

**STUDIES ON SOME ASPECTS OF SOIL AND WATER
IN RELATION TO RESOURCE MANAGEMENT IN
NORTH EASTERN HILL REGION**

**By
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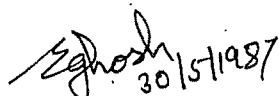
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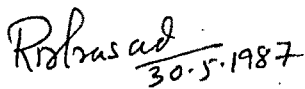
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C E R T I F I C A T E

This is to certify that the thesis entitled "Studies on some aspects of soil and water in relation to resource management in North Eastern Hill Region" submitted by Shri Akshayaber Singh to the Bidhan Chandra Krishi Viswavidyalaya, Kalyani, for the award of the Degree of Doctor of Philosophy in Agricultural Engineering, is a record of bonafide research work carried out by him in our supervision and guidance. Shri Singh has worked on this problem for over a decade, and the thesis is, in our opinion, worthy of consideration for the award of the Degree of Doctor of Philosophy in accordance with the regulations of the University. The results embodied in this thesis have not been submitted to any other University or Institute for the award of any Degree or Diploma.


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LIST OF ABBREVIATIONS

Agri	Agriculture
Amer	American
Av.	Average
Bull.	Bulletin
CC	Cubic centimetres
Ch.	Chemistry
Cons.	Conservation
Dept.	Department
Dr.	Doctor of Philosophy
Engg.	Engineering
Er.	Engineer
FAO	Food and Agricultural Organisations, Rome
Fig.	Figure
F.F.	Form Factor
gm	Gram
ha	Hectare
Horti	Horticulture
hr.	Hour
ICAR	Indian Council of Agricultural Research
Ind	Indian
IMD	Indian Meteorological Department
ISAE	Indian society of Agricultural Engineers
J	Journal
Km	Kilometer
m	Meter
Max.	Maximum
ml	Milliliter
mm	Millimetres
m ²	Square metre
NE	North East
NEH	North Eastern Hill
Proc.	Proceedings
Sci.	Science
Soc.	Society

Symp.	Symposium
t	Tonne (s)
Trans	Transactions
U.C.	Uniformity Coefficient
USDA	United States Department of Agriculture
U.P.	Uttar Pradesh
Vol.	Volume
W.B.	West Bengal

LIST OF SYMBOLS

C	Threshold rainfall
C.F.	Conservation Factor
Comp.	Computed
Cons.	Conservation
Expt.	Experimental
Ob.	Observed
L	Horizontal length of slope
Q_p	Peak runoff
r	Correlation coefficient in a two variable equation
r^2	Coefficient of determination in a two parametric equation
R	Multiple correlation coefficient
R^2	Coefficient of determination (multiple)
W_1	Experimental watershed under shifting cultivation
W_2	Experimental watershed under Agri-horti landuse.
W_3	Experimental watershed under bench terraced base Agri. landuse
W_4	Experimental watershed under contour bund base Agri. landuse
W_5	Experimental watershed under terrace and contour bund based Agri. landuse.
W_6	Experimental watershed under secondary forest
X	Daily rainfall
X_1	Annual rainfall
X_2	Slope
X_3	Conservation factor
X_4	Compactness coefficient
X_5	Form factor
X_m	Monthly rainfall
X_{mc}	Mean monthly cumulative rainfall
X_{1m}	Mean annual rainfall
X_{mct}	Monthly cumulative rainfall for the entire period of study
Y_1	Daily rainfall
Y_{1m}	Monthly runoff
Y_{1mc}	Monthly cumulative runoff
Y_{1a}	Annual runoff

Y_{1am}	Mean annual runoff
Y_{1mct}	Monthly cumulative runoff for the entire period of study
Y_2	Daily soil loss
Y_{2m}	Monthly soil loss
Y_{2mc}	Monthly cumulative soil loss
Y_{2a}	Annual soil loss
Y_{2am}	Mean annual soil loss
Y_{2mct}	Monthly cumulative soil loss for the entire period of study

ABSTRACT

Studies on micro watersheds in steep hill slopes (0.42, 0.43, 0.43, 0.44, 0.45 and 0.49 m/m) having provisions of six different land use systems were conducted at Burnihat (26°N, 91.5°E and 100 m elevation above mean sea level) in Meghalaya during 1976 to 1983 to evaluate the performance of mechanical soil and water conservation measures and to formulate strategies on resource management. The land uses viz., traditional or shifting cultivation locally known as Jhuming (W_1), Agri-horticulture (W_2), agriculture with bench terraces (W_3), agriculture with contour bunds (W_4), agriculture with bench terraces plus contour bunds (W_5) and secondary forest (bamboo - W_6) were considered herein. The soil and water conservation measures like contour bunds, bench terrace or half moon terrace, grassed water ways etc. were developed in the watersheds utilising local manpower and natural resources.

The effect of rainfall on runoff and soil erosion in real hill slopes (58, 59, 62, 64, 64, 65, 67, 68, 70, 70 percent) was also studied in bare fallow runoff plots during 1982 and 1983.

The conservation measures, land use, human and animal interference etc. have been effectively accommodated in "Conservation factor" specially evolved by the author. Based on these investigations, empirical models have been established. These can be gainfully used to estimate or predict runoff, peak runoff and soil loss with the help of easily measureable parameters such as annual rainfall, slope, conservation factor, threshold rainfall (beyond which runoff gets initiated) etc. Statistical probe indicates that the coefficients of determination of the proposed models are reasonably high.

The study reveals that within 3 years of the development of micro watersheds, runoff, peak runoff and soil erosion may be restricted to a safe limit if appropriate conservation measures are taken. It is observed that in favourable soil conditions along with appropriate measures for soil and

water conservation about 80 to 100 percent of annual rainfall may be retained or conserved in the deep soil profile of the watersheds and/or allowed to percolate upto the ground water or streams or ponds situated below, even if the slope is very steep and rainfall is high. Consequently, heavy reduction in runoff and soil loss seems probable. Thus gain through afforestation and gain through the above mentioned measures are quite similar in nature. However, the retention of rainfall in flat land (zero slope) is about 71.67 percent which seems to be dubious. This is because in steep hill slopes the undisturbed porous soil has had been eliminated to make the land flat. This led to the exposure of comparatively compact bare soil which has further been encrusted by rainfall impact. The soil and not the slope is a dominating factor here to control infiltration of rain water. Thus land levelling alone is not an effective measure for all situations to reduce runoff and soil loss.

Relationships between rainfall and each of runoff and soil loss are not linear as often claimed. The conception of cumulative monthly rainfall, cumulative monthly runoff, cumulative monthly soil loss and threshold rainfall is found to be more meaningful in the modelling processes. It is also observed that total rainfall (in absence of rainfall intensity, erosivity and other characters) may also be an effective tool in modelling runoff, peak runoff and soil loss.

Though it is very difficult to accept, but is a reality, that runoff and soil loss increase as well as decrease with the increase in slope following sinusoidal path which seems to be a peculiarity of the north eastern hill region.

Chapter - I

INTRODUCTION

Management of soil and water resources in hilly region has assumed great importance, because of gradual increase in the exploitation of such regions for agricultural and allied purposes, endangering the ecological balance. Degradation of the natural ecosystem in the hills and its effect in the plain areas is well recognised. In the North Eastern Hill (NEH) region of India, majority of the people are farmers and that too shifting cultivators. A combination of socio-political and techno-economic factors are causing large scale soil erosion. Exposure of rocks due to soil loss as a result of shifting cultivation is conspicuous in NEH region. Cultivation of tuber and rhizomatus crops on hill slopes, pineapple along the slopes, improper use of soil conservation measures, and opening of roads have reportedly resulted in soil loss from 16.8 to 170.2 t ha⁻¹yr⁻¹ (Singh and Singh, 43, 47, Ghosh, 12). The rising level of indiscriminate use of soil and water resources in NEH region is corroborated by various studies including the one by Sharma and Anklesaria (38), who have reported a rise of 0.5 to 1.35 m in bed level of Puthimari a tributary of Brahmaputra during the period of 1968 and 1975. This is a clear case of geological form of soil erosion accelerated by the biotic factors.

Notwithstanding the prevailing farm technology in the NEH region, the farmers have all along been aware of the need for land management and have indeed developed their own practices based on local natural resources (Singh, 47). However, these land management practices have remained localised and as yet no concerted effort has been made to catalogue, elucidate and propagate these. Rather there is a tendency on the part of the experts to propagate expensive text book type alternative technology which the farmers are neither able to understand nor have the capability to implement, with the result that there is no significant change in the suboptimal land management practices. Failures are often mentioned to be the imposition of imported ideas without adequate consideration of the level of development of people

and local conditions, lack of peoples' participation, non-coordination between sectoral departmental activities, inadequate marketing infrastructure and adoption of large schemes. In the NEH region, farmers generally do not have ownership right over land, individuals only have the right to use and the product thereof; the absence of individual land ownership rights does not provide them the necessary incentive to develop and maintain production base which consequently leads to degradation.

Research works on soil and water conservation during the past half century have centred around rainfall factors confining to milder slopes, mulches, cropping patterns and in developing prediction models/relationships. Most of the studies conducted by various workers have been confined upto 9 per cent slope and have pivoted around universal soil loss equation (USLE) of Wischmeier and Smith (61) for working out various factors to compute soil loss. Roose (35) concluded that the USLE in the humid parts can predict sheet and rill erosion in zones away from mountains. He also cautioned on data obtained from small plots which may pose some problems, especially if the results are to be extrapolated for larger catchments.

In India, and particularly in NEH region where land holdings are small, field bunding, contour bunding and bench terracing in small patches of land on varying degrees of slopes are common practise, there needs to be a functionally satisfactory model to fit the above conditions which are at variance from conditions under which certain models were developed elsewhere in the world.

Some research workers in the field of soil and water conservation have developed models using data from small plots having slopes ranging between 0.1-20.0 per cent which has increased the understanding of the processes of soil erosion as affected by degree of slope, slope length and rainfall characteristics etc., but these can not be converted into ready made working models to be put in actual field conditions of NEH region where shifting cultivation is being practised on slopes even more than 100 per cent.

In developing land management models in hilly terrains, best possible management practices applicable to these terrains should be selected. Thus, soil conservationist has to feed the field level planner with answers to the questions, such as, how to retain more rain water in hill slopes without causing

erosion and adverse effect on crops, how to estimate water yield from slopes with the help of simple models, and how to control soil erosion and runoff with the use of local resources.

In this background the present study was undertaken to investigate on

- i) the retention of rainfall in situ under various land use practices,
- ii) the minimum time period required for a newly established land use for stabilisation in runoff, soil erosion and peak flow rate behaviour,
- iii) the influence of land slope in yielding runoff and soil loss,
- iv) the capacity and impact of total annual rainfall (in place of rainfall intensity and erosivity) to characterise and/or predict the runoff, soil erosion and peak flow rate,
- v) the uniformity of soil moisture distribution pattern in the soil profile under various land use practices and conservation measures,
- vi) the possibilities of introduction of a new parameter which will reflect the land use practices in estimating runoff, soil erosion and peak flow rate,
- vii) the establishment of some useful models for soil erosion, runoff and peak flow rate prediction in order to utilise them as guidelines for the management of soil and water resources on steep slopes.

Chapter - II

REVIEW OF LITERATURE

2.1 Introductory Remarks

North Eastern Hill Region is characterised by large variations in topography, climates and soil conditions. Interestingly, this region is inhabited by a large number of ethnic groups. Arunachal Pradesh alone has as many as 110 scheduled tribes, Assam 23, Manipur 28, Tripura 18, Meghalaya 12 and Nagaland 5 with very little in common between many of them. The area comprises mainly of mountain ranges and narrow valleys. Barring Assam plains and Imphal valley in Manipur, flat land is rare. Annual rainfall varies from about 2,000 to 4,000 mm. Mawsynram near Cherrapunjee has the distinction of receiving the highest rainfall in the world recording above 10,000 mm of rain annually. The hilly terrain with high rainfall, continuing primitive forms of Agriculture and indiscriminate exploitation of natural resources has reached to a stage where the resource base itself is gravely endangered (Singh and Singh, 47). Swaminathan (57) have attributed the main reason for such degradation to over population and over stocking of cattle. The influence of other factors on resource base deserves in depth consideration. Therefore, in this review attempts have been made to look into the causes influencing the resource base (soil and water) in hilly terrain of NEH region.

2.2 Land Use System

Land use systems throughout the world, have undergone tremendous changes since the dawn of the human civilization. The history of agriculture is about 10,000 years old (Sharma, 40) in which we have largely reached to a stage of permanent settled agriculture barring some pockets where primitive system, such as, shifting cultivation is still in vogue.

Such areas are normally confined to hilly tracts and are found in Korea, Phillippines, Indo-China, Malaysia, Burma, Ceylon and India. NEH region, part of Orissa, Andhra Pradesh and Madhya Pradesh in India are such

areas where shifting cultivation and other traditional forms of land uses are common (Borthakur *et al*, 8). Most of the land use systems prevalent in hills are detrimental to the land resource base as they result in excessive loss of soil from hill slopes. However, in the midst of such harmful systems, there are some excellent land and water management techniques which have been evolved during the long course of experience of the people, reflecting the ingenuity and intelligence of people living in these hills (Singh, 50).

2.2.1 Forest

In general, forest land uses are considered ecologically sound systems as deterioration to the soil base is practically nil. Negligible soil loss from such ecosystem has been reported from Malaysia and Phillipines (Lal, 23). Most of the available literature supports the protective and fertility regeneration value of forest land use systems.

2.2.2 Shifting cultivation (Jhum)

Shifting cultivation (Fig. 2.1) is largely practised on steep hill slopes (upto 100 per cent or more). It is also known as slash and burn agriculture, milpa, conuco, monte, chaco, kaingin, chena, Lua, ray, ladong, bush fallowing, swidden farming, land rotation etc. in various parts of the world. But there may exist minor differences in exact practice. In this present context, the local name **Jhum** is being coined to mean the two years cultivation using local method plus three years fallow and its repetition on a same piece of land. The process starts with the clearing and burning operations of existing vegetation and planting of a mixture of crops on the cleared and untilled slopes. The crops are raised without any support of mechanical soil and water conservation measures or fertilizer input. The cultivation is done only for two years and thereafter new site is selected for repeating the process. The land is thus left fallow for natural regeneration of soil fertility. With the rapid growth of population the area under shifting cultivation is increasing with the result that the cycle of cultivation has reduced from 20 to 30 years to 2 to 3 years at present. In NEH region about 4,94,000 tribal families practice this system of farming and nearly 2.7 million hectares of land is affected due to shifting cultivation (Borthakur *et al*, 7). Initially, opinions on associated hazards with the system differed and it was thought that soil erosion from the areas may not be so alarming as the practice does not involve any serious

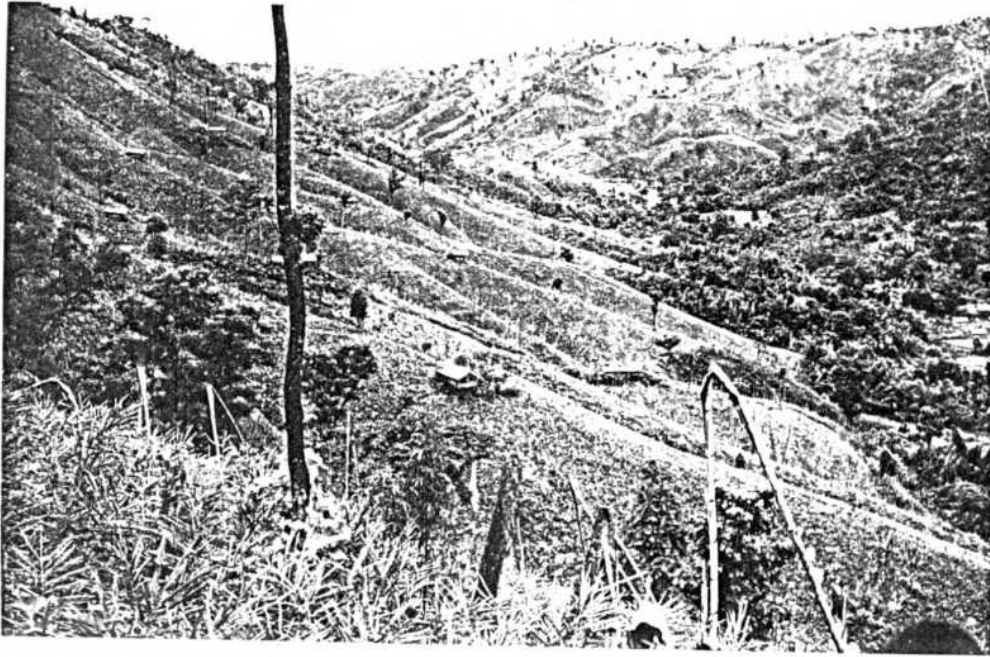


Fig.2.1 Deforested hill slopes under shifting cultivation in Garo hills (Meghalaya)

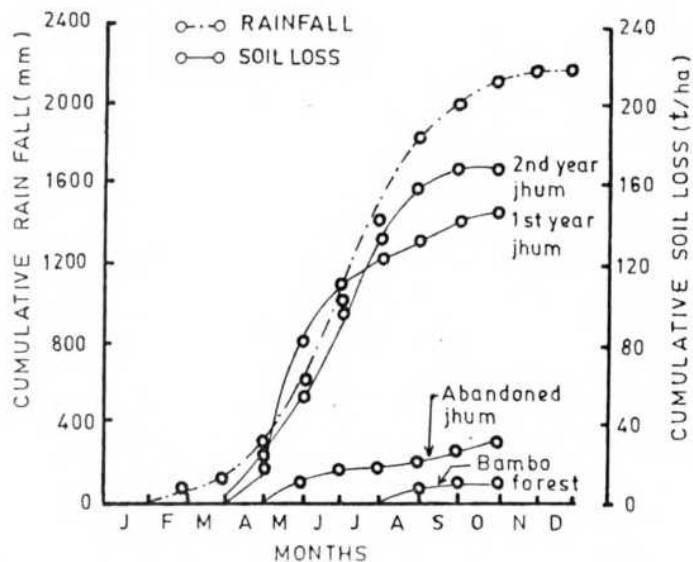


Fig.2.2 Soil erosion from 60-70 percent slopes under various stages of shifting cultivation (Jhum)

disturbance to soil (Chaturvedi and Uppal, 9). As a result of shifting cultivation in Garo Hills of Meghalaya, fertile top soil is washed and rocks are exposed (Goswami, 13). Das (10) opined that the sedimentation problem in Muchkund reservoir is due to the system of shifting cultivation widely practised in the catchment by the tribal people. Quantitative assessments in NEH region of India indicate severe soil erosion (Fig. 2.2) problem associated with the practice of shifting cultivation (Singh, 42; Singh and Singh, 43 and Rai 32).

2.2.3 'Bun' for tuber crops

Cultivation of tuber crops on series of beds (Fig. 2.3) formed on slopes is common in some parts of the NEH region. The system known as 'Bun' in Meghalaya involves arranging of dried vegetation material in the form of beds along the slope, covering of these beds with soil collected from surroundings, burning of the covered vegetation and planting of tuber crops on the beds. When sufficient dried vegetation is not available, the beds are raised out of soil material only. Since the beds are made along the slope the system results in heavy soil wash from the slopes. It has been observed by Singh (45) that nearly 2 kg of soil is lost annually for every kg of tuber crops produced. In areas under such system of cultivation, clear spacing in between two parallel beds was found to vary from 1 to 2 m mainly due to lack of availability of soil. Abandoned sites with remains of earlier used beds reflect on the damages done to the land due to this practice.

2.2.4 Agriculture on bench terraces

Bench terraces on hill slopes are universally accepted as sound system for permanent agriculture. Though in NEH region, bench terraces have been successfully used in some pockets, the majority of the tribal farmers have not accepted this technique of soil conservation due to lack of skill. The system is only common in the areas where farmers themselves have done terracing for irrigated agriculture by diverting hill streams through gravity flow. Large areas in Sikkim and some pockets in Nagaland and Manipur present excellent examples of such land use systems. Soil loss from bench terraced land is negligible (Kurian, 22 and Singh 48).

2.2.5 Agriculture on contour banded slopes

Mostly, non-tribal farmers use bunds across the steep hill slopes while



Fig.2.3 Beds (raised) are laid along the slope (bun) for raising tuber crops on hill slopes. The system results in to heavy soil loss .

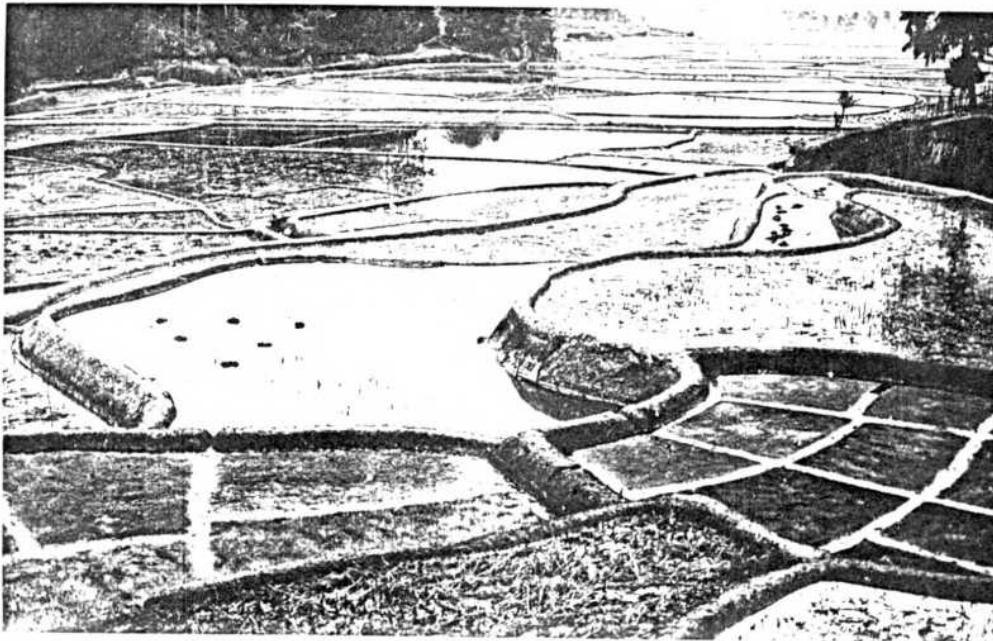


Fig.2.4 Example of indigenous skill and use of local natural resources for land management at Apatani plateau in Arunachal Pradesh.

practising agriculture and horticulture land use systems. Bunds, in general do not prove effective due to lack of proper alignment. Singh and Singh (47) reported $68 \text{ t ha}^{-1}\text{yr}^{-1}$ soil loss from such agricultural land use and attributed the soil loss to inadequacy in maintenance.

2.2.6 Agriculture in valley lands

Valley lands in general are well used and maintained (for rice production) since these are the most productive areas. Indigenous technique of land use and water management evolved and used by Apatani tribe in Arunachal Pradesh at an elevation of 1600 m is an excellent example of intensive land use for valley lands (Fig. 2.4). Practically all the available areas have been utilized for crop production except the one occupied under house sites, roads and water areas. Layout of fields and channels are made in such a way that the entire plateau functions as a water course without inflicting any appreciable damage to the land. Bamboo and wood log pipes of various sizes are used as prefabricated water management structures such as, conduit for water inlet and outlets, waste weirs and energy discipators (Singh and Singh 47).

2.2.7 Agro-forestry

It is a common practice to grow various kinds of plant species namely trees (timber, fodder, fuel and fibre), vegetables, spices, fruits in a mixture on steep hill slopes near dwellings. Such land uses are termed as agro-forestry land use and meet some of the requirements of the farmers. These land uses are safe enough as they provide protective and productive value without much of recurring input. It is reported by Singh (46) that a generation old indigenous technique of bamboo drip irrigation system is being extensively used on steep hill slope for irrigating betal leaf and arecanut plantation in Meghalaya (Fig. 2.5). The system as reported enables the distribution of 15 to 25 litres of water per minute entering into the main channel to 10 to 80 drops per minute at the site of water application without any leakage at any point. Local experiences in the region on such land uses are infact quite rich and are a couple century ahead of the modern invention on drip irrigation, but very little is known about them.

2.2.8 Farmstead and Development

Farmstead and development activities result into considerable damage



Fig.2.5 Century old bamboo drip irrigation system used in agro-forestry land uses on hill slopes. This is an example of local skill and ingenuity utilising natural resources.



Fig.2.6 Disappearing agricultural practices due to degradation of hill slopes. Agriculture is confined with in the valleys where some soil is available.

to the natural eco-system. Singh and Singh (49) observed $16.8 \text{ t ha}^{-1}\text{yr}^{-1}$ soil loss from 6.9 ha watershed which was under farmstead land use. Development of sites for construction of buildings, kitchen gardens and road sides were reported to be the major areas susceptible to soil erosion. Increasing communication facilities, particularly of road network have made the exploitation of forest resources rather easy and convenient.

2.2.9 Animal Husbandry

Highly degraded areas are generally devoid of soil and have scanty vegetation which is constituted of mainly grasses, shrubs and thin stand of uneconomic trees. In such areas people lead a difficult life through livestock farming and as wage earners engaged for road works. Such situations have cropped up around Cherrapunjee area. Goat is the common animal reared as the people have no other alternative for their livelihood (Verma *et al.*, 58). Runoff from such areas carry considerable amount of sand as eroded material.

2.2.10 Horticulture

Citrus, pineapple, ginger, turmeric and colocasia are horticultural crops grown on hill slopes as pure or mix stand. In general, cultivation of tuber crops induces soil erosion and its extent depends on the method used for crop production. Crops raised on beds (Bun) result in excessive soil erosion (Singh, 45). Pineapple crop is planted in rows mostly aligned along the slope. Ghosh (12) reported 24.0 to $62.6 \text{ t ha}^{-1}\text{yr}^{-1}$ of soil loss during first year of its plantation which is reduced to $6.3 \text{ t ha}^{-1}\text{yr}^{-1}$ during second year.

2.3 Problem of Degradation

Traditionally, hill people (tribals) prefer to stay on high hills and earn their livelihood while producing food crops in hill slopes. In the long history of agriculture in NEH region, very little change has taken place in traditional methods of food production. Most of the systems are followed without soil and water conservation measures and have resulted in heavy soil loss (Singh and Singh, 46 and Rai, 32). Hill slopes are the worst affected areas exposed to severe degradation (Fig. 2.1). Soil erosion in these areas has resulted in emergence of flat valleys in between hills which are usually being used for intensive paddy production and have become valuable agricultural lands. Imphal valley in Manipur, Apatani plateau in Arunachal Pradesh and Sung valley in

Meghalaya are known as rice bowls in the region. In some areas the hills have become barren and unfit for agricultural use. In other areas the fertile valley lands are being squeezed by regular annual deposition of sand and stone from the degraded watersheds (Fig. 2.6). Though from the quantitative evaluation of degradation status no presentable data have yet been emerged, but the meagre information tends to corroborate the reported high degradation level based on their field observations (Mawthoh 27, Ingty, 20; Bahuguna, 5; Shaiza, 37)

While reporting on the dangerous sign of land degradation Mawthoh (27) identified a belt in Meghalaya (Fig. 2.7) from Khliehriat to Amalrer - the Rapbleng area, the Pynursla area, the Cherrapunjee area, and then over to Garo Hills in the Siju area, Monsongiri area, Rongram, Rongchagiri and Sedengiri etc., as areas where stone chips and also parent rocks have cropped up, because of depletion of soils. Study on a major northern tributary of Brahmaputra river (Puthimari river) revealed an average rise of 0.5 m to 1.35 m in the river bed between 1968-75 (Sharma and Anklesaria, 38). This reflects the behaviour of catchment in producing silt and phenomenon of degradation as a consequence of it.

Excess felling of forest for commercial purposes as well as for shifting cultivation is greatly endangering the environment (Ingty, 20). Yet, on the basis of raw observations of life, one can assert that the empirical propensity of individuals to make quick money irrespective of its long term adverse consequences on the social assets is propelling individual forest owners to fell trees indiscriminately. Sharma and Anklesaria (38) reported that Garo Hills (a district in Meghalaya) which only a few years ago had barely 15 to 16 licensed timber contractors operating within the forests, today (1984) have almost 800 licensed contractors. The bleak hills which were once covered with sal trees are an eloquent testimony to the pillaging of the forest. In Cherrapunjee today, a few sacred groves which have been protected from human depredation stand as reminder of what the area once was.

In the NEH region, many minor irrigation and drinking water schemes are failing because the original status of the catchment areas have degraded in the intervening period.

2.4. Developmental Efforts

2.4.1 Schemes

Land and water management aspects in NEH region have been taken

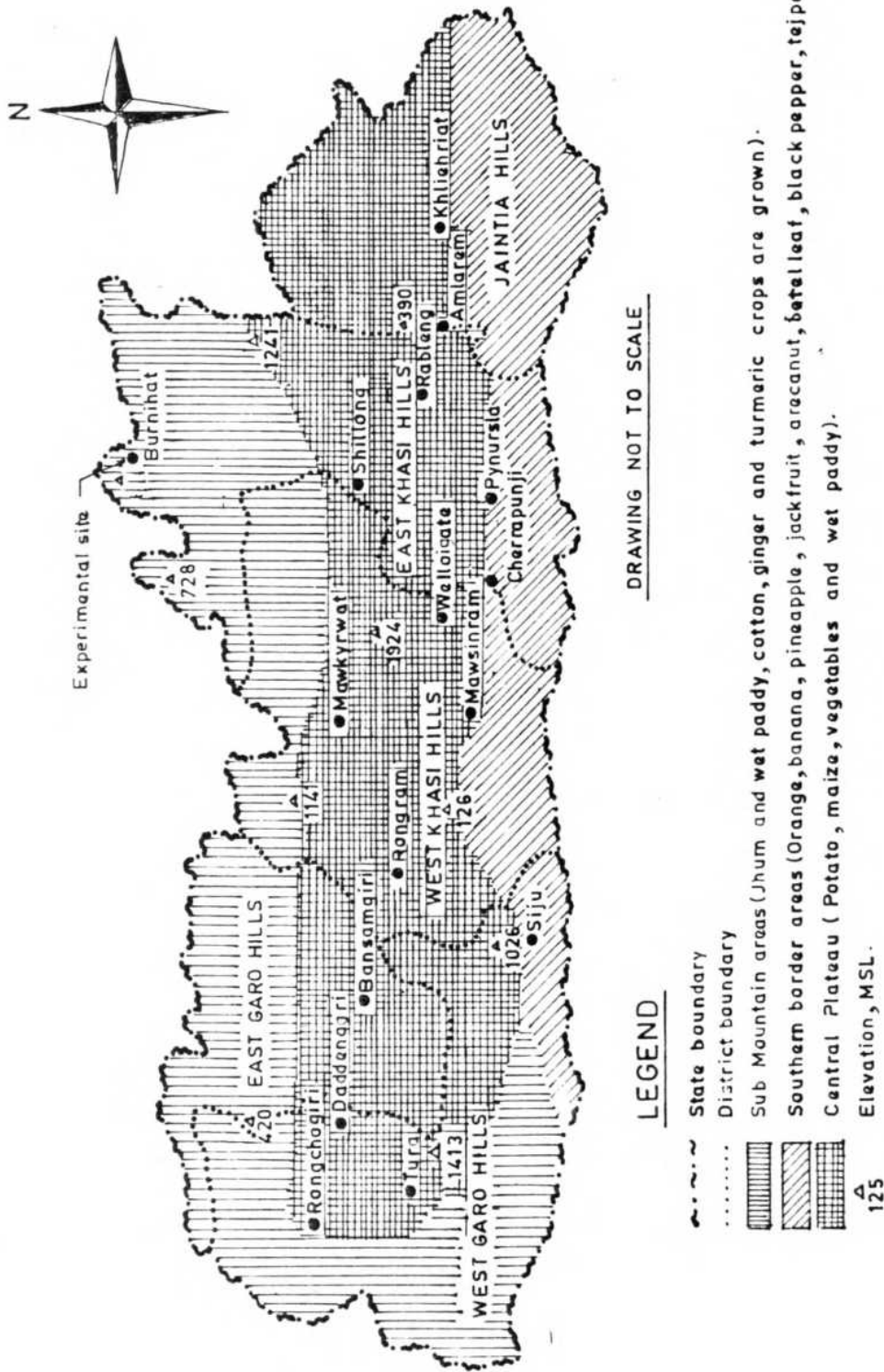


Fig.2.7 Central plateau in Meghalaya reported to be under tremendous depletion of the soil.

up mainly in Jhum (shifting cultivation) areas and under afforestation programmes. After 1947, Assam Government introduced schemes on plantation crops such as rubber, coffee, black pepper and cashew nut to encourage shifting cultivators to take these crops. During fifth Five Year Plan this effort was strengthened with programmes such as, (i) soil conservation schemes in the State plans, (ii) centrally sponsored scheme and pilot project for control of shifting cultivation and (iii) regional river basin schemes for the control of shifting cultivation under North-Eastern Council plan. The objectives and programmes in various States are summarised in Table 2.1.

Table 2.1 Programmes for improvement in land management systems in various states of NEH region[†]

States	Programmes [*]
Assam	Soil conservation programmes to settled farmers with permanent agriculture of varying form
Manipur	Settling farmers on 1 to 2 ha irrigated terraced land for agriculture
Nagaland	-do-
Mizoram	Settling farmers on dry and irrigated terraced land for horticultural crops
Meghalaya	-do-
Tripura	Schemes under forest sector to engage farmers as wage earners in rubber plantations and settling them on forest land in small colonies with provision of basic civic facilities like schools, sales department etc. whereas the schemes under agricultural sectors aimed to settle farmers on new areas away from their jhum fields and allotment of "tilla" land for agricultural and horticultural crops
Arunachal Pradesh	Settling farmers on developed land with assured irrigation facilities, Watershed management schemes with integrated programme of agriculture, horticulture, forestry, animal husbandry on the basis of land use classification

^{*}Incentives of other kinds such as supply of bullocks, farm machinery, construction of houses etc. were provided.

[†]Borthakur et. al., (8)

2.4.2 Impact of schemes

Largely the programmes have proved ineffective. Mathur (26) while reviewing the progress of soil and water conservation programmes in Mizoram reported that only 300 out of 10,000 families who joined the programmes gave up the practice of shifting cultivation. Similarly, in Meghalaya and Tripura, only 150 and 250 out of 3,000 and 7,500 respectively joined the programmes. Other efforts to improve the systems did not bring commensurate result. Alternatives without adequate consideration of the local situation and need of the people met with failures (Ingty and Goswami, 19). Short sighted projects, lack of coordination amongst development departments, lack of peoples' participation in programmes, too much reliance on new technological introductions, land ownership pattern are some of the factors against the adoption of effective methods.

2.4.3 Social constraints

Land ownership pattern is another hurdle in the way of development. Land is owned by people in the name of Maharies, Clans and individuals are given usufructuary rights on allotted portion of land only. Lack of sense of ownership has frustrated their sense of responsibility over the land.

2.5 Research Efforts

2.5.1 Universal soil loss equation

Most of the research works during the past half century on soil erosion centred around rainfall factors on milder slopes, mulches, cropping patterns and in developing prediction models. Studies have mostly been conducted upto 9 per cent slope, keeping in view USLE, the universal soil loss equation (Wischmeir and Smith, 61) for working out various factors and for computing soil loss for the site.

Researchers throughout the world have tried and are trying to work out the values of factors for various locations. Consequently voluminous literature related to this equation are now available. Roose (35) who studied the application of USLE for Africa found that in the humid parts the equation can predict sheet and rill erosion for areas away from mountains. He also cautioned that data obtained from small plots which may pose some problems, especially, if the results are to be extrapolated for higher catch-

ments. Close examination of the various factors involved in the equation indicate that initiators of this equation basically incorporated the dominant characters of land features and agricultural systems of United States where farm holdings are sufficiently large. Countries where land holdings are small, field bunding is common practice, bench terracing is essential conservation practice, land uses are of more complex nature, the applicability of this particular equation from practical point of view needs to be looked into more carefully.

2.5.2 Effect of slope steepness and length on soil erosion

On 4 per cent slope, the following relation was suggested by Balasubramaniam and Sivanappan (6)

$$E = 0.296 Y_1^{1.325} X_2^{1.514} \dots\dots\dots (2.1)$$

Where

E = soil loss (kg ha^{-1})

Y_1 = daily rainfall (mm)

X_2 = slope in per cent

The relation was significant at 1 per cent level.

Wischmeir and Smith (62) reported a non linear form of the relationship between soil loss and slope. Meyer (29) found that soil loss rate increases with slope length and steepness. Studies conducted in tropical Africa (Lal, 24) revealed that the effect of slope length is less important than that of slope steepness and of slope form. Lal (23) in an exhaustive review concluded that soil losses from complex slopes are least understood. Singh and Hakim (54) developed the following relationship for 15 per cent slope.

$$E = 0.026 S^{1.37} L^{1.6} \dots\dots\dots (2.2)$$

E = soil loss (t acre^{-1})

Where

X_2 = land slope in per cent

L = horizontal length of land slope in (ft)

Runoff and organic carbon increases with the land slope upto 21 per cent and the former decreases linearly with further increases in slope (Rai, 32). But Rai (32) was wrong in his interpretations. The increase and decrease with the increase in slope was sinusoidal in nature and were of

the forms (Singh, 53).

$$E = 17.28 + 4.32 \sin \left(\frac{X_2 - 35.1}{20.66} \right) \dots\dots\dots (2.3)$$

$$Y_{1a} = 546.75 - 84.1 \sin \left(\frac{X_2 - 64.9}{20.66} \right) \dots\dots\dots (2.4)$$

Where

E = soil loss (t ha⁻¹ yr⁻¹)

Y_{1a} = Runoff (mm, yr⁻¹)

X₂ = slope in per cent

2.5.3 Effect of land use on soil erosion

Movement of soil on hill slopes towards foot hills occurs as sliding, rolling and transporting away of detached soil particles or aggregate because of running water and due to movement of men and animals on the slope. The quantum and extent of soil removal from slopes depends on the land use and supporting conservation measures. Most of the information on the effect of land use practices in the catchment on soil erosion are either qualitative or are inferred by the measurement of silt load in the river systems. Measurement of soil erosion from field size plots located on steep hill slopes under various land uses were reported from hills of NEH region (Table 2.2). Singh *et. al.*, (48) while presenting engineering procedures for efficient land use systems in hills, concluded that from resources management point of view mixed land use planned in an independent microwatershed proved superior as the system provided maximum retention of rain water in the area.

Table 2.2 Soil losses from steep hill slopes under various land use systems without any mechanical measures⁺

Land use	Soil loss (t ha ⁻¹ yr ⁻¹)
Forest (Bamboo)	0.04 - 0.52
Shifting cultivation	5.10 - 76.80
Farmstead	16.80

⁺Singh, (51)

2.5.4 Effect of cropping pattern on soil erosion

Barring few, studies on this aspect have been done on small runoff plots and that too on mild slopes. Suarez de Castro (56) who studied soil erosion problem in a coffee producing region of Columbia, reported water losses in excess of 50 per cent of the total rainfall and soil losses of over $500 \text{ t ha}^{-1} \text{ yr}^{-1}$ on 43 per cent slope from base plots. He also observed that during the same period adjacent plots having good vegetative cover had negligible water and soil losses though the slope of the plot was 53 per cent. Awasthi (3) who studied production potential, runoff, soil and nutrient losses under different systems of cropping and management practices on 58 to 70 per cent slope in runoff plots concluded that on steep slope, arable cropping for three successive years under minimal cultivation (slashing, burning and dibbling mixed crops), accelerated soil and nutrient losses which resulted in fast deterioration in productivity. Soil and water losses (average of 3 years) under various potential cropping systems were reported to vary from 52.94 to 83.77 $\text{t ha}^{-1} \text{ yr}^{-1}$ and 110.17 to 174.00 mm respectively. Rai (32) studied toposequential cropping systems with rice and maize on 55 per cent slope in 16 x 3 m plot sizes in which 25, 50, 75 and 100 per cent of the slope towards foot hills was converted into bench terraces. Maize was grown on slopy portion of the plot whereas paddy in the terraces. Runoff and soil losses were higher from slopes (6.58 per cent of rainfall and 21.0 $\text{t ha}^{-1} \text{ yr}^{-1}$) and decreased considerably (0.5 per cent and 1.1 $\text{t ha}^{-1} \text{ yr}^{-1}$) due to complete and partial terracing of slopes.

2.6 Economic Consideration and Evaluation

While reviewing the land management works in India, Vohra (59) concluded that bulk of the programmes were implemented in financially wasteful, technically defective and administratively uncoordinated manner. Terracing as a land treatment measures needs to be taken as an intensive self employment programme (Singh and Rai, 44). Large agricultural areas in Sikkim, Nagaland and Manipur are under bench terracing as peoples' programme without any direct financial input. Similarly, on evaluation aspect, Singh (41) suggested a simple method of resource gain assessment for waste land development and testing the correctness of the proposed land uses.

$$\text{R.G.} = \text{V.TL} - (\text{V.UTL} + \text{C.T.}) \quad \dots\dots\dots (2.5)$$

Where R.G. = Resource gain (Rs. ha⁻¹)
 V.TL = value of treated land (Rs. ha⁻¹)
 V.U.TL = value of the untreated land (Rs. ha⁻¹)
 C.T. = cost of the treatment (Rs. ha⁻¹)

For positive resource gain (gain due to the treatment of the land), the land use plan with estimated investment should be considered justified. Whereas for negative gains, it would be necessary to change the land use.

2.7 Concluding Remarks

Runoff and its associated influencing parameters are the main agents of land degradation. These depend on slope, conservation practices, watershed characteristics (including geographical and geomorphological characters), rainfall, sunlight and time etc. So far attempts have mostly been confined to study rainfall characteristics and its relationship with dependent variables. Current efforts throughout the world are concentrating on working out various parameters of USLE.

Rainfall management in microwatersheds with bench terracing, contour bunds (earthen barriers across the hill slope passing through the points of same elevation), grassed waterways for safe disposal of runoff and water harvesting (whenever feasible) at the foot hills in dugout-cum-embankment type ponds provides opportunity for effective management. Study of some of the important variables related to land use may provide insight and help in adoption of effective approach for land management in hills.

From the present review the following conclusions can be drawn:

- i) It indicates that general awareness exists about the problem of soil erosion and degradation. However, appreciation to the effectiveness of the control measures are rather lacking.
- ii) Most of the available information on soil erosion and its management are for slopes lower than 30 per cent and do not tell about higher slopes. Broadly, research efforts are being made to study the problems on slopes below 9 per cent even in hilly areas just for the sake of data fitting in USLE. But such slopes are rarely available in hill areas for cultivation.

- iii) Soil erosion phenomenon on higher slopes in high rainfall area are not clearly understood.
- iv) Almost all the studies describe relationship between various uncontrollable parameters of rainfall and soil erosion based on laboratory tests. These can not be used in solving the field problems. Besides broader conclusions are drawn for large catchments based on meagre data. This is a dangerous trend in research particularly for solving the real world problem.
- v) The review provides ample evidence that the degradation problem in hills is the result of interaction in between infinite number of variables and the man which is the most important one.
- vi) Research and development works on soil and water conservation are mostly tailored to suit the requirements of plain land. Accordingly, mechanised agriculture at individual farmer's level has been popularised. But these are misfit in small farm holdings of slopy areas.

Considering the above conclusions, one may agree for a change in present approach so as to arrive on practical suggestions for solving field problems in the areas of soil and water conservation in hilly regions. The following points in this connection deserve consideration:

- i) Thorough study, evaluation and documentation of existing potential land use systems may provide solution to many regional problems.
- ii) Research needs to be directed towards solving specific field problems of the region in which man must be considered as an important factor.
- iii) The approaches shall be that the contribution of the individual land users is ensured in managing rain where it falls.
- iv) Input component in projects aiming at management of natural resources needs to be specified in man-days per un
in FAO.

Chapter - III

MATERIAL AND METHODS

3.1 Description of the NEH region

The present study was undertaken in NEH region of India (Fig. 3.1) which is dominated by three land form associates - the greater Himalayas, well dissected high lands and low lying riverine plains. The greater Himalayas in the north form a series of roughly parallel east west ridges composed of the sedimentary rocks of tertiary age like sand stones, shales, schists, slates etc., the Naga-Mizo hills in the east and Shillong plateau in the south rising to over 1600 m have a land scape of steep sides, winding valleys with boulder stream river beds, rapid water falls (Anonymous, 1 and 2). The hills mainly consist of Archaen complexes (gneiss, amphibolite, quartzite, phyllite and granite and granitic intrusions) with surface cover of younger sedimentaries and tertiary rocks which are folded, faulted, eroded and dissected by streams. The Brahmaputra and Surma-Barak valleys in the middle and further south respectively have been formed of recent alluvium and intercepted occasionally by Archaens exposed in the form of denuded hill rocks.

The demographic feature of the region is that hills are predominantly inhabited by scheduled tribes while the plain belongs to other communities.

3.2 Climate

North-Eastern India lies to the south of the eastern end of the great Himalayan range. Important geographical features like the Khasi-Jaintia and Garo hills and to some extent the Mikir hills do influence on the climate of the area. Brahmaputra and its tributaries also affect the climate of the region. The south west monsoon has considerable influence on the climate due to the proximity of the region to the northern part of Bay of Bengal. The main features of the weather have been described by Indian Meteorologi-

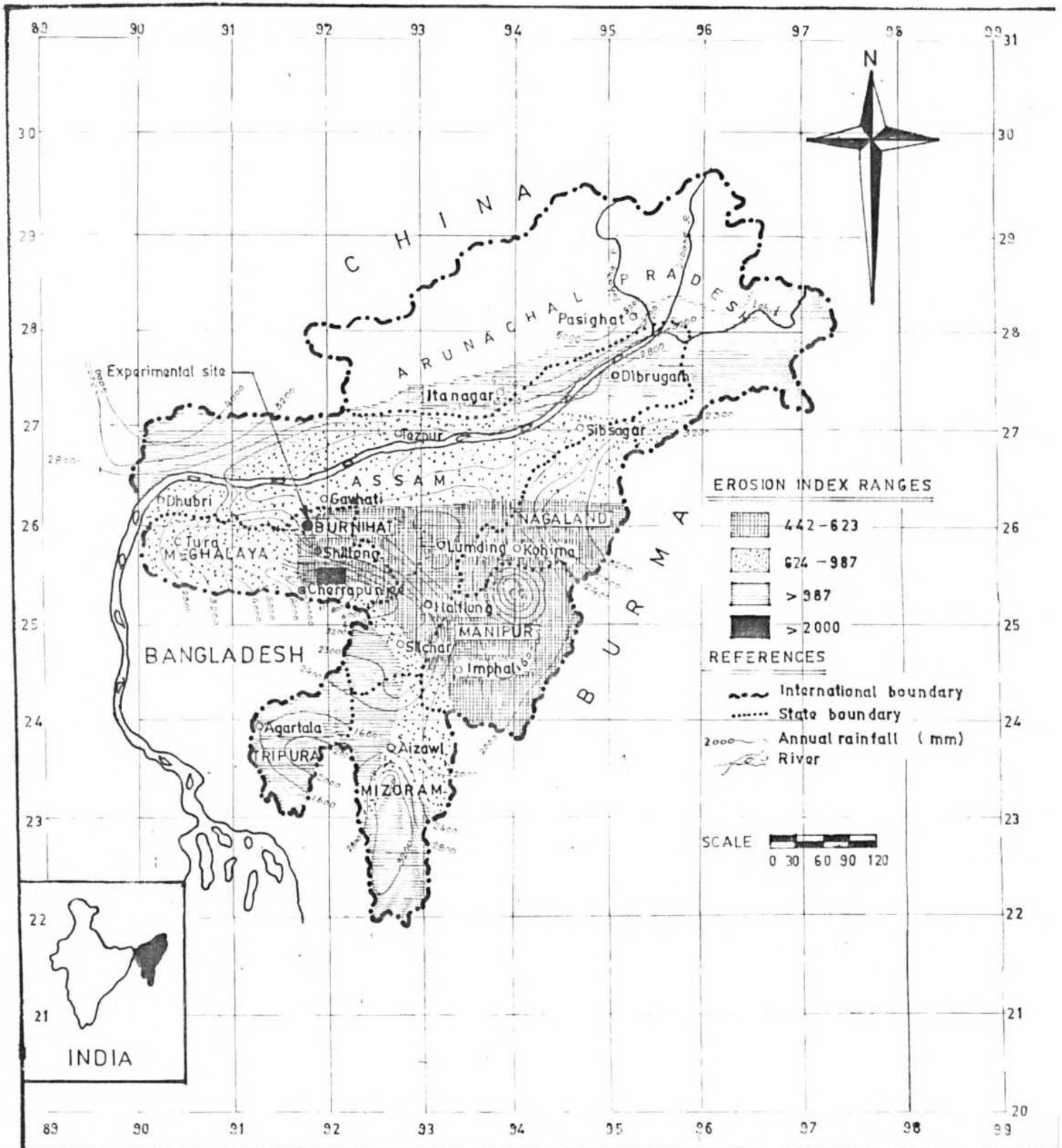


Fig. 3.1. Map showing experimental site along with annual rain fall, rain fall erosion index and major river systems in N.E.H. Region.

cal Department (IMD), Pune (18). Meteorological data are presented in Appendix (Table A-1 to A-7).

3.2.1 Rainfall

Rainfall occurs all through the year in NEH region. Striking variation in rainfall is observed in the hills and mountains. On the southern sides of Khasi-Jaintia hills, the annual rainfall is over 10,000 mm. It drops down to 2,000 mm in the north of the Brahmaputra valley.

The rainfall of Meghalaya (the place of present investigations) varies considerably from place to place. The central parts of Meghalaya are famous for the phenomenally high rainfall. The average annual rainfall on this area exceeds 7,000 mm. The central upland zone has an east-west orientation and brings the northern and adjoining central Meghalaya in the rain shadow region. This factor is responsible for the large variation in rainfall from south to north. Cherrapunjee in the south records an annual rainfall of 10,869 mm whereas Shillong, which lies 50 kms to the north of this place records an annual rainfall of 2,253 mm only. Even though the period of availability of rainfall data is not long, a village Mawsynram situated about 16 kms west of Cherrapunjee records the world's highest annual average rainfall of 11,406 mm. In contrast, the Imphal-Lumding region which partly lies in the rain shadow of the Mikir hills range records the lowest annual monsoon rainfall. Seasonal and annual rainfall of some stations in NEH region is given in Table A-1.

Rainfall at the experimental site is presented in Table A-2. The average annual rainfall is around 1618 mm. Over 80 per cent of the total annual rainfall is received during the period May to September. The highest rainfall recorded in a single day (24 hours) during the period of the 8 years was 129.8 mm in the year 1982, whereas the highest annual rainfall (2243.5 mm) was in 1983.

3.2.2 Temperature

Hot and cold waves are very rare in NEH region. So far as temperature is concerned, there is no difference between the hot weather and the monsoon seasons. At many places average maximum temperature during the monsoon season is higher than during the hot season. Temperature is highest during July/August despite of the rains. The day temperature in the monsoon season

often increases due to decrease in cloudiness and rainfall during the periods of formation of monsoon depression over the head of Bay of Bengal. In the Brahmaputra valley foehn effect (a hot dry wind blowing down a mountain valley) may also be present. Nights in Assam are very warm during July and August. Mean maximum and mean minimum temperature for a number of stations in NEH region are presented in Table A-3 and A-4.

3.2.3 Humidity

Weather over NEH region is humid in all the seasons. The relative humidity rarely goes below 75 per cent. This is the main cause of human discomfort, particularly during the hot weather and the monsoon season. Mean seasonal relative humidity of the morning (8-30 am) and evening (5-30 pm) hours for some stations in the region are presented in Table A-5.

3.2.4 Surface wind

Surface winds are generally light during the year. During the pre-monsoon season, they are slightly stronger particularly on occasion of passage of low pressure systems to the north of the region. Winds are generally from the north in the winter months. They are, however, easterly in the northern region in the pre-monsoon season. Winds are from the south-east in the southern parts and from the east in the northern parts of the region during the post-monsoon season. Mean monthly wind velocity recorded at some stations in the region are presented in Table A-6.

3.2.5 Evaporation

In general, evaporation decreases from the south west to the north-east of the region. The mean daily evaporation is generally about 5 mm in winter season. It varies from 15 to 20 mm during the pre-monsoon season being much less in the north-eastern parts of the region. It is generally about 15 mm during the monsoon season and less than 10 mm in the post-monsoon season (IMD, 18).

3.2.6 Evapotranspiration

The mean annual potential evapotranspiration in this region is 1000-1200 mm. It varies from 100 to 150 mm in winter and 300-400 mm in the pre-monsoon season. In the south west it is 400-500 mm in monsoon season and falls down to about 200 mm in the post-monsoon season.

3.2.7 Sunshine

The average duration of bright sunshine over the area is lowest (4 hours) in the monsoon season. It is 6 to 7 hours in pre and post monsoons and 7 to 8 hours in the winter.

3.2.8 Radiation

Intensity of solar radiation in NEH region varies between 350 to 550 calories $\text{cm}^{-2} \text{day}^{-1}$ (Table A-7).

3.2.9 Weather

The main features of weather in north eastern hill region during four seasons are as follows:

3.2.9.1 Winter season

Rain and thunder showers in association with the passage of western disturbances is an important phenomenon in this season (January - February). Morning fog is common in Assam particularly over the southern banks of Brahmaputra where fogs are frequent.

3.2.9.2 Hot weather season

Temperature during this season March to May is not high due to frequent cloudiness. The weather is very humid and uncomfortable. Thunder storms, frequently accompanied by squalls are the main weather phenomena during this season.

3.2.9.3 Monsoon season

South west monsoon's relatively cool and humid current sets in over southern parts in the last week of May. The monsoon advances into northern parts of the region during the first week of June. The major portion of the annual rainfall is received during this season. Floods are regular feature during this season (June to September).

3.2.9.4 Post-monsoon season

Rainfall is the main phenomenon during the earlier parts of this season (October to December). Morning fog occurs on some days towards the end.

3.2.10 Weather hazards

Droughts are rare in NEH region, but floods in the valleys are annual

menace. The Brahmaputra with its tributaries carries tremendous volume of water and silt discharge during the rains. Melting of snow over the Himalayas augments this discharge. Rainfall is one of the major factors responsible for soil erosion. Its erosion potential is quite high towards north west and southern parts of the region, whereas it is minimum in Manipur valley (Fig. 3.1).

3.3 Location

The actual place of field investigation was located in Meghalaya at the Indian Council of Agricultural Research Complex farm within the premises of Conservation Training Institute, Burnihat (Fig. 3.1). The place is located at an elevation of 100 m above mean sea level about 80 km north of Shillong and 20 kms south of Gauhati along Gauhati-Shillong National highway.

3.4 Soil and Vegetation

Soil in the experimental area belongs to oxisol order having plinthitic nodules within one metre from the soil surface. The parent material is of sand stone. With sandy loam texture, internal drainage of the soil is quite good. The area originally supported climax forest of sal (Shorea robusta). Due to the practice of shifting cultivation in the past the present vegetation around the study area consisted mostly of shrub forests. When the study was undertaken the secondary forest vegetation was dominated by Dendrocalamus hamiltonie.

3.5 Description of the Experiment

Behaviour of rainfall in causing soil erosion and runoff on steep hill slope was studied in two parts (i) in microwatersheds with six landuses and (ii) in ten runoff plots under bare fallow condition with and without soil conservation measures. Microwatersheds and runoff plots were developed during the course of initial stages of the present research in NEH region by the present author. Data for the period of 1976-83 have been used here.

3.5.1 Watershed based land use systems

Six land use practices were selected for the study. Mechanical soil and water conservation measures to the selected land uses were provided appropriately.

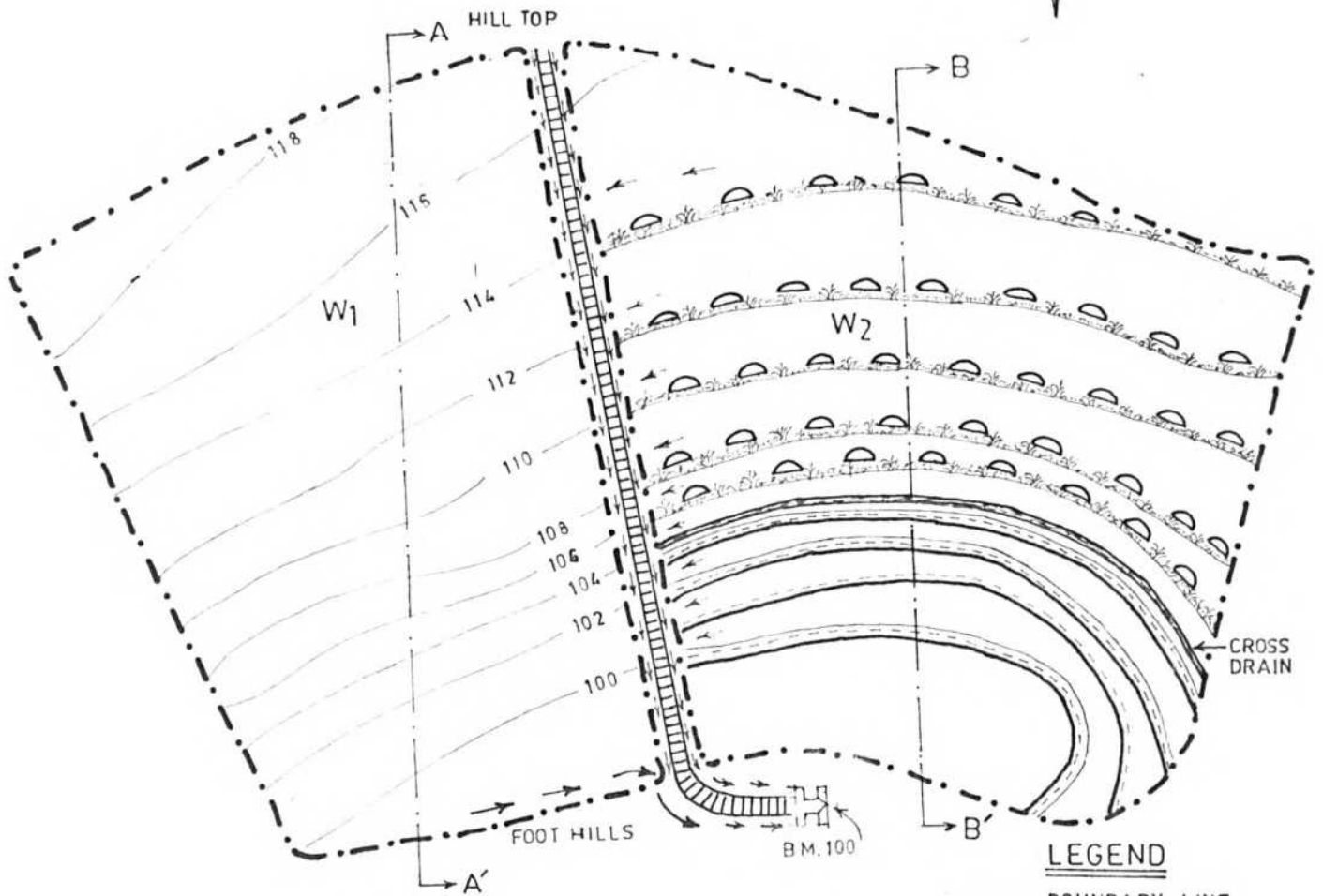
Two of the selected land uses were of traditional type namely the practice of shifting cultivation and secondary forest. Details of the land use system are given in Table 3.1.

Table 3.1 Land use systems and soil conservation measures in experimental watersheds

Land use	Crops grown	Soil & water conservation measures	Land use notation	Period of observation
Traditional [*] Agriculture (Shifting cultivation)	Cereal, tuber, cucurbits, vegetables in mixture	Nil	W ₁	1976-83
Agriculture 1/3rd lower area and 2/3rd upper area in horticulture	Cereal, tuber lemon (Citrus) pineapple, cowpea	Bench terraces and pineapple rows on contours	W ₂	1976-83
Agriculture	Cereal and tuber	Bench terraces	W ₃	1976-83
Agriculture	Cereal and tuber	Contour bunds	W ₄	1976-83
Agriculture	Fodder legumes and grasses	Bench terrace and contour bunds	W ₅	1978-80
Secondary forest	Bamboo	Nil	W ₆	1978-80

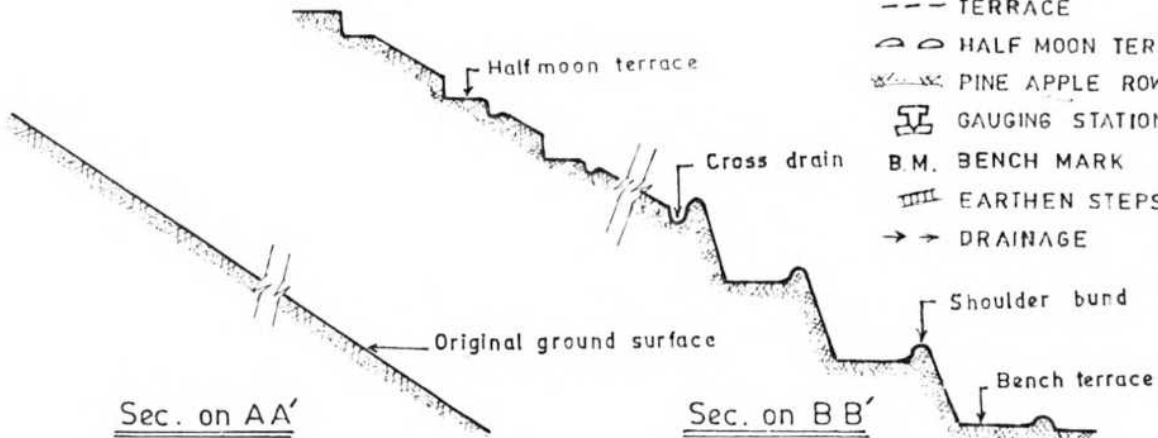
^{*} Watershed under shifting cultivation completed 2 cycles of cropping (1976-77 and 1980-81) during the period of study.

All the experimental watersheds were located on natural hill slopes having soil depth greater than 1.5 m. Demarcation of physical boundaries of the watersheds was done carefully so that each one of them functioned as independent basin. The watersheds were extended upto top of the hill and bunds were erected as far as possible on natural ridges except along the dividing line (in the form of a bund) raised in the middle of the natural watershed boundaries for W₁, W₂, W₃ and W₄. The bunds thus raised were also used as steps to go up and down. Topographical details of the experimental watersheds are shown in Fig. 3.2, 3.3, 3.4, and Table 3.2.



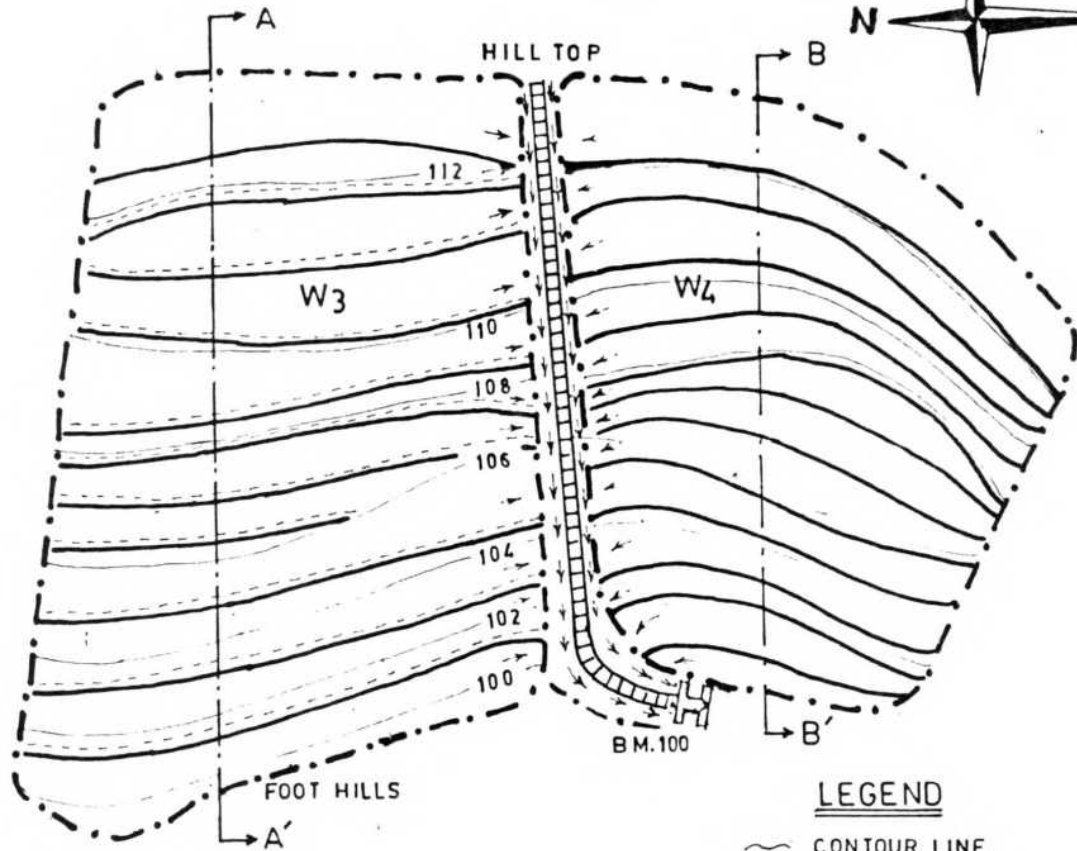
LEGEND

- BOUNDARY LINE
- ~ CONTOUR LINE
- - - TERRACE
- ⌒ HALF MOON TERRACE
- ⊘ PINE APPLE ROWS
- ⊞ GAUGING STATION
- B.M. BENCH MARK
- ▨ EARTHEN STEPS
- DRAINAGE




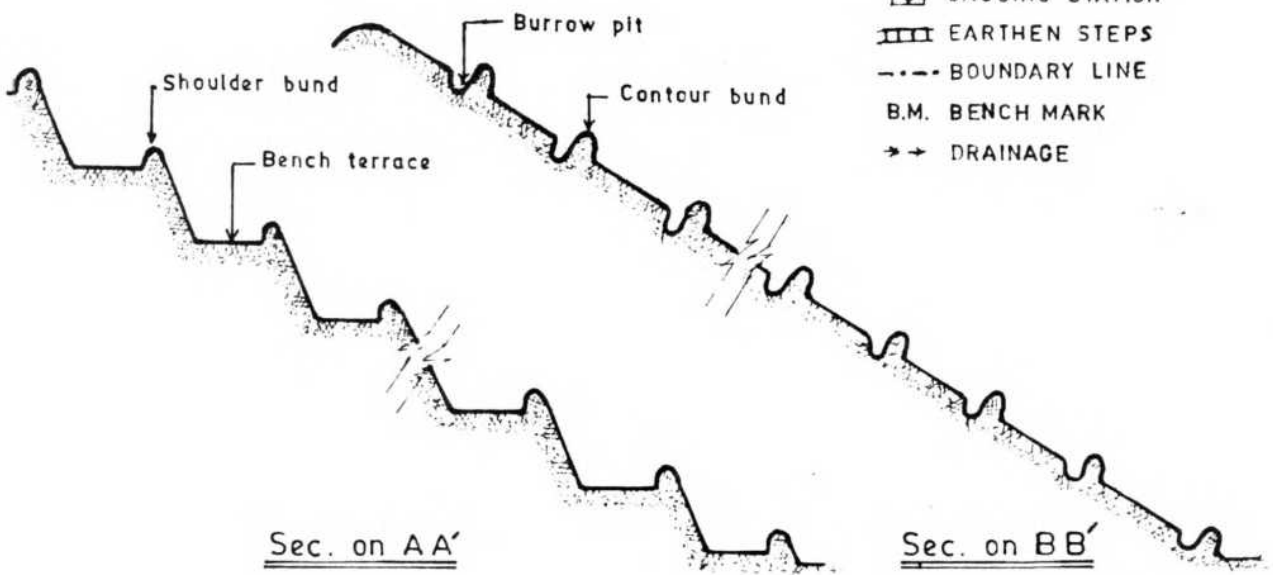
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Fig. 3.2. Topographical details and schematic views of ground surface profile for W₁ and W₂



LEGEND

- ~ CONTOUR LINE
- CONTOUR BUND
- - - TERRACE
-  GAUGING STATION
-  EARTHEN STEPS
- - - BOUNDARY LINE
- B.M. BENCH MARK
- - - DRAINAGE



Drawing not to Scale

Fig.3.3. Topographical details and schematic views of ground surface profile for W₃ and W₄.

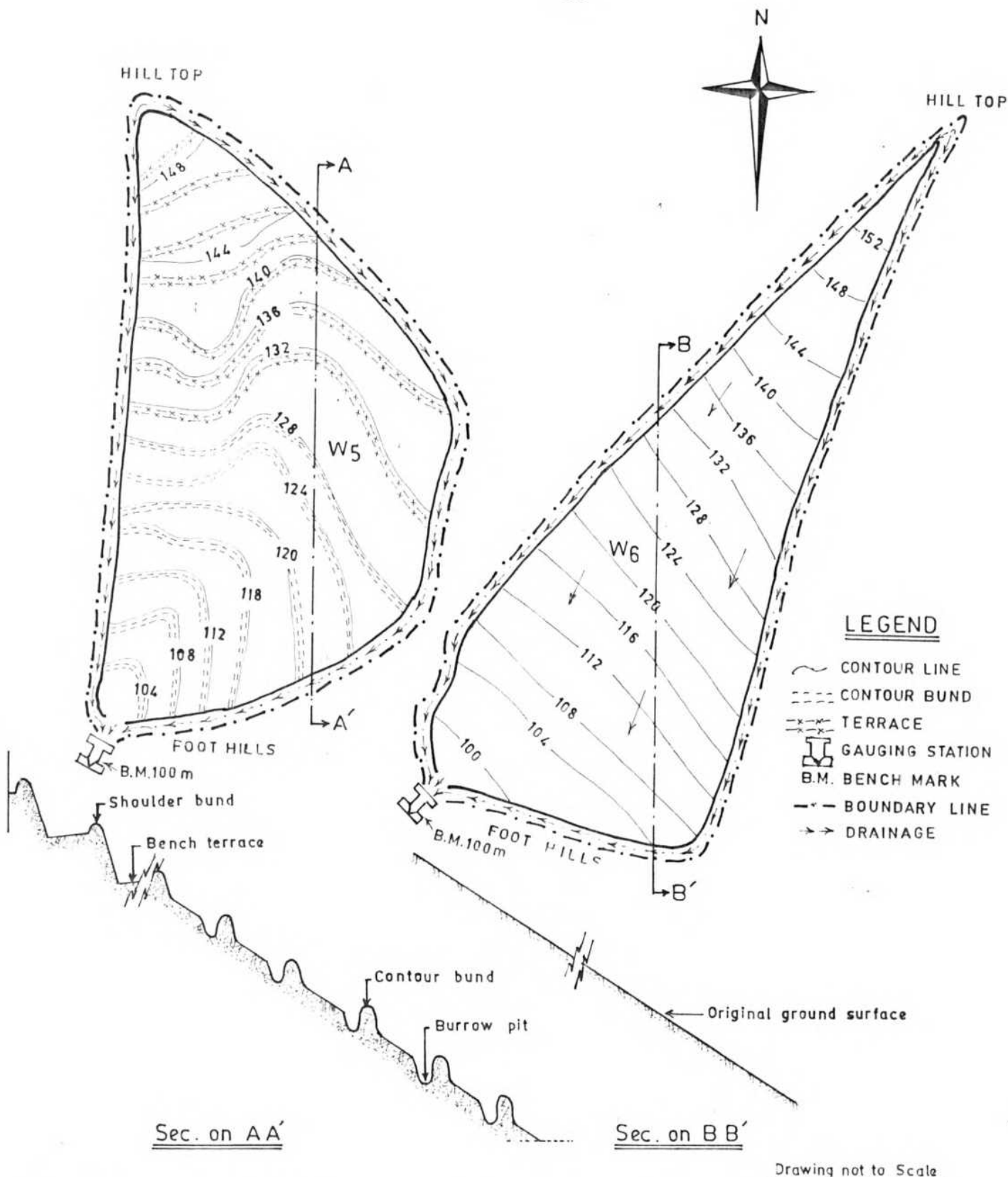


Fig.3.4 Topographical details and schematic views of ground surface profile for W₅ and W₆

Table 3.2 Information on experimental microwatersheds

Particulars	Microwatersheds					
	W ₁	W ₂	W ₃	W ₄	W ₅	W ₆
Area (ha)	0.15	0.19	0.11	0.09	0.41	0.47
Max.length (m)	52.00	55.00	52.00	50.00	102.50	152.50
Max. width (m)	38.00	52.00	42.00	36.00	40.00	30.80
Form Factor	0.46	0.65	0.54	0.64	0.45	0.20
Slope (m/m)	0.40	0.44	0.42	0.43	0.43	0.45
Drainage	Good	Good	Good	Good	Good	Good
Man hrs. required for development	135	409	750	254	409	-

3.5.1.1 Measurement of runoff and soil losses from experimental watersheds

Watersheds were gauged for recording runoff and soil losses. H flumes, F type water level recorders and Coshocton wheel samplers were used in each watershed (Fig. 3.5). At the foot hills, arrangements were made with the use of diversion bund so as to divert the runoff through the respective gaugings. Total flow and peak flow for each hydrograph was calculated from the recorded charts, whereas the soil loss from the watersheds was estimated from the integrated samples collected through the coshocton wheel runoff samplers. A 500 ml of the runoff sample (mixed with silt) after thorough stirring was collected from each watershed. The sediment was filtered and dried in the laboratory to estimate the soil erosion. Runoff and soil erosion values were converted into mm and $t\ ha^{-1}$ units respectively. These observations were recorded for every day of runoff occurrences.

3.5.1.2 Soil and water conservation measures in the experimental watersheds

Soil and water conservation measures in the chosen land use were applied with a view to manage rain water to minimize physical damage to

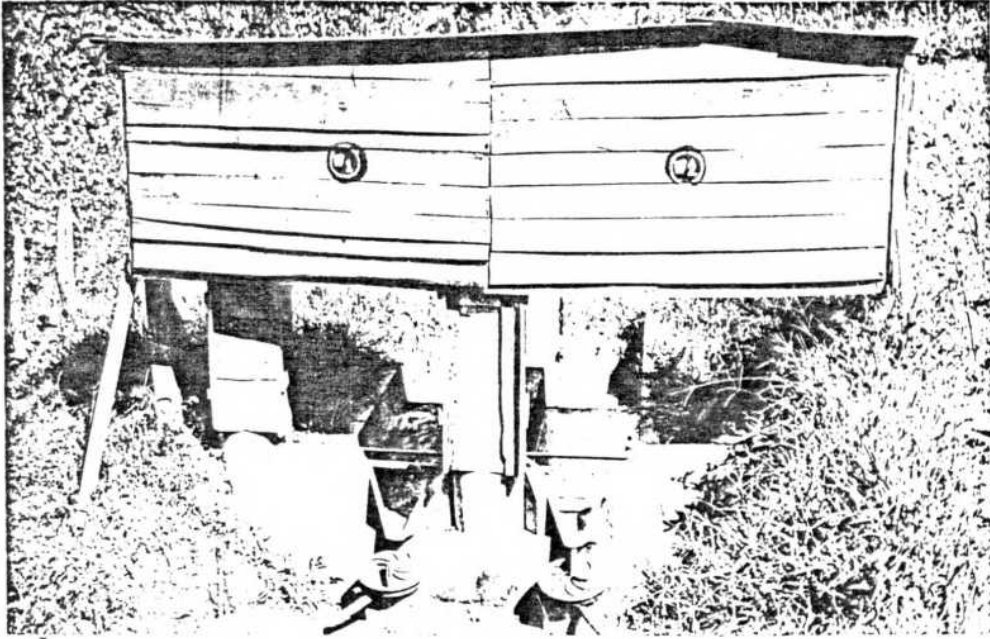


Fig. 3.5 Hydrological gauging station for measuring runoff and soil loss for W_1 and W_2

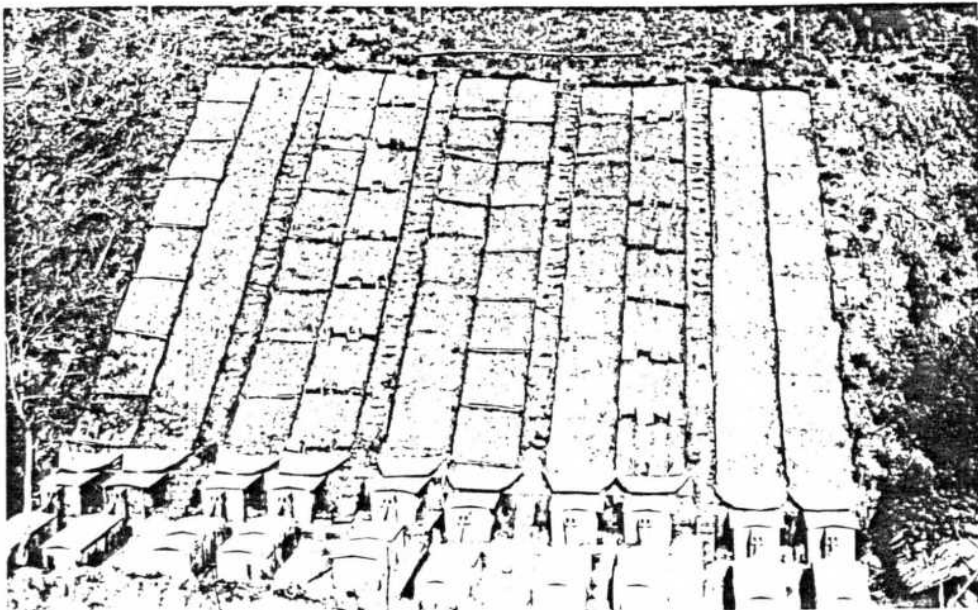


Fig. 3.6 Runoff plots seen with mechanical measures

soil. Bench terrace and contour bunds were designed in such a way that the vertical interval did not exceed 1.25 m and all the terraces drained their excess runoff into a common grassed waterway. Schematic views of ground surface profile under various land uses are shown in Figs. 3.2, 3.3 and 3.4.

3.5.1.3 Infiltration characteristics

Infiltration characteristics of soil under the land uses W_1 , W_2 , W_3 , W_4 and W_6 were studied during the year 1983 as exploratory trial using 30 cm diameter single ring infiltrometer. Observations were recorded at three locations on top, middle and foot of the hill slope, 6 times during the period between August and December. Detailed study on this aspect was not possible due to various limitations.

3.5.1.4 Moisture in the soil profile

Soil moisture observations were made from 0-60 cm soil depth to study the behaviour of residual soil moisture on hill slopes as affected by land uses and application of soil conservation measures. The observations were recorded from August, 1977 to December, 1978 at 9 locations (3 each from top, middle and foot hills of the slope) in W_1 , W_2 , W_3 , W_4 and W_6 at fortnightly intervals. Moisture content of the soil was determined by gravimetric method.

3.5.2 Studies on bare fallow runoff plots

Runoff plots of 20 x 2 m size constructed on 58 to 70 per cent slopes of a real hill were used for recording observations on runoff and soil erosion (Fig. 3.6). The plots constructed 'in situ' condition were under minimal cultivation (slashing, burning and dibbling mixed crops) during 1979-81. Plots were kept weeds free. The study was conducted in 1982 and 1983. During 1982, all the plots were kept without any soil and water conservation measures. In 1983, some appropriate soil and water conservation measures were used to study the effectiveness of such mechanical measures on steep hill, devoid of vegetation. During 1983, the plots were also kept free from weeds. In a nearby place a 5 m² plot having zero slope was gauged to record runoff and soil loss for comparison purposes.

3.5.2.1 Soil and water conservation measures in runoff plots

Five treatments were assigned in 2 replications in the runoff plots at 2.5 m spacing. The treatments were (i) without any measure, (ii) tie ridge, (iii) contour bunds, (iv) trash bunds (bamboo and wood pieces used as barrier across the slope) and (v) level contour strips with half moon terraces. Provisions were kept for safe disposal of excess runoff with the conservation measures. The outlets were placed diagonally with a view to increase the length of flow and opportunity time for increased infiltration. Details of conservation measures are given in Fig. 3.7.

3.5.2.2 Measurement of runoff and soil loss in runoff plots

All the runoff plots were equipped with multi-slot divisors (5 slots), stilling tank and runoff collection tanks. Runoff was measured every morning following a runoff producing rain. The runoff was analysed in the laboratory for silt content in the way described in article 3.5.1.1. The volumetric values of runoff were converted into mm over the runoff plot and soil loss was expressed into $t\ ha^{-1}$.

3.6 Analysis

Graphical, statistical and empirical approaches have been followed to analyse the available data. Wherever possible, models have been established and for the rest, the general trends have been explained. Considering practical aspect of land management at land users level the following variables have been studied for explaining the behaviour of the runoff, soil loss and peak runoff on steep hill slopes.

3.6.1 Rainfall (X_1)

Rainfall amount as recorded using Symon type ordinary rain gauge.

3.6.2 Slope (X_2)

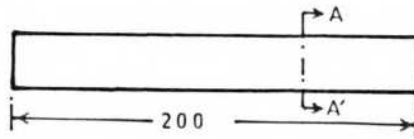
The average watershed slope in m/m as determined by topographic map with the following formula

$$X_2 = \frac{MN}{A} \quad \dots\dots\dots (3.1)$$

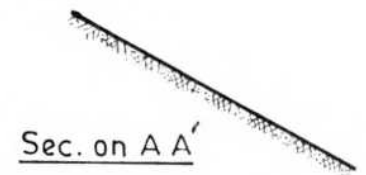
Soil and Water Conservation Measure

No Conservation measure

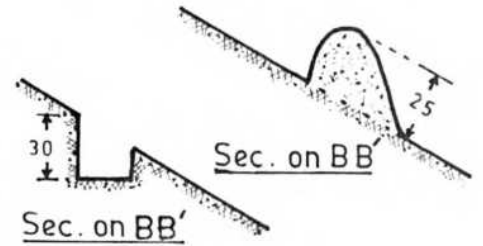
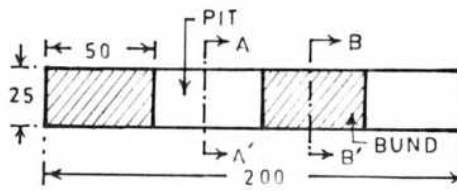
Plan



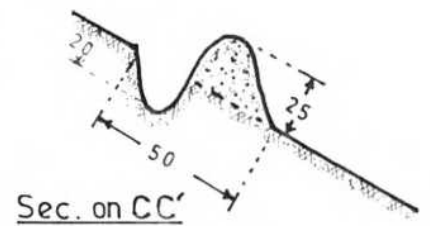
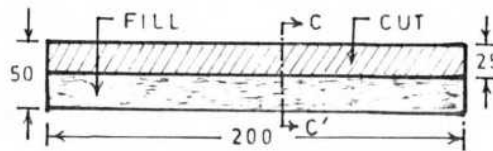
Sectional View



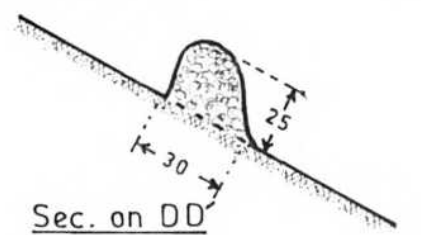
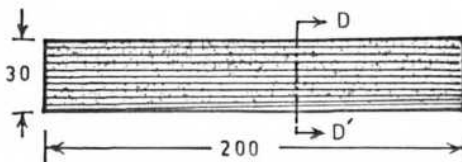
Tie Ridge



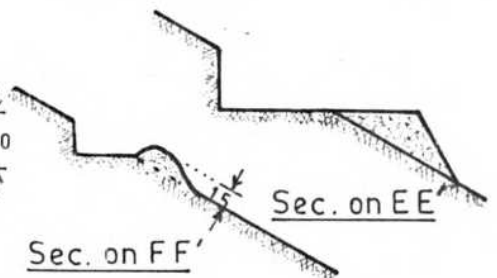
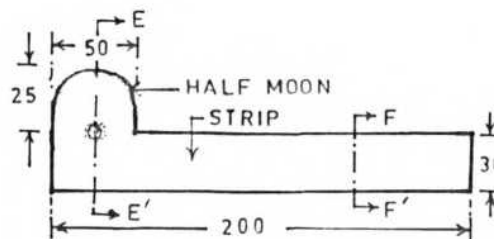
Contour Bund



Trash Bund



Level Contour Strips



Drawing not to scale
All dimension in cm.

Fig. 3.7 Mechanical soil and water conservation measures tried in runoff plots.

Where M is the total length of contours within the microwatershed in m, N is the contour interval in m and A is the size of the watershed in m² (Sharma, 39).

3.6.3 Conservation factor (X₃)

The effect of conservation measures, land use as well as human or animal interference have been accommodated in X₃, evolved through experience of the author. Leaving rainfall as a separate factor, land use, soil conservation measures and human or animal activities are the major factors which govern the amount of runoff and soil loss from hill slopes. The combined effect of these factors has been termed as conservation factor (CF). In order of risk involved for soil erosion, major land uses have been listed serially and assigned priority numbers from 1 to n (Table 3.3). Similarly, the conservation measures and human or animal interferences are listed in order of effectiveness and intensity respectively (Table 3.3). Through trial and error it was found that Fig. (3.2) suits well and tallies with the order of effectiveness of land uses in the present study.

$$CF = X_3 = \frac{A_1 (NL_1 + NC_1 + NHA_1) + \dots + A_n (NL_n + NC_n + NHA_n)}{A_1 + \dots + A_n} \dots (3.2)$$

- Where A₁ A_n = areas under various land used in ha
- NL₁ NL_n = allotted numbers shown in Table 3.3 to various land uses
- NC₁ NC_n = allotted numbers shown in Table 3.3 to various conservation measures
- NHA₁ NHA_n = allotted numbers shown in Table 3.3 to various human or animal activities

Values of CF or X₃ for various land uses are presented in Table A-8.

Table 3.3 Numerical values assigned for various items of conservation factor

Land use	Assumed numerical value	Conservation measures	Assumed numerical value	Human or animal activity	Numerical value
Waste land (fallow)	1	No measure	1	Intensive [*]	1
Development works	2	Bunds	2	Moderate ^{**}	2
Agriculture	3	Contour trench	3	Negligible ^{***}	3
Habitation	4	Bench terrace	4		
Horticulture	5				
Pasture	6				
Secondary forest	7				
Forest	8				

^{*} agriculture, pasture, habitation and wastelands;

^{**} Horticultural land use;

^{***} Secondary forest lands and forest lands.

3.6.4 Compactness coefficient (X_4)

$$X_4 = \frac{P}{2\pi R} \quad \dots\dots\dots (3.3)$$

Where P is the perimeter of watershed and R is the radius of a circle of equivalent area to the watershed (Sharma, 39).

3.6.5 Form factor (X_5)

$$X_5 = \frac{B}{L} = \frac{A}{L^2} \quad \dots\dots\dots (3.4)$$

Where L is axial length from outlet to be remotest point in the basin and B is the average width obtained by dividing the area (A) by axial length (Sharma, 39).

Chapter - IV

OBSERVATIONS AND RESULTS

4.1. Soil Properties

Soil properties of micro-watersheds under various land uses and of undisturbed runoff plots in bare fallow conditions are presented in Table 4.1. Soil texture of the study area was sandy loam.

Table 4.1 Soil properties of experimental watersheds and runoff plots

Experimental plot	Sample depth (cm)	pH	Free iron oxide (%)	Organic matter (%)	Percentage of			Dry bulk density (g cm ⁻³)
					Sand	Silt	Clay	
W ₁	0-15	5.00	5.57	1.97	60.9	22.4	16.7	1.27
	15-30	4.75	5.69	1.33	66.1	12.2	22.7	1.36
W ₂	0-15	5.05	6.25	1.41	68.1	14.4	17.5	1.36
	15-30	5.00	6.48	1.28	66.8	12.4	20.8	1.37
W ₃	0-15	5.45	5.59	1.48	65.5	13.8	20.7	1.37
	15-30	4.95	6.25	1.38	64.3	12.4	23.3	1.33
W ₄	0-15	4.95	7.25	1.36	66.8	11.7	21.5	1.33
	15-30	4.70	7.45	1.00	65.5	12.9	21.6	1.31
W ₅	0-15	5.35	6.87	1.90	63.8	17.3	18.9	1.32
	15-30	5.15	7.21	1.28	67.6	12.3	20.1	1.29
W ₆	0-15	5.25	8.20	2.03	69.5	11.0	19.5	1.27
	15-30	5.10	8.37	1.62	72.1	13.0	14.9	1.28
Runoff plots	0-15	5.35	4.87	1.35	66.9	13.0	20.1	1.32
	15-30	4.90	5.05	1.21	65.0	15.1	19.9	1.35

4.2 Results of Microwatersheds

4.2.1 Runoff, soil loss and peak rate of runoff

Monthly values of runoff, soil loss and peak flow obtained from experimental watersheds under various land uses are presented in Table A-9 to A-14. In general runoff and soil loss were higher in those months which witnessed the higher rainfall for all the cases of W_1 through W_7 . General behaviour of the land uses is described as follows:

4.2.1.1 Shifting cultivation (W_1)

Annual runoff and soil loss values from the experimental watersheds under two phases of the land use, varied between 13.30 to 214.80 mm and 5.10 to 83.30 t ha⁻¹yr⁻¹ and 0.86 to 27.11 mm and 0.04 to 0.88 t ha⁻¹ yr⁻¹ respectively (Table A-9). In general, the monthly values of runoff were higher in the months which recorded highest amount of rainfall (Table A-2 and A-9). However, this trend was not found always true with the soil loss, particularly in the initial years (1976 and 1977) of this study. During the fallow period the losses were negligible as regeneration of natural vegetation covered the soil surface. Annual soil loss values expressed as t ha⁻¹ yr⁻¹ per mm of rainfall varied between 0.4×10^{-2} to 0.5×10^{-1} and 0.2×10^{-4} to 0.7×10^{-3} during the period of cultivation and fallow respectively (Table A-9). The highest amount of soil loss observed was 83.3 t ha⁻¹ yr⁻¹.

Runoff, soil loss and peak flow during the period of study followed identical pattern (Fig. 4.1). The magnitude was higher during the years of cultivation and lower when plot was left fallow.

4.2.1.2 Agri-Horti landuse (W_2)

Annual runoff and soil loss values from experimental watershed which had support of bench terraces and vegetative barriers of pineapple rows on contours varied between 0.30 to 147.70 mm and 0.04 to 10.30 t ha⁻¹ yr⁻¹ during the period of study (Table A-10). In general, the monthly values of runoff were higher in months which recorded higher values of rainfall. However, this was not the case with occurrences of soil loss during the initial years (Table A-2 and A-10). Annual soil loss varied between 0.2×10^{-4} to 0.5×10^{-2} t ha⁻¹ yr⁻¹ per mm of rainfall (Table A-10).

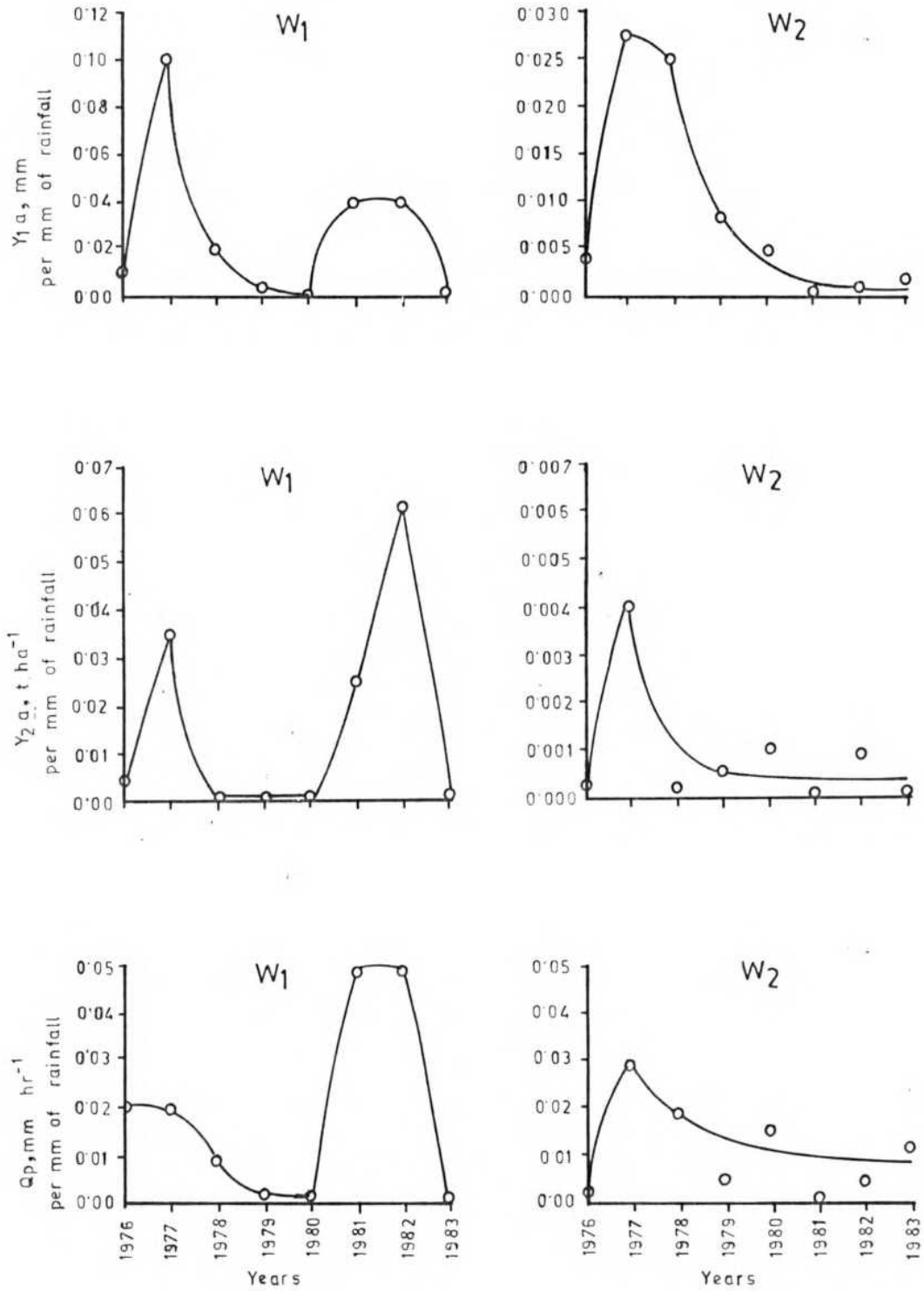


Fig.4.1 Annual pattern of runoff (Y1a) soilloss (Y2a) and peak runoff (Qp) in W1 and W2

Runoff, soil loss and peak flow values expressed as per unit of rainfall declined from third year onwards (Fig. 4.1).

4.2.1.3 Agricultural landuse (W_3)

Annual runoff and soil loss values from experimental watershed which had the support of bench terracing varied from 0.0 to 76.70 mm and 0.0 to 7.70 t ha⁻¹ yr⁻¹ during the period of study. In general the monthly values of runoff were higher in the months having higher rainfall. However, this was not the trend with occurrences of soil loss particularly during first year when the slope was converted into benches (Table A-2 and A-11). Annual soil loss varied between 0.0 to 0.4 x 10⁻² t ha⁻¹ yr⁻¹ per mm of rainfall (Table 11).

Runoff, soil loss and peak flow declined from third year onwards (Fig. 4.2).

4.2.1.4 Agriculture landuse (W_4)

Annual runoff and soil loss values from experimental watershed which had the support of contour bunds varied between 3.40 to 425.30 mm and 0.60 to 68.20 t ha⁻¹ yr⁻¹ respectively during the period of study. In general, monthly values of runoff were higher in months having higher rainfall (Table A-2 and A-12). However, this was not the trend with soil loss particularly during initial years when plot was disturbed due to raising of the contour bunds. Annual soil loss values expressed as t ha⁻¹ yr⁻¹ per mm of rainfall varied between 0.6 x 10⁻⁴ to 0.3 x 10⁻¹ (Table A-12).

Annual runoff, soil loss and peak flow expressed as per unit of rainfall declined with year but the pattern was different than the other watersheds (Fig. 4.2).

4.2.1.5. Agricultural landuse (W_5)

Annual runoff and soil loss from experimental watershed having bench terrace and contour bunds as conservation measures for raising fodder crops varied between 4.49 to 46.64 mm and 0.88 to 14.23 t ha⁻¹ yr⁻¹ respectively (Table A-13). In general, monthly runoff and soil loss were higher in months which recorded higher amount of rainfall (Table A-2 and A-13).

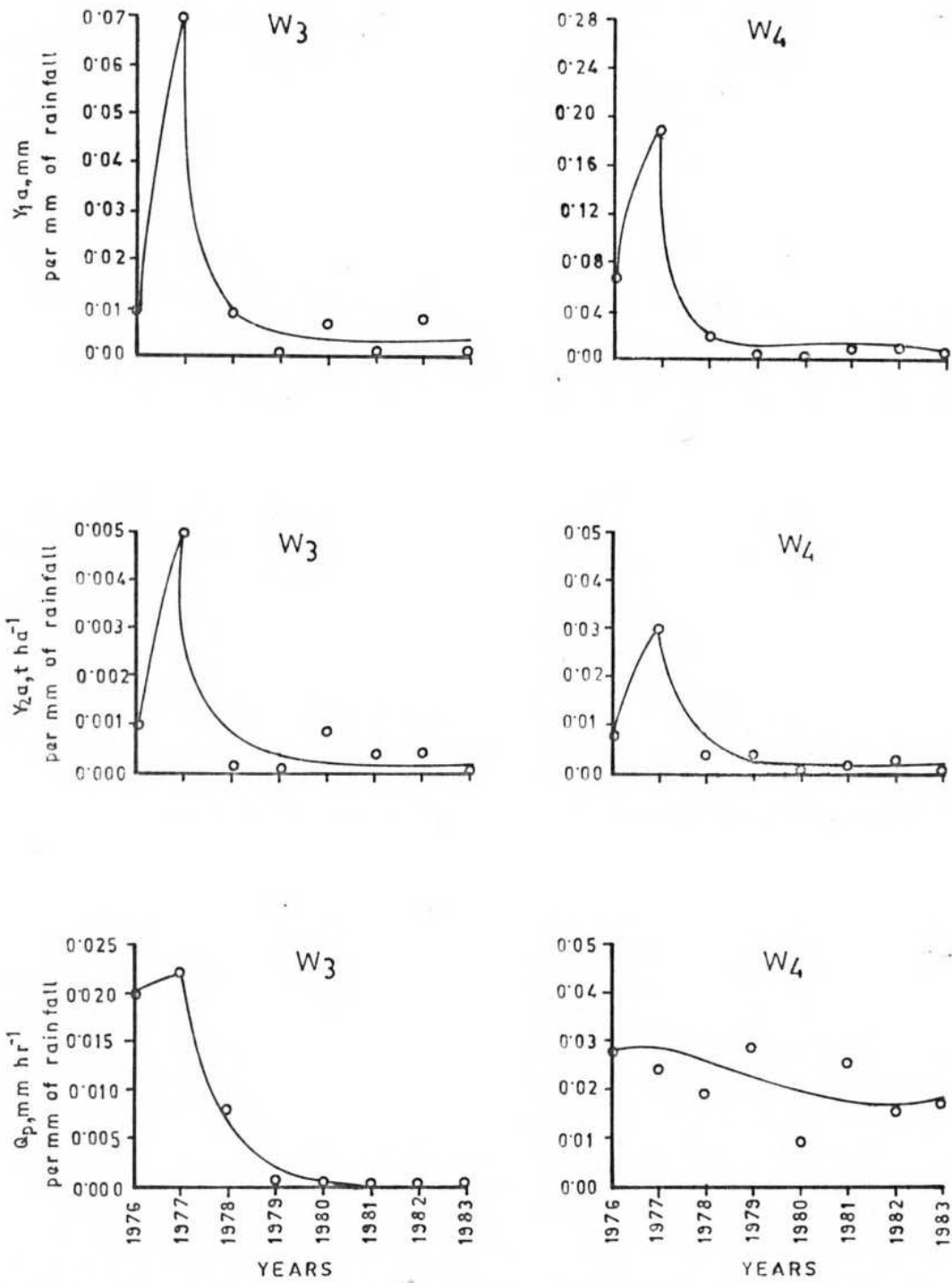


Fig. 4.2 Annual pattern of run off ($Y_1 a$) soil loss ($Y_2 a$) and peak run off (Q_p) in W_3 and W_4

Annual soil loss per mm of rainfall varied between 0.6×10^{-3} to 0.1×10^{-1} $t \text{ ha}^{-1} \text{ yr}^{-1}$. Annual trends in occurrence of runoff, soil loss and peak flow could not be studied as only three years data were used in the study.

4.2.1.6 Secondary forest (Bamboo - W_6)

Annual runoff and soil loss from the experimental watershed varied between 1.10 to 7.27 mm and 0.04 to 0.52 $t \text{ ha}^{-1} \text{ yr}^{-1}$ respectively (Table A-13). In general the monthly values of runoff and soil loss were higher in months which received highest amount of rainfall (Table A-2 and A-13). Annual soil loss per mm of rainfall varied between 0.2×10^{-4} to 0.4×10^{-3} $t \text{ ha}^{-1} \text{ yr}^{-1}$. Annual trends of occurrences of runoff, soil loss and peak runoff could not be studied for reasons explained in article 4.2.1.5.

4.2.2. Comparative behaviour of landuses

Soil loss in all land uses (Fig. 4.3) except under shifting cultivation (W_1) was well within safe limit of $12.0 t \text{ ha}^{-1} \text{ yr}^{-1}$ (McCormack and Young, 28). For comparative scrutinisation, range of runoff, soil loss and peak rate of runoff are presented in Table 4.2.

Table 4.2. Runoff, soil loss and peak rate of runoff from experimental watersheds under various landuses during period of study (1976-83)

Landuse	Rainfall retained within the area (% of annual total)	Soil loss ($t \text{ ha}^{-1} \text{ yr}^{-1}$ per mm of rainfall)	Peak rate of runoff (mm. hr^{-1})
W_1	90.30-98.94	$0.3 \times 10^{-1} - 0.5 \times 10^{-1}$	24.15 - 74.44
W_1^*	97.96-99.96	$0.2 \times 10^{-4} - 0.7 \times 10^{-3}$	0.27 - 16.57
W_2	93.33-99.98	$0.2 \times 10^{-4} - 0.5 \times 10^{-2}$	1.13 - 38.45
W_3	95.21-100.00	0.0 - 0.4×10^{-2}	0.00 - 64.09
W_4	80.74-99.79	$0.6 \times 10^{-4} - 0.3 \times 10^{-1}$	14.95 - 55.69
W_5	97.08-99.66	$0.6 \times 10^{-3} - 0.1 \times 10^{-1}$	1.85 - 33.83
W_6	99.55-99.92	$0.2 \times 10^{-4} - 0.4 \times 10^{-3}$	5.10 - 18.70

* Abandoned shifting cultivation plot under fallow phase.

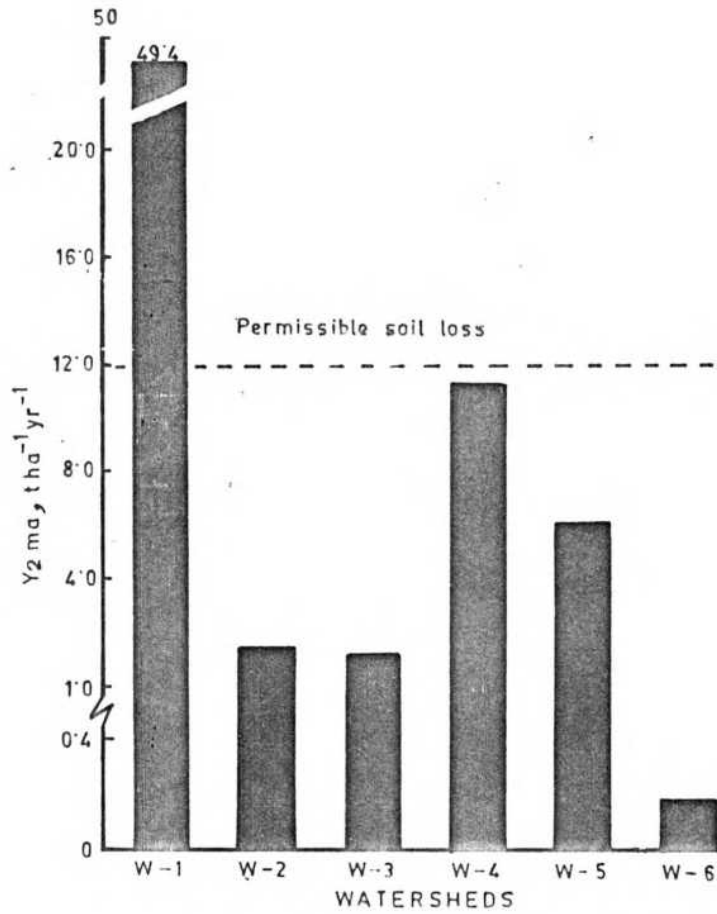


Fig.4.3 Mean annual soil loss(Y_{2ma})in experimental watersheds

4.2.3. Rainfall-runoff and rainfall-soil loss relations

Attempts were made to use daily rainfall, runoff and soil loss data to examine the relationships between these factors. Data were processed to various manners to find out best possible equations.

Initially efforts were made to find out relationship between daily rainfall, runoff and soil loss. Plots between rainfall-runoff and rainfall-soil loss for isolated storm events revealed a concentration of the plotted points towards the origin and the rainfall axis (Fig. 4.4). This trend was in all the cases and effect of landuses could only be seen in terms of the cumulative magnitude of runoff, soil loss and peak rate of flow. The plotting of these events for W_1 and W_2 are depicted in Figs. 4.4 and 4.5. These show scattering of points in a wider range. Further trials with monthly values of rainfall, runoff and soil loss did not give any conclusive result and most of the data points were seen to be concentrated around rainfall axis (Figs. 4.4 and 4.5). This pattern of relationship was almost similar in all cases, irrespective of landuses.

Further examination of data did show some trend when monthly cumulative values of runoff and soil loss were plotted against monthly cumulative rainfall for entire period of study (1976-83). An indication of exponential type of relation (Fig. 4.6) was observed. This was the pattern of relationship with all landuses. Landuse effect in producing runoff and soil loss is seen with steepness and flatness of the curve (Fig. 4.6) indicating static position during the period when there were no runoff and soil loss or the values were negligible to trace. Flattening (reduction in slope of the curve) of curve with time indicates about the behaviour of landuse (W_2) towards stability in relation to runoff and soil loss. In shifting cultivation watershed (W_1) flat portion of the curve indicates fallow period when runoff and soil loss was negligible.

On the basis of the clues obtained from Figs. 4.6, mean monthly cumulative rainfall (X_{mc}) and mean monthly cumulative runoff (Y_{1mc}) were plotted on plain graph paper (Fig. 4.7) which showed that runoff begins after having received a minimum amount of rainfall during the year. This amount of rainfall was termed as 'Threshold' rainfall (C). Similar relationship was found to exist between monthly cumulative values of rainfall (X_{mc}) and monthly cumulative values of soil loss (Y_{2mc}) as well. Hence, the relationship

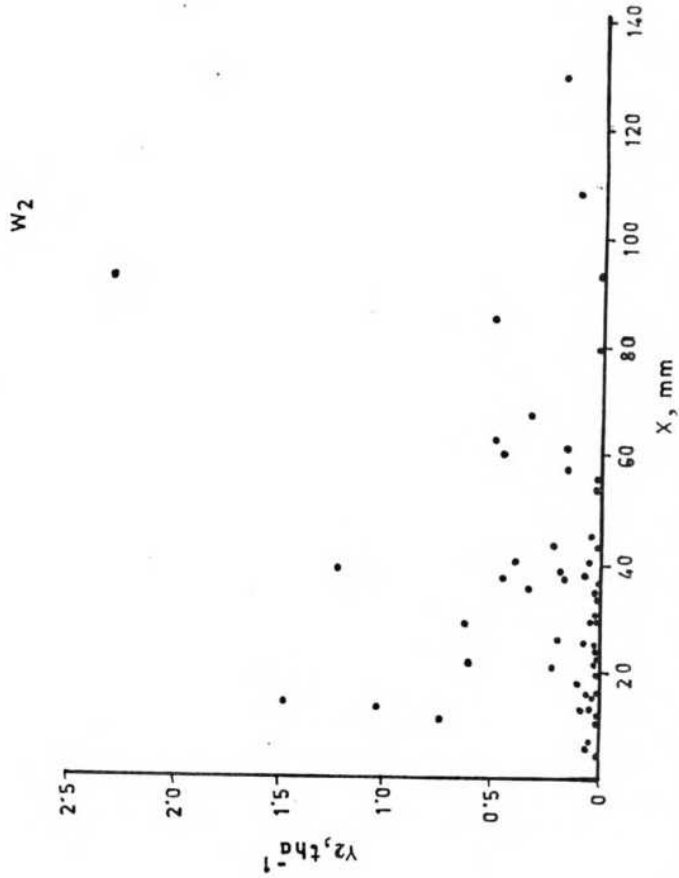
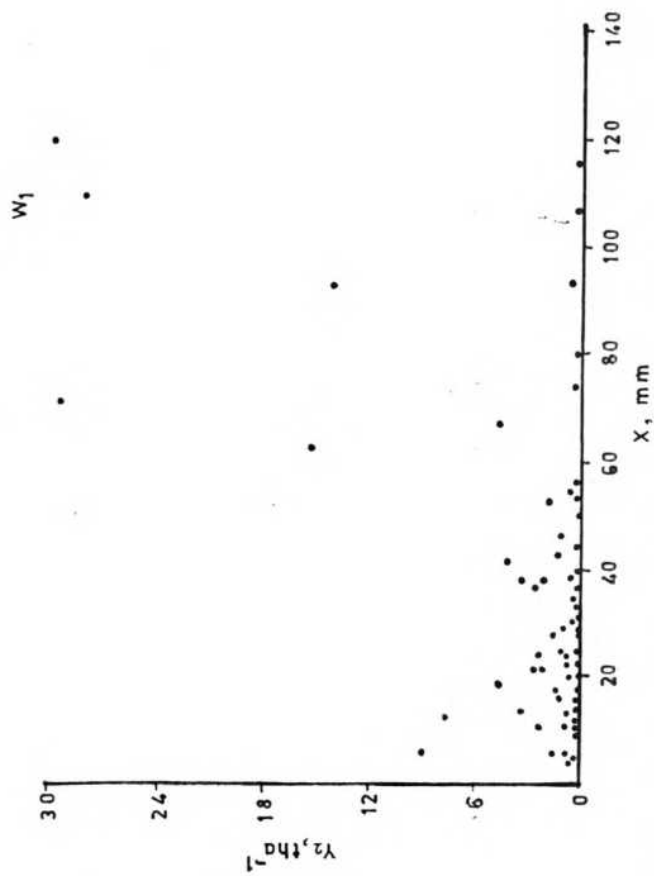
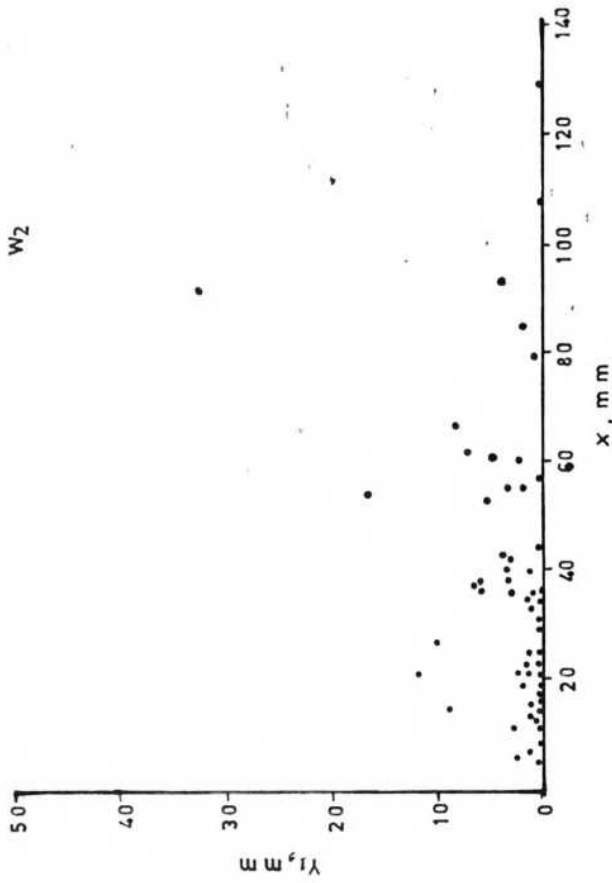
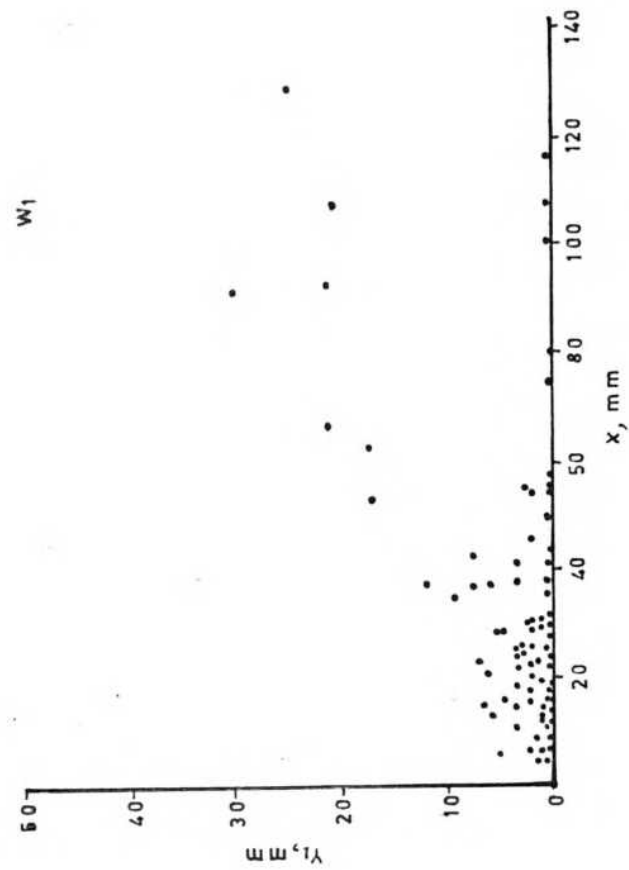


Fig. 4.4 Plot of daily rainfall (X) against runoff (Y_1) and soil loss (Y_2) in W_1 and W_2 (1976-83)

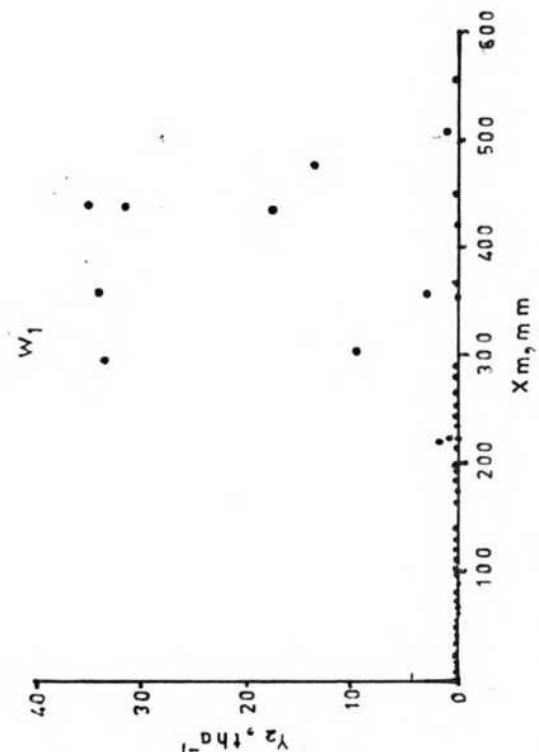
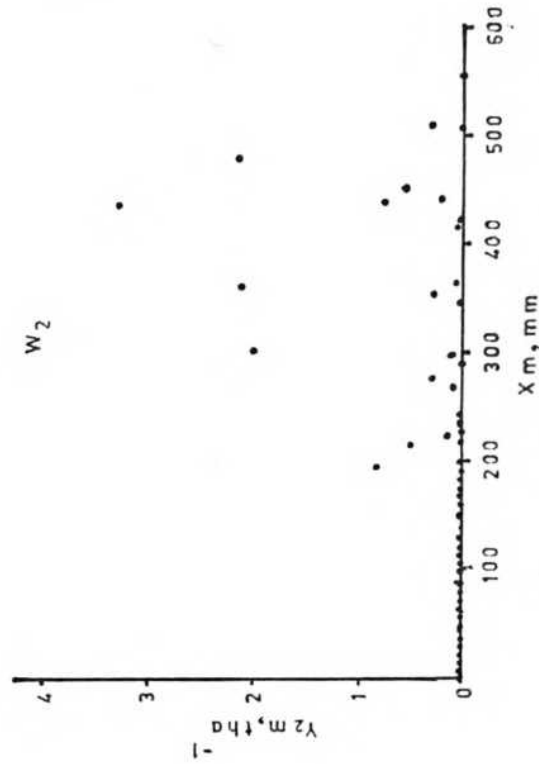
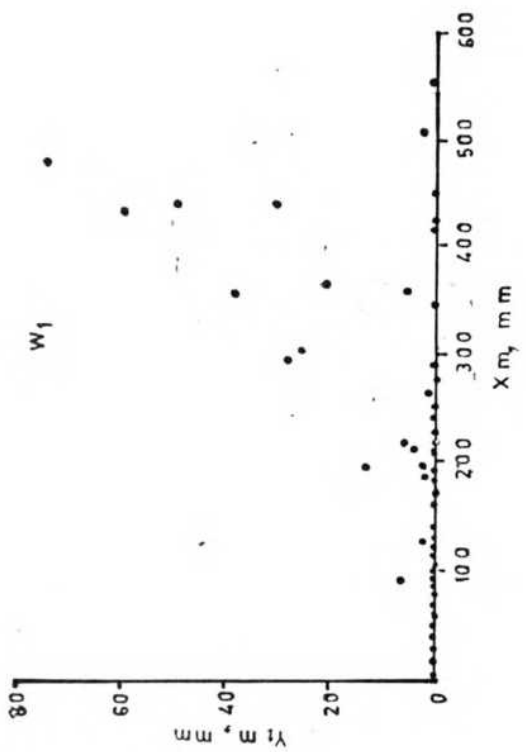
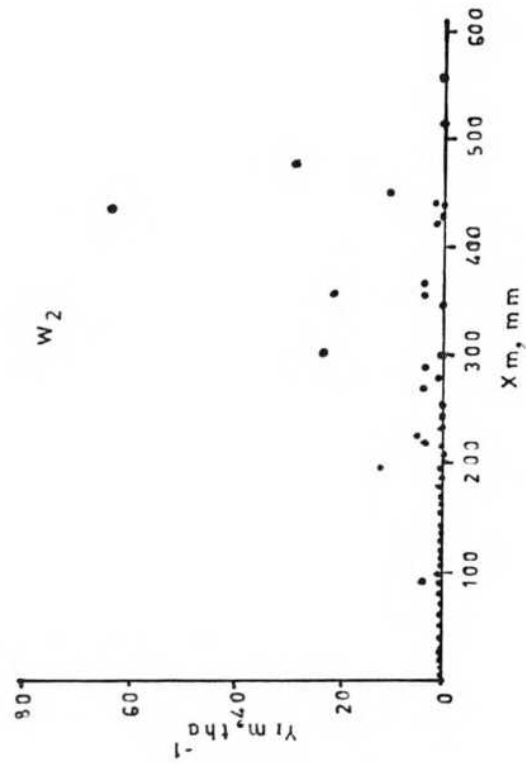


Fig. 4.5 Plot of monthly rainfall (X_m) against runoff (Y_1m) and soil loss (Y_2m) in W_1 and W_2 (1976-83)

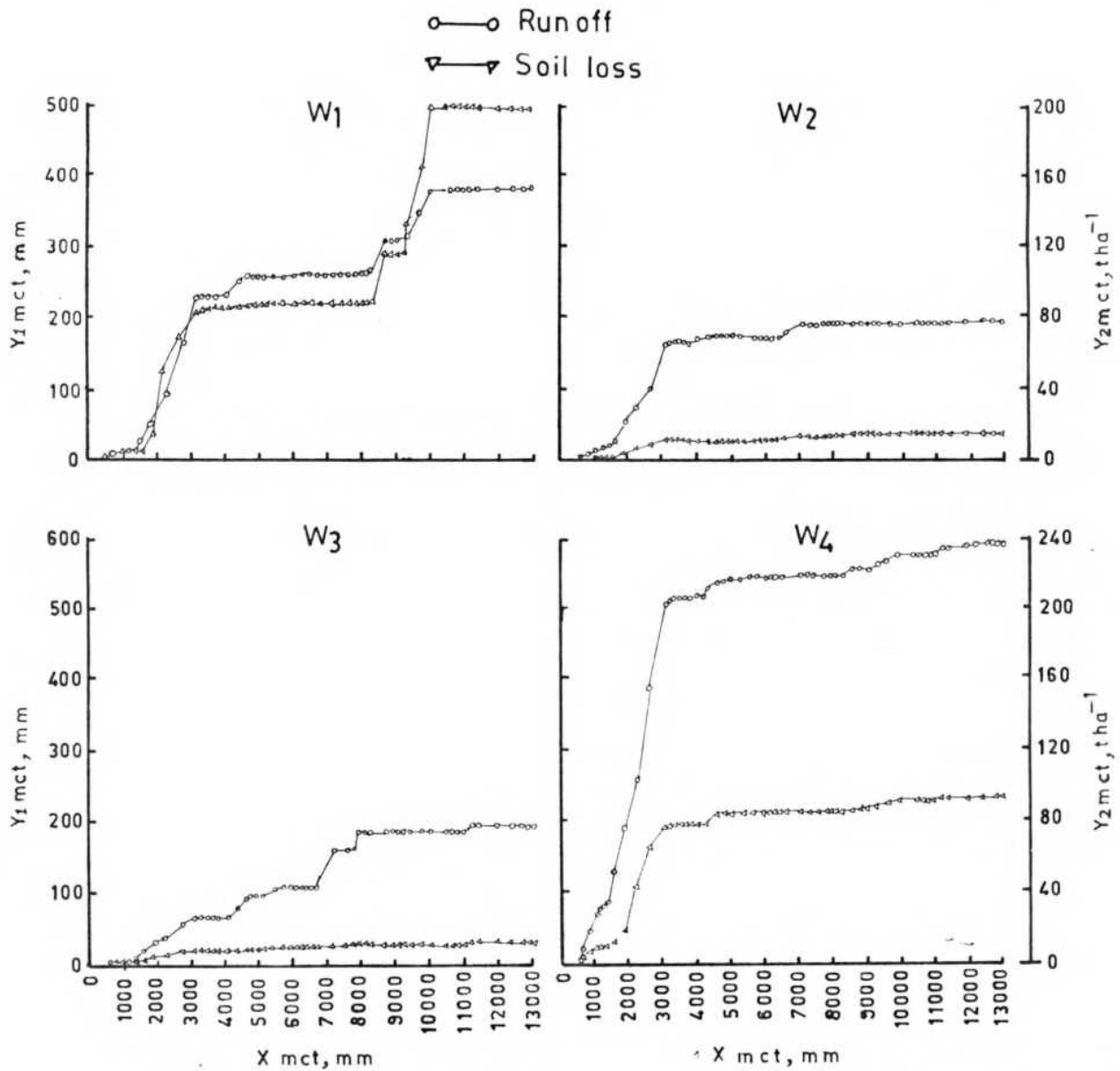


Fig.4.6 Relationship between monthly cumulative rainfall(X_{mct})and each of runoff (Y_{1mct})and soil loss (Y_{2mct}) for the period of 1976-83 in W_1 W_2 W_3 and W_4 .

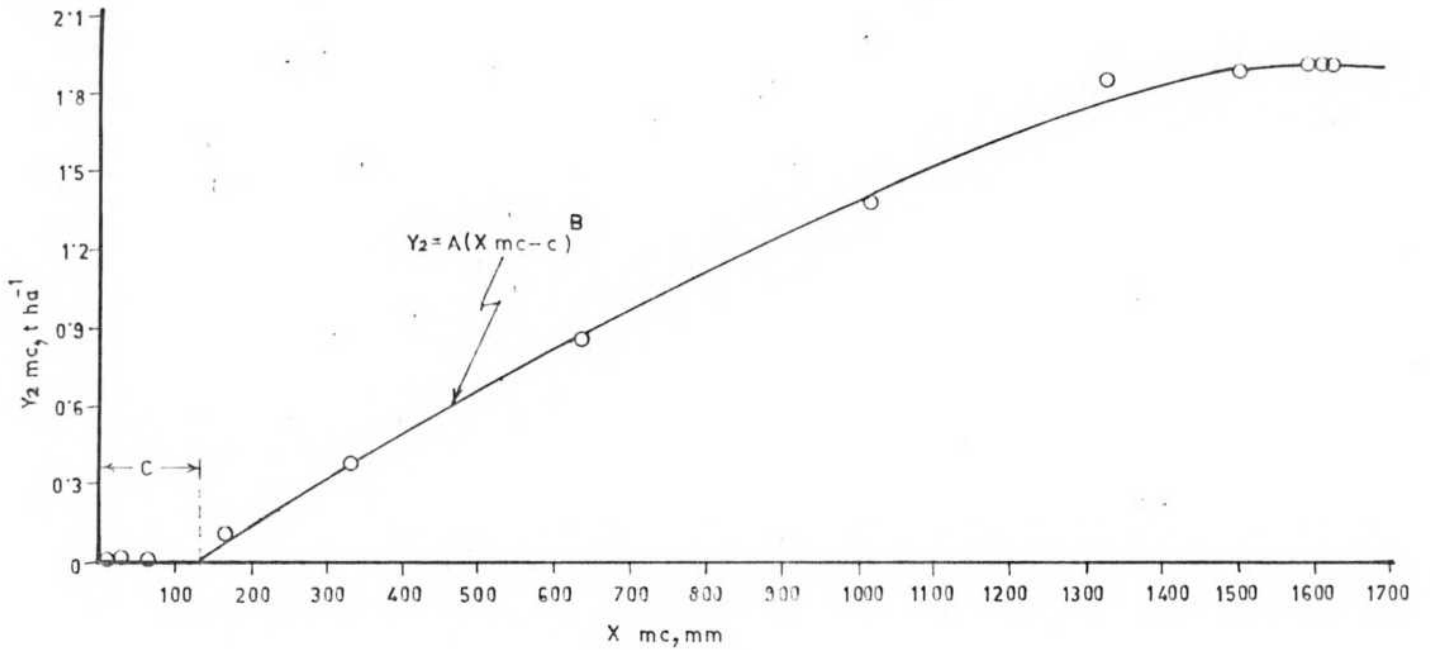
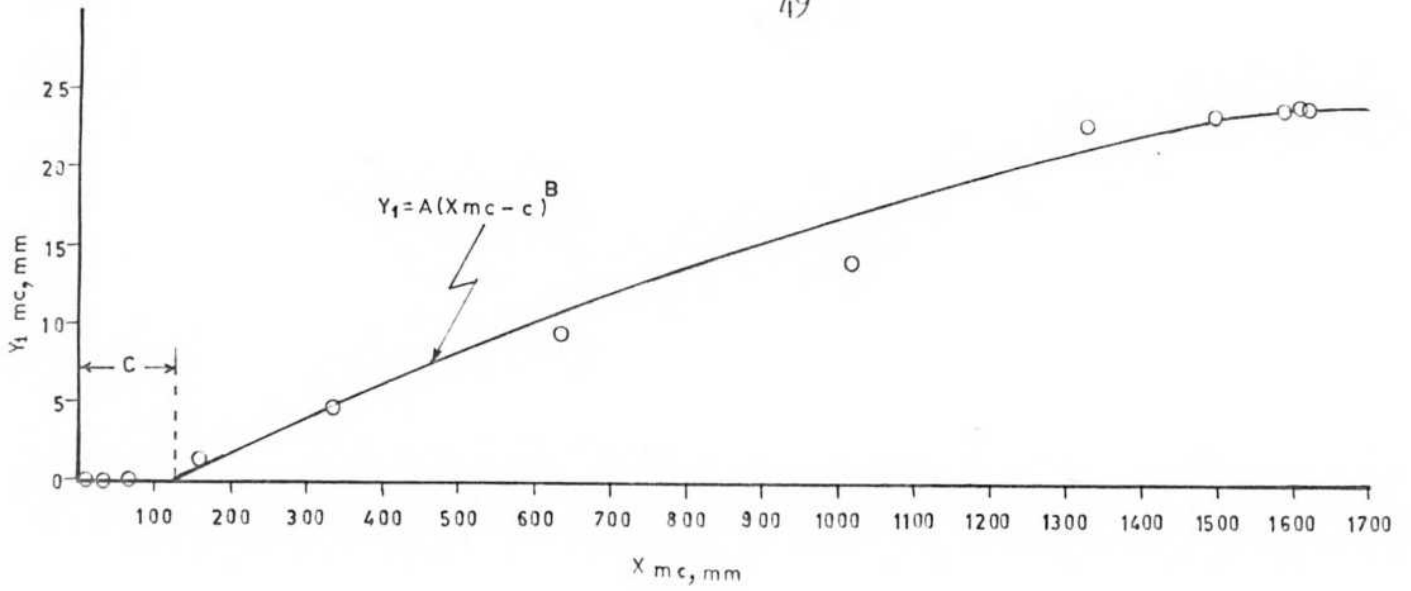


Fig. 4.7 Relationship between mean monthly cumulative rainfall (X_{mc}), and each of runoff (Y_1_{mc}) and soil loss (Y_2_{mc}) in W_2

between these parameters was found to be of following form.

$$Y_{1mc} \text{ or } Y_{2mc} = A (X_{1mc} - C)^B \quad \dots\dots\dots(4.1)$$

For the study areas the values of C varied from 115 to 540.

A = 0.0073 to 0.3154 for Y_{1mc}

= 0.11×10^{-6} to 0.0691 for Y_{2mc}

B = 0.7449 to 0.9637 for Y_{1mc}

= 0.8166 to 2.1091 for Y_{2mc}

The Eq. (4.1) gave fairly good curve fit with coefficient of determination varying from 0.957 to 0.990 for Y_{1mc} and 0.783 to 0.998 for Y_{2mc} . The inter relationship between Y_{2mc} and Y_{1mc} was found as:

$$Y_{2mc} = AY_{1mc}^B \quad \dots\dots\dots (4.2)$$

Where A = 0.0046 to 0.0764

B = 1.0187 to 2.275

The correlation coefficient of Eq. (4.2) varied between 0.930 to 0.996.

The relationships (Eqs. 4.1 and 4.2) for various landuse are shown in Figs. 4.8 to 4.11.

4.2.4. Multi-variate regression models

Equations (4.1) and (4.2) may be simple but have limited scopes for their use because these are specific to the similar field situations. In such cases many believe that multi-variate regression models have wider applicabilities. Accordingly the following types of multi-variate regression models were attempted:

$$Y_{1a} \text{ or } Y_{2a} \text{ or } Qp = a_0 + a_1 X_1 + \dots + a_5 X_5 \quad \dots\dots\dots (4.3)$$

where Y_{1a} = annual runoff (mm)

Y_{2a} = annual soil loss ($t \text{ ha}^{-1} \text{ yr}^{-1}$)

Qp = annual peak flow (mm hr^{-1})

X_1 = annual rainfall (mm)

X_2 = average slope of the watershed (m/m) as in Eq. (3.1)

X_3 = conservation factor (unitless) as in Eq. (3.2)

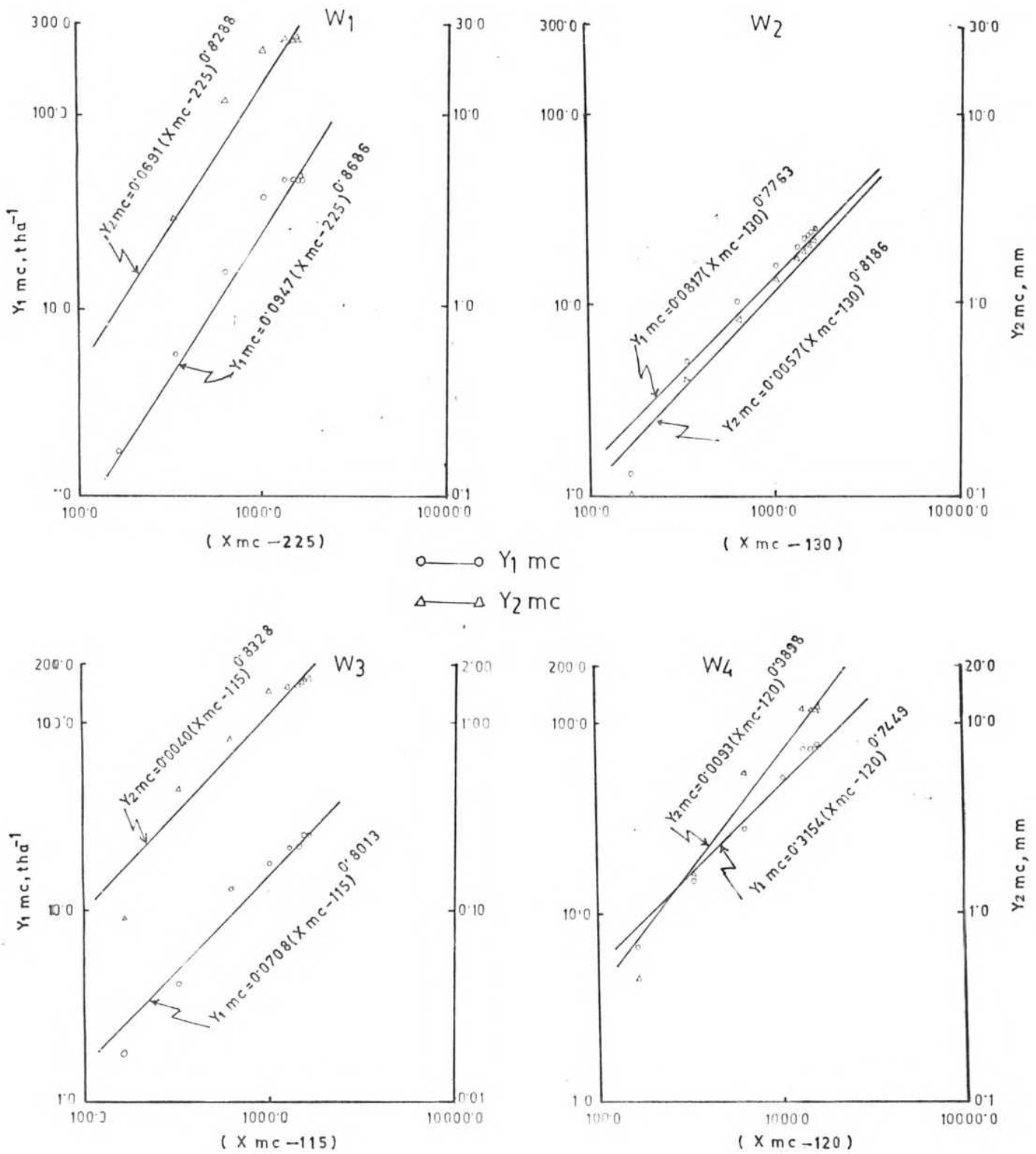


Fig.4.8 Logarithmic plot of cumulative mean monthly rainfall (X_{mc}), runoff (Y_1_{mc}) and soil loss (Y_2_{mc}) in W_1, W_2, W_3 and W_4 .

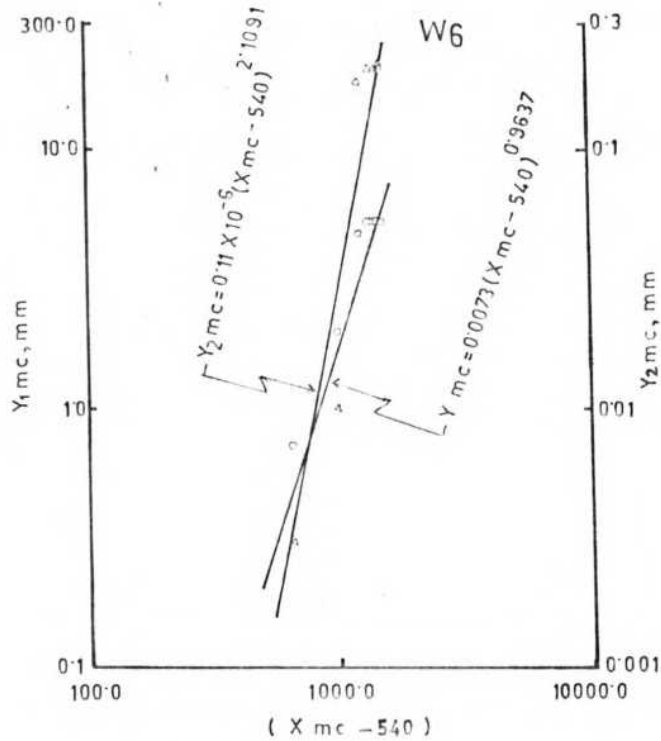
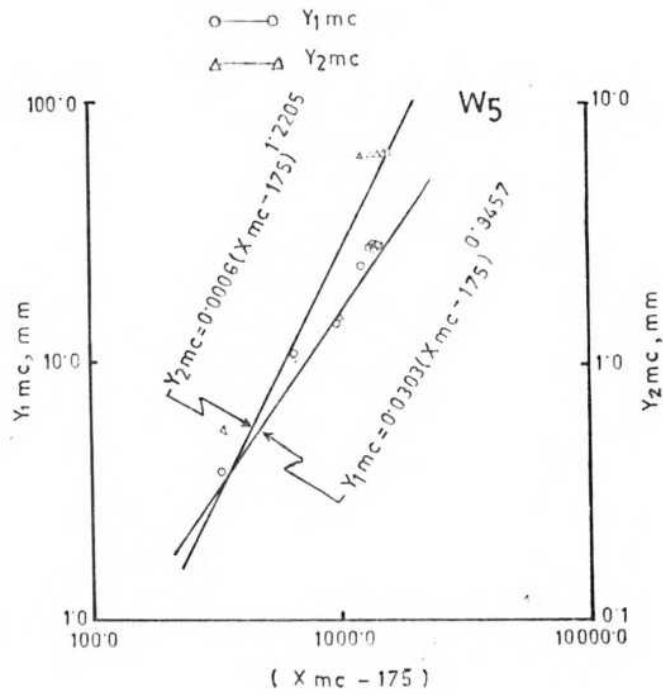


Fig.4.9 Logarithmic plot of cumulative mean monthly rainfall ($X mc$), runoff ($Y_1 mc$) and soil loss ($Y_2 mc$) in W5 and W6

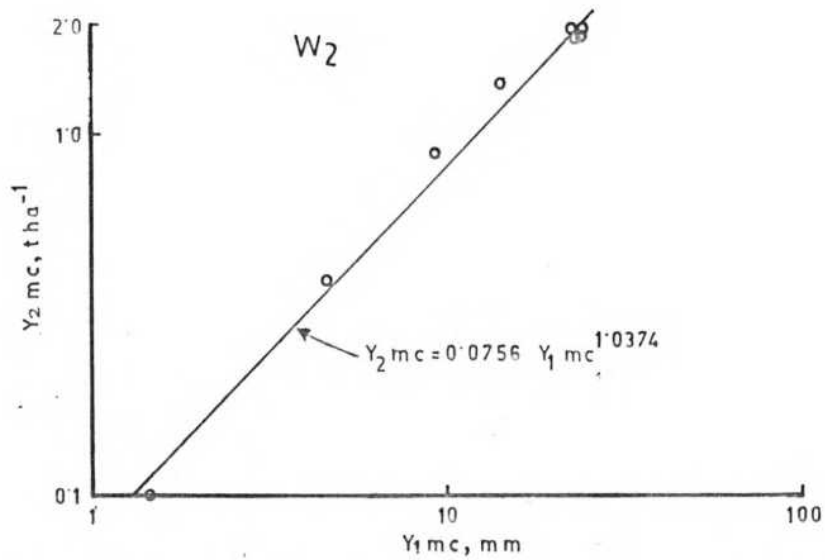
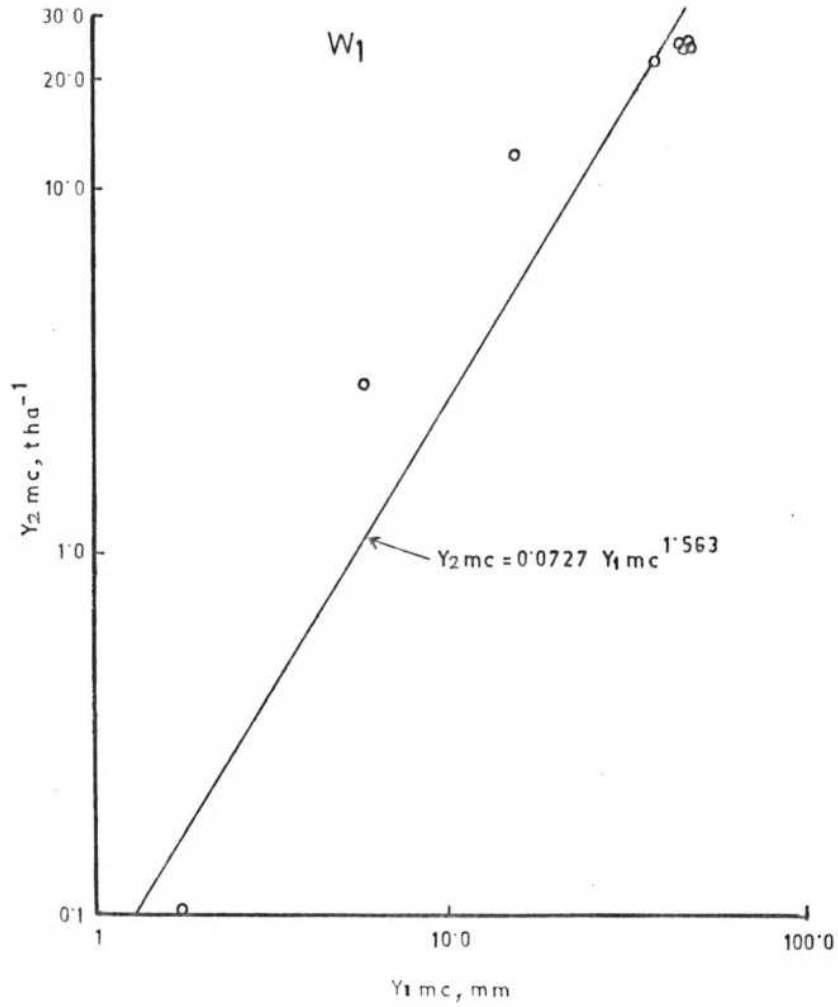


Fig.4.10 Logarithmic relationship between mean monthly runoff (Y_{1mc}) and soil loss (Y_{2mc}) in W₁ and W₂

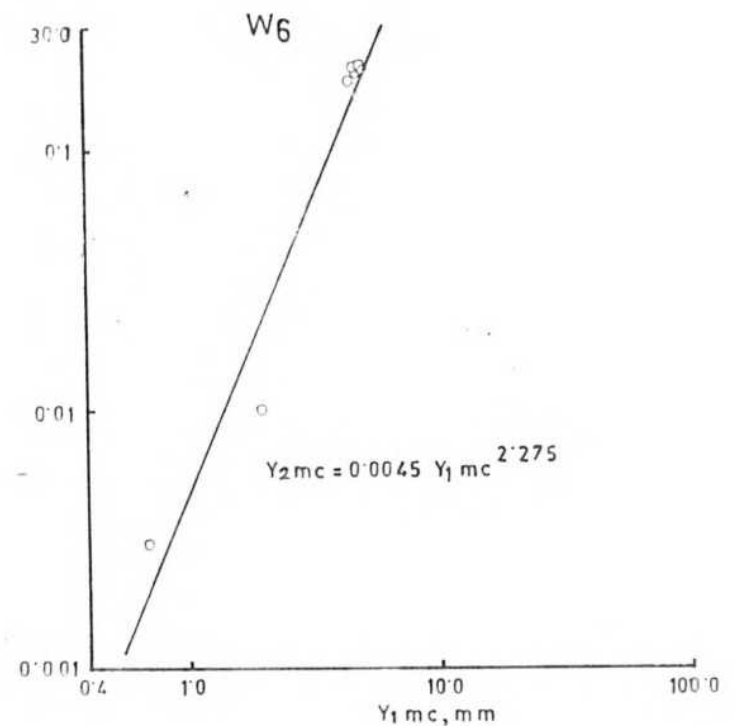
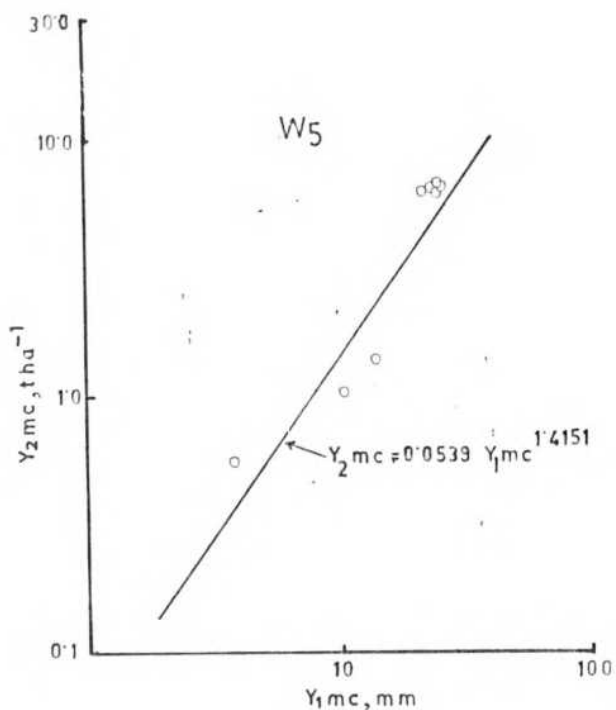
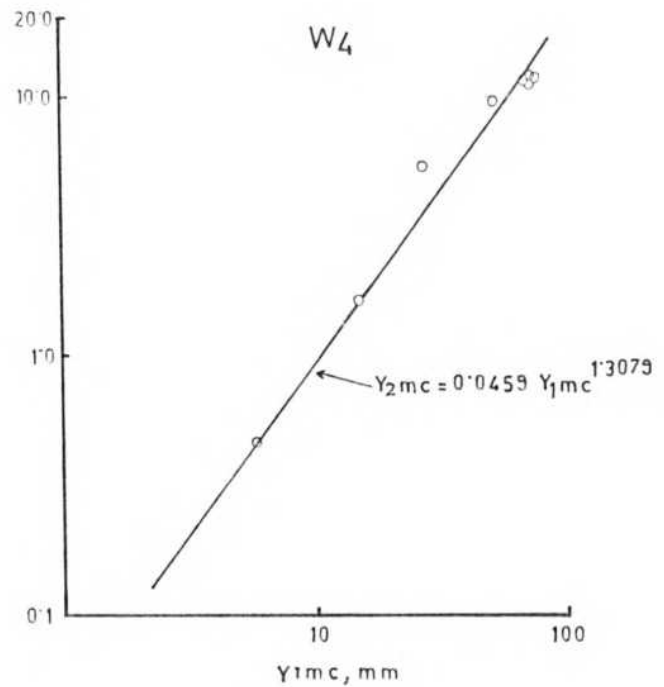
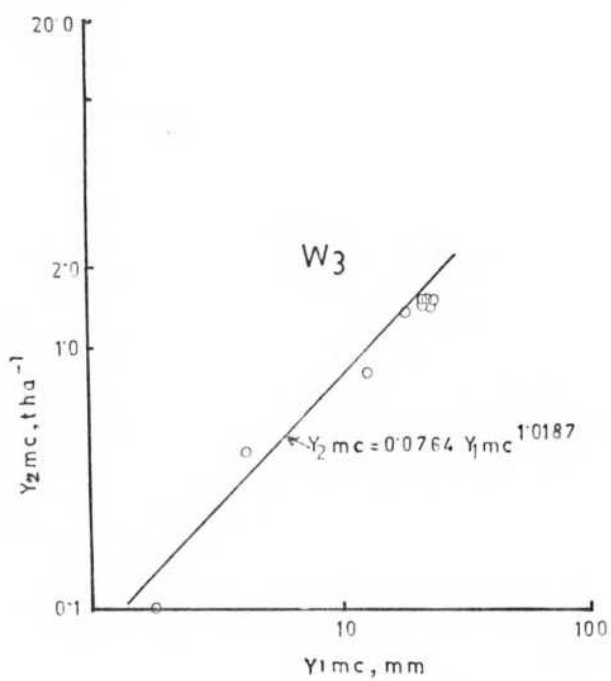


Fig.4.11 Logarithmic relationship between mean monthly cumulative runoff (Y_{1mc}) and soil loss (Y_{2mc}) in W3, W4, W5 and W6 .

X_4 = compactness coefficient (unitless) as in Eq. (3.3)

X_5 = form factor (unitless) as in Eq. (3.4)

$a_0, a_1 - - - a_5$ are empirical coefficients determined statistically.

The same data sets were also fitted in

$$Y_{1a} \text{ or } Y_{2a} \text{ or } Q_p = b_0 X_1^{b_1} X_2^{b_2} X_3^{b_3} X_4^{b_4} X_5^{b_5} \dots\dots\dots(4.4)$$

having the same significance of the symbols used in Eq. (4.3) and b_0 is a coefficient, $b_1, b_2 - - - b_5$ are exponents determined statistically.

The observed values of X_2, X_3, X_4, X_5 in Eqs. (4.3) and (4.4) were kept unchanged. The observed data X_1 were modified as i) rainfall recorded in plain area; ii) rainfall recorded in plain area but converted to the equivalent amount in slopy area; iii) rainfall volume received in the slope area and iv) rainfall minus threshold rainfall (C). Changes in the left hand sides of the Eqs. (4.3) and (4.4) were modified as i) $\sqrt{Y_{1a} + 0.5}$ or $\sqrt{Y_{2a} + 0.5}$ and ii) Y_{1a}/X_1 or Y_{2a}/X_1 or Qp/X_1 excluding X_1 from the right hand side. In some of the fittings the data for initial two years were neglected. In another attempt the data of initial two years were neglected replacing X_1 by $(X_1 - C)$.

Following permutation and combination of the above mentioned techniques about two hundred alternatives were tried. The values of R^2 obtained in all such attempts were so poor (0.1024 to 0.6872) that none could be accepted. It may be worthwhile to mention that the values of $a_0, a_1, - - - a_5$ and $b_0, b_1 - - - b_5$ obtained through these trials are not shown in this thesis.

4.2.5 Other relationships

Since the multi-variate models (Eq. 4.3 and 4.4) could not be made acceptable, further exploration was made for alternative linear and exponential forms. Results of these attempts are presented as follows:

Relationship between conservation factor (X_3) and threshold rainfall (C) was found to be

$$C = 59.46 + 21.807 X_3 + 1.999 X_3^2 \dots\dots\dots (4.5)$$

The corelation coefficient was found to be 0.929.

4.2.5.1 Relationships of X_3 with Y_{1a} , Y_{2a} and Q_p using mean values

$$Y_{1a} = 18621.46 X_3^{-3.208} \quad (r = 0.982) \quad \dots\dots\dots(4.6)$$

$$Y_{2a} = 706592 X_3^{-6.029} \quad (r = 0.989) \quad \dots\dots\dots(4.7)$$

$$Q_p = 6358.20 X_3^{-2.562} \quad (r = 0.852) \quad \dots\dots\dots (4.8)$$

4.2.5.2 Relationships of X_1/X_3 with Y_{1a} , Y_{2a} and Q_p using mean values

$$Y_{1a} = 0.478 (X_1 / X_3) - 60.81 \quad (R = 0.993) \quad \dots\dots\dots (4.9)$$

$$Y_{2a} = 0.238 (X_1 / X_3) - 37.92 \quad (R = 0.883) \quad \dots\dots\dots (4.10)$$

$$Q_p = 0.323 (X_1 / X_3) - 23.75 \quad (R = 0.823) \quad \dots\dots\dots (4.11)$$

Using pool data

$$Y_{1a} = 0.612 (X_1 / X_3) - 91.461 \quad (R = 0.591) \quad \dots\dots\dots (4.12)$$

$$Y_{2a} = 0.188 (X_1 / X_3) - 30.89 \quad (R = 0.677) \quad \dots\dots\dots (4.13)$$

$$Q_p = 0.198 (X_1 / X_3) - 20.40 \quad (R = 0.725) \quad \dots\dots\dots (4.14)$$

4.2.5.3 Relationships of Y_{1a} with X_1 , X_2 , X_3 and using C using mean values

$$Y_{1a} = 1.216 (X_1 X_2 / X_3) - 68.64 \quad (R = 0.992) \quad \dots\dots\dots (4.15)$$

$$Y_{1a} = 0.183 (X_1 / X_2 X_3) - 52.72 \quad (R = 0.976) \quad \dots\dots\dots (4.16)$$

$$Y_{1a} = 1.047 (X_1 - C / X_3) - 31.72 \quad (R = 0.968) \quad \dots\dots\dots (4.17)$$

$$Y_{1a} = 0.168 (X_1 - C / X_2 X_3) - 25.573 \quad (R = 0.963) \quad \dots\dots\dots (4.18)$$

4.2.5.4 Relationships of Y_{2a} with X_1 , X_2 , X_3 and C using mean values

$$Y_{2a} = 0.573 (X_1 X_2 / X_3) - 39.01 \quad (R = 0.834) \quad \dots\dots\dots (3.19)$$

$$Y_{2a} = 0.096 (X_1 / X_2 X_3) - 36.10 \quad (R = 0.911) \quad \dots\dots\dots (4.20)$$

$$Y_{2a} = 0.475 (X_1 - C / X_3) - 20.48 \quad (R = 0.785) \quad \dots\dots\dots (4.21)$$

$$Y_{2a} = 0.084 (X_1 - C / X_2 X_3) - 20.46 \quad (R = 0.859) \quad \dots\dots\dots (4.22)$$

4.2.5.5 Relationships of Q_p with X_1 , X_2 , X_3 and C using mean values

$$Q_p = 0.707 (X_1 - C / X_3) - 4.38 \quad (R = 0.822) \quad \dots\dots\dots (4.23)$$

$$Q_p = 0.121 (X_1 / X_2 X_3) - 17.05 \quad (R = 0.808) \quad \dots\dots\dots (4.24)$$

$$Q_p = 0.114 (X_1 - C / X_2 X_3) - 0.16 \quad (R = 0.817) \quad \dots\dots\dots (4.25)$$

$$Q_p = 0.773 (X_1 X_2 / X_3) - 25.15 \quad (R = 0.793) \quad \dots\dots\dots (4.26)$$

From amongst, above models Eqs. (4.6), (4.7) and (4.8) are statistically acceptable but these are single parametric equations and the most relevant parameters like rainfall (X_1) and slope are missing. The Eqs. (4.15), (4.20) and (4.23) are more appropriate and statistically significant because these incorporate rainfall (X_1), slope (X_2) and conservation factor (X_3) and may possibly be applied outside the present study area. Observed and generated values of runoff (Y_{1a}), Soil loss (Y_{2a}) and peak runoff (Q_p) using these models for each microwatersheds are shown in Table 4.5. Chai square tests reveals that Eq. (4.15) fits at (0.01) probability level and Eqs. (4.20) and (4.23) fit at 0.05 levels of probability. Thus the computed values did not differ statistically with the observed values.

Table 4.3 Observed and computed values (using Eqs. 4.15, 4.20 and 4.23) of annual runoff (Y_{1a}), soil loss (Y_{2a}) and peak runoff (Q_p)

Experimental water- sheds.	Observed and computed annual values					
	Runoff (mm)		Soil loss (t ha ⁻¹)		Peak runoff (mm hr ⁻¹)	
	Ob.	Com.	Ob.	Com.	Ob.	Com.
W ₁	86.70	85.14	43.38	39.65	74.44	71.19
W ₁ [*]	8.65	4.51	0.44	-0.07	16.57	26.37
W ₂	23.85	21.29	1.80	0.51	38.45	35.32
W ₃	24.69	24.40	1.59	5.47	64.09	34.35
W ₄	73.51	72.32	11.38	23.98	55.69	64.70
W ₅	27.20	35.36	6.21	8.22	33.83	43.62
W ₆	5.25	6.82	0.21	-6.74	5.10	12.63

Ob. - Observed. Com. -Computed, * Abandoned shifting cultivation plot.

4.2.6 Infiltration characteristics

Data on initial rates of infiltration for W₁, W₂, W₃, W₄ and W₆ are presented in Table A-16. Infiltration rates were found quite high as upto five minutes it ranged between 97.56 to 124.69 cm hr⁻¹ (Table A-16). It was highest in W₄ and lowest in W₃ watershed.

4.2.7 Soil moisture distribution pattern in various land uses.

Distribution of soil moisture in 0 - 60 cm soil depth in hill slopes under W_1 , W_2 , W_3 , W_4 , W_6 land use systems are shown in Figs. 4.12 and 4.13. It indicates higher uniformity coefficient in less disturbed slopes. A glance to the Table 4.4 reveals that the soil moisture did not vary widely from one watershed to another.

Table 4.4 Mean soil moisture in 0 - 60 cm soil depth at different locations.

Landuse	Location/soil moisture (% by weight)					
	Top of the hill slope		Middle of the hill slope		Foot hills of the slope	
	1977	1978	1977	1978	1977	1978
W_1	27.87	26.07	26.10	26.67	22.42	26.60
W_2	27.26	25.68	25.86	25.90	23.86	28.27
W_3	24.73	25.64	27.01	27.81	25.94	27.37
W_4	25.93	25.49	27.46	28.22	26.49	26.38
W_6	26.46	28.16	30.21	28.01	26.22	28.39

4.3 Results from Runoff Plots

Data on runoff and soil loss from ten runoff plots under bare fallow conditions with 58, 59, 62, 64, 64, 65, 67, 68, 70, 70 and zero (during second year only) per cent slopes are presented in Table A-17 to A-20. The study was done keeping all plots fallow during first year and with mechanical soil conservation measures during second year. Behaviour of rainfall in steep hill slopes affecting runoff and soil loss was studied.

4.3.1 Runoff and soil loss

The highest amount of runoff and soil loss was recorded in months of highest rainfall. Under bare fallow condition, annual soil loss per mm of rainfall varied between 0.16 to 0.34 t ha⁻¹ yr⁻¹ respectively. On the other hand, observations indicate that application of conservation measures

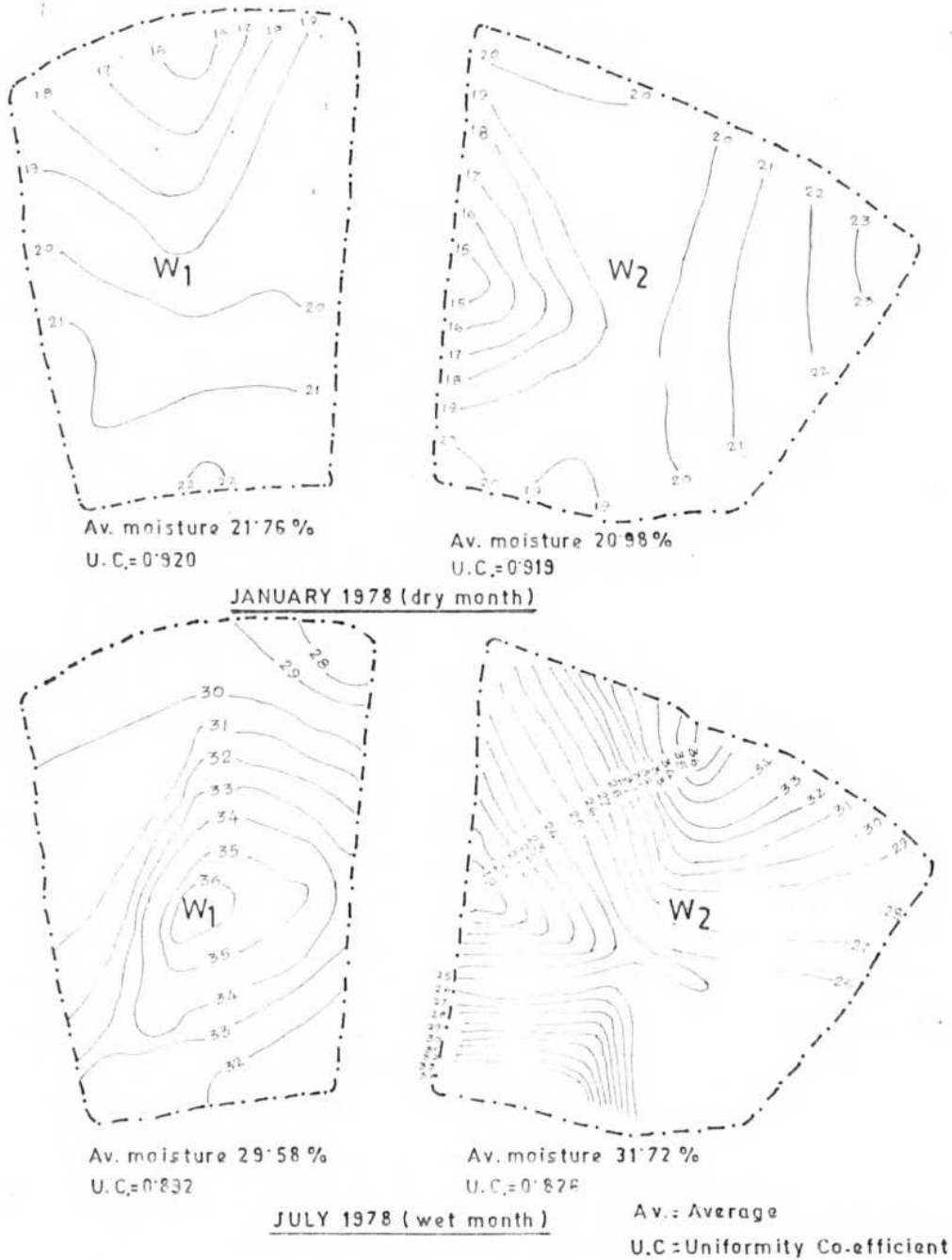


Fig.4.12 Soil moisture distribution in 0-60cm depth of soil for January (dry month) and July (wet month) in W₁ and W₂ watersheds.

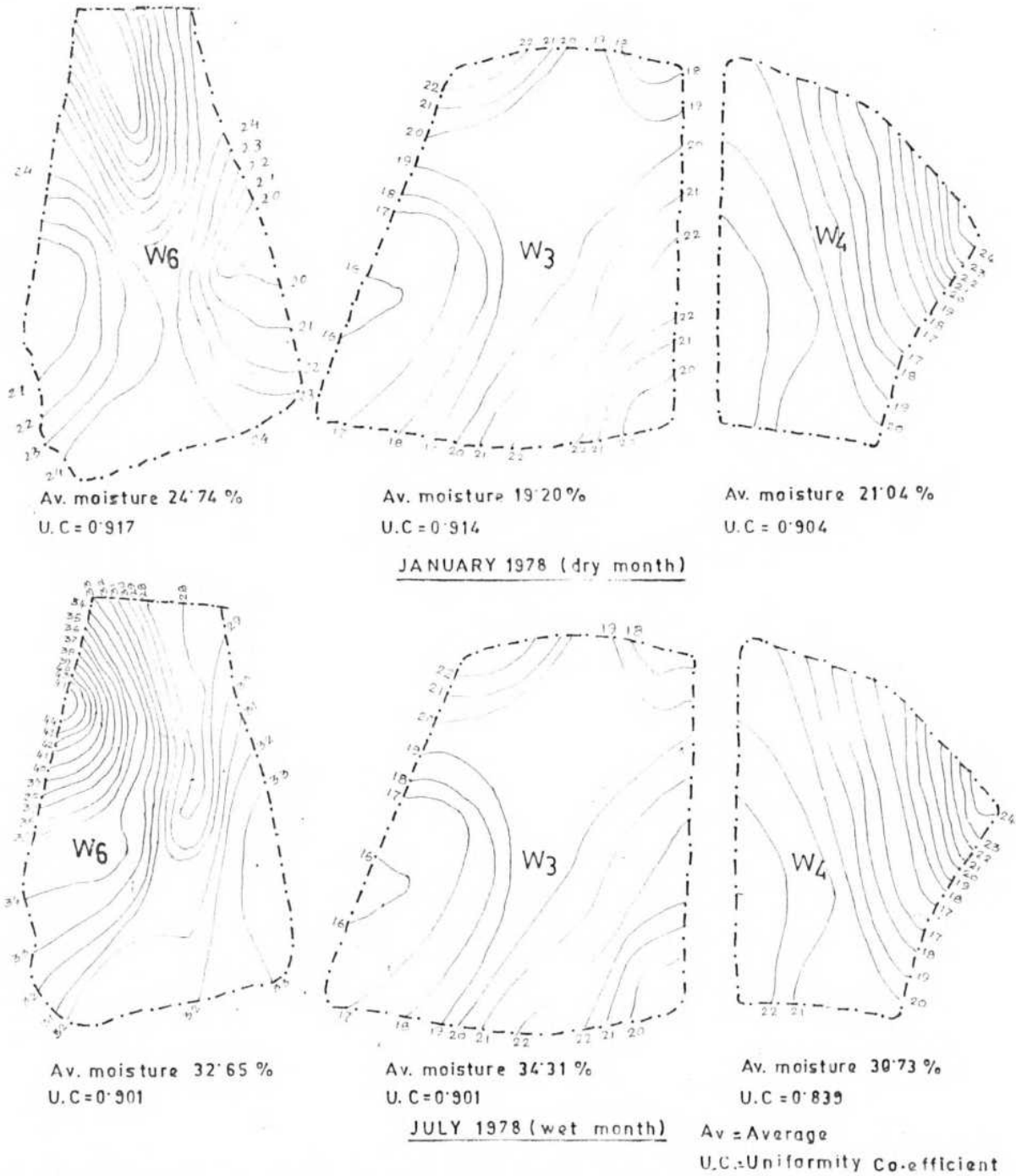


Fig.4.13 Soil moisture distribution in 0-60 cm depth of soil for January (dry month) and July (wet month) in W3, W4 and W6 watersheds.

in bare fallow runoff plots produced 0.06 to 0.15 t ha⁻¹ yr⁻¹ soil loss per mm of rainfall (Table-20). The runoff and soil erosion values from zero slope were 0.28 mm and 0.66 t ha⁻¹ yr⁻¹ per mm of rainfall.

4.3.1.1 Daily rainfall (X_1) runoff (Y_1) and daily rainfall soil loss (Y_2) relations

As described in article 4.2.3, attempts were made with the data of runoff plots to work out linear forms of relationships viz., X_1 versus Y_1 and X_1 versus Y_2 but not shown here. The values of 'r' for runoff (Y_1) and soil loss (Y_2) with respect to X_1 varied between 0.52 to 0.86 and 0.44 to 0.86 respectively.

Trials for the logarithmic relationships (Eqs. 4.1 and 4.2), for the data of runoff plots were made. The values of correlation coefficients (0.990 to 0.998) obtained were satisfactory. The generated data using these newly established equations were very close to the observed values (Table 4.5).

4.3.1.2. Runoff (Y_{1a}) and soil loss (Y_{2a}) relationships with slope (X_2)

Singh (52) reported sinusoidal form of relationship as illustrated in Eqs. (2.3) and (2.4). Accordingly, the present data sets were fitted in to obtain Eqs. (4.27) and (4.28):

Table 4.5 Established models with cumulative monthly rainfall (X_{1mc}), runoff (Y_{1mc}) and soil loss (Y_{2mc}) along with generated data in comparison to observed values applicable in untilled bare fallow runoff plots under various soil conservation measures.

Conservation measure	Relationship	Correlation coefficient r	Observed values Y_{1mc}/Y_{2mc}	Generated values Y_{1mc}/Y_{2mc}
Without measure	$Y_{1mc} = 1.881(X_{1mc} - 80)^{0.6996}$	0.995	400.1	401.1
Trash bunds	$Y_{1mc} = 0.761(X_{1mc} - 70)^{0.7001}$	0.991	321.1	321.9
Contour strips	$Y_{1mc} = 1.997(X_{1mc} - 55)^{0.9892}$	0.992	378.4	426.6
Tie ridges	$Y_{1mc} = 0.185(X_{1mc} - 320)^{0.9892}$	0.997	311.4	322.0
Contour bunds	$Y_{1mc} = 0.300(X_{1mc} - 125)^{0.9697}$	0.968	453.6	490.1
Level plot	$Y_{1mc} = 0.630(X_{1mc} - 120)^{0.9162}$	0.998	656.6	694.1
.....				
Without measure	$Y_{2mc} = 1.766(X_{1mc} - 80)^{0.7761}$	0.976	523.7	676.1
Trash bunds	$Y_{2mc} = 1.072(X_{1mc} - 70)^{0.7364}$	0.963	284.6	304.1
Contour strips	$Y_{1mc} = 1.880(X_{1mc} - 55)^{0.6737}$	0.935	306.0	331.3
Tie ridges	$Y_{2mc} = 0.130(X_{1mc} - 320)^{1.0109}$	0.985	224.5	266.9
Contour bunds	$Y_{2mc} = 0.923(X_{1mc} - 125)^{0.8208}$	0.990	462.9	489.7
Level plot	$Y_{2mc} = 0.006(X_{1mc} - 120)^{1.3082}$	0.988	125.0	130.1
.....				
Without measure	$Y_{2mc} = 0.989(Y_{1mc} - 1.085)$	0.960	523.7	659.0
Trash bunds	$Y_{2mc} = 1.296(Y_{1mc} - 0.9475)$	0.987	284.6	307.4
Contour strips	$Y_{2mc} = 0.856(Y_{1mc} - 0.989)$	0.990	306.0	303.4
Tie ridges	$Y_{2mc} = 0.784(Y_{1mc} - 1.008)$	0.974	224.5	255.6
Contour bunds	$Y_{2mc} = 2.589(Y_{1mc} - 0.845)$	0.989	462.9	460.1
Level plot	$Y_{2mc} = 0.013(Y_{1mc} - 1.408)$	0.976	125.0	119.5

$$Y_{1a} = 291.96 - 35.0 \sin [(X_2 - 64.9) / (20.66)] \quad \dots (4.27)$$

$$Y_{2a} = 280.00 + 64.0 \sin [(X_2 - 35.1) / (20.66)] \quad \dots (4.28)$$

where Y_{1a} is the annual runoff, Y_{2a} is the annual soil loss, and

X_2 is the Slope (%)

Observed and computed (using Eqs. 4.27 and 4.28) values of runoff and soil loss are presented in Table 4.6. The computed values are so close to the observed values that the above equations can not be rejected.

Table 4.6 Comparison between observed and computed (using Eqs. 4.27 and 4.28) values of runoff and soil loss for runoff plots studied here.

Slope (%)	Runoff (mm)		Soil loss (t ha ⁻¹ yr ⁻¹)	
	Observed	Computed	Observed	Computed
58	312.1	303.4	258.7	340.0
59	305.8	301.8	302.5	341.3
62	312.0	296.9	473.7	344.6
64	290.9	293.5	305.2	346.0
64	327.9	293.5	454.1	346.0
65	389.3	292.2	361.5	346.5
67	288.9	295.5	413.8	346.9
68	251.8	297.2	274.9	347.0
70	210.8	300.5	226.1	346.5
70	235.8	300.8	407.1	346.5
Mean	292.5	297.5	347.7	345.0

4.4 Analysis of published and unpublished works

4.4.1 Results of microwatersheds

Studies on occurrence of runoff and soil loss under various land uses at different locations indicate similar trend (Singh, 52) as in article 4.2 and Table 4.2. On 32 and 53 per cent slope, 97.86 to 99.98 percent of

the annual rainfall were retained and consequently soil losses were negligible (Table A-21).

4.4.2 Results from runoff plots

Awasthi (3) reported following relationship between monthly rainfall and runoff as well as monthly rainfall and soil loss from bare fallow runoff plots on 59 percent slope.

$$Y_1 = 16.92 + 0.25 X \dots (r = 0.901) \dots (4.29)$$

$$Y_2 = 6.18 + 0.099 X \dots (r = 0.501) \dots (4.30)$$

Due to large number of observations these equations have been found statistically significant though the values of correlation coefficients were very low. Comparison of computed values with observed one using Eqs. (4.27), (4.28) and (4.29), (4.30) are shown in Table 4.7. It seems Eqs. (4.27) and (4.28) are superior than Eqs. (4.29) and (4.30).

Table 4.7 Observed and computed data on runoff (mm) and soil loss ($t\ ha^{-1}\ yr^{-1}$) for bare fallow runoff plots using Awasthi's (3) and present models.

	Observed	Computed	
	Awasthi (3)	Eqs. 4.29) and (4.30) Awasthi (3)	Eqs. (4.27) and 4.28) (Present study)
Runoff (mm)	211.9	108.9	291.8
Soil loss ($t\ ha^{-1}\ yr^{-1}$)	205.6	50.3	281.2

Chapter - V

DISCUSSION

The review on behaviour of land uses in hills shows that forest allows maximum retention of rainfall in steep slopes and protects soil from erosion. The present study reveals that similar achievements are possible in micro watersheds along with appropriate land use systems. The efficacy of conservation measures in protecting land on lower slopes is well established and need not be over emphasized. A glance of Table 4.2 reveals that 80 to 100 percent of annual rainfall is retained in soil (in situ) with most of the land uses tried in the present study. It is a well established fact that retention of rainfall in situ helps in recharging of streams and ground water reserves. Singh (51) reports that ponds located in the foot hills of well managed slopes receive bulk of water storage from subsurface or base flow (75.3 percent), the contribution from direct rain is 22.4 percent and that of surface runoff is 2.3 percent. This point seems to be quite interesting. But, there is a snag in the findings of retention of rainfall in land having zero slope. It is noted that level plot retains about 71.67 percent of rainfall and thus, surface runoff is expected to be more (28 percent of total rainfall) in flat land (Table A-22). This is contrary to our common senses. The level plot (zero slope) in the present study was prepared on a slopy land by cutting the original ground surface. Thus, the top soil was disturbed. Moreover, the land was bare fallow and hence encrustation due to rainfall impact is probably the main cause of low infiltration (absorption) and thus high surface runoff, while in other cases, conditions were quite conducive for high infiltration.

One may be astonished to see that the micro-watersheds are retaining 80 - 100 per cent of annual rainfall. This goes against the common experience of hydrological data analysis of much flatter lands where runoff from individual storms ranges between 20 - 50 per cent i.e., retention of 50 - 80 per cent. How can one explain such a little runoff in steep slopes of NEH region? If that be the case, there is no need of soil conservation measures in slopy land. Hundred odd questions in the similar

way may be raised in. But this happens and the answer lies in the high infiltration rate. Infiltration is influenced by soil character and infiltration governs runoff. A close visual observation to the soils of the study area reveals that it is highly a porous soils. A lot of root holes, micro channels (visible in a soil profile) are present. Activities of soil fauna, high organic matter (Table 4.1), soil aggregation due to the presence of iron oxide, low pH (Table 4.1) yielding higher water stable aggregates etc. are responsible to make the soils of the study area as a highly porous medium. It may also be noted that the soil is quite deep here. High infiltration rates because of the above mentioned reasons have been reported by Moura and Buol (31) on oxisol soil. It was 82 cm hr^{-1} as against 118.9 cm hr^{-1} in bush fallow plots of Wilkinson and Ania (60). Thus the higher infiltration rates (vide Table A-16) recorded in the present study as 64.6 cm hr^{-1} (for 15 min), 124.7 cm hr^{-1} (for 5 min) and 157.2 cm hr^{-1} (for 2 min) are not unusual. Moreover, there is a snag in reporting the infiltration rates in the published literature. Very rarely the time period is mentioned therein. Conceptually infiltration rate is a time dependent function. It is said that the rate becomes small at infinite time and quite large in and around initial time. In the present study, the rates are for the initial 2 - 15 min time period and hence high. So, it can not be rejected on this plea only. Infiltration in NEH region is mainly soil dominated because the porosity is so high that it only augments our findings on infiltration rates. Moreover the published documents (Table A-22) on runoff and soil loss in NEH region also corroborated the fact that there was no personal error in the author's experimentation except that a buffer ring infiltrometer has not been used. But it may also be noted that the ponded infiltration tests do not project the true condition of rain infiltration which is our point of discussion. It may further be noted that in the foot hills of this region water oozes out from many points just like that of small springs. This generally appears in the post monsoon period and continues for a sufficiently long time. It appears that whatever high retention of rain water occurs the same starts percolating until the points of oozing. Though a quantitative measurement has not been comprehensively made at all such points but Singh (51) observed that ponds located at the foot hills of such localities gets about 75.3% water from these sources (Fig. A-1). The amount is quite high and is in conformity with the high retention of rain water in the upper portions of the watersheds.

Thus it can not altogether be said that so much high retention of rain water is physically impossible in this region.

Though the soil erosion from the experimental watershed under shifting cultivation (W_1) was much higher during cropping years but the trend is akin to that of W_6 when the plot was abandoned for regeneration of vegetation. Singh *et al.*, (43) reported similar trend from field survey data where drastic reduction in soil erosion was observed in abandoned plots. Soil erosion during first year of shifting cultivation (W_1) in 1976 was only 5.1 tonnes ha^{-1} which may be attributed to rainfall characteristics and good crop cover. In both the cycles of cultivation during the period of study second year cropping was found more hazardous than first year. This trend was similar to that of Singh and Singh (43).

From the observations on annual runoff and soil loss it can be concluded that use of conservation measures developed from local resources (soil, vegetation and manpower) as reinforcement to the desired land use is capable to perform functions as that of forest (or natural vegetation) in the matter of receiving rainfall, retaining it and contributing towards ground water recharge.

Peak rate of runoff from shifting cultivation (W_1) was higher (74.44 $mm\ hr^{-1}$) than the other land uses (Table 4.1). Landuses having the support of bench terrace (W_3) and contour bund (W_4) also produce quite high rate of peak flow (64.00 and 55.69 $mm\ hr^{-1}$). The reasons of this behaviour are (i) disturbance of top soil which reduces infiltration and (ii) channelization of runoff water in concentrated form towards grassed water ways. When soil profile is saturated and rainfall intensity is high, it is likely that large portion of rainfall may find way towards outlet. However, considering the total volume of annual rainfall during the year this phenomenon is insignificant in causing destruction of the land resources. The unusual hydrological behaviour of contour bunded areas (W_4) during first two years was due to lack of maintenance (Table A-12).

Annual pattern of occurrences of runoff, soil loss and peak rate of runoff shows declining and stabilizing trend from third to fourth year. Initially it was rising to reach the peak during second year and then falling

afterwards. This may be because of the disturbances caused in establishing the landuse systems in the initial period (Figs. 4.1 and 4.2).

Research workers in the field of soil and water conservation and hydrology try to develop relationships of rainfall with runoff, soil loss and peak runoff. Linear, exponential, multivariate (simple/logarithmic) and other forms of relations are mostly tried. Slope length, slope, size and characteristics of the watershed are used for developing the models. Such models often fail in similar and alike situations. Sometimes data of runoff from one watershed (land use) is correlated with that of other watersheds and such relations are useful in a limited scale, as one is supposed to know the data of at least one land use.

With this background in view, the present author does not claim that his models are free from all defects. Every model is built on certain assumptions. These assumptions are often untested and arbitrary. The results change if the assumptions are changed. Sometimes the assumptions are concealed and are required to be explicit and clear. All these points are also applicable in the models suggested here. But the correlation coefficients in the present models are reasonably high in comparison to the existing models. The author does not agree with his predecessors to fit the data in some linear relationships knowing fully well that the correlation coefficients in such cases are very low. Accordingly some meaningful parameters like threshold rainfall and conservation factors have been introduced herein. With these and after a little bit manipulation in the data fitting, the relationships having high correlation coefficients have been arrived at. Since it is difficult to secure required participation of farmers for large watershed viz., 1000 hectares or so in the present study the concept of microwatershed has been considered as an essential unit of measure which can be practised at individual and farmer's levels. This was tested in micro size watersheds (Figs. 4.4 and 4.7). Because of the natural advantage of having one outlet, it was found convenient to plan, execute and control surface runoff towards the lower most point while developing the conservation measures with the use of local resources (men and material).

A critical examination of Fig. 4.1 reveals that in Jhum land, soil erosion, peak flow and runoff follow a cyclic path in resonance with

the cyclic activities of the Jhum cultivators. On the other hand in cases of W_2 , W_3 and W_4 all these start dropping down after a period of 1 year or so and become asymptotic with time axis within 3-4 years and afterwards (Fig. 4.1 and 4.2). In the initial period of land use practices, the top soil/or environment loses its dynamic stability which is brought back within 3-4 years. This may be the reason of initial rise and then stabilization of soil erosion, peak flow and runoff. A probe was made to understand moisture status of the soil in W_1 , W_2 , W_3 , W_4 and W_6 throughout the year at an interval of a fortnight. Table 4.4 reveals that so far as average moisture status is concerned in 0-60 cm soil depth, there is practically no difference amongst various landuses. To investigate this aspect further uniformity coefficient of soil moisture storage was determined during dry month (January) as well as in wet month (July). Uniformity coefficient varies from 0.90 to 0.92 and 0.84 to 0.94 in the months of January and July respectively. In dry months since drying of soil is uniform irrespective of land use practices that is why the uniformity coefficient is practically constant in all the watersheds/land uses. The question of soil moisture storage is important in wet months and it is noted that it is high in W_1 , W_3 and W_7 (Jhum, bench terrace and forest). This in effect means that the distribution is quite good if the land slope is kept undisturbed or the land is made nearly flat like that of a bench terrace.

In order to make the things manageable runoff plots have been suggested and widely used in the past to study on the mechanics of soil erosion and runoff. It also helps to vary some of the measureable variables (viz., slope, crop practices etc.) in the same geographic location. This is also convenient from physical points of view. Slope is one of the important parameters in the genesis of runoff and soil erosion. Attention was therefore, concentrated for several decades on slope parameter.

Many aspects of slope have been studied widely. On a same locality rainfall pattern does not vary significantly and thus, it is obvious that the soil loss will increase with the increase in slope and vice-versa (Balasubramaniam and Sivnappan, 6; Zingg, (63), Meyer, 29). Singh (53) and Rai (32) differ on this point. They noted that soil loss increased with the increase in slope but to a certain limit and afterwards it decreases with the increase in slope (ICAR Complex, 17). The sinusoidal nature of Eqs. (4.27) and (4.28)

supports this view and gives at least some idea that at zero slope there will be some soil loss. The result is in conformity with that of Singh (53), Rai (32) and Sengupta (36) in contrary to the age old notion that at slope $S = 0$, soil loss is nil.

One may ask the question that why the soil loss equation is sinusoidal instead of exponential or parabolic and if this is accepted there will be no serious problems in high slopes and no management will be required in hilly areas. This point has also bewildered the present author. But it is true that this is not because of personal error. Had this been so Rai (32), Singh (53) and ICAR (17) could not have obtained the similar results. The only point in favour of less erosion in high slopes is that if the rain falling on the ground surface is 1 cm it will be less in slopy land and thus the probability to wash out top soil decreases. But the low force of rainfall to cause erosion is expected to be over powered by high component of gravitational force and hence the sinusoidal phenomenon is not beyond doubt, if the soil in sufficient depth is available on the spot. Incidentally Morgan (30) also opined that sinusoidal soil loss equation is not an impossibility.

Equations (4.27) and (4.28) have been developed to predict the annual runoff and annual soil loss. The applicability of these equations have been proved by the fact that there is little difference in the observed and computed values of runoff and soil loss. Under similar condition Awasthi (3) developed linear equation relating rainfall with runoff and soil loss. While the predicted values of runoff and soil loss obtained through Awasthi's (3) model for 1981 are 109.42 mm and $50.3 \text{ t ha}^{-1} \text{ yr}^{-1}$ against the observed values of 211.9 mm of runoff and $205.6 \text{ t ha}^{-1} \text{ yr}^{-1}$ of soil loss, those obtained by using Eqs. (4.27) and (4.28) are 281.2 mm and $205.61 \text{ t ha}^{-1} \text{ yr}^{-1}$ respectively. In spite of all these points in favour of Eqs. (4.27) and (4.28) we can not just expect that the parameter slope alone is sufficient to describe all the field situations outside the present study area.

Accordingly in watershed studies, attempts have been made to include as many variables as practicable. Rainfall is one such variable. Of the various characteristics of rainfall, intensity and erosivity have been considered to be measureable, but collection of relevant data on rainfall intensity and erosivity is quite costly, time consuming, difficult and laborious. Thus, emphasis has been given here on "total rainfall" which is available from almost all parts of the world.

Monthly runoff (mm) and monthly soil loss ($t\ ha^{-1}$) are linearly related with monthly rainfall (mm) (Gupta and Ram Babu, 15). Maintaining the same theme Ram Babu and Narayana (33) concludes further that linear relations between daily rainfall and daily runoff as well as daily rainfall and daily peak flow do exist. They further conclude that logarithmic relations are not significant. The present author differs with them. The values of correlation coefficients (r) obtained in their linear equations are low and lower in logarithmic relations.

To make these equations significant attempt was made with cumulative monthly data. This leads to higher values of correlation coefficient in both linear and logarithmic relations; but logarithmic relations are observed to be superior than linear equations. One may say that the land slope of Gupta and Ram Babu (15) was 4 per cent and that of Ram Babu and Narayana (33) was 2-10 per cent but in the present case it was 40 to 70 per cent. That's why there exists differences. But this is not tenable. A further improvement is obtained if one considers cumulative monthly rainfall minus 'threshold rainfall' as an independent variable (Eq. 4.1). Thus contrary to the earlier notions it may safely be said that the logarithmic relationship is best.

In case of soil loss model (Eq. 4.1) with zero slope, the coefficient is lowest and exponent is highest indicating the limiting situations which seem to be logical. But in case of runoff model for zero slope, this is not so.

Since the phenomenon of soil erosion, runoff and peak flow are very complex in nature and are influenced by quite a good number of variables, it has not yet been possible to formulate these into manageable functional forms containing easily measureable parameters. Moreover, the interactions between one variable over the other(s) bring further complications in such equations. Because of these difficulties workers in the past have considered one, two or three variables only to establish models (Balasubramaniam and Sivappan, 6; Singh and Hakim, 54; Zing 63, Smith 55; Singh 53). Land use pattern prevalent in the region is one of the most important point which deserves to be given due weightage in tackling such situations but unfortunately none of the previous workers could consider this point and

accommodate it into their models.

Following the same philosophy of the past efforts of various workers as mentioned above, the present author also tried to correlate soil erosion, runoff and peak flow with daily and/or monthly rainfall. Attempts on linear relationships failed and some sort of logarithmic relationships were found to be acceptable with certain limitations. Afterwards it was thought that a parameter like that of "conservation factor" may help to overcome these difficulties. Accordingly numerical values to various land use conditions have been assigned. The success of this method is revealed in Eqs. (4.6) to (4.8) and (4.15), (4.20) and (4.23). Since this procedure involves the personal experience of the present author, one may disagree to accept this. But this is not the peculiarity in the proposed conception of "conservation factor" only. In the field of soil and water resource management, various other workers have also been compelled to adopt such techniques because of lack of human knowledge to tackle this complex phenomenon in a mathematical manner. For example, to determine peak rate of flow different numerical values have been assigned to relief, soil infiltration, vegetal cover and surface storage in Cook's method (Frevert *et al.*, 11). Similar factor is incorporated in Universal Soil Loss Equation (Wischnier and Smith, 61) and some sort of factor in Krikby (21) and Smith (55) approaches.

The concept of conservation factor is unique of its kind. Though there exists factors which are akin to conservation factors but are not exactly same. In case of factors of Cook (Frevert *et al.*, 11), Wischnier and Smith (61), Krikby (21) and Smith (55), experimentation and/or monographs are essentially required to evaluate the correct values. In order to calculate peak rate of flow following Cook's method (Frevert *et al.*, 11) one is compelled to exercise discretion and personal judgement for deciding the ranges of extreme, high, normal or low. The conservation factor proposed in this thesis is free from such defects.

The models containing this conservation factor (Eqs. 4.6 to 4.8 and 4.15, 4.20 and 4.23) are statistically significant and can generate data which are very close to the Observed values.

Though the conservation factor has been evolved for hilly

conditions having high rainfall but there is enough scope to modify it suitably in order to accommodate the conditions of plain and low rainfall areas.

Suitable changes in the assigned numerical values for various situations will presumably elevate the status of this factor to be applicable universally. If one can afford to collect all the relevant data from all parts of this world it is expected that the value of conservation factors may be obtained in a rational manner through empirical and/or mathematical methods. Hence the potentiality inherent in this conception seems to be meaningful and effective.

Out of all the formulae established in the present thesis it is, therefore, felt that Eqs. (4.6) to (4.8) and (4.15), (4.20) and (4.23) are the best because these give due weightage to the land use practices which deserves to be considered in the local perspective vis-a-vis ecosystem.

Chapter - VI

SUMMARY AND CONCLUSIONS

6.1 Summary

North East Hill (NEH) region comprising the states of Meghalaya, Arunachal Pradesh, Manipur, Mizoram, Nagaland, Tripura and part of Assam is characterised by difficult hilly terrain which ranges from a very low level to 6000 metres in elevation from mean sea level. With its wide variation in rainfall (1100 to 12500 mm) and climate there exists tremendous scope for development of Animal Husbandry, Horticulture, Fisheries and Agriculture. However, the region as a whole is extremely susceptible to soil erosion and degradation of eco-system.

Prevalence of shifting cultivation (Jhuming) and other traditional agricultural systems have proved to be hazardous from soil erosion point of view.

The process of degradation is so conspicuous that many places, where once farming was in vogue, are now unfit for agriculture because parent rocks have been exposed.

A glaring example of such degradation is the area, in and around Cherrapunjee ($91^{\circ} 44' E$ $25^{\circ} 15' N$). During monsoon period these hilly region yield a large quantum of runoff and silt causing rise in the bed levels of the rivers in the plains and thus floods too.

Realistic assessment of the problems of soil and water resources and its management in hilly regions keeping in view of the man's agricultural needs and other activities is very important. This is also important to reduce the degradation of the natural resources and to be in line with the dynamic balance of the eco-system. With these ideas in view the present study was undertaken to investigate on:

- i) the retention of rainfall 'in situ' under various land use systems,
- ii) the minimum time period required for a newly established land use for stabilisation in runoff, soil erosion and peak flow rate behaviour,

- iii) the influence of land slope in yielding runoff and soil erosion,
- iv) the capacity and impact of total rainfall (in place of rainfall intensity and erosivity) to characterise and/or predict the runoff, soil erosion and peak flow rate,
- v) the uniformity of soil moisture distribution in the soil profile under various land use practices and conservation measures,
- vi) the possibilities of introduction of a new parameter which will reflect the land use practices in estimating runoff, soil erosion and peak flow rate, and
- vii) the establishment of some useful models for soil erosion, runoff and peak flow rate in order to utilise them as guidelines for the management of soil and water resources on steep slopes.

To achieve these objectives investigations were carried out for eight consecutive years during the period of 1976 to 1983 on the experimental farm of ICAR Research Complex for NEH Region at Burnihat (26° N, 41.5° E, 100m elevation from MSL), Meghalaya. The soil in the experimental farms is mostly sandy loam. In all six land uses viz., traditional agriculture or shifting cultivation or Jhuming (W_1), agri-horticulture (W_2), agriculture on bench terraces (W_3), agriculture on contour bunded area (W_4), agriculture (fodder crops) in bench terraces and contour bunded area (W_5) and secondary forest (W_6) were considered for this study. The watersheds were extended from bottom to the top of the hill. Ridge bunds were erected as far as possible on natural ridges. Bunds were also erected in the watersheds W_1 , W_2 and W_3 , W_4 as dividing lines.

The average slopes (m/m) of W_1 , W_2 , W_3 , W_4 , W_5 and W_6 were 0.40, 0.44, 0.42, 0.43, 0.43 and 0.45 respectively.

All these watersheds were gauged for recording runoff and soil losses. H-flumes, F-type water level recorders and Coshocton wheel samplers were installed at suitable locations. Total runoff and peak runoff for each case was evaluated from recorded charts, whereas the soil loss was determined by analysing the integrated samples collected through the runoff samplers.

The runoff was analysed in the laboratory for estimating soil loss. Runoff and soil erosion thus obtained were expressed in mm and $t\ ha^{-1}$ respectively.

Bench terraces and contour bunds were designed in such a way that the vertical interval did not exceed 1.25 m and the runoff from all the terraced land is drained into a common grassed water way and passed through the gauging station.

Infiltration rates of soils in W_1, W_2, W_3, W_4, W_6 and fallow level terraces were measured in 1983. The observations were taken at three locations (top, middle and bottom of the hill slopes) and six times during the period between August and December. Single ring cylinder infiltrometers (30 cm in diameter) were used for this purpose.

Observations on soil moistures were made in 0-60 cm soil depth to study the pattern of residual moisture on slopy land masses as a result of land uses and soil conservation measures. At every fortnight the observations were recorded during the period of August, 1977 to December, 1978 at nine locations (3 each from top, middle and bottom of the slopes) in five watersheds. Gravimetric method was followed to determine soil moisture contents.

The effect of rainfall on steep hill slopes in yielding runoff and soil loss was studied in ten runoff plots under bare fallow conditions. Runoff plots of 20 m x 2 m size prepared on 58, 59, 62, 64, 64, 65, 67, 68, 70, 70 per cent slopes were used. These plots were equipped with multislot divisors and runoff collecting tanks and were located adjoining to experimental watersheds having more or less similar soil conditions. The plots thus prepared were under minimal cultivation (slashing, burning and dibbling mixed crops) during 1979-81. Plots were kept bare fallow. The study was conducted in 1982 and 1983 (in 1982 without any measures and in 1983 with appropriate soil and water conservation measures namely Tie Ridges, Contour bunds, Trash bunds and Level contour strips with half moon terraces). Close to the runoff plots, a zero slope plot of $5\ m^2$ area was also gauged for recording observations in the line of runoff plots. The runoff samples were analysed in the laboratory for silt content ($t\ ha^{-1}$).

The data of runoff, peak runoff and soil loss for eight years (W_1 , W_2 , W_3 and W_4), three years (W_5 and W_6) and two years (bare fallow runoff plots) were processed.

It has been observed that all land uses except Jhumming are good because the soil losses from these plots are well below $12.0 \text{ t ha}^{-1} \text{ yr}^{-1}$ which is considered as the safe limit of soil erosion, while for Jhumming the soil loss is $49.4 \text{ t ha}^{-1} \text{ yr}^{-1}$ (Fig. 4.3).

In general the monthly runoff and soil loss were high in the months of high rainfall. The percentage of annual rainfall retained in the watersheds W_1 , W_1^* , W_2 , W_3 , W_4 , W_5 and W_6 ranged between 90.30 to 98.94, 97.96 to 99.96, 93.33 to 99.98, 95.21 to 100.00, 80.74 to 99.79, 97.08 to 99.66 and 99.55 to 99.92 respectively.

From third to fourth year and afterwards the runoff, soil loss and peak flow got stabilised in W_2 , W_3 and W_4 whereas in W_1 the pattern was same (a cyclic one) as of Jhum cultivation. However, this could not be studied for W_5 and W_6 as the data were available only for three years.

In the process of modelling based on the data of micro-watersheds, it has been found that daily or monthly rainfall is not at all related with soil loss and/or runoff. But the cumulative monthly runoff^{**} in mm (Y_{1mc}) or cumulative monthly soil loss^{**} in t ha^{-1} (Y_{2mc}) is significantly related with cumulative monthly rainfall^{**} in mm (X_{mc}). In general the best fit model is :

$$Y_{1mc} \text{ or } Y_{2mc} = A (X_{mc} - C)^B \quad \dots (6.1)$$

Where C = threshold rainfall (mm). It is the sum total rainfall during a calendar year beyond which runoff gets initiated. For the study areas its value varies from 115 to 540.

$$\begin{aligned} A &= 0.0073 \text{ to } 0.3154 \text{ for } Y_{1mc} + \\ &= 0.11 \times 10^{-6} \text{ to } 0.0691 \text{ for } Y_{2mc} + \\ B &= 0.7449 \text{ to } 0.9637 \text{ for } Y_{1mc} + \\ &= 0.8166 \text{ to } 2.1091 \text{ for } Y_{2mc} + \end{aligned}$$

* Same as W_1 but fallow.

** The data of 8 years were pooled to find out mean for Jan., Feb., etc. Thus in all, twelve mean monthly values were obtained. From these twelve mean cumulative monthly values were calculated. For W_5 and W_6 the data were for 3 years only.

+ Individual values of constants with respect to different plots may be had from Figs. 4.8 and 4.9.

The coefficient of determination for Eq. (6.1) varies from 0.957 to 0.990 for Y_{1mc} and 0.783 to 0.998 for Y_{2mc} .

The interrelation between Y_{2mc} and Y_{1mc} is expressed as follows :

$$Y_{2mc} = AY_{1mc}^B \quad \dots (6.2)$$

Where

$$A = 0.0046 \text{ to } 0.0764^*$$

$$B = 1.0187 \text{ to } 2.275^*$$

The coefficient of determination of Eq. (6.2) lies between 0.865 to 0.992.

Many workers in this branch of science and technology believe that multi-variate regression models may explain the phenomena in question. The genesis of this belief is the complexities of the phenomena and interaction effects of one variable on the other. Accordingly the following equations were fitted:

$$Y_{1a} \text{ or } Y_{2a} \text{ or } Q_p = a_0 + a_1 X_1 + a_2 X_2 + \dots + a_5 X_5 \quad \dots (6.3)$$

where Y_{1a} is the annual runoff (mm); Y_{2a} is the annual soil loss ($t \text{ ha}^{-1} \text{ yr}^{-1}$); Q_p is the annual peak flow (mm hr^{-1}); X_1 is the annual rainfall (mm); X_2 is the average slope of the watershed (m/m); X_3 , X_4 and X_5 are the unitless conservation factor, compactness coefficient and form factor respectively as explained in Eqs. (3.2) to (3.4), whereas a_0 , a_1 , ... a_5 are the empirical coefficients to be determined statistically.

Similarly the same data sets were also fitted in

$$Y_{1a} \text{ or } Y_{2a} \text{ or } Q_p = b_0 X_1^{b_1} X_2^{b_2} X_3^{b_3} X_4^{b_4} X_5^{b_5} \quad \dots (6.4)$$

having the same significance of the symbols used in Eq. (6.3), b_0 is the coefficient and b_1 , b_2 ... b_5 are the exponents to be determined statistically.

The Eqs. (6.3) and (6.4) failed miserably to describe the situations. Thus alternative but simpler models like the following were established:

$$Y_{1a} = 18621.46 X_3^{-3.21} \quad \dots (6.5)$$

$$Y_{2a} = 706592.92 X_3^{-6.03} \quad \dots (6.6)$$

$$Q_p = 6358.20 X_3^{-2.56} \quad \dots (6.7)$$

* Individual values of constants with respect to each plot may be had from Figs. 4.10 and 4.11.

The values of r for Eqs. (6.5), (6.6) and (6.7) are noted to be 0.982, 0.989 and 0.852 respectively. Thus statistically these are reasonably good. The main drawback with these three equations is that these are single parametric equations and the most relevant parameters like rainfall and slope are missing. Hence it may be difficult to apply these outside the present study area. Accordingly attempts were made to incorporate rainfall and slope suitably and the following relations were obtained.

$$Y_{1a} = 1.26 (X_1 X_2 / X_3) - 68.64 \quad \dots (6.8)$$

$$Y_{2a} = 0.096 (X_1 / X_2 X_3) - 36.10 \quad \dots (6.9)$$

$$Q_p = 0.707 (X_1 - C / X_3) - 4.38 \quad \dots (6.10)$$

The values of R^2 were found to be 0.984, 0.830 and 0.676 for Eqs. (6.8), (6.9) and (6.10) respectively.

Outside the present study area, it may not always be possible to estimate conservation factor (X_3) because of non-availability of the relevant data. Also it may happen that X_3 as a whole is estimatable but the threshold rainfall (C) is not available. To overcome such temporal difficulties it was thought to be useful to examine their interrelation so as to enable one to find X_3 from C or vice-versa. Accordingly the following relationship is suggested.

$$C = 59.46 + 21.807 X_3 + 1.999 X_3^2 \quad \dots (6.11)$$

The r value is reasonably high (0.929).

Upto five minutes the infiltration rates were 125, 110, 106, 100 and 98 cm/hr in W_4 , W_1 , W_6 , W_2 and W_3 respectively. Thus infