Prediction Of Water Availability In Sukhna Lake, Chandigarh For Summer 2015

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***Abstract*— Sukhna Lake at Chandigarh is facing water availability problems in recent years. The lake got dried almost completely during 2012 summer. Since deficit rainfall has been received during 2014 monsoon, there are apprehensions about its drying in the summer. So, present investigations have been carried out to predict the water availability scenario for the lake during the coming summer of 2015. The analysis has been carried out using water balance approach. Average rates of evaporation based on the past 10 years data have been considered. Average rainfall for the various post monsoon months have been obtained based on the average values observed for the past 50 years data. The results indicate that if climatic conditions like rainfall and evaporation rates during the post monsoon months remain normal, then the lake shall not dry out completely. However, it is going to be on the verge of drying with less than half a meter of average water depth. If the rainfall for post monsoon months is significantly below normal and if evaporation rates are higher than the normal rates or if the onset of monsoon for 2015 is significantly delayed, the lake may dry out almost completely. The water levels are predicted to be at 351.89, 351.69., 351.39, 351.08 and 351.01m amsl on 1st of March, April, May, June and July respectively.**

Keywords: Water Availability, Sukhna Lake, Water Balance Lake Hydrology, Lake Level Prediction

I. INTRODUCTION

Sukhna Lake is an important lake of Chandigarh region. The lake has been in limelight in recent years due to water scarcity problems. Water levels in the lake have been observed to go down considerably in some of the recent years. The quantitative degradation reduces the aesthetic value of the lake, causing threats to tourism. Since the lake is mainly used for recreation, availability of water is an important issue for the management of Sukhna lake. Therefore, detailed hydrological investigations on Sukhna Lake for the period 2011-2013 have been carried out by the National Institute of Hydrology, Roorkee to understand the hydrological regime of the lake and to suggest measures for proper management and conservation of the lake. During the year 2011 deficit rainfall was received at Chandigarh. The possible impact of this on water availability in the lake was investigated during December, 2011 by Khobragade et al. (2012) and communicated to Chandigarh Administration and it was predicted that about 80-90 % of the lake would go dry by the end of June, 2012. True to the prediction, almost 85 % lake dried at the end of summer, 2012. During the monsoon of 2012 normal rainfall was received by the lake but a very high rate of decline in the water levels of the lake was observed in the post monsoon months of October to December, 2012 compared to the previous year and there were apprehensions among people and administrators that the lake may dry out completely by the end of summer, 2013. So, investigations were carried out to predict the water availability by Khobragade et al (2013a) and it was predicted that the lake shall not face any water scarcity problems during 2013 summer. The prediction of water levels for summer 2013 was very reasonable. During 2014 monsoon the rainfall has been deficit. The lake has not received adequate inflows from the catchment and there are again apprehensions that the lake may dry up completely during summer 2015 as it did during summer 2012.

II. OBJECTIVE

With the above background in mind, the present investigation has been carried out to predict the water availability in Sukhna lake during summer months of 2015.

III. STUDY AREA

Chandigarh is popularly known as City Beautiful for its beautiful and planned layout designed by the French architect Le-Corbusier. One of the landmarks of Chandigarh is the Sukhna lake with its beautiful surrounding. It is a shallow manmade lake with a mean depth of 3.2 m and maximum depth of 5.33 m. The present storage capacity of the lake is 5.32 Mcum and the maximum water spread area is 166.24 Ha. The deepest point of the lake lies at 349.15 m (1145.51) amsl while the highest elevation (top of the dam) lies at 354.48 m (1162.99 ft) amsl. The lake has a maximum length of 2.32 km and a maximum width of 1.06 km. Tourism and recreation are important activities associated with the lake. The lake also serves as a sanctuary for a large number of birds while major part of the catchment area serves as a protected wildlife sanctuary. The lake is rainfed. Two major ephemeral streams, locally called Choe, namely Kansal and Saketri, join to form the Sukhna choe which drains into the lake.

