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Impact of soil conservation measures on soil properties in Sukhna Lake catchment

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ABSTRACT

Sukhna, a recreational Lake of Chandigarh suffered from rapid siltation as its catchment at Shivalik hills are affected by severe soil erosion. Intensive soil conservation measures taken for three decades reduced silt loads but ameliorative effects in terms of soil properties were not evaluated. Comparing with an untreated comparable adjoining control watershed, the ameliorative impacts of 30 years of closure and intensive soil conservation measures were evaluated during 2008-09. The catchment was divided into 27 slopes and elevation based classes in 560 ha micro watershed. The enumeration of vegetation cover and soil analysis from each plot was carried out using standard methodology. The data on impact of soil properties is presented in this paper.

The mean soil pH in treated area decreased from 8.19 to 7.72 but EC increased from 0.11 to 0.15 dsm^{-1}. The overall soil organic carbon increased from 0.44 to 0.70%. The available phosphorus was 22.23 kg ha^{-1} in control against 32.56 kg ha^{-1} in the surface soil of treated Sukhna Lake catchment. The status of available soil potassium was 116.63 kg ha^{-1} in control against almost double *i.e.* 219.71 kg ha^{-1} in the treated area. The leaf litter increased from 2.04 t ha^{-1} yr^{-1} to 4.49 t ha^{-1} yr^{-1}.

The growth of Sorghum plants raised in pots filled with soil taken from plots of control and treated under conditions of no water stress was 15.1 and 19.3 cm and survival as 86.4 and 100% in one month. However, when water stress was applied in a separate set of pots, the plant growth was 8.0 and 11.2 cm and survival percentage as 43.2 and 70.8% in one month in control and treated pots. In case of control area, the soil moisture in 0-120 cm profile varied from 4.1 to 11.0% before rain and 5.0 to 11.4% after the monsoon rain. However, in case of treated area, the soil moisture varied from 5.6 to 13.6% before and from 6.5 to 15.0% after the monsoon rains. The soil profile of Sukhna Lake catchment stored 2.9 cm more water up to 0-120 cm depth as compared to the control area which over 2540 ha catchment area would mean 73.66 ha-m of additional water stored in the soil profile. Such an improvement in soil fertility and moisture regime was responsible for rejuvenation of the vegetation cover.

1. INTRODUCTION

The Shivalik foothills covering 4.2 m ha area in north India constitute one of the seven most degraded eco-systems of the country (Jain *et al.,* 1998). These low hills of recent origin are made up of heterogeneous muds which remained covered with thick forests for centuries (Grewal, 1995). However, in the last 400 years, protective vegetation cover was destroyed by human needs and greed which triggered the phenomenon of mass soil erosion under the impact of intense monsoon rains (Bhumbla, 1976). The man made Sukhna Lake of Chandigarh fed by three Shivalik torrents started silting at a fast rate due to lack of attention to high runoff and soil loss potential of degraded Shivaliks (Bansal and Grewal, 1990). Anticipating pre-mature death of the Lake, intensive soil and water conservation measures were taken systematically for more than three decades which included complete closure, afforestation, construction of 180 silt detention dams and equal number of masonry check dams in drainage lines which over a span of time reduced the siltation rate of the lake from more than

140 to less than 5t ha^{-1} yr^{-1} (Sohal, 2000). As the soil loss decreased, the water yield also decreased adding another problem of inadequate filling of the Lake.

The soils of Sukhna lake catchment of Chandigarh were surveyed and analysed by Grewal and Juneja (1984). It was observed that large patches of alkali soils in upper reaches generously contributed to the rapid siltation of the lake. Low productivity, poor vegetation cover, high run off and soil loss and presence of deep and wide net work of gullies characterized the upper catchment area of the lake. No systematic studies were conducted to generate quantitative and qualitative information on the transformations which have taken place in the process of recovery over a period of 35 years. Keeping in view the importance of ecological rehabilitation of the catchment areas and sustainable long term management of the Sukhna Lake, a study on impact of the soil conservation measures in the catchment of Sukhna Lake on the ground water, soil and geology was carried out during 2008-09. The results of the study are presented in series. The paper at hand covers a review of erosional behaviour of Shivaliks in general and catchment soils of the Lake in particular and impact of treatment measures on soil properties.

