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Role and significance of silt detention dams to sustain the functional life of a rapidly silting lake at Chandigarh

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ABSTRACT

A detailed study was conducted during 2010-2011 to find out the present Storage Capacity (SC) of all the water bodies (WB) created behind the Silt Detention Dams (SDDs), their siltation rate, amount of silt arrested and possibilities of release of water to augment lake storage. 150 functional WBs were identified having combined SC of 254.2 hectare meters (ha-m) which was 48% of Lake SC of 532 ha-m. In the good monsoon season of 2010 when 1332 mm of rainfall was recorded against the average of 1120 mm, these WBs retained 217 ha-m or 41% of Lake storage indicating that a substantial part of runoff was retained by the SDDs. The subsequent loss of 137 ha-m through seepage and evaporation till May, 2011 was loss of much needed water by the Lake. Out of 150 WBs, 28 were totally silted, 38 had less than one and 36 between 1 to 2 ha-m storage and likely to silt in next 6 to 8 years. The silt load to these WBs was still around $40 \text{ t ha}^{-1} \text{ yr}^{-1}$ necessitating the desiltation of these 102 WBs so that silt flow to the Lake remains under check. There were 48 WBs with SC between 2 to 7 ha-m which would not need desiltation for long and could donate with proper mechanism around 83.3 ha-m in good, around 60 in normal and 40 in low rainfall years after retaining sufficient water for wildlife and also keep tourist interest alive. The quantity of silt arrested by SDDs was worked out as 137.76 ha-m or 20,66,400 tons. The study concluded that the degraded micro-catchments continued to release silt load of $40 \text{ t ha}^{-1} \text{ yr}^{-1}$ inspite of best treatment and hence the provision of SDDs was necessary to bring down initial silt loads to the Lake. The desiltation of these WBs would be necessary on reducing scale to save the Lake from further siltation. It was possible to release water to the Lake depending upon rainfall situation from 48 larger WBs.

1. INTRODUCTION

The Shivalik foot-hills of north India covering 4.2 million hectare (m ha) area were characterized as young, fragile, heterogeneous, deforested and erosion prone which remained associated with environmental and ecosystem instability problems since long (Glover, 1944 and Gorrie, 1946) and constitute one of the seven most degraded eco-systems of the country (Jain *et al.*, 1998). The illicit cutting of vegetation and over grazing accentuated the problems of hill denudation, floods and siltation of reservoirs in this region (Bhumbla, 1976, Grewal *et al.*, 1990). Grewal (1995) extensively dwelt on the extent, causes, characteristics and

control measures for the menace of torrents emerging from the denuded Shivalik hills.

Incidentally, Sukhna, a man-made recreational Lake at Chandigarh (North India) formed in 1958 by constructing a 12.8 m high earthen embankment across three Shivalik torrents was caught in the web of rapid siltation from day one due to severe soil erosion in its 2540 ha degraded forest catchment forming part of the Shivaliks hills (Grewal and Juneja, 1984; Bansal and Grewal, 1986 & 1990; Grewal *et al.*, 1988; Grewal and Juneja, 1991 and Grewal, 2014). By the time remedial measures were initiated in mid seventies, 2/3rd of its SC was lost due to siltation (Sohal, 2000). The

severity of such a serious soil erosion problem was not well realized before the Lake was planned. It was then decided to go in for intensive Soil and Water Conservation (SWC) measures in the catchment which included construction of more than 180 earthen SDDs, an equal number of dry stone and masonry check dams supported by vegetative conservation measures, tree plantation and effective closure ensured by fencing the area. These measures were systematically taken for a period of three decades (1975 to 2006) and as a result, the siltation rate was reduced from 140 to around $5 \text{ t ha}^{-1} \text{ yr}^{-1}$ by 1990 (Bansal and Grewal, 1990).

As the silt loads reduced to tolerable limits, a second generation problem in terms of decreasing water yield to the lake emerged impacting its tourist potential. Apprehensions were expressed that lot of water was retained by large number of SDDs and as a result, sufficient rain water was not reaching the lake. Such an issue of SWC works executed to reduce silt load also reducing inflow to lakes having high recreational and drinking water importance for the public was not well addressed by the earlier hydrological studies in this region (Brandt, 2000; Nallanathel and Santhanam, 2014). A detailed study was, therefore, conducted during 2010-2011 to critically analyse the role and significance of SDDs constructed to trap silt laden inflow to the Lake and increase its functional life. The study aimed to find out the present SC of all the WBs created behind these SDDs, their silt trap efficiency determined from rate of their siltation, amount of silt arrested by the SDDs and actual spill over and possibilities for release of post-monsoon stored water to augment Lake storage. There was no information about these parameters with the executing agency.