Fig. 1 presents the map of the study area. The lake has a catchment area of about 42.33 sq. km. Most of it falls in the Union Territory of Chandigarh while some parts fall in the states of Punjab and Haryana. The major land use in the catchment area is Forest which is about 83 % of the total catchment area followed by barren/open land and agricultural land with 4 % and 9% respectively. The study area has a humid subtropical climate with four distinct seasons. Summer is from about mid march to mid June which is followed by monsoon season that lasts upto mid September. Mid September to mid-November is the post monsoon

autumn/transition season. The winter season is from mid November to mid-March. Average annual rainfall is 1121.6 mm of which about 80% rainfall occurs in the three monsoon months of July to September (Agnihotri et al., 2006). May and June are the hottest months of the year with temperatures going to about 400 C and above. January is the coldest month with minimum temperatures going down to about 30C and sometimes even below. Winds are generally light.

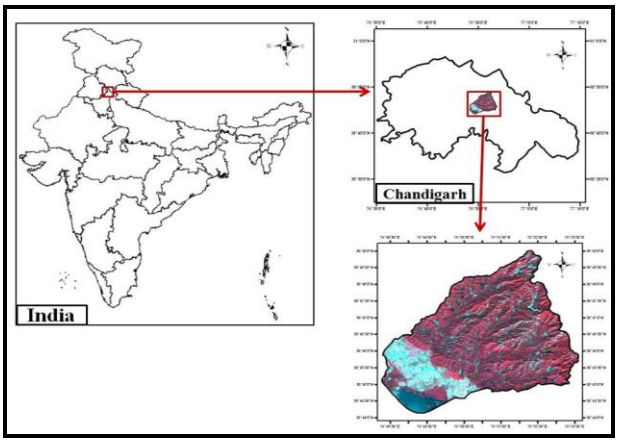


Fig. 1: Map of the study area showing the lake and its catchment

IV. MATERIALS AND METHODS

In the present study water availability in the lake during different months of summer 2015 has been investigated based on the prediction of water levels and corresponding water spread area of the lake. The analysis has been carried out using the water balance approach. Water balance of the lake has been estimated for the post-monsoon months of October, 2014 to June, 2015.

V. WATER BALANCE OF SUKHNA LAKE

A simple water balance equation of a lake can be written as is:

$$\Delta S = Is + Iu + P1 - Qs - Qu - E1$$

where,
ΔS = change of lake storage
Is = surface inflow (including overland flow)
Iu = underground inflow
P1 = inflow due to direct precipitation over lake
Qs = surface outflow (including overflow and withdrawal)
Qu = underground outflow (including seepage loses)
E1 = lake evaporation

For most lakes the major factors which contribute to the lake inflow are runoff from the catchment (including overland flows) and 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, except in those lake which are fed by ground water. The major factors which contribute to the outflow are outflow through sluice gates or overflows from the lake, water loss through evaporation/evapo-transpiration, water 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 or dams.

As far as Sukhna lake is concerned, the components of water balance of the lake are as follows:

(i) The major inflow components are inflow coming through the catchment 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 post monsoon period the sluice gates are not opened. Also, there is no overflow from the lake. Similarly, no leakage from the sluice gates is observed.

(iv) Detailed investigations on lake-ground water interaction carried out by NIH using ground water level data and isotopic analysis indicate that there is no ground water inflow to the lake (Khobragade et al., 2013 b).