2. MATERIALS AND METHODS

It is important that the changes in the soil properties in the treated area are compared with a reliable and comparable control. Since the base level observations taken before the start of catchment treatment were not available, the next best alternative was to take observations from untreated contiguous area having similar bio-physical conditions. It is a fact that no two watersheds are similar, but taking adjoining area having same soil, slope, aspect, drainage pattern, geological formation and vegetation types except closure and treatment with soil and water conservation measures appeared the best alternative. Such an area was available in the catchment of adjoining Karoran *choe* near Prempura village and the same was selected as control. Prempura is the first village of Haryana on northern side of Kansal *Choe*.

It was decided that out of three torrents feeding the lake, *Ghareri* is the most representative of the area and hence taken for intensive study. It was also decided that changes in the vegetation cover be recorded to capture the changes in soil properties. Three landscape regions were selected as Lower, Middle and Higher. In each region, three slope positions were selected along the topo-sequence i.e. lower, middle and high. This way, there were three regions, three slopes and three replications and hence 27 plots represented the landscape of this 560 ha forest micro-watershed. The size of the plot for the study of general landscape features was taken as 100 m x 100 m and was kept 10 m x 10 m for enumeration of bushes and 1 x 1 m for grasses and litter accumulation. The number of trees in each block with girth was noted. The soil samples and litter samples were collected from this 1 m x 1 m area from each plot. Two representative sites were taken for soil moisture measurement from 0-120 cm depth before and after monsoon rains and moisture determined gravimetrically.

Three approaches were followed to assess the ameliorative changes in the nature and properties of soils:

Changes in the chemical soil properties (soil pH, electrical conductivity, organic carbon and available phosphorus and potassium) were analyzed following standard analytical techniques. Leaf litter accumulation on the soil surface and formation of humus in the A0 soil horizon is important to assess the status of vegetation cover, initiation of the process of nutrient cycling, reduction in sheet and rill erosion and reduced soil dispersion under the kinetic energy of rain drops and formation of CO_2 at the initiation of decomposition process, formation of H_2CO_3 and thus lowering of soil pH and release of more calcium and phosphorus. The accumulation of leaf litter was, therefore, noted from all sampling plots.

A total of 12 soil samples from 0-15 cm soil depth were collected from 4 landscape regions (lower, middle and 2 higher) and 3 topo-sequences (lower, middle and higher) both from treated Sukhna catchment area and comparable control watershed of *Karoran choe* from *Prem Pura* village upwards. This *choe* runs parallel to *Nepli* and *Kansal choes* and have similar bio-physical conditions except that Sukhna catchment area is closed and treated with soil and water conservation measures and *Karoran choe* catchment is not treated. These soil samples were filled in small pots @ 250 grams soil per pot and 4 sorghum plants were planted at a depth of 2 cm in each pot and watered like normal irrigation. These pots were placed in the sun and kept moist by weekly watering to eliminate the chances of water stress. The plant growth and survival was recorded on weekly basis for 30 days. In first set of 30 days, the plants were allowed to grow normally and harvested after 30 days. In the second set, plants were allowed to grow normally for 10 days and then moisture stress was imposed by restricting irrigation.

The cumulative effect of changes in soil properties are best explained by the plant growth. Plants of Sorghum were raised in pots filled with surface 0-15 cm soil collected from the sampling sites. This experiment demonstrated the combined effect of all physical, chemical and biological soil properties. All standard and accepted techniques of soil analysis were used.

3. RESULTS AND DISCUSSION

Impact on Soil pH

The overall soil pH in both treated and control plots were in the range of 7.3 to 8.5. The inter plot differences were clearly indicated by the data. The soil pH in the control plots varied from 8.10 to 8.50 with an overall mean of 8.19. The soil pH was relatively higher in two plots of upper slopes whereas in the middle and lower slopes, the soil pH ranged between 8.1to 8.3 (Table 1).