2. MATERIALS AND METHODS

Location and Background

Sukhna, a man-made recreational Lake at Chandigarh (longitude: 76.48 to 76.54 and latitude: 30.44 to 30.49, altitude from 275 to 589 m above msl) was formed in 1958 by constructing a 12.8 m high earthen dam across three Shivalik torrents (Fig. 1). Intensive soil and water conservation measures in the 2540 ha forest catchment of the Lake were carried out which included tree plantation, effective closure ensured by fencing the area, construction of more than 180 earthen SDDs and equal number of masonry check dams supported by vegetative conservation measures. The field work of the study was initiated in May, 2010 and continued upto May, 2011. A torrent-wise list of SDDs was compiled from the records of the Forest Department, U.T. Chandigarh. All dam bodies were marked by actually traversing the catchment area of Sukhna Lake on the Survey of India topo-sheets of 1:50,000 scale and a list of 150 functional WBs was finalized against 180 claimed.

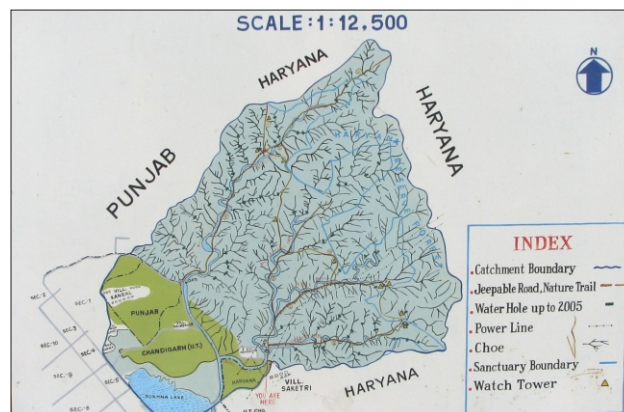


Fig. 1. Catchment area of Sukhna Lake at Chandigarh

Rainfall Amount and Distribution

The rainfall and pan evaporation records of the meteorological observatory of the ICAR-Indian Institute of Soil and Water Conservation, Research Centre, Chandigarh located at the Mansa Devi Farm which is 2 to 5 kms from the study area were collected. Two ordinary rain gauges were installed in *Kansal* and in *Saketri Choe* (a torrent is locally called *Choe*).

Storage Capacity Survey

The water level in the reservoirs was lowest during May-June 2010, so topographic survey was done during this time following direct contouring method and contours drawn at one meter contour interval. The reservoirs having water up to one meter could be surveyed easily by taking staff to each grid point. However, when depth of water was more, an inflated truck tube was used as a boat to reach the grid points. In the WBs having no SC due to complete siltation, we could draw only one contour of spillway level and were marked as dry. The surveyors recorded the water levels in reservoirs round the year at fortnightly interval from spillway levels taken as bench mark with the help of dumpy levels.

Gain and Loss in Storage Capacity

Water levels from all the WBs were recorded from temporary gauges at fortnightly interval and gain or loss was worked out from depth vs storage capacity curves. Evaporation losses were worked out from open pan evaporimeter data and related to small reservoirs by multiplying with 0.8 as suggested by Frevert *et al.*, 1955. Total loss minus evaporation was taken as seepage loss.

Calculations for Spill-over

With each rainfall event, the rise in reservoir level was recorded from fixed reference points from 10 representative reservoirs. The catchment area of reservoirs was determined from topo-sheets on which the location of dams was marked in advance. From the depth versus storage curves, the volume of water received in the

reservoir with the given rainfall event was calculated (A). This was given by the rise in water level with each rainfall event. The catchment area (sq m) x rainfall of the event = Volume of water that fell as rain (B). When we divided the reservoir received volume (A) by Rainfall volume (B) and multiplied by 100, we got the value of runoff coefficient (C). The C values for number of storms received till the reservoir spills over were averaged out to get the mean C-value of the catchment. The C values for Haryana area were assumed to be slightly more because of less vegetation and more bare slopes. From the run off volumes received, the SC of WBs was deducted to get amount of water that may have spilled over.

The siltation rates of 10 more reservoirs were worked out by actual measurements of fresh silt bars in all the gullies and creeks draining into the reservoirs. The total SC of the reservoir divided by silt volume received per year provided the number of years that would be required to exhaust the entire storage by silt. The reservoirs were then classified into categories based on the years required for siltation. The categorization of the WBs was carried out based on their present capacity and need of desiltation.

Silt Arrested by Water Bodies

In the absence of data on original storage capacity just after construction, an attempt was made to find the present SC. Most of the WBs were silted up to varying depth. The present level of the original nala bed close to the spillway toewall was taken as the base level of the reservoir. The difference between present bed level of the reservoir close to spillway and base level of nala was taken as silted depth. The first contour was drawn at the level of spillway and given value of 100.00; the next lower contour was at 99.00, then down to the lowest level with one meter contour interval.

Ten cross sections of probable dam sites were taken randomly and sections drawn on graph sheets. The depth was measured every five meters from the top taken as spillway level and average depth of the sections was worked out. The overall depth was found as 0.4 x maximum depth up to the spillway level. The total height of dam was taken by taking level at the crest of spillway minus the level at the nala bed near the foot of the spillway. The submergence area at full supply level was worked out by finding area under contour drawn at the spillway crest level.

