SILTATION PROBLEMS IN SUKHNA LAKE IN CHANDIGARH, NW INDIA AND COMMENTS ON GEOHYDROGICAL CHANGES IN THE YAMUNA-SATLUJ REGION

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INTRODUCTION

During the last hundred years or so, deforestation and wind-water borne soil erosion have been steadily increasing and have now become the major environmental problems the world over (Menard, 1963; Sioli, 1985; Endlicher, 1990; Barrow, 1991; Boardman and Favis Mortlock, 1993; Jones, 1993) and in India especially in the Himalya (Rieger, 1981; S. Singh, 1981; Ives, 1981; G. Singh *et al.,* 1990; J. Singh *et al.,* 1984; Kayastha, 1992) and NW Indian Siwalik Hill region (Glover, 1946; Gorrie, 1946; Bansal and Mittal, 1982; Mittal *et al.,* 1986; Grewal *et al.,* 1990 ; Y. Singh, 1990a; Kukal *et al.,* 1991; Saha *et al.,* 1991; Kukal and Sur, 1992). Chandigarh and Morni Siwalik Hills (CMSHs) lying in the present day states of Punjab and Haryana received special attention during the last decade because their location is adjacent to Chandigarh, the City Beautiful built as the Capital City of the erstwhile State of Punjab and now of Haryana and Union Territory (U.T.) of Chandigarh too (Mehta and Y. Singh, 1995; Y. Singh, 1990b, 1990c, 1992, 1996, 2001, 2002).

Y. Singh (2001) elaborated the state of forests in the Chandigarh and Morni Hills between the years 1966-1991 and indicated that by and large, these hills supporting open and scrub forests reflect ‘badland’ topography. Due to high rate of water-soil erosion there has been a change in the profile of stream beds with the result during rainy season the water often overflows their banks and floods the adjacent lands. It has also been shown by him (Y. Singh, 1996) that the Chandigarh Siwalik Hills (CSHs) lying at 30° 43′.1 - 31° 1.7′ N. Lat. and 76° 32.7′ - 76° 54.5′ E. Long. between Satluj and Ghaggar rivers covering an area of 302.55 sq km have experienced vast change due to environmental vicissitudes consequential to high rate of developmental boom experienced by Chandigarh, as reflected by the fact that these hills suffer from high rate of soil loss averaging 367.5 tons/ha/yr.

The man-made Sukhna Lake brought into existence through blocking of the water flow in the Sukhna Choe originating from these hills by raising of stone-cum-earthen embankments, is experiencing siltation over the years right from its completion in 1958. The present paper projects the geographical location of the lake with catchment area, the extent of water spread, changes in water storage capacity, vegetational aspects, as well as the extent of siltation in spatial frame work and the remedial measures taken over the time period of its existence for 43 years. Such a comprehensive study of the structure and ecology of the picturesque water body has not been attempted earlier.

Location and characteristics of the lake

Roughly kidney shaped, the lake is located at 32° 42′ N Lat. and 76° 54′ E Long. with its concavity facing the Siwalik Hills (Figs. 1-3). Its northern boundary adjoining the Siwalik Hills is natural and irregular and SW embankment, artificially built out of hewed stones, has a rockfill earth dam 12.8 m high. The lake is 1.52 km long and 1.49 km wide with initial storage capacity of 1,074 ha-m of water. The submergence area is 228 ha (565 acres) at a maximum lake level of 353.57 m (1,160 ft) above mean sea level(msl) with maximum flood level being at 354.02 m (1,161 ft) above msl. 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.

The dam’s SW embankment is downstream Sukhna Choe at the confluence with it of two seasonal tributaries namely, Kansal and Suketri (Ghareri and Nepli tributaries) Choes (seasonal streams).

Out of the total catchment area of 4,027 ha, 76.4% lies in hilly forest catchment of Kansal, Nepali and Ghareri streams in the Siwaliks wherein the average slop is of 30°. The catchment areas of these streams in the Siwalik Hill are 214.31 ha, 1,285.48 ha and 514.00 ha respectively. The remaining 23.6% of Sukhna catchment (993.21 ha 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.