In case of surface soil samples of treated Sukhna lake catchment area, the overall soil pH varied from 7.3 to 7.9 with an overall mean of 7.72. There was no significant difference in soil pH between surface soil samples of upper, middle and lower hill slopes. The most important conclusion was that, (a) the mean soil pH of control plots was 8.19 and that of treated plots (Sukhna Lake) was 7.72, (b) being a log scale there is considerable difference between 7.7 and 8.2. The trend of consistent lowering of soil pH in treated area is clearly indicated by the data. It appears that the improvement in soil moisture and organic matter content results in increased carbon dioxide production which ultimately mixes with water and produce carbonic acid which lowers the soil pH. The lowering of soil pH is, therefore, a combined effect of these positive attributes.

Impact on Electrical condictivity (EC)

The concentration of soluble salts in the surface soil samples of both the treated and control plots as reflected by electrical conductively (EC), is very low and it is a well known fact that in the hilly ecosystems, the soluble salts seldom get accumulated in the surface soil.

The overall mean EC in control plots was 0.11dsm^{-1} while the same was 0.15 ds m^{-1} in the treated Sukhna Lake catchment samples (Table 2).

There was no difference in EC values across slope classes in untreated control plots. However, there was slightly higher EC in upper areas and lower in lower areas. The soil samples were taken in the month of April May, 2008, when due to high temperature on upper exposed slopes, the salts tend to come up to the surface layers. But due to higher moisture and more shade in lower areas, the soluble salts do not come to the soil surface. In the control areas, the salts are repeatedly washed down the eroded

Table: 1
Soil pH in surface soil samples of treated and control plots

Treatment	Soil pH (1:2) on three slopes in treated and control plots			
	Upper	Middle	Lower	Mean
Control 1	8.50	8.10	8.00	8.20
Control 2	8.10	8.10	8.30	8.17
Control 3	8.50	8.10	8.00	8.20
Mean	8.36	8.10	8.10	8.19
Treated 1	7.90	7.90	7.60	7.80
Treated 2	7.90	7.90	7.50	7.77
Treated 3	7.30	7.50	7.70	7.50
Treated 4	-	7.80	7.90	7.85
Treated 5	-	-	7.70	7.70
Mean	7.70	7.78	7.68	7.72

Table: 2
Electrical conductivity of surface soil in treated and control plots

Treatment	EC (ds m^{-1}) on three slopes of control and treated plots			
	Upper	Middle	Lower	Mean
Control 1	0.08	0.12	0.13	0.11
Control 2	0.14	0.12	0.09	0.12
Control 3	0.11	0.10	0.13	0.11
Mean	0.11	0.11	0.12	0.11
Treated 1	0.15	0.14	0.09	0.13
Treated 2	0.16	0.10	0.16	0.14
Treated 3	0.16	0.20	0.13	0.16
Treated 4	-	0.15	0.12	0.14
Treated 5	-	-	0.18	0.18
Mean	0.16	0.15	0.14	0.15

exposed slopes and this lowers the soluble salts concentration.

Impact on Organic Carbon

Out of three most essential macro-nutrients which plant require, nitrogen is the one which plants need the most and its status is reflected by the organic carbon percentage in the soil which is usually maximum in the surface soil. The status of organic carbon in the soil denotes status of nitrogen. It also signify the cation exchange capacity or the ability to hold nutrients and water and in addition, the presence of biological life and ability of nutrient transformations. The surface 0-15 cm soil taken from control and treated plots produced very convincing evidence of organic carbon build up in the Sukhna Lake catchment. The overall soil organic carbon was 0.44% under control and 0.70% in Sukhna Lake catchment samples. This 59% increase when converted to nutrient terms, it would turn out to be a substantial amount (Table 3).

