ERODIBILITY STATUS OF TORRENT AFFECTED AREA AND ITS STABILIZATION THROUGH BIO-ENGINEERING MEASURES IN LOWER SHIWALIKS OF HIMACHAL PRADESH

Thesis

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YOGENDER SHARMA

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Dr I P Sharma
(Prof. & Head)

Department of Soil Science and Water Management
College of Forestry
Dr. Y.S. Parmar University of Horticulture and Forestry, Nauni-Solan – 173 230 (H.P.)

CERTIFICATE-I

This is to certify that the thesis entitled, **"Erodibility status of torrent affected area and its stabilization through bio-engineering measures in lower Shiwaliks of Himachal Pradesh"**, submitted in partial fulfilment of the requirements for the award of degree of **DOCTOR OF PHILOSOPHY** in **SOIL SCIENCE AND WATER MANAGEMENT** to Dr. Yashwant Singh Parmar University of Horticulture and Forestry, Nauni, Solan (H.P.) is a bonafide record of research work carried out by **Mr. Yogender Sharma (F-2003-11-D)** under my guidance and supervision. No part of this thesis has been submitted for any other degree or diploma.

The assistance and help received during the course of investigation has been fully acknowledged.

Place: Nauni-Solan
Dated: 16th July, 2008

(I P Sharma)
Chairman
Advisory Committee

CERTIFICATE-II

This is to certify that the thesis entitled, **"Erodibility status of torrent affected area and its stabilization through bio-engineering measures in lower Shiwaliks of Himachal Pradesh"**, submitted by **Mr. Yogender Sharma (F-2003-11-D)** to Dr. Yashwant Singh Parmar University of Horticulture and Forestry, Nauni, Solan (H.P.), in partial fulfilment of the requirements for the award of degree of **DOCTOR OF PHILOSOPHY** in **SOIL SCIENCE AND WATER MANAGEMENT** has been approved by the Student's Advisory Committee after an oral examination of the same in collaboration with the external examiner.

Dr. I.P. Sharma
Chairman, Advisory Committee

External Examiner

Members, Advisory Committee

Dr. Veena Sharma
Professor
(Co-opted in place of Dr. S.S. Sharma)

Dr. J.C. Sharma
Scientist

Dr. D.R. Bhardwaj
Scientist

Er. Rohitashaw Kumar
Assistant Professor

Dean's Nominee

Professor and Head
Department of Soil Science and Water Management

Dean
College of Forestry

CERTIFICATE-III

This is to certify that all the mistakes and errors pointed out by the external examiner have been incorporated in the thesis entitled, **"*Erodibility status of torrent affected area and its stabilization through bio-engineering measures in lower Shiwaliks of Himachal Pradesh*"** submitted to Dr Y.S. Parmar University of Horticulture and Forestry, Nauni, Solan (H.P.) by **Mr. Yogender Sharma (F-2003-11-D)** in partial fulfilment of the requirements for the award of degree of **DOCTOR OF PHILOSOPHY** in **SOIL SCIENCE AND WATER MANAGEMENT.**

Major Advisor
Dr. I.P. Sharma
Prof. and Head

Professor and Head
Department of Soil Science and Water Management
Dr Y S Parmar UHF, Nauni, Solan (H.P.)

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Yogender

(Yogender Sharma)

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INTRODUCTION

Chapter-1

INTRODUCTION

Soils are the most valuable and vital natural resource for the socio-economic development of a country. In India, soil degradation due to water erosion is a serious problem causing decline in land resource and its productivity by eroding the value of valuable agricultural land. Out of the total geographical area of the country, about 187 Mha (57%) is reported to be suffering from soil degradation processes of various types and degrees. The area affected by soil erosion is estimated to be 150 Mha, out of which 69 Mha is in critical stage of deterioration. It has been estimated that more than 5334 million tons of topsoil is being eroded every year out of which 1600 million tons representing about 30 per cent of total eroded mass is permanently getting lost to the sea and about 10 per cent gets deposited in the reservoirs, reducing their capacity by 1-2 per cent every year (Singh *et al.*, 1992; Narain *et al.*, 1993).

Water erosion is a major problem in the soils of Himachal Pradesh especially in the Shiwalik region and is attributed to high soil erodibility and sparse vegetation. The soils of the region are under severe stress due to sheet and gully erosion (Plate 1) The main causative factors are intense and heavy monsoon rains, large scale deforestation, weak and unstable geology, undulating topography having steep slopes, unscientific cultivation, overgrazing, relentless mining/quarrying for sand, shingle, stones etc. Nearly 43.2 per cent (2.16 lakh ha) of the total cultivated land (6.16 lakh ha) in the state is under the impact of high to very high intensity erosion (Anonymous, 2000). The lands in Shiwalik foothills of Himachal Pradesh are subjected to serious problem of erosion due to aforesaid causes.

The Shiwalik hill region lies between 30^0 $10'$ to 33^0 $37'$ N Latitudes and 73^0 $37'$ to 77^0 $39'$ E Longitudes and the foothills of the region covering an area of 3.08 Mha is in the states of Himachal Pradesh, Punjab, Haryana, Uttarakhand and Jammu & Kashmir (Yadav *et al.*, 2005) and out of this 1.14 Mha is in Himachal Pradesh. Shiwaliks in foot hills of Himachal Pradesh commonly called as "Kandi", constitute 21.0 per cent of total geographical area of the state and lies in Paonta valley in District Sirmour, Doon valley in Solan district, Soan area of Una District and some parts of Nurpur Tehsil of Kangra District. The soils of Shiwaliks exhibit varying pedogenic stages and have been classified into Inceptisol and Entisol orders (Sidhu *et al.*, 2000). These soils vary widely in their depth, texture, organic carbon, pH and erosional behavior depending upon physiography, parent material, vegetation cover and climatic conditions. More than 80 per cent of the area is affected by moderate to severe erosion and constitutes the principal causative factor for soil degradation in the region. The other soil problems are low available water capacity due to coarse/gravely texture and low fertility status which restrict the productivity of this region. The area is exposed to greater biotic pressure due to its proximity to plains. This Shiwalik hill region because of peculiar geological formations represents the most fragile ecosystem and has torrents as a major land degradation problem (Das, 1985)

The lands in the Shiwalik foot hill region are severely affected by seasonal hill streams (torrents) popularly called as *'choes'* or *'raos'*, rendering the once fertile agricultural lands unproductive and highly erodible (Patnaik and Sikka, 1988). Torrents are ephemeral mountain streams emanating from the outer Himalayas and Shiwaliks and empty into major rivers and cause extensive damage to life and property in the valley areas by scouring their beds, undermine and erode their banks. In India, torrents have been mostly taken as small mountainous streams rushing down the slopes with flashy floods and often loaded with sediments. On reaching the milder slopes such as foothills they develop the channel problem of large volume and low velocity of flow. This is aggravated by high sediment load and depositions obstructing the channel flow. The torrents in Indian foothills have therefore been linked with the problem of channel as well as riverine land and the flood plain areas are affected by depositions, shifting of course and inundation of banks. Latest estimates revealed that about 2.73 Mha has been degraded by torrents at the interface of hills and plains in India (Anonymous, 1995).

The denudation of fragile area of Shiwalik started about 150 years ago and continued unabated in spite of legislative and control measures (Mishra and Sarin, 1987) as a result, area once protected with thick vegetation got converted into bush lands of little economic importance (Bhumbla, 1976). The gentle streams in the area got converted

A. Upper catchment

B. Lower catchment

Plate 1. Severe gully erosion in torrent catchment, Site-1 (Barotiwala, Solan)

into ferocious torrents laden with sediments eroded and washed down from barren hills. The torrents are menacing problem in the entire Shiwalik region and this problem did not decrease even in the post independence era as well in spite of repeated erosion control measures. Due to heavy monsoon rains, these cause extensive damage to civic amenities, habitation, agricultural lands, pastures, forest areas etc.

All the torrents which cause extensive damage to environment constitute rehatic ecosystem in Himachal Pradesh, have been divided into three types (Kaul, 1991), viz. rainfed, glacier/snow fed and mixed type (fed both by winter snow melts and rain). The rainfed torrents found in Shiwalik hills are made up of loose soils, embedded with small and medium size round stones/boulders, gravels etc. The heavy rains make these streams to swell up and water flows with very high velocity cutting down the loose soil, thus causing a lot of erosion and slope failure. Most of the torrent beds are many times wider than the space needed for discharge of the flood waters owing to the reason of deposition, meandering and bank cutting. During high floods, these torrents usually overflow their banks and render vast agricultural lands unproductive due to deposition of boulders, shingle, sand etc., over them (Gorrie, 1957). Therefore, there is urgent need of torrent training to channelise the stream flow of torrent to a reasonably narrow channel, reclamation of the area under bed for protection of the adjoining cultivated fields, habitations, forest lands etc. from destructive action of floods (Madan, 1951 and Sethi, 1960).

Various soil characteristics alongwith topography, vegetation and biotic interference provide fairly good idea about the erodibility. Some of the soil properties have been correlated well with erodibility by various workers. The pioneer workers on this aspect were Middleton (1930), who established a quantitative relation of erosion ratio and dispersion ratio with erodibility and Bouyoucos (1935) who suggested clay ratio as possible index of erodibility. It has been observed that soils under similar conditions of topography, climate and vegetative cover, differ naturally in the extent of their erosion. Such differences are due to physical make up of soils. The physical properties of surface or subsurface soils are not easily modified. Consequently, soil properties such as texture, bulk density, water holding capacity, permeability to water, aggregation etc. are more important than chemical data, in determining the potential possibilities of lands. In the lands or areas having similar climate but different land use/land cover, the variations in erodibility of the soils might be due to the physical properties of the soils like texture, water stable aggregates etc., in addition to topography and other inherent properties which classify the soils into erosive or non-erosive categories.

The quantitative assessment of soil erosion hazards in torrent affected areas requires in depth knowledge of many factors related to soil properties, rainfall characteristics and land conditions (Wischimeir and Smith, 1965). The differential erosional behavior of two soils under similar environment and management conditions is attributed to their inherent characteristics called as erodibility and measured through its different indices called "erodibility indices". It is a quantitative measure of inherent soil susceptibility to erosion by wind and water. Erodibility involves soil properties that affect the rate of water entry into soil profile, dispersion and splashing force of rainfall. However, in relation to erodibility, the stresses associated with rain drop impact and erosion ratio are most important and significant and the stability of stresses applied by rainfall simulations is probably the most important criteria (McCalla, 1944).

Soil erodibility characterization can be a major consideration in developing sound land management practices. Thus indices of soil erodibility can be worked out by measuring some soil properties. Therefore knowledge of soil erodibility of the torrent affected lands will considerably help in planning the soil conservation practices for reduction of the land degradation due to torrents.

Therefore, for mitigating the menace of torrents, there is urgent need to assess the erodibility of torrent affected lands and also devise suitable preventive measures to prevent their further deterioration. At present no detailed and precise information on the erodibility status of torrent affected areas and their stabilization is available. A study had therefore, been undertaken in three representative torrent affected areas in the lower Shiwaliks of Himachal Pradesh with following broad objectives:

1. To assess the erodibility of the torrents affected lands.
2. To study the effect of bio-engineering measures on runoff and sediment yield.
3. To study the impact of bio-engineering measures on torrent stream flow channelisation and its stabilization.

Chapter - II

REVIEW OF LITERATURE

Chapter-2

REVIEW OF LITERATURE

Soil erodibility refers to the inherent susceptibility of soil to erosion by rainwater and runoff. This is a function of complex interaction of physical and chemical properties of soils affecting detachability, transportability and infiltration capacity. Soil erodibility is influenced by soil properties through their effect on the rate of water entry into the soil profile, its retention and release and the ability of the soil to resist the forces causing its dispersion, splashing, abrasion and transportation in run-off. The structural stability of a soil has a close relationship with soil properties, which in turn, are governed by soil texture, orientation of particles, organic carbon contents and the nature and extent of exchangeable cations in the exchange complex. The torrents in an area also impart significant effect on soil physico-chemical and hydraulic characteristics. There is meagre information on the erodibility status of torrent affected areas and their stabilization through bio-engineering measures. The pertinent relevant literature on the soil hydro-physical, chemical and erodibility characteristics, torrent channelisation and stabilization is reviewed under the following heads:

2.1 Soil physico-chemical and hydraulic properties

2.2 Soil erodibility

2.3 Interrelations between and among different soil properties and erodibility and stability indices

2.4 Torrent channelisation and stabilization through bioengineering measures

2.1 SOIL PHYSICO-CHEMICAL AND HYDRAULIC PROPERTIES

Chester *et al.* (1957) reported that a pH of 6.5 was found to be optimum for aggregation. Wishchmeier and Mannering (1969) indicated that the relation of pH to erodibility depends on soil structure and silt content. For a high silt containing soil, increased pH increased erodibility when the structure was very fine or fine granular.

When the structure was medium or coarse granular, subgranular, or angular erodibility decreases with increased pH.

Kolay *et al.* (1975) in their study on physical and chemical characteristics of water stable aggregates under different land uses found that bigger sized aggregates (>2.0 mm in dia) were higher in grassland soils while smaller sized aggregates (0.25-0.50 mm in dia) dominated in cultivated and uncultivated lands. With the reduction in the sizes of soil aggregates, there was a decrease in bulk density and humus content with an increase of water holding capacity and pore space was also reported.

Mahto *et al.* (1977) reported that the land use that promotes erosion is likely to have higher percentage of sand compared to an identical soil in the region that has not been subjected to erosion. Water holding capacity of the soils was reported not to be directly related to land use. Available phosphorus was also reported to be having no influence of land use. Gullied and uncultivated lands had several times higher hydraulic conductivity than the soils under cultivation citing reason for the blocking of micropores in the cultivated lands.

Obi and Asiegbu (1980) studied the physical properties of some eroded soils of South Eastern Nigeria and found higher hydraulic conductivity as well as infiltration values in coarse textured soils between 0-80 cm tension showing thereby that these soils had lower cohesive power and more erosion by water.

Gupta *et al.* (1983), in their study found that water retention at 1/10 bar and that between 1/10 and 15 bar was maximum in both surface and sub-surface horizons under grasslands followed by forest lands. At 15 bar, the highest water retention was in surface horizons of forest lands and in sub-surface ones of cultivated lands. Available water was found to be higher under grasslands in both surface and sub-surface horizons. Organic matter content was found to be higher in grasslands and forest lands and highly significant relationship with water retention was reported in these land uses.

Khan *et al.* (1998) evaluated that there was high accumulation of clay in the lower horizons of seasonally flooded Bangladesh soil. They further observed that in general particle density and bulk density were higher in the subsurface than in the surface horizon, which may be due to higher content of organic matter in the surface horizon. But in some surface horizons bulk density of some soils was higher which may be due to dispersion and migration of clays and clogging of pores.

Kumar *et al.* (2002) in a study revealed that organic carbon, clay, CEC, water stable aggregates (WSA), mean weight diameter (MWD) were the dominating factors influencing water retention characteristics, erosion ratio (ER) and dispersion ratio (DR). Forest soils had higher water retention, infiltration rate, WSA, MWD and lower DR and ER than the cultivated and orchard soils.

Kumar *et al.* (2005) studied the soil texture, saturated hydraulic conductivity and soil moisture characteristics of the area between the Sher river, Umar river and Bargi left bank canal falling in Narsingpur district of Madhya Pradesh at eleven locations. They observed that majority of study area is under clay followed by silt clay and clay silt. The saturated hydraulic conductivity of clay, clay silt and silty clay were found to be 0.049, 0.205, and 0.343 m day^{-1}, respectively. The field capacity, wilting point and available water were in the order of 33.1, 16.7 and 16.5 per cent for clay, 26.5, 11.0 and 15.5 for silty clay and 33.3, 14.0 and 19.3 per cent for silty clay soil, respectively.

Nikam *et al.* (2006) conducted a study on water retention characteristics of shallow soils of basaltic origin supporting forest, grassland and agriculture. They observed that forest soils and other soils viz. grassland and agriculture had more than 60 and 30 per cent clay content, respectively. The bulk density increased with depth and ranged from 1.39 to 1.88 Mg m^{-3}. There was higher organic carbon in forest soils followed by grassland and cultivated soil. They further concluded that the clayey soils exhibited gradual slope and higher water retentions than grassland soils. In general, field capacity and permanent wilting point of the soils ranged from 16.3 to 41.9 per cent and 6.4 to 23.5 per cent, respectively.

Khybri (1965) observed high infiltration in soils having high organic matter content, friable in consistency, having crumb structure and relation between time and infiltration was curvilinear. Sur and Singh (1973) on soil series of Patiala in Punjab concluded that water intake was lower in fine textured soils in general and lowest in silt loam where sodium was present in appreciable amount on the exchange complex.

McGinty *et al.* (1979) in their study reported that a heavily continuously grazed pasture exhibited less than half the infiltration rate and had great sediment load, as compared to a rotation pasture. Both infiltration rate and sediment production were significantly influenced by plant biomass, bulk density and soil depth.

Mathur *et al.* (1982) in a comparative study of infiltration in soils under forest cover and agriculture in temperate climate reported that forest lands had higher initial and final infiltration rates as compared to agricultural lands. Forest land also exhibited higher contents of organic matter, higher moisture equivalent, higher pore space and moisture holding capacity as compared to agricultural lands.

Mohan and Gupta (1983) reported that land use wise average infiltration rates were in the order as: good terraced croplands > poorly terraced crop plants > grass lands > forest lands. Forest lands showed conspicuously lower infiltration rates which were mainly due to compacted condition of soil, scanty litter deposit on the floor to hold and intercept water.

Saha *et al.* (1995) reported that OC content in cultivated lands were lowest of all land use systems. Highest equilibrium infiltration was however observed in the cultivated fallow lands. They attributed this to lowering of bulk density after tilling the sandy loam soil. Soils under *Eucalyptus* and Bhabbar grass showed drastic reduction in the infiltrability than other land use systems. Similarly Saha *et al.* (1999), in their study on physico-chemical properties of soils under different land uses (different silvi-pastoral systems) found that pH and soil texture generally remained same under different land uses and no effect was reported, whereas, OC contents were higher in silvi-pastoral system, than in cropped lands.

The behaviour of vertical infiltration in layered soil was studied by Bhattacherjee *et al.* (2004) in soil columns of sandy loam and a clay loam, having a fine sand layer of varying thickness (0.10, 0.15, 0.20 m) situated at 0.15, 0.25, 0.35 m depth from soil surface. Irrespective of depth and thickness of impeding sand layer, a sharper decrease in infiltration rate was noticed once the water front reached the sandy layer. The period of reduced rate was followed by an instantaneous increase and its amplitude was found to be incremental with the thickness of the impeding layer. It was also observed that the time taken for peak rise of infiltration rate was longer in fine soil compared to coarse soil for similar thickness of sand layer.

2.2 SOIL ERODIBILITY

2.2.1 Soil erodibility indices

Benett (1926) was the first to recognize formally the variability in erosion-resistant properties of the soils. Subsequently, terms "soil erosivity" by Middleton (1930) and "soil erodibility" by Cook (1936) were given. Soil erodibility may be assessed by actual measurements of soil loss under controlled conditions, or by the isolation of certain soil properties as indices of erodibility. Middleton (1930) was the first to attempt and devise an index of erodibility based on detailed laboratory analysis and classified the soils as "erodible" and "non-erodible" on the basis of ease with which the soil would disperse, and the ease with which it could transmit water. Since then, various indices have been evolved by several workers to assess the erodibility of soils.

2.2.1.1 Dispersion ratio (DR)

Middleton (1930) observed a positive significant correlation between the amount of silt plus clay present in a dispersed soil sample and its erodibility. He suggested the ratio of amount of silt plus clay in an undispersed soil to the amount of silt plus clay in dispersed soil as an index of erodibility of soils and termed this as DR. For erodible soils, DR was found to be generally above 15 per cent and for non-erodible soils below 15 per cent.

Bryan (1967) reported that dispersion ratio can be used as an efficient index of erodibility when the soil is composed of at least 30 per cent silt plus clay. Chakrabarti (1969) reported that erodibility appears to be significantly and directly related to dispersion ratio and clay ratio, where as the correlation was negative with clay/moisture equivalent ratio. Many workers have found very close relationship between dispersion ratio and erosion ratio (Haridassan and Chhiber, 1971, Singh and Gupta, 1991, Dabral *et al.*, 2001).

2.2.1.2 Erosion ratio (ER)

Middleton (1930) combined the colloid content/moisture equivalent (ME) ratio with the DR as a further direct measure of erodibility, and termed this as erosion ratio (ER). He considered it to be the most accurate index of erodibility. The soils having values of ER more than 10 were generally characterized as erodible, while soils having values less than 10 were considered as non-erodible.

Various workers characterized the erosional behaviour of soils based on ER as Chibber *et al.* (1961) in some soils of Himachal Pradesh, Bhatia and Sarmah (1976) in some Assam soils, Bhola and Jayaram (1978) in black soils of Bellary; Narain *et al.* (1979) in the soils of Chambal command area, Sharma and Aggarwal (1980) in Kangra district of H.P., Bhatia and Hari Shankar (1981) in Central tract of UP, Sambyal and Sharma (1986), Singh and Gupta (1991), Kumar *et al.* (2002) in some soils of North-West Himalayas and Singh and Om Parkash (2000) in degraded soils of hill region of Uttar Pradesh.

Oleson and Wischimeier (1963) evaluated erodibility factor for eight soils, previously grouped with respect to their ER by Middleton *et al.* (1932). It was found that ER tended to become inconsistent in soils with small amounts of silt and clay. Also, ER was not found to be a reliable index of erodibility of soils by Dube and Mandal (1967). It has been seen that ER of coarse sand of foot hill soils of Punjab was 21 per cent, yet no loss of soil took place from these soils even when rainfall intensity was 10 cm h^{-1} (Singh and Verma, 1978). These results indicate that ER is not yet an infallible index of erodibility.

2.2.1.3 Clay ratio (CR)

Bouyoucos (1935) proposed CR, "the ratio between sand plus silt and clay present in a dispersed soil sample", as a direct index of erodibility. He compared it with ER using the same soils and reported that with few exceptions, these two indices agreed fairly well. Bryan (1968) proposed modified CR to overcome the objections raised by some workers including organic matter to the binding fraction. He suggested modified CR as most suitable index of erodibility. Later on various other workers like Bhattacharjee (1957), Bhatia and Sarmah (1976) and Bhatia and Hari Shankar (1981) reported a significant positive relationship between CR and ER. Contrary to this, Bhola and Jayaram (1978) and Narain *et al.* (1979) found no correlation between CR and ER of the soils.

2.2.1.4 Erosion index (EI)

Erosion index - a new index of soil erodibility was suggested by Sahi *et al.* (1977). It exhibited significant correlation with ER and hence they suggested that EI may be regarded as a good substitute for ER. Bhatia and Srivastava (1984) and Singh and Gupta (1991) also found positive correlation between EI and ER and advocated its use as a good index of erodibility.

2.2.1.5 Silt: clay ratio (SCR)

Singh and Om Parkash (1985) used ratio between silt percentage and clay percentage to characterize the hill soils of Uttar Pradesh under varying land uses.

2.2.1.6 Raindrop erodibility index

One of the most important factors governing soil loss by water is structural stability, which among other factors, depends on the nature of organic and inorganic constituents of the soil. Soil erosion begins when the kinetic energy of falling raindrops disrupts the binding forces of soil aggregates and breaks them into individual components (Ellison, 1944). The amount of soil removed by run-off water therefore depends to a large extent on the stability of soil aggregates to resist the disruptive forces of raindrop impact.

Bruce and Lal (1975) also pointed out that one of the limiting factors in characterizing the soils for their erodibility is the lack of technique for determining the structural stability of the soils and advocated the use of raindrop impact technique. Sambyal and Sharma (1986) have also concluded that water drop test provides a useful single means of indicating erodibility.

2.2.1.7 Water stable aggregates (WSA)

Aggregate stability has been considered as a major factor influencing erosion of soil by water. The soil structural units once stabilized, have strong cohesive forces between particles within the aggregates and are able to resist disintegration by the forces of rainfall and runoff. Agents affecting the formation and stabilization of soil aggregates undoubtedly include such attributes as size distribution of elementary soil particles, presence of organic and inorganic cementing agents, types of clay minerals present, nature of saturating cations and presence of soluble salts.

According to Lutz (1934) the content of WSA >0.25 mm may be used as it influences both dispersion and permeability of soil. Dube and Mandal (1967) suggested the measurement of WSA to obtain better estimates of soil erodibility as it matched with field observations.

Elwell (1986) and Gollany *et al.* (1991) reported that aggregate stability is a measure of the ability of soil to withstand the disruptive forces of rain and advocated that high organic carbon and clay in the soil largely explains the proportion of water stable aggregates.

2.2.2 Soil erodibility under different land uses

Mishra and Khanvilkar (1972) reported that coarse textured soils had higher permeability and due to their single grained structure, these were more susceptible to erosion than fine textured soils. They also pointed out that organic matter had greatest effect on the soil structure and thereby affected erodibility behaviour.

Study by Sharma and Aggarwal (1980) on soil erodibility under different land uses revealed that cultivated soils, in general, were more prone to erosion, than soils under grasses and forest cover. However, appreciable difference was found in the erodibility of soils under the grasses, tea and forest land uses. Soils under continuous cropping were found to be low in organic carbon and exhibited poor aggregation. Jha and Rathore (1981) after their study on erodibility of soils in shifting cultivation areas of Tripura and Orissa, concluded that the soils under Jhumming indicated a higher degree of erosion. The difference in erodibility of Orissa soils were quite high due to comparatively coarser texture. Likewise, Mathur *et al.* (1982) compared the soils under coniferous forest cover and agricultural lands in Kufri (H.P.) for their infiltration behaviour and found that both initial as well as final rates of infiltration were higher in coniferous forests than in agricultural lands.

A study conducted by Bhatia and Srivastava (1984) concluded that according to erodibility, the soils under different types of land uses could be arranged in the order: bare soil > maize > maize + Urd > forest soil > grass land. They also recorded high values of WSA in forest and grass lands as compared to soils under cropping and bare soils. Higher amount of organic matter in forest soils and grass lands appeared to have brought out the aggregation.

Parvathappa and Murthy (1993) observed that water retention and MWD varied with land use. Pastures and forests recorded higher values, indicating better aggregation and were also less prone to erosion by run-off water.

Chaudhary *et al.* (1999) observed that lands under shifting cultivation were highly erodible due to burning of organic matter, degradation of soil structure and low permeability. They also recorded that forest lands were less erodible as compared to sparsely vegetated and biotically disturbed lands. This was due to good permeability and higher content of organic matter in former. Sharma *et al.* (2000) reported that forest soils were more stable than the soils under orchards and cultivation. Maximum soil loss was recorded from croplands, followed by orchards and minimum under forests.

Dabral *et al.* (2001) in their study on erodibility status under different land uses in Dikrong river basin of Arunachal Pradesh reported lower erosion ratio of forest soils as compared to soils under other land uses. Similarly, study by Kumar *et al.* (2002) on water retention characteristics and erodibility indices of soils under different land uses in North-West Himalayas concluded that OC, clay content, CEC, WSA and MWD were the dominating factors influencing water retention characteristics, ER and DR. Forest soils were found superior for these parameters as compared to cultivated and orchard soils. Dispersion ratio and ER of forest soils was found to be lower than cultivated land orchard soils indicating that forest soils are less prone to erosion.

Mehta *et al.* (2005) studied erodibility of natural lands and cultivated lands in Punjab and observed higher DR under natural conditions. Similar trends were observed for CR, clay/ME ratio and silt: clay ratio. He concluded that soils under natural conditions showed higher values of these erodibility indices as compared to cultivated soils. The lower values of erodibility indices under cultivated conditions may be ascribed to high organic matter content, better aggregation, leading to high infiltration rate and corresponding low runoff.

Soil characteristics and erodibility indices of three soil depths viz. 0-5, 5-15 and 15-30 cm under five different land uses namely land under *Leuceana, Prosopis,* rainfed agriculture, grasses and open gullied lands were determined in south-east Rajasthan (Singh *et al.,* 2006). They reported lowest OC and clay content in open gullied land as compared with other land uses. They also observed that ER and DR, the erodibility of soils was in the order: open gullied> rainfed agriculture> *Prosopis,*> *Leuceana,*> grass lands. They further suggested that open gullied lands may be managed with cost effective mechanical and vegetative measures and gully plugging.

2.3 INTERRELATIONS AMONG DIFFERENT SOIL PROPERTIES AND ERODIBILITY AND STABILITY INDICES

Biswas *et al.* (1961), Arca and Weed (1965), Thamhne and Datta (1965), Singh and Chatterjee (1966), Azuma *et al.* (1968), Lavti and Paliwal (1980) reported the positive correlation between WSA and clay content.

Many workers have reported a positive significant correlation between structural stability and organic matter in different soils (Biswas *et al.*, 1961; Bhatia and Hari Shankar, 1980; Datta *et al.*, 1990 and Prasad *et al.*, 1993).

Chakarbarti (1971) found that there was very close correlation between ER and other soil properties such as DR, CEC, aggregate percentage and OC. Water stable aggregates were significantly correlated with WHC, OC, CEC, DR and SP but not with clay.

Chakrabarti (1971) and Chakrabarti and Gupta (1977) observed a positive significant correlation between WSA and CEC in forest and alluvial soil but no relationship was established in lateritic soils.

Sharma and Datta Biswas (1972) investigated the erodibility of four different soils of Sirkhad, a tributary of Sutlej and reported that erosion ratio of a soil was positively correlated with DR, clay: ME ratio, fine sand: silt + clay ratio, sand: silt clay ratio and with CEC of the soils. However clay: ME ratio, ratio of clay to silt + sand, CEC, WHC and percentage of pore space were negatively correlated with ER.

Kalla *et al.* (1973-74) worked out erodibility indices of Karewa soils of the Kashmir valley and found that ER is well correlated with DR and were of the opinion that EI can be a good substitute of ER. Bruce and Lal (1975) concluded that erodibility as determined by rain drop impact, varied directly with sand and inversely with clay content. Sarmah and Bhatia (1979) studied the physico-chemical properties and erodibility of some soils of Assam and found that pH was positively correlated while OC and CEC were found to be negatively correlated with the erodibility of soils.

Laskar and Govindrajan (1980) reported that soils derived from sand stones and shales were more resistant to erosion than those derived from sand stone alone. Resistant soils contained more organic matter, free Fe_2O_3 and Al_2O_3 and were well aggregated. Clay ratio, clay : ME ratio, percolation ratio, pore space : CR, silt : sand ratio were highly correlated with ER.

Bhatia and Shankar (1981) recorded negative correlation of ER with OC, WSA, and CEC. But ER and DR ratio were positively and significantly correlated.

Bhatia and Vardani (1982) suggested that ER was significantly and positively correlated with sand, CR, stability index, DR and EI and negatively with silt and clay contents. However, the relationship was found highly significant and negative between ER and moisture holding capacity, ME, WSA (>0.25 mm), OC, and CEC. ER was significantly and positively correlated with clay ratio, stability index, and DR and ER.

Sambyal and Sharma (1986) found that higher erodible nature of sub soils of Entisols and Inceptisols soil orders of lower Himalayan forest soils was due to their lower organic matter contents. They further revealed that organic matter, CEC and sand contents were the factors significantly contributing to the variation in erodibility and organic matter had a dominant effect.

Datta *et al.* (1990) concluded that with respect to the various soil properties, non-erodible soils were richer in clay and OC. Clay and OC contents were significantly and negatively correlated with ER.

Singh and Gupta (1991), while studying erodibility status of different forest soils in Himachal Pradesh found that there was a highly significant and positive relation between ER and DR. Erosion index also showed highly significant and positive correlation with DR and ER. Kumar *et al.* (1995) reported that ER was positively related with DR, CR, silt: clay ratio, EI, but negatively correlated with OC.

Singh and Om Prakash (1998) determined interrelationships in some erodibility indices of the hill soils of Uttar Pradesh and revealed that the CR, silt: clay ratio, DR, ER and EI were significantly positively correlated with each other, while all of them were negatively correlated with clay/ME ratio.

Kumar *et al.* (2000) analyzed WSA (<0.25 mm) in different soil series of Rendhar watershed in Bundelkhand region and found that WSA among various soil series were positively correlated with clay, silt and clay, MWD, WHC and OC, while it was negatively correlated with DR, ER and EI.

In a study conducted by Dabral *et al.* (2001), it was reported that DR was directly proportional to ER. The correlation between ER and DR was found to be highly significant and positive. Clay/ME ratio was found to be inversely proportional to ER. Correlation of ER with organic matter, hydraulic conductivity, bulk density and pH were found to be non-significant.

Sharma and Bhatia (2003) studied correlation of soil physical properties with soil erodibility and concluded that soils having higher macroporosity, hydraulic conductivity, hydrophobicity and with higher degree of aggregation are less erodible and therefore can withstand greater erosive forces of water. Both ER and DR were almost equally correlated with soil properties, hence they were judged to be equally good indices of soil erodibility.

Kohli *et al.* (2005) investigated, soil and water characteristics of 13 soils of the submontaneous tract of Punjab and reported that soil erodibility and soil textural parameters namely the sand, silt and clay percentage in the soil matrix were strongly correlated with soil moisture characteristics only at the low and high soil moisture tensions i.e. during dry and wet conditions. At low soil moisture tension (0-1.0 bars), water is held in larger pores associated with coarser particles in the soil, whereas, at high soil moisture tension (10.0-15.0 bars) water is held in largely in the capillary size pores associated with finer soil particles.