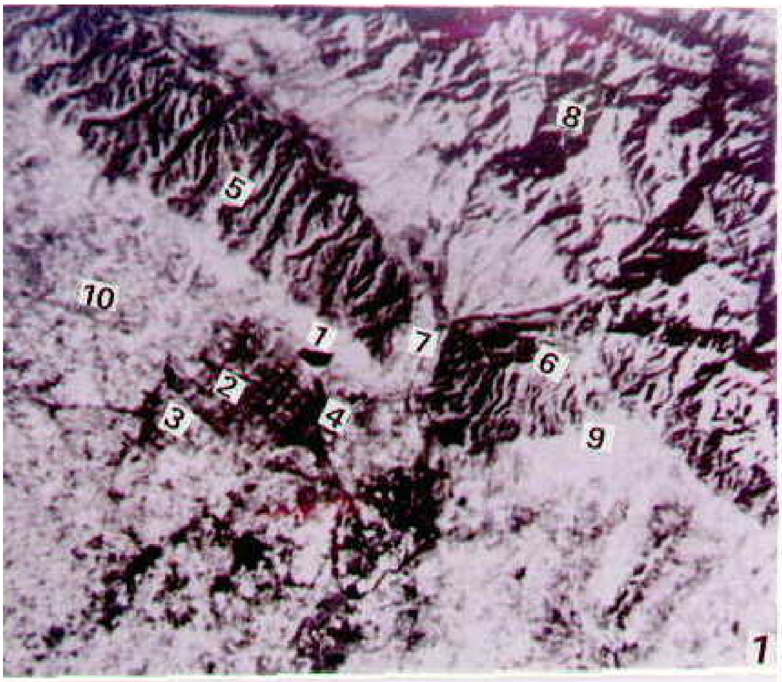

Figure 1.Chandigarh Terrain and drainage lines based on Satellite Imagery IRS IA LISS 1, November 1991 (Courtesy Central Ground Water Board, Chandigarh). 1. Sukhna Lake; 2. Chandigarh City; 3. SAS Nagar (Mohali); 4. Panchkula; 5. Chandigarh Siwalik Hills; 6. Morni Siwalik Hills; 7. Ghaggar river; 8. Himalayan Hills, Kalka Range; 9. Haryana region; 10. Punjab region.

Figure 2.View of Sukhna Lake, when full of water after the rainy season it provides recreational avenues for the residents of Chandigarh and its two satellite towns.

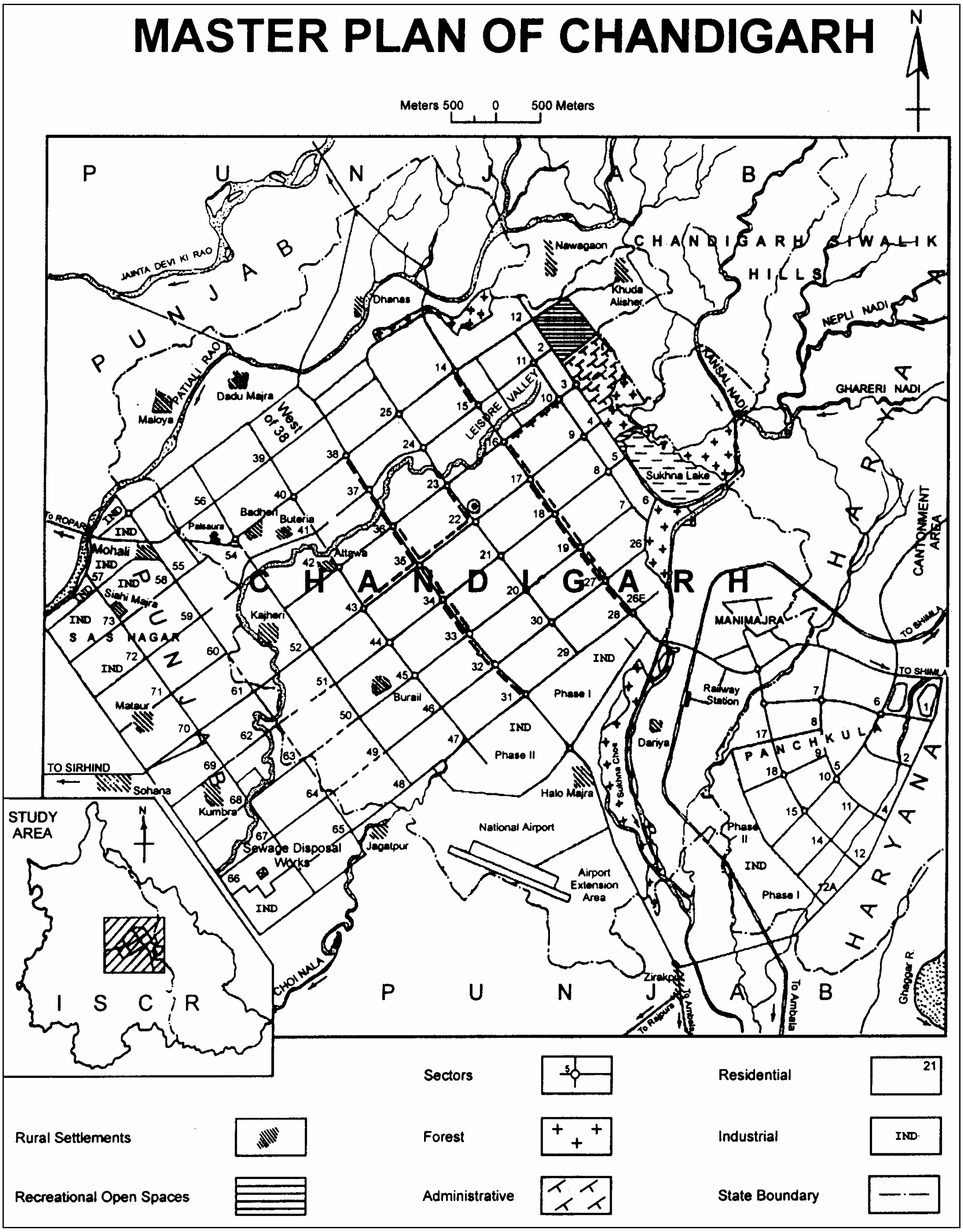

Figure 3. Master Plan of Chandigarh illustrating the salient features of residential and road systems (November 1993). [Based on: A. SOI Guide Map of Chandigarh; B. Landsat TM, FCC, June 13, 1988; C. Chief Architect Chandigarh (U.T.); D. Divisional Town Planner Punjaba & Haryana.]