Volume of silt in water body = (0.4 x maximum height x submergence area) - present SC.

The time required to completely silt the WB was calculated by the following method:

Suppose the storage capacity of a water body is 1 ha-m.

The siltation rate is 100 t ha⁻¹yr⁻¹ or 66 cum ha⁻¹yr⁻¹.

Assume the catchment area of the water body as 20 ha,

$$\text{Years required to silt water body} = \frac{\text{Silt volume in cum (100 x 100 x 1)}}{\text{Siltation rate cum (66) x catchment area ha (20)}} = 7.5 \text{ years}$$

It would take 7.5 years to completely silt the WB when siltation rate is 100 t ha⁻¹yr⁻¹.

The author would call the above methods as the best possible options to reach nearer to the exact values not available with the executing department. This required calculation of runoff coefficient, runoff contributing area, runoff producing rainfall and net storage gained from the monsoon rains. The methodology of working out these parameters is explained as under:

Determination of Runoff Co-efficient

The runoff coefficient (C) values for number of storms over 10 reservoirs till the reservoirs spilled over were averaged out to get the mean C-value of the catchment which was 0.11 or 11% of rainfall volume of water reached the reservoir and the rest was retained in the catchment. According to Shrimali (1999), Sukhna Lake Catchment can generate runoff off about 20% from runoff causing rainfall. His estimates were for the entire 4207 ha catchment of the Sukhna Lake while the present estimates are for only forest catchments. The runoff coefficient values for forest areas are much less than cultivated farm lands. In addition, his estimates are almost 12 years old and vegetation cover is continuously improving in the forest catchment areas of the Lake. Under a very comparable landscape of the ICAR-IISWC, Research Centre near Mansa Devi, the average annual runoff from small well treated watershed closed since sixties and gauged regularly, was 3 to 7% (Bansal and Grewal, 1990). The average runoff coefficient of 0.11 for good rainfall year seems well within the range of 0.03-0.07 to 0.20.

3. RESULTS AND DISCUSSION

Rainfall Amount and Distribution

The rainfall and distribution formed the basis of water storage created in different water bodies. In the good monsoon season of 2010, 1332 mm of rainfall was recorded against the average of 1120 mm annual and 900 mm monsoon rainfall. There were 9 rainfall storms above 60 mm but 3 flood producing storms above 100 mm were also received which were mainly responsible for filling the reservoirs and spill over (Fig. 2).

The reservoir storage versus rainfall data indicated that small rainfall storms less than 30 mm did not produce much runoff and did not add to the reservoir storage.

Storage Capacity of Reservoirs

Though SC of all the WBs was determined by contour

survey but the contour plans of four typical WBs with low, medium, good and very good SC as represented by

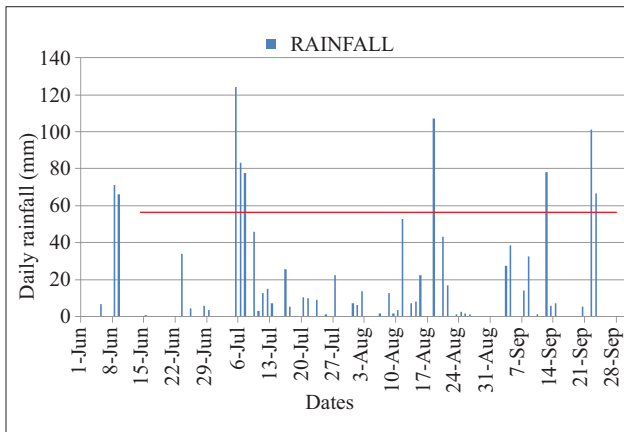


Fig. 2. Distribution of moonsoon rainfall (mm) during of 2010

D, C, B and A, respectively are reported to clarify the methodology (Fig. 3).

The water spread area at spillway level of these WBs was 3170, 7900, 13750 and 21660 sq m and respective SC as 0.653, 1.800, 2.799 and 6.746 ha-m, respectively. The cumulative SC at different depths (indicated in the Tables) was used to generate depth versus SC curves (Fig. 4).

The combined SC of all the WBs located in catchment of six *choes* was worked out as 254.229 ha-m which was 48% of the total capacity of 532 ha-m of Sukhna Lake (Table 1).

Almost 44% of total SC was generated by 54 WBs located in the catchment of *Kansal choe*. The WBs in *Nathewala*, *Nepli* and *Ghareri* had SC of 20.54, 14.06 and