The highly significant correlation was observed between ER, DR, and CR, indicating their important role in eroding soils (Singh *et al.*, 2006). Nikam *et al.* (2006) observed that clay content were positively correlated with the moisture held at field capacity and permanent wilting point. The OC and CEC had linear relationship with moisture retentions.

2.4 TORRENT CHANNELISATION AND STABILIZATION THROUGH BIO-ENGINEERING MEASURES

There are a total of 2.73 Mha of land affected by torrents in the country as per the estimates prepared by the Soil Conservation Division of the Ministry of Agriculture, Govt. of India in 1985. Out of 15 Mha geographical area of three states of India namely Punjab, Haryana and Himachal Pradesh 9.30 Mha suffers from land degradation problem of one or other type. About half of the problem area is degraded through soil erosion and mainly fall in Shiwalik hill region (Katiyar and Mittal, 2000).

Adequate statistics about the area converted into *choe* beds and cultivated land affected by the deposition of sand, debris and other sediments etc. are not available and these figures are likely to fluctuate from year to year depending upon the amount, intensity and distribution of rainfall. Hoshiarpur torrents are frequently mentioned in the published literature which highlight the problems of land degradation and its consequences as manifested through flash floods (Holland, 1928 and Gorrie, 1946). In 1900, area damaged by the rain torrents in Hoshiarpur and Jullundhar has been reported to be 15,713 ha. The area affected by seasonal torrents in Hoshiarpur district of Punjab increased from 192 sq. km in1852 to 286 sq. km in 1886 to 2000 sq. km in 1939 (Kaith *et al.*, 1948) and to 3000 sq. km in 1988. The devastation was later on reported to have afflicted an area of 25,000 sq. km by the National Commission of Agriculture (Anonymous, 1976).

Nearly 33 per cent of the geographical area of Doon Valley is under current or old torrent beds (Patnaik, 1995). Estimates of Soil Conservation Division of the Ministry of Agriculture, Govt. of India (Das, 1985) revealed that the heavy rainfall in the year of 1988, deposited sand by flash floods in fertile and productive agricultural lands.

From studies on spur angle varying from 30 to 150 degrees, Sastry (1962) concluded that the maximum depth of scour increased with the angle of inclination while the position of scour bed relative to the spur shifted continuously towards upstream side as angle of spur was increased. Hence, as the angle of the inclination of the spur along the flow direction increased, its sedimentation capacity also increased but stability decreased due to greater scour. Schwab *et al.* (1993) suggested that the spur should be projected at an angle of 45 degree from the downstream.

Singh *et al.* (1971) evaluated the effect of various vegetative and engineering measures on torrent training and stream bank protection. For live hedge planting and reinforcement of spurs, *Vitex negundo, Arundo donax* and *Ipomea carnea* were found to be most suitable among the various species. The species found suitable for stabilizing the sloped banks were *Aristida cynantha, Chrysopogon montanus, Arundo donax, Pennisetum* spp. and *Cynodon plectostachyus.* Repelling type of spurs were found to be most suitable for quick reclamation of concave banks since these spurs induced heavy siltation both on upstream sides. Deflecting spurs were effective in straight reaches and protection was needed against scour near the nose. Attracting type of spurs diverted the current to the opposite bank. Among the various types of spurs tried, boulder spurs reinforced with vegetation and crated at the nose and gabion spurs gave better performance in terms of their function and life.

Gole *et al.* (1975) experimented with slotted spurs having vertical slots and found that in a straight reach, the length of bank protected by it was 32 and 38 per cent longer on the up stream and down stream, respectively than that by a solid spur. Similarly in a curved reach the total length of bank protected was 68 per cent longer with a slotted spur. The maximum scour depth at the nose of a slotted spur in straight and curved reach was 35 and 27 per cent less than obtained with a solid spur, respectively.

Nema *et al.* (1982) studied the sediment deposition against earth-cum-brick masonry check dams of 1.20 m fall constructed as a soil conservation measures in the five ravenous subcatchments. The results showed that the subcatchment having high upstream bed slope give high sediment yield, and therefore, fall requirement of check dam will be more. The average trapped sedimentation measured from the subcatchments having agricultural crop in table land as well as in gully bed was 24.51 $m^3ha^{-1}yr^{-1}$. The average sediment deposition from same sub-watersheds having agricultural crop in table land and natural regeneration in gully bed was 4.20 $m^3ha^{-1}yr^{-1}$.

Pathak and Katiyar (1987) reported that mechanical measures like retards, spurs, revetments and grade stabilization structures are very useful as torrent control works. Check dams and cross barriers are very much helpful in reducing channel gradient and scouring action.

Patnaik *et al.* (1987) studied geomorphological aspects of torrent and their control measures involving vegetative and mechanical spurs (repelling type), retaining walls, cross barriers and live hedges. It was observed that the spur helped in pushing the flow towards the centre of the stream. However excessive scouring at the nose of the spurs resulted in their failure at many places. The flow when attacked the retaining wall, the base got undermined and needed support of the deflecting spurs. Vegetative spurs were effective for low flows only. They also found that the torrents upto one meter depth consists of more than 74 per cent boulders of various sizes and only 5-10 per cent soils (sand + silt + clay). The soils have poor water retentivity and are easily erodible.

In a study of channel geometry of a typical torrent of Doon Valley, the bed slope was 0.18 to 1.55 per cent only. The width of torrent varied from 29 to 95 m and depth of flow 0.5 to 1.5 m (Patnaik, 1988).

No accurate and detailed assessment of the extent and damage by torrents is available. However, Ram Mohan Rao *et al.* (1995) attempted to assess the changes in the width and course of five torrents in the Western U.P. Shiwaliks. Their results indicated that in most of the cases the torrents had widened, though in some cases there was a constriction in the torrent width. The maximum widening of the torrents was from 150 to 350 m whereas, the maximum constriction was observed from 550 to 195 m. There was a general conspicuous shift in the course of the torrents which varied from as low as 15 m to as large as 243 m.

Juyal *et al.* (1995) carried out extensive laboratory studies on spurs in the hydraulic flume and based on that constructed prototype structures in the field which performed well. They also found that *Arundo donax* (*Narkul or Nada*) was ideal for reinforcement of the structures.

Shanwal, *et al.* (2002) conducted experiments for five years in *Kandi* area of Haryana under Integrated Watershed Development Project (IWDP) to develop site specific technology for soil and water conservation using grasses and forest trees as bio-remedial measures. They revealed that the combination of Vetiver (*Vetivera zizaniodes*) and Bhabbar (*Eulaliopsis binata*) (2 row each) proved most effective as specific soil conservation measures and produced 5 per cent runoff and 10.9 t ha^{-1} yr^{-1} soil loss. Among various soil working methods, V-ditch produced minimum runoff (2.32%) and soil loss (13.9 t ha^{-1} yr^{-1}).

Juyal and Sastry (2002) observed that the attracting type of spurs needed scour protection along the upstream side and nose of the spur, the deflecting and repelling type of spurs required apron for scour protection on the nose side only, though of larger size. The repelling type of spurs experienced excessive scour and therefore need special protection. Further, the trapezoidal cross-sectional shape with slanting face towards the nose of spur experienced lesser scour as a result of dissipation of energy of incoming flow.

Juyal and Tripathi (2002) observed that attracting type spurs with an angle 15^0-30^0 from downstream were found effective in flow guidance and bank protection whereas toe/guide walls along with 90^0 short spurs spaced 3 times the length were found useful in land reclamation along the torrent banks. They suggested that the structures should be reinforced with vegetative plantations viz. *Arundo donax*, *Vitex negundo*, *Arundo donax* etc.

Ranade *et al.* (2003) reported that gully plug structures (gabion) were found to effective in arresting sediment on the upstream side. These structures reduced the runoff velocity and thus, allowed more time for sediment to settle on the beds, which slowly stabilized the gullied portion. The silt trapped in the upstream bed of all the five structures was found as 67, 31, 81, 38 and 51 m^3, respectively and increase in silt deposition was observed to the tune of 30-35 per cent.

Juyal *et al.* (2005) evaluated the performance of spurs and found that short spurs (about 3 m in length) and with an angle of 45^0 projecting downstream (attracting type), spaced at 4 times the length, were suitable for flow guidance. A long spur (15 m) provided at lesser angle (30^0) also performed well and is suitable for protecting hoses or other vital installation near the torrent bank. Spurs caused deposition of sediment behind them which consequently helped in stabilization of the torrent bank. They also observed that vegetative reinforcement of structures and torrent bank protection was affected by planting different soil conservation plant species. The overall performance of vegetation considering the factors of survival, site suitability, hydraulic properties etc. were in the order of *Ipomoea carnea* (Besharm) > mulberry (shahtoot) > *Vitex negundo* (Shimalu) > Bamboo >Napier (Hathi ghas). *Arundo donax* (Narkul) did not survive well, may be because the site did not have the needed fine soil and moisture for its establishment. *Saccharum munja* (munj grass) planted on the earthen embankments performed well and provided the requisite protection. They concluded that vegetative measures along with engineering measures were found to be most suitable combination for stabilizing the torrents and enhancing the sediment deposition between the spurs and along the bank.

Tiwari *et al.* (2005) observed that mechanical spurs with improved design have proved effective in controlling torrents and induced better deposition with least of scouring which used to be the main cause of failure of structures. The technology of installing mechanical spurs with vegetative reinforcement proved to be most effective in stabilizing the banks of the torrent. They also found that Nada and Munj grasses were identified as the best vegetative reinforcement measure in retarding the torrent velocity thereby increasing deposition downstream of attracting and deflecting spurs. Ipomoea and Bans have been successful at other places. Dub, Bhabbar, Munj and Kans were identified as the best treatment to stabilize the embankments which were constructed of torrent bed material. They concluded that the vegetation not only helped in stabilizing the structure but also encouraged the sediment deposition. Brush wood check dams and vegetative filters were also established and were found to be effective in controlling the gully advancement, resulting in the reduction of sediment load downstream.

Yadav *et al.* (2006) studied the impact of various soil and water conservation measures in different micro-watersheds in Panchkula district of Haryana and reported that survival percentage ranged from 0 to 86 in different mechanical and vegetative structures: lowest being with brushwood check dams and highest with dugout sunken ponds. They also observed that amount of sediment retained per structure for 5 years was found to be 3, 68 and 99 m^3 for loose boulder check dams, dugout sunken ponds and earthen gully plugs, respectively. However, for organic matter and nutrient retention the order was: dugout sunken ponds > earthen gully plugs > loose boulder check dams.

Chapter - III

MATERIALS AND METHODS

Chapter-3

MATERIALS AND METHODS

The present study entitled **"Erodibility status of torrent affected area and its stabilization through bio-engineering measures in lower Shiwaliks of Himachal Pradesh"** was carried out in the department of Soil Science and Water Management, Dr. Y.S. Parmar University of Horticulture and Forestry, Solan (H.P.) during the period of July 2004 to August 2006. Three representative torrent affected sites were selected in lower Shiwaliks one each in district of Solan, Una and Kangra of Himachal Pradesh. One torrent of 2.0-2.5 km length in Solan district was selected for detailed study. Detailed information about the study area and materials and methods followed in carrying out this investigation are given as below:

3.1 General description of the study area
3.2 Sampling details
3.3 Laboratory studies
3.4 Field studies
3.5 Statistical analysis

3.1 GENERAL DESCRIPTION OF THE STUDY AREA

3.1.1 Location and climate

Three study sites varying in altitude from 350-1000 m a.m.s.l. and situated in lower Shiwalik foothills Kasauli and Nalagarh tehsils of district Solan ($30^0\ 05'$ -$31^0\ 15'$ N latitude and $76^0\ 42'$ -$77^0\ 20'$ E longitude), Pekhuwala area near Una of district Una ($31^0\ 17'$- $31^0\ 50'$ N latitude and $75^0\ 58'$- $76^0\ 23'$ E longitude) and Nurpur-Jachh area of district Kangra ($32^0\ 00'$- $32^0\ 24'$ N latitude and $75^0\ 40'$- $76^0\ 11'$ E longitude) in Himachal Pradesh were selected. Climate of these sites is sub-tropical to sub-humid with warm summers and cold winters. The mean annual rainfall varies from 800-1000 mm, bulk (80%) of which is received during monsoon period i.e. July to September. Mean annual temperature varies from 18- 25 °C and maximum is observed in the month of June. The soil temperature and moisture regimes of the area are 'hyperthermic' and 'ustic', respectively (Sehgal *et al.* 1987).

3.1.2 Geology

Geologically, the soils of the area are complex. Lower Shiwaliks are characterized by grey to light grey, micaceous, fine to medium sand stone occasionally with pseudo-conglomerates containing pebbles of calcareous clay and shale. Soils are gravelly and shallow with high sand contents.

3.1.3 Vegetation

The natural vegetation consists mainly of khair (*Acacia catechu*), babool (*A. nilotica*), shisham (*Dalbergia sissoo*), bihul (*Grewia optiwa*), Neem (*Azadirachta indica*), amaltash (*Cassia fistula*), and bamboos. The dominant shrubs comprise of *Lantana camara, Carissa spinarum, Woodfordia floribunda*, ber (*Zizyphus jujuba*), ipomoea (*Ipomoea spp.*), bana (*Vitex negundo*) and *Adhatoda vasica*. Lumb grass (*Heteropogon contortus*), bhabbar grass (*Eulaliopsis binata*), jhund (*Saccharum munja*), *Chrysopogon fulvus*, congress grass etc. are the dominant grasses.

3.2 SAMPLING DETAILS

At three representative sites, three typical soil profiles at each site were exposed at a horizontal distance of 25-50 m from the bank of the torrent and horizon-wise soil samples were collected. Samples were brought to the laboratory for further analysis. Each sample was air dried and divided into two equal parts. One part was processed i.e. properly ground in pestle and mortar and passed through 2 mm sieve, to analyze the soils for different physico-chemical and hydraulic properties. Remaining part was kept unprocessed and unsieved for the determination of aggregate size distribution and raindrop impact studies. After the monsoon season, the sediment was collected at upper, middle and lower parts of the torrent was analysed for nutrient status and D_{50} analysis. All the laboratory studies were carried out in the Department of Soil Science and Water Management, Dr. Y.S. Parmar University of Horticulture and Forestry, Nauni, Solan (H.P.).

S1 S2 S3

Plate 2. Soil profiles of Site-1 (Barotiwala, Solan)

The sites from where the profiles (Plates 2, 3, 4 and 5) were taken and the symbol used are given below:

Site-1: **Barotiwala, Solan (Kulhadiwala-Joharanpur, torrent, near Barotiwala)**

S_1 . Profile from upper part of the torrent

S_2 - Profile from middle of the torrent

S_3 - Profile from lower part of the torrent

Site-2: **Pekhuwala, Una (Pekhuwala torrent, near Pekhuwala)**

U_1 . Profile from upper part of the torrent

U_2 - Profile from middle of the torrent

U_3 - Profile from lower part of the torrent

Site-3: **Nurpur, Kangra (Chakki torrent near Nurpur-Jachh)**

K_1 . Profile from upper part of the torrent

K_2 - Profile from middle of the torrent

K_3 - Profile from lower part of the torrent

3.3 LABORATORY STUDIES

3.3.1 Physical properties

3.3.1.1 Mechanical composition

Particle size fractionation was carried out by the International Pipette Method as described by Piper (1966). The texture of the soil was determined by relative distribution of sand, silt and clay in the sample and textural classification was made using ISSS textural triangle.

3.3.1.2 Bulk density (BD) and particle density (PD)

Bulk density and particle density of disturbed soils were determined in the laboratory by standard pycnometer method (USDA Handbook No. 60). Porosity was calculated by using the formula:

$$\text{Porosity (\%)} = \left(1 - \frac{BD}{PD}\right) \times 100 \quad \text{------------------------------------} \quad (3.1)$$

Where,

BD = Bulk density ($Mg\ m^{-3}$)
PD = Particle density ($Mg\ m^{-3}$)

3.3.1.3 Aggregate size distribution and mean weight diameter (MWD)

Aggregate size distribution was determined by following the standard wet sieving method outlined by Yoder (1936). From this data, water stable aggregates (WSA), >0.25 mm and <0.25 mm in diameter were worked out. MWD was calculated according to the formula of Yonker and McGuinness (1957) as under:

$$MWD = \sum_{i=1}^{n} diWi \quad \text{--} \quad (3.2)$$

Where,

di = Mean diameter of each size fraction (mm)
Wi = Proportion of sample weight (g)

3.3.2 Hydraulic properties

3.3.2.1 Moisture retention characteristics

Moisture retention of disturbed soil samples was determined at 33, 50, 70, 100, 500, 1000 and 1500 kPa suctions by using pressure plate apparatus (Richards, 1947). Moisture retention between 33 and 1500 kPa suction was computed to calculate available water contents. Available water capacity (AWC) of the soils was calculated by using the following formula:

$$AWC = \frac{(FC - WP) \times BD}{100} \times di \quad \text{------------------------------} \quad (3.3)$$

Where,

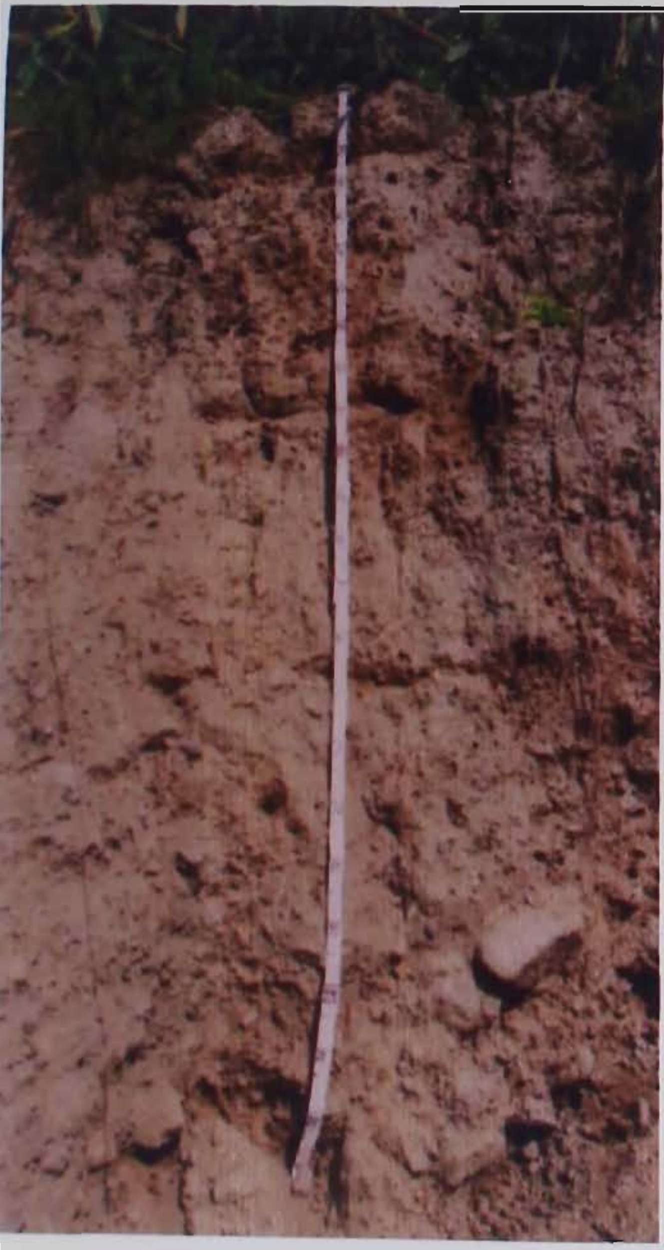
AWC = Available water capacity (cm/0.90m)
FC = Field capacity (%)
WP = Wilting point (%)
BD = Bulk density ($Mg\ m^{-3}$)
di = Soil depth (cm)

U1

U2

U3

Plate 3. Soil profiles of Site-2 (Pekhuwala, Una)



K1

K2

K3

Plate 4. Soil profiles of Site-3 (Nurpur, Kangra)

A. Upper part

B. Middle part

C. Lower part

Plate 5. View of torrent of Site-1 (Barotiwala, Solan) at upper, middle and lower part

Following ratings were used to describe and discuss different soils.

Profile water storage capacity (cm/m depth)	Category
<5	Very low
5-10	Low
10-15	Medium
15-20	High
>20	Very high

3.3.2.2 Saturated hydraulic conductivity (Ks)

Saturated hydraulic conductivity was determined by following constant head method and calculated according to Darcy's equation (USDA Handbook No. 60).

$$Ks = \left(\frac{Q}{At}\right) \times \frac{L}{L+H} \quad \text{--------------------------------} \quad (3.4)$$

Where,

Ks = Saturated hydraulic conductivity (cm min^{-1})
Q = Volume of percolate collected (cm^3)
A = Cross section area of permeameter (cm^2)

$\frac{H+L}{L}$ = Hydraulic gradient (cm cm^{-1})

Following ratings of Ks were used to describe and discuss different soils.

Ks (cm h^{-1})	Rating
<0.125	Very slow
0.125-0.50	Slow
0.50-2.00	Moderately slow
2.00-6.25	Moderate
6.25-12.50	Moderately rapid
12.50-25.00	Rapid
>25.00	Very rapid

3.3.2.3 Moisture equivalent (ME)

ME was determined by Briggs-Malane centrifuge method (Piper, 1966).

3.3.2.4 Maximum water holding capacity (MWHC)

MWHC was determined by K.R. box method (Piper, 1966).

3.3.3 Chemical properties

Different soil chemical properties determined and methods followed are presented in the Table 3.1.

Table 3.1. Soil chemical properties and methods

Sr. No.	Parameters	Method and references
i)	pH and EC	1:2.5 soil water suspension and measured with the help of digital pH and EC meter, respectively (Jackson, 1973)
ii)	Organic carbon (OC)	Walkley and Black's rapid titration method (Walkley and Black, 1934)
iii)	Available N	Alkaline potassium permanganate method (Subbiah and Asija, 1956)
iv)	Available P	Olsen's method (Olsen *et al.*, 1954)
v)	Available K	Ammonium acetate method (Merwin and Peech, 1951)
vi)	Exchangeable cations	Neutral normal NH_4OAc (Jackson, 1967)
vii)	Available SO_4-S	Turbidimetric method (Chesnin and Yien, 1950)

3.3.4 Erodibility indices

Different hydrophysical properties determined in the laboratory were incorporated into different empirical equations to calculate the erodibility indices as follows:

3.3.4.1 Clay ratio (CR)

Clay ratio as suggested by Bouyoucos (1935) was calculated by dividing total sand and silt percentage in the soil by the percentage of clay it contains i.e.

$$CR = \frac{\%\ Sand + \%\ Silt}{\%\ Clay} \quad \text{------------------------------------} \quad (3.5)$$

3.3.4.2 Silt : Clay ratio (SCR)

Silt : clay ratio was determined by dividing total percentage of silt with total percentage of clay i.e

$$SCR = \frac{\%\ Silt}{\%\ Clay} \quad \text{--} \quad (3.6)$$

3.3.4.3 Dispersion ratio (DR)

Middleton (1930) proposed this ratio as an index of erodibility and was calculated as:

$$DR = \frac{\%\ (Silt + Clay)\ dispersed\ in\ water}{\%\ (Silt + Clay)\ by\ mechanical\ analysis} \times 100 \quad \text{-------} \quad (3.7)$$

The threshold value of DR is 15 i.e., soils having DR greater 15 have been classified as erodible.

3.3.4.4 Erosion ratio (ER)

ER was determined from dispersion ratio and clay/ moisture equivalent ratio by using the following equation (Middleton, 1930):

$$ER = \frac{Dispersion\ ratio}{Ratio\ of\ clay\ to\ moisture\ equivalent} \quad \text{------------------} \quad (3.8)$$

The threshold limit of ER is 10 i.e., soils having ER greater 10 have been classified as erodible.

3.3.4.5 Erosion index (EI)

EI was calculated by using the expression (Sahi *et al.*, 1977) as:

$$EI = \frac{Dispersion\ ratio}{Ratio\ of\ clay\ to\ half\ of\ MWHC\ of\ soil} \quad \text{--------------} \quad (3.9)$$

The threshold value of EI is 2.8 i.e., soils having EI greater than 2.8 have been classified as erodible.

3.3.4.6 Raindrop impact (RDI)

RDI was determined by using simulated rain drops. The apparatus consisted of a reservoir of water and raindrop former. One litre flask was used as a reservoir for the supply of water at constant head. Hundred drops from the raindrop simulator were collected and diameter (D) of one drop was determined as:

$$V = \frac{4}{3} \Pi r^3 \qquad (3.10)$$

V = Volume of 100 drops (ml)

r = Radius of drops (mm)

An air dry soil aggregate of 0.8-1.2 g was placed on 2 mm sieve kept on the top of a beaker to bear the impact of these drops. Water drops were released from the simulator one meter above the soil aggregate at an average rate of 52 drops per minute. The number of drops required to disperse the aggregate sufficiently to fall through the sieve was recorded. The end point was obtained clearly as the soils were coarse textured. Three aggregates of each sample were studied and data was averaged for the presentation in erodibility curve. Experiment was conducted under constant temperature conditions.

The erodibility index (I) was calculated by the following relation (Bruce and Lal, 1975).

$$I = \sum_{o}^{N} (0.5\ mv^2)^{-1} \qquad (3.11)$$

Where,

I = Erodibility index

N = Number of drops required to destroy the soil aggregate

m = Mass of water drop (g)

v = Terminal velocity (cm sec^{-1})

Since, in the experiment m and v were kept constant; N^{-1} was used as a measure of raindrop erodibility index.

Following ratings of I, were used to describe and discuss different soils:

Rainfall Erodibility index	$N^{-1} \times 10^{-2}$
Highly erodible	>3.35
Moderately erodible	2.40-3.35
Slightly erodible	1.80-2.40
Stable	0.65-1.80
Very stable	<0.65

3.3.5 D-50 value of sediment

D-50 analysis of sediment was determined by sieve analysis and particle size distribution curve or cumulative frequency curve (Braja, 1979). The sediment was oven dried and broken into individual particles before it was passed through the set of the sieves. The mass of sediment retained on each sieve was determined. The results of sieve analysis were generally expressed in terms of percentage of total weight of soil passing through different sieves. This percentage was also referred to as per cent finer. Particle size distribution curve was plotted by using particle diameters and per cent finer by weight. The diameter in the particle size distribution curve corresponding to 50 per cent finer was defined as the D_{50}.

3.4 FIELD STUDIES

3.4.1 Infiltration characteristics

Infiltration studies were carried out at upper, middle and lower part of the torrent by using double ring metallic infiltrometers. The infiltrometers were installed in duplicate at each part. Water was added slowly to avoid dispersion of soil at the surface. Constant head of water was maintained inside the infiltrometer. The volume of water required to replenish the quantity of water that infiltered in the soil was recorded as a function of time. Experiment was run upto 120 minutes. Both infiltration rate (m s^{-1}) and cumulative infiltration (m) were plotted against time for each replicate separately. Smooth curves were drawn through the data obtained from the replicates. These averaged out curves were plotted to represent the average infiltration rate and cumulative infiltration at each site of the torrent.

3.4.2 Field experimentation (Torrent channelisation and stabilization):

At one site in the district of Solan, the torrent channelisation and stabilization through following bio-engineering measures was carried out (Plates 6a, 6b, 7 and 8). Total catchment area of the torrent was 655.52 ha. The details of total number and dimensions of bioengineering measures are presented in Tables 3.2 and 3.3.

3.4.2.1 Treatment details

I. Source Area Treatment

1. **Mechanical Measures/Treatments**
   a) Loose boulder check dams
   b) Gabion check dams

2. **Vegetative Measures**
   a) Brushwood check dams
   b) Vegetative filters

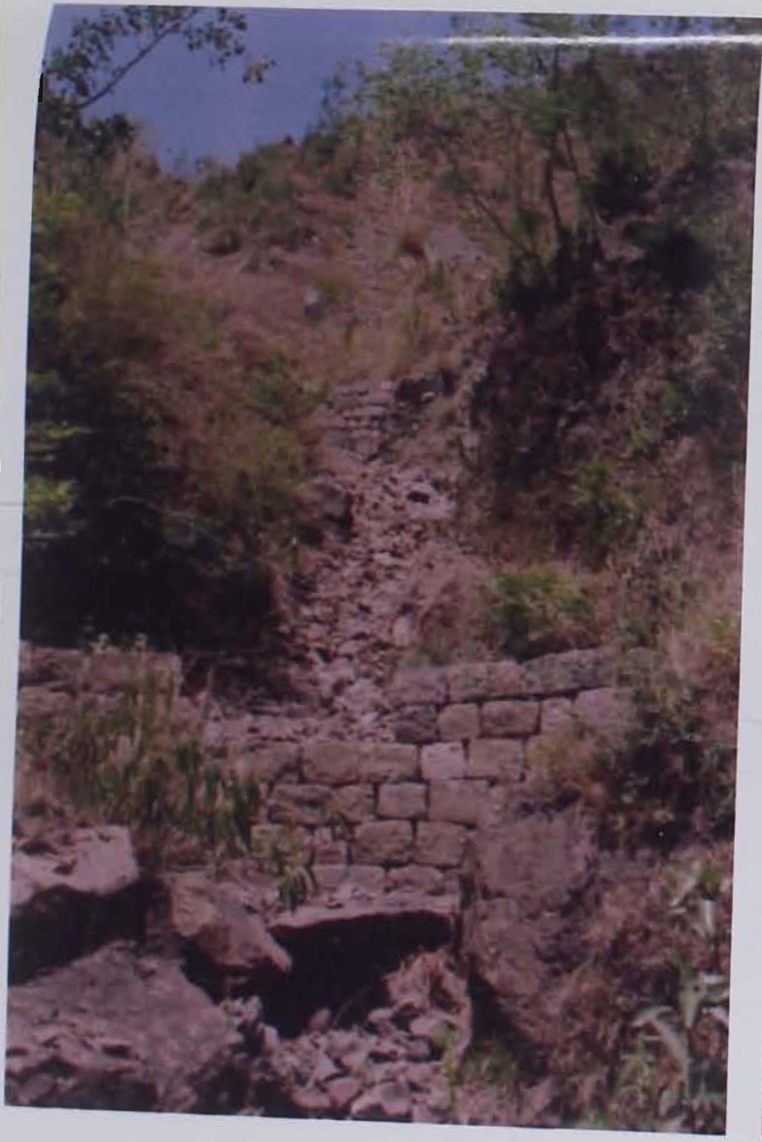
3. **Mechanical + Vegetative Measure (Mechanical measures reinforced with suitable vegetation of cutting of *Ipomoea* spp., *Vitex negundo* and *Saccharum munja*)**

II. Channelisation of stream flow in the torrent bed

1. **Mechanical Measures/Treatments**
   a) Attracting type spurs
   b) Gabion walls

2. **Vegetative Measures**
   a) Vegetative spurs and filters of locally available vegetation (cutting of *Ipomoea* spp., *Vitex negundo* and *Saccharum munja*)

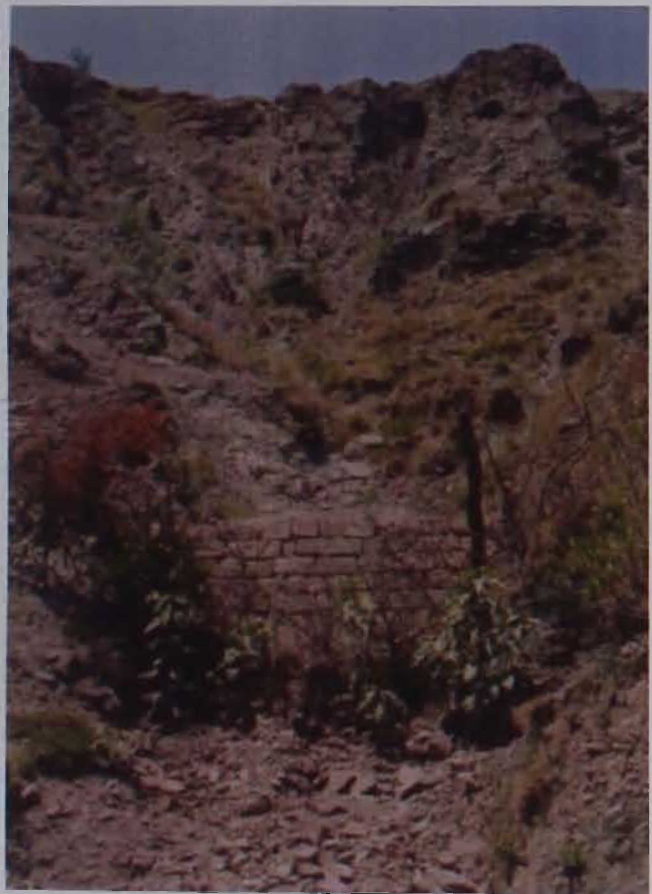
3. **Mechanical + Vegetative Measure (Mechanical measures reinforced with suitable vegetation of cutting of *Ipomoea* spp., *Vitex negundo* and *Saccharum munja*)**



A. Loose boulder check dams

B. Gabion Check dam

Plate 6a. Bio-engineering measures constructed in torrent catchment, Site-1 (Barotiwala, Solan)



A. Mechanical+vegetative measures in upper part of catchment (Loose boulder check dam reinforced with *Ipomoea* cuttings)

B. Mechanical+vegetative measures in lower part of catchment (Loose boulder check dam reinforced with *Ipomoea* cuttings)

C. Vegetative filters at lower catchment

Plate 6b. Bio-engineering measures constructed in torrent catchment, Site-1 (Barotiwala, Solan)

A. Mechanical measure - retaining wall (Gabion wall)

B. Mechanical measure - Attracting type spur

C. Mechanical +vegetative measure

Plate 7. Bio-engineering measures in torrent bed, Site-1 (Barotiwala, Solan)

A. *Ipomoea spp.* spur

B. *Saccharum munja* spur

C. Mixed type vegetative spur

Plate 8. Vegetative measures in torrent bank, Site-1 (Barotiwala, Solan)

Table 3.2. Dimensions of spurs and gabion retaining walls

Spur No.	Foundation depth (m)	Above ground height (m)	Part of spur	Dimensions (m)		
				Length	Breadth	Height
1	0.60	1.75	Bottom Top	6.00 5.75	1.70 1.27	1.50 0.85
2	0.60	1.80	Bottom Top	9.00 8.50	1.54 1.22	1.50 0.90
3	0.60	2.10	Bottom Top	5.90 5.70	1.60 1.20	1.60 1.10
4	0.60	2.10	Bottom Top	5.90 5.70	1.60 1.20	1.60 1.10
5	0.60	1.90	Bottom Top	6.00 6.00	1.55 1.30	1.50 1.00
6	0.60	2.25	Bottom Top	10.15 10.15	1.60 1.30	1.60 1.25
7	0.60	1.90	Bottom Top	8.00 8.00	1.52 1.25	1.50 1.00
8	0.60	2.30	Bottom Top	7.00 7.00	1.68 1.30	1.70 1.20
9	0.60	2.20	Bottom Top	6.20 6.20	1.53 1.30	1.55 1.25
10	0.60	2.15	Bottom Top	10.10 10.10	1.60 1.30	1.50 1.25
11	0.60	2.20	Bottom Top	10.25 10.25	1.70 1.30	1.55 1.25
12	0.60	2.20	Bottom Top	10.30 10.30	1.60 1.30	1.55 1.25
13	0.60	1.10	Bottom & Top	8.70	1.60	1.55
14	0.45	1.10	Bottom & Top	8.10	1.60	1.55
15	0.45	1.05	Bottom & Top	8.18	1.60	1.50
16	0.45	2.20	Bottom Top	10.45 10.45	1.65 1.30	1.55 1.25
17	0.60	2.15	Bottom Top	10.65 10.65	1.50 1.25	1.50 1.25
18	0.60	2.15	Bottom Top	11.75 11.75	1.50 1.25	1.50 1.25
19	0.60	2.15	Bottom Top	10.20 10.20	1.60 1.20	1.55 1.20
20	0.60	2.15	Bottom Top	10.20 10.20	1.60 1.20	1.55 1.20
Gabion retaining wall						
1	0.45	1.00		30.00	0.75	1.45
2	0.45	2.00		20.00	0.50	2.45

Table 3.3. Bioengineering structures constructed for torrent control

Sr. No.	Bioengineering structures	Number
1	Loose boulder check dams	29
2	Gabion check dams	10
3	Gabion spurs	20
4	Gabion retaining walls	2
5	Brush wood check dams and vegetative filters	30
6	Vegetative spurs and filters	25

3.4.2.2 Sediment retention

Sediment retention was determined average volume formula by using average height/depth, length and width of the sediment retained up and down stream of spurs, retaining walls, vegetative filters and check dams. The average volume was multiplied by 0.0275 to get mass of sediment in tons.