Broadly speaking, the Sukhna and its catchment areas form part of Semi Natural Drainage Ecosystem (SNDE) which itself is dependent upon Natural Hilly Ecosystem (NHE) of CSHs. The origin and functioning of drainage lines (rivulets, streams and rivers) give rise to the SNDE. Its functioning is dependent upon the inequalities in the nature of rock formation, vegetation and soils and the fact that the land areas must possess some degree of slope, run off accumulating quickly in small gulleys which coalesce to form lager channels and ultimately these channels converge to form streams, rivulets and eventually the rivers.

Obviously from the above it can be derived that the balanced existence of the Sukhna Lake is entirely dependent upon efficient functioning of NHE and SNDE in the CSHs. Any deviation in the functioning of NHE and SNDE resulting in increased water run off with heavy silt load will effect the life of the lake. That is what has actually happened in case of Sukhna which is experiencing heavy siltation load as shown hereafter.

Siltation of the sukhna lake

The catchment area of the *choes* feeding the lake has rugged terrain, steep slopes, plenty of gulleys, very deep water table and the soils are predominantly alluvial sandy embedded with layers of clay and are highly susceptible to soil erosion by water run-off action. The impact of rain drops, quick flow of run-off and exposed soil coupled with hill denudation due to deforestation and animal grazing, are ideal conditions in the area for soil erosion. Naturally, the water flowing into the lake is heavily loaded with silt. The situation is accentuated by the fact that on an average 50% of the total rain in the Siwalik ends in run-off (Misra *et al.,* 1978). Thus due to higher run-off there is accelerated pace of erosion in the catchment areas of the seasonal stream tributaries of Sukhna choe resulting in the higher rate of sedimentation in the reservoir of Sukhna Lake and stream beds. Naturally, the silt deposited year after year in the lake bed reduces the water storage capacity, depth, water spread area and submergence area at lake level (Tables 1-5, Figs. 3-4).

Table 1. Sukhna reservoir: sedimentation and changes in water storage capacity (ha-m)

Year/period	Average annual sediment inflow	Total sediment yield	Cumulative sediment yield	Water storage capacity	Percent loss in original storage capacity
1958	Formation of the lake			1.074.40	
1959-64	49.95	249.75	249.75	824.65	23.24
1964-69	32.19	160.95	410.70	663.70	38.22
1969-74	23.80	119.00	529.70	544.70	49.30
1974-79	12.45	62.25	591.95	482.45	55.09
1979-84	4.03	20.15	612.10	462.30	56.97
1984-89	13.02	65.10	677.20	397.20	63.03

Based on information provided by CSWCR & TI, Chandigarh (see Bansal and Grewal, 1986,1990)

Table 2. Sukhna lake: changes in water storage capacity, 1958-1989

Year	Water storage capacity (ha-m)	Percent of original storage capacity	Percent loss in original storage capacity
1958	1074.40	100.00	-
1976	338.00	31.45	68.55
1978	590.00	54.91	45.09
1988	366.00	34.06	65.94
1989	397.20	36.96	63.04

Source: CSWCR & TI (1993)

Table 3. Sukhna lake: changes in submergence area at full lake level (353.57m above msl), 1958-1989

Year	Submergence area (ha)	Percent loss in submerged area
1958	228.60	-
1982	157.60	31.06
1987	152.80	33.16
1989	142.00	37.89

Source: Bansal and Grewal (1986, 1990) and CSWCR & TI (1993).

Table 4. Sukhna lake: changes in average water spread area, 1958-1990

Year	Water spread area	Percent loss in water spread area
1958	188.00	-
1982	118.00	37.24
1990	115.90	38.36

Source: Bansal and Mishra (1982) and CSWCR & TI (1993).

Figure 4. Although full of water, the stored water level has fallen in the winter and summer months as indicated by mark on the stone embankment in the SW (Photo 24th March, 2002).

Figure 5. Heavy sedimentation of Sukhna Lake bed. The resultant vegetation consists of mainly *Typha* in the foreground. Members of Hydrocharitaceae and Ceratophyllaceae as well as grasses and sedges commonly grow on Lake margins (Photo June 1993).

Table 5. Sukhna lake: level of the deepest point in the lake bed, 1958-1990

Year	Deepest point (m above msl)	Rise in lake bed (m)
1958	343.20	-
1983	349.65	6.45
1987	349.85	6.65
1990	350.30	7.10

Based on information provided by Department of Environment, U.T. Chandigarh Administration.

