156.3 or below, the fall in water level of the lake would generally be higher if the lake water at the end of the monsoon season is over 1156.3 ft or so. The decline in lake water level is very high as the lake water level comes down from 1162.4 to 1161.05 (about 9 mm/d). The decline in lake water level between water levels at about 1161.0 ft and 1160.0 is about 7mm/d to 7.5 mm/d. From this level upto 1156.5 the change is about 5 mm/d to 6 mm/d. After the lake water level of about 1156.3 and below is reached, the average daily decline reduces significantly to a very low range of about 3 mm/d. Of course, there would be some variations from this generalization depending upon the month in which the various lake water levels occur as evaporation rates would vary from month to month. Below the water level of 1156.3 ft, there does not appear to be any significant seepage losses. The water level at the end of the monsoon season of 2011 was at 1156.35 ft and the water balance carried out for the post monsoon period of 2011-12 (discussed subsequently under the water balance section) does not indicate any significant seepage losses except for the month of October, 2011.

The high rate of decline in lake water level when the post monsoon lake water level is in the range of 1160-1163 ft indicates that in this portion there may be more seepage losses from the lake bed at these elevations comprising the upper periphery. Below the level of about 1156.3 ft or so, the lake bottom and sides being silted, the seepage losses become negligible. Further, it should be noted that the maximum height of the dam was located at an elevation of 1160 ft (353.57 m) at the time of its construction in year 1958 which was subsequently increased twice first upto 1161.5 ft and subsequently to attain the present maximum height at an elevation of 1163 ft. Since the water losses are higher within this zone, there may actually be seepage losses from the intercept portions at the elevations of 1160 ft and 1161.5 ft which may also be a reason for increased rate of water loss from the lake as seepage, till the water level comes below this level. Further, dredging operations carried out in many years prior to the onset of monsoon, particularly in northern part of the lake, disturbs the compactness of the settled and stabilized soil,

thereby opening up soil pores. This may also be working as an aid to the seepage losses particularly till the pores are filled up again with the clay.

## 6.6 Water balance of lake

Detailed water balance has been carried out for 2011-12, 2012-13 and monsoon season of 2010. Two of these three (2010 and 2012) monsoon seasons were normal monsoons while 2011 was a deficit rainfall year. These are discussed below.

### 6.6.1 Water Balance for the Water Year 2011-12

The estimation of water balance components starts with estimation of change in storage during different months. The change in storage has been estimated using the data on observed water levels in lakes and then interpolating the corresponding volumes (capacity) of the water from the hypsographic curve (depth-capacity curve). The various observed water levels have already been presented and discussed previously. The hypsographic curve has been developed for the lake by IPRI, Amritsar after the bathymetric survey of the lake carried out during the post monsoon season of 2010 (Fig. 37). The values of volumes at various water levels have been interpolated from this curve. The calculations of change in lake volumes are presented in Table 19

Positive values in the table 19 indicate a rise in the lake level and negative values indicate fall. The increase in water levels during July to September, 2011 and consequent change in lake volume are due to the inflows of water to the lake as well as direct rainfall over the lake. By September end, the rain stopped and inflows from inflowing channel more or less stopped. Although due to intermittent rains in later months, some water got added to the lake through direct rainfall into the lake, but it was not adequate to rise the lake levels as it was less than the corresponding evaporation and other losses during these months. As such, the change in lake level always shows a negative sign from October, 2011 onwards. A steady fall can be seen from January, 2012 onwards. However, the fall in lake level in April, 2012 is less compared to March, 2012. It was not because losses were less in April 2012, but because there was a significant addition of water to the lake due to the rainfall directly falling over the lake in the month of April, 2012 (Table 20).

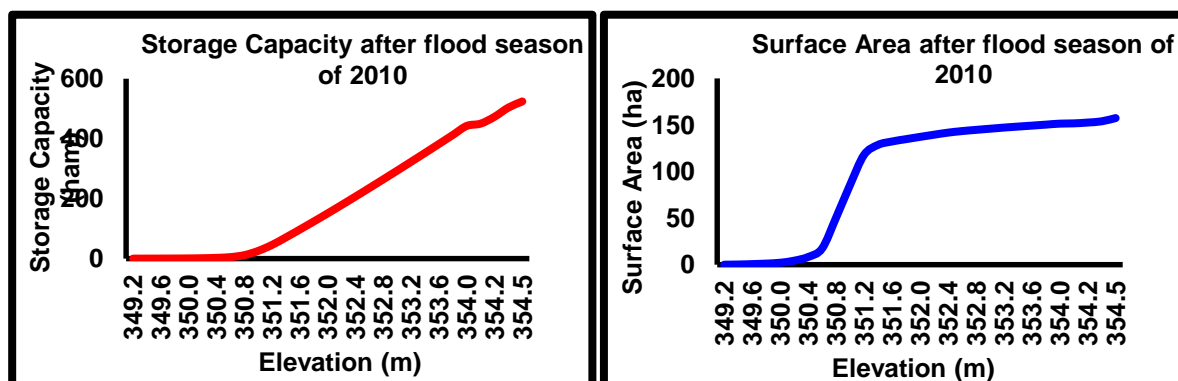


Fig. 37: Depth-area-capacity curves for Sukhna lake (Source: IPRI, 2011)  
Volume of water added to lake by direct rainfall over lake

**Table 19: Change in lake storage during different months**

Month	Water level on the first day of the month in meters above msl	Corresponding capacity (Volume) (Ham)	Water level on the last day of the month in meters above msl	Corresponding Capacity (Volume) (Ham)	Net change in storage (volume) of lake (Ham)
Jul, 2011	351.75	123.93	351.80	130.74	6.81
Aug, 2011	351.80	130.74	352.20	185.92	55.18
Sep, 2011	352.20	185.92	352.46	222.77	36.85
Oct., 2011	352.46	222.77	352.18	183.10	-39.67
Nov, 2011	352.17	181.69	352.01	159.48	-22.22
Dec, 2011	352.01	159.48	351.89	142.99	-16.48
Jan., 2012	351.89	142.99	351.82	133.46	-9.53
Feb, 2012	351.82	133.46	351.71	118.58	-14.88
Mar, 2012	351.71	118.58	351.51	91.95	-26.63
Apr. 2012	351.51	91.95	351.39	76.26	-15.69
May, 2012	351.39	76.26	351.16	47.12965	-29.13
June, 2012	351.16	47.12965	350.82	16.5621	-30.57

As explained earlier, for generating data on rainfall at lake, a rain gauge has been installed at the lake site. The rainfall data for the lake site is shown in the Table 20. The table also shows the volume of water received by the lake due to rainfall falling directly over the lake which has been estimated by multiplying the maximum water spread area of the lake (157.57 Hectares) with the rainfall depth in meters.