3.4.2.3 Scouring and maximum nose scour

Scouring and maximum nose scour was measured by using measuring tape.

3.4.2.4 Capacity left for siltation in different years

Capacity left for siltation was determined by measuring the average volume of empty space remaining after sediment deposition up and down stream side of the spur and check dams.

3.4.2.5 Assessment of condition of the structures

Assessment of condition of the structures was determined by visual observation.

3.4.2.6 Runoff yield

Runoff yield was determined by using velocity area method by using the formula:

$$\text{Discharge} = \text{Area} \times \text{Velocity}$$

$$Q = A \times V \qquad (3.12)$$

Where

Q = Discharge rate, m^3/s

A = Area of cross section of channel, m^2

V = Velocity of flow, m/s

Runoff yield (m^3) = Discharge × Time

Peak runoff rate (m^3/s) was calculated by Rational formula:

$$Q = \frac{CIA}{36} \quad \text{--} \quad (3.13)$$

Where C = Runoff coefficient

I = Rainfall intensity (cm/hr) for given time of concentration

A = Area of catchment (ha)

Velocity of flow was measured by using floats. The velocity of float was obtained by the distance by time. (The values of surface velocities obtained by surface float were higher and were multiplied by 0.85 to get mean velocity of flow.)

3.4.2.7 Plant survival

Plant survival was calculated on the basis of the following formula:

$$\text{Survival (\%)} = \frac{\text{No. of plants survived till the date of observation}}{\text{Total number of plants planted}} \times 100 \quad \text{----(3.14)}$$

3.4.2.8 Growth Performance

Growth performance of vegetative measures was determined by measuring height and basal/clump diameter of plants. Height was measured by measuring tape and basal diameter of *Ipomoea spp.* and *Vitex negundo* and clump diameter of *Saccharum munja* by using vernier caliper.

3.5 STATISTICAL ANALYSIS

Data generated from the investigations were analyzed statistically by the standard procedures and Bartlett's χ^2 test for testing the coefficient of variability outlined by Gomez and Gomez (1984). Depth of soil was taken as weight for the calculation of mean weighted average of profile and site. The relationships among and between different hydraulic and physico-chemical properties and erodibility and stability indices were studied by simple linear correlation and regression analysis.

Chapter - IV

EXPERIMENTAL RESULTS

Chapter-4

EXPERIMENTAL RESULTS

In order to study the erodibility status, hydro-physical and chemical characteristics of a torrent affected area and its stabilization through bio-engineering measures in lower Shiwaliks of Himachal Pradesh, both field and laboratory studies were carried out at three representative torrent affected sites. The impact of bio-engineering measures on runoff, sediment yield, torrent channelisation and its stabilization was studied only at Site-1 (Barotiwala, Solan). The results emanated from the study pertaining to various aspects have been described under the following broad heads:

4.1 Physical properties of soils of torrent affected areas
4.2 Hydraulic properties of soils of torrent affected areas
4.3 Chemical properties of soils of torrent affected areas
4.4 Erodibility status of soils of torrent affected areas
4.5 Correlation between and among soil properties, erodibility and stability indices of torrent affected areas
4.6 Torrent channelisation and stabilization through bio-engineering measures

The detailed data of torrent affected areas/sites on various soil characteristics and erodibility indices are given in Appendices I-VIII. Various parameters have been described on the basis of range and mean value as given below:

4.1 PHYSICAL PROPERTIES OF SOILS OF TORRENT AFFECTED AREAS

4.1.1 Mechanical composition

The data depicted in Table 4.1 indicate the mechanical composition and texture of soils in different torrent affected areas. Bartlett's χ^2 test was applied to test the variation for mechanical composition among sites. The significant variation was observed for fine sand only.

A perusal of data in Table 4.1 reveals that as per the coefficient of variability, maximum variation in gravel contents was in Site-3 (Nurpur, Kangra) soils. The torrent affected soils of Site-1 (Barotiwala, Solan) recorded the highest gravel contents ranging from 0.00-83.60 per cent with a mean value 46.26 per cent. The lowest gravel contents were recorded in the soils of Site-3 ranging from 0.00-87.60 with a mean value of 30.97 per cent.

Maximum variation (74.38 %) and highest coarse sand percentage was recorded in Site-2 (Pekhuwala, Una) soils which ranged from 0.91-93.14 per cent with a mean value of 74.38 per cent. Lowest contents were recorded in Site-1 soils which ranged from 1.58-72.17 per cent with a mean value of 44.42 per cent.

Fine sand contents varied widely in site-2 soils, however, highest contents were recorded under Site-1 soils with a mean of 37.67 per cent and lowest in Site-3 soils which ranged from 7.16-79.32 per cent with a mean value of 36.02 per cent. Total sand contents were recorded highest in Site-2 soils which ranged from 77.99-99.34 per cent with a mean value of 91.35 per cent and lowest in Site-1 soils, ranging from 57.42-92.02 per cent with a mean value of 82.10 per cent.

Silt contents were found to be highest under Site-1 soils, ranging from 5.48-36.32 per cent, with a mean value of 13.25 per cent and lowest contents were observed in Site-2 soils ranging from 0.48-17.34 per cent with mean value of 7.05 per cent.

Clay contents were found to be highest in Site-1 soils, ranging from 2.50-7.08 per cent with mean value of 4.65 per cent. Lowest contents, ranging form 0.18-5.64 per cent with a mean value of 1.60 per cent were observed in the soils under torrent affected areas of Site-2.

The soils of the torrent affected areas, in general, were coarse textured and the textural class was found to be gravelly loamy sand. Large amount of cobbles and stone were observed in Site-1 (Barotiwala, Solan) soils.

Table 4.1. Mechanical composition and texture of soils of torrent affected areas

Location /site		Gravel (%)	Coarse sand (%)	Fine sand (%)	Total sand (%)	Silt (%)	Clay (%)	Textural class
Site-1 (Barotiwala, Solan)	Range	0.00-83.60	1.58-72.17	17.01-63.23	57.42-92.02	5.48-36.32	2.50-7.08	gls
	Mean	46.26	44.42	37.67	82.10	13.25	4.65	
	SD ±	33.21	24.75	15.47	10.75	9.53	1.81	
	CV (%)	71.79	55.71	41.07	13.10	71.96	38.87	
Site-2 (Pekhuwala, Una)	Range	0.00-82.30	0.91-93.14	5.68-84.13	77.99-99.34	0.48-17.34	0.18-5.64	gls
	Mean	31.88	54.65	36.70	91.35	7.05	1.60	
	SD ±	35.88	40.65	35.66	8.20	6.76	1.72	
	CV (%)	112.55	74.38	97.17	8.98	95.90	107.83	
Site-3 (Nurpur, Kangra)	Range	0.00-87.60	5.53-90.22	7.16-79.32	69.38-98.77	1.06-25.72	0.12-5.78	gls
	Mean	30.97	50.13	36.02	86.15	11.72	2.12	
	SD ±	41.88	31.90	22.64	14.51	12.43	2.17	
	CV (%)	135.20	63.63	62.84	16.85	106.07	102.28	
	χ^2	0.55	2.26	6.36*	3.37	3.71	0.64	

Mean - Combined mean
SD - Combined standard deviation
CV - Coefficient of variation
gls - gravelly loamy sand
χ^2 - Bartlett's statistics Chi Square test ($\chi^2_{(k-1)}$) value or χ^2 value
* - Significant at 5% level

4.1.2 Bulk density (BD)

Bulk density of the soils under different torrent affected areas is presented in Table 4.2 and a perusal of the data reveals that there was no significant variation among sites. However, maximum variability within sites was in Site-3 soils. Highest bulk density was recorded in Site-2 soils, ranging from 1.38-1.91 Mg m^{-3} with a mean value of 1.72 Mg m^{-3}. Lowest value was observed in Site-1 soils, ranging from 1.49-1.72 Mg m^{-3} with a mean value of 1.65 Mg m^{-3}.

4.1.3 Particle density (PD)

There was significant variation in particle density among sites (Table 4.2) and the maximum variability was in Site-2 soils. The highest value was recorded for the Site-3 soils, ranging from 2.62-2.74 Mg m^{-3} with a mean value of 2.68 Mg m^{-3}. Lowest value, ranging from 2.59-2.67 Mg m^{-3} with a mean value of 2.65 Mg m^{-3} was recorded under torrent affected soils of Site-1.

Table 4.2. Physical properties of soils of torrent affected areas

Location/site		Bulk density (Mg m^{-3})	Particle density (Mg m^{-3})	Porosity (%)
Site-1 (Barotiwala, Solan)	Range	1.49-1.72	2.59-2.67	35.09-43.35
	Mean	1.65	2.65	37.60
	SD ±	0.10	0.03	3.16
	CV (%)	5.78	1.22	8.41
Site-2 (Pekhuwala, Una)	Range	1.38-1.91	2.56-2.78	29.26-47.53
	Mean	1.72	2.66	35.18
	SD ±	0.15	0.08	5.59
	CV (%)	8.92	2.93	15.89
Site-3 (Nurpur, Kangra)	Range	1.47-1.92	2.62-2.74	29.93-43.89
	Mean	1.68	2.68	37.39
	SD ±	0.16	0.04	5.11
	CV (%)	9.62	1.58	13.67
	χ^2	3.05	8.15*	3.33

Mean - Combined mean
SD - Combined standard deviation
CV - Coefficient of variation
χ^2 - Bartlett's statistics Chi Square test ($\chi^2_{(k-1)}$) value or χ^2 value
* - Significant at 5% level

4.1.4 Porosity

Porosity of soils exhibited little variations i.e. 35.18-37.60 per cent under different torrent affected areas (Table 4.2). Maximum variability was in Site-3 soils. As is evident from data, highest porosity ranging from 35.09-43.35 per cent with mean value of 37.60 per cent was recorded under Site-1 soils and lowest under Site-2 soils, ranging from 29.26-47.53 per cent with mean value of 35.18 per cent.

4.1.5 Aggregate size distribution

Aggregate size distribution of soils of torrent affected areas is presented in Table 4.3. It is evident that aggregates greater than 5 mm in diameter were found to be highest in soils under torrent affected areas of Site-1, ranging from 0.00-88.75 per cent with mean value of 15.16 per cent.

Aggregates >0.25 mm in diameter were found to be highest in Site-1 soils, ranging from 0.00-96.75 per cent with a mean value of 40.88 per cent. Lowest percentage of these aggregates (> 0.25 mm in diameter) was recorded in the Site-2 soils, ranging from 0.00-72.34 per cent with a mean value of 24.74 per cent.

4.2 HYDRAULIC PROPERTIES OF SOILS OF TORRENT AFFECTED AREAS

4.2.1. Moisture retention

Soil moisture retention at different suctions in different torrent affected areas is presented in Table 4.4. and Fig. 1. Water retention varied appreciably in torrent affected areas and it decreased with the increase in suction (ψ), there was no significant variation in moisture retention at any suction among different torrent affected areas. At any given suction, more water was retained by Site-1 soils followed Site-3 soils except at 10 kPa where Site-2 soils retained maximum water. Amongst the torrent affected areas under study, Site-2 soils retained the highest amount of water at 10 kPa ranging from 5.77-27.38 per cent with a mean value of 14.25 per cent. Lowest moisture retention at 33 and 1500 kPa suction was observed in Site-2 soils, ranging from 1.94-15.50 and 0.65-5.49 per cent with mean value of 7.16 and 1.81 per cent at 33 kPa at 1500 kPa, respectively. There was an abrupt decrease in water content with increase in 'ψ' upto a value of 500 kPa and

Table 4.3. ***Aggregate size distribution (%) of torrent affected areas***

Location/site		Aggregate size distribution (%)					
		>5mm	2-5mm	1-2mm	0.5-1mm	0.25-0.5mm	0.1-0.25mm
Site-1	Range	0.00-88.75	0.00-8.80	0.00-8.78	0.00-19.43	0.00-38.20	0.00-61.65
(Barotiwala, Solan)	Mean	15.16	2.68	2.57	7.46	13.01	15.48
	SD ±	34.38	3.83	3.52	9.75	17.58	24.28
	CV (%)	226.80	142.91	136.98	130.68	135.07	156.86
Site-2	Range	0.00-21.02	0.00-15.49	0.00-16.69	0.00-17.13	0.00-34.11	0.00-51.41
(Pekhuwala, Una)	Mean	4.46	2.56	4.18	5.92	7.36	15.53
	SD ±	9.24	5.44	6.85	7.77	11.48	22.68
	CV (%)	207.29	212.12	163.79	131.32	156.08	146.08
Site-3	Range	0.00-50.91	0.00-25.84	0.00-11.41	0.00-17.08	0.00-39.85	0.00-42.46
(Nurpur, Kangra)	Mean	6.27	3.25	2.87	5.04	7.94	12.27
	SD ±	16.93	9.26	5.16	8.30	14.70	19.99
	CV (%)	270.09	285.01	180.17	164.59	185.23	162.96
	χ^2	14.65**	8.12*	4.11	0.55	1.64	0.40

Mean - Combined mean
SD - Combined standard deviation
CV - Coefficient of variation
χ^2 - Bartlett's statistics Chi Square test ($\chi^2_{(k-1)}$) value or χ^2 value
* - Significant at 5% level
** - Significant at 1% level

Table 4.4. Moisture retention (%) at different suctions (Ψ) in torrent affected areas

Location/site		Water retention (w/w) at kPa						AW (w/w, %)
		10	33	100	500	1000	1500	
Site-1 (Barotiwala, Solan)	Range	7.85-32.14	5.48-27.61	4.23-17.53	2.93-10.05	2.38-8.62	2.22-6.94	3.20-20.67
	Mean	13.60	10.65	7.43	4.56	3.82	3.31	7.35
	SD ±	7.80	6.84	4.12	2.18	1.91	1.48	5.50
	CV (%)	57.31	64.24	55.50	47.81	49.98	44.93	74.88
Site-2 (Pekhuwala, Una)	Range	5.77-27.38	1.94-15.50	1.17-11.33	0.90-6.76	0.74-6.16	0.65-5.49	1.29-11.25
	Mean	14.25	7.16	4.12	2.39	2.08	1.81	5.35
	SD ±	8.94	5.80	3.46	1.94	1.79	1.56	4.51
	CV (%)	62.76	80.94	83.90	80.95	85.78	86.24	84.22
Site-3 (Nurpur, Kangra)	Range	3.18-27.30	2.04-19.73	1.45-10.71	0.89-8.75	0.83-4.62	0.79-4.14	1.01-16.29
	Mean	13.48	9.10	5.77	3.29	2.53	2.31	6.79
	SD ±	10.23	8.16	4.83	3.02	1.88	1.62	6.61
	CV (%)	75.94	89.64	83.69	91.88	74.03	70.17	97.40
	χ^2	0.69	1.22	1.15	2.29	0.04	0.07	1.52

Mean - Combined mean
SD - Combined standard deviation
CV - Coefficient of variation
χ^2 - Bartlett's statistics Chi Square test ($\chi^2_{(k-1)}$) value or χ^2 value
AW - Available water = 33- 1500 k Pa

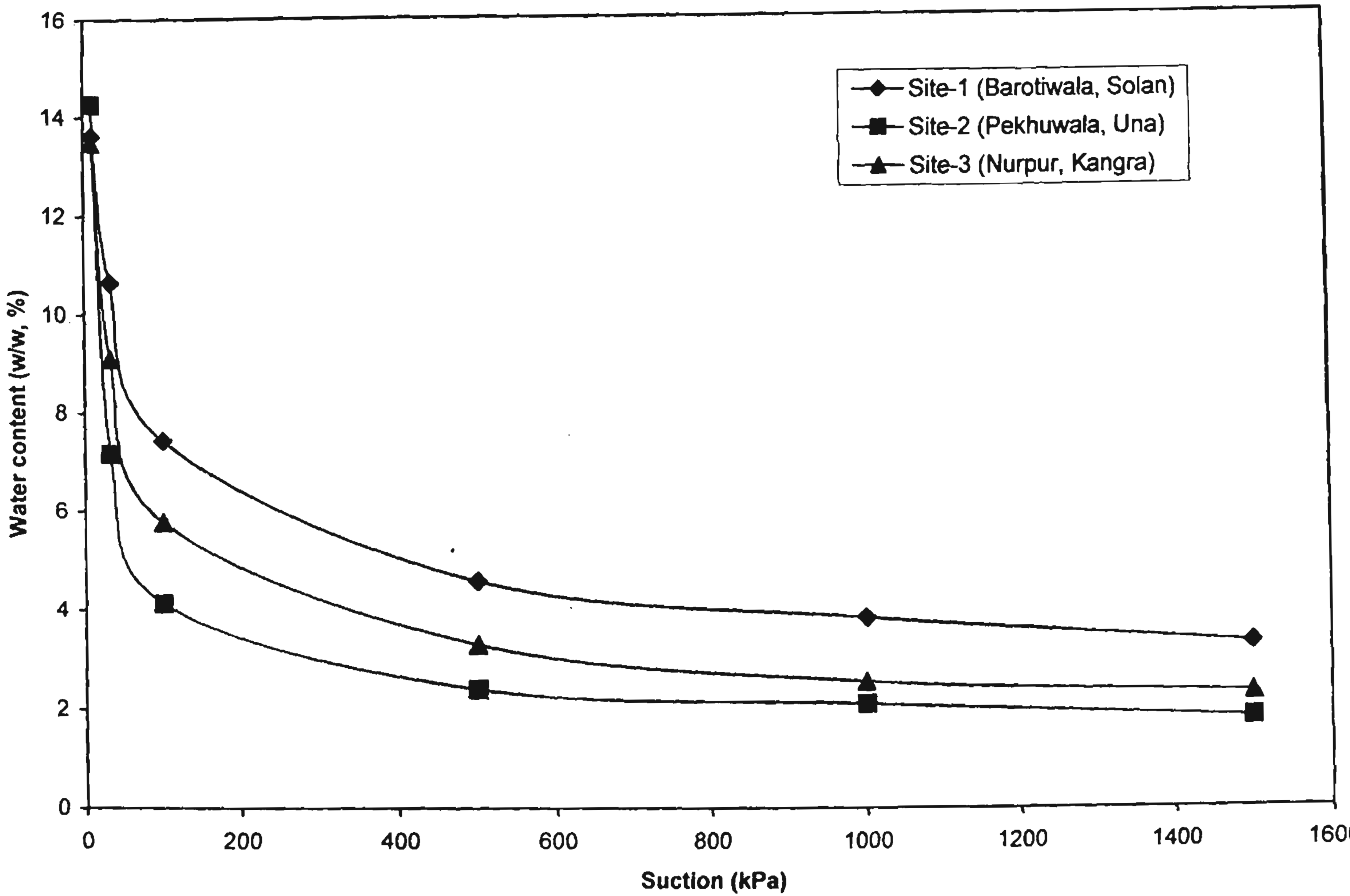


Fig. 1. Average moisture retention in different torrent affected areas

beyond this suction, the decrease in water content with increase in 'ψ' became gradual. The site-wise water retention behavior in general, was in the order:

Site-1 > Site-3 > Site-2.

4.2.2 Available water capacity (AWC)

A perusal of data in Table 4.5 reveals that the highest AWC was observed in Site-1 soils ranging from 8.43-15.36 cm/0.90 m with a mean value of 11.12 cm/0.90 m profile depth. The lowest value was recorded in Site-2 soils, ranging from 4.74-15.94 cm/0.90 m with a mean value of 8.74 cm/0.90 m profile depth. According to the rating criteria of AWC, soils of torrent affected area of Site-2 and Site-3 fell under low category and Site-1 soils qualified for medium category.

Table 4.5. Hydraulic properties of soils of torrent affected areas

Location/site		AWC (cm/0.90m)	MWHC (%)	K_s (cm hr^{-1})
Site-1 (Barotiwala, Solan)	Range	8.43-15.36	27.04-41.14	0.70-26.63
	Mean	11.12	31.87	4.12
	SD ±		5.84	8.33
	CV (%)		18.32	201.99
Site-2 (Pekhuwala, Una)	Range	4.74-15.94	20.06-53.10	2.53-49.46
	Mean	8.74	28.22	20.87
	SD ±		10.25	23.24
	CV (%)		36.31	111.35
Site-3 (Nurpur, Kangra)	Range	6.75-15.47	18.23-42.30	1.15-28.69
	Mean	9.74	29.98	10.28
	SD ±		8.62	12.63
	CV (%)		28.75	122.85
	χ^2		3.01	9.79**

Mean - Combined mean
SD - Combined standard deviation
CV - Coefficient of variation
χ^2 - Bartlett's statistics Chi Square test ($\chi^2_{(k-1)}$) value or χ^2 value
MWHC - Maximum water holding capacity (%)
Ks - Saturated hydraulic conductivity (cm hr^{-1})
ME - Moisture equivalent (%)
AWC - Available water capacity (cm/0.90m)
** - Significant at 1% level

4.2.3 Maximum water holding capacity (MWHC)

Data on MWHC presented in Table 4.5 indicates that maximum variability was in soils of Site-2. However, among sites there was no significant variation. The MWHC was observed to be highest in soils under torrent affected area of Site-2, ranging from 27.04-41.14 per cent with a mean value of 31.87 per cent. The lowest MWHC was recorded in the soils of Site-1 ranging from 20.06-53.10 per cent with a mean value of 28.22 per cent.

4.2.4 Saturated hydraulic conductivity (K_s)

Saturated hydraulic conductivity of soils of different torrent affected areas, determined for disturbed soils is presented in Table 4.5. It varied significantly under different torrent affected areas and maximum variability (201.99 %) was in Site-1 soils. The highest of K_s was recorded under Site-2 soils, ranging from 2.53-49.46 cm hr^{-1} with mean value of 20.87 cm hr^{-1}. The lowest value of K_s was observed under Site-1 soils, ranging from 0.70-26.63 cm hr^{-1} with a mean value of 4.12 cm hr^{-1}. On the basis of K_s, the torrent affected areas can be arranged in order:

Site-2 > Site-3 > Site-1.

4.2.7 Infiltration characteristics

The infiltration rate and cumulative infiltration under different parts of torrent at Site-1 (Barotiwala, Solan) are presented in Figs. 2, 3 and 4. Both of these varied appreciably and highest infiltration rate ($3.0 \times 2.78 \times 10^{-6}$ ms^{-1}) and highest cumulative infiltration (14.3×10^{-2} m) were recorded in lower part of torrent. The lowest infiltration rate was observed in the soils under middle part of the torrent, which was of the order of $2.4 \times 2.78 \times 10^{-6}$ ms^{-1} and the lowest cumulative infiltration (8.6×10^{-2} m) in the upper part of torrent.

4.3 CHEMICAL PROPERTIES OF SOILS OF TORRENT AFFECTED AREAS

4.3.1 pH

A perusal of data presented in Table 4.6 reveals that the soils of the torrent affected area were alkaline in reaction and highest pH was recorded in Site-3 soils, ranging from 7.60-8.20 and the lowest value under Site-1 soils, ranging from 7.20-8.00.

Table 4.6. Chemical properties of soil of torrent affected areas

Location/site		pH (1:2.5)	EC (dS m^{-1})	OC (g kg^{-1})
Site-1 (Barotiwala, Solan)	Range	7.20-8.00	0.10-0.22	1.60-5.50
	Mean	7.71	0.14	3.38
	SD ±	0.30	0.04	1.54
	CV (%)	3.43	31.26	45.66
Site-2 (Pekhuwala, Una)	Range	7.50-8.20	0.09-0.24	0.50-5.10
	Mean	7.92	0.14	2.31
	SD ±	0.23	0.05	2.18
	CV (%)	2.62	37.46	94.29
Site-3 (Nurpur, Kangra)	Range	7.60-8.20	0.09-0.20	0.80-7.90
	Mean	7.94	0.14	3.07
	SD ±	0.24	0.03	2.44
	CV (%)	2.64	24.47	79.65
	χ^2	0.75	2.03	1.90

Table 4.7. Available nutrient status (kg ha^{-1}) of torrent affected areas

Location/site		N	P	K	S
Site-1 (Barotiwala, Solan)	Range	56.4-238.3	14.3-24.8	48.2-116.5	1.5-47.5
	Mean	155.6	18.4	84.42	10.8
	SD ±	71.6	3.5	24.1	14.2
	CV (%)	46.0	19.2	28.6	131.5
Site-2 (Pekhuwala, Una)	Range	25.2-213.9	1.6-23.6	0.0-142.2	1.3-76.4
	Mean	90.2	7.2	21.5	7.1
	SD ±	89.6	8.8	57.2	27.1
	CV (%)	99.3	122.0	266.3	379.7
Site-3 (Nurpur, Kangra)	Range	35.4-498.7	4.7-33.8	0.0-132.2	2.7-79.2
	Mean	127.0	13.7	25.2	25.7
	SD ±	152.9	9.7	46.8	35.7
	CV (%)	120.5	71.0	185.5	138.9
	χ^2	6.1*	8.3*	6.1*	6.8*

Mean - Combined mean
SD - Combined standard deviation
CV - Coefficient of variation
χ^2 - Bartlett's statistics Chi Square test ($\chi^2_{(k-1)}$) value or χ^2 value
* - Significant at 5% level