Vegetation of the lake

The common water weeds of Sukhna are not many. Only few species of grasses and sedges on the margins and, *Typha,* Hydrocharitaceae and Ceratophyllaceae growing in water are noticeable. Over 100 species of flowering plants have been reported from Sukhna Lake catchment area. Along with grasses and sedges many of these grow on the lake margins and even the summer dried up lake bed has several weeds (Fig. 5). Trees, bushes and herbaceous elements are in plentiful in the vicinity of the lake. This vegetation does not differ much from that is present elsewhere in CMSHs (cf. Y. Singh, 2001).

Animals

Sukhna Lake serves as a sanctuary for a large number of birds. About 30 species are residents and the rest are migratory, mainly the winter migrants. So far, about 150 different species of birds have been spotted from Sukhna Wetland Bird Sanctuary. Kansal Khol comprises the wild life sanctuary where large deer (grey and brown) with massive antlers, wild bear, spotted deer, jackal, Indian mangoose and wild cat can often be seen.

Pissiculture is the main economic activity associated with the lake. According to the information provided by U.T. Administration the annual fish catch had been 30 tons in 1987, 33 tons in 1988, 35 tons in 1989 and 37 tons in 1990. Fish seed of about a dozen different fishes is introduced in the lake periodically (thrice a year) and few wild types also occur.

Sukhna Reservoir: changes in water storage capacity

In the early years, after the lake came into existence, the annual rate of siltation was very high. The crucial factor before 1980s was the mass deforestation in the catchment basins of Sukhna, Nepli, Suketri and Kansal rendering steep slopping bare hills prone to excessive erosion. By 1971 about half the storage capacity of the reservoir was lost. Sedimentation further increased and in the year 1976 the loss in water storage capacity rose to about 68.5% of the total i.e. water storage capacity dropped from 1,074.4 ha-m to 338 ha-m (Tables 1,2 Fig.4). Storage capacity was partially recouped by desilting the area near Boat Club (Constructed in 1960 near the western end of the lake) for restoring boating activities which had almost come to stand still. The average annual sedimentation inflow came down to 4.03 ha-m during 1979-1984 from original 49.95 ha-m during 1959-1965 due to vegetative (aforestation and reforestation) and mechanical measures taken to check erosion as annual average sediment yield declined with slow run-off. However, it increased once again during 1984-1989 to 13.02 ha-m due to mass deforestation in 1986 in CSHs especially the Sukhna catchment.

It may be noted that due to siltation there has been an average annual loss of 2.91% in storage capacity of Lake reservoir over a period of twenty year (1958-1978). It got reduced to 2.03% in 1989. Water storage capacity of the lake declined in 1988 to 34.06% of the original but “Shramdan” (voluntary physical help) carried out in 1988 and 1989 with removal of 99,052 m^3 (9.905 ha-m) and 353,750 m^3 (35.375 ha-m) respectively, raised the reservoir capacity to 36.97% (Tables 1,2,7).

1. Within three decades the cumulative sediment deposition till 1989 resulted in a total loss of 677.20 ha-m in water storage capacity of lake (see Fig. 9). The average density of sediment deposit in the lake in 1989 was 1.20 gm/cc. Subsequently, with this deposition there was rise in the lake bed and decline of submergence and water spread area of the lake.
2. The loss of submergence area at full lake level (353.57 m above msl) during the first 24 years (1958-1982) has been to the tune of 31.06% i.e. an average annual loss of 1.29%. But during the next 5 years (1982-1987) there was a decline of 2.1%, however, during 1987-1989, a sharp decline of 4.73%, brought down water submerged area to 62.11% of the original (Table 3).

3. The water spread area decreased by 37.24% during 1958-1982 and rose to 38.36% in 1990 reducing it to 61.64% of the original in 1958 (Table 4, Fig. 4).
4. With sedimentation, the deepest point in the lake bed rose by 6.45m during the first 25 years (1958-1983) at an average annual rate of 0.26m. But during the next four years the deepest point rose by 0.2m only. However, in the next three years (1987-1990) there was an abrupt rise of 0.45m raising the deepest point in lake by 7.10m in just 32 years (1958-1990)period (Table 5). From the original water depth of 8.53m (Bansal and Misra, 1982) during summers at normal water level, the water depth has come down to less than 1.8m because of gradual inflow of silt due to erosion in the adjoining Sukhna catchment of CSHs. With this enormous siltation, often unwanted vegetation comes up over the lake bed (Figs. 5,7). In spite of all the efforts to control and remove siltation of lake, large patches of dry land with vegetation emerge during summer season which are indicative of the changes in vegetation succession taking place in various parameters of the lake reservoir.