One may expect variations in organic matter content even in homogeneous soil samples in uncultivated and variously placed soils in a landscape and topo-sequence. Taking the overall mean, the organic carbon was 0.35, 0.59 and 0.38% in control and 0.76, 0.73 and 0.55% in treated plots on upper, middle and lower hill slopes, respectively. One soil sample in control and one in treated plots indicated low organic carbon which appears to be the analysis error and could be ignored.

Organic carbon build up is a slow and difficult process as high summer temperatures in tropical ecosystems practically burn the organic matter. In the forest ecosystems, forest fires also burn the leaf litter and slow down the formation of humus which ultimately forms organic carbon on decomposition. The excessive grazing and over exploitation of above ground vegetation (trees, bushes and grasses) leads to heavy soil erosion during monsoon rains which results in loss of organic matter with runoff water. In case, all the above biotic factors are controlled and nature is allowed to play its role of providing protective biological cover on the soil surface, then the real process of nutrient cycling operates and build up of soil organic carbon becomes the starting point of that process. Precisely, the same has happened in the catchment of Sukhna Lake. There has been total protection of the vegetation cover for over a period of 30 years. The vegetation cover development process of nature worked uninterrupted and as per the soil, slope and other site conditions; different type of vegetation developed and provided a thick layer of leaf litter which gradually increased the content of organic carbon. In areas outside the catchment, though similar in all respect but biotic interference and forest fires continued and leaf litter accumulation was hampered.

Impact on Available Phosphorus

The second most important plant nutrient is phosphorus which is present in much less quantity and is least mobile. It remains held up and chelated by calcium as calcium phosphate when pH is in alkaline range. It is interesting to note that overall soil pH was 8.19 in control plot and 7.72 in soils of treated Sukhna Lake catchment. This means higher concentration of available phosphorus in soil where pH was lowered down towards the optimum range. The same was precisely revealed by the status of available phosphorus. The overall available phosphorus was 22.23 kg ha^{-1} in control area, the same was 32.56 kg ha^{-1} in the surface soil of treated Sukhna Lake catchment area. In the control area, the available phosphorus slightly increased in middle and lower areas but reverse was noted in overall phosphorus in the soil of treated area (Table 4).

The reduction in phosphorus from 34.40 to 32.06 and 29.18 kg ha^{-1} and K_2O from 289.41 to 218.40 and 151.33 kg

Table: 3
Organic Carbon (C) in surface soil samples of treated and control sample plots

Treatment	Soil organic carbon in surface soil (%)			
	Upper	Middle	Lower	Mean
Control 1	0.23	0.86	0.08	0.39
Control 2	0.39	0.51	0.59	0.50
Control 3	0.43	0.39	0.47	0.43
Mean	0.35	0.59	0.38	0.44
Treated 1	0.59	0.79	0.16	0.48
Treated 2	0.51	0.39	0.39	0.43
Treated 3	1.17	0.86	0.90	0.90
Treated 4	-	0.98	0.35	0.67
Treated 5	-	-	0.94	0.94
Mean	0.76	0.73	0.55	0.70

Table: 4
Available phosphorus (kg ha^{-1}) in surface soil samples of treated and control plots

Treatment	Available P (kg ha^{-1}) on three slopes of control and treated plots			
	Upper	Middle	Lower	Mean
Control 1	15.4	28.7	16.9	20.33
Control 2	23.2	20.1	25.1	22.80
Control 3	22.6	21.3	26.8	23.57
Mean	20.4	23.4	22.9	22.20
Treated 1	32.9	28.5	22.5	27.97
Treated 2	34.9	27.6	29.2	30.57
Treated 3	35.4	33.8	27.6	32.27
Treated 4	-	38.2	27.4	32.80
Treated 5	-	-	39.2	39.20
Mean	34.40	32.06	29.18	32.56

ha^{-1} and reduction in organic carbon from 0.76 to 0.73 and 0.55 from upper to middle and lower hill slopes in treated catchment area was observed. This is probably due to deposition of soil sediments on the soil surface of upper, middle and lower hill slopes. Grewal and Juneja (1984) reported that eroded soil mass when carried down the slope by rainwater, the finer soil fractions are carried by runoff water leaving coarser materials on deposition sites.