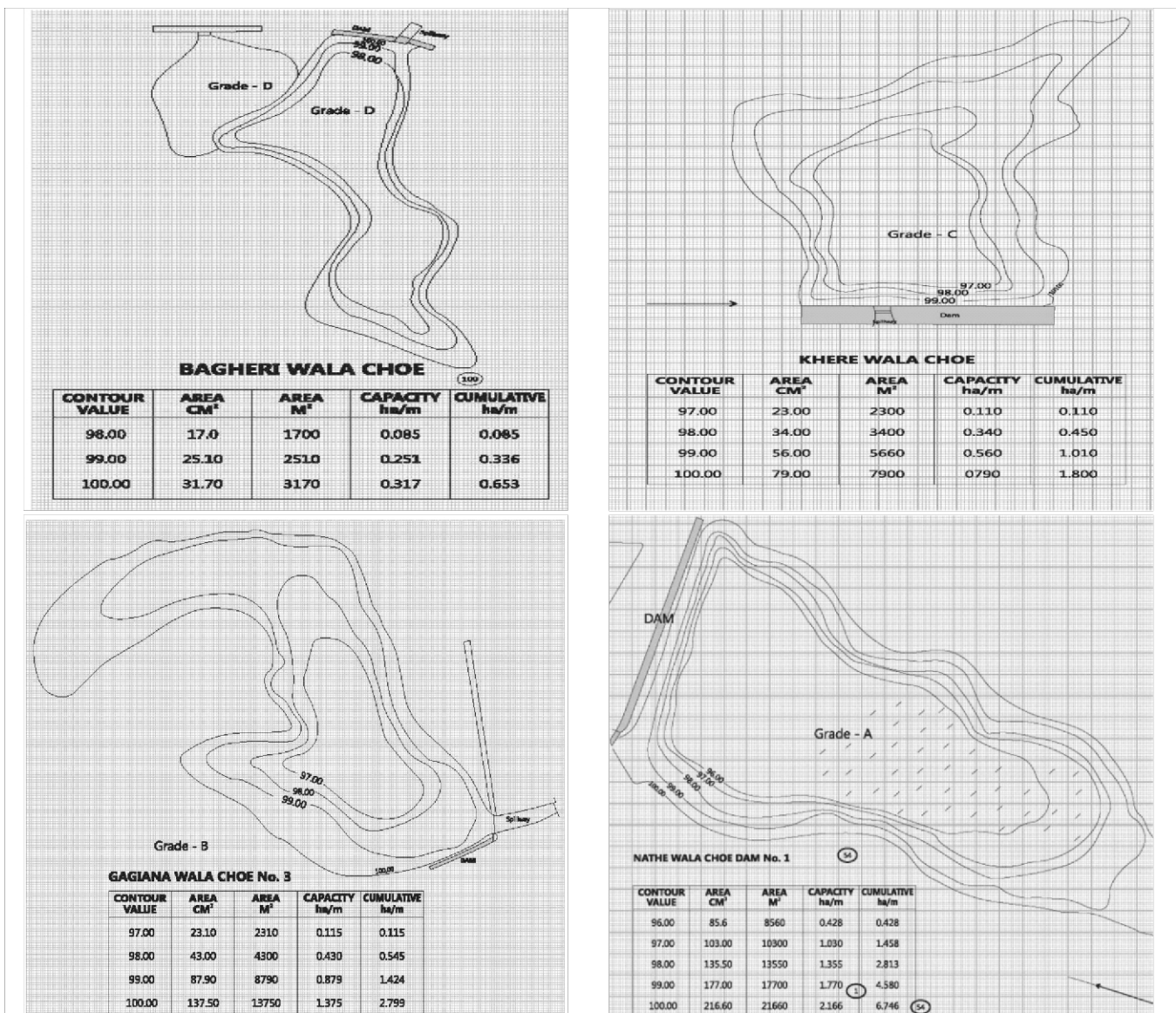


Fig. 3. Capacity survey plans of four typical categories of water bodies

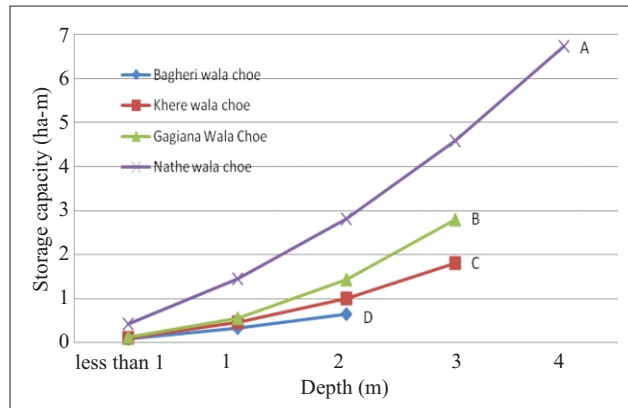


Fig. 4. Depth vs. storage curves of four water bodies

14.44% of total whereas WBs in *Mahadev* and *Khuda Alisher choes* had limited SC (Table 1). During the rainy season of 2010, with 1332 mm of rainfall, 85.4% of the total available capacity was utilized by storing run off

from upper forest areas. The remaining 14.6% capacity remained unutilized as some WB remained partly filled due to another dam above them. In fact the SDDs were not designed on the basis of water yield from catchment areas. The SC of all the reservoirs was full by 15.9.2010 except *Ghareri*, so run off from two heavy storms received between 21 and 28.9.2010 (Fig. 5) spilled over from the reservoirs.

Categorization of Water Bodies According to Storage Capacity

As the management of large number of WBs required siltation rate and SC based categorization, so all the WBs were divided into five categories as per detail given in Table 2.