Measures already taken to check siltation of sukhna

1. First of all, the problems of siltation of Sukhna Lake was taken up by the Irrigation Department of the Punjab Government in 1971. During 1972-1973 Kansal Choe was diverted into Suketri Choe which joined the lake at its eastern end. But because of steep slopes of the diversion channel and due to reduction in the length, the inflow of silt into the lake got accelerated, especially in the area near Spillway Regulator. This step worked. in negative way.
2. Silt was removed from the Spillway Regulator area during dry season (April-June) every year creating a basin which receives silt during next monsoons. This helped in checking the spread of the silt in the remaining part of the lake.
3. At present the regional break up of the total 10,292.12 acres catchment area of Sukhna Lake being (a) Chandigarh 7,184 acres; (b) Punjab 583.19 acres; and (c) Haryana 2,524.93 acres. Earlier, for the proper maintenance of the water shed area of the lake, the Punjab Goveronment before state Reorganization in 1966 acquired an area of 6,172 acres which under. Punjab Reorganization Act 1966 was redistributed as 2,155.72 acres in Punjab and 4,016.28 acres in Haryana. However, the control of the whole area was later on vested with U.T. Chandigarh for undertaking composite soil conservation measures.
4. During 1972 detailed survey of catchment area was conducted by Indian Agricultural Research Institute(IARI), New Delhi. It was concluded that critical sources contributing sediment load in Sukhna Lake were stream bank erosion, steep sloping hills and steep bare hills which were severely gullied and suffered from landslips. The survey recommended that in order to check erosion evaluation of catchment or subcatchment on smaller unit basis was necessary.
5. During 6^{th} Plan (1977-1978 to 1982-1983) the Forest Department of U.T. Chandigarh executed Central Government sponsored scheme of soil conservation at a cost of Rs. 73.41 lacs.
6. Scientists of Central Soil Water Conservation Research and Training Institute (CSWCR and TI), Chandigarh started work in 1974 for anti-erosion measures for the lake. They identified a village Sukhomajri located at the head of Kansal Choe for model water shed management. The process of sediment control was speeded up with the start of this work and also with the implementation of a subsequent Centrally Sponsored Scheme for Sediment Control of Sukhna Lake in 1978. Under these projects villagers were pursuaded to do away with their goats (which grazed freely over the hills of catchment area) and instead advised to go in for agriculture. A number of small dams were constructed for storing run off water to be made available for agriculture round the year. Soil conservation measures such as contour bunding and tree plantation were adopted which helped in reducing the silt in Sukhna from 141 tons/ha in 1974 to 14 tons/ha after 1979. The success of Sukhomajri Project provided an opportunity for the rejuvenation of the lake by operating new vistas of development of foothill areas.
7. In 1986, the annual auctions for seasonal lease of fodder grass from the forest areas adjoining villages on the periphery of the lake catchment were stopped by the Haryana Forest Department and the lease was given to Hill Management Societies of these villages. These societies in turn under took to protect the area from grazings. Since 1986, Haryana Government (Forest

Department) also stopped the auction of *bhabar* grass and instead the lease was given to the village societies under Social Fencing as well as Generation of Rural Employment Schemes.

8. Over the years a number of gabion structures and check dams have been constructed along the streams feeding the lake.
9. CSWCR andTI Chandigarh under the aegis of the IARI, New Delhi was entrusted with the task of monitoring the stream flow and sediment yield from Sukhna catchment since 1979.
10. Earlier, Irrigation and Power Research Institute, Amritsar had been carrying out studies on sedimentation of Sukhna Lake since sixties on yearly basis. Monitoring stations had been established on each of the three streams draining into Sukhna (Table 6).
11. In 1988, Ministry of Environment and Forest, Government of India, recognized 228.66 ha of Sukhna Lake as one of the National Wetlands that needed priority far conservation. The measures taken to conserve the Sukhna Wetland included plantation of locally suitable varieties of trees numbering 160,000 during 1989-1990, aerial spray of seeds and fertilizes in the entire catchment area and provided two decantations tanks near the Regulator to arrest silt (CSWCR and TI, 1993).

Table 6. Sukhna lake catchment: Monsoon water and sediment yield from forest area

A. Water yield (mm)

Gauging station	Average				
	(1958-1970)	(1971-1978)	(1979-1989)	1989	1990
Kansal	-	-	56.9	105.8	114.0
Nepli	-	-	77.0	130.7	124.9
Ghareri	-	-	37.9	62.1	67.1
Weighted average	215.9	294.7	63.0	110.3	111.9

B. Sediment yield (ha-m/km^2)

Gauging station	Average			
	(1958-1978)	(1979-1989)	1989	1990
Kansal	-	0.10	0.20	0.25
Nepli	-	0.16	0.31	0.37
Ghareri	-	0.05	0.10	0.17
Weighted average	0.94	0.12	0.24	0.29

Source: Bansal and Grewal (1990).

Benefits incurred from anti-erosion and anti-siltation measures:

Previously, enumerated measures to control grazing and fodder collections, reforestation and afforestation programmes, and the erosion control measures in the catchment area of Sukhna Lake proved to be highly effective in the restoration of the hills and in benefiting the local people. It has been found that the average annual deposit of 0.94 ha-m/ km^2 of earlier years (1958-1978) declined to 0.31 ha-m/ km^2 during 1980. The corresponding figure for 1985 was 0.04 ha-m/km^2 as compared to the average of 0.10 ha-m/ km^2 for 1979-1984. The corresponding figures for 1985, 1986 and 1989 were 0.04, 0.09 and 0.24 ha-m/ sq. km, respectively. This again indicates a rising trend of deposits however, providing average annual deposits of 0.12 ha-m/ km^2 during 1979-1989 with further rise in sediment yield to 0.29 ha-m/km^2 in 1990 (Table 6). While some of the silt from hilly forest area (76.4%) of the Sukhna catchment does not reach the lake and gets deposited in the piedmont plain, additional sediment is contributed by 23.6% piedmont plain area of the catchment extending from northern margin of the lake to the gauging station in the foot hills (Bansal and Grewal, 1986).

