SUMMARY OF RESULTS

Shrinking of 'natural resource base' and ever-rising population are the two global challenges of the 21st century that need to be addressed on priority. Due to this, pressure on the remaining natural resources in any terrestrial ecosystem is naturally much more than it can normally sustain. The overexploitation of the resources results in degradation of the land. The problem is most severe in the Shiwaliks range of the Himalayas—one of the most degraded, threatened and fragile ecosystems of our country. Here, the erratic distribution of rainfall, lack of irrigational facilities, limited availability of suitable land for cultivation, heavy soil erosion and fertility depletion, small and fragmented holdings, low yields, frequent crop failures, scarcity of food, fodder, fuel-wood and large scale dependence and heavy biotic pressure on natural forests are the major associated problems. Such cumulative problems lead to social unrest and / or exodus from the area.

In view of the worldwide thrust and immediate need for India, an urgent attention towards improvement of degraded land here has become indispensable. Though our Government is making all sincere efforts to tackle this chronic problem yet the success remains elusive without the systematic environment impact assessment.

Keeping this in view, evaluation of the treatment of soil through engineering interventions has been done in terms of its vegetational analysis—being the strongest indicator. In the vegetational analysis, all those parameters, which are characterized by imparting understanding on one aspect or the other of the vegetational structure, have been studied. Vegetation being the most important basic indicator of soil and water
conservation, in turn, becomes a synonym of the success of the constructed structure. Such structures are required and designed according to the topography, soil structure, runoff etc. It is an established fact that ecological indices are the measures of the sustainable management of environment and thus socio-economic improvement of the people, especially where land management has been practiced.

Study of the available measures and models of soil and water conservation adopted in Shiwaliks has been done to evaluate the impact of the engineering interventions on the soil management in terms of vegetational structure. This has been accomplished by conducting reconnaissance of the functional and non-functional engineering interventions, vegetational analysis, soil analysis and socio-economic evaluation in each of the three study areas.

The observations made on the basis of field study made over a period of 3 years in the 3 study areas are summarized below:

- The three study areas differ in their topography and geological structure. The Sukomajri study area had quite steep slopes in contrast to Bhagwasi study area, which was comparatively flat. The topography at Sukhna lake catchment was both slopy and flat at different areas, though the slope was less as compared to Sukhomajri study area.

- As far as type of engineering interventions in each of the three study areas are concerned, Sukhomajri study area was found to be characterised by bigger engineering interventions consisting primarily of four big earthen dams. On the other hand, Sukhna catchment study area represented a large number of smaller engineering interventions in terms of a small earthen dams, stone check dams, Gabion check dams, Spurs, Grade stabilizers, etc. In contrast, the emphasis in Bhagwasi study area was characterized by smaller cost effective engineering interventions involving extensive use of vegetation in combination with engineering structures to reduce the designed dimensions of the structures.
The number of stone check dams in Sukhomajri study area were observed to be 15, with a density of 0.072/ha whereas in Sukhna catchment study area, the number was 55, with a density of 0.013/ha. In Bhagwasi study area, four brick masonry check dams were seen, with a density of 0.007/ha. This area was also characterised by the setting up of cost-effective brick masonry safe water disposal structures, which were observed to be 7 in number, with a density of 0.012/ha.

As far as major engineering interventions in terms of spillways are concerned, at Sukhomajri and Sukhna catchment study area, they were found to be numbering 3 and 6 with a density of 0.014/ha and 0.002/ha, respectively. However, in Bhagwasi study area, straight drop spillway, cement pipe chute spillway and drop inlet spillways were seen, numbering 2, 4 and 2 and a density of 0.003/ha, 0.007/ha and 0.003/ha, respectively.

Gabion check dams were seen in all the three study areas of Sukhomajri, Sukhna catchment and Bhagwasi and numbered 8, 46 and 6 respectively, while the density varied from 0.038/ha, 0.01/ha and 0.01/ha, respectively.