As per the above characterization, the number of WBs was 28, 38, 36, 20 and 28 in the category of E, D, C, B and A, respectively (Table 3).

Table: 1

Summary of storage capacity related data of water bodies in the catchment of six choes

S.No.	Name of choe	No. of Dams		Storage capacity (ha-m)	Storage attained (ha-m)	Percent of total	% capacity attained	Date on which attained
		Sr. No.	Total					
1	Kansal	1 - 54	54	112.556	99.998	44.27	88.83	15.09.10
2	Nathe Wala	55 - 84	30	52.197	46.015	20.54	88.16	17.08.10
3	Nepli	85 - 106	22	35.754	30.745	14.06	86.00	15.09.10
4	Ghareri Wala	107 - 136	30	36.719	32.614	14.44	88.82	15.10.10
5	Mahadev	137 - 145	9	11.832	6.783	4.66	57.23	15.09.10
6	Khuda Alisher	146 - 150	5	5.171	0.962	2.03	18.60	15.08.10
Total			150	254.229	217.117	100.00	85.40	

Table: 2

Categorization of water bodies according to the storage capacity

Category	S.C class	Description of class
E	No capacity	Water bodies were totally silted up with no storage capacity left.
D	Limited capacity	Total SC was upto one ha-m. Maximum water depth varied from 1 to 2 m during rains but all gradually dried up. Water remained standing in pockets upto February-March and rest of the reservoir areas dried up.
C	Moderate capacity	Total SC was between 1 to 2 ha-m and maximum depth of water during monsoon end varied from 2 to 3 m in most cases and went up to 4 m in few cases. These WBs retained 1 to 1.5 m depth of water throughout the year.
B	Good capacity	Total SC was between 2 to 3 ha-m and maximum depth during monsoon end varied from 3 to 4 m in most cases and retained 2 to 3 ha-m of water round the year.
A	Very good capacity	Total SC was more than 3 hams and maximum went up to 9.5 ha-ms. The depth of water varied from 3 to 5 m and went up to 6 m in few cases The average depth during monsoon was 4.8 m. These Wbs were real store houses of water.

Table: 3

Distribution of water bodies according to their storage capacity and siltation

Name of choe	Number of water bodies in different storage capacity classes					Total
	Totally silted E	< 1 ha-m D	1-2 ha-m C	2-3 ha-m B	>3 ha-m A	
Kansal	11	8	11	10	14	54
Nathe	6	7	10	2	5	30
Nepli	4	6	5	2	5	22
Ghareri	4	13	6	4	3	30
Mahadev	2	3	3	1	1	10
Khuda	1	1	1	1		4
Total	28	38	36	20	28	150

The results revealed that out of 150 WB, 28 were totally silted up with no storage, another 38 had limited storage of less than one ha-m storage and 36 had moderate storage capacity between 1 to 2 ha-m. As per calculations, the later two categories would silt in 2 to 4 and 6 to 8 years, respectively. These 102 WBs would require desiltation so that silt flow to the lake remains under check. The remaining 48 WBs with SC between 2 to 3 and above would not need desiltation for 20 to 30 years. As per the present condition, it was clear that 108 WBs would not be able to donate any water during post monsoon period due to their limited left over capacity unless desilted. However, the remaining 48 reservoirs remained filled round the year and could donate water to the lake when needed with appropriate mechanism.

Trend of Storage Gain during Monsoon Season and Loss during Post Monsoon

The overall trend in gain of storage during monsoon season and subsequent loss during post-monsoon season in all the WBs of six *choes* is given in Table 4.

Storage Gain from Monsoon Rains

Before the onset of the monsoon rains in middle of May, 2011, the combined carried over storage of all the WBs from previous rains was 35.858 ha-m. This was very low storage mainly because 2009 was a very low rainfall year. However, in the month of June, 2010, very heavy rainfall of 71 and 66 mm was received on 7-8 June, 2010 (Fig. 2) which created storage of 98.774 ha-m. Up to the middle of June, 2010, no rain water was lost as runoff from these WBs except 29 having no SC at all. The July 2010 rainfall of 459 mm was almost 30% above the mean monsoon rainfall of about 350 mm of this month which raised the storage of the reservoirs to 187.152 ha-m by 15.7.2010. Between 9th July and 10th August, 2010, there were small rainfall storms and hence gain in SC was very small. However, two heavy storms in August, 2010 raised the total SC from 187.152 to 205.462 ha-m. By this time, 60 out of 121 WBs started overflowing. A very heavy rainfall of 107 mm on August, 17, 2010 followed by 43.2 mm on August 20, 2010 was received when maximum storage was gained. By September 15, 2010, almost entire storage was saturated and maximum SC of 217.153 ha-m was reached (Table 4 and Fig. 5).