From foregoing account, it is amply clear that the average annual silt deposits are variable due to ineffectiveness of the measures taken as well as periodic differences in whether conditions. The monsoon water yield from the area of the catchment for the years 1979-1989 at weighted average of 63 mm is less than 367.77% of the average of 294.7 mm for 1970-1978 period. The water yield for 1990 is about 1.77 times the average for the proceeding 11 years (1979-1989) due to exceptionally heavy rains during the rainy season as indicated by the consistent increase in water yields from the three subcatchments (Table 6). All this points to the fact that anti erosion and anti-siltation measures in the catchment area and Sukhna Lake respectively need to be taken simultaneously and on a continuall basis.

Figure 6. Manual desilting of the dried up portion of the Sukhna Lake bed. Peoples' effort 'Shramdan' has been mounted since 1988 for this purpose. The silt has collected towards the SW embankment. In the basin adjoining the Siwalik Hills there is still enough water though shallow (Photo June, 1993).

Figure 7. Mechanical desilting of the Sukhna Lake bed. The foreground vegetation on the silted Lake bed consits of grasses, *Ipomea* and *Polygonum* SW - Dried up Spill Way on SW embankment (Photo June 1993).

Figure 8. *Shramdan* efforts by school children for removing of silt from the dried up lake bed portion near SW end. There is lot of vegetation (Photo June 1993).

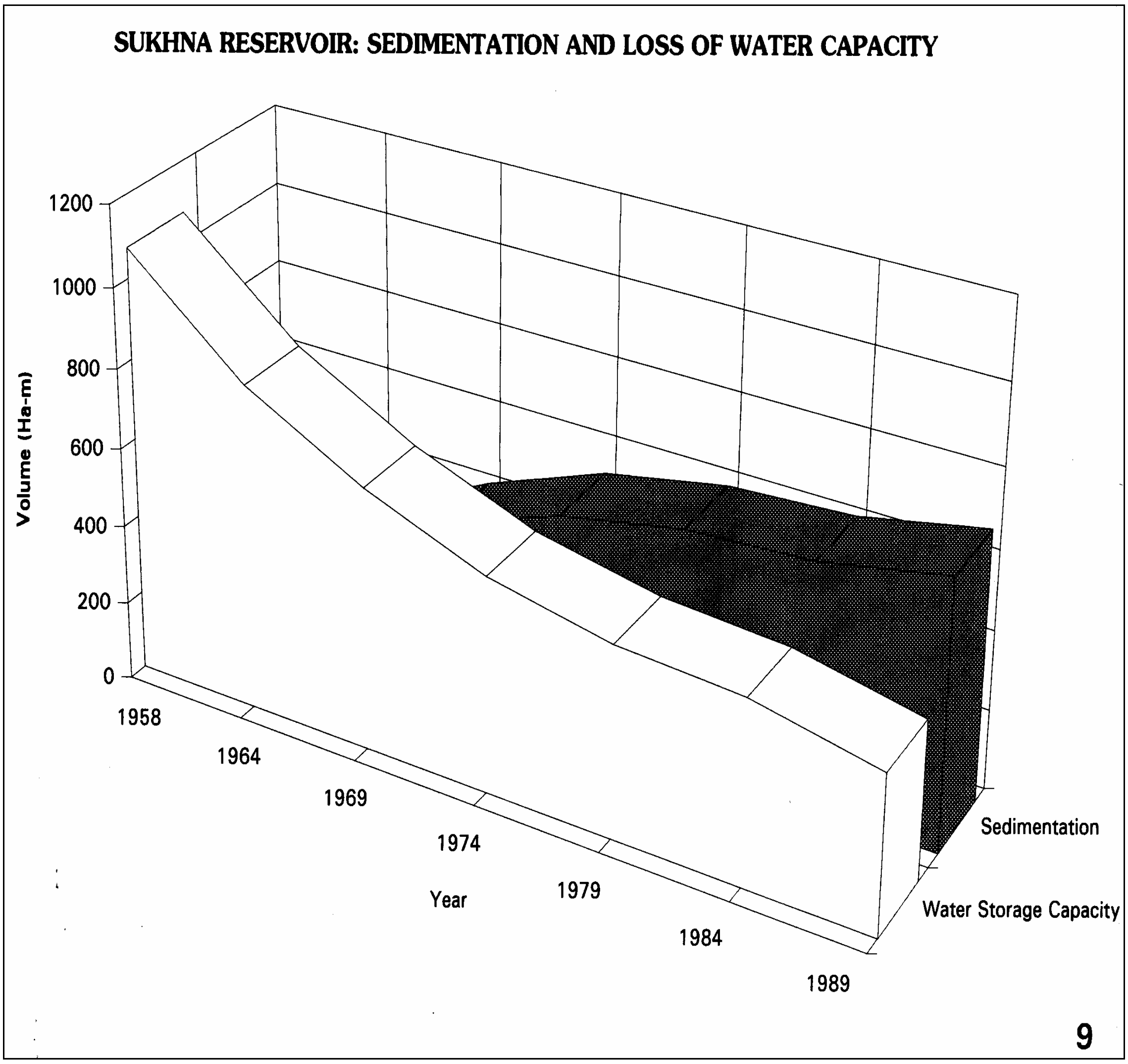

Figure 9. Graphic representation of sedimentation and water storage capacity of the Sukhna Lake during the years 1958-1989.