Analysis of historical water levels and studies on water balance carried out by NIH (Khobragade et al., 2013 b) indicates that there are significant seepage losses from the lake upto the water level of 1156.3 ft amsl. Below this level seepage losses become more or less negligible. Since the water level at the end of Monsoon season 2014 (i.e. on 1st of October, 2014) was at 1156.25 ft amsl which was already lower than the critical level of 1156.3 ft, there are no likely seepage losses during the post monsoon months. Moreover, in the post monsoon months, no inflow occurs to the lake from the catchment. Whatever little rainfall is received in the catchment is abstracted by the large number of silt detention structures (check dams) which are present in the catchment. About 150 silt detention structures have been mapped in the lake catchment by Semwal et al. (2013) (Fig. 2) having a total capacity of about 260 Ham. The inflow to the lake during the post monsoon months is mainly through direct rainfall falling over the lake. In the present investigations these facts have been used in carrying out the water balance of the post monsoon months. Thus, the water balance equation for Sukhna Lake for the post monsoon period can be further simplified as:

$$\Delta S = P1 - Qw - Qu - E1$$

where,
ΔS = change of lake storage (=S2-S1)
S1 = Initial Storage (storage at the end of monsoon i.e. on 1st October)
S2 = Storage at the end of the period (for any post monsoon month)
P1 = inflow due to direct precipitation over lake
Qw = outflow due to withdrawal (for irrigation and cleaning)
Qu = underground outflow due to seepage loses
E1 = lake evaporation

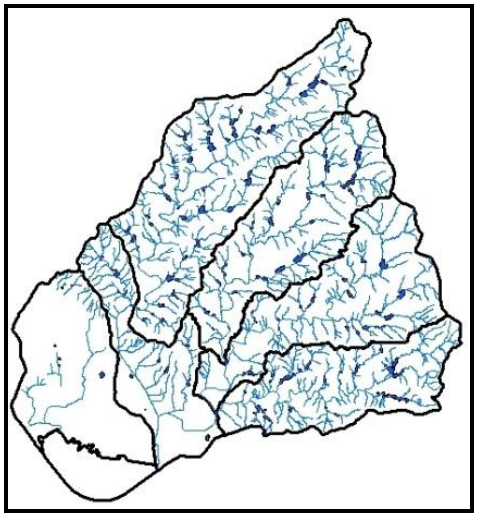


Fig. 2: Silt detention structures in Sukhna lake Catchment

Since change in storage during a period is the difference between storage at the beginning and end of the period, the storage at the end of the period can be estimated by reorganizing the water balance equation as:

$$S2 = S1 + P1 - Qw - Qu - E1$$

Using the above water balance for the lake, first storage on 1st April, 1st May, 1st June and 1st July, 2015 have been determined. Then using the depth-area-capacity curves, corresponding water levels in the lake and water spread areas of the lake on these days have been determined. Depth area capacity curve for the year 2012 prepared from bathymetric survey of the lake by IPRI, Amritsar after the monsoon season of 2011 is available (IPRI, 2012) and has been used (Fig.3). The bathymetric map indicating elevations at different locations in the lake was available in raw format. This map has been digitized and processed using GIS, and has been used to graphically represent the water spread area at different predicted water levels.

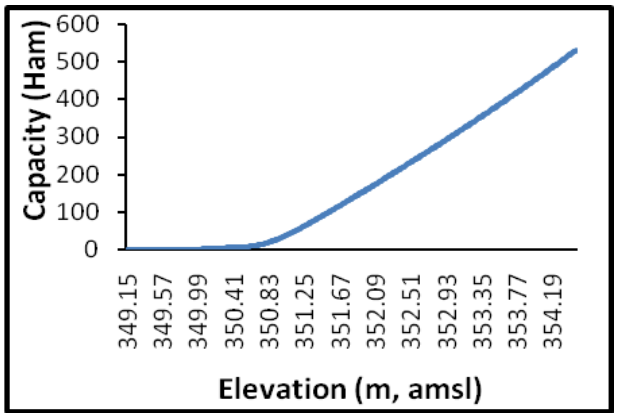
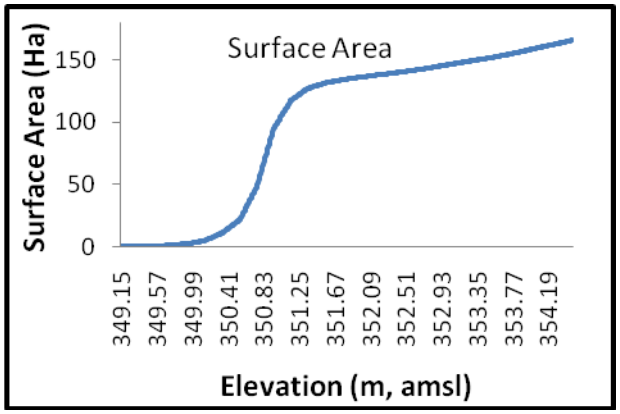