**Table 20: Rainfall at lake**

Month	Rainfall over lake (mm)	Volume of water in lake due to rain over lake (Ham)
July, 2011	264.6	41.70
Aug, 2011	236.1	37.20
Sep., 2011	195.1	30.74
Oct., 2011	0	0.00
Nov., 2011	0	0.00
Dec., 2011	16	2.52
Jan., 2012	21.6	3.40
Feb., 2012	0.0	0.00
Mar, 2012	0.0	0.00
April, 2012	84.0	13.24
May, 2012	0	0.0
June, 2012	0	0.0

6.6.1.1 *Estimation of “Total Losses” from the lake*

After determining the change in storage, the next important step is to determine the losses from the lake. For the sake of convenience, the losses from lake during post monsoon months have been estimated first and then the estimates of losses in the monsoon months have been obtained.

6.6.1.2 *Total losses from lakes during non monsoon months*

During the post-monsoon period from October, 2011 to April, 2012, there is almost no rainfall or very insignificant rainfall in the catchment and, as has been verified in the field also, there have been no flows in the river (Sukhna choe) during this period. Since there have been no observed flows in the inflow channel during this post- monsoon period of 2011, it is safe to assume that whatever increase in volume of lake is observed, it is due to direct rainfall falling over the lake which has been estimated above (Table 8.16). Moreover, for those months, which did not receive any rainfall at the lake site, there is no contribution from the rain falling directly over the lake to the lake storage. The total change in lake storage in such months directly represents the total losses from the lake.

Now, following the water balance for these non-monsoon months, we can find out the total losses of water in these months as follows:

$$\text{Total inflow} - \text{Total losses from the lake} = \text{Total change in lake storage}$$

Therefore,

$$\text{Total losses from the lake} = \text{Total inflow to the lake} - \text{Total change in lake storage}$$

As explained above, there has been no flow (surface runoff) coming to the lake through the inflow river during the post monsoon months. The total inflow to the lake consists of only the volume contributed by the direct rainfall over the lake. Thus, for these non-monsoon months, when there has been no runoff to the lake from the catchment, the equation becomes:

$$\text{Total losses from the lake} = (\text{Total volume of water due to direct rainfall over the lake}) - (\text{Total change in lake storage})$$

The total losses from the lake for the non-monsoon months have been thus estimated using the equation above. The estimated values are presented in Table 21.

**Table 21: Total losses from the Lake**

Month	Volume of water added to lake due to rain over lake (Ham) (a)	Total change in lake storage (Ham) (b)	Total losses from lake (Ham) (a-b)
Oct., 2011	0.00	-39.67	39.67
Nov., 2011	0.00	-22.22	22.22
Dec., 2011	<b>2.52</b>	-16.48	19.00
Jan., 2012	<b>3.40</b>	-9.53	12.93
Feb., 2012	0.00	-14.88	14.88
Mar, 2012	0.00	-26.63	26.63
April, 2012	<b>13.24</b>	-15.69	28.94
May, 2012	<b>0</b>	-29.13	29.13
June, 2012	<b>0</b>	-30.57	30.57

As already mentioned, the total losses of water from Sukhna lake are because of:

- (i) Water losses due to evaporation
- (ii) Volume of water pumped by horticulture department for irrigating the gardens around the lake
- (ii) Water pumped by CITCO for cleaning and washing of area around boating

No precise data are available on the water being pumped from the lake. The total estimated evaporation losses from the lake are presented in Table 22 again for the sake of convenience.

**Table 22: Evaporation losses from the lake**

Month	Average evaporation rate (mm/day)	Total evaporation losses in volume (Ham)
Oct., 2011	5.11	27.10
Nov., 2011	4.45	23.03
Dec., 2011	2.99	16.34
Jan., 2012	2.50	11.89
Feb., 2012	3.83	14.86
Mar, 2012	4.83	19.67
April, 2012	6.32	23.81
May, 2012	8.05	30.91
June, 2012	8.86	34.13

The total evaporation losses when subtracted from the total losses from the lake give the losses due to other reasons such as pumping from the lake and seepage losses from lake, if any, referred to as “other losses” in this study. The estimated other losses are given in Table 23.

**Table 23: Estimated “Other losses” from the lake**

Month	Total losses from lake (Ham)	Total evaporation losses (Ham)	Other losses from lake (Ham)
Oct., 2011	39.67	27.10	12.57
Nov., 2011	22.22	23.03	-0.81
Dec., 2011	19.00	16.34	2.66
Jan., 2012	12.93	11.89	1.04
Feb., 2012	14.88	14.86	0.02
Mar, 2012	26.63	19.67	6.96
April, 2012	28.94	23.81	5.13
May, 2012	29.13	30.91	-1.78
June, 2012	30.57	34.13	-3.56

Table 23 shows that other losses (which are due to pumping for irrigation for gardens, pumping for cleaning and washing, and may be seepage from lake also) are relatively very less except for the month of October. It has already been demonstrated earlier (in the section on post monsoon water level variation) that there are some seepage losses when the lake water level is at elevation of about 1156.3 ft or above. A negative value for the months of November, May and June, 2012 means either the water balance has some errors or that there is some sub-surface inflow to the lake (possibly as groundwater flow from the part of catchment just south of Kansal diversion channels from which overland flow occurs. However, for reasons explained earlier, and also because there have been no rains in these months, underground inflow of water as lateral seepage or sub-surface flow to the lake in the months of November, May and June does not appear feasible and therefore it can be attributed to error of water balance only.

From the values of “other losses” for the lake as shown in the Table 23, the average values of other losses can be considered 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 is reasonable to assume that of the average 2-3 Ham water being pumped for 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.

Table 8.19 also indicates a relatively high “other losses” for October month compared to other months. This is because of seepage losses from upper elevations of the lake bed. This may also be because of opening of pores because of dredging which was carried out prior to monsoon. Assuming average “other losses” from the lake for irrigation and cleaning to be about 2-3 Ham as discussed above, these seepage losses come out to be about 10 Ham for the month of October, 2011. Thus, the various losses terms have been approximately separated and approximate errors of water balance have been estimated (Table 24).