Minor engineering interventions in terms of bunding only, levelling and bunding and bench terracing and bunding were a typical characteristic of Bhagwasi study area, where they covered an area of 1, 22 and 18 hectares, respectively, with a density of 0.18/ha, 0.04/ha and 0.008/ha. Such interventions were not prominently observed in other study areas of Sukhomajri and Sukhna catchment area, because it is anticipated that even if such minor engineering interventions were at all set up, they would have got dilapidated/worn out by now.

As regards vegetational analysis, at the Sukhomajri study area, average number of plants seen per location were 493.46 of 91 species belonging to 39 families with mainly Asteraceae being represented by 10, Poaceae and Leguminosae by 8 each, Euphorbiaceae by 6, Fabaceae, Acanthaceae and Malvaceae by 4 each, Solanaceae and Rutaceae by 3 each, Adiantaceae, Amaranthaceae, Caryophyllaceae,
Chenopodiaceae, Convolvulaceae, Moraceae, Myrtaceae, Nyctaginaceae, Rubiaceae, Scrophulariaceae and Verbenaceae by 2 each.

- In contrast, at Sukhna catchment, the average number of plants counted per location were 423.64 of 67 types. These belonged to 34 families with Asteraceae being represented by 9, Leguminosae by 6, Euphorbiaceae by 6, Poaceae by 5, Acanthaceae and Malvaceae by 3 and Solanaceae, Fabaceae, Caryophyllaceae, Chenopodiaceae, Moraceae, Myrtaceae, and Rutaceae by 2 each.

- Similarly, at Bhagwasi study area the average number of plants counted here per location were 410.11 of 62 species. These belonged to 31 families with Asteraceae being represented by 9, Euphorbiaceae by 6, Poaceae by 5, Solanaceae by 4, Leguminosae by 3, and Amaranthaceae, Fabaceae, Caryophyllaceae, Convolvulaceae, Polygonaceae, Acanthaceae, Meliaceae, Myrtaceae and Scrophulariaceae by 2 each.

- There were 42 species of plants that were commonly present at all the three study areas. These were mainly *Acacia nilotica, Achyranthes aspera, Adhatoda vasica, Anagallis arvensis, Bambusa arundinacea, Blumea obliqua, Calotropis procera, Chenopodium murale, Citrus spp., Cynodon dactylon, Datura stramonium, Erigeron spp., Eucalyptus spp., Eulaliopsis binata, Euphorbia prostrata, Ficus religiosa, Fumaria indica, Gnaphalium purpureum, Lathyrus odurada, Malva sylvestris, Mangifera indica, Mazus pumilus, Melilotus indica, Parthenium hysterophorus, Peristrophe spp., Phalaris minor, Phyllanthus emblica, Populus deltoides, Prosopis juliflora, Psidium guajava, Ricinus cummins, Saccharum munja, Solanum nigrum, Spergula arvensis, Stellaria media, Trigonella incisa, Vernonia cinerea, Vicoa vestita and Zizyphus jujuba*.

- Species of Plants that were counted exclusively at Sukhomajri study area were *Abrus precatorius, Anetium spp., Bougainvillea glabra, Butea monosperma, Cassia fistula, Corchorous aestuans, Cordisepalum spp., Cuscata hyalina, Dicliptera spp., Eragrostis ciliaris, Grevillea robusta, Hibiscus micranthus, Lindenbergia spp., Murraya koengii, Pongamia glabra, Setaria glauca and Sisymbrium irio*. However,
Crotalaria spp. was the only species of plant that was found to have no representative at Sukhomajri or Bhagwasi but only at Sukhna catchment. Similarly, Artemisia scoparia, Avena sativa, Azadirachta indica and Eclipta alba were found to have no representative at Sukhomajri or Sukhna catchment but were seen only at Bhagwasi study area.