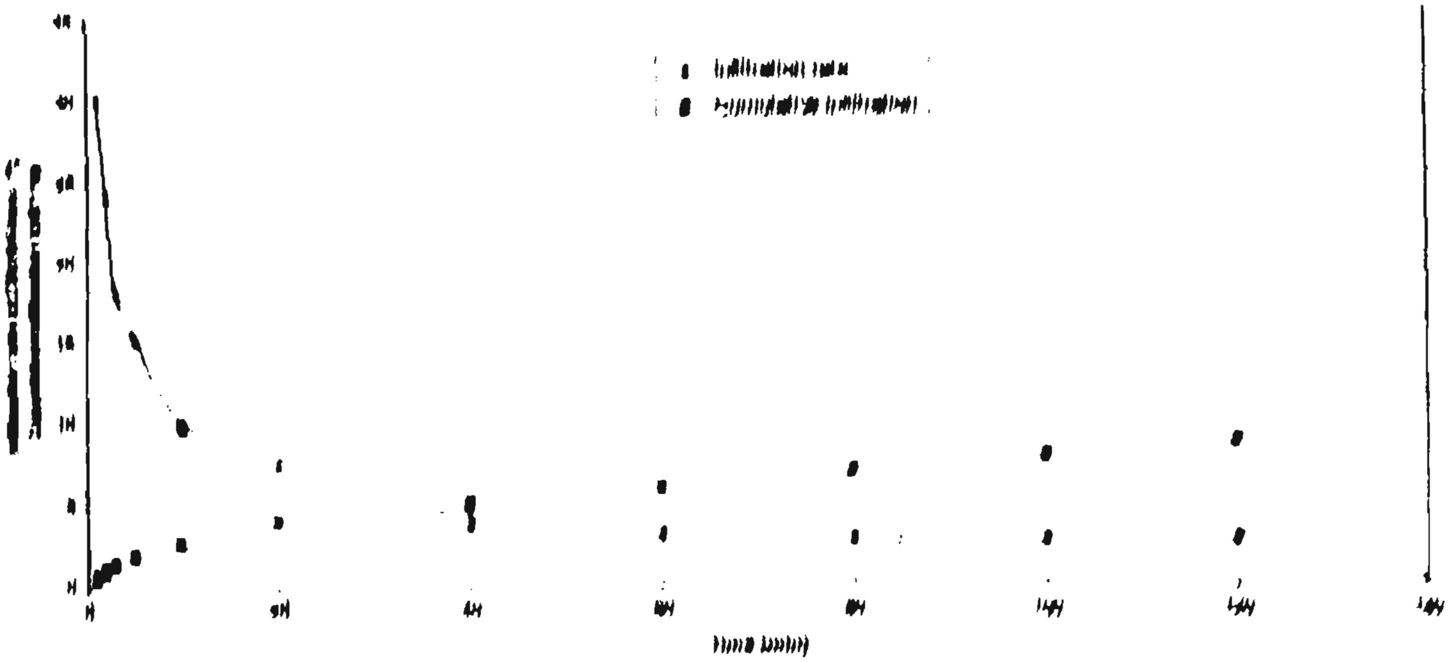


Fig. 2. Infiltration characteristics at the upper part of torrent

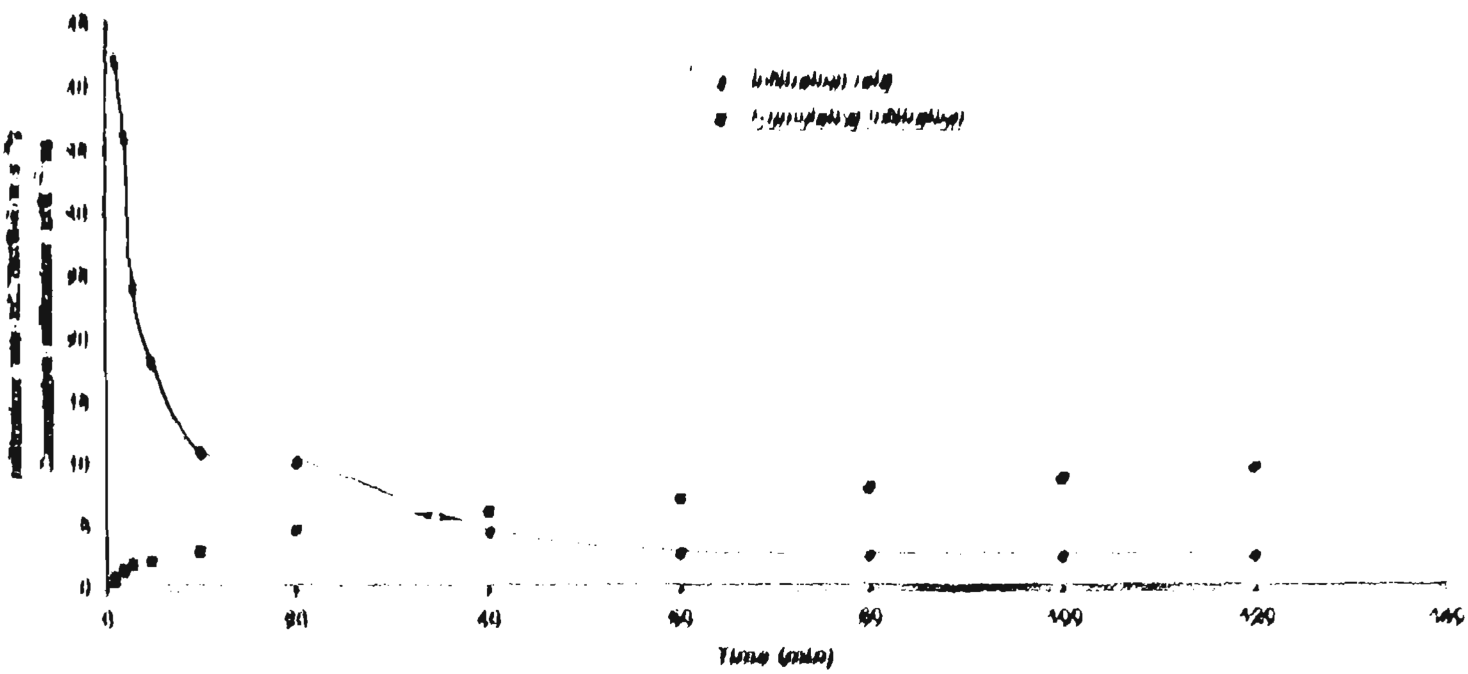


Fig. 3. Infiltration characteristics at the middle part of torrent

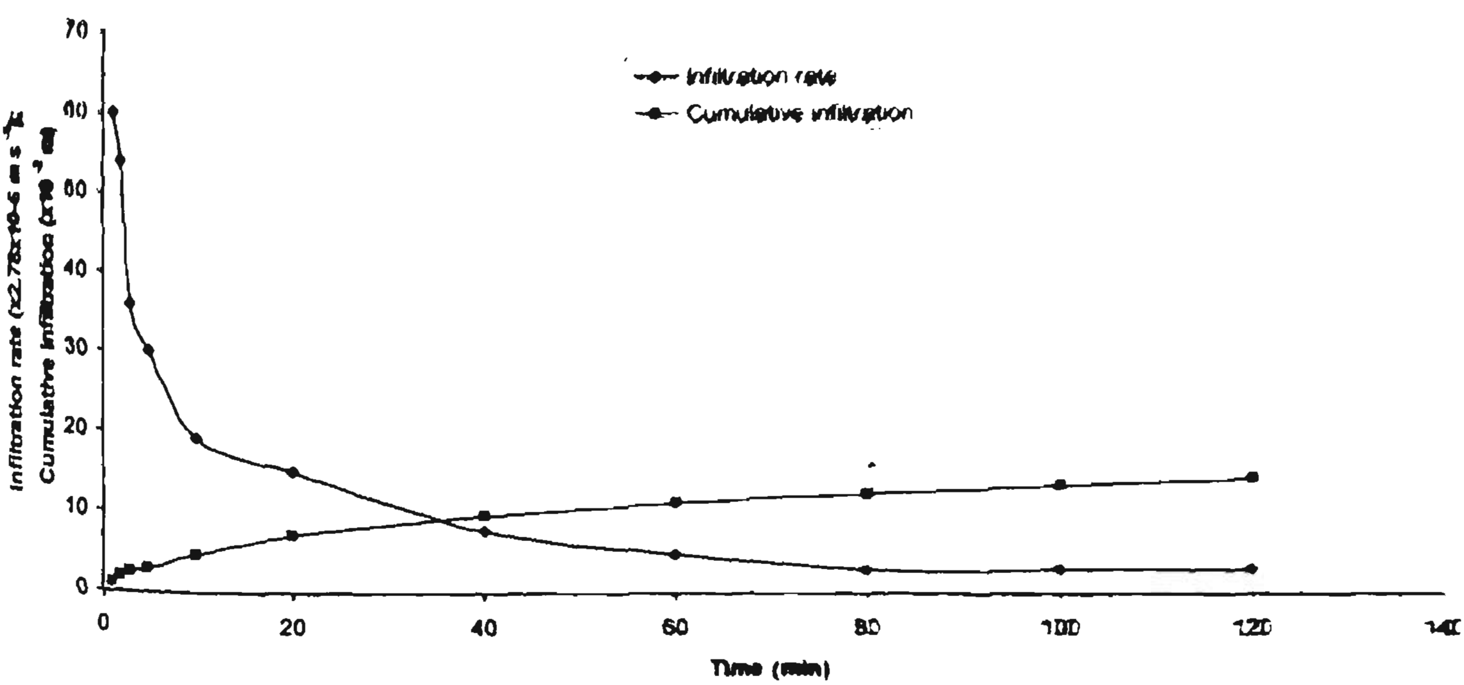


Fig. 4. Infiltration characteristics at the lower part of the torrent

4.3.2 Electrical conductivity (EC)

The data presented in Table 4.6 reveals that maximum variability in EC was under Site-2 soils (37.46 %) but there was no significant variation among different torrent affected areas. It ranged from 0.10-0.22, 0.09-0.24 and 0.09-0.20 dS m^{-1} under Site-1, Site-2 and Site-3 soils, respectively. Mean EC values of all the torrent affected areas were equal (0.14 dS m^{-1}).

4.3.3 Organic carbon (OC)

Soil organic carbon contents under different torrent affected areas had no significant variation (Table 4.6). The Site-2 soils exhibited maximum variation, but among the sites, contents were lowest which ranged from 0.05-0.51 g kg^{-1} with a mean value of 2.31 g kg^{-1}. The Site-1 soils had highest OC contents being 1.60-5.50 g kg^{-1} with mean value of 3.38 g kg^{-1}.

4.3.6 Available N

Data presented in Table 4.7 reveals that all soils in the torrent affected area were low in available N contents except some soils of Site-3. There was significant variation in available N content among different torrent affected areas. The highest contents were recorded in the soils of Site-1 which ranged from 56.4-238.3 kg ha^{-1} with a mean value of the order of 155.6 kg ha^{-1}. The lowest available N contents, ranging from 25.2-213.9 kg ha^{-1} with a mean value of 90.2 kg ha^{-1} were recorded in the Site-2 soils.

4.3.7 Available P

Data on available P presented in Table 4.7 indicates that the soils were low to medium in available P contents. It varied significantly under different torrent affected areas and maximum variability was under Site-2 soils. Amongst the sites, comparatively higher P contents, ranging from 14.3-24.8 kg ha^{-1} with a mean value of 18.4 kg ha^{-1} were recorded in the Site-1 soils. The lowest contents were recorded in Site-2 soils ranging from 1.6-23.6 kg ha^{-1} with a mean value of 7.2 kg ha^{-1}.

4.3.8 Available K

Data on available K presented in Table 4.7 clearly reveals that its contents did not vary significantly within and amongst the torrent affected areas under study and Site-2 soils had maximum variability. All soils were recorded low to medium in available K and highest contents, ranging from 48.2-116.5 kg ha^{-1} with mean value of 84.4 kg ha^{-1} were recorded in the soils under Site-1 soils. The lowest available K contents were recorded under Site-2 soils, ranging from 0.0-142.2 kg ha^{-1} with mean value of 21.5 kg ha^{-1}.

4.3.9 Available S

A perusal of data presented in Table 4.7 reveals that there was significant variation in available S contents of different torrent affected areas and maximum variability was in Site-2 soils. The highest available S contents, ranging from 2.7-79.2 kg ha^{-1} with mean value of the order of 25.7 kg ha^{-1} were observed in the soils under torrent affected area of Site-3. The lowest contents were recorded in Site-2 soils ranging from 1.3-76.4 kg ha^{-1} with mean of 7.1 kg ha^{-1}.

4.3.10 Exchangeable cations

The data presented in Table 4.8 reveals that all exchangeable cations except Mg^{2+} had significant variation among different torrent affected areas. Maximum variability in exchangeable Ca^{2+} was observed under Site-3 soils, whereas, for exchangeable Mg^{2+}, Na^{+} and K^{+}, maximum variability was observed under Site-2 soils.

The highest contents of exchangeable Ca^{2+} were observed in Site-3 soils which ranged from 5.07-21.71 cmol (p^{+}) kg^{-1} with a mean value of 9.55 cmol (p^{+}) kg^{-1} and lowest value in Site-2 soils which ranged from 1.65-8.19 cmol (p^{+}) kg^{-1} with mean value of 4.59 cmol (p^{+}) kg^{-1}, respectively.

Highest value of exchangeable Mg^{2+} and K^{+} contents was recorded in Site-1 soils, which ranged from 0.00-2.14 and 0.05-0.13 cmol (p^{+}) kg^{-1} with mean value of 1.26 and 0.10 cmol (p^{+}) kg^{-1}, respectively. The lowest exchangeable K^{+} was recorded in Site-2 soils

Table 4.8. Exchangeable cations in soils of different torrent affected areas

Location/site		Exchangeable cations [cmol (p^+) kg^{-1}]			
		Ca^{2+}	Mg^{2+}	Na^+	K^+
Site-1 (Barotiwala, Solan)	Range	3.25-8.66	0.00-2.14	0.72-1.11	0.05-0.13
	Mean	5.22	1.26	0.93	0.10
	SD ±	1.88	0.67	0.13	0.03
	CV (%)	35.97	53.54	13.77	28.58
Site-2 (Pekhuwala, Una)	Range	1.65-8.19	0.14-1.44	0.82-1.95	0.00-0.16
	Mean	4.59	0.83	1.02	0.02
	SD ±	2.56	0.56	0.34	0.07
	CV (%)	55.89	67.92	33.20	266.27
Site-3 (Nurpur, Kangra)	Range	5.07-21.71	0.14-0.99	0.55-1.30	0.00-0.15
	Mean	9.55	0.55	0.87	0.03
	SD ±	5.65	0.31	0.27	0.05
	CV (%)	59.15	56.72	31.71	185.48
	χ^2	12.58**	5.50	7.40*	6.06*

Mean - Combined mean
SD - Combined standard deviation
CV - Coefficient of variation
χ^2 - Bartlett's statistics Chi Square test ($\chi^2_{(k-1)}$) value or χ^2 value
* - Significant at 5% level
** - Significant at 1% level

and that of Mg^{2+} in Site-3 soils which ranged from 0.00-0.16 and 0.14-0.99 cmol (p^+) kg^{-1} with mean value of 0.02 and 0.55 cmol (p^+) kg^{-1}, respectively.

Exchangeable Na^+ was recorded to be highest under Site-2 soils, ranging from 0.82-1.95 cmol (p^+) kg^{-1} with a mean value of 1.02 cmol (p^+) kg^{-1} and lowest value under Site-3 soils, ranging from 0.55-1.30 cmol (p^+) kg^{-1} with a mean value of 0.87 cmol (p^+) kg^{-1}.

4.4 ERODIBILITY STATUS OF SOILS OF TORRENT AFFECTED AREAS

To evaluate the erosional behaviour of soils under different torrent affected areas, various erodibility and stability indices were determined by incorporating the data on basic soil properties into different empirical formulae. All the erodibility indices varied significantly with the torrent affected areas and data have been presented in Table 4.9 and 4.10 and described in subsequent paragraphs.

4.4.1 Clay ratio (CR)

Soils of torrent affected area of Site-3 exhibited maximum variability in CR. The highest value for the index was recorded in Site-3 which ranged from 16.30-832.25 with mean value of 183.79. The lowest CR was recorded in the Site-1 soils ranging from 13.12-39.00 with a mean value of 23.47. On the basis of CR, different torrent affected areas can be arranged for erosional behaviour in the order:

Site-3 (Nurpur, Kangara)> Site-2 (Pekhuwala, Una) > Site-1 (Barotiwala, Solan)

4.4.2 Silt: clay ratio (SCR)

As evident from the data presented in Table 4.9, there was wide variation for SCR in soils of torrent affected area of Site-2. However, Site-3 soils recorded the highest SCR, ranging from 1.36-13.44 with a mean value of 5.55. The lowest SCR was observed in the soils under torrent affected area of Site-1, ranging from 1.73-5.80 with mean value of 2.79. On the basis of SCR, different sites followed the order:

Site-3 > Site-2 > Site-1

4.4.3 Dispersion ratio (DR)

Dispersion ratio varied widely in the Site-3 soils and highest ratio was recorded in the Site-2 soils, ranging from 48.31-68.75 with mean value of 59.14. While Site-1 soils recorded the lowest DR which ranged from 42.83-62.11 with a mean value of 50.83. In general, the DR under different study sites was in the order:

Site-2 > Site-3 > Site-1

4.4.4 Erosion ratio (ER)

Erosion ratio varied very widely and maximum variability was observed under Site-2 soils (135.64 %). It was found to be highest in the soils under torrent affected area of Site-3, ranging from 79.26-1125.82 with mean value of 292.64. The Lowest ER was

Table 4.9. Erodibility indices of soils of torrent affected areas

Location/site		CR	SCR	DR	ER	EI
Site-1 (Barotiwala, Solan)	Range	13.12-39.00	1.73-5.80	42.83-62.11	60.08-153.97	100.52-230.77
	Mean	23.47	2.79	50.83	94.48	164.59
	SD ±	10.00	1.29	7.17	32.86	58.77
	CV (%)	42.62	46.17	14.11	34.78	35.71
Site-2 (Pekhuwala, Una)	Range	16.73-554.56	0.69-14.06	48.31-68.75	105.63-1126.29	244.36-4599.66
	Mean	120.14	4.11	59.14	226.76	1007.97
	SD ±	161.33	4.44	8.11	307.59	1360.81
	CV (%)	134.29	108.13	13.71	135.64	135.01
Site-3 (Nurpur, Kangra)	Range	16.30-832.25	1.36-13.44	30.92-67.21	79.26-1125.82	180.93-7791.12
	Mean	183.79	5.55	53.62	292.64	1421.65
	SD ±	336.26	4.00	15.88	394.21	2966.76
	CV (%)	182.96	72.04	29.62	134.71	208.68
	χ^2	51.51**	11.55**	7.68*	31.54**	58.98**

Mean - Combined mean
SD - Combined standard deviation
CV - Coefficient of variation
χ^2 - Bartlett's statistics Chi Square test ($\chi^2_{(k-1)}$) value or χ^2 value
* - Significant at 5% level
** - Significant at 1% level

observed in the soils under torrent affected area of Site-1, ranging from 60.08-153.97 with mean value of 94.48. On the basis of ER, different sites can be arranged as:

Site-3 > Site-2 > Site-1

4.4.5 Erosion index (EI)

As is clearly evident from Table 4.9, amongst different erodibility indices, EI exhibited maximum variability. Among sites, the soils of Site-3 had maximum variation (208.68 %). It was found to be highest in the soils under Site-3 soils, ranging from 180.93-7791.12 with a mean value of 1421.65. The soils under torrent affected area of Site-1 recorded lowest EI ranging from 100.52-230.77 with a mean value of 164.59. On the basis of EI, different sites/areas can be arranged in the order:

Site-3 > Site-2 > Site-1.

4.4.6 Soil Stability Characteristics

4.4.6.1 Raindrop impact

A perusal of data in Table 4.10 reveals that RDI was found to be highest in Site-3 soils and ranged from 0.69-100.00 $x10^{-2}$ with mean value of 61.75 $x10^{-2}$. It was lowest in soils under torrent affected area of Site-1 and ranged from 0.40-100.00 $x10^{-2}$ with mean value of the order of 44.83 $x10^{-2}$. On the basis of RDI, different torrent affected areas can be arranged in the order:

Site-3 > Site-2 > Site-1

4.4.6.2 Mean weight diameter (MWD)

Mean weight diameter, is an index of water stable soil aggregates varied considerably under different torrent affected area (Table 4.10). Amongst the sites, highest MWD was found to be in Site-1 soils, ranging from 0.00-4.61 mm with a mean value of 1.02 mm. The lowest MWD was recorded for the soils under torrent affected area of Site-2, ranging from 0.00-1.68 mm with a mean value of 0.47 mm. On the basis of MWD, the torrent affected areas can be arranged in the order:

Site-1 > Site-3 > Site-2

Table 4.10. Stability indices of soils of torrent affected areas

Location/site		RDI ($N^{-1} x10^{-2}$)	MWD (mm)	WSA(>0.25 mm) (%)	WSA (<0.25 mm) (%)
Site-1 (Barotiwala, Solan)	Range	0.40-100.00	0.00-4.61	0.00-96.75	0.00-61.65
	Mean	44.83	1.02	40.88	15.48
	SD ±	59.04	1.79	46.00	24.28
	CV (%)	131.70	175.35	112.53	156.86
Site-2 (Pekhuwala, Una)	Range	0.85-100.00	0.00-1.68	0.00-72.34	0.00-51.41
	Mean	59.01	0.47	24.47	15.53
	SD ±	56.54	0.73	32.28	22.68
	CV (%)	95.82	153.96	131.88	146.08
Site-3 (Nurpur, Kangra)	Range	0.69-100.00	0.00-3.10	0.00-82.72	0.00-42.46
	Mean	61.75	0.84	25.36	12.27
	SD ±	62.15	1.53	41.51	19.99
	CV (%)	100.65	182.60	163.67	162.96
	χ^2	0.09	6.60*	1.15	0.40

Mean - Combined mean
SD - Combined standard deviation
CV - Coefficient of variation
χ^2 - Bartlett's statistics Chi Square test ($\chi^2_{(k-1)}$) value or χ^2 value
* - Significant at 5% level

4.4.6.3 Water stable aggregate (WSA)

A perusal of data presented in Table 4.10 reveals that WSA varied with the torrent affected areas. Amongst different sites, WSA (>0.25 mm in diameter) were found to be highest in the Site-1 soils, ranging from 0.00-96.75 per cent with a mean value of 40.88 per cent. The lowest value was recorded in Site-2 soils which ranged from 0.00-72.34 per cent with mean value of 24.47 per cent.

The WSA (<0.25 mm in diameter) exhibited wide variation under different torrent affected areas. Highest value was recorded to be in Site-2 soils, ranging from 0.00-51.41 per cent with a mean value of 15.53 per cent. The lowest value was recorded in the soils under torrent affected area of Kangra (Site-3), ranging from 0.00-42.46 per cent with a mean value of 12.27 per cent. The torrent affected areas on the basis of WSA can be arranged as:

WSA (>0.25mm): Site-1 > Site-3 > Site-2,

WSA (<0.25 mm): Site-2> Site-1 > Site-3

4.5 CORRELATION AMONG SOIL PROPERTIES, ERODIBILITY AND STABILITY INDICES OF TORRENT AFFECTED AREAS

4.5.1 Interrelationship between soil properties

Organic carbon (OC) was found to be positively and significantly correlated with MWHC, FC, and WP under Site-3 torrent affected area soils with r-values of 0.60, 0.71 and 0.72, respectively (Table 4.11). It was however, found to be negatively correlated with these properties under soils of Site-1 (Barotiwala, Solan) but did not reach the level of significance. OC was positively correlated with MWHC and FC but negatively correlated with WP in soils under torrent affected areas of Pekhuwala, Una.

The AWC of the soils under all the torrent affected areas was found to be correlated negatively with total sand, but significant correlation was recorded under Site-1 and Site-3 soils with r- values of -0.88 and -0.62, respectively (Table 4.10). It was found to be positively correlated with silt and clay contents and significant relationship were observed in Site-1 (for silt, r = 0.88 and for clay, r = 0.60) and Site-3 soils (r = 0.64 for clay).

4.5.2 Relationship between soil properties and erodibility / stability indices

Total sand contents were observed to be correlated positively and significantly with DR (r = 0.62) in the torrent affected areas of Site-1 (Table 4.12). However, the clay contents of these soils exhibited a significant and negative correlation with DR (r = -0.74).

A perusal of data presented in Table 4.11 reveals that OC was found to be positively correlated with WSA >0.25 mm dia. in all the torrent affected areas. But, the significant correlation (r = 0.78) was observed only under Site-1. Similarly, the WSA <0.25 mm in dia. also exhibited positive relationship with OC of the Site-1 and Site-3 soils but did not reach the level of significance. The MWD was observed to be positively related to OC contents in all the torrent affected areas but the correlations were significant (r = 0.68) only in the Site-1 soils.

The erosion ratio (ER) of Site-2 and Site-3 soils was found to be correlated positively with total sand contents but ER of Site-1 soils was negatively correlated with total sand. Total silt contents were observed to be negatively correlated with ER in Site-2 and Site-3 soils but positively correlated in Site-1 soils. ER was found to be correlated negatively with clay content in all the torrent affected areas. RDI and OC were found to bear negative correlation but significant correlation was recorded under Site-3 soils (r = -0.62).

Total sand contents were found to be correlated positively with erosion index (EI) in all the torrent affected areas, however, significant relationships was found in Site-2 soils (r = 0.58). Clay contents were found to be negatively and significantly correlated with EI in all the torrent affected areas with r values of - 0.81, -0.57 and -0.56 for Site-1, Site-2 and Site-3 soils, respectively. Similarly, silt contents were also negatively correlated with EI in all the torrent affected areas but significant effects were observed only in Site-2 soils (r = -0.56).

4.5.3 Relationship among different erodibility indices

Both DR and ER were found to be positively correlated in all the torrent affected areas but the significant correlation was observed only under Site-3 soils (r = 0.98). DR and CR were found to be correlated negatively for Site-2 and Site-3 torrent affected area soils but correlated positively and significantly under Site-1 soils with r-value of 0.64. ER and SCR were observed to be correlated positively and significantly under all the torrent affected areas with r-values 0.83, 0.81 and 0.58 for Site-1, Site-2 and Site-3, respectively.

Erosion index proposed by Sahi *et al.* (1977) was found to have positive and significant correlation with ER under all the torrent affected areas. The values of correlation coefficient (r) were found to be 0.70, 0.69 and 0.98 for Site-1, Site-2 and Site-3, respectively.

MWD and WSA (>0.25 mm in diameter) were found to have a positive correlation, in all the torrent affected areas under study significantly with r-values 0.94, 0.92 and 0.82 under Site-1, Site-2 and Site-3, respectively.

Table 4.11. **Correlation coefficients (r-values) between different hydraulic, physical and chemical properties**

S. No.	Soil properties	Torrent affected areas		
		Site-1 (Barotiwala, Solan)	Site-2 (Pekhuwala, Una)	Site-3 (Nurpur, Kangra)
1.	OC and MWHC	-0.22	0.08	0.60*
2.	OC and FC	-0.24	0.04	0.71**
3.	OC and WP	-0.17	-0.07	0.72**
4.	OC and AWC	-0.21	-0.29	0.39
5.	Total Sand and FC	-0.97**	-0.97**	-0.97**
6.	Total Sand and WP	-0.92**	-0.88**	-0.95**
7.	Total Sand and AWC	-0.88**	-0.52	-0.62*
8.	Silt and AWC	0.88**	0.52	0.64*
9.	Clay and AWC	0.60*	0.40	0.48

Table 4.12. **Correlation coefficients (r-values) between and among some erodibility/stability indices and soil properties**

S. No.	Soil properties	Torrent affected areas		
		Site-1 (Barotiwala, Solan)	Site-2 (Pekhuwala, Una)	Site-3 (Nurpur, Kangra)
1.	DR and total sand	0.62*	-0.46	-0.50
2.	DR and silt	-0.56	0.44	0.51
3.	DR and clay	-0.74**	0.44	0.42
4.	OC and WSA (>0.25 mm)	0.78**	0.06	0.26
5.	OC and WSA (<0.25 mm)	0.11	-0.24	0.07
6.	OC and MWD	0.68**	0.18	0.41
7.	MWD and WSA (>0.25 mm)	0.94**	0.92**	0.82**
8.	ER and total sand	-0.41	0.18	0.39
9.	ER and silt	0.51	-0.13	-0.38
10.	ER and clay	-0.26	-0.36	-0.46
11.	RDI and OC	-0.53	-0.17	-0.62*
12.	EI and total sand	0.28	0.58*	0.52
13.	EI and silt	-0.17	-0.56*	-0.51
14.	EI and clay	-0.81**	-0.57*	-0.56*
15.	DR and ER	0.09	0.35	0.98**
16.	DR and CR	0.64*	-0.23	-0.10
17.	ER and SCR	0.83**	0.81**	0.58*
18.	EI and ER	0.70*	0.69*	0.98**

* - Significant at 5% level

** - Significant at 1% level

4.6 TORRENT CHANNELISATION AND STABILIZATION THROUGH BIO-ENGINEERING MEASURES

4.6.1 Impact of bio-engineering measures on source area (torrent catchment)

4.6.1.1 Sediment retention

In the source area variable amount of sediment was retained behind every bio-engineering measure (Table 4.13). The highest amount of sediment was retained by mechanical and vegetative measure (MVMs) together to the tune of 96 kg each during 2004 and 2005 and 99 kg in the year 2006 with a mean value of 97 kg during the study. While lowest amount of sediment (1 kg) was retained by vegetative filters (VFs).

Table 4.13. Sediment retention (kg) behind bioengineering measures in source area in different years

Measures	2004	2005	2006	Mean
Mechanical measures				
Loose boulder check dams (LBCDs)	55	55	56	55
Gabion check dams (GCDs)	86	92	95	91
Vegetative measures				
Brush wood check dams (BWCDs)	2	2	2	2
Vegetative filters (VFs)	1	1	1	1
Mechanical + Vegetative measures (MVMs)	96	96	99	97

4.6.1.2 D_{50} analysis of sediment

Data presented in the Table 4.14 (Figs. 5, 6 and 7) reveals that the D_{50} value of sediment collected in source area under different bio-engineering measures, ranged from 0.71-1.10 mm (50% finer than this size). Every year maximum D_{50} value was recorded under mechanical measures and lowest under mechanical and vegetative measures together with mean values of 0.99 and 0.75 mm, respectively.

Table 4.14. D_{50} value (mm) of sediment collected in source area under different bioengineering measures

Measures	2004	2005	2006	Mean
Mechanical Measures	1.10	0.91	0.95	0.99
Vegetative Measures	0.95	0.71	0.78	0.81
Mechanical + Vegetative Measures	0.78	0.72	0.76	0.75

4.6.1.3 Nutrient status of sediment in source area

It is evident form the Table 4.15 that sediment retained behind bio-engineering measures in source area was low in available N, medium to high in available P and medium in available K during the study period. The highest available N, P and K contents were recorded under MVMs i.e. 143.3, 154.2 and 156.8 kg/ha available N, 31.4, 32.0 and 31.1 kg/ha available P and 203.2, 195.1 and 228.5 kg/ha available K in the year 2004, 2005 and 2006, respectively. While the lowest available N contents were recorded under GCDs (119.7 kg/ha) during 2004 and under LBCDs during 2005 (112.3 kg/ha) and 2006 (137.53 kg/ha). The lowest available P contents were recorded under LBCDs to the tune of 20.44, 21.23 and 22.68 kg/ha during the year 2004, 2005 and 2006, respectively. The available K contents were found to be lowest under VFs to the tune of 145.36, 135.69 and 150.14 kg/ha during 2004, 2004 and 2005, respectively.

4.6.2 Impact of bio-engineering measures on torrent channelisation and stabilization

4.6.2.1 Sediment Deposition

A perusal of the data in Table 4.16 reveals that on an average 0.37-13.06 and 0.05-11.22 tons upstream sediment deposition from spur was recorded in the year 2004 and 2006, respectively during monsoon in Site-1 torrent near Barotiwala (Solan). Downstream deposition from spur was on an average recorded to the tune of 0.01-16.66 and 0.05-0.87 tons in the years 2004 and 2006, respectively. Total average upstream and downstream sediment deposition of all the spurs was 46.27 tons and 25.58 tons in 2004 and 44.73 tons and 4.32 tons in 2006, respectively. The percentage change in deposition

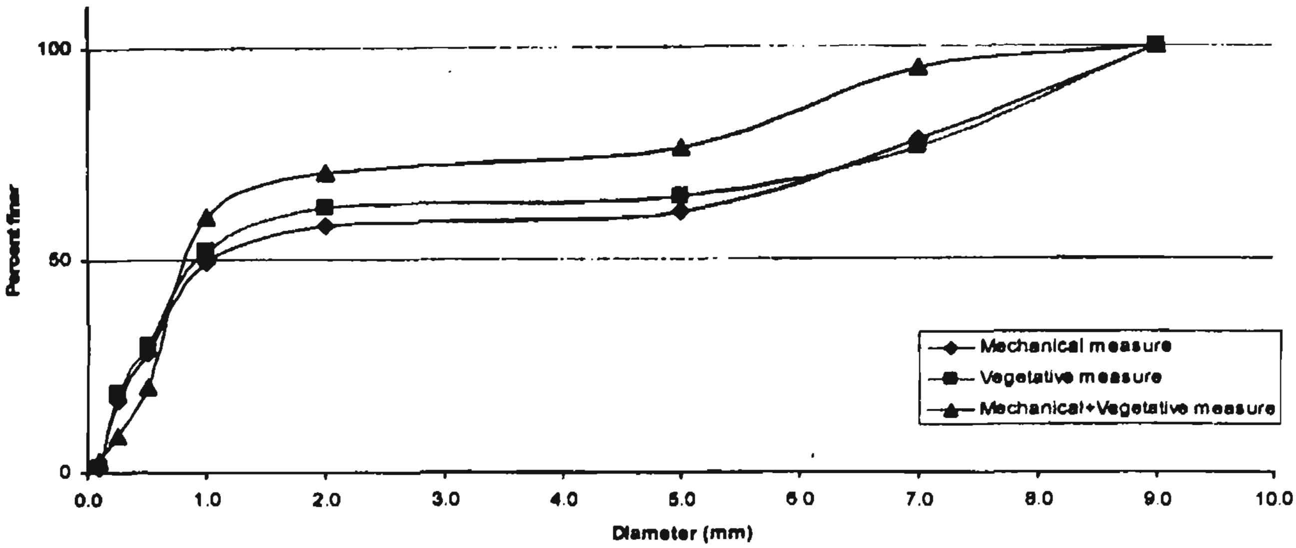


Fig. 5. Cumulative frequency curve for sediment collected in source area under different bio-engineering measures (2004)

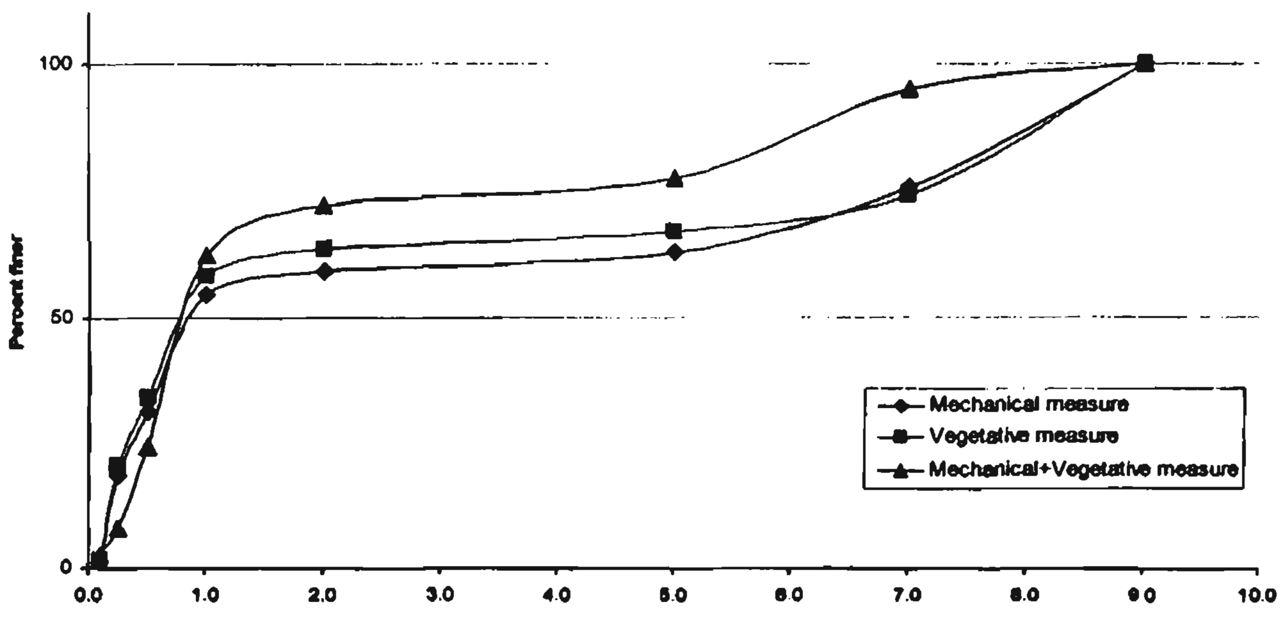


Fig. 6. Cumulative frequency curve for sediment collected in source area under different bio-engineering measures (2005)