**Table 24: Errors of water balance**

Month	Total losses from lake (Ham) (a)	Total evaporation losses (Ham) (b)	Seepage Losses (Ham) (c)	Assumed losses of pumping (Ham) (d)	Error of water balance (Ham) (a-b-c-d)
Oct., 2011	39.67	27.10	10	2.57	0
Nov., 2011	22.22	23.03	--	2	-2.81
Dec., 2011	19.00	16.34	--	1	1.66
Jan., 2012	12.93	11.89	--	1	0.04
Feb., 2012	14.88	14.86	--	2	-1.98
Mar, 2012	26.63	19.67	--	2	4.96
April, 2012	28.94	23.81	--	2.5	2.63
May, 2012	29.13	30.91	-	3	-4.78
June, 2012	30.57	34.13	-	3	-6.56

**6.6.1.3 Errors of Water Balance**

Table 24 above shows that the errors in estimation of water balance components, range from -6.56 Ham to 4.96 Ham. Negative sign indicates that the errors may be due to over estimation of the evaporation and positive sign indicates errors to be due to under estimation. Alternatively, the errors could be due to underestimation or overestimation of “change in storage capacity” component respectively (based on which the total losses have been determined). The errors in “change in storage capacity” component could be caused due to errors of bathymetric survey or errors in recording water levels. After the bathymetric survey was carried out, there has been dredging which must have changed the profile of the lake bed to lower elevations. Moreover, the sediments move within the water body due to water movements thereby changing the bottom profile. It is also important to know that the lake was almost drying during the latter parts of summer, 2012 and measurement of water level itself was difficult, as the level went below the minimum gauge mark. The errors of evaporation possibly relate to over estimation particularly during warmer months. Errors upto 20% for evaporation estimation have also been reported by Rosenberry et al (2007). Since evaporation losses can be at the most equal to total losses but certainly not more than total losses, so the value of evaporation can be corrected to be maximum as total losses (as no significant groundwater inflow is expected in these months). However, it should be noted that the errors of evaporation can only affect the estimation of other losses and not total losses. Because total losses have been estimated from change in storage which have been estimated from observed water levels and volume of water due to direct rainfall over lake in the post monsoon months is very less except for April (Table 20). Nevertheless, the errors are within the acceptable limits and being a very small quantity, it is not expected to significantly affect the water balance estimates. In any case the purpose of the water balance of post-monsoon months is only to get an idea of the “other losses” (other than evaporation losses) and not for estimating the inflow to the lake. The estimates of ‘other losses’ are needed for water balance computation of monsoon months, as it is difficult to estimate them from the water balance of these months owing to contributions of inflows to the change in storage. Since the ‘other losses’ are significantly less as compared to the

change in storage during the monsoon months, no significant errors are expected in water balance of monsoon months because of these errors.

#### 6.6.1.4 *Corrections for losses terms*

To avoid discrepancy in the overall water balance, the errors of losses terms have been adjusted by adjusting the errors of evaporation, as the losses together cannot be more than estimated total losses. The corrected evaporation losses are presented in Table 25.

**Table 25: corrected evaporation losses**

Month	Total losses from lake (Ham)	Total evaporation losses (Ham)	Seepage Losses (Ham)	Losses due to pumping (Ham)
Oct., 2011	39.67	27.10	10	2.57
Nov., 2011	22.22	20.22	0	2
Dec., 2011	19.00	18	0	1
Jan., 2012	12.93	11.93	0	1
Feb., 2012	14.88	12.88	0	2
Mar., 2012	26.63	24.63	0	2
April, 2012	28.94	26.44	0	2.5
May, 2012	29.13	26.13	0	3
June, 2012	30.57	27.57	0	3

With estimation of the various parameters of losses and in particular the losses due to pumping, the water balance for the monsoon months of July to September, 2011 has been determined.

#### 6.6.1.5 *Water Balance of monsoon months (July-September, 2011)*

During the months of monsoon, 2011 there is generally no pumping for irrigation (as has been informed by the Engineering Department), so there are hardly any losses due to pumping for irrigation, except probably for the warmer initial period of July. So, apart from the evaporation losses, the other losses in these months are basically the losses due to pumping for cleaning/washing (which have been assumed to be 0.5 Ham on an average for a month). Thus, for the months of August and September, when there is no pumping for irrigation, total losses can be estimated as:

$$\text{Total losses from lake} = \text{Total evaporation losses} + \text{Pumping losses for washing/ cleaning}$$

Further, we know from the water balance of post monsoon months discussed above, that the seepage losses for the month of October, 2011 are about 10 Ham. So, it is reasonable to assume that if the seepage was there in October, it must have been there in September also, because the water level reached the above 1156.3 mark on 10<sup>th</sup> September, 2011 (the level at which seepage losses are expected to start from lake). Since water levels in July and most part of August were always below this level, we assume no seepage losses during these months. Further, the seepage rate of September, 2011 has to be slightly

higher than October, 2011 because water level was at a higher level in September. So, it is reasonable to assume the seepage loss in September to be slightly higher, say 12 Ham. This can also be explained in other way also. Since no seepage losses have been observed in November (Table 8.21), it may be assumed that the seepage which was observed in October month did not take place exactly upto 31<sup>st</sup> October and stopped exactly on 1<sup>st</sup> November. Based on the water level data (and the critical water level for seepage as 1156.3 ft) the seepage can be assumed to have taken place for about 10 days. This assumption implies that seepage loss from the lake during October, 2010 was 1.0 Ham/day (Total 10 Ham for 10 days). Since seepage in September is expected to be slightly higher than October it can be assumed as 1.2 Ham/day. The lake water level reached the above 1156 mark on 10<sup>th</sup> September, 2011 and continued to stay above that level almost throughout the month. So we can expect seepage losses for September month for 20 days at the rate of 1.2. Ham/day for 20 days. It comes to be around 24 Ham.

The estimated average rate of daily evaporation and total losses for monsoon months have already been presented in Chapter 7. The various terms contributing to Total Losses and estimates of Total Losses for monsoon months are presented in Table 26

**Table 26: Water losses from lake during monsoon 2011**

Month	Total evaporation losses (Ham)	Pumping losses for gardening (Ham)	Pumping losses for cleaning (Ham)	Seepage Losses (Ham)	Total losses (Ham)
<b>Jul, 2011</b>	23.84	2	0.5	0	26.34
<b>Aug, 2011</b>	22.45	0	0.5	0	22.95
<b>Sep 2011</b>	23.67	0	0.5	24	48.17

The change in volume has been estimated from the water levels as explained before and the total losses have been estimated. The estimated water balance obtained for the three monsoon months is presented in Table 27.

**Table 27: Water balance of Monsoon months of 2011**

Month	Change in storage (Ham)	Total losses (Ham)	Total Inflow (Ham)
July, 2011	6.81	26.34	33.15
Aug. 2011	55.18	22.95	78.13
Sep., 2011	36.85	48.17	85.02
Total			

But, total inflow does not represent the amount of water coming as inflow from catchment alone, as explained earlier. It also consists of contribution by direct rainfall over the lake. The total volume of water received from the inflow channels (as surface runoff) is thus calculated as total inflow minus volume directly contributed by rainfall over the lake. The calculations are presented in Table. 28. The negative sign for inflow in July (Table 28) indicates error which could be because of error in recording rainfall at the lake or water level of 1<sup>st</sup> July thereby giving less quantity of change in storage. It could

also be because of error in assumption about pumping losses. It may also be associated with evaporation, being the largest component. Alternatively there may be error in hypsographic curve, making under or over estimation of water spread area. Nevertheless, it's a small quantity and as such, the inflow can be considered as negligible, say zero during July, 2011.