Table: 4
Trend of storage gain and loss from water bodies in major *choes* (ha-m)

S.No.	Name of <i>choe</i>	Dates of 2010-11										
		15.05.10	15.06.10	15.07.10	15.08.10	15.09.10	15.10.10	15.11.10	15.12.10	15.03.11	15.4.11	15.5.11
1	Kansal	10.817	41.888	83.368	92.184	99.998	94.918	83.432	74.864	50.933	42.448	33.963
2	Nathe Wala	9.735	27.215	41.374	46.015	46.013	44.584	39.622	37.036	28.376	23.648	18.920
3	Nepli	6.284	11.749	28.609	29.581	30.745	29.121	26.574	23.622	17.739	14.782	11.826
4	Ghareri Wala	7.979	14.498	27.119	30.078	32.614	33.077	28.706	26.518	21.003	17.503	14.003
5	Mahadev Mandir	1.043	2.788	5.351	5.922	6.783	5.722	4.536	3.594	1.990	1.660	1.330
6	Khuda Alisher	0.000	0.636	1.331	1.682	0.962	0.832	0.581	0.000	0.000	-	-
7	Total	35.858	98.774	187.152	205.462	217.115	208.254	183.451	165.634	120.041	100.041	80.042

Storage Loss in Post Monsoon Period

Due to evaporation and seepage loss, water storage got reduced from 217.115 to 208.254 ha-m by 15.10.2010. The gradual loss in storage continued and by March 31, 2011 storage was reduced to 120.041 ha-m and by May 15, 2011 to 80 ha-m. The trend in reduction of storage was variable in different *choes* and also reservoirs. The reservoirs having some perennial flow from upper areas and no leakage, maintained the storage capacity for longer period. The loss was 24.803 ha-m between Oct.15 and Nov. 15, 2010 (Table 5).

This loss got reduced to 17.817 ha-m between Nov.15 and Dec.15, 2010. In the last three months from Dec.15 to

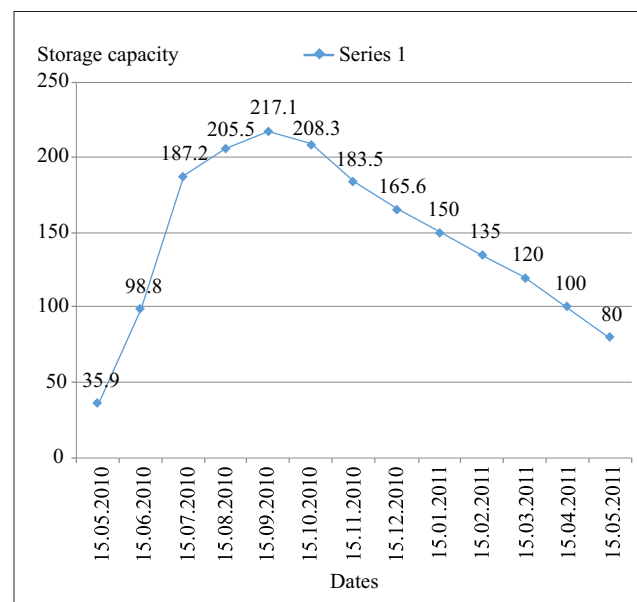


Fig. 5. Trend of storage gain and loss (ha-m) from water bodies on different dates

Table: 5
Trend in loss of storage capacity during post monsoon period

Dates	Storage capacity (ha-m)	Loss of storage (ha-m month ⁻¹)
Oct.15, 2010	208.245	
Nov.15, 2010	183.451	24.803
Dec. 15, 2010	135.634	17.817
March 15, 2010	120.041	45.59 (@15 month ⁻¹)
May 15, 2010	80.00	40.00 (@20 month ⁻¹)

March 15, 2010, the average storage loss was around 15 ha-m. With the loss of 20 ha-m month⁻¹ in April and May 2010, the SC left was 80 ha-m against 35 ha-m on May 15, 2010. This was because of very heavy rainfall storms received during monsoon season. The overall trend of storage gain during monsoon season and loss during post monsoon season is depicted in Fig. 5.

Extent of Spill over to the Sukhna Lake

The estimation of spill over required data on overall runoff co-efficient, runoff contributing area, rainfall and runoff producing rainfall and net gain from the monsoon rains. These parameters are explained as under:

The overall run-off coefficient for Sukhna Lake: The calculations for good rainfall year for UT forest area have been made with C value of 0.11. The C values for normal and below normal monsoon years would be less than this value. The Haryana forest area above UT forest was not that well covered with vegetation and composed of steep bare hill slopes. So higher C values have been assumed. The C value for build up area outside forest was assumed as 0.60.

Computed C value = $(2540 \times 0.11) + 1022 \times 0.15 + (645 \times 0.6) / 4207 = 0.19$.

Where, 2540, 1022 and 645 are areas of forest under UT Chandigarh, forest area under Haryana and area under habitation and undulating farm lands and roads outside forest area. So, at the Sukhna Lake, the runoff could be around 19% of runoff producing rainfall in the catchment.