Fig. 3(a): Elevation -capacity curve for Sukhna lake



(b)

Fig. 3(b): Elevation -area curve for Sukhna lake

To estimate total losses from the lake, knowledge of pumping losses and evaporation losses is required. No historical data are available on the water being pumped from the lake. Pumping losses for the various post monsoon months have been assumed based on the information provided by the Engineering Department about withdrawal from the lake, which has also been verified from the water balance studies carried out by NIH for the years 2011-12 and 2012-13 (Khobragade et al., 2013b). The pumping includes water pumped for irrigating the gardens on the dam site as well as for cleaning of floor near the boating area. Based on the water balance carried out by the Institute, the pumping losses come out 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 Ham) is being used for irrigation. Moreover, it is also reasonable to assume that pumping for irrigation is marginally higher in warmer months of October, March, April, May and June compared to the cooler months of November to February. Differential pumping losses have been accordingly assumed. These are presented in Table 1.

Table 1: Assumed pumping losses from the lake for the post monsoon months

Month	Approximate Pumping Losses (Ham)
October, 2014	2.5
November, 2014	2
December, 2014	1
January, 2014	1
February, 2014	2
March, 2014	2
April, 2014	2.5
May, 2014	3
June, 2014	3

To estimate evaporation losses from the lake for post monsoon months, average evaporation rates for the various post monsoons have been estimated based on the monthly meteorological data of 2000-2013, using Penman method. The Penman combination equation as per Nokes (1995) is:

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

where,

E =Lake evaporation
R_n =net radiation
G = heat flux density
U_2 =wind speed measured at 2 m above the ground
e_s =saturated vapour pressure at air temperature
e_a = actual vapour pressure at air temperature
Δ =slope of saturation vapour–pressure-temperature curve
ϒ = psychometric constant, and
λ = latent heat of vapourization

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 as per Allen et al. (1998). The meteorological data have been collected from Central Soil and Water Research and Training Institute, Chandigarh. The evaporation in volume terms have been obtained by applying the evaporation rates to surface area of the lake on daily basis. Inflow due to direct rainfall over the lake has been estimated by multiplying the maximum surface area of the lake by average rainfall for the various post-monsoon months. The average rainfall has been obtained from the historical rainfall data available for the period 1958-2005. Daily water level data of the lake has been monitored and water level on 1st October, 2014 was observed to be 1156.25 ft.

VI. RESULTS AND DISCUSSION

Fig. 4 shows the digital elevation map of the lake prepared from the bathymetric map of 2012. The average depth of the lake has been calculated to be 3.2 m. The maximum depth of the lake is 5.33 m which is located at the regulator end. In general, the deepest parts of the lake are located towards the regulator end as well as near the boating area end (to the north-east and south east of the island). The shallowest parts are located all along the periphery of the lake. Barring some parts of the lake, the depths in most parts of the lake (i.e. middle potion) are in the range of 3-4 mts.