**Table 28: Estimates of surface runoff during monsoon of 2011**

Month	Total inflow to the lake (Ham)	Inflow due to direct rain over lake (Ham)	Inflow due to Surface runoff (Ham)
July, 2011	33.15	41.70	-8.55 (say zero)
Aug.2011	78.13	37.20	40.93
Sep., 2011	85.02	30.74	54.28

**6.6.1.6 Corrections for error**

To avoid any discrepancy in the overall water balance, corrections have been applied to the computation of water balance term for July by adjusting the error. The error has been adjusted by distributing it equally as 50% each to the two components of 'total inflow' and 'inflow due to direct rain'. The corrected estimates of inflows are presented in Table 29.

**Table 29: Corrected estimates of inflows during monsoon of 2011**

Month	Total inflow to the lake (Ham)	Inflow due to direct rain over lake (Ham)	Inflow due to Surface runoff (Ham)
July, 2011	37.43	37.43	0
Aug.2011	78.13	37.20	40.93
Sep., 2011	85.02	30.74	54.28
<b>Total</b>	<b>200.58</b>	<b>105.37</b>	<b>95.21</b>

However, correction to the inflow component would need correction to be applied to total losses term. The total losses are therefore corrected as 30.62 Ham. Accordingly, the evaporation losses have been corrected as 28.12 Ham.

The various corrected water balance terms can be integrated to get the complete picture for the water year 2011-12 (July, 2011-June, 2012) as shown in Table 30.

**Table 30: Complete water balance of 2011-12**

Month	Inflow due to direct rainfall over lake	Runoff from catchment	Total inflow	Evaporati on losses	Seepage losses	Pumping losses	Total losses	Change in storage
	Ham	Ham	Ham	Ham	Ham	Ham	Ham	Ham
Jul, 11	37.43	0	37.43	28.12	0	2.5	30.62	6.81
Aug, 11	37.20	40.93	78.13	22.45	0	0.5	22.95	55.18
Sep,11	30.74	54.28	85.02	23.67	24	0.5	48.17	36.85
Oct,11	0.00	0	0.00	27.1	10	2.57	39.67	-39.67
Nov,11	0.00	0	0.00	20.22	0	2	22.22	-22.22
Dec,11	2.52	0	2.52	18.00	0	1	19.0	-16.48
Jan, 12	3.40	0	3.40	11.93	0	1	12.93	-9.53
Feb, 12	0.00	0	0.00	12.88	0	2	14.88	-14.88
Mar, 12	0.00	0	0.00	24.63	0	2	26.63	-26.63
Apr,12	13.24	0	13.24	26.44	0	2.5	28.94	-15.69
May,12	0	0	0	26.13	0	3	29.13	-29.13
Jun, 12	0	0	0	27.57		3	30.57	-30.57
<b>Total</b>	<b>124.53</b>	<b>95.21</b>	<b>219.74</b>	<b>269.14</b>	<b>34</b>	<b>22.57</b>	<b>325.71</b>	<b>-105.96</b>

Thus, the complete water balance of the water year of 2011-12 (Table 30), indicates that out of the total 219.74 Ham of inflow received by the lake during the water year, 124.53 Ham was contributed by the rain directly falling over the lake while the remaining 95.21 Ham was contributed by the runoff from the catchment. Although only 219.74 Ham of inflow volume was added to the lake, the total volume of water lost through the lake during the year was 325.71 Ham through various processes. This included 269.14 Ham of water lost through evaporation, 34 Ham lost through seepage and 22.57 Ham lost through pumping. The more loss of water than the inflow, produced a negative balance for the lake causing a net change of -105.96 Ham in the storage volume of lake (negative sign indicates reduction in storage volume). This resulted in lake water levels coming down. The observed water level in the lake was 351.75 on 1<sup>st</sup> July, 2011 and 352.46 m msl at the end of September, 2011. It came down drastically to 350.82 m amsl on 30<sup>th</sup> June, 2012, causing significant drying of the lake at the end of the summer, 2012.

As far as monsoon, 2011 is concerned, we know from the water balance that of the total 200.58 Ham of inflow received by the lake during the monsoon- 2011, 105.37 Ham was contributed by the rain directly falling over the lake while the remaining 95.21 Ham was contributed by the runoff from the catchment. Of the total 200.58 Ham of inflow volume added to the lake, 101.74 Ham of water was lost through various processes. This included 74.24 Ham of water lost through evaporation, 24 Ham lost through seepage and 3 Ham lost through pumping. 101.74 Ham through various losses left a balance of 98.84 Ham of change (increase) in volume of the lake. So, the water level of the lake, which was at 351.75 m msl on 1<sup>st</sup> July, 2011 increased to 352.46 m msl at the end of September, 2011. However, this meager addition of volume of water was not adequate to sustain the demands of the total losses of the post monsoon months. So, the lake levels continued to decline throughout the post monsoon months and eventually the lake almost dried during summer end, 2012.

## 6.6.2 Water balance for the year 2012-13

Contrary to the deficit year of 2011, monsoon of 2012 was normal so it is interesting to know the water balance of 2012 and to compare it with that of 2011. Since the estimation procedure has already been explained for the year 2011-12 in details, it is not repeated here. For estimating storage capacity, depth-area-capacity curve prepared by IPRI, after the bathymetric survey of monsoon 2012 was used. The results obtained are presented in various Tables below.

**Table 31: Change in lake storage during different months**

Month	Water level on the first day of the month amsl (m)	Corresponding capacity (Volume) (Ham)	Water level on the last day of the month amsl (m)	Corresponding Capacity (Volume) (Ham)	Net change in storage of lake (Ham)
Jul, 2012	350.82	17.984	350.92	25.586	7.60
Aug, 2012	350.92	25.586	351.86	141.664	116.08
Sep, 2012	351.86	141.664	354.04	460.398	318.73
Oct., 2012	354.04	460.398	353.61	393.182	-67.22
Nov, 2012	353.61	393.182	353.31	347.709	-45.47
Dec, 2012	353.3	347.709	353.10	316.486	-31.22
Jan., 2013	353.10	316.486	352.96	295.921	-20.57
Feb, 2013	352.96	295.921	352.88	284.335	-11.59
Mar, 2013	352.88	282.890	352.67	254.157	-28.733
Apr, 2013	352.67	254.157	352.39	214.600	-39.56
May, 2013	352.39	214.600	352.14	179.864	-34.76
June, 2013	352.14	179.864	352.82	275.663	95.80

Since the change in storage shows an increase in storage for the month of June, 2013, unlike other months of post monsoon, so we shall carry its water balance separately, after carrying out the water balance for the post monsoon months.