Runoff contributing area: The UT forest area is 2540 ha, out of which 40 ha drains towards the periphery with no water body and hence excluded from the runoff going out from water bodies' calculations. The WBs are spread over remaining 2500 ha forest area. In addition, 1022 ha forest area of Haryana drains to the Sukhna Lake through UT forest area and most of it passes through series of SDDs constructed across the *choes*. Thus the total forest catchment area contributing runoff to the Lake was $2500 + 1022 = 3522$ ha.

Runoff producing rainfall: It was assumed that only monsoon rainfall would produce runoff which may go to the Lake as most of rainwater from winter rains would be retained in the WBs. Secondly, all the rainfall events did not produce runoff as indicated by rainfall versus storage gain data. Most of small rainfall storms were intercepted by vegetation or runoff infiltrated into the soil or absorbed by sand deposited in drainage lines and failed to reach the WBs. We noted from the data that rainfall storms less than 30 mm hardly produced any runoff. So for the study year, the total of all the monsoon rainfall storms above 30 mm was 1023 mm or 77% of the total 1333 mm of monsoon rainfall. This ratio would be low in low rainfall years. The monsoon season rainfall was taken as 635 and 504 mm in normal and low rainfall years, respectively.

Net storage gained from the monsoon rains: The net storage gain was worked out by deducting the left over storage of previous year from the total water harvested. The 2009 monsoon rainfall was low and left over storage was only 35 ha-m which was dismally low. In the present situation, water bodies stored upto 217 ha-m of runoff and rest was overflow. With these clarifications, we worked out spill overs under different rainfall situations.

Spill over from Functional Water Bodies

A. Spill over in good rainfall years

Monsoon rainfall received during the study year	1333 mm
Effective/runoff producing rainfall (all storms above 30 mm)	1023 mm
Catchment area contributing runoff to water bodies (Leaving 40 ha on periphery)	2500 ha
Total water harvested by functional water bodies upto 15/09/10	217 ha-m
Left over water storage from previous year as on 15/5/2010	35 ha-m
Net storage gained from the monsoon rains (217-35)	182 ha-m
Average run off co-efficient as worked out for representative reservoirs	0.11 C
Rainwater volume received over the catchment area $(2500 \times 1023 \times 0.11) \% 1000$	281.325 ha-m
Runoff volume received in the catchment of Har. $(1022 \times 1023 \times 0.15) \% 1000$	156.825 ha-m
Total runoff received over the entire catchment area $(281.325 + 156.825)$	438.175 ha-m
Run off which spilled over from water bodies $(438.175 - 182.00)$	256.175

B. Spill over in normal rainfall years (runoff producing rainfall as 635 mm)

Total rainwater volume expected over the catchment of UT forest area $(2500 \times 635 \times 0.10) \% 1000$ (1000 mm = one meter)	158.75 ha-m
Runoff received in the catchment of Haryana forest $(1022 \times 635 \times 0.12) \% 1000$	77.88 ha-m
Total runoff received over the entire catchment area $(158.75 + 77.88)$	236.63 ha-m
Run off which may spill over from the WB = $236.63 - 135$	101.63 ha-m

C. Spill over in low rainfall year (runoff producing rainfall taken as 504 mm)

Total rainwater volume received over the catchment of UT forest area $(2500 \times 504 \times 0.08) \% 1000$ (1000 mm = one meter)	100.8 ha-m
Runoff received in the catchment of Haryana forest $(1022 \times 504 \times 0.10) \% 1000$	51.5 ha-m
Total runoff received over the entire catchment area $(100.8 + 51.5)$	152.3 ha-m
Run off which may spill over from WB or remain unharvested $(152.3 - 100.8)$	= 51.5

So in good, normal and low rainfall years, 256, 102 and 52 ha-m (Round figures) of water may spill over after satisfying the present SC of the WBs. The above results are summarized in Table 6.

Table: 6
Amount of spill over from water bodies in different rainfall situations

Type of rainfall year	Monsoon rainfall (mm)		C value		Vol. of run off received (ha-m)	Storage capacity of water body (ha-m)	Amount of spill over (ha-m)
	Total	Effective*	UT Forest	Haryana Forest			
Good rainfall	1333	1023	0.11	0.15	438	182	256
Normal rainfall	905	635	0.10	0.12	237	135	102
Low rainfall	504	504	0.8	0.10	152	100	52

*In the absence of long-term data, these values were based on experience and judgement.

Amount of Silt Arrested by SDDs

The SC of WBs at the time of construction was not worked out. Based on the methodology adopted, the silt deposited under 150 WBs was 137.76 ha-m or 20,66,400 tons (Table 7).

If a tipper carries around four tones trip⁻¹, almost 5 lakh truck loads of silt was arrested behind the SDDs. Had these SDDs not been there, the Lake would have lost another 137 ha-m of its storage out of 532 ha-m it had by 2010. It is sufficient to suffice that SDDs would have to be retained and desilted when required if Sukhna Lake is to survive.