- *Eulaliopsis binata* was counted in all the three study areas but it was found to have maximum Importance Value Index (IVI) in Sukhomajri with the value of 32.31 as compared to 19.17 at Sukhna catchment and 0.89 at Bhagwasi. It’s average number of plants per location at Sukhomajri were 118.60 which was maximum out of all the three study areas while Sukhna catchment was way behind with 65.29 plants and Bhagwasi had just 1.50 plants. At Sukhomajri it derived its IVI value because of its highest value of abundance (43.93) and density (23.72). At Sukhna catchment too it derived its IVI value due to its highest abundance value of 59.36 and density value of 13.06.

- Similarly, *Cynodon dactylon*- a surface feeder- had maximum number of average plants per location (160.90) at Bhagwasi study area while Sukhomajri and Sukhna catchment study areas closely followed with 112.24 and 114.80 average number of plants per location, respectively. In terms of its IVI, the values at Bhagwasi, Sukhna catchment and Sukhomajri study areas were 54.40, 40.43 and 31.40, respectively while its abundance values were 50.28, 35.88 and 31.18, respectively and density values 32.18, 22.96 and 22.45, respectively.

- *Achyranthes aspera, Datura stramonium, Zizyphus jujuba* and *Croton variegatum* were present at all the three study areas i.e Sukhomajri, Sukhna catchment and Bhagwasi. The average number of plants of *Achyranthes aspera* at each of the three study areas were 20.11, 7.61 and 3.49, respectively while its IVI value was 7.08, 7.50 and 6.17, respectively. The abundance values at the three study areas were 16.68, 5.07 and 2.68, respectively while its density values were 4.00, 1.52 and 0.70, respectively. Similarly, *Datura stramonium* had the average number of plants at each of the three study areas as 11.11, 10.30 and 4.40, respectively while its IVI value was
4.61, 5.84 and 3.76, respectively. Its abundance values at the three study areas were 13.89, 11.44 and 5.51, respectively. Zizyphus jujuba too was counted at all the three study areas i.e Sukhomajri, Sukhna catchment and Bhagwasi and its average number of plants at each of the three study areas were 1.10, 1.11 and 0.20, respectively while its IVI value was 2.08, 5.13 and 0.58, respectively. The average number of plants per location in case of Croton variegatum at each of the three study areas i.e Sukhomajri, Sukhna catchment and Bhagwasi were 0.20, 0.50 and 1.01, respectively while its IVI value was 0.50, 1.05 and 1.40, respectively.

- Asphedelus tenuifolius was present at Sukhomajri, Sukhna catchment and Bhagwasi study areas with average of total no. of plants per location as 18.41, 28.19 and 22.59, respectively while its IVI value was 5.42 (due to its abundance value of 26.30), 12.24 (due to its abundance value of 18.79) and 17.09 (due to its abundance value of 12.55), respectively. Similarly, Adhatoda vasica was also present at Sukhomajri, Sukhna catchment and Bhagwasi study areas with average of total no. of plants per location as 14.60, 12.71 and 0.60, respectively while its IVI value was 7.58 (due to its abundance value of 8.59 and dominance value of 2.92), 7.27 (due to its abundance value of 11.56 and dominance value of 2.54) and 1.59 (due to its abundance value of 1.20), respectively.

- Saccharum munja too was present at all the three locations i.e Sukhomajri, Sukhna catchment and Bhagwasi study areas with average of total no. of plants per location as, 11.01, 5.80 and 2.90, respectively while its IVI value was 8.94, 6.20 and 8.87, respectively.

- Oxalis corniculata was also present at two locations only i.e Sukhomajri and Sukhna catchment with IVI values of 5.23 (due to its abundance value of 12.09) and 3.05 (due to its abundance value of 8.33), respectively while average no. of plants per location were counted to be 13.30 and 5.00, respectively at each of the two study areas. Similarly, Malvastrum coromandelianum was also present at two locations only i.e Sukhomajri and Sukhna catchment with IVI values of 2.77 and 2.79 respectively while average no. of plants per location were counted to be 4.40 and 3.70,
respectively at each of the two study areas. In contrast, *Euphorbia hirta* was present at all the three study areas viz Sukhomajri, Sukhna catchment and Bhagwasi study areas with average of total no. of plants per location as 4.80, 0.80 and 4.40, respectively while its IVI value was 2.37 (due to its abundance value of 8.00), 0.50 and 2.73 (due to its abundance value of 7.34), respectively.