Impact on Available Potassium

The overall status of available soil potassium was 116.63 kg ha^{-1} in control plots whereas the same was almost double *i.e.* 219.71 kg ha^{-1} in case of Sukhna Lake catchment soil. However, considerable inter plot variation was noted from as low as 91 kg ha^{-1} to as high as 365 kg ha^{-1} in treated area (Table 5).

Such a variability was more pronounced in control area where K_2O status varied from low of 32.26 kg ha^{-1} to a high of 215.04 kg ha^{-1}. One may expect such variations in most heterogeneous soils of the Shivaliks having uneven, undulating and sloping forest lands.

Impact on Leaf Litter Accumulation

The litter accumulation was split up into dry leaves and dried small twigs on the forest floor. Litter accumulation is the combined index of canopy cover on a particular site but it is modified by the type of vegetation. The deciduous trees would shed more leaves and twigs as compared to evergreen trees. Same is the case with bushes. While Lantana (*Lantana camara)* sheds lot of leaves and there was thick cover of leaves underneath Lantana bushes but the bushes like Karipatta (*Murraya keonigii*) are evergreen and produce very negligible litter. In case of treated area of *Sukhna Lake*, the overall mean litter accumulation of leaves was 2.07 and that of twigs as 2.42 t ha^{-1} which totalled up to 4.49 t ha^{-1} (Table 6).

In case of comparable control, the overall leaf litter accumulation was only 0.76 t ha^{-1} and that of twigs was 1.28 t ha^{-1} which added up to 2.04 t ha^{-1}. The litter accumulation on the surface of soil in treated area was 2.2 times more as compared to untreated control which has great significance

Table: 5
Available potassium in surface soil samples of treated and control plots

Treatment	Available potassium (kg ha^{-1}) on three slopes in control treated area			
	Upper	Middle	Lower	Mean
Control 1	69.89	173.38	124.99	122.75
Control 2	150.53	130.37	64.51	115.14
Control 3	32.26	88.70	215.04	112.00
Mean	84.23	130.82	134.85	116.63
Treated 1	401.86	91.39	165.31	219.52
Treated 2	307.78	94.08	219.07	206.98
Treated 3	158.59	322.56	112.90	198.02
Treated 4	----	365.57	123.65	244.61
Treated 5	---	---	135.74	135.74
Mean	289.41	218.40	151.33	219.71

Table: 6

Litter accumulation on landscape regions and positions of treated and control area

Region	Litter accumulation ($t ha^{-1}$)								Total
	Biomass of leaves				Biomass of Twigs				
A.	Upper	Middle	Lower	Mean	Upper	Middle	Lower	Mean	
A. Treated area									
Lower Maljan wala	1.40	1.52	2.60	1.84	0.80	2.10	3.60	2.17	4.01
Middle Tarkhan wala	0.80	1.60	5.30	2.57	1.20	2.40	3.10	2.23	4.80
Higher Khere wala	0.30	0.90	5.60	2.27	0.80	1.60	4.00	2.13	4.40
Higher Bade Pathran wala	0.75	2.10	1.95	1.60	1.30	4.40	3.80	3.17	4.77
Mean	0.81	1.53	3.86	2.07	1.03	2.63	3.63	2.42	4.49
B. Untreated control									
Control 1	0.60	0.30	1.70	0.87	1.20	1.00	1.90	1.37	2.24
Control II	0.90	1.00	0.60	0.83	1.00	1.20	1.60	1.27	2.10
Control III	0.40	1.10	0.30	0.60	0.80	1.30	1.5	1.20	1.80
Mean	0.63	0.80	0.87	0.76	1.0	1.16	1.67	1.28	2.04

as an indicator of ecological recovery of a degraded area.