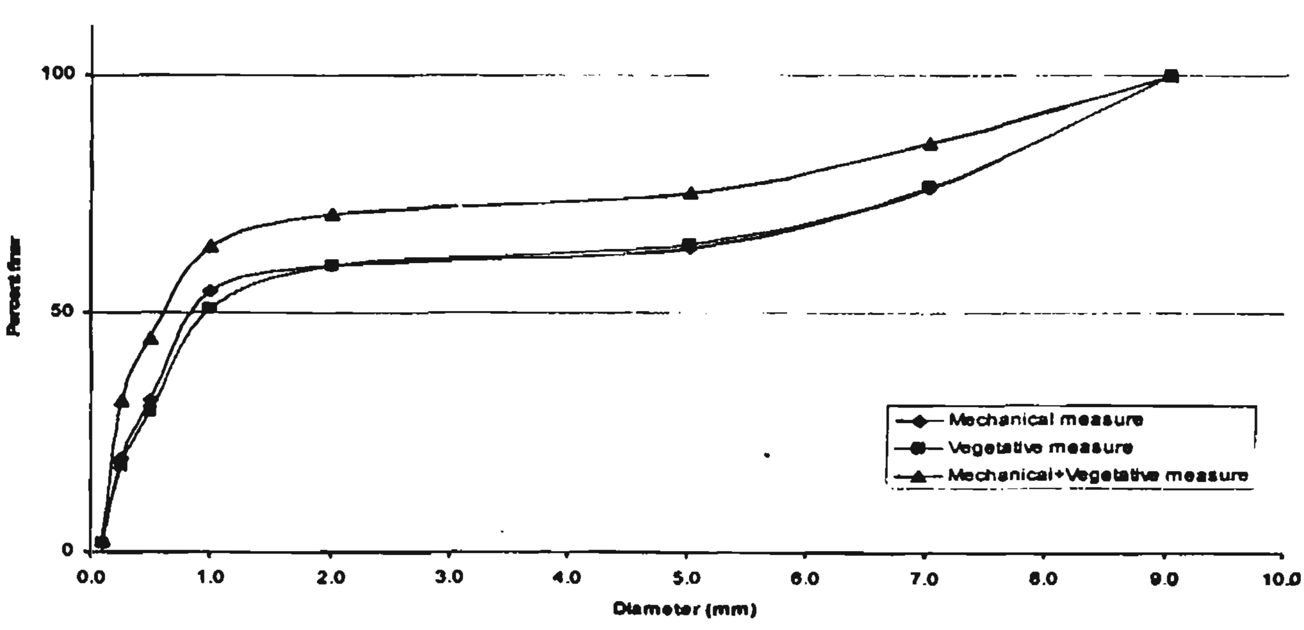


Fig. 7. Cumulative frequency curve for sediment collected in source area under different bio-engineering measures (2006)

Table 4.15. Effect of bio-engineering measures on nutrient status (kg/ha) of sediment retained behind bioengineering measures in source area (torrent catchment)

Measures	2004			2005			2006		
	N	P	K	N	P	K	N	P	K
Mechanical measures									
Loose boulder check dams (LBCDs)	128.51	20.44	183.92	112.28	21.23	174.81	137.53	22.68	196.53
Gabion check dams (GCDs)	119.72	21.82	189.68	118.96	22.39	168.53	140.42	22.68	191.60
Vegetative measures									
Brush wood check dams (BWCDs)	130.98	24.92	150.31	121.97	21.28	147.84	145.44	26.48	158.16
Vegetative filters (VFs)	135.45	23.16	145.36	135.82	26.36	135.69	149.36	28.08	150.14
Mechanical + Vegetative measures (MVMs)	143.35	31.36	203.16	154.20	32.01	195.11	156.80	31.12	228.54

Table 4.16. Upstream and downstream sediment deposition in different mechanical structures during monsoon at Barotiwala, Solan

Spur No.	2004		2006		% Change in deposition over initial year		2004		2006	
	Upstream deposition (tons)	Downstream deposition (tons)	Upstream deposition (tons)	Downstream deposition (tons)	Upstream deposition	Downstream deposition	Max. downstream deposition (m)		Max. downstream deposition (m)	
							Height	Distance	Height	Distance
1.	1.49	1.33	0.65	0.33	+56.38	75.19	1.40	10.00	1.05	12.10
2.	-	0.01	0.06	0.05	-	-257.14	0.25	2.00	0.35	1.55
3.*	0.93	0.05	0.05	0.05	+94.62	9.09	0.45	15.00	0.40	11.50
4.	4.38	3.23	0.08	0.05	+98.17	98.45	1.00	23.00	0.95	18.20
5.*	1.86	0.06	0.38	0.07	+79.57	-16.67	0.60	8.00	0.50	8.00
6.	-	2.67	-	0.16	-	94.01	0.75	10.00	0.90	11.60
7.	13.06	2.64	1.26	0.29	+90.35	89.02	1.40	10.00	0.75	12.80
8.*	8.78	0.22	0.98	0.05	+88.84	77.27	0.80	12.00	0.80	11.05
9.	0.39	0.77	1.28	0.31	-228.21	59.74	0.35	6.00	0.50	8.40
10.	6.00	9.90	0.88	0.14	+85.33	98.59	1.00	12.00	0.60	11.50
11.	0.61	0.62	1.32	0.07	-116.39	88.71	0.30	5.00	0.20	6.70
12.*	0.37	2.23	1.03	-	-178.38	100.00	0.25	4.00	0.40	5.10
13.	0.45	0.51	2.14	0.25	-375.56	50.98	0.15	7.00	0.80	4.50
14.	0.44	16.66	-	0.22	+100.00	98.68	0.60	28.00	0.55	9.80
15.	1.37	3.46	-	-	+100.00	100.00	0.60	5.00	-	-
16.*	-	-	0.82	-	-	-	-	-	-	-
17.	1.74	0.30	0.38	0.43	+78.16	-43.33	0.80	3.00	1.15	3.00
18.	-	-	11.22	0.82	-	-			1.20	15.90
19.	4.40	0.07	2.38	0.87	+45.91	-1142.86	0.80	5.00	0.80	10.60
20.	-	-	0.67	0.16	-	-	-	-	0.60	5.00
Total	46.27	44.73	25.58	4.32	+44.72	+90.34				

+ Decrease in deposition over initial year

- Increase in deposition over initial year

* Spur reinforced with cuttings of *Ipomoea spp.*, *Vitex negundo* and *Saccharum munja*

over initial year (2004) was recorded for each spur and highest increase in upstream and downstream deposition was recorded to the tune of 375.56 and 1142.86 per cent at spur number 13 and 19, respectively. Generally, there was decrease in upstream and downstream deposition over initial year to the tune of 44.72 and 90.34 per cent, respectively. The maximum height of downstream deposition of 1.40 and 1.20 m at a distance 10.00 and 15.90 m from spur was recorded under spur number 1 and 18 during 2004 and 2006, respectively.

4.6.2.2 Scouring

The scouring during monsoon rains at different spurs varied from 0.007 tons to 0.231 tons. The maximum nose scour depth of 1.75 m at a distance of 1.00 m from spur was observed in the monsoon season of 2004 (Table 4.17). During, 2006 monsoon rains, scouring varied widely with spurs and ranged from 0.016-0.338 tons and maximum nose scour depth of 0.90 m was recorded at a distance of 1.00 m from spur.

4.6.2.3 Capacity left for siltation

The capacity left for siltation in up and downstream sides of different spurs varied from 11.00-195.55, 18.35-204.25 and 15.35-240.00 m^3 in the upstream side and 3.20-425.20, 15.00-463.9 and 4.50-390.00 m^3 in the downstream side during the monsoon period of 2004, 2005 and 2006, respectively (Table 4.18). The total capacity left for siltation of all the spurs in the torrent was recorded to be 1811.80, 2166.30 and 1835.00 m^3 on the upstream side and 1246.50, 1552.25 and 1165.65 m^3 on the downstream side of the spur during the years 2004, 2005 and 2006, respectively.

4.6.2.4 Sediment retention under vegetative spurs

It is evident from the data presented in the Table 4.19 that among different vegetative spurs, highest total sediment retention was recorded under spur made up of mixture of species to the tune of 11.84 and 8.85 tons during the year 2004 and 2006, respectively, whereas, lowest total sediment was retained by *Ipomoea spp.* to the tune of 3.95 and 2.16 tons during the years 2004 and 2006, respectively.

Highest average sediment was retained by *Saccharum munja* (0.30 tons/m) spur during the years 2004 and by spur made up of mixture of species (0.13 tons/m) during the year 2006, whereas lowest average sediment was retained by *Ipomoea spp.* to the tune of 0.15 and 0.08 tons/m during the years 2004 and 2006, respectively.

4.6.2.5 D_{50} analysis of sediment

Data presented in Table 4.20 and Figs. 8, 9 and 10 shows that the D_{50} value of sediment (torrent bed material) collected from different parts of torrent in different years ranged from 1.08- 3.08 mm. Highest D_{50} value was recorded in upper part of torrent during the years 2004 (3.08 mm) and 2005 (2.25 mm) but in the middle part during 2006 (1.33 mm) and lowest in upper part of the torrent during the years 2004 (1.46 mm) and 2005 (1.50 mm) but in the middle part during 2006 (1.08 mm). Highest mean D_{50} value during the study period was recorded in upper part and lowest in middle part of the torrent.

4.6.2.6 Nutrient status of sediment of torrent bed

A glance of data presented in Table 4.21 reveals that sediment retained behind bio-engineering measures in different parts of torrent was very low in available N, medium to high in available P and low to medium in available K during the study period. The highest available N, P and K contents were recorded under mechanical and vegetative measures together (except available N which was highest under vegetative measures in middle part of torrent during 2006) in the middle part of the torrent (except available P which was highest in upper part of torrent in the year 2006), during the years 2004, 2005 and 2006. Highest available N, P and K contents were recorded to the tune of 81.54, 87.81 and 130.16 kg/ha available N, 25.01, 26.73 and 33.42 kg/ha available P and 141.12, 133.26 and 158.92 kg/ha available K during the years 2004, 2005 and 2006, respectively under mechanical and vegetative measure together. The lowest available N, P and K contents were recorded under vegetative measures (except available N which was lowest under mechanical measures in 2006) during the years 2004 (48.96, 12.60 and 104.16 kg/ha) and 2006 (54.60, 13.44 and 129.18). Whereas, in the year 2005, lowest N,

Table 4.17. Scouring and maximum nose scour in different mechanical structures during monsoon at Barotiwala, Solan

Spur No.	2004			2006		
	Scouring (tons)	Max. nose scour (m)		Scouring (tons)	Max. nose scour (m)	
		Depth	Distance		Depth	Distance
1.	0.165	0.55	0.85	-	-	-
2.	-	-	-	-	-	-
3.*	-	-	-	-	-	-
4.	0.024	0.55	0.75	-	-	-
5.*	-	-	-	-	-	-
6.	-	-	-	-	-	-
7.	-	-	-	0.016	0.65	1.00
8.*	-	-	-	-	-	-
9.	-	-	-	0.049	0.45	1.50
10.	-	-	-	0.037	0.45	0.75
11.	-	-	-	0.124	0.55	2.00
12.*	-	-	-	-	-	-
13.	-	-	-	0.264	0.90	1.00
14.	0.036	1.20	1.50	0.077	0.35	1.00
15.	-	-	-	-	-	-
16.*	-	-	-	0.033	-	-
17.	-	1.75	1.00	0.293	0.40	2.00
18.	0.007	0.60	0.35	0.338	0.85	2.30
19.	0.231	-	-	0.080	0.90	3.50
20.	-	-	-	0.124	0.80	1.00

* Spur reinforced with cuttings of *Ipomoea spp., Vitex negundo* and *Saccharum munja*

Table 4.18. Capacity left for siltation in different mechanical structures at Barotiwala, Solan

Spur No.	Capacity left for siltation (m^3)					
	2004		2005		2006	
	Upstream	Downstream	Upstream	Downstream	Upstream	Downstream
1.	95.20	70.45	130.65	95.65	105.00	45.20
2.	18.60	3.20	23.4	15.00	15.75	4.50
3.*	102.10	60.00	154.20	72.00	90.00	60.00
4.	12.60	20.25	29.25	56.55	18.05	48.30
5.*	185.30	14.25	193.10	31.05	168.20	15.55
6.	11.00	20.35	18.35	35.65	15.35	30.65
7.	52.30	165.40	55.00	145.50	60.00	150.40
8.*	195.00	21.55	200.10	22.20	240.00	19.20
9.	65.40	18.20	65.80	28.50	55.80	25.60
10.	18.80	16.55	18.80	18.05	16.50	12.35
11.	32.40	28.60	30.70	22.50	30.70	22.50
12.*	105.85	38.20	150.70	65.00	120.80	40.60
13.	83.25	39.30	85.20	47.65	187.50	36.85
14.	145.55	42.90	164.00	63.65	60.00	48.25
15.	60.00	8.25	83.20	36.05	60.00	24.65
16.*	120.10	12.20	195.50	52.25	147.20	21.35
17.	12.20	30.10	42.60	43.05	33.60	21.00
18.	150.10	425.20	165.20	463.90	195.00	390.00
19.	150.50	55.30	156.30	45.05	75.20	36.20
20.	195.55	156.25	204.25	193.00	140.35	112.50
Total	1811.80	1246.50	2166.30	1552.25	1835.00	1165.65

* Spur reinforced with cuttings of *Ipomoea spp.*, *Vitex negundo* and *Saccharum munja*

Table 4.19. Sediment retention under vegetative spurs

Vegetative spur/filter no.	Plant species	Spur length (m)	Sediment retention (tons)		Sediment retention (tons/m)	
			2004	2006	2004	2005
1.	*Ipomoea spp.*	12	2.32	1.02	0.19	0.09
2.	-do-	5	0.08	0.06	0.02	0.01
3.	-do-	10	1.55	1.08	0.16	0.11
		Σ = 27	Σ = 3.95	Σ = 2.16	Avg. = 0.15	Avg. = 0.08
4.	*Saccharum munja*	10	3.38	1.27	0.34	0.13
5.	-do-	8	2.20	1.10	0.28	0.14
6.	-do-	12	3.50	1.15	0.29	0.10
		Σ = 30	Σ = 9.08	Σ = 3.52	Avg. = 0.30	Avg. = 0.12
7.	Mixture*	30	5.28	4.56	0.18	0.15
8.	-do-	40	6.56	4.29	0.16	0.11
		Σ = 70	Σ = 11.84	Σ = 8.85	Avg. = 0.17	Avg. = 0.13

*Mixture - *Ipomoea sp, Vitex negundo, Saccharum munja*

Table 4.20. **D_{50} value (mm) of torrent bed material**

Torrent part	2004	2005	2006	Mean
Upper	3.08	2.25	1.08	2.14
Middle	1.46	1.50	1.33	1.43
Lower	2.25	1.75	1.25	1.75

Table 4.21. **Effect of bio-engineering measures on nutrient status (kg/ha) of sediment in the different parts of torrent bed**

Measures	Torrent part	2004			2005			2006		
		N	P	K	N	P	K	N	P	K
Mechanical measures										
	Upper	50.18	13.44	114.16	28.76	12.60	92.96	100.24	32.60	141.12
	Middle	67.63	22.68	134.82	47.82	19.47	102.50	63.48	28.42	146.72
	Lower	58.82	15.60	128.17	68.16	18.92	98.60	54.60	20.73	137.96
Vegetative measures										
	Upper	48.96	12.69	104.16	37.63	13.44	96.74	74.11	13.44	129.18
	Middle	78.54	18.92	119.12	40.44	15.60	106.22	125.44	29.47	147.84
	Lower	68.01	12.60	107.06	32.60	12.69	102.50	68.93	18.92	132.16
Mechanical + Vegetative measures										
	Upper	60.44	15.60	132.16	38.08	18.92	118.92	130.16	33.42	148.52
	Middle	81.54	25.01	141.12	87.81	26.73	133.26	88.29	23.42	158.92
	Lower	72.82	19.47	126.08	59.53	21.27	128.83	83.63	22.68	147.84

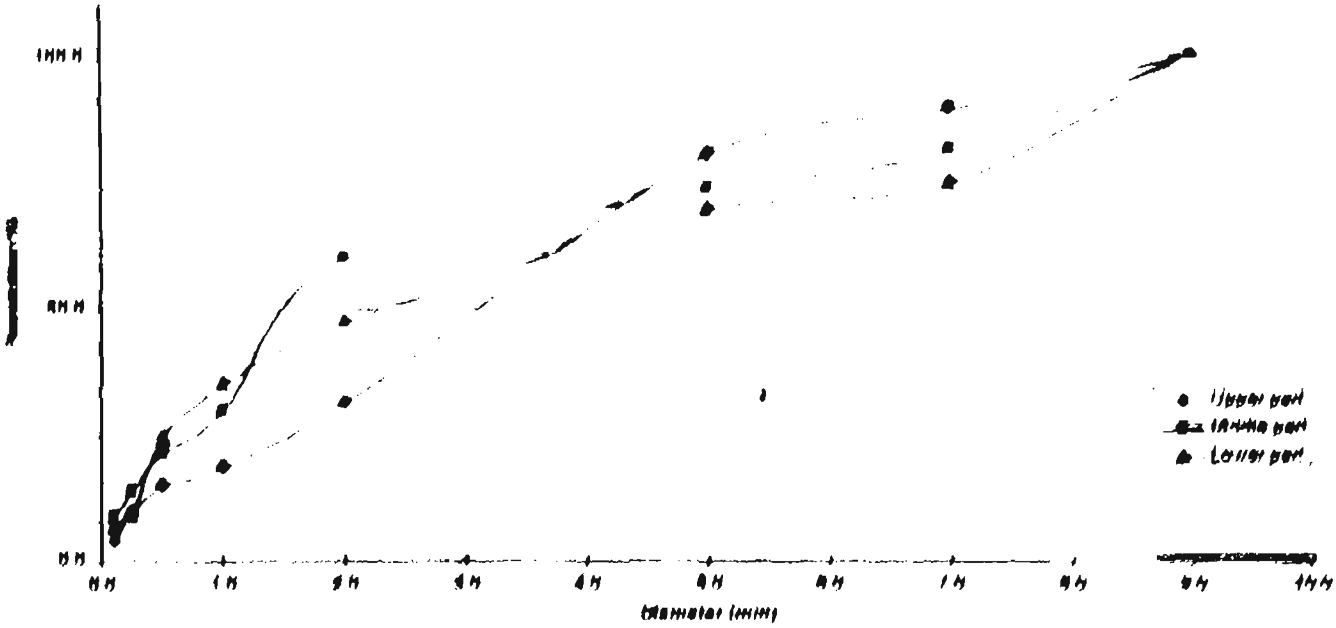


Fig. 8. Cumulative frequency curve for sediment collected from different parts of torrent bed (2006)

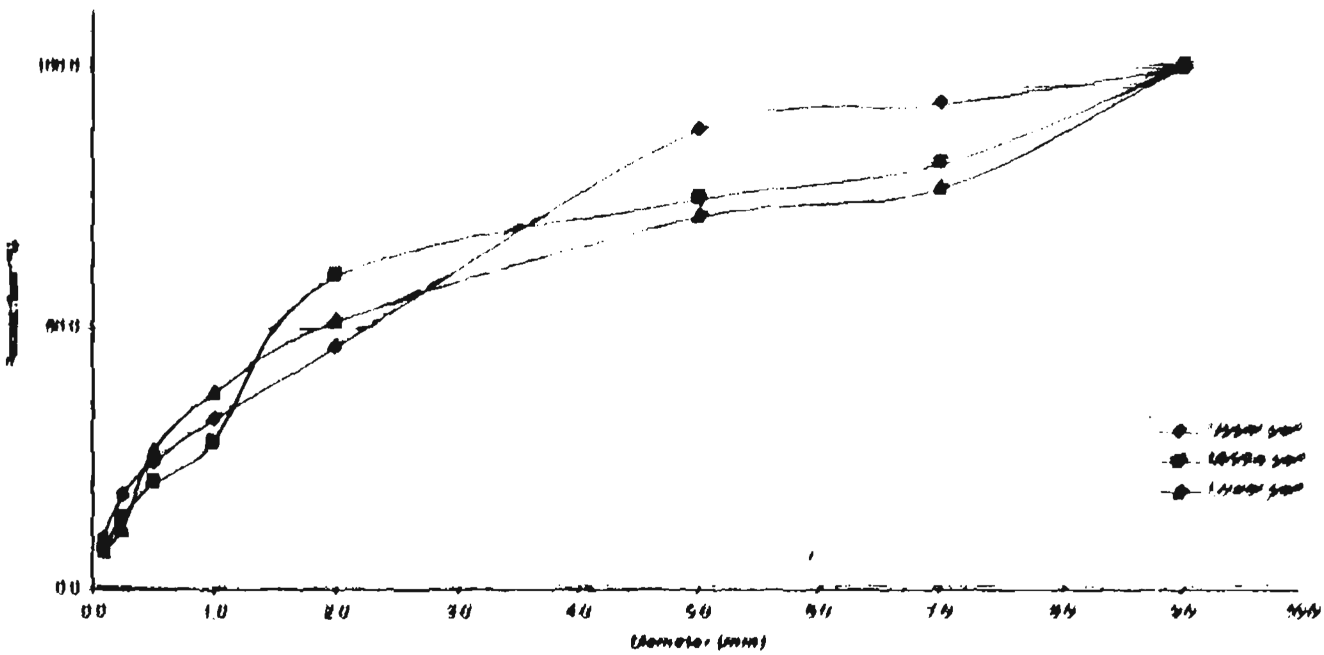


Fig. 9. Cumulative frequency curve for sediment collected collected from different parts of torrent bed (2006)

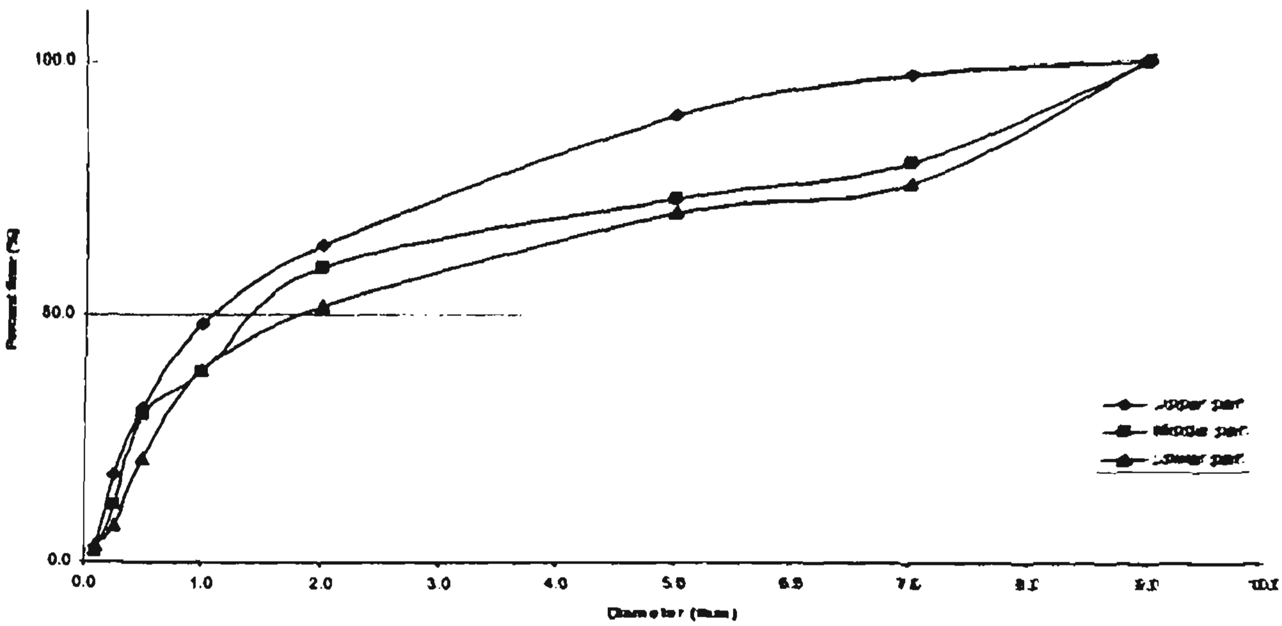


Fig. 10. Cumulative frequency curve for sediment collected from different parts of torrent bed (2006)

P and K contents were recorded under mechanical measures to the tune of 28.76, 12.60 and 92.96 kg/ha, respectively.

4.6.2.7 Survival and growth performance

The live hedges and vegetative spurs of *Ipomoea spp. Vitex negundo* and *Saccharum munja* were planted for torrent treatment. A perusal of data (Table 4.22) indicated that the survival percentage decreased every year and maximum survival was shown by *Ipomoea spp.* i.e. 90, 88 and 71 per cent during 2004, 2005 and 2006, respectively. While *Vitex negundo* showed minimum survival percentage during 2005 (30%) and 2006 (12 %). Growth parameters i.e. height and basal diameter increased every year and maximum growth increment in height was exhibited by *Ipomoea spp.* (200 cm) and minimum by *Saccharum munja* (56 cm). While maximum increment in basal diameter was shown by *Saccharum munja* (9.8 cm) and minimum by *Vitex negundo* (0.5 cm).

4.6.2.8 Peak runoff rate, runoff and sediment yield

The data on peak runoff rate, runoff and sediment yield are presented in Table 4.23. The peak runoff rate was recorded highest in the monsoon, 2006 with a mean value of 36.0 m^3 s^{-1} and lowest during 2005 with as mean value of 9.5 m^3 s^{-1}. Runoff and sediment yield were recorded highest in monsoon, 2004 in both upper (10800 m^3 and 2.21 kg m^{-3}) and lower part (90000 m^3 and 36.08 kg m^{-3}) of torrent, respectively. The lowest runoff and sediment yield were recorded during monsoon, 2005 both in upper (3650 m^3 and 1.17 kg m^{-3}) and lower part (17100 m^3 and 10.41 kg m^{-3}) of the torrent, respectively.

4.6.2.9 Effect of spur and spur length on water course channelisation

The data reported in Table 4.24 depicts that different attracting type of spurs of variable length deflected the water course or steam flow towards the central line to the tune of 9.0 m to 23.0 m in the year 2004 and 10.5 to 24.5 m during 2006. Maximum deflection was exhibited by spur number 18 (11.75 m) upto 23.0 and 24.5 m and minimum by spur number 3 (5.90 m) and 4 (5.90) upto 8.5 and 10.0 m during the years 2004 and 2006, respectively.

4.6.2.10 Assessment of condition of the structures

The condition of bio-engineering structures was visually assessed for damaged by torrent flow, human activities, animal pressure etc. and damaged structures were repaired every year. The spur no. 18 and 20 were badly damaged in the year 2004 and 2006 and were repaired subsequently. Out of the two retaining walls on wall was not even touched by the torrent because of the presence of big spur in the front and second retaining wall was buried under landslide. The vegetative spur made up of mixture was damaged by torrent flow. Some of *Ipomoea spp.* and *Saccharum munja* spur were also damaged by torrent and local people.

4.6.2.11 Effect of bio-engineering measures on dimensions (length, breadth and area) of torrent

The data pertaining to dimensions of torrent (breadth, length and area) before and after treatment is presented in Table 4.25. Highest decrease in torrent area was recorded in upper Joharanpur site (45.83 %) and minimum decrease in lower Joharanpur site (0.83 %). Maximum breadth (200 m) was recorded in upper Joharanpur site before treatment of the torrent which was reduced to 150 m after torrent treatment.

Table 4.22. Survival and growth performance of different species used as vegetative measure

Plant species	Survival (%)			Growth(cm)						Growth increment (cm)	
				Height			Basal diameter			Height	Basal diameter
	2004	2005	2006	2004	2005	2006	2004	2005	2006		
Ipomoea spp.	90	88	71	54	183	254	1.8	2.2	2.7	200	0.9
Vitex negundo	55	30	12	49	82	108	2.1	2.3	2.6	59	0.5
Saccharum munja	50	42	33	35	58	91	3.0	6.2	12.8	56	9.8

Table 4.23. Peak runoff rate, runoff and sediment yield in different years

Particulars	Torrent part	2004	2005	2006
Peak runoff rate ($m^3 s^{-1}$)		25.0	9.5	36.0
Runoff yield (m^3)	Upper	10800	3650	9060
	Lower	90000	17100	64800
Sediment yield ($kg\ m^{-3}$)	Upper	2.21	1.17	2.05
	Lower	36.08	10.41	26.50

Table 4.24. Effect of spur length on water course deflection towards central line of torrent

Spur No.	Spur length (m)	Water course deflected towards central line (m)	
		2004	2006
1.	6.00	10.0	12.5
2.	9.00	14.5	19.5
3.*	5.90	9.0	10.5
4.	5.90	8.5	10.0
5.*	6.00	11.0	13.0
6.	10.15	16.5	22.5
7.	8.00	13.5	15.5
8.*	7.00	12.0	12.5
9.	6.20	11.0	14.0
10.	10.10	16.0	21.0
11.	10.25	18.0	23.5
12.*	10.30	18.5	24.0
13.	8.70	13.0	18.5
14.	8.10	14.0	17.0
15.	8.18	14.5	18.0
16.*	10.45	19.0	23.0
17.	10.65	20.5	23.0
18.	11.75	23.0	24.5
19.	10.20	17.0	22.0
20.	10.20	18.0	23.0

* Spur reinforced with cuttings of *Ipomoea spp.*, *Vitex negundo* and *Saccharum munja*

Table 4.25. Average breadth, length and area under torrent before and after treatment

S.No.	Location/Site	Before treatment			After treatment			% Decrease in area
		Breadth (m)	Length (m)	Area (ha)	Breadth (m)	Length (m)	Area (ha)	
1.	Upper Kulhadiwala	7	150	0.10	6	150	0.09	10.00
2.	Middle Kulhadiwala	20	300	0.60	13	300	0.39	35.00
3.	Lower Kulhadiwala	40	150	0.60	36	150	0.54	10.00
4.	Upper Johranpur	200	750	15.00	130	625	8.12	45.87
5.	Lower Johranpur	150	400	6.00	170	350	5.95	0.83
6.	Upper Sansiwala	150	300	4.50	110	300	3.30	26.67
7.	Lower Sansiwala	120	200	2.40	95	200	1.90	20.83
	Total	687	2250	29.20	560	2075	20.29	30.51

Chapter - V

DISCUSSION

Chapter-5

DISCUSSION

To evaluate the erodibility of soils under different torrent affected areas of lower Shiwaliks of H.P. and stabilization of torrent course near its central line through different bio-engineering measures, the soils of three representative sites in the lower Shiwaliks of H.P. were studied for their physical, hydraulic and chemical characteristics in fields and in laboratory. These were assessed for their erodibility behavior by computing different erodibility indices, proposed by different workers (Middleton, 1930; Bruce and Lal, 1975 and Sahi *et al.*, 1977). The Site-1 (Barotiwala, Solan) was studied for the impact of bio-engineering measures on torrent channelisation and stabilization. The results emanated from the present study have been discussed under the following heads in the light of pertinent literature:

5.1 Physical properties of soils of torrent affected areas
5.2 Hydraulic properties of soils of torrent affected areas
5.3 Chemical properties of soils of torrent affected areas
5.4 Erodibility status of soils of torrent affected areas
5.5 Torrent channelisation and stabilization through bio-engineering measures

5.1 PHYSICAL PROPERTIES OF SOILS OF TORRENT AFFECTED AREAS

The data depicting the physical properties of torrent affected areas are given in Tables 4.1 to 4.3. Among sites, the highest gravel contents were found in Site-1 (46.26 %). This may be due to the type of geology of torrent catchment in lower Shiwaliks. Mechanical analysis of the soils revealed that sand constituted a major fraction and its contents ranged from 82.10-91.35 per cent (Table 4.1). Total sand was found to be highest in Site-2 (Pekhuwala, Una) soils (91.35 %). But the significant variation was recorded only for fine sand in different torrent affected sites and maximum contents (37.67 %) were found in Site-1 soils. This may be due to the reason that larger soil fractions being carried by the runoff water get deposited in the flood plains as the velocity of runoff water gets reduced there. The lowest percentage (36.02 %) of fine sand was noted in Site-3.

The data on the distribution of silt and clay contents revealed a reverse trend as compared to total sand distribution. Highest percentage (13.25 and 4.65 %) was recorded in soils under Site-1 soils. Whereas, lowest (7.05 and 1.60 %) values were recorded in Site-2 soils, respectively. The soils were generally low in clay contents which may be attributed to continuous removal of clays by runoff water during heavy rainfall.

Coarser texture (gls) was observed in all the soils under torrent affected areas (Table 4.1). This is in accordance with the results reported by Saha *et al.* (1995) and Sidhu *et al.* (2000) who also recorded coarser texture of Shiwalik hill soils in the state of Himachal Pradesh.

The bulk density of soils in different torrent affected areas varied from 1.65-1.72 Mg m^{-3} but did not reach the level of significance (Table 4.2). It was highest (1.72 Mg m^{-3}) under Site-2, probably due to higher total sand contents and lower organic carbon, whereas, lowest values (Table 4.1) were found in Site-1 soils (1.65 Mg m^{-3}).

The particle density was significantly higher in Site-3 (2.68 Mg m^{-3}). This might be due to the fact that Site-3 area soils contained iron oxides and other heavy minerals. Porosity, an index of soil permeability and important for water and air movement, was found to be highest (37.60 %) in Site-1 and may be due to lower bulk density and higher percentage of finer fractions of soil.