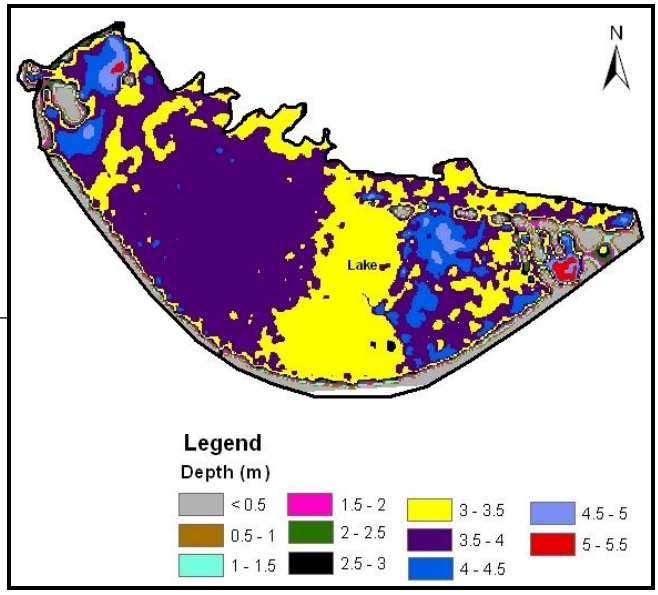


Fig. 4: Depths in different parts of the lake

However, it should be noted that these are the depths based on the bathymetric map prepared after the post monsoon season of 2011. However, desilting of the lake has been carried out after this during 2012 (post monsoon), particularly in the eastern part of the lake and actual depths hence, may be little different at those locations where the desilting has been carried.

The average evaporation rates for the lake have been estimated form the Penman equation using historical meteorological data. Average monthly evaporation varies from 2.99 (January) to 10.99 (May). However, the evaporation rates themselves do not give the volumes of water lost from the lake during a specific period. This has been obtained based on the corresponding surface area of the lake. This is expected to vary between 12.48 Ham (January, 2015) to 39.97 Ham (May, 2015). The average evaporation rates for different post monsoon months and the corresponding expected total volume of water loss through the process of evaporation from the lake during different post monsoon months is presented in Fig. 5. Higher losses of water are expected for the warmer months of summer 2015 and lower losses are expected for the cooler months of winter 2014-15.

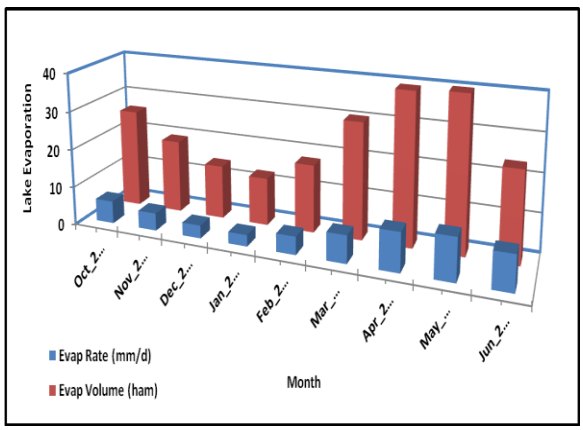


Fig. 5: Expected evaporation from lake during post monsoon months of 2014-15

To estimate the expected contribution of water from rainfall falling directly over the lake during the post monsoon months, average data of 1958-2005 was used and average rainfall in different post monsoon months was obtained. Based on the water spread area of the lake, the possible contribution from the post monsoon rainfall has been estimated. It is presented in Fig. 6. The total expected post monsoon contribution of rainfall volume comes out to be about 57 Ham.

The various estimated water balance components for the post monsoon months of 2014-15 are presented in Table 2. As can be seen from the table, the lake is expected to experience a significant decline is storage during the warmer months of April and May, 2015. The decline is expected to be 39.23 Ham and 37.67 Ham respectively. The major reason for this is the expected heavy evaporation losses during these months. In the months of October, 2014 and March 2015 when the weather is warm, but not as warm as April, May or June, the decline is expected to be around 25-27 Ham. As far as June, 2015 is concerned, although being a warm month the evaporations loses are expected to be high (23.5 Ham), the overall decline in lake storage is not expected to be high compared to April and May, 2015. This is because significant volume of water (20.3 Ham) is expected to be added to the lake storage in this month due to rains (122.2 mm) which is expected to increase the lake storage and compensate for the evaporation losses.