- *Lantana camara* was a weed that was counted at Sukhomajri and Sukhna catchment areas only catchment with IVI values of 4.77 and 3.10, respectively. Average no. of plants of this weed per location were counted to be 7.90 and 4.70, respectively at each of the two study areas. It was observed to be absent at Bhagwasi.

- *Agave spp.*, was seen only at Sukhomajri and only 0.20 average no. of plants per location were counted. It had a very low IVI value of 0.51.

- *Bambusa arundinacea* was also present at Sukhomajri, Sukhna catchment and Bhagwasi study areas with average of total no. of plants per location as 0.20, 0.10 and 0.31, respectively while its IVI value was 0.97, 0.39 and 4.02, respectively.

- *Parthenium hysterophorus* was observed to be present in all the three study areas i.e Sukhomajri, Sukhna catchment and Bhagwasi with average of total no. of plants per location as 6.49, 6.30 and 4.60, respectively while its IVI value was 3.96 (due to its abundance value of 5.90), 5.26 (due to its abundance value of 5.72) and 7.09 (due to its abundance value of 3.83), respectively.

- As far as different indices of Ecological Parameters i.e. Richness, Diversity and Evenness are concerned, the no. of types of plants counted at Sukhomajri, Sukhna catchment and Bhagwasi were 91, 67 and 62, respectively. The species richness of the area, based on all the species in the Sukhomajri area, was calculated to be 14.16 as compared to 10.46 in Sukhna catchment and 10.23 in Bhagwasi. However, considering the dominating species, the species richness in the Sukhomajri area was 3.79 in comparison to 2.85 and 3.14 in Sukhna catchment and Bhagwasi areas, respectively. As regards diversity of species, the index of diversity ($\lambda$) based on dominant species in all the three study areas was almost the same and varied
relatively very little at Sukhomajri, Sukhna catchment and Bhagwasi with values of 0.02, 0.03 and 0.04, respectively.

- Based on the species abundance, the diversity of vegetation in Sukhomajri area was about one and half times that of Bhagwasi with values of 54.14 and 37.57, respectively while at Sukhna catchment it was almost same as Bhagwasi with value of 39.58. When diversity was compared with very abundant species, the difference between the Sukhna catchment and Bhagwasi was brought down drastically to 28.53 and 26.12, respectively while at Sukhomajri area it was much higher than these two study areas with value of 40.5.

- Regarding the values of species evenness in the scale of 1 to 5 depending upon the abundance of the species, it was observed that for all the 5 indices of evenness, the variation between all the three study areas was very less.

- The mean soil pH for Sukhomajri varied between 8.1 and 8.4 at different soil depths. In contrast, in Sukhna catchment it varied between 8.2 and 8.5 and in Bhagwasi in the range of 8.5 to 8.7. The pH values were found to be higher in case of Bhagwasi followed by Sukhna catchment and Sukhomajri. In all the three study areas it was further noticed that with the depth, there was hardly any difference in pH values except that the top layers were less basic.

- The mean % organic carbon (OC) values of Sukhomajri varied between 0.9 and 1.7 at different soil depths. For Sukhna catchment, mean percent organic carbon values varied between 1.1 and 1.4. While in Bhagwasi area it varied between 0.6 and 1.1. Further, OC values decreased with the increase in depth.

- The mean values of available nitrogen for Sukhomajri varied between 133.53 and 268.27 kg/ha at different soil depths. The values for Sukhna catchment varied between 112.48 and 245.33 kg/ha and for Bhagwasi it varied between 89.62 and 185.62 kg/ha. It is evident that the available nitrogen decreased with the increase in depth at all the three study areas and the available nitrogen content was highest at Sukhomajri followed by Sukhna catchments and Bhagwasi study areas.
The mean values of available Phosphorous for Bhagwasi varied between 32.47 and 65.24 kg/ha at different soil. Similarly the values for Sukhomajri varied between 42.08 and 107.72 kg/ha and for Sukhna it varied between 45.16 and 87.63 kg/ha. Further available phosphorus decreased with the increase in depth at all the three study areas.