Aggregates >0.25 mm in diameter were found to be highest in Site-1 soils, ranging from 0.00-96.75 per cent with mean value of 40.88 per cent. This may be due to higher organic matter coupled with higher amounts of clay in Site-1 soils. Lowest percentage of these aggregates (> 0.25 mm in diameter) was recorded in the Site-2 soils, ranging from 0.00-72.34 per cent with mean value of 24.74 per cent.

5.2 HYDRAULIC PROPERTIES OF SOILS OF TORRENT AFFECTED AREAS

The soils under different torrent affected areas varied widely between themselves for their moisture retention characteristics (Table 4.4 and Fig.1). In general, water held at different suctions decreased with the increase in suction. There was an abrupt decrease in water content with an increase in 'ψ' upto a value of 500 kPa and beyond this suction, the decrease in water content with increase in 'ψ' became gradual. Most of the water retained (60-70%) by the soils under all the torrent affected sites was depleted upto 500 kPa matric suction. These results were within the range reported by Khan *et al* (1998). Highest moisture retention at 33 and 1500 kPa suctions was observed in the soils under Site-1 (10.65 and 3.31 %). This may be due to higher organic matter coupled with higher amounts of clay in Site-1 soils (Table 4.1 and 4.6) as increased organic matter contents encouraged soil aggregation, which in turn increased the water retained at 33 and 1500 kPa (Ojeniyi and Dexter, 1984). Lowest values of moisture retention at these suction levels were observed in the soils under Site-2. (7.16 and 1.81 %) which may be due to higher amounts of total sand and very low percentage of clay (Table 4.1). The results are in close conformity with the findings of Gajbhiye (1990).

Available water capacity was found to be highest in Site-1 soils (11.12 cm/0.90m), whereas, lowest was observed in the soils under Site-2 (8.74 cm/0.90m) (Table 4.5 and Fig. 11). This may be due to higher organic carbon contents coupled with higher contents of clay in Site-1 soils than in Site-2. These results are in consonance with the findings of Gajbhiye (1990). These results are also supported by positive relationship of AWC with silt and clay under all the torrent affected sites (Table 4.11) but the relationship was significant only in Site-1 ($r = 0.88^{**}$ for silt and $r = 0.60^{**}$ for clay) and Site-2 ($r = 0.64^{*}$ for silt).

Maximum water holding capacity (Table 4.5) was observed to be highest (31.87 %) in the soils under Site-1. This may be due to additive effect of higher organic carbon contents, clay contents and porosity and lower bulk density. Lowest MWHC was recorded in Site-2 (28.22), which might be due to higher percentage of total sand contents.

Among different torrent affected sites, saturated hydraulic conductivity was found to be highest (20.87 cm hr^{-1}) in Site-2 (Table 4.5). This may be attributed to the coarse texture i.e. higher sand contents (Table 4.1). Khan *et al.* (1998) have also concluded that hydraulic conductivity is controlled mainly by sand contents. Lowest values were recorded in the soils under Site-1 (4.12 cm hr^{-1}). According to the ratings (K_s), Site-1 soils placed under moderately slow to moderate class and Site-2 and Site-3 soils qualified for moderate to very rapid category, suggesting that both Site-2 and Site-3 are highly permeable.

The infiltration process reveals the rate of water entry into the soil profile and affected by surface conditions, organic matter, soil structure, porosity etc. It governs the total volume of runoff and soil loss over the land surface and also important for the water storage in soil profile which is subsequently made available for plant growth. Both steady state infiltration and cumulative infiltration varied widely at different parts of torrent in the site-1 (Figs. 2, 3, and 4). Of the three parts of torrent, lower part had comparatively higher infiltration rate (3.0 x 2.78 x 10^{-6} m s^{-1}) as well as cumulative infiltration (14.3 x 10^{-2} m). This could be probably due to coarser texture and preponderance of pebbles and gravels in the lower part which made the soils it more porous and permeable, thus providing easy path for water to infiltrate down the profile. Mathan and Mahendran (1994) have also reported a positive and significant correlation between infiltration rate and sand content. Lowest steady state infiltration rate and cumulative infiltration (2.4 x 2.78 x 10^{-6} m s^{-1} and 8.6 x 10^{-2} m) were recorded in the soils of upper part of torrent, which may be due to clogging of soil pores, compact surface layers in the torrent catchment and movement of water down the profile is not easier. The results are similar to the findings of Bhattacherjee *et al.*, (2004).

5.3 CHEMICAL PROPERTIES OF SOILS OF TORRENT AFFECTED AREAS

All soils are alkaline in reaction (7.71-7.94) under different torrent affected sites (Table 4.6). Among the sites, comparatively lower pH (7.71) was recorded in Site-1 and highest under Site-3 (7.94). All the study sites are characterized by 'hyperthermic' soil temperature regime and normal rainfall and the soils of the area are developed from soft

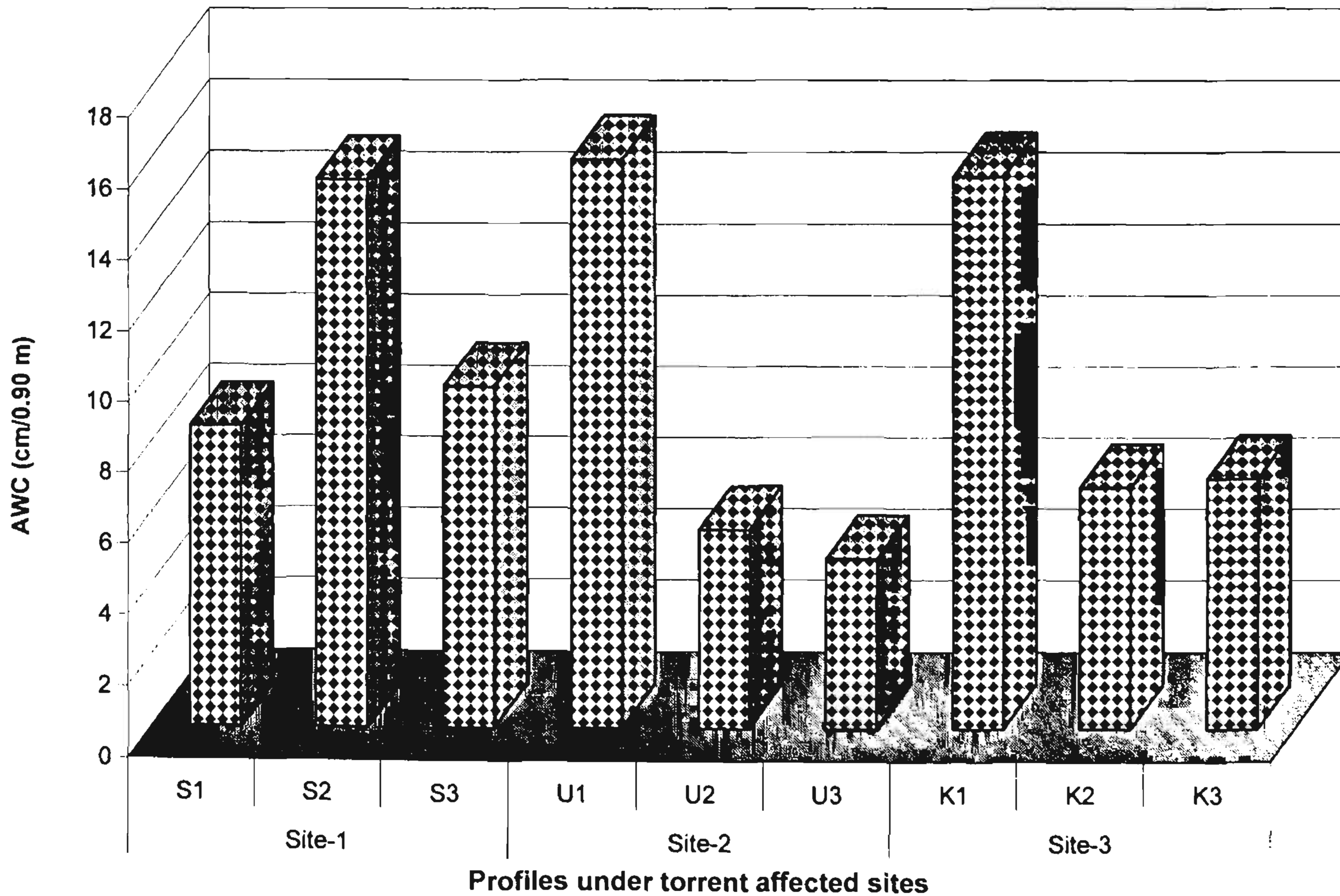


Fig. 11. Available water capacity (cm/0.90 m) of soils of different torrent affected areas

sandstones and flood plains from alluvium of the adjoining hills (Sehgal *et al* 1987; Chaudhri, 2000). Under such conditions, alkaline reaction in the soils is as per expectations. Kaishta *et al.* (1990) have also reported a pH range of 5.7-9.8 in such type of soils. EC was found to be same under all sites (0.14 dS m^{-1}). This indicates that the soils in the Shiwalik foothills of district Solan, Una and Kangra do not have any problem of soil salinity/alkalinity.

Among the torrent affected areas the highest organic carbon contents (Table 4.6)., were found under Site-1 (3.38 g kg^{-1}) followed by Site-3 (3.07 g kg^{-1}), whereas, lowest (2.31 g kg^{-1}) were observed under Site-2 soils. This may be due to better vegetative cover in the catchment of site-1. Higher organic matter under grass cover compared to bare cropped soil was also reported by Saha *et al.* (1999).

According to its critical limits available N contents under all the sites were found in low category (Table 4.7). However, among different sites, comparatively higher contents were found in Site-1 (155.6 kg ha^{-1}), which may be due to high OC content (Table 4.6) whereas, lowest in the soils under Site-2 (90.8 kg ha^{-1}). Secondly, higher infiltration rate might have facilitated leaching of available N in such torrent affected site.

All the soils in Shiwalik foot hills are well supplied with available P and according to critical limits; its status was low to medium in all the sites. However, among the sites, highest contents were recorded in the soils under Site-1 (18.4 kg ha^{-1}) which also may be due to high OC content (Table 4.6) and lowest (7.2 kg ha^{-1}) in Site-3 (Table 4.6).

Available K was found in low to medium range in all the sites under study. However, comparatively, higher contents were recorded in Site-1 (84.4 kg ha^{-1}), followed by Site-3 (25.2 kg ha^{-1}), whereas, lowest values were recorded in Site-2 (21.5 kg ha^{-1}) (Table 4.7). The availability of K in low to medium range may be due to lesser abundance of K bearing minerals, muscovite and biotite in the study area (Chaudhri, 2000).

The highest value of available S contents ranging from 2.7-79.2 kg ha^{-1} with mean value of the order of 25.7 kg ha^{-1} was observed in the soils under torrent affected area of Site-3 (Table 4.7). The lowest contents were recorded in Site-2 soils ranging from 1.3-76.4 kg ha^{-1} with mean of 7.1 kg ha^{-1}.

Exchangeable cations viz. Ca^{2+}, Mg^{2+} Na^{+} and K^{+} varied widely among the three torrent affected sites (Table 4.8). Highest exchangeable Ca^{2+} were observed in Site-3 soils (9.55 cmol (p^{+}) kg^{-1}) and lowest in Site-2 soils (4.59 cmol (p^{+}) kg^{-1}). These soils were found to be rich in exchangeable Ca^{2+} and this might be due to soft sandstone (basic in nature) parent material in the area. Yadav (1976) also observed higher exchangeable Ca^{2+} in the soils of lower Shiwalik in Himachal Pradesh. Whereas, highest values of exchangeable Mg^{2+} and K^{+} were recorded in Site-1 soils (1.26 and 0.10 cmcl (p^{+}) kg^{-1}), respectively. The lowest value of exchangeable K^{+} was recorded in Site-2 (0.02 cmol (p^{+}) kg^{-1}) and that of Mg^{2+} in Site-3 soils (0.55 cmol (p^{+}) kg^{-1}). Exchangeable Na^{+} was recorded to be highest under Site-2 (1.02 cmol (p^{+}) kg^{-1}) and lowest values under Site-3 soils (0.87 cmol (p^{+}) kg^{-1}). Higher exchangeable Mg^{2+} contents in Site-1 may be due to presence of vermiculite clay mineral in the parent material. Yadav (1976) while working on soils of Himachal Pradesh observed the exchangeable Mg^{2+} to vary from 0.40-3.30 c mol (p^{+}) kg^{-1}. Higher contents of exchangeable K^{+} in Site-1 may be due to abundance of K-bearing minerals (muscovite and biotite). Presence of albite feldspars may be responsible for more exchangeable Na^{+} in the soils, as feldspars make large fractions of sedimentary rocks.

5.4 ERODIBILITY STAUS OF SOILS OF TORRENT AFFECTED AREAS

Though the total erosion is a sum product of the erosivity of the rain and erodibility of soils, the later which is highly complex involving multiple variables associated with physical and chemical properties and their interactions. Serious problem of erosion by water is being faced in foot-hills of lower Shiwaliks. Soil erodibility is a major consideration in developing sound land management practices for different torrent affected areas. Knowledge of the erodibility of torrent affected area will considerably help in saving lands, especially the marginal lands from erosion hazards and putting such areas to suitable land use after rehabilitation. The study of the surface horizons is very important in ascertaining erosional behavior of soils, but the lower strata have a decisive bearing not only on the damage due to erosion but sometimes they determine the type and intensity of erosion to occur. Hence, the study of behavior of sub-surface soils is also important from the view point of channel and gully formation.

Soil erodibility, a property of detachment of soil particles by different agents was assessed by different indices (Middleton, 1930). Different workers have employed different erodibility indices for assessing the erosional behavior of the soils. However, none of the index has been found to have universal application for characterizing the soils with regard to their susceptibility to erosion. It is due to the fact that all soil properties influencing erodibility have not been considered in any of the index. In the present study, various erodibility indices such as DR, ER, EI, WSA (>0.25 mm), RDI etc. were employed, as these have been widely used to assess the erodibility behavior of soils under different landuses/ecosystems and agro-climatic conditions (Middleton, 1930, Chakrabarti, 1971; Bruce and Lal, 1975; Bhatia and Sarmah, 1976; Sahi *et al.*, 1977 and Sambyal and Sharma, 1986).

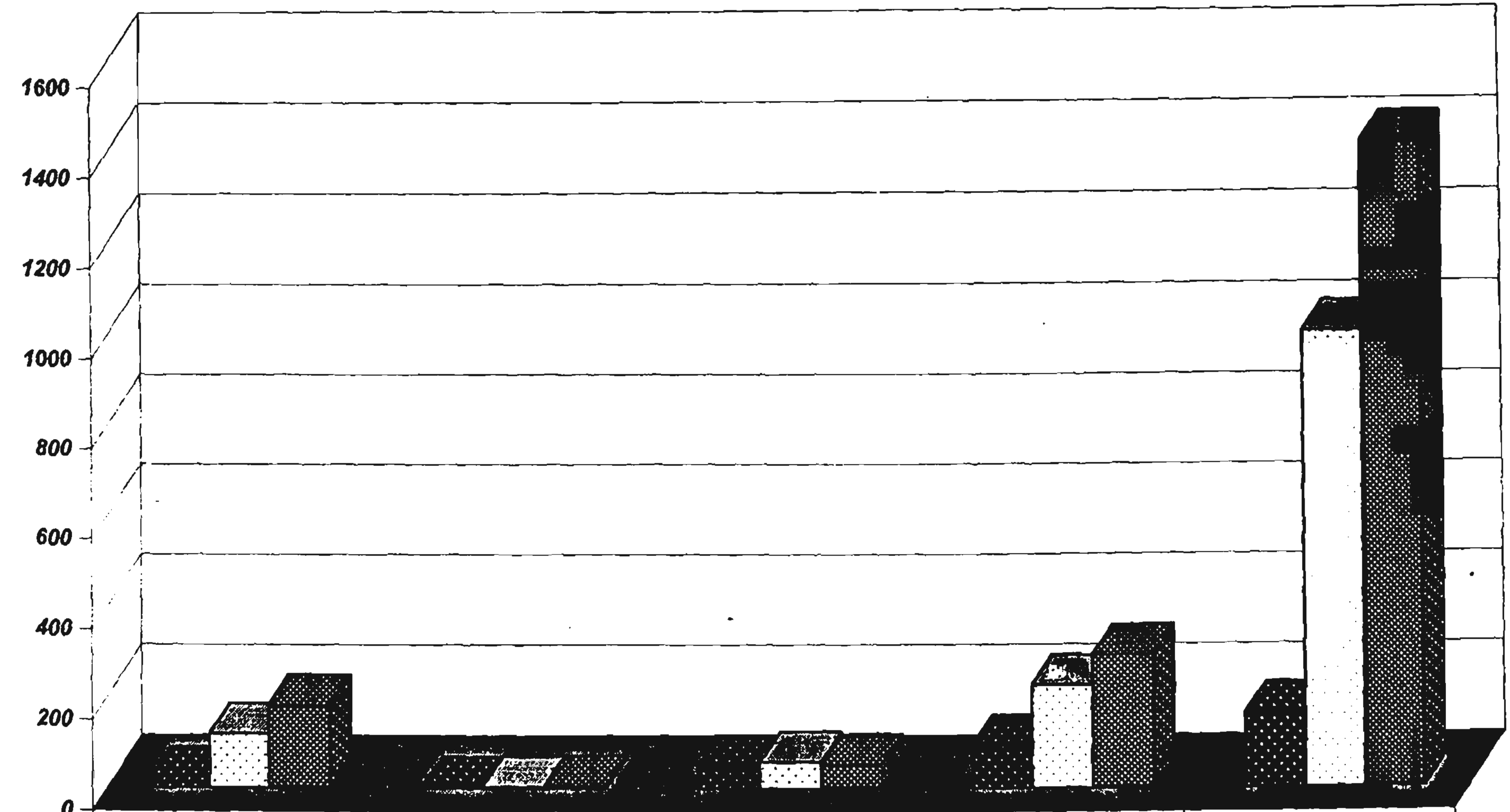
Silt: clay ratio was recorded highest in Site-3 (5.55) and lowest in Site-1. SCR and ER were found to be correlated positively and significant relations were recorded for all the torrent affected sites of lower Shiwaliks.

Various workers have widely used DR as an effective index to assess erosional behavior of soils. Considering 15 threshold value of DR between erodible and non-erodible soils, all the torrent affected sites were found highly erodible (Fig. 12). However, among the sites, the soils under Site-2 were found comparatively more erodible as the DR under this site was highest i.e. 59.14 than the prescribed threshold value. These soils are more vulnerable to erosion hazards. Soils under Site-2 have comparatively lower organic carbon contents and poor aggregation (Table 4.3 and 4.6).Dispersion ratio and ER were found to be positively correlated and significant relations were observed for the soils under Site-3 ($r = 0.98^{**}$). Various workers have also reported similar results for DR and ER (Singh and Gupta, 1991; Sannigrahi, 1999; Dabral *et al.*, 2001 and Kumar *et al.*, 2002).

As depicted in Fig. 12, ER was found to be highest (292.64) in Site-3 followed by Site-2 which recorded ER value of 226.76. Lowest ER i.e. 94.48 was observed in Site-1. This suggests that torrent lands are subjected to heavier erosion. However, considering 10 as threshold value between erodible and non-erodible soils, all the torrent affected sites according to ER, were found to be erodible. These results are in line with the findings of Sharma and Aggarwal (1980) who also reported that, virgin soils were found to be more erodible as compared to the soils under forest and grasslands soils, under cultivation and tea. Erosion ratio has been recommended as an effective index of soil erodibility by various workers (Ballal, 1954; Sharma and Datta Biswas, 1972 and Snarma and Aggrawal, 1980).

Erosion index, proposed by Sahi et al (1977) is considered a reliable index of soil erodibility. Considering 2.8 a threshold value between erodible and non-erodible soils, all the soils under all the torrent affected sites were found to be erodible. Among the sites, EI was found to be highest (Fig. 12) in soils under Site-3 (1421.65), whereas, lowest value was observed under Site-1(164.59). According to EI, Site-1 and Site-2 are subjected to lesser degree of erosion as compared to the soils under Site-3. EI and ER were found to be significantly and positively correlated in all the torrent affected sites under study and correlation coefficient (r) were of the order of 0.70^{*}, 0.69^{*} and 0.98^{**} for Site-1, Site-2 and Site-3, respectively. Thus, for determining erodibility of soil, EI can be safely used in place of ER as determination of EI is easier and less time consuming than ER. Similar findings for the alluvial soils of Bihar and Uttar Pradesh have been reported by Sahi *et al.* (1977) and Bhatia and Shankar (1981), respectively and for Bundelkhand region of Uttar Pradesh by Bhatia and Vardani (1982).

WSA (>0.25 mm) and MWD were observed to be highest in the soils under Site-1 i.e. 40.88 per cent and 1.02 mm, respectively (Table 4.10). The lowest values of WSA (>0.25 mm) and MWD were observed in Site-2 (24.47 and 0.47 mm). This suggests that Site-1 have higher percentage of bigger aggregates and are less susceptible to erosion



	CR	SCR	DR	ER	EI
Siite-1,	23.47	2.79	50.83	94.48	164.59
Site-2	120.14	4.11	59.14	226.76	1007.97
Site-3	183.79	5.55	53.62	292.64	1421.65

Fig. 12. Erodibility status of soils of torrent affected areas

than in other torrent affected sites. Comparatively higher values of MWD under Site-1 indicate that these soils are less erodible than the soils under other sites. Better aggregation under Site-1 may be due to presence of higher organic carbon which help in binding aggregation of soil particles. These results are further supported by significantly positive correlation of MWD with organic carbon under Site-1 soils ($r = 0.68^{**}$). Organic carbon was also found to be positively correlated with WSA (>0.25 mm) in all the three site under study and significant values of 'r' (0.78^{**}) were observed in Site-1. Similar results for WSA and MWD were reported by Kumar *et al.* (2002).

As per the ratings of RDI, soils under all the sites were found to be highly erodible but there was no significant difference in erodibility among sites. However, soils under Site-3 were found to be highly erodible as RDI was of very high order i.e. 61.75×10^{-2}. RDI exhibited negative correlation with organic carbon and significant effects were observed in the soils under Site-3 ($r = -0.62^{*}$). Similar relations for organic carbon with RDI were also reported by Sambyal and Sharma (1986).

5.6 TORRENT CHANNELISATION AND STABILIZATION THROUGH BIO-ENGINEERING MEASURES

5.6.1 Impact of bio-engineering measures on source area (torrent catchment)

5.6.1.1 Sediment retention

The data depicting sediment retention in source area is given in Table 4.13. The highest amount of sediment was retained by MVMs (mechanical + vegetative measure) to the tune of 96 kg during 2004 and 2005 and 99 kg during 2006. This may be due to sieving effect of vegetative reinforcement coupled with stabilization of mechanical structures. The findings are in close conformity with those of Juyal *et al.* (2005).Vegetative filters retained lowest amount of sediment (1 kg) every year because sediment passed easily through the wider spacing within vegetative filter.

Most of the bio-engineering structures were filled upto their full capacity in the year 2004 except some bigger check dams in lower part of catchment. In the year 2005, there was comparatively less rainfall and thus less sediment production. But during 2006 again there was heavy rainfall 'which produced high peak runoff rate consequently lesser sediment generation increased subsequently which was retained by bio-engineering structures.

5.6.1.2 D_{50} analysis of sediment

The median size, D_{50} value of sediment was found to be maximum (0.99 mm) under mechanical measures (Table 4.14) which may be due to the fact that finer particles escaped through the mechanical structures and only bigger size particles retained behind. Whereas, lowest D_{50} value (0.75 mm) was recorded under MVMs due to retention of only finer particles. Theses results are in close conformity with the findings of Juyal *et al.* (1995).

5.6.1.3 Nutrient status of sediment in source area

Available N, P and K contents were recorded highest under MVMs i.e. 143.3, 154.2 and 156.8 kg/ha available N, 31.4, 32.0 and 31.1 kg/ha available P and 203.2, 195.1 and 228.5 kg/ha available K in the year 2004, 2005 and 2006, respectively (Table 4.15 and Fig. 13). This may be due to favourable effect vegetative reinforcement on mechanical measures resulting in accumulation of more sediment and finer particles under MVMs and also due to addition of organic matter by the in-situ vegetation to the retained sediment in such measures. Lowest available N, P and K contents were recorded under GCDs, LBCDs and VFs, respectively during whole of the study period. As these structures retained only bigger sized sediment fraction which was deficient in nutrients. These results are in consonance with the findings of Yadav *et al.* (2006).

5.6.2 Impact of bio-engineering measures on torrent channelisation and stabilization

5.6.2.1 Sediment Deposition

The maximum increase in upstream and downstream deposition over initial year was recorded to the tune of 375.56 and 1142.86 per cent at spur numbers 13 and 19, respectively (Table 4.16). In the year 2005, there was no sediment retention by the spurs

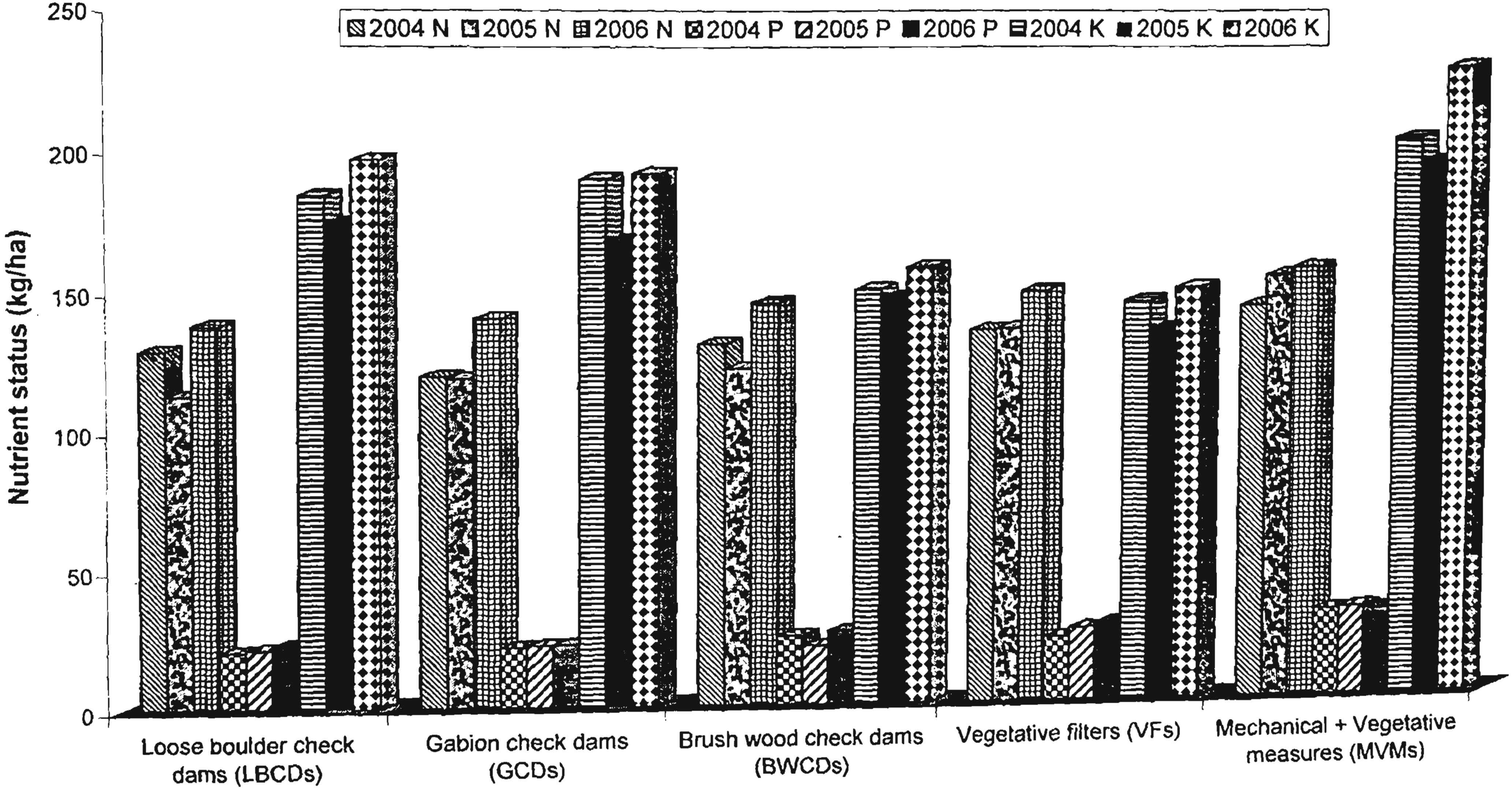


Fig. 13. Effect of bio-engineering measures on nutrient status (kg/ha) of sediment retained behind bioengineering measures in source area

due to less rainfall. There was no regular pattern of sediment deposition at every spur because some spurs were not at all touched by torrent flow and also there was illegal mining of stones, shingle and sand deposited around the spur. Therefore, exact picture of sediment deposition was not clear. The maximum height of downstream deposition of 1.40 and 1.20 m at a distance 10.00 and 15.90 m from spur was recorded under spur numbers 1 and 18 during 2004 and 2006, respectively which may be due to facing direct hit of torrent flow at a curve.

5.6.2.2 Scouring

The scouring varied from 0.007 tons to 0.231 tons during 2004. The maximum nose scour depth of 1.75 m was observed in the monsoon season of 2004 (Table 4.17). During 2006 monsoon rains, scouring varied widely with spurs (0.016-0.338 tons) and maximum nose scour depth of 0.90 m was recorded. The increase in scouring over initial year might be due to deepening of torrent bed by illegal removal of sediment (sand and shingle) and stones (Plate 9).

5.6.2.3 Capacity left for siltation

The capacity left for siltation in upstream and downstream sides of different spurs varied from 11.00-195.55, 18.35-204.25 and 15.35-240.00 m^3 in the upstream side and 3.20-425.20, 15.00-463.9 and 4.50-390.00 m^3 in the downstream side during the monsoon period of 2004, 2005 and 2006, respectively (Table 4.18). The changing irregular pattern of the capacity left for siltation may be due to meandering behaviour of torrent and removal of sediment by local people. Furthermore, the deposition at one spur during one flood may be shifted to other spur during other heavy torrent flow. The total capacity left for siltation of all the spurs in the torrent was recorded to be 1811.80, 2166.30 and 1835.00 m^3 on the upstream side and 1246.50, 1552.25 and 1165.65 m^3 on the downstream side the spur during the years 2004, 2005 and 2006, respectively. The increase in capacity left for siltation in the year 2005 was due to the fact that there was less sediment deposition because of less rainfall/runoff and whatever sediment was left in the torrent bed was removed by illegal sand and stone mining. Activities of local people further decrease in capacity during 2006 were due to fresh deposition of sediment.

5.6.2.4 Sediment retention under vegetative spurs

Among different vegetative spurs, maximum sediment retention was recorded under spur made up of mixture of species to the tune of 6.56 and 4.56 tons during the years 2004 and 2006 (Table 4.19) which may be ascribed to comparatively more thick plantation and more length of such vegetative spur. Whereas, lowest sediment was retained by Ipomoea spp. to the tune of 0.08 and 0.06 tons in the years 2004 and 2006, respectively. This was due to the fact that vegetative spur *Ipomoea spp.* was short in length and single stem plants of this species were unable to hold more sediment.

Among different vegetative spurs, maximum average sediment retention was recorded under *Saccharum munja* (0.30 tons/m) spur during the years 2004 and under spur made up of mixture of species (0.13 tons/m)·during the year 2006 (Table 4.19) which may be ascribed to comparatively fast growth and easy establishment of *Saccharum munja* in the initial year but damage due to torrent flow during 2006 decreased its retention. While the spur made up of mixture of species established well and spread in area around it during 2005 and retained more sediment. Whereas, lowest average sediment was retained by *Ipomoea spp.* to the tune of 0.15 and 0.08 tons/m during the year 2004 and 2006, respectively. The vegetative spur *Ipomoea spp.* was short in length and single stem plants of this species were unable to hold more sediment.

5.6.2.5 D_{50} analysis of sediment

Maximum D_{50} value was recorded in upper part of torrent (Table 4.20 and Figs. 8, 9 and 10) during the years 2004 (3.08 mm) and 2005 (2.25 mm) but in the middle part during 2006 (1.33 mm). On an average D_{50} value decreased every year and during study period maximum D_{50} value was recorded in upper part and lowest in middle part of the torrent. This may be due to less width, slightly more slope than middle part which was wider and gently sloping and thus at upper part there was increased velocity of torrent flow which left behind only bigger size sediment material and smaller sized material got

Plate 9. Sand, shingle and stone extraction from torrent bed, Site-1 (Barotiwala, Solan)

washed away and settles down in the middle part of torrent. Lower part again has less width and increased slope. Theses results are in consonance with the findings of Juyal *et al.* (1995).