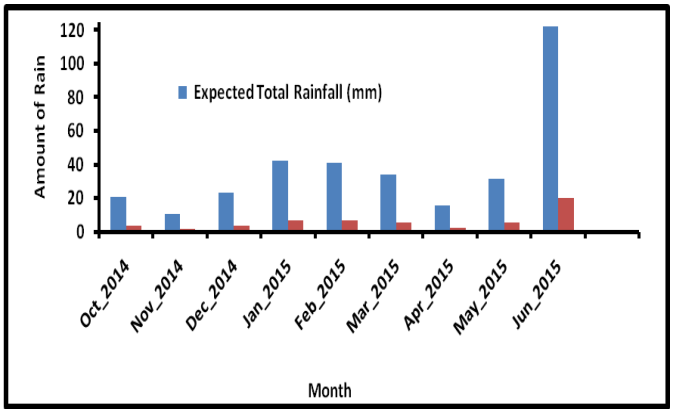


Fig. 6: Expected rainfall and rainfall volume for post monsoon months of 2014-15

Table 2: Estimated water balance components for post monsoon months of 2014-15

Month	Expected lake storage on the first day of the month (Ham)	Total expected evaporation losses (Ham)	Assumed Pumping Losses (Ham)	Expected volume of water due to rain falling directly over the lake (Ham)	Expected lake storage on the last of the month (Ham)
Oct-2014	220.22	25.98	2.5	3.4	195.14
Nov-2014	195.14	19.16	2	1.8	175.78
Dec-2014	175.78	14.06	1	3.9	164.62
Jan-2015	164.62	12.48	1	7	158.14
Feb-2015	158.14	17.71	2	6.8	145.23
Mar-2015	145.23	30.30	2	5.6	118.53
Apr-2015	118.53	39.33	2.5	2.6	79.30
May-2015	79.30	39.97	3	5.3	41.63
Jun-2015	41.63	23.50	3	20.3	35.43

(Note: Storage on 1st October, 2014 is observed storage)

Table 3 presents the predicted water levels and corresponding expected lake surface areas for different months of the summer of 2015. The expected surface areas have also been presented as percent of maximum surface area of the lake. Thus, it can be observed that by the end of June, the surface area of the lake is likely to be only about 60% of the maximum surface area of the lake, with not all of it having water. Some of it shall be exposed dry bed of the lake. About 70% of it is expected to have water and the remaining about 30% is expected to be dry area. The expected water level on 1st July, 2015 is likely to be 351.01 m amsl.

The expected surface areas of the lake corresponding to the various predicted water levels on 1st March, 1st April, 1st May, 1st June and 1st July, 2015 are also presented graphically in Fig. 6. As a reminder, the surface area has been derived from the bathymetric map of 2012. However, since dredging was carried out in the lake after this bathymetric survey, some minor errors are inevitable in prediction and graphical presentation. But, the variation is not expected to be very significant because the lake is shallow and also because dredging was carried out mostly in the eastern and northern parts of the lake. However, since capacity in this part was increased due to dredging, the error in storage estimation is likely to be little higher, compared to the error in water level or surface area. Even for storage, the expected error is mostly for the lower elevations. So, predictions of storages for March to June are likely to have lesser errors than July.

It may be noted that as per the prediction, the surface area of the lake on 1st July, 2015 is likely to be about 100 Ha. So, apparently as can be seen in Fig. 6, the lake will not look completely dry. There will be water spread in about 70% of the surface area. But it is worth noting that the expected mean depth of water in the lake at this water level is only about 0.34

m (just about 1 feet). So the lake is very vulnerable to almost complete drying if following conditions occur:

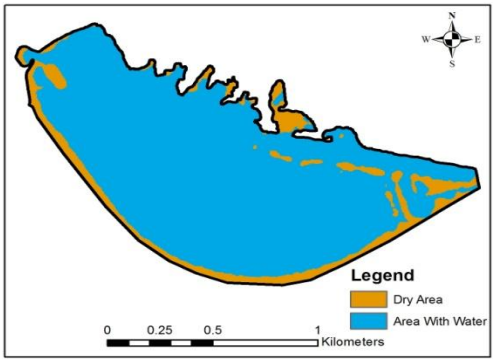
i) If the rainfall for post monsoon months is less than the historically observed average rainfall for these months which have been assumed in the study.

ii) If meteorologically it happens to be a relatively warmer year and therefore, causes more evaporation than the average evaporation rates observed in the past one decade.