Desilting of the lake (*Shramdan*):

During April-July 1988 a unique 'peoples' effort '*Shramdan*' was mounted exhorting people of Chandigarh to render voluntary help in the removal of silt from the lake bed through manual labour (Figs. 6,8). In this effort all sections of society participated with great enthusiasm. In addition, excavation of silt was also carried out through mechanical measures (Fig. 7). This voluntary work for silt removal continued in the subsequent years till 1993 except for 1990 when no Shramdan was undertaken. The total silt so far removed from the lake bed comes to 10,18,800m^3 (Table 7). In 1989 for holding Third Asian Rowing Championship, Indian's longest Rowing Channel (2,170 m long, 62.5m wide and 3.00m deep) was constructed. These measures, though temporary, greatly helped in saving the lake from extinction due to siltation.

Desilting of Sukhna Lake as done by U.T. Administration by using man and animal, fossil fuel and electricity to generate mechanical power seems to be an unproductive exercise undertaken year after year as the amount of sediment removal is negligibly small as compared to expenditure involved and the magnitude of the siltation/sedimentation in the lake since silt removed every year constitutes far lesser proportion of the annual siltation in the lake.

Table 7. Desiltation of Sukna lake through *Shramdan*+

Year	Silt removed (m^3)
1988	99,050
1989	3,53,750
1990	No Shramdan
1991	84,900
1992	1,98,100
1993	2,83,000

+Silt removal figures given by Manchanda (1993) are highly variable as indicated by following year-wise data:

1988: 35,00,000 ft^3 (94,799.56 m^3)
1989: 1,25,00,000 ft^3 (3,38,569.88 m^3)
1990: No *Shramdan*
1991, 1992, 1993: 50,00,000 ft^3 x 3 (1,35,427.95 m^3 x 3)

Source: CSWCR & TI (1993)

Geo-hydrology of the Yamuna-Satluj Siwalik region

Coupled with the echo of the advancing Rajasthan desert, the problem of desiccation of the 'Yamuna-Sutlaj Divide' has been attracting the attention of the geographers, geologists, meteorologists and engineers for the past several decades. The region is bounded by the two great rivers of North India, the Yamuna on the east and Satluj on the west. These have perennial flow of water through out the year. Within the SNDE of CMSHs does not lie any river except the Ghaggar which is now a seasonal stream rising from the CMSHs and drying up before entering Rajasthan. Based on historical, archeological and physiographic evidences, G. Singh (1952) postulated that:-

(i) Ghaggar river was formerly a major and perennial stream and the Yamuna, the Satluj and small streams within the Divide which now fall into these rivers formerly drained into Ghaggar making it an important river system.

(ii) The small streams and torrents of Siwaliks which are thought to have deserted Ghaggar river and have joined Satluj (Budhki and Siswan *Nadis*) and Yamuna (Somb/Som and Holi *Nadis*) are much younger than the changes in the hydrography of the Divide. Some of the streams of the Siwaliks came into existence only about a century back when Siwaliks were deforested (also see Glover, 1946; Gorrie, 1946; Y. Singh, 1990a). Old Saraswati was in fact the Yamuna which in Vedic period pursued a westerly course to the sea and subsequently, it broke its course eastward to join the Ganga or the Ganges.

(iii) The Satluj has now shifted a great deal westward. Toward the end of 15th century it was flowing nearly 10 miles (16km) eastwards and then gradually its shift took place.

The above mentioned changes in the hydrograhpy of the rivers of CMSHs were possibly the chief causes of the desiccation of the Divide. The rate of desiccation in the region has been accelerating increasingly, particularly for the last one hundred years due to deforestation in NW Siwalik and the adjoining Himalayan region (see Bir, 2002). During the historic times there had been gradual decrease of surface and subterranean waters (due to poor infiltration, quick surface run-off and accelerated rate of extraction of underground waters e.g. Chandigarh over last 50 years) rather than any major climate changes being responsible for the desiccation of the 'Yamuna-Satluj Divide'. Over the periods, the deforestation in the NW Siwalik has been devastatingly high particularly in CMSHs. There has been redistribution of sand over fertile lands due to soil erosion in the hills. All these changes have continuously increased the desiccation of the region Field observations show that the intermittent choes of CMSHs highly dissect the hills and piedmont plains and dissipate from north to south into the upland and flood plains (see Y.Singh, 2001: Figs. 1-2, 3a, b, 4,6). By and large, now the Trans, Satluj-Yamuna region, suffers from lack of perennial surface water flows in its numerous streams or choes while earlier there used to be the fresh water flowing in some of them till about the middle of the 20th century. This change is the result of gradual desiccation of CMSHs where water infiltration during rains has greatly been reduced due to the destruction of vegetation over major portion of CMSHs.