5.6.2.6 Nutrient status of sediment of torrent bed

The highest available N, P and K contents were recorded under mechanical and vegetative measures together (except available N which was maximum under vegetative measures in middle part during 2006) in the middle part of the torrent (except available P which was maximum in upper part of torrent in the year 2006), during 2004, 2005 and 2006 (Table 4.21 and Fig. 14). In general available N, P and K contents were maximum under MVMs and in the middle part of torrent, which may be due to the fact that MVMs retained more sediment because of slowing down of torrent flow in the middle part of torrent and also contributed organic matter to sediment consequently retention of more sediment. Maximum available N, P and K contents were recorded to the tune of 81.54, 87.81 and 130.16 kg/ha available N, 25.01, 26.73 and 33.42 kg/ha available P and 141.12, 133.26 and 158.92 kg/ha available K during the years 2004, 2005 and 2006, respectively. The available nutrients in general increased every year which might be due to increase mineralization of organic matter. The lowest available N, P and K contents were recorded under vegetative measures (except available N which was lowest under mechanical measures in 2006) during the years 2004 (48.96, 12.60 and 104.16 kg/ha) and 2006 (54.60, 13.44 and 129.18) which might be due to retention of very less amount of sediment and whatever retained was of bigger size devoid of clay and organic matter. Whereas, in the year 2005 lowest N, P and K contents were recorded under mechanical measures i.e. 28.76, 12.60 and 92.96 kg/ha N, P and K, respectively, which may be due to absence of vegetative material in the measure. These results are in agreement with the observations of Yadav *et al.* (2006).

5.6.2.7 Survival and growth performance

The survival percentage decreased every year and maximum survival was shown by *Ipomoea spp.* i.e. 90, 88 and 71 per cent during 2004, 2005 and 2006, respectively

(Table 4.22). Better survival of *Ipomoea spp.* may be due to favourable climatic conditions in the area, secondly due to fast growing and easy sprouting properties of the species even in the difficult sites. The decrease in survival of other plant species may be due to climatic factors and damage by human activities, trampling or grazing by animal and destruction by torrent flow. These findings are in close agreement with those of Tiwari *et al.* (2005). *Vitex negundo* showed lowest survival percentage during 2005 (30%) and 2006 (12 %) and this may be due to less adaptability to the harsh weather conditions during the study period. Maximum growth increment in height was exhibited by *Ipomoea spp.* (200 cm) due to its genetic nature and lowest by *Saccharum munja* (56 cm). While maximum increment in basal diameter was shown by *Saccharum munja* (9.8 cm) and lowest by *Vitex negundo* (0.5 cm). *Saccharum munja* being a grass increases in clump or basal diameter, while, *Vitex negundo* being a bushy species grows in height and very slow in diameter growth.

5.6.2.8 Peak runoff rate, runoff and sediment yield

The peak runoff rate was recorded maximum (36.0 $m^3 s^{-1}$) in the monsoon, 2006 and lowest (9.5 $m^3 s^{-1}$) during 2005 (Table 4.23). This may be due to more concentrated rainfall during 2006 and very less rainfall in 2005. Runoff and sediment yield were recorded highest in monsoon, 2004 in both upper (10800 m^3 and 2.21 kg m^{-3}) and lower part (90000 m^3 and 36.08 kg m^{-3}) of torrent, respectively due to more rainfall during the monsoon season of the year 2004. The minimum runoff and sediment yield were recorded during monsoon, 2005 in both upper (3650 m^3 and 1.17 kg m^{-3}) and lower part (17100 m^3 and 10.41 kg m^{-3}) of the torrent, respectively.

5.6.2.9 Effect of spur and spur length on water course channelisation

The different attracting types of spurs of variable length deflected the water course or steam flow towards the central line to the tune of 9.0 m to 23.0 m in the year 2004 and 10.5 to 24.5 m during 2006 (Table 4.24). Maximum deflection was exhibited by spur number 18 upto 11.75 m and minimum by spur numbers 3 and 4 upto 5.9 m. The deflection of water course towards central line increased with the increase in the length of

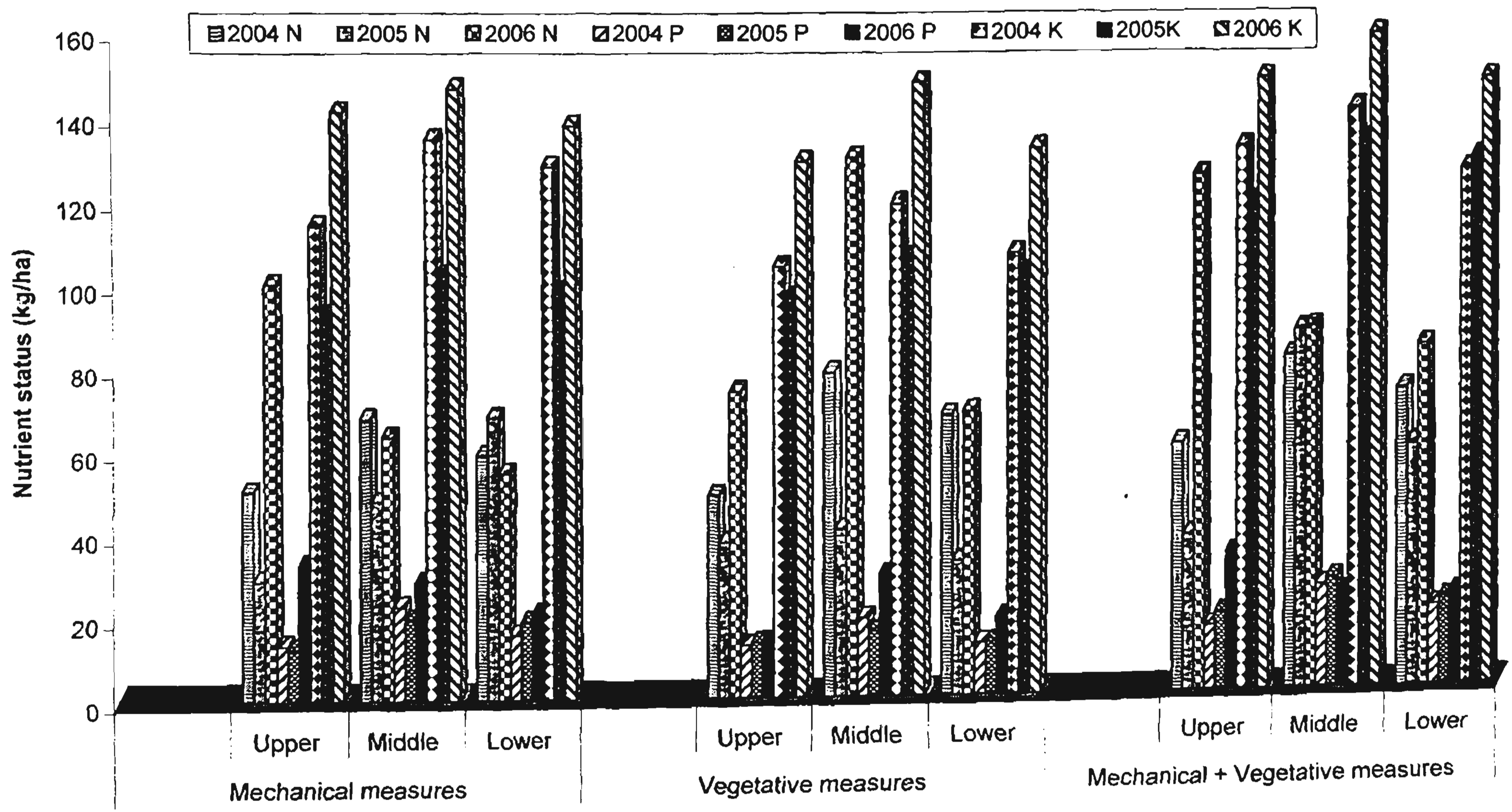


Fig. 14. Effect of bio-engineering measures on nutrient status (kg/ha) of sediment in the different parts of torrent bed

spur (Fig. 15). Slight variation in deflection of torrent flow may be due to several biotic and abiotic factors. The deflection of water course towards central line was 1.5 to 2.0 times the length of spur.

5.6.2.10 Assessment of condition of the structures

The spur no. 18 and 20 were badly damaged in the year 2004 and 2006 which were repaired subsequently. The vegetative spur made up of mixture of species was damaged by torrent flow. Out of the two retaining walls, one wall was not even touched by the torrent because of the presence of big spur in the front and second retaining wall was buried under landslide. Some of *Ipomoea spp.* and *Saccharum munja* spur were also damaged by torrent and local people (Plates 10a and 10b).

5.6.2.11 Effect of bio-engineering measures on dimensions (length, breadth and area) of torrent

Maximum decrease in torrent area was recorded in upper Joharanpur site (45.83 %) and minimum decrease in lower Joharanpur site (0.83 %). Maximum breadth (200 m) was recorded in upper Joharanpur site before treatment of the torrent which was reduced to 150 m after torrent treatment (Table 4.25 and Fig. 16). The decrease (30.51 %) in the torrent area may be due to stabilization of catchment area and channelisation of torrent towards central line by different bio-engineering measures. These results are also supported by the findings of Tiwari *et al.* (2005).

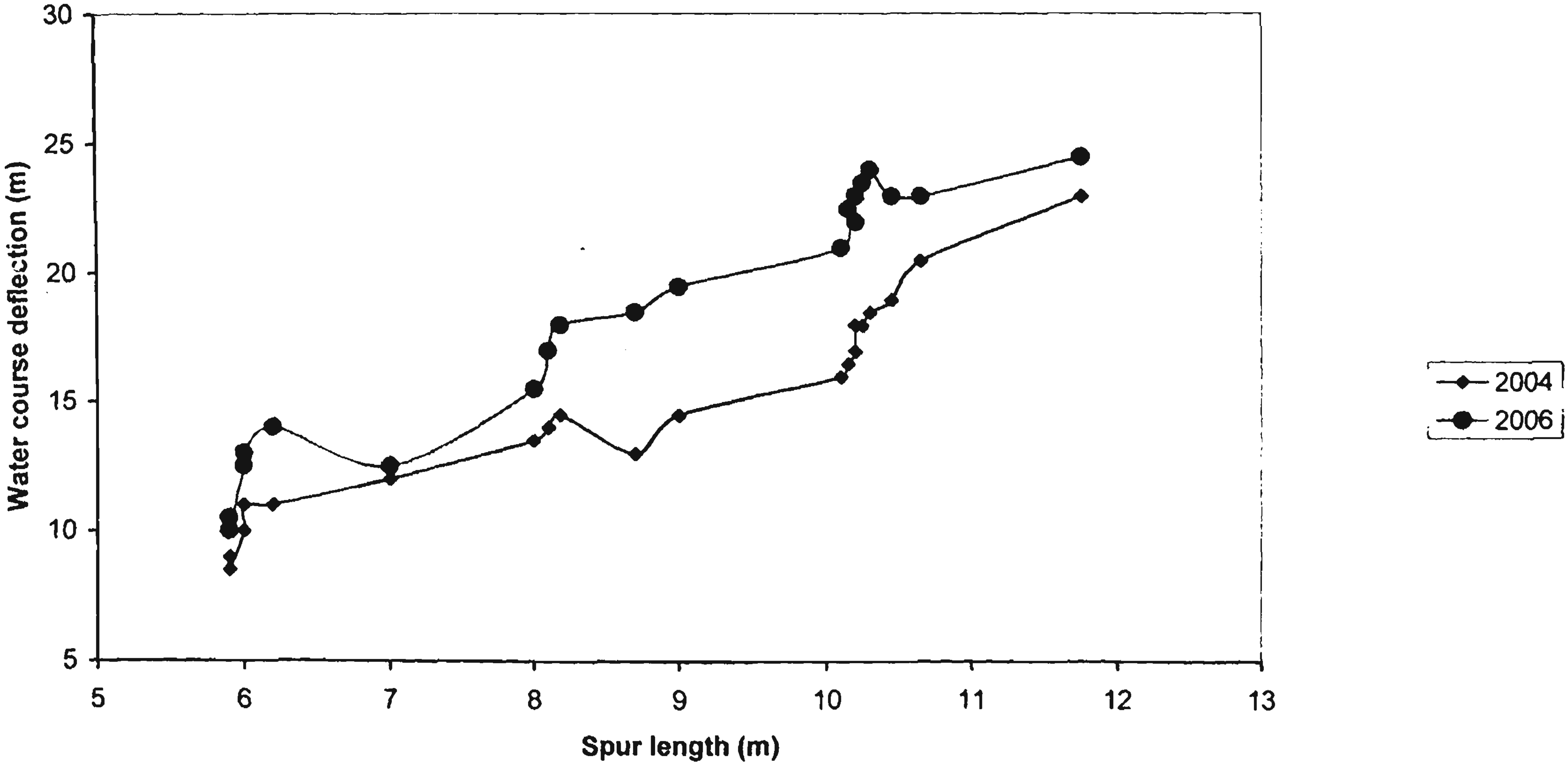


Fig. 15. Effect of spur length on water course deflection towards central line of torrent

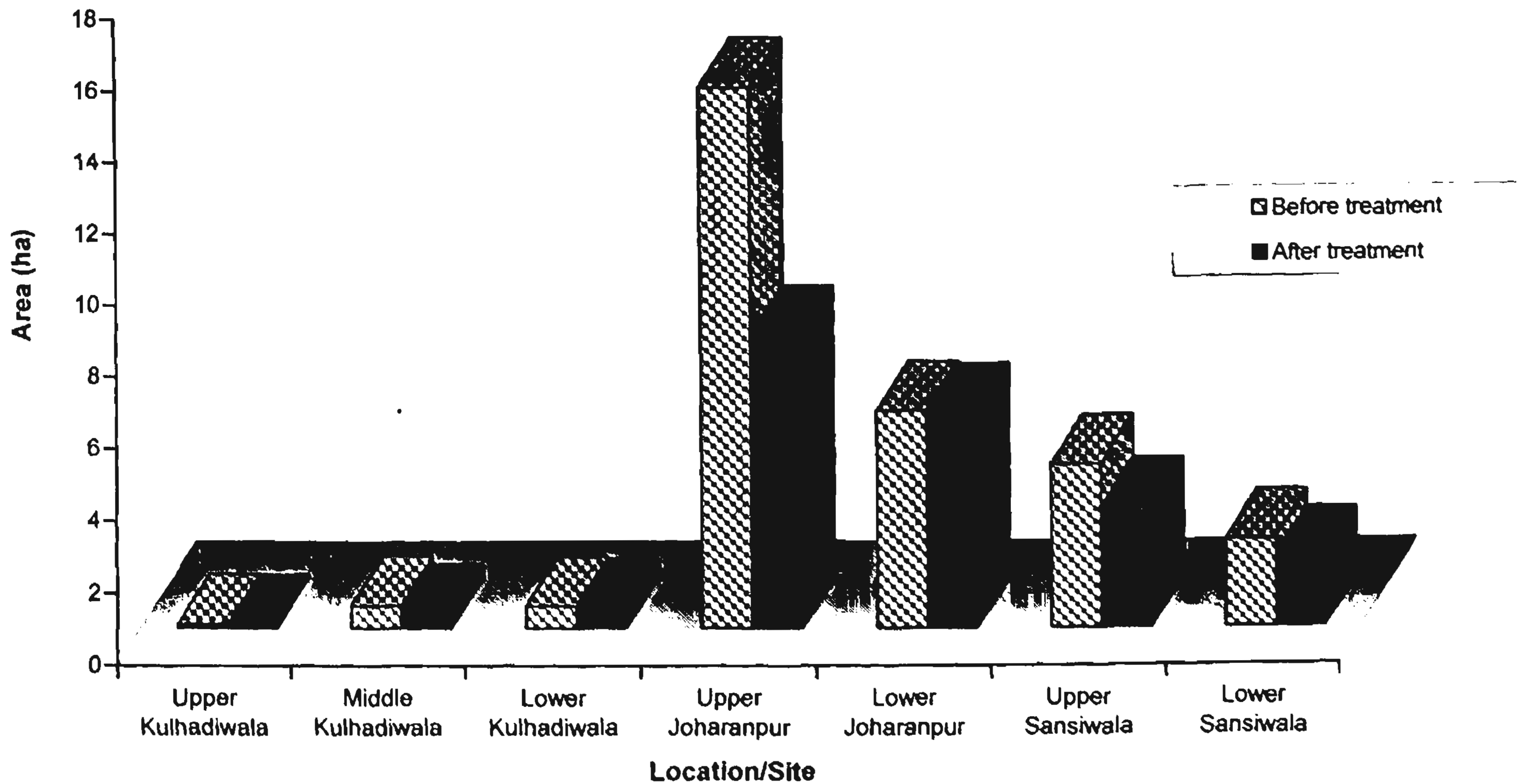


Fig. 16. Area under torrent before and after treatment

A. Retaining wall constructed in 2004

B. Retaining wall buried under landslide in 2006

Plate 10a. Damage to engineering structures – retaining wall

A. Damage to engineering measure (Spur)

B. Vegetative spur before flash flood

C. Damage to vegetative spur by flash flood

Plate 10b. Damage to bio-engineering structures – mechanical & vegetative spur

Chapter - VI

SUMMARY AND CONCLUSIONS

Chapter-6

SUMMARY AND CONCLUSIONS

An investigation entitled "Erodibility status of torrent affected area and its stabilization through bio-engineering measures in lower Shiwaliks of Himachal Pradesh" was undertaken to have an appraisal of the erodibility and stabilization of the torrent affected areas during the year 2004-2006. Study areas were parts of lower Shiwalik of Himachal Pradesh. On the basis of reconnaissance survey of the Shiwalik foothills, three torrent affected sites (one each in the district of Solan, Una and Kangra) were selected for the study. On the basis of area under different torrent affected sites three representative profiles were exposed at each site. Representative soil samples of each profile from different depths were collected. The samples were analyzed for various hydro-physical and chemical properties in the department of Soil Science and Water Management, Dr. Y.S. Parmar University of Horticulture and Forestry, Solan (H.P.). Soils were assessed for their erodibility behavior by computing and comparing various erodibility indices. The impact of bio-engineering measures on runoff, sediment yield, torrent channelisation and its stabilization was studied only at Site-1 (Barotiwala, Solan) falling in Nalagarh tehsil of Solan district of Himachal Pradesh. The results obtained are summarized as below:

6.1 PHYSICAL PROPERTIES

Mechanical composition revealed that soils are coarser in texture with abundance of gravels and sand fraction and coarsest texture (gls) was observed in all the sites.

The bulk density of soils in different torrent affected areas varied from 1.65-1.72 Mg m^{-3}. It was highest (1.72 Mg m^{-3}) under Site-2, probably due to coarse texture and lower organic carbon, whereas, lowest values were found in Site-1 soils (1.65 Mg m^{-3}).

The particle density was significantly higher in Site-3 (2.68 Mg m^{-3}). Porosity was found to be highest (37.60 %) in Site-1 and may be due to lower bulk density and higher percentage of finer fractions of soil.

Aggregates >0.25 mm in diameter were found to be highest in Site-1 soils. Lowest percentage of these aggregates (> 0.25 mm in diameter) was recorded in the Site-2 soils.

6.2 HYDRAULIC PROPERTIES

Water retention was found to be comparatively higher in Site-1 as compared to other sites. In general, soils were found to have poor moisture retention because of their coarse texture. Highest moisture retention at 33 and 1500 kPa suctions was observed in the soils under Site-1 (10.65 and 3.31 %). Lowest values of moisture retention at these suction levels were observed in the soils under Site-2. (7.16 and 1.81 %). AWC was found to be highest in Site-1 soils (11.12 cm/0.90m), whereas, lowest was observed in the soils under Site-2 (8.74 cm/0.90m) On the basis of available water capacity, different torrent affected sites can be arranged in the following order: Site-1 > Site-3 > Site-2. Similar trend was followed in MWHC which was found to be highest (31.87 %) in the soils under Site-1. Lowest MWHC was recorded in Site-2 (28.22). Saturated hydraulic conductivity was found to be highest (20.87 cm hr^{-1}) in Site-2 and lowest in the soils under Site-1 (4.12 cm hr^{-1}). It was found to be moderate to very rapid in Site-2 and Site-3 soils, suggesting that both the sites are highly permeable due to coarser texture.

The lower part of torrent had comparatively higher infiltration rate (3.0 x 2.78 x 10^{-6} m s^{-1}) as well as cumulative infiltration (14.3 x 10^{-2} m) which indicate that these soils have poor water storage and rain water is quickly lost due to deep percolation. This could be probably due to coarser texture and preponderance of pebbles and gravels in the lower part of the torrent which made it more porous and permeable, thus providing easy path for water to infiltrate down the profile. Lowest infiltration rate and cumulative infiltration (2.4 x 2.78 x 10^{-6} m s^{-1} and 8.6 x 10^{-2} m) were recorded in the upper part of torrent, which may be due to clogging of soil pores, compact surface layers in the torrent catchment and movement of water down the profile is not easier which consequently leads into increased surface runoff.

6.3 CHEMICAL PROPERTIES

All the soils are alkaline in reaction (7.71-7.94) under different torrent affected sites (Table 4.6). Among the sites, comparatively lower pH (7.71) was recorded in

Site-1 and highest under Site-3 (7.94). EC was found to be same in the soils of all sites (0.14 dS m^{-1}).

The highest OC contents were found under Site-1 (3.38 g kg^{-1}) whereas, lowest (2.31 g kg^{-1}) under Site-2 soils. On the basis of OC, the sites can be arranged as:

Site-1 > Site-3 > Site-2

According to its critical limits, available N contents under all the sites were found in low category. However, among different sites, comparatively higher contents were found in Site-1 (155.6 kg ha^{-1}), whereas, lowest in the soils under Site-2 (90.8 kg ha^{-1}).

Available P status was in low to medium in all the torrent affected sites. Among the sites, highest contents were recorded in the soils under Site-1 (18.4 kg ha^{-1}) and lowest (7.2 kg ha^{-1}) in Site-3.

Available K was found in low to medium range in all the sites under study. However, comparatively higher contents were recorded in Site-1 (84.4 kg ha^{-1}), followed by Site-3 (25.2 kg ha^{-1}), whereas, lowest values were recorded in Site-2 (21.5 kg ha^{-1}).

Highest exchangeable Ca^{2+} was observed in Site-3 soils (9.55 cmol (p^+) kg^{-1}) and lowest in Site-2 soils (4.59 cmol (p^+) kg^{-1}). Whereas, highest values of exchangeable Mg^{2+} and K^+ were recorded in Site-1 soils (1.26 and 0.10 cmol (p^+) kg^{-1}), respectively. Exchangeable Na^+ was recorded to be highest under Site-2 (1.02 cmol (p^+) kg^{-1}) and lowest under Site-3 soils (0.87 cmol (p^+) kg^{-1}). The highest available S contents (25.7 kg ha^{-1}) were observed in the soils of Site-3.

6.4 ERODIBILITY STATUS OF SOILS OF TORRENT AFFECTED AREAS

Based upon analytical data, erodibility indices viz. CR, SCR, DR, ER, EI, and soil stability indices like WSA (>0.25 mm), MWD and RDI were computed. Based on threshold limit of DR, all soils under torrent affected areas were found highly erodible. On an average, it varied from 50.83-59.14 in the three torrent affected sites. However, among the sites, the soils under Site-2 were found comparatively more erodible in nature as the DR under this site was highest i.e. 59.14 and Site-1 was found to be less erodible than other sites. On the basis of average values of DR, the torrent affected sites can be arranged in the following order for erodibility status:

Site-2 > Site-3 > Site-1

Erosion ratio was found to be highest (292.64) in Site-3 and lowest i.e. 94.48 was observed in Site-1. All the torrent affected sites according to ER, were found to be highly erodible. The torrent affected sites can be arranged in the order of their erodibility as follows:

Site-3 > Site-2 > Site-1

Erosion index was found to be positively correlated with ER, in all the sites. According to this index, soils under all the torrent affected sites were found to be erodible. Among the sites, EI was found to be highest in soils of Site-3 (1421.65), whereas, lowest value was observed under Site-1(164.59). Based upon this index, the torrent affected sites can be arranged in the order of their erodibility as:

Site-3 > Site-2 > Site-1

Aggregate stability regarded as an infallible index of inherent susceptibility of soil to erosion, expressed in terms of WSA (>0.25 mm) and MWD was found to be comparatively higher in the soils of Site-1 i.e. 40.88 per cent and 1.02 mm, respectively (Table 4.10). The lowest values of WSA (>0.25 mm) and MWD were observed in Site-2 (24.47 and 0.47 mm). On the basis of average values of WSA and MWD, the torrent affected sites can be arranged in the following order for the stabilityy :

Site-1>Site-3 > Site-2

As per the ratings of RDI, soils of all the sites were found to be highly erodible but there was no significant difference in erodibility among sites. However, soils under Site-3 were found to be comparatively more erodible as RDI was of very high order i.e. 61.75 x 10^{-2}.). Different torrent affected sites can be arranged in the order of their resistance to erodibility according to this index, as follows:

Site-3 > Site-2 > Site-1

6.6 TORRENT CHANNELISATION AND STABILIZATION THROUGH BIO-ENGINEERING MEASURES

6.6.1 Impact of bio-engineering measures on source area (torrent catchment)

The highest amount of sediment was retained by MVMs (mechanical + vegetative measure) to the tune of 99 kg during the study period. Vegetative filters retained lowest amount of sediment (1 kg) every year.

The median size, D_{50} value of sediment was found to be highest (0.99 mm) under mechanical measures (Table 4.17) and lowest (0.75 mm) under MVMs.

Available N, P and K contents were recorded highest under MVMs i.e. 143.3, 154.2 and 156.8 kg/ha available N; 31.4, 32.0 and 31.1 kg/ha available P and 203.2, 195.1 and 228.5 kg/ha available K in the year 2004, 2005 and 2006, respectively. Lowest available N, P and K contents were recorded under GCDs, LBCDs and VFs, respectively during whole of the study period.

6.6.2 Impact of bio-engineering measures on torrent channelisation and stabilization

The highest increase in upstream and downstream deposition over initial year (2004) was recorded to the tune of 375.56 and 1142.86 per cent at spur numbers 13 and 19, respectively. In the year 2005, there was no sediment retention by the spurs due to less rainfall. The maximum height of downstream deposition of 1.40 and 1.20 m at a distance 10.00 and 15.90 m from spur was recorded under spur numbers 1 and 18 during 2004 and 2006, respectively.

The scouring varied from 0.007 tons to 0.231 tons during 2004 and maximum nose scour depth of 1.75 m was observed in the monsoon season of 2004. During 2006 monsoon rains, scouring varied widely with spurs (0.016-0.338 tons) and maximum nose scour depth of 0.90 m was recorded.

The capacity left for siltation in upstream and downstream sides of different spurs varied widely and had irregular pattern due to meandering behaviour of torrent flow and human activities. The total capacity left for siltation of all the spurs in the torrent was recorded to be 1811.80, 2166.30 and 1835.00 m^3 on the upstream side and

1246.50, 1552.25 and 1165.65 m^3 on the downstream side of the spur during the years 2004, 2005 and 2006, respectively.

Highest average sediment retention was recorded under vegetative spur made up of *Saccharum munja* (0.30 tons/m) spur during the years 2004 and under spur made up of mixture of species (0.13 tons/m) during the year 2006. Whereas, lowest average sediment was retained by *Ipomoea spp.* to the tune of 0.15 and 0.08 tons/m during the year 2004 and 2006, respectively.

Highest D_{50} value was recorded in upper part of torrent during the years 2004 (3.08 mm) and 2005 (2.25 mm) but in the middle part during 2006 (1.33 mm). On an average D_{50} value decreased every year and highest D_{50} value (2.14 mm) during study period was recorded in upper part and lowest in middle part of the torrent.

Available N, P and K contents in general were highest under MVMs and in the middle part of torrent. Highest available N, P and K contents were recorded to be 81.54, 87.81 and 130.16 kg/ha available N; 25.01, 26.73 and 33.42 kg/ha available P and 141.12, 133.26 and 158.92 kg/ha available K during the years 2004, 2005 and 2006, respectively. The available nutrients in general increased every year. The lowest available N, P and K contents were recorded under vegetative measures (except available N which was lowest under mechanical measures in 2006) during the years 2004 (48.96, 12.60 and 104.16 kg/ha) and 2006 (54.60, 13.44 and 129.18). Whereas, in the year 2005 lowest N, P and K contents were recorded under mechanical measures i.e. 28.76, 12.60 and 92.96 kg/ha N, P and K, respectively.

The survival percentage of each species decreased every year and highest survival was shown by *Ipomoea spp.* i.e. 90, 88 and 71 per cent during 2004, 2005 and 2006, respectively. While *Vitex negundo* showed lowest survival percentage during 2005 (30%) and 2006 (12 %). Highest growth increment in height was exhibited by *Ipomoea spp.* (200 cm). While highest increment in basal diameter was shown by *Saccharum munja* (9.8 cm) and lowest by *Vitex negundo* (0.5 cm).

The peak runoff rate was recorded to be highest (36.0 $m^3 s^{-1}$) in the monsoon, 2006 and lowest (9.5 $m^3 s^{-1}$) during 2005. Runoff and sediment yield were recorded to be highest in monsoon, 2004 in both upper (10800 m^3 and 2.21 kg m^{-3}) and lower part (90000 m^3 and 36.08 kg m^{-3}) of torrent, respectively.

Maximum deflection of water course towards central line was exhibited by spur numbers 18 upto 11.75 m and minimum by spur numbers 3 and 4 upto 5.9 m. The deflection of water course towards central line increased with the increase in the length of spur.

The spur no. 18 and 20 were badly damaged in the year 2004 and 2006. The vegetative spur made up of mixture of species was damaged by torrent flow. Out of the two retaining walls, one wall was buried under landslide. Some of *Ipomoea spp.* and *Saccharum munja* spur were also damaged by torrent and local people.

Maximum decrease in torrent area (45.83 %) and increase in breadth (200 m) were recorded in upper Joharanpur site. Maximum breadth before treatment which was reduced to 150 m after torrent treatment. There was an appreciable decrease (30.51 %) in the total torrent area.

CONCLUSIONS

Present investigations reveal that soils of lower Shiwalik of Himachal Pradesh are coarse in texture and sand constituted the dominant fraction. Soils are characterized by high bulk density and low porosity due to their mechanical composition. Among the torrent affected sites, Site-1 has better aggregate stability due to higher organic matter contents and presence finer fractions of soil.

The soils of the area are poor in moisture retention, highly permeable and have low available water capacity and will be unable to supply sufficient water for better vegetation/crop performance. All these observations amply make clear that the vegetation of the torrent affected area may encounter frequent severe moisture stress conditions, thus suggesting the need for appropriate soil and water conservation measures. Fertility status of the soils indicates that these are poor in available N, low to medium in P and K status. These soils require some nitrogen fixing and drought hardy species for the rehabilitation of such torrent affected areas.

Erodibility indices viz. ER and EI agreed fairly well with the field behaviour of the soils and all the soils were found highly erodible, however, Site-1 (Barotiwala, Solan) soils were comparatively less erodible. Secondly, determination of EI is simpler and less time consuming compared to ER. Hence, it can be considered as good index of erodibility for torrent affected areas of lower Shiwaliks of H.P.

Raindrop erodibility index agreed well with the field observations as soils under Site-1 were found in stable category.

Considering the status of various soil hydro-physical and chemical characteristics and catchment characteristics, these torrent affected areas need special management practices for soil and water conservation, nutrient management and permanent vegetative cover to check land degradation. So, different bio-engineering measures were tried to reclaim such torrent affected areas.

Mechanical measures reinforced with vegetative cutting of *Ipomoea spp.*, *Saccharum munja* and *Vitex negundo* were found to be effective in reducing sediment yield to the torrent and stabilization of source area (torrent catchment). These measures retained of the sediment (which otherwise escape from mechanical or vegetative measure alone) and thus reduced the sediment load in the torrent and decreased the D_{50} value of sediment. These measures also retained highest amount of available nutrients in the sediments of the source area as well as of torrent bed.

Attracting type spurs of different lengths retained appreciable amount of sediment both on upstream and downstream side. Most of the spurs still had get some capacity left for siltation. Scouring and maximum nose score increased due to illegal removal of sediment (sand and shingle) and stones.

Vegetative spur of *Saccharum munja* retained maximum sediment. However, for longer life of spur, good stabilization and maximum sediment retention, spurs made up of mixture of species (*Ipomoea spp.*, *Saccharum munja* and *Vitex negundo*) were found to be more effective.

The survival percentage of species tried decreased every year and maximum survival was shown by *Ipomoea spp.* and minimum by *Vitex negundo*. Maximum growth increment in height was exhibited by *Ipomoea spp.* and in basal diameter by

Saccharum munja. So, *Ipomoea spp.* and *Saccharum munja* are most suitable species for torrent affected areas.

The nutrient status was found to be highest under MVMs (mechanical + vegetative). Middle part of the torrent contains finer particles and has more available nutrients as compared to upper and lower parts of the torrent.

Sediment and runoff yield was checked and due to stabilizing effect of bio-engineering measures and torrent flow was channelized towards central line of torrent. But due to removal of sediment, sand and shingle and damage by torrent to the bio-engineering measures, desired effects of these measures could not be ascertained.