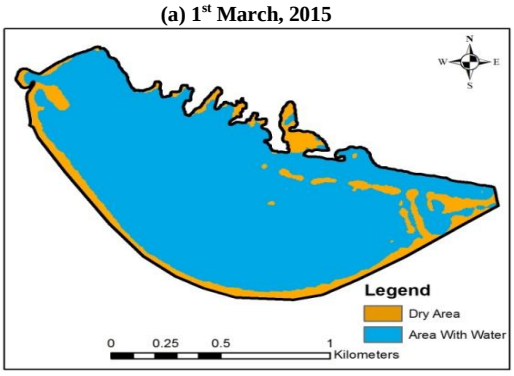
iii) If the monsoon is significantly delayed and if the rainfall of June or July is significantly low than the normal.

Table 3: Predicted water levels and surface area of the lake for summer 2015

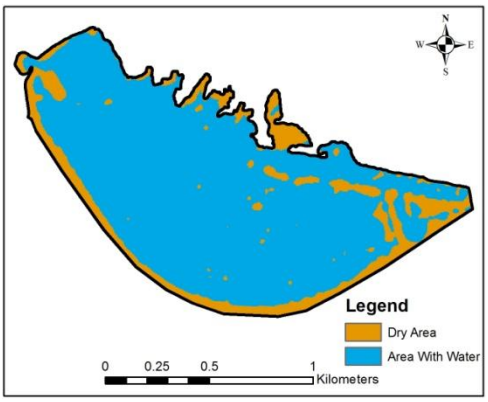
Month	Predicted water level elevation (m, amsl)	Corresponding surface area of lake (Ha)	Surface area as % of maximum lake surface area (%)	Expected mean depth of water in lake (m)
1st March, 2015	351.89	135.53	81.53	1.08
1st April, 2015	351.69	133.36	80.22	0.89
1st May, 2015	351.39	128.07	77.04	0.62
1st June, 2015	351.08	109.65	65.96	0.38
1st July, 2015	351.01	101.75	61.21	0.34