**Table 32: Volume of water in lake due to direct rain**

Month	Rainfall over lake (mm)	Volume of water in lake due to rain over lake (Ham)
Jul, 2012	187.00	31.08
Aug, 2012	332.20	55.24
Sep, 2012	254.00	42.52
Oct., 2012	0	0
Nov, 2012	0	0
Dec, 2012	0	0
Jan., 2013	82.01	13.63
Feb, 2013	92.46	15.37
Mar, 2013	0	0
Apr, 2013	0	0
May, 2013	10.60	1.76
June, 2013	238.88	39.71

**Table 33: Total losses from the lake for post monsoon months**

Month	Total Change in lake storage (Ham)	Volume of water added to lake due to rain over lake (Ham)	Total losses from lake (Ham)
Oct., 2012	-67.22	0	67.22
Nov, 2012	-45.47	0	45.47
Dec, 2012	-31.22	0	31.22
Jan., 2013	-20.57	13.63	34.20
Feb, 2013	-11.59	15.37	26.96
Mar, 2013	-28.73	0	28.73
Apr, 2013	-39.56	0	39.56
May, 2013	-34.74	1.76	36.50

Evaporation rates and evaporation losses in volume terms have already presented earlier. For the sake of convenience, the total evaporation losses in volume are presented again in Table 8.30. However, daily meteorological data has been collected only up to March, 2013. So in the Table 8.30 below, average evaporation rates for the months July, 2012 to February, 2013 only are based on the estimates obtained from daily evaporation rates using the daily meteorological data of the study period (as explained in Chapter 7). For the remaining months, monthly average evaporation rates obtained from monthly meteorological data of 2000-2012 have been used.

**Table 34: Evaporation losses from the lake**

Month	Total evaporation losses in volume (Ham)
Jul, 2012	16.48
Aug, 2012	15.41
Sep, 2012	22.24
Oct., 2012	25.99
Nov, 2012	15.04
Dec, 2012	10.66
Jan., 2013	9.64
Feb, 2013	13.49
Mar, 2013	25.11
Apr, 2013	33.38
May, 2013	36.95
June, 2013	30.14

**Table 35: Estimated "Other losses" from the lake**

Month	Total losses from lake (Ham)	Total evaporation losses (Ham)	other losses from lake (Ham)
Oct., 2012	67.216	25.99	41.226
Nov, 2012	45.473	15.04	30.433
Dec, 2012	31.223	10.66	20.563
Jan., 2013	34.195	9.64	24.555
Feb, 2013	26.956	13.49	13.466
Mar, 2013	28.73	25.11	3.62
Apr, 2013	39.56	33.38	6.18
May, 2013	36.50	36.95	-0.45

The negative values for May (Table 35) are actually because of error of water balance. For the month of May it has been caused by overestimation of evaporation. (over-estimation by 0.45 Ham). If we add assumed pumping losses of 3 Ham for May to it, the error becomes -3.45 Ham which is a small error. Adjusting it for evaporation losses gives us corrected estimates of evaporation as 33.50 Ham. Subtracting pumping losses which are about 1-3 Ham from the Total other losses give us seepage losses. The various separated losses are presented in Table 36.

**Table 36 Various losses from the lake for post monsoon months**

Month	Total evaporation losses (Ham)	Pumping losses (Ham)	Seepage losses (Ham)	Total Losses (Ham)
Oct., 2012	25.99	2.5	38.73	67.22
Nov, 2012	15.04	2	28.43	45.47
Dec, 2012	10.66	1	19.56	31.22
Jan., 2013	9.64	1	23.56	34.20
Feb, 2013	13.49	2	11.47	26.96
Mar, 2013	25.11	2	1.62	28.73
Apr, 2013	33.38	2.5	3.68	39.56
May, 2013	33.50	3	0.00	36.50

It can be seen from the Table 36 that seepage losses are significant in year 2012-13 as compared to 2011-12. This was also observed in field and is evident in higher per day decline observed in lake water during 2012 post monsoon as compared to 2011 post monsoon. This is because the lake water level was at a significantly higher level at the end of monsoon 2012.

**6.6.3 Water balance of June, 2013**

In view of unprecedented high rainfall during June, 2013, it would be interesting to assess water balance for the month of June, 2013 separately. First we shall discuss the seepage losses from the lake for June, 2013. Since the lake level reached the level of 1156.75 ft on 16.6.2013, seepage must have started from lake. It stayed there at this level up to June end. Based on the estimates of 2011 (for this level observed in September, 2011) the seepage losses can be assumed as 1.2 Ha m. So for the last 15 days of June, 2013 since 16.6.2013, they work out to be 18 Ham as total. Since there was significant rain in June so we do not expect any losses for pumping for irrigation. We shall only assume 0.5 Ham of losses due to pumping for cleaning. The various losses for June are presented in Table 37.

**Table 37: Various losses from lake during June, 2013**

Month	Total evaporation losses (Ham)	Pumping losses for gardening (Ham)	Seepage losses (Ham)	Total losses (Ham)
<b>June, 2013</b>	30.14	0.5	18	48.64

The estimated water balance component of June, 2013 is presented in Table 38.

**Table 38: Water balance components for June, 2013**

Month	Change in storage (Ham)	Total losses (Ham)	Total Inflow (Ham)
June, 2013	95.799	48.64	144.439

**Table 39: Estimates of river inflows (runoff) during June, 2013**

Month	Total inflow to the lake (Ham)	Inflow due to direct rain over lake (Ham)	Inflow due to surface runoff (Ham)
June, 2013	144.439	39.71	104.729

#### 6.6.4 Losses during monsoon months

Using the information on losses during post monsoon months, losses during monsoon months can be derived. Since the lake water reached level of about 1956.3 ft on 13 September and reached a high level of 1962 by 23<sup>rd</sup> September, it is reasonable to believe that there were considerable seepage losses during the month of September, after 13 September. Analysis of data in Table 37 above shows that seepage losses were about 20 Ham in December-January, about 30 Ham in November and about 40 Ham in October. This increasingly higher value from December to October (backwards) gives us a value of about 50 Ham for the month of September at an average rate of 1.67 Ham per day. However, since the seepage has occurred since 13<sup>th</sup> September (for 17 days during September) the seepage losses can be assumed as 28 Ham (at 1.67 Ham per day for 17 days), for the month of September, 2012. With this assumption of seepage loss for September month, the various losses terms can be written for the monsoon months, as presented in Table 40. It may be noted that irrigation is not done in the months of August and September because of the rainy season but done during July. So, losses for pumping (for irrigation and cleaning) have been accordingly assumed.

**Table 40: Various losses from lake during monsoon 2012**

Month	Total evaporation losses (Ham)	Pumping losses for gardening (Ham)	Seepage losses (Ham)	Total losses (Ham)
Jul, 2012	16.48	2.5	0	18.98
Aug, 2012	15.41	0.5	0	15.91
Sep 2012	22.24	0.5	28	50.74

From the change in storage and total losses from the lake, the Total inflow to the lake has been estimated and presented in Table 41.