Role and Significance of Silt Detention Dams

Sediment release to Sukhna Lake was last worked out as less than 5 t ha⁻¹yr⁻¹ (Bansal and Grewal, 1990). This figure was based on measurements from gauging stations installed at the end of all the three main *choes* draining the runoff from 2540 ha forest area. This is a fact that such a drastic reduction in silt load was not possible without intercepting silt laden runoff in the reservoirs of SDDs. The above conclusion is supported by the fact that the reduction in water yield to the Lake was inversely proportional to the progress of construction of SDDs. The data provided by Sohal (2000) was reproduced to show the cumulative progress of construction of SDDs and decrease of inflow to the Lake (Fig. 6).

Complete data were available to Sohal (2000) for 107 SDDs. However 43 SDDs were raised, remodeled and renovated by 2010, all 150 SDDs were in position. The reduction in inflow from 8800 to 7400 between 1958 and 1978 could be attributed to overall vegetation cover

Table: 7
Summary of live and dead storage of water bodies in six Choes

Name of Choe	Live storage capacity (ha-m)	Dead storage by silt deposition (ha-m)
Kansal Choe	112.556	53.513
Nathewala Choe	52.197	27.790
Neple Choe	35.754	18.158
Ghareri Choe	36.719	28.583
Mahadev Mandir Choe	11.832	8.823
Khuda Alisher Choe	5.171	0.893
Total	254.229	137.76

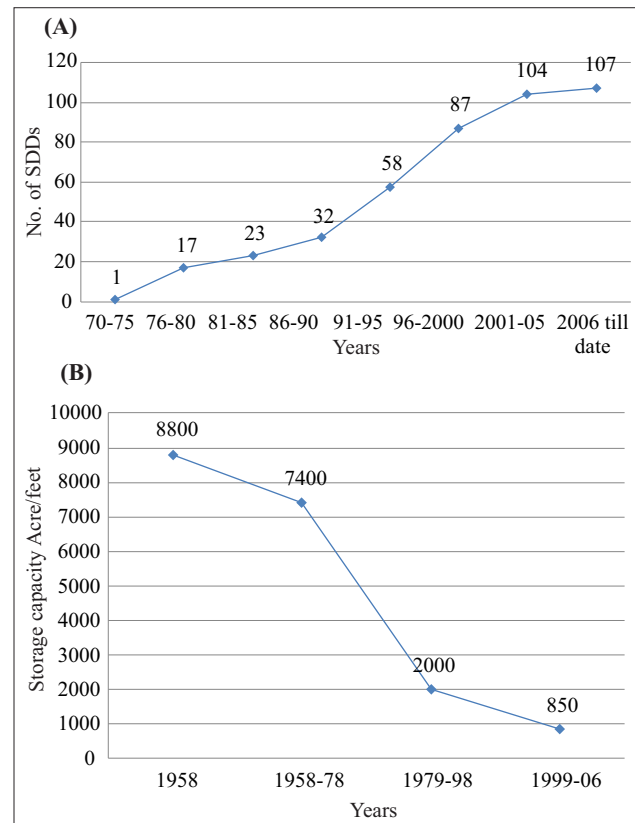


Fig. 6. (a) Progressive increase in the construction of silt detention dams (b) Progressive decrease in inflow of water to Sukhna Lake

improvement but further drastic reduction from 7400 to 2000 by 1998 and further down to 850 acre feet was attributed to the construction of SDD.

In the previous study by SPACE (2009), it was noted that the range of siltation rate in *Ghareri Choe* varied from 2.04 to 64.65 t ha⁻¹yr⁻¹ and overall siltation rate was 39.82 t ha⁻¹yr⁻¹. This rate was worked out on the basis of actual measurement of recent depositions of silt bars/humps formed around the water bodies indicating recent siltation rates. Simply stating, if Sukhna Lake has been getting only 5 t ha⁻¹yr⁻¹ of silt in recent times, but water bodies in the catchment were still getting around 40 t ha⁻¹yr⁻¹ of silt from their forest catchments, then the remaining 35 t ha⁻¹yr⁻¹ was being retained by the Wbs.

4. CONCLUSIONS

One would have to retain water to retain silt in this type of topography. The study concluded that the life of the lake is strongly related to the functional efficiency of the SDDs and WBs behind them and hence the construction of SDDs appears fully justified. Had this area not been closed and intensive SWC measures taken, there was no way that we could save the Sukhna Lake till this time. The siltation rate of Sukhna Lake must be maintained at a level of 3 to 5 t ha⁻¹ of catchment yr⁻¹. In case the silt load from the catchment of some of the reservoirs is more than 3 t ha⁻¹yr⁻¹, the WBs would have to be desilted or existing dams raised to retain the excess silt. The original design of SDDs was defective as no water release system below spillway was provided otherwise surplus water after settlement of silt could be released to the lake. The release of water seems possible but transmission losses, mechanism of release, taking away water from wildlife area, economic feasibility and financial viability needs to be worked out. The authors would like to reiterate that all WBs have storage life which can be prolonged by the management of soil and vegetation cover complex and appropriately designed management regimes. There is no escape from the conclusion that desiltation regime shall have to be followed regularly to keep the siltation of Sukhna Lake under control.

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