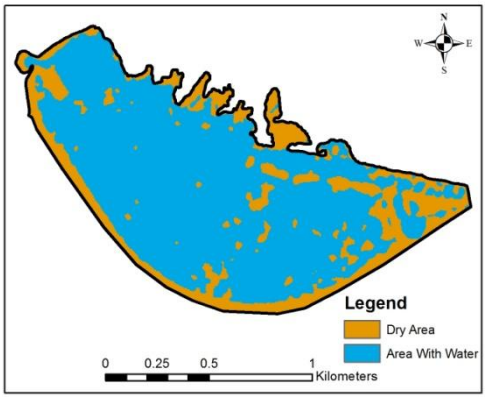


(a) 1st March, 2015

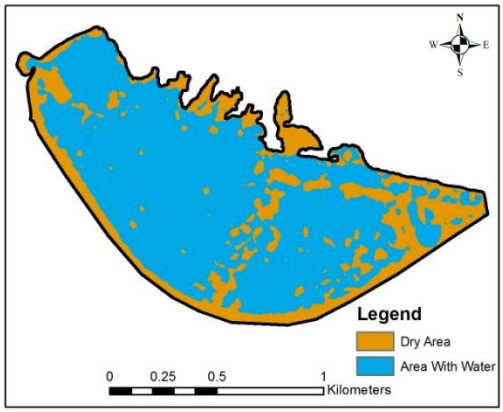


(b) 1st April, 2015





(d) 1st June, 2015

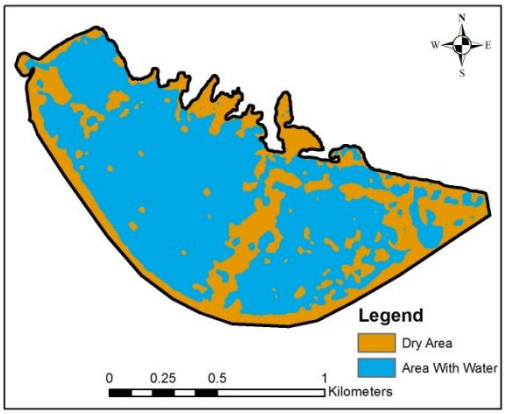


(e) 1st July, 2015

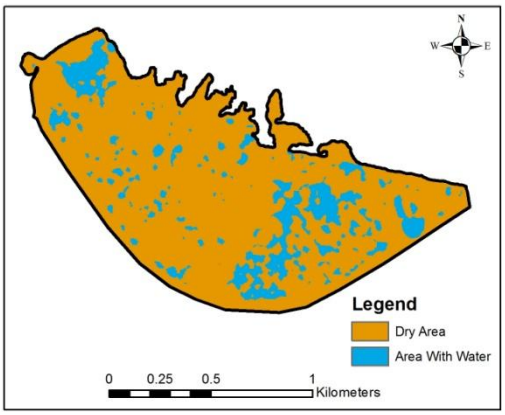
Fig. 6: Graphical representation of the predicted water spread area duringdifferent months of summer, 2015

As can be observed from Fig. 6, some portion of the lake bed is likely to start getting exposed by the end of June, 2015, but the lake shall not look totally dry. Generally monsoon reaches northern India by around 20th June. However, if it is delayed upto July 15th then it shall have further impact on the water availability. Fig. 7 (a and b) below represent two scenarios of lake water availability: (i) if the monsoon is erratic with normal rainfall in June, 2015 but thereafter no rains in July upto 15th July, and (ii) if the monsoon is significantly delayed with no rainfall during 1st June to 15th July. In the first case the predicted water level is 350.92 m amsl with surface area of 87.88 Ha and storage of 25.59 Ham. In the second case of delayed monsoon, the storage is

expected to be 5.25 Ham only with water level at 350.41 m amsl having a surface area of 14.46 ha only which is more or less a complete drying of the lake (Fig. 7 b).



a) If normal rainfall in June, 2015 but there after no rains upto 15th July



b) If almost no rainfall from 1st June to 15th July, 2015

Fig. 7: Likely lake condition if monsoon is erratic or delayed till 15th July, 2015

Even if we assume an error of about 10-20 % on account of various factors, including those of the bathymetric survey, it is reasonable to believe that the lake will be on the verge of drying at the end of summer. As explained earlier, some errors in graphical representation are expected mostly on eastern and northern side, because desilting was done mostly in these areas, although some of it may have been compensated due to sedimentation in 2014 monsoon. Therefore, some small parts of the eastern and northern areas which are being shown as dry in Fig. 6 and 7 above may actually be having water during the prediction period.

VII. CONCLUSIONS

Water balance of the post monsoon months of 2014-15 has been carried out in the present study to predict water levels of the lake for the summer months of 2015. On the basis of the results obtained it can be concluded that the lake shall be on the verge of drying at the end of the summer 2015, although it shall not dry out completely. By the end of June, the surface area of the lake is likely to be only about 60% of the maximum surface area of the lake, with some of it being exposed dry bed of the lake. The expected water level on 1st July, 2015 is likely to be 351.01 m amsl with a storage capacity of about 35 Ham, surface area of about 100 Ha and mean depth of water of about 0.34 m. However, if the rainfall for post monsoon months is less than the historically observed average rainfall and if the evaporation rates are higher than the average evaporation rates observed in the past decade, the lake is likely to dry up significantly. Further, if the monsoon is significantly delayed, and if the rainfall of June or July is significantly low than the normal, then the lake may dry out completely with only about 5-10 Ham of water expected to be left in it by 15th July, 2015.

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