**Table 41: Water balance of monsoon months of 2012**

Month	Change in storage (Ham)	Total losses (Ham)	Total Inflow (Ham)
July, 2012	7.60	18.98	26.58
Aug, 2012	116.08	15.91	131.99
Sep., 2012	318.73	50.74	369.47

The inflow due to runoff from catchment obtained by subtracting the “inflow due to direct rain over lake” from the “total inflow” is presented in Table 42. The negative sign for inflow in July again indicates error which could be because of error in estimation of change in storage. This is because in July 2012, the water level of the lake went below the water level gauge mark thereby making it difficult to exactly measure the initial water level. However, it's a small quantity and as such the inflow can be considered as negligible, say zero.

**Table 42: Estimates of river inflows (runoff) during monsoon of 2012**

Month	Total inflow to the lake (Ham)	Inflow due to direct rain over lake (Ham)	Inflow due to surface runoff (Ham)
July, 2012	26.58	31.08	-4.5 (Say negligible)
Aug.2012	131.99	55.24	76.75
Sep., 2012	369.47	42.52	326.95

#### 6.6.5 Corrections to water balance terms

To avoid discrepancy in the water balance, corrections have been applied to the inflow terms for July by adjusting the error. The error has been adjusted by distributing it equally as 50% each to the two components of ‘total inflow’ and ‘inflow due to direct rain’. The corrected estimates of inflows are presented in Table 43.

**Table 43: Corrected estimates of inflows during monsoon of 2012**

Month	Total inflow to the lake (Ham)	Inflow due to direct rain over lake (Ham)	Inflow due to Surface runoff (Ham)
July, 2012	28.83	28.83	0
Aug.2012	131.99	55.24	76.75
Sep., 2012	369.47	42.52	326.95
Total	530.29	126.59	403.7

However, correction to the inflow component would also need correction to be applied to total losses term. The total losses for July are therefore corrected as 21.23 Ham. Accordingly the evaporation losses for July have been corrected as 18.73 Ham.

The various corrected water balance terms can be integrated to get the complete picture for the water year 2012-13 (July, 2012-June, 2013) as shown in Table 44.

Thus, the complete water balance of the water year of 2012-13, indicates that out of the total 705.5 Ham of inflow received by the lake during the water year, 197.1 Ham was contributed by the rain directly falling over the lake while the remaining 508.4 Ham was contributed by the runoff from the catchment. Of the 705.5 Ham of total inflow volume added to the lake, the total volume of water lost through the lake during the year was 446.4

Ham through various processes. This included 253.3 Ham of water lost through evaporation, 173.1 Ham lost through seepage and 20 Ham lost through pumping. The total loss of water being lesser than the total inflow, produced a positive balance for the lake causing a net increase of 259.1 Ham in the storage volume of lake during the year 2012-13. This resulted in lake water levels going up by as much as 2 m from the observed water level in the lake from 350.82 on 1<sup>st</sup> July, 2012 to 352.82 m msl at the end of June, 2013.

**Table 44: Complete water balance of 2012-13 (July, 12-June, 13)**

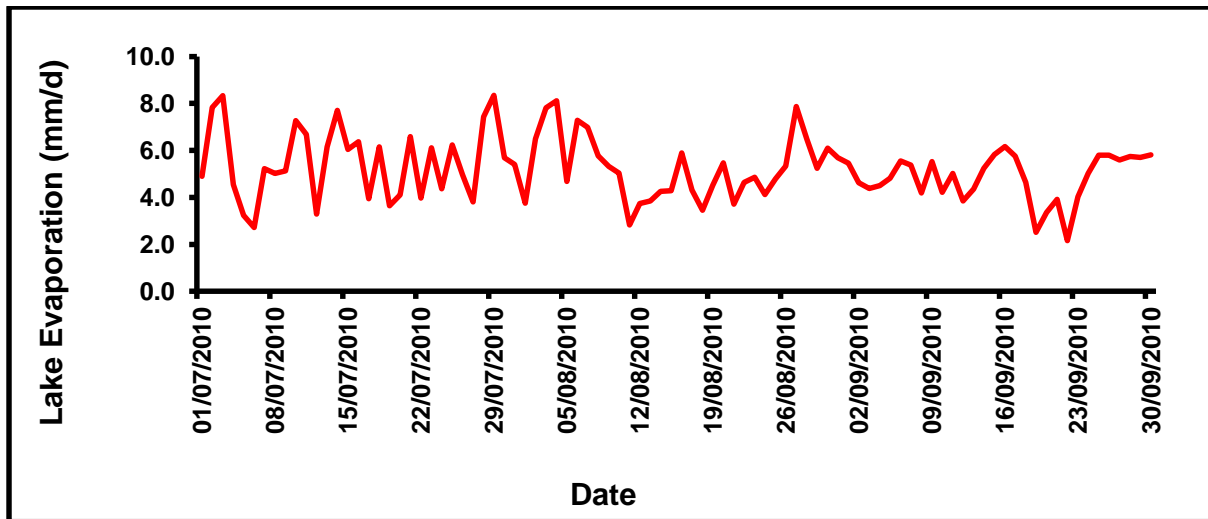
Month	Inflow due to direct rainfall over lake	Runoff from catchment	Total inflow	Evaporati on losses	Seepage losses	Pumping losses	Total losses	Change in storage
	Ham	Ham	Ham	Ham	Ham	Ham	Ham	Ham
Jul, 12	28.83	0	28.83	18.73	0	2.5	21.23	7.60
Aug 12	55.24	76.75	131.99	15.41	0	0.5	15.91	116.08
Sep12	42.52	326.95	369.47	22.24	28	0.5	50.74	318.73
Oct,12	0	0	0	25.99	38.73	2.5	67.22	-67.22
Nov,12	0	0	0	15.04	28.43	2	45.47	-45.47
Dec,12	0	0	0	10.66	19.56	1	31.22	-31.22
Jan, 13	13.63	0	13.63	9.64	23.56	1	34.20	-20.57
Feb, 13	15.37	0	15.37	13.49	11.47	2	26.96	-11.59
Mar, 13	0	0	0	25.11	1.62	2	28.73	-28.73
Apr, 13	0	0	0	33.38	3.68	2.5	39.56	-39.56
May, 13	1.76	0	1.76	33.50	0.00	3	36.50	-34.74
June, 13	39.71	104.73	144.449	30.14	18	0.5	48.64	95.80
<b>Total</b>	<b>197.1</b>	<b>508.4</b>	<b>705.5</b>	<b>253.3</b>	<b>173.1</b>	<b>20.0</b>	<b>446.4</b>	<b>259.1</b>

As far as monsoon season of 2012 is concerned, the water balance indicates that of the total 530.29 Ham of total inflow received by the lake during the monsoon of 2012, 126.59 Ham was contributed by the rain directly falling over the lake while the remaining 403.7 Ham was contributed by the runoff from the catchment. Of the total 530.29 Ham of inflow volume added to the lake during monsoon, 87.88 Ham of water was lost through various processes. This included 56.38 Ham of water lost through evaporation, 28 Ham lost through seepage and 3.5 Ham lost through pumping. These total losses left a balance of 442.41 Ham of change (increase) in volume of the lake. So, the water level of the lake, which was at 350.82 m msl on 1<sup>st</sup> July 2012, increased by more than 3 meters to 354.04 m msl at the end of September, 2012.