Percolating type of gully plugs (BWCDs, GCDs, LBCDs etc.) were found suitable and effective up to some extent in checking the sediment. However, it was found that with the passage of time, the percolating type gully plugs become clogged and have a risk of being washed away in large volume of flow. Combination of vegetative measures (Spurs of *Ipomoea spp.*, *Saccharum munja* and *Vitex negundo*) with the mechanical/engineering measure gave good performance. The reinforced vegetation in mechanical measure not only helped in stabilizing the structure but also encouraged the sediment deposition, as vegetation grows further and provides long term protection on sustainable basis. Consequently, reductions in the sediment load in the downstream. Vegetative measures along with engineering measures were found to be most suitable combination for stabilizing the torrents and enhancing the sediment deposition between the spurs and along the bank. On account of these measures, about 40 hectares of land was protected from the menace of torrent and a reduction of 30.51 per cent in the torrent spread was recorded in the present investigation. Adoption of appropriate site specific bio-engineering measures in torrents reclaims and protects hundreds of hectares of land from degradation by gully and stream bank erosion within a period of 3-4 years. The reclaimed land could be further utilized for agricultural, horticultural and fodder crops cultivation, resulting in improvement in economy of the farmers. Hence, torrent treatment should form an important component of watershed development in the torrent affected areas of lower Shiwaliks of H.P. and other States. People participation is very necessary for such type of study. There should be a complete ban on removal of sediment, sand and shingle etc. from torrent bed and awareness camps about torrent menace and its reclamation need to be arranged in such areas.

Chapter - VII

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ABSTRACT

Dr. Y.S. Parmar University of Horticulture and Forestry, Nauni, Solan (H.P.) 173 230
Department of Soil Science and Water Management

Title of Thesis	:	**Erodibility status of torrent affected area and its stabilization through bio-engineering measures in lower Shiwaliks of Himachal Pradesh**
Name of the Student	:	**Yogender Sharma**
Admission Number	:	F-2003-11-D
Major Advisor	:	Dr I P Sharma
Major Field	:	Soil Science and Water Management
Minor Field(s)	:	i) Plant Physiology ii) Silviculture and Agroforestry
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ABSTRACT

Present investigations entitled "Erodibility status of torrent affected area and its stabilization through bio-engineering measures in lower Shiwaliks of Himachal Pradesh" were conducted in lower Shiwaliks of HP at three sites viz. Site-1 (Barotiwala, Solan), Site-2 (Pekhuwala, Una) and Site-3 (Nurpur, Kangra) during 2004-2006. Results of the study revealed that the torrent affected sites on the basis of erodibility indices viz. clay ratio (CR), silt: clay ratio (SCR), erosion ratio (ER), erosion index (EI) and raindrop impact (RDI) followed the order for their erosional behaviour as: Site-3 > Site-2 > Site-1. On the basis of dispersion ratio (DR), the sites can be arranged in the order: Site-2 > Site-3 > Site-1. Both ER and EI agreed fairly well with the field observations and all soils were found highly erodible, however, Site-1 (Barotiwala, Solan) soils were comparatively less erodible and Site-3 highly erodible. On the basis of WSA and MWD, torrent affected sites can be arranged in the order: Site-1> Site-3 > Site-2. Mechanical measures reinforced with vegetative cuttings of *Ipomoea spp., Saccharum munja* and *Vitex negundo* were effective in reducing sediment yield to the torrent and stabilization of source area /torrent catchment. Attracting type spurs of different lengths retained ample quantity of sediment both on upstream and downstream sides. Highest increase in upstream and downstream deposition was to the tune of 375.56 and 1142.86 per cent over initial year (2004). *Ipomoea spp.* and *Saccharum munja* are the most suitable species for studied torrent affected areas. Nutrient status of sediment was found to be highest under MVMs (mechanical + vegetative). Peak runoff rate was highest (36.0 $m^3 s^{-1}$) in the monsoon, 2006 and lowest (9.5 $m^3 s^{-1}$) during 2005. Runoff and sediment yield were highest in monsoon, 2004 and lowest in 2005. Stabilizing effect of bio-engineering measures on channelisation of torrent flow towards central line decreased sediment and runoff yield. Vegetative measures along with engineering measures were found most suitable combinations for stabilizing the torrents and enhancing the sediment deposition between the spurs and along the bank which consequently protected about 40 hectares of land from the menace of torrent. An appreciable reduction i.e. 30.51 per cent in the torrent spread was recorded in the present investigation. Adoption of site specific bio-engineering measures in the torrents can reclaim and protect hundreds of hectares of land within a period of 3-4 years from inundation and degradation by gully and stream bank erosion.

Signature of the Major Advisor **Signature of the Student**

Countersigned

Professor and Head,
Department of Soil Science and Water Management
Dr. Y.S. Parmar University of Horticulture & Forestry, Nauni, Solan, (H.P.) - 173 230

APPENDICES

Appendix –I

Mechanical composition of soils of torrent affected areas

Location/ Site	Depth (cm)	Gravel %	Coarse sand %	Fine sand %	Total sand %	Silt %	Clay %
Site-1 (Barotiwala, Solan)							
S1	0-12	18.15	41.51	40.69	82.20	12.72	5.08
	12-53	83.60	58.02	28.84	86.86	10.24	2.88
	53-80	52.00	63.18	23.86	87.04	8.22	4.74
	80-100	49.60	72.17	17.01	89.18	7.20	3.62
S2	0-32	29.33	34.54	44.00	78.54	15.20	6.26
	32-88	60.33	36.91	42.26	79.17	14.82	6.01
	88-130	0.00	1.58	55.84	57.42	36.32	6.26
S3	0-45	2.60	12.90	63.23	76.13	16.78	7.08
	45-95	46.60	53.37	36.49	89.86	6.96	3.18
	95-135	75.33	63.29	28.73	92.02	5.48	2.50
Site-2 (Pekhuwala, Una)							
U1	0-18	0.00	18.91	61.25	80.16	17.34	2.50
	18-30	0.00	29.97	54.13	84.10	14.18	1.72
	30-100	0.00	0.91	84.13	85.04	13.00	1.96
U2	0-10	5.30	32.23	57.05	89.28	8.50	2.22
	10-20	32.60	40.89	49.67	90.56	7.94	1.50
	20-50	43.00	58.19	35.35	93.54	5.20	1.26
	50-90	27.33	63.65	30.95	94.60	4.42	0.98
U3	0-5	8.45	25.67	69.21	94.88	4.78	0.34
	5-20	58.35	92.47	6.87	99.34	0.48	0.18
	20-35	1.00	91.26	7.29	98.55	0.59	0.86
	35-110	82.30	93.14	5.68	98.82	0.68	0.50
	110-140	5.60	53.33	24.66	77.99	16.36	5.64
Site-3 (Nurpur, Kangra)							
K1	0-25	1.60	31.04	39.16	70.20	25.72	4.08
	25-90	5.90	37.14	39.74	76.88	19.90	3.22
	90-150	10.60	42.80	29.38	72.18	24.44	3.38
	150-230	34.45	33.38	44.26	77.64	19.40	2.96
K2	0-20	0	25.81	47.84	73.65	22.30	4.04
	20-50	7.33	88.09	10.68	98.77	1.10	0.12
	50-60	87.6	90.22	7.16	97.38	1.97	0.65
K3	0-35	24.3	15.38	68.72	84.10	13.12	2.78
	35-50	2	13.93	79.32	93.25	5.32	1.42
	50-67	1.6	5.53	63.85	69.38	24.84	5.78
	67-90	3.6	35.28	62.12	97.40	2.42	0.18
	90-190	85.3	79.22	18.94	98.16	1.06	0.78

Appendix –II
Physical properties of soils of torrent affected areas

Location/ Site	Depth (cm)	BD (Mg m^{-3})	PD (Mg m^{-3})	PROSITY %
Site-1 (Barotiwala, Solan)				
S1	0-12	1.51	2.62	42.37
	12-53	1.56	2.65	41.13
	53-80	1.64	2.65	38.11
	80-100	1.71	2.67	35.96
S2	0-32	1.49	2.63	43.35
	32-88	1.64	2.65	38.11
	88-130	1.66	2.67	37.83
S3	0-45	1.67	2.61	36.02
	45-95	1.72	2.65	35.09
	95-135	1.54	2.59	40.54
Site-2 (Pekhuwala, Una)				
U1	0-18	1.67	2.78	39.93
	18-30	1.68	2.78	39.57
	30-100	1.38	2.63	47.53
U2	0-10	1.69	2.60	35.00
	10-20	1.78	2.63	32.32
	20-50	1.79	2.64	32.20
	50-90	1.81	2.66	31.95
U3	0-5	1.59	2.59	38.61
	5-20	1.71	2.66	35.71
	20-35	1.66	2.56	35.16
	35-110	1.83	2.63	30.42
	110-140	1.91	2.70	29.26
Site-3 (Nurpur, Kangra)				
K1	0-25	1.53	2.62	41.60
	25-90	1.67	2.65	36.98
	90-150	1.53	2.66	42.48
	150-230	1.66	2.66	37.59
K2	0-20	1.47	2.62	43.89
	20-50	1.68	2.68	37.31
	50-60	1.69	2.67	36.70
K3	0-35	1.62	2.68	39.55
	35-50	1.60	2.67	40.07
	50-67	1.51	2.66	43.23
	67-90	1.63	2.67	38.95
	90-190	1.92	2.74	29.93

Appendix –III
Aggregate size distribution of soils of torrent affected areas

Location/ Site	Depth (cm)	Aggregate size distribution (%)					
		>5mm	2-5mm	1-2mm	0.5-1mm	0.25-0.5mm	0.1-0.25mm
Site-1 (Barotiwala, Solan)							
S1	0-12	28.67	6.50	7.69	13.60	18.85	24.70
	12-53	6.05	5.04	3.72	19.43	32.82	32.95
	53-80	5.94	4.63	8.78	15.24	30.32	35.10
	80-100	1.73	1.76	3.49	19.16	38.20	35.65
S2	0-32	61.19	7.35	4.27	6.33	10.82	10.05
	32-88	0.00	0.00	0.00	0.00	0.00	0.00
	88-130	0.00	0.00	0.00	0.00	0.00	0.00
S3	0-45	88.75	3.64	1.20	1.68	1.48	3.25
	45-95	7.03	4.35	4.82	10.40	11.76	61.65
	95-135	18.52	8.80	4.43	15.87	20.70	31.69
Site-2 (Pekhuwala, Una)							
U1	0-18	21.02	4.34	16.69	16.34	13.96	27.66
	18-30	20.98	4.21	15.63	17.13	14.02	28.02
	30-100	0.00	1.56	3.15	12.49	34.11	48.70
U2	0-10	0.00	0.00	0.00	0.00	0.00	0.00
	10-20	0.00	0.00	0.00	0.00	0.00	0.00
	20-50	0.00	0.00	0.00	0.00	0.00	0.00
	50-90	0.00	0.00	0.00	0.00	0.00	0.00
U3	0-5	0.00	0.00	0.00	0.00	0.00	0.00
	5-20	0.00	0.00	0.00	0.00	0.00	0.00
	20-35	1.93	15.49	6.23	12.85	12.08	51.41
	35-110	0.00	0.00	0.00	0.00	0.00	0.00
	110-140	0.00	0.00	0.00	0.00	0.00	0.00
Site-3 (Nurpur, Kangra)							
K1	0-25	28.99	25.84	4.66	6.01	10.92	23.59
	25-90	0.00	0.00	0.00	0.00	0.00	0.00
	90-150	0.00	0.00	0.00	0.00	0.00	0.00
	150-230	0.00	0.00	0.00	0.00	0.00	0.00
K2	0-20	50.91	9.28	7.87	6.71	7.95	17.26
	20-50	28.32	14.92	3.88	7.46	15.24	30.19
	50-60	11.71	7.89	11.41	17.08	18.06	33.85
K3	0-35	0.00	0.00	0.00	0.00	0.00	0.00
	35-50	0.00	0.00	0.00	0.00	0.00	0.00
	50-67	0.03	0.52	2.55	14.60	39.85	42.46
	67-90	0.00	0.00	0.00	0.00	0.00	0.00
	90-190	0.00	0.00	0.00	0.00	0.00	0.00

Appendix –IV
Moisture retention at different suctions (ψ) of soils of torrent affected areas

Location/ Site	Depth (cm)	Water retention (w/w %) at kPa					
		33	50	70	100	500	1000
Site-1 (Barotiwala, Solan)							
S1	0-12	11.56	8.87	6.31	3.57	2.91	2.41
	12-53	9.31	7.34	5.00	3.08	2.56	2.22
	53-80	9.50	7.50	6.10	4.07	3.48	2.78
	80-100	9.27	7.98	4.42	3.16	2.63	2.35
S2	0-32	14.68	11.32	8.67	5.68	4.54	4.28
	32-88	14.51	11.10	8.63	5.26	4.51	4.24
	88-130	32.14	27.61	17.53	10.05	8.62	6.94
S3	0-45	18.49	13.26	8.57	4.53	3.64	2.99
	45-95	10.19	7.34	5.43	3.68	3.07	2.69
	95-135	7.85	5.48	4.23	2.93	2.38	2.28
Site-2 (Pekhuwala, Una)							
U1	0-18	18.48	12.66	6.90	3.61	3.16	2.52
	18-30	18.16	12.17	6.53	3.22	2.90	2.41
	30-100	27.38	13.64	6.13	3.27	2.92	2.39
U2	0-10	9.73	7.19	4.52	2.92	2.39	2.12
	10-20	9.41	7.15	4.30	2.39	2.13	1.93
	20-50	12.58	5.68	3.58	2.05	1.67	1.54
	50-90	13.86	3.94	2.56	1.48	1.21	1.12
U3	0-5	11.45	7.05	4.04	2.05	1.88	1.79
	5-20	5.79	1.96	1.19	0.91	0.76	0.65
	20-35	5.78	1.95	1.18	0.91	0.74	0.65
	35-110	5.77	1.94	1.17	0.90	0.75	0.65
	110-140	21.78	15.50	11.33	6.76	6.16	5.49
Site-3 (Nurpur, Kangra)							
K1	0-25	19.62	15.94	10.34	5.27	4.20	3.78
	25-90	19.71	13.01	8.11	4.33	3.61	3.51
	90-150	17.80	14.06	8.26	4.27	3.52	3.25
	150-230	21.50	15.18	10.35	5.37	4.40	4.14
K2	0-20	23.41	16.62	10.71	8.75	4.62	3.79
	20-50	4.58	2.04	1.64	1.24	1.07	1.03
	50-60	3.18	2.48	1.82	1.32	1.21	1.15
K3	0-35	17.77	12.89	7.02	3.15	2.60	2.46
	35-50	12.39	6.01	3.68	1.62	1.53	1.37
	50-67	27.30	19.73	10.60	4.80	4.18	3.44
	67-90	6.55	2.15	1.45	0.89	0.83	0.79
	90-190	4.98	2.46	1.86	1.08	0.95	0.86

Appendix –V
Hydraulic properties of soils of torrent affected areas

Location/ Site	Depth (cm)	AW (w/w, %)	AWC (cm/0.90 m)	MWHC %	K_s (cm hr^{-1})
Site-1 (Barotiwala, Solan)					
S1	0-12	6.46	8.43	35.72	1.72
	12-53	5.12		30.70	1.40
	53-80	4.72		29.86	2.22
	80-100	5.63		27.13	26.63
S2	0-32	7.04	15.36	38.48	1.29
	32-88	6.86		37.44	1.31
	88-130	20.67		36.68	1.55
S3	0-45	10.27	9.57	27.04	0.70
	45-95	4.65		27.52	3.44
	95-135	3.20		41.14	6.45
Site-2 (Pekhuwala, Una)					
U1	0-18	10.14	15.94	30.07	2.53
	18-30	9.76		29.83	3.08
	30-100	11.25		53.10	2.99
U2	0-10	5.07	5.55	24.16	10.57
	10-20	5.22		21.18	5.92
	20-50	4.14		22.35	13.32
	50-90	2.82		20.06	13.45
U3	0-5	5.26	4.74	33.27	7.21
	5-20	1.31		28.76	48.70
	20-35	1.30		33.23	46.66
	35-110	1.29		26.28	49.46
	110-140	10.01		23.61	7.33
Site-3 (Nurpur, Kangra)					
K1	0-25	12.16	15.47	36.77	1.15
	25-90	9.50		34.49	1.20
	90-150	10.81		34.60	1.19
	150-230	11.04		32.50	1.25
K2	0-20	12.83	6.75	40.11	1.96
	20-50	1.01		27.82	28.41
	50-60	1.33		25.95	28.69
K3	0-35	10.43	7.00	34.95	1.98
	35-50	4.64		30.54	6.04
	50-67	16.29		42.30	1.37
	67-90	1.36		28.96	15.62
	90-190	1.60		18.23	17.22

Appendix –VI
Chemical properties of soils of torrent affected areas

Location/ Site	Depth (cm)	pH	EC	OC %	N (kg/ha)	P (kg/ha)	K (kg/ha)	S (kg/ha)	Ca2+	Mg2+	Na+	K+
									[cmol (p^+) kg^{-1}]			
Site-1												
S1	0-12	7.90	0.12	0.43	194.08	18.58	113.12	7.28	4.24	1.39	1.02	0.13
	12-53	8.00	0.10	0.27	168.99	14.34	92.96	4.90	4.63	1.76	0.99	0.11
	53-80	7.80	0.17	0.55	238.34	20.30	116.48	47.46	4.63	2.14	1.11	0.13
	80-100	8.00	0.10	0.18	61.54	18.06	97.44	14.42	4.52	1.75	0.96	0.11
S2	0-32	7.30	0.12	0.45	189.17	18.51	98.56	7.00	4.28	1.26	0.72	0.11
	32-88	7.20	0.12	0.42	185.05	18.20	96.21	8.25	4.38	1.43	0.74	0.11
	88-130	7.80	0.22	0.16	56.45	15.62	89.60	4.76	8.66	1.24	0.82	0.10
S3	0-45	7.50	0.16	0.47	196.80	24.78	50.40	8.52	3.25	0.38	0.92	0.06
	45-95	7.80	0.13	0.27	158.81	21.65	48.16	1.54	7.42	0.00	0.99	0.05
	95-135	7.80	0.15	0.22	81.54	15.68	51.52	3.36	5.96	1.08	1.05	0.06
Site-2												
U1	0-18	7.80	0.24	0.45	147.42	23.60	50.40	76.40	7.34	0.93	1.10	0.06
	18-30	7.80	0.14	0.23	107.33	3.44	0.00	4.06	8.19	0.88	1.00	0.00
	30-100	8.00	0.14	0.16	50.88	1.65	0.00	2.38	6.65	1.44	1.11	0.00
U2	0-10	7.90	0.20	0.51	213.95	10.68	90.72	6.44	7.14	0.85	1.95	0.10
	10-20	8.10	0.16	0.47	113.60	8.99	52.64	4.90	7.00	0.48	0.85	0.06
	20-50	8.10	0.18	0.45	170.05	8.82	0.00	3.54	6.38	0.41	0.96	0.00
	50-90	8.20	0.17	0.33	157.50	4.20	0.00	6.16	5.07	0.28	1.02	0.00
U3	0-5	7.90	0.14	0.49	213.60	12.40	81.76	42.84	1.65	0.29	0.93	0.09
	5-20	7.90	0.11	0.18	62.90	5.40	0.00	3.68	3.98	0.15	0.93	0.00
	20-35	7.80	0.09	0.05	25.20	1.92	0.00	2.24	1.90	0.14	0.82	0.00
	35-110	7.80	0.10	0.08	33.90	4.80	0.00	1.82	1.80	1.16	0.93	0.00
	110-140	7.50	0.11	0.06	26.62	20.72	142.24	1.34	2.00	1.06	0.93	0.16
Site-3												
K1	0-25	7.60	0.16	0.79	498.70	33.76	132.16	72.80	18.58	0.99	0.98	0.15
	25-90	7.70	0.16	0.45	256.80	18.40	57.12	69.72	12.61	0.73	0.90	0.07
	90-150	7.90	0.16	0.41	112.90	15.68	62.72	4.90	9.19	0.70	1.25	0.07
	150-230	8.20	0.16	0.25	44.26	13.44	0.00	3.92	10.41	0.72	1.30	0.00
K2	0-20	7.70	0.15	0.51	176.80	22.40	61.60	37.10	9.73	0.66	0.93	0.07
	20-50	8.00	0.09	0.18	65.53	8.96	0.00	2.66	5.26	0.72	0.70	0.00
	50-60	7.90	0.12	0.08	36.27	6.72	0.00	2.66	5.07	0.86	0.67	0.00
K3	0-35	7.90	0.15	0.53	250.35	23.44	58.24	5.60	9.01	0.43	0.55	0.07
	35-50	8.10	0.12	0.08	37.98	5.20	0.00	5.60	8.20	0.34	0.76	0.00
	50-67	7.70	0.20	0.31	168.99	9.96	0.00	79.24	21.71	0.82	0.90	0.00
	67-90	8.20	0.13	0.08	35.44	4.72	0.00	9.10	6.72	0.35	0.77	0.00
	90-190	8.00	0.12	0.20	76.45	8.96	0.00	36.82	8.64	0.14	0.70	0.00

Appendix –VII
Erodibility indices of soils of torrent affected areas

Location/ Site	Depth (cm)	CR	SCR	DR	ER	EI
Site-1 (Barotiwala, Solan)						
S1	0-12	18.69	2.50	47.64	71.46	113.29
	12-53	33.72	3.56	60.21	122.94	221.41
	53-80	20.10	1.73	48.92	78.54	115.33
	80-100	26.62	1.99	62.11	75.66	172.08
S2	0-32	14.97	2.43	46.60	71.31	111.92
	32-88	15.64	2.47	47.91	75.42	118.90
	88-130	14.97	5.80	43.49	153.97	184.47
S3	0-45	13.12	2.37	42.83	60.08	100.52
	45-95	30.45	2.19	53.45	105.22	220.87
	95-135	39.00	2.19	48.87	98.14	230.77
Site-2 (Pekhuwala, Una)						
U1	0-18	39.00	6.94	68.75	297.00	529.10
	18-30	57.14	8.24	55.72	285.10	606.48
	30-100	50.02	6.63	61.63	257.22	576.69
U2	0-10	44.05	3.83	66.79	205.49	537.34
	10-20	65.67	5.29	56.14	219.34	574.54
	20-50	78.37	4.13	61.92	217.21	733.70
	50-90	101.04	4.51	61.11	217.63	845.89
U3	0-5	293.12	14.06	68.75	1126.29	3363.69
	5-20	554.56	2.67	57.58	479.80	4599.66
	20-35	115.28	0.69	61.38	105.63	964.94
	35-110	199.00	1.36	48.31	141.05	1329.36
	110-140	16.73	2.90	67.00	149.44	244.36
Site-3 (Nurpur, Kangra)						
K1	0-25	23.51	6.30	63.02	169.91	283.98
	25-90	30.06	6.18	62.89	222.85	336.81
	90-150	28.59	7.23	56.22	183.79	287.75
	150-230	32.78	6.55	60.73	235.34	333.42
K2	0-20	23.75	5.52	59.76	177.64	296.64
	20-50	832.25	9.17	67.21	1125.82	7791.12
	50-60	152.85	3.03	30.92	104.16	617.13
K3	0-35	34.97	4.72	63.77	180.08	400.88
	35-50	69.42	3.75	55.49	171.16	596.71
	50-67	16.30	4.30	49.44	120.10	180.93
	67-90	554.56	13.44	33.08	417.14	2660.85
	90-190	127.21	1.36	39.13	79.26	457.27

Appendix – VIII
Stability indices of soils of torrent affected areas

Location/ Site	Depth (cm)	RDI (N^{-1} x10^{-2})	WSA(>0.25 mm) (%)	WSA (<0.25 mm) (%)	MWD (mm)
Site-1 (Barotiwala, Solan)					
S1	0-12	0.40	75.30	24.70	1.99
	12-53	1.47	67.05	32.95	0.86
	53-80	3.13	64.90	35.10	0.88
	80-100	3.57	64.35	35.65	0.55
S2	0-32	0.98	89.95	10.05	3.49
	32-88	100.00	0.00	0.00	0.00
	88-130	100.00	0.00	0.00	0.00
S3	0-45	0.44	96.75	3.25	4.61
	45-95	100.00	38.35	61.65	0.81
	95-135	100.00	0.00	0.00	0.00
Site-2 (Pekhuwala, Una)					
U1	0-18	2.33	72.34	27.66	1.68
	18-30	100.00	71.98	28.02	1.65
	30-100	4.00	51.30	48.70	0.41
U2	0-10	0.85	0.00	0.00	0.00
	10-20	100.00	0.00	0.00	0.00
	20-50	7.14	0.00	0.00	0.00
	50-90	100.00	0.00	0.00	0.00
U3	0-5	3.13	0.00	0.00	0.00
	5-20	4.00	0.00	0.00	0.00
	20-35	2.78	48.59	51.41	0.96
	35-110	100.00	0.00	0.00	0.00
	110-140	100.00	0.00	0.00	0.00
Site-3 (Nurpur, Kangra)					
K1	0-25	1.67	76.41	23.59	2.55
	25-90	100.00	0.00	0.00	0.00
	90-150	100.00	0.00	0.00	0.00
	150-230	100.00	0.00	0.00	0.00
K2	0-20	0.69	82.72	17.26	3.10
	20-50	1.18	69.81	30.19	2.16
	50-60	3.23	66.15	33.85	2.88
K3	0-35	1.56	57.54	42.46	0.39
	35-50	100.00	0.00	0.00	0.00
	50-67	100.00	68.31	31.69	1.55
	67-90	100.00	0.00	0.00	0.00
	90-190	1.75	0.00	0.00	0.00

APPENDIX - IX

Daily rainfall (mm) data for the year 2004

Date	Jan.	Feb.	March	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
1	-	9.4	-	-	24.0	-	0.2	-	-	-	-	6.0
2	-	-	-	-	-	7.0	-	36.0	-	5.0	-	-
3	-	-	-	-	-	-	-	115.0	-	3.0	-	-
4	-	-	-	-	-	-	9.2	43.6	-	3.8	-	-
5	-	-	-	-	-	-	2.6	-	-	-	-	-
6	-	-	-	-	-	0.2	2.6	-	-	-	-	-
7	-	-	-	-	-	19.4	-	1.8	-	-	-	-
8	-	-	-	3.4	-	5.0	16.0		-	-	-	-
9	-	-	-	-	-	6.0	6.6	11.0	-	-	-	-
10	-	-	-	1.2	-	-	30.0	2.0	-	3.0	-	-
11	-	-	-	-	-	2.2	-		-	16.0	-	-
12	-	-	-	-	-	-	-	21.2	-	65.0	-	-
13	-	-	-	-	-	3.0	1.6	25.6	-	-	-	-
14	-	-	-	-	-	27.8	1.6	9.0	-	-	-	-
15	-	-	-	-	-	-	-	-	73.4	-	-	-
16	-	-	-	-	-	-	-	-	4.8	-	-	-
17	-	-	-	-	-	2.4	2.0	8.6	-	-	-	-
18	4.0	-	-	-	-	10.8	-	34.2	-	-	-	-
19	-	-	-	-	-	-	-	-	-	-	-	-
20	-	-	-	-	-	-	-	-	-	-	-	-
21	-	-	-	-	-	5.2	-	-	10.2	-	-	-
22	16.2	-	-	-	-	0.6	-	30.4	-	-	-	-
23	50.4	-	-	9.0	21.4	2.2	-	31.8	-	-	-	-
24	9.8	-	-	-	17.6	-	-	20.0	-	-	-	-
25	-	-	-	4.0	-	-	-	9.4	-	-	-	-
26	-	-	-	-	-	-	-	-	-	-	-	-
27	-	-	-	-	-	-	-	-	-	-	1.8	-
28	-	-	-	-	1.8	-	2.0	-	-	-	2.2	-
29	-	-	-	7.8	-	-	-	-	-	-	-	-
30	-	-	-	9.6	-	-	4.8	-	-	-	-	-
31	-	-	-	-	-	-	8.0	-	-	-	-	-
Total	80.4	9.4		35	64.8	91.8	87.2	399.6	88.4	95.8	4	6

Daily rainfall (mm) data for the year 2005

Date	Jan.	Feb.	March	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
1	9.2	-	-	-	-	-	10.6	-	-	-	-	-
2	-	-	3.2	-	-	-		-	-	-	-	-
3	4.4	-	-	-	10.4	-	1.2	5.0	-	-	-	-
4	2.0	-	-	-	-	-	-	-	-	-	-	-
5	-	-	-	-	-	-	116.2	3.8	-	-	-	-
6	-	-	-	-	-	-	39.8	10.0	-	-	-	-
7	-	25.4	-	-	-	-	0.6	5.2	-	-	-	-
8	-	35.0	-	-	-	1.8	6.0	-	-	-	-	-
9	-	1.0	11.4	-	-	-	-	-	27.0	-	-	-
10	-	4.6	6.2	-	-	-	-	-	22.4	-	-	-
11	-	4.2	-	-	-	-	4.4	-	-	-	-	-
12	-	-	-	-	-	-	2.6	-	2.4	-	-	-
13	-	2.4	-	-	-	-	-	-	9.4	-	-	-
14	-	-	-	-	-	-	-	-	8.8	-	-	-
15	-	22.4	-	-	-	-	62.6	-	2.8	-	-	-
16	0.8	33.0	-	-	-	-	30.8	5.0	-	-	-	-
17	17.8	-	-	-	-	-	3.2	19.8	42.0	-	-	-
18	-	-	3.3	-	-	3.4	-	9.4	21.0	-	-	-
19	-	-	4.4	-	-	-	-	-	-	-	-	-
20	-	14.4	2.8	-		-	6.8	-	-	-	-	-
21	5.2	-	5.0	-	1.0	-	1.8	-	-	-	-	-
22	9.8	-	-	-	-	-	13.2	-	-	-	-	-
23	-	-	-	-	-	3.2	-	-	-	-	-	-
24	-	-	-	-	-	-	39.2	-	-	-	-	-
25	-	-	-	2.0	-	-	-	-	-	-	-	-
26	-	-	-	3.0	-	9.6	4.6	-	-	-	-	-
27	17.4	-	-	-	-	9.0	6.6	-	-	-	-	-
28	1.2	-	-	-	-	-	7.2	-	-	-	-	-
29	-	-	-	-	-	-	4.6	-	-	-	-	-
30	-	-	-	-	-	-	6.6	-	-	-	-	-
31	-	-	-	-	-	-	-	-	-	-	-	-
Total	67.8	142.4	36.3	5	11.4	27	368.6	58.2	135.8			

Daily rainfall (mm) data for the year 2006

Date	Jan.	Feb.	March	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
1	-	-	-	-	-	7.6	2.2	-	4.6	-	-	-
2	-	-	-	-	-	-		-	16.4	-	-	-
3	24.0	-	-	-	-	-	1.4	4.6	4.2	-	-	-
4	-	-	-	-	-	-		9.6	-	-	-	-
5	-	-	-	-	-	7.2	8.8	14.0	-	-	-	4.4
6	-	-	-	-	-	-		14.6	-	-	-	4.4
7	-	-	10.8	-	-	-		22.2	-	-	-	-
8	-	-	2.2	-	-	-	6.7	6.0	-	-	-	-
9	-	-	-	-	21.0	-	14.6	8.0	13.0	-	-	-
10	-	-	1.2	9.6	-	-	88.0	9.8	7.8	-	-	-
11	-	-	45.2	-	-	-		1.4	-	-	-	3.4
12	-	-	4.8	-	-	-	14.6	-	-	-	-	1.0
13	-	-	-	-	-	2.2	35.2	34.4	-	-	-	-
14	-	-	3.1	-	-	-	1.6		-	-	-	-
15	-	-	8.4	-	-	23.8	-	12.4	-	4.6	-	-
16	2.2	-	22.8	-	-	23.0	-	13.6	-	-	-	-
17	39.0	-	-	-	8.4	2.0	-	38.0	0.8	-	-	-
18	2.8	-	-	15.0	-	-	-	-	-	-	-	-
19	-	-	-	-	-	-	6.6	-	-	-	3.6	-
20	-	-	-	-	22.2	-	3.2	3.2	-	-	-	-
21	-	-	-	-	1.2	14.2	-	-	-	3.4	-	-
22	-	-	-	-	14.0	-	6.4	-	1.0	1.4	10.6	-
23	-	-	-	-	7.6	-	20.0	-	-	-	-	-
24	-	-	-	-	-	-	13.2	-	-	-	-	-
25	-	-	3.8	-	-	14.2		2.8	-	-	-	-
26	-	0.4	4.4	-	-	-	5.8	33.6	-	-	-	-
27	-	4.0	-	-	-	1.0	1.2	3.0	-	-	-	2.8
28	-	-	-	-	4.4	-	9.8	12.0	-	-	-	-
29	-	-	-	-	-	2.2	1.2	-	-	-	-	-
30	-	-	-	-	-	6.0	3.4	-	-	-	-	-
31	-	-	-	-	-	-	-	9.0	-	-	-	-
Total	68	4.4	106.7	24.6	78.8	103.4	243.9	252.2	47.8	9.4	14.2	16

Source: Meteorological Observatory, Department of Soil Science and Water Management, Dr. Y. S. Parmar University of Horticulture and Forestry, Nauni-Solan (H. P.)

CURRICULUM VITAE

Name : **Yogender Sharma**

Father's Name : Sh. Khem Chand Sharma

Date of Birth : 13.03.1977

Sex : Male

Marital Status : Married

Nationality : Indian

Educational Qualifications :

Certificate/ degree	Class/ grade	Board/ University	Year
Matric	First	Himachal Pradesh School Education Board, Dharamshala, (H.P.)	1992
10+2	Second	Himachal Pradesh School Education Board, Dharamshala, (H.P.)	1996
B.Sc. (Forestry)	First	Dr. Y.S. Parmar UHF Nauni, Solan	2000
M.Sc. (Soil Science and Water Management)	First	Dr. Y.S. Parmar UHF Nauni, Solan	2002

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(Yogender Sharma)