DISCUSSION

Sukhna Choe and its tributary seasonal streams (Choes) are of intermittent nature as they receive water primariliy from seasonal surface run-off and stream flow occurs during rainy periods. These inlects of water into the Sukhna Lake carry sheets of soil run off down the surface slopes of hills in the catchment area. Over all, on an average 50% of total rain in the Siwaliks ends, in run-off (Misra *et al.,* 1978). Due to higher run-off, there has been accelerated pace of erosion in the catchment areas through which the seasonal streams flow and consequently higher rate of sedimentation in the water reservoir of Sukhna Lake and the beds of streams draining into it as shown earlier (Ref. Tables 1-7). The sedimentation rate in the lake is fluctuating over the years depending upon the condition of forest vegetation.

The catchment area of choes feeding the Sukhna Lake is large has steep slopes and the soils are predominantly alluvial in nature, obviously the water flowing into the lake is heavily loaded with silt which gets deposited year after year in the lake bed reducing its water storage capacity, depth, water spread area and full submergence area at full lake level as refereed to relier. According to Burgis and Moris (1987), if the ratio of the drainage area to the surface area of the lake is larger for a reservoir than for the natural lake, then the events in the catchment area have a great influence on the reservoir which responds very rapidly to the changes. This is what has actually happened in case of Sukhna Lake with respect to siltation.

Since there is no natural lake in the region, the man-made Sukhna Lake (actually the reservoir) has proved to be a boon for measurement of the amount of soil erosion taking place in the catchment area through siltation in the water body. Drainage basin or catchment area of a lake, stream or a set of streams is widely recognized as a fundamental unit in the geomorphogical milieu because (a) basins provide opportunity to estimate the amount of erosion, (ii) it is easy to estimate the volume of material which has accumulated in the reservoir and if the date of construction of the reservoir is known (as in case of Sukhna Lake) this, can provide the basis for an estimate of land erosion rate and (iii) the study of deposits within the basin mouth can provide considerable information about the environmental processes and about the chronology of events which occurred in the past (Gregory and Walling, 1979). Similar observations need to supplement the data on siltation about Sukhna Lake. Studies carried out on an experimental watershed near Chandigarh demonstrate that the burning of forests, felling of trees and over grazing increased the peak discharge of run off by 69%, 34% and 32% respectively (S. Singh, 1981); Since siltation in Sukhna Lake is a continuing process, preparation of future plans for control of siltation in Sukhna Lake should take into consideration these factors. Alongwith, data are essential on (i) nature of soil (porosity and solubility), (ii) development and type of vegetation (infiltration capacity), (iii) degree of surface slope and (iv), local climate conditions such as temperature, wind, humidity and of course, volume and intensity of precipitation since differences have been found in these parameters in various water sheds of the region. Any generalized approach for larger region e.g. NW Siwalik Hills as a whole is fraught with dangers of failure of anti-soil erosion scheme or their poor performance results.

Wetzel's (1983) remarks that "in such lake systems in which sedimentation has reduced water depths sufficiently for littoral dominance and in shallow lake basins which predominate the earth, rates of lake ontogeny (successional development of lake ecosystem) greatly accelerate" are highly appropriate for Sukhna Lake where in spite of all the efforts so far made to control and remove siltation, large patches of dry land with vegetation emerge during summer season which are indicative of the changes taking place in various parameters of the lake reservoir.

It will be appropriate to mention that at Hubbard Brook where O' Sullivan (1979) studied water shed ecosystem, large changes in sediment yield from the areas of the catchment which were clear-fell, indicate than man's impact upon watershed ecosystem may be profound even under normal land use regimes. Continuing he said that most man induced changes in watershed result in increased sediment yield although the reverse may, of course, apply if stabilization of the area is the object, like during reclamation of derelict land. This aptly applies to Sukhna Lake which though of 43 years existence, is till highly unstable and the problems of siltation remain the same as before since siltation rate has not stabilized at the minimal level suitable for the long life of the lake. The geoclimatic conditions in the Sukhna catchment require sustainble forestry and vegetation conservation efforts. Obviously, the biotic activity in the catchment area has to be at minimal level for the success of afforestation and reforestation schemes and other anti-erosion measures are taken at regulated periodic intervals. This can happen and the lake can be saved for prosterity.

Finally, it may be stated with satifaction that the pictorial represantation of the vegetation of the catchment area of Sukhna Lake projected by Singh *et al.* (1998: 68-72) depicts an encourging situation as far as forests of Nepali Choe and Kansal Choe (*Nadis*) areas are concerned. Forest canopy is thick with plenaty of ground vegetation thus providing effective checks for slowing down the land erosion over the hillocks and ultimatly siltation in the lake.

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