#### **6.6.6 Water balance for monsoon months of 2010**

Since some reasonable water level data for the lake was available for the monsoon months of 2010, water balance of these months have been carried out. Year 2010 was a normal rainfall year. The annual total rainfall received at Kansal rest house station in the catchment was 1172 mm and at Nepli station it was 1107 mm. Rainfall received during

the monsoon months of July to August was 865.3 for the Kansal station. The data of Kansal station have been used for the purpose, for the reason of more reliability. Limited water level data for monsoon were available. The observed water levels were available for 3<sup>rd</sup> July, 19 July, 13<sup>th</sup> August to 31<sup>st</sup> August, 1<sup>st</sup> September and 26<sup>th</sup> September, 2010. So combined water balance for July and August (for the period 3<sup>rd</sup> July-31<sup>st</sup> August) and a separate water balance for the period 1<sup>st</sup> September-26<sup>th</sup> September (as water balance for the month of September) have been carried out. For estimating evaporation losses, meteorological data obtained from CSWCRTI, Chandigarh was used. The evaporation for the months of July to September, 2010 are shown in Fig. 8.29. The obtained evaporation rates were applied to the water spread area to get the evaporation losses in volume terms. The average evaporation rates for the monsoon months of July to September and the volume of water lost from the lake due to these rates are shown in Table 45.



**Fig. 38: Evaporation rates for the months of July-September, 2010**

**Table 45: Evaporation losses during monsoon months of 2010**

Month	Evaporation rate (mm/d)	Total Losses due to evaporation (Ham)
July	5.5	45.01
August	5.2	
September	5.0	28.82

Based on the seepage characteristics of lake at different post monsoon water levels and based on the seepage losses estimated during the water balance of years 2011 and 2012 monsoon period, the assumed seepage losses for the months of July and August are 10 Ham each and those for September are 30 Ham. Since it has consistently rained all through the monsoon, pumping losses for irrigation have been considered as zero while only 0.5 Ham losses for cleaning have been considered. The estimated total losses from the lake are presented in Table 46.

The estimated components of total inflow, inflow due to direct rainfall over lake and inflow due to surface runoff from catchment are presented in Table 47 while the complete water balance for the monsoon months is given in Table 48.

**Table 46: Different loss components and total loss from lake for monsoon 2010**

Month	Evap losses (Ham)	Seepage losses (Ham)	Pumping losses (Ham)	Total Losses (Ham)
July-Aug	45.01	20	0.5	65.51
Sep	28.82	30	0.5	59.32
Total	73.83	50	1.0	124.83

**Table 47: The estimated inflow components from monsoon 2010**

Month	Net change in storage (Ham)	Total losses (Ham)	Total inflow (Ham)	Volume of water received by lake through direct rainfall over it (Ham)	Surface runoff from catchment (Ham)
July-Aug	227.48	65.51	292.99	100.04	192.95
Sep	208.05	59.32	267.37	36.24	231.13
Total	435.53	124.83	560.36	136.28	424.08

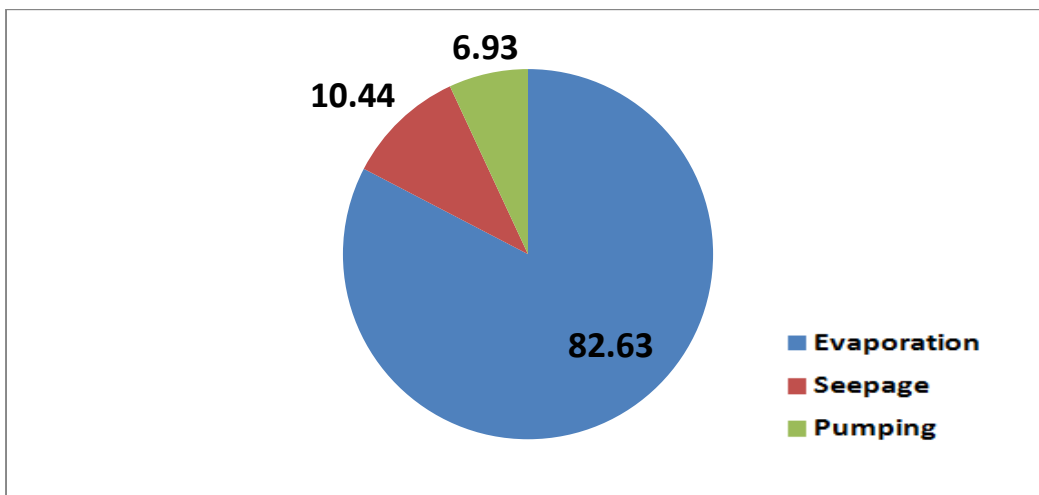
**Table 48: The complete water balance components for monsoon 2010**

Month	Inflow due to direct rainfall over lake	Runoff from catchment	Total inflow	Evaporation losses	Seepage losses	Pumping losses	Total losses	Change in storage
	Ham	Ham	Ham	Ham	Ham	Ham	Ham	Ham
Jul - Aug	100.04	192.95	292.99	45.01	20	0.5	65.51	227.48
Sep	36.24	231.13	267.37	28.82	30	0.5	59.32	208.05
<b>Total</b>	136.28	424.08	560.36	73.83	50	1	124.83	435.53

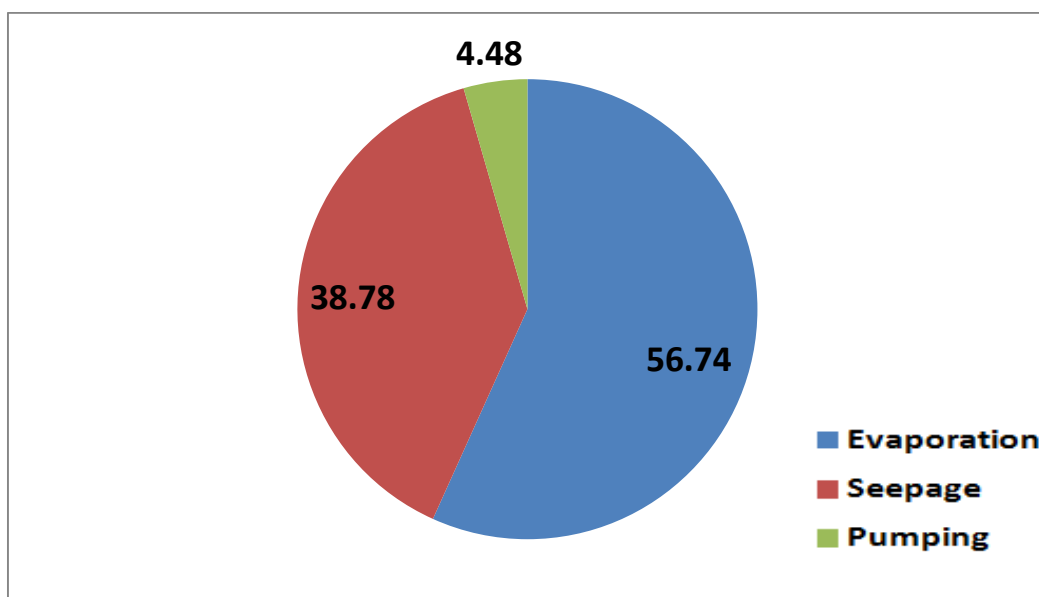
From the water balance of monsoon 2010 (Table 48), it can be observed that, out of the total 560.36 Ham of inflow received by the lake during July-Sept., 2010, 136.28 Ham was contributed by the rain directly falling over the lake while the remaining 424.08 Ham was contributed by the runoff from the catchment. Of the total 560.36 Ham of inflow volume added to the lake 126.83 Ham of water was lost through various processes. This included 73.83 Ham of water lost through evaporation, 50 Ham lost through seepage and 1 Ham lost through pumping. The loss of 126.83 Ham through various losses left a balance of 435.53 Ham of change (increase) in volume of the lake. So, the water level of the lake which was at 1152.03 ft at the beginning of monsoon, 2010 increased to 1162 at the end of monsoon, 2010.