The mean available potassium at Bhagwasi village varied between 235.86 and 354.72 kg/ha at different soil depths. The values for Sukhomajri varied between 282.54 and 402.23 kg/ha and for Sukhna, it varied between 275.61 and 389.34 kg/ha. It was further observed that available potassium decreased with the increase in depth at all the three study areas.

Based on the socio-economic evaluation, the percentage of the persons representing the age group of 25-35 and 35-50, were maximum (35.5%) in the Sukhna catchment area as compared to Sukhomajri and Bhagwasi village where they were 27 % and 28.5%, respectively. The senior citizens were quite less as compared to the younger age groups in all the areas especially in the Sukhna catchment and their relative percentage in each of these areas was 6.0, 8.5 and 7.5, respectively. The population in the age group of 0-6 years was 14% in Sukhomajri village as compared to in 15.25% in Sukhna catchment and 12.5% Bhagwasi village.

In the adult sex ratio females were maximum in Bhagwasi area (45.1%) followed by Sukhna catchment and Sukhomajri. In contrast to this, males were counted to be maximum in Sukhomajri followed by Sukhna catchment and Bhagwasi areas. In child (0-6 years) sex ratio, female children were found to be maximum in Sukhna catchment followed by Sukhomajri and Bhagwasi.

As far as marital status is concerned, singles like, divorced/widow/widower were counted to be maximum in the Sukhomajri area i.e. 14 percent followed by Bhagwasi 11.5 % and Sukhomajri 10.25%.
In the parameter of family status, it is observed that the people in Sukhna catchment mostly live in joint families and they constitute 80% of the total families as compared to 65% in Bhagwasi and 70% in Sukhomajri.

In the segment of formal education, professionals were found to be about 3.0, 6.0 and 0.5 percent, those with formal education between 15-17 years were 2.0, 4.0 and 1.0 percent and the persons who had acquired education only upto the 12th class was 25, 30 and 5 percent in Sukhomajri, Sukhna catchment and Bhagwasi areas, respectively. Similarly, the percentages of the persons who have had formal education only upto 8th class were about 25, 20 and 14 in Sukhomajri, Sukhna catchment and Bhagwasi areas, respectively. In contrast, the percentage of the persons (this percentage included housewives and old persons too) who did not have any formal education was quite low in Sukhomajri (4.65%) and Sukhna catchment (1.5%) but quite high in Bhagwasi village (46.28%).

As far as monthly income per family is concerned, almost same percentage (about 35-40) of families in Sukhomajri and Bhagwasi areas were in the range of Rs 1000-5000 as their monthly family income. But in Sukhna catchment, this segment accounts for only 10 percent of the total population. In Sukhna catchment, 75% of the persons were in the monthly family income range between Rs 5000-50,000. Not only this, about 10% of the population was found to be in the range of greater than Rs 50,000.

Regarding the residency status parameter of socio-economic evaluation, the persons residing permanently outside the village and rarely visiting the village was maximum in Sukhna catchment (2.27%) and minimum in Sukhomajri (0.74%). The persons residing in village and working outside constituted the persons who work in the nearby areas. Their number was also quite significant and maximum percentage was found to be in Sukhna catchment (63.25) followed by Bhagwasi (42.25) and way behind was Sukhomajri (32.60). Similarly, the percentage of the persons residing outside the village and visiting the village for specific purpose like harvesting of crops, social functions or exercise of voting rights etc was maximum in Sukhna catchment (15.15) and minimum in Bhagwasi (2.11).
As far as economic activity is concerned, maximum percentage of cultivators (19%) were found in Sukhomajri, as compared to 18% in Sukhna and only about 6% in Bhagwasi study areas while percentage of agricultural labourers were found to be maximum in Bhagwasi area (10.3%). Percentage of other workers that included the persons residing in the village but going outside for gainful employment were found to be maximum in Sukhna catchment (43.95%). On the other hand, non-workers including students and housewives were found to be maximum in the Bhagwasi area (66.28%).