Results of Plant Study

Soil is the stomach of the plant. When there is adequate and nutritious food and sufficient water in the stomach, plants attain good growth which of course is modified by environmental factors. When soil fails to supply nutrient and water to plants as per requirement, growth slows down, plants wilt and then die. The physical, chemical and biological conditions prevalent in the rhizosphere determine the rate of plant growth. Often, it becomes difficult to quantify all these properties (the interactions are complex) and relate these properties to rate of plant growth. An easier and convenient way is to raise plants in pots filled with the given soil samples and study their rate of growth and survival over a short period of time as pots hold limited soil. Better and healthier the plants better are the nature and properties of the soil in which these are raised. In case, the soil moisture and light conditions are maintained at near normal, then soil fertility and potential for biological productively is indicated by the plant growth in various types of soils. The results of this plant study are presented in the Table 8.

Under conditions of no water stress, the growth and survival was clearly better in the soils of treated area of Sukhna Lake catchment than the soil of untreated control area. However, when water stress was applied, the plant growth was reduced in both control and treated plots but the rate of growth was much better in treated as compared to control. In control area soils, the mean survival percentage decreased drastically from 70.0 to 43.2% under water stress where as such a drop was very small from 81.1 to 70.8% in soil of treated area. The plant height was much better in soil of treated samples. The improvement in physical and chemical properties of soils in treated catchment particularly more moisture retention capacity were clearly reflected by this pot study.

Improvement in Soil Moisture

The soil moisture samples were taken from representative location in the Sukhna lake and control area up to a depth of 120 cm before and after the monsoon rains of 2008. The soil moisture increased with depth both before and after the rains. In case of control area, the soil moisture varied from 4.1 to 11.4% before rain and 5.0 to 11.4% after the monsoon rains. However, in case of Sukhna Lake catchment area, the soil moisture varied from 5.6 to 13.6 before and from 6.5 to 15.0% after the monsoon rains (Fig.1). The soil profile of Sukhna Lake catchment stored 2.9 cm more water up to 0-120 cm soil depth as compared to

Table 8

Plant growth and survived with and without water stress under treated and control plot soil

Treatment *	Growth	Without stress	With stress	
		30 Days	10 days	30 days
Control	Plant height (cm)	15.1	3.7	8.0
	Survival (%)	86.4	70.0	43.2
Treated	Plant height (cm)	19.3	4.3	11.2
	Survival (%)	100.0	81.1	70.8

*Pooled data of 12 samples in each case.

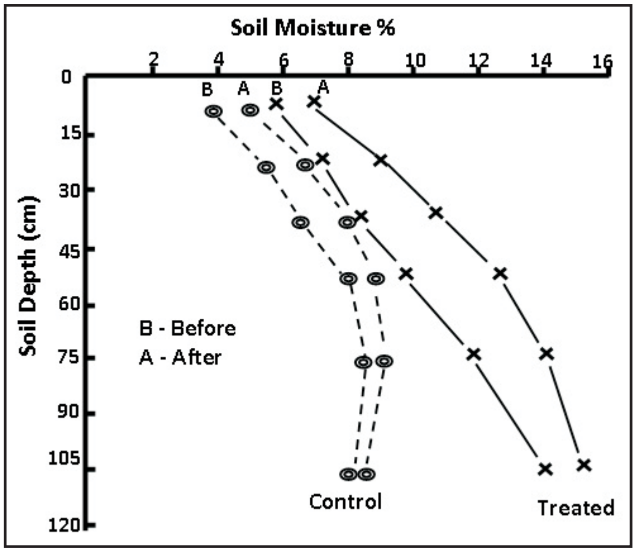

Fig. 1. Soil moisture % at different soil depth in treated and control plots.

the control area. This 2.9 cm additional water over 2540 ha area would mean 73.66 ha-m of additional water stored in the soil mass of 0-120 cm depth.

Based on one time analysis, the exact values may not be possible but this data support the results of both pot and field study that better soil moisture and nutrient conditions prevailed in treated area as compared to control area.

There is sufficient evidence of soil related properties contributing to high soil erosion in Shivaliks in general and Sukhna Lake catchment in particular. But the long term impacts of watershed treatment on soil properties have been reported by few studies. After holistic treatment of three Shivalik watersheds, Dhar (1994) reported reduction in soil pH and increase in leaf litter, available nitrogen, phosphorus and potash in treated watersheds as compared to contiguous untreated control watershed.

The relationship of soil properties with micro topography and tree canopy structure was successfully demonstrated based upon tree density and thickness of A-horizon of soil by Murthy and Shankaranarayana (1977) and Verma *et al.* (1965). Grewal and Juneja (1984) characterized the soils of the Sukhna lake catchment and reported that texture of the soils vary from loamy sand to silty clay , presence of parent material namely sand stone and shale occur side by side, high clay and silt content and poor hydraulic conductivity leads to more runoff and soil loss from bare hill slopes. They reported that high pH, low EC, high silt and clay content, low organic carbon, highly compact sub-stratum, presence of calcium carbonate nodules, pink colour bands, cracking on exposed soil surfaces, high drainage density, geological heterogeneity, meandering pattern of drainage lines, landslides, tunnel erosion all combined together made Sukhna Lake catchment soils as one of the most erodible soils. This is also the reason that Acacia species dominate on alkali soils (Grewal and Abrol, 1986) which occur in patches in Shivaliks.

Grewal *et al.* (1990) reported that the percolation losses from stored water in the storage reservoirs is strongly modified by soil properties such as silt and clay content, bulk density, hydraulic conductivity and presence of calcium carbonate. They concluded that aspect (orientation of landscape with respect to sun), nature and properties of soils and vegetation cover strongly influence the erosional behaviour of soils. After detachment from the original soil matrix, and transport with runoff to lower level, the silt and clay content of the deposited material increased in case of sandy loam soils and decreased in case of heavy silty clay soil. In the process of transport, the properties were moderated in favour of plant growth in case of both the soil types. This was explained as the reason of better vegetation cover on silt deposited sites in the Shivalik watersheds. Sharmaq *et al.* (2013) through a similar plot study in Shivalik foothills reported significantly higher tomato yield, soil organic carbon, soil moisture, phosphate activity with organic treatment of degrated soil. The organic matter additions resulted in significant improvement in soil health in terms of soil aggregation, structure fertility, moisture holding capacity and biological activities (Tajeda *et al.,* 2010; Das *et al.,* 2011).

The result of the above quoted studies combined with the results of the present study developed a fair good understanding of erosional behaviour of watersheds and ameliorative impacts of long term rehabilitation measures on watersheds feeding the lakes and water bodies in the Shivalik region.

4. CONCLUSIONS

The intensive soil conservation measures consistently taken over a period of three decades improved vegetation cover of trees, grasses and bushes and control of forest fires helped in the leaf litter accumulation and organic matter build up. The shade provided by muli-layer vegetation helped in organic matter build up and overall impact was reflected in reduced pH, improved soil fertility and over all better soil health.

The results of this study indicated trend of consistent lowering of soil pH in treated area as compared to untreated control. The overall mean EC in control plots was 0.11 ds m^{-1} while the same was 0.15 ds m^{-1} in the treated catchment samples. The overall soil organic carbon was 0.44 % under control and 0.70% in treated area soil samples. The mean available phosphorus was 22.23 kg ha^{-1} in control and 32.56 kg ha^{-1} in the surface soil of treated area. The available soil potassium was 116.63 kg ha^{-1} in control plots and 219.71 kg ha^{-1} in Sukhna Lake catchment soils. The mean litter accumulation was 4.49 t ha^{-1} in treated and 2.04 t ha^{-1} in case of control. The litter accumulation on the surface of soil in treated area was 2.2 times more as compared to untreated control which has great significance as an indicator of ecological recovery of a degraded area. In case of control area, the soil moisture varied from 4.1 to 11.0% before rain and 5.0 to 11.4 after the monsoon rain. However, in case of Sukhna Lake catchment area, the soil moisture varied from 5.6 to 13.6 before and from 6.5 to 15.0% after the monsoon rains. This improvement in moisture retention and favourable chemical soil properties was confirmed by a supporting plant study where plants raised on soils of treated area attained better growth and survival as compared to untreated control.

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