## 6.7 Relative significance of different components in water balance

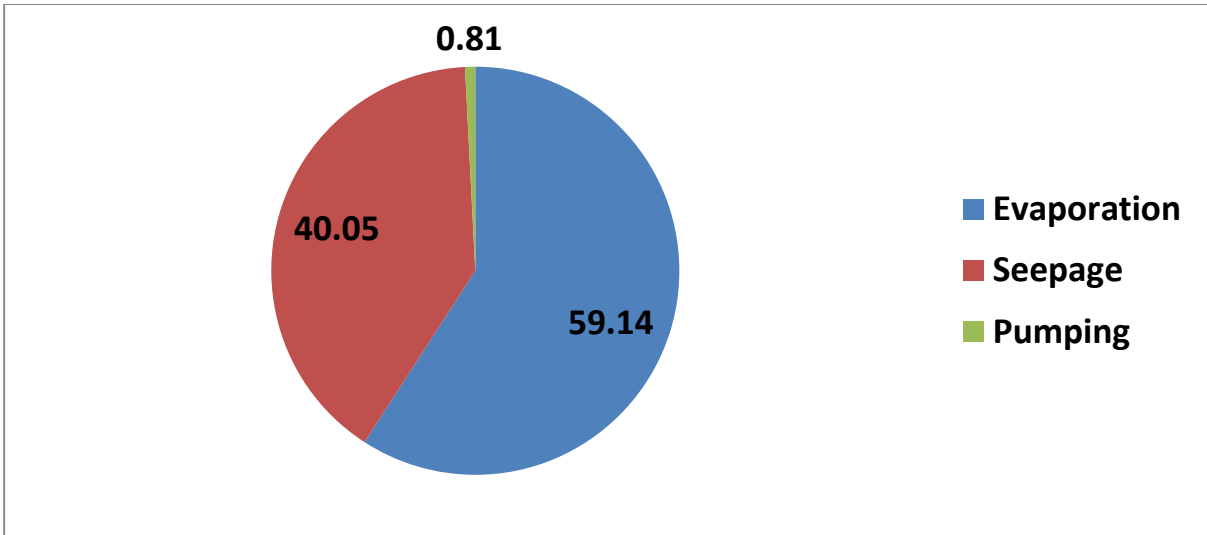
Fig. 39, 40 and 41 below presents the statistics related to the significance of various components of water balance in the overall water balance. It can be seen that the significance, in particular of evaporation and seepage losses, varies depending upon whether it is a normal rainfall year or a deficit rainfall year (which determines the water availability in the lake. Even if two years are similar in terms of normality of rainfall, the significance varies, depending upon the water level reached by the lake during monsoon. If the water levels are high, seepage plays a significant role in overall losses while evaporation dominates the total losses if water levels are lower, particularly below the critical level of 1956.3 ft amsl. The significance also varies from month to month within a single year.



**Fig 39: Relative contribution of various components in total losses-2011**



**Fig. 40: Relative contribution of various components in total losses-2012**



**Fig. 41: Relative contribution of various components in total losses-2010**

**7.0 CONCLUDING REMARKS**

Detailed water balance has been carried out for 2011-12, 2012-13 and monsoon season of 2010. Two of these three (2010 and 2012) monsoon seasons were normal monsoons while 2011 was a deficit rainfall year. Following inferences can be drawn from the water balance analysis:

- (i) Depending upon the rainfall characteristics, the lake can get a total inflow of about 200 Ham to 700 Ham in a water year (July to June), including direct rainfall over it and through surface runoff from the catchment. The contribution of direct rainfall may vary from 120 Ham to 200 Ham while the contribution by surface runoff from catchment may vary from 80 Ham to 500 Ham. During deficit rainfall years, the contribution from direct rainfall over the lake may be more than the runoff from the catchment.
- (ii) Depending upon the rainfall characteristics, during monsoon season (July to September), the lake can receive about 200 Ham to 560 Ham of total inflow. The contribution of direct rainfall may vary from 100-150 Ham while the contribution of runoff from catchment may vary from 100-410 Ham.
- (iii) Depending upon the water received by the lake during monsoon, the total losses from the lake in a water year (July to -June) may vary from 300 Ham - 450 Ham.
- (iv) Depending upon the water levels of the lake, the seepage losses from the lake in a water year (July-June) can vary from 0 (zero) to 175 Ham. The seepage losses may vary from 0-60 Ham during monsoon (July-September) and 0-150 Ham during the post monsoon months (October-June). Higher is the post monsoon water level reached by the lake, more would be the seepage losses. At levels of 1956.3 m and below, the losses would be almost zero or negligibly small.
- (v) Depending upon the water available in the lake, evaporation losses in a water year can be upto 300 Ham. The water losses due to evaporation during monsoon can

be upto 80 Ham. As far as post monsoon season of October to June is concerned, the evaporation losses may vary from about 150 Ham- 220 Ham.

- (vi) If rainfall in June is considered as part of monsoon only, then post monsoon rains do not generate any runoff from the catchment and inflow to lake in post monsoon season is almost 100% by rainfall falling directly over the lake.
- (vii) In deficit rainfall years when the water levels are significantly low, evaporation is the single most important factor determining water losses from the lake with contribution above 90%, (if the water level is below 1156.3 ft level). Evaporation is always the important cause of water loss in summer irrespective of the water availability in lakes.
- (viii) Seepage losses are very significant during monsoon months and during the months immediately succeeding the monsoon months till the water levels come down to the below critical mark. If the water levels are above the critical mark, then in the winter months, when evaporation rates are generally very low, seepage is a dominant factor in deciding the decline in water level.

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