In the parameter of families having domesticated animals, out of the total pets, buffalo was about 76% in Sukhna catchment followed by Sukhomajri (68%) and Bhagwasi (28%). On the other hand, the percentage of goat, pig and sheep was found to be maximum in Bhagwasi area (65.62%) and minimum in Sukhna catchment (15.17%). Percentage of the pets like dog, cat, parrot etc which are indirect indicators of the economic strength of the family were found to be maximum in Sukhomajri (23%) and minimum in Bhagwasi village (2%).

Regarding the parameter of types of fuel being used by households, percentage of households using solar energy/electricity was just 5% in Sukhna catchment and nil in Bhagwasi. On the other hand, households using kerosene and petro-gas as fuels was found to be 65%, 85% and 25% in Sukhomajri, Sukhna catchment and Bhagwasi areas, respectively. Another source of fuel being used in these areas was wood. The percentage of households using wood as a fuel was found to be maximum in Bhagwasi (35%), followed by Sukhomajri (5%) and Sukhna catchment (2.5%).

In terms of type of residential construction taken up in the study areas, it was observed that Sukhna catchment had maximum number of permanently constructed residences followed by Sukhomajri and Bhagwasi and their respective percentages were 80, 70 and 20. Though the percentage of the thatched houses was very less in all the three study areas yet the temporarily constructed houses were found to be maximum (60%) in Bhagwasi village.
As far as the ownership of residential accommodation is concerned, in Sukhna catchment 90% of the households owned their houses whereas in Bhagwasi village this percentage was only 50. On the other hand, the percentage of the homeless or those living in rent free accommodation / a public place was quite negligible in all the three study areas.

Regarding the mode of transport being used by the residents, 20% of the households in Sukhna catchment used car in addition to other modes of transport. The most popular mode of transport in all the three areas was found to be cycle. Similarly, about 75% of the households used scooter as one of their modes of transport in Sukhna catchment region followed by 20% in Sukhomajri and 10% in Bhagwasi village. In Sukhna catchment bus, apart from other modes, was also quite a popular mode of transport and 87% of the households used it for commuting purposes.

In the parameter of modem gadgets being used by households, in all the 3 study areas, most of the households owned more than one modern gadget. Refrigerator and Television were found to be most popular and 40, 92.5 and 45 percentages of households in Sukhomajri, Sukhna catchment and Bhagwasi areas, respectively owned either one or both of these two. In Sukhna catchment 10% of the households had a computer-synonym of latest technology. The percentage of households owning a cell-phone was maximum in Sukhna catchment (22.5%) whereas it was only 5% each in Sukhomajri and Bhagwasi study areas.

An area, especially in a developing country like India, is presumed to be most strong economically and socially if the girl child is not discriminated in any manner against the male child. Sending a girl child to an educational institution outside the village and giving her nourishing diet and not exposing her to daily household chores, is considered as an indicator of the socio-economic growth of the society in real terms. In Sukhna catchment about 35% of the female children fell in this category while in Bhagwasi and Sukhomajri each it was only about 27. On the other hand, in all the study areas parents encouraged the girl child to study and as a result on an average
more than 80% of the girl children in each of the three study areas were observed to at least attend some school.

- Out of the 16 parameters (in terms of contribution towards the socio-economic upliftment) there was dominance of Sukhna catchment in 13 parameters (except Adult sex ratio, residency status and child sex ratio). Bhagwasi dominated only in the parameter of Child sex ratio while Sukhomajri dominated in the adult sex ratio and residency status. Out of the 3 study areas, Bhagwasi study area was found to be economically (in terms of materialistic conveniences) as well as socially, not as rich as the other 2 study areas. On the other hand, Sukhna Lake catchment was observed to be the richest of all the three while Sukhomajri comes in between the two.

Based on the above results, the impact assessment of engineering interventions on ecology of the three study areas, keeping vegetational analysis as the basic indicator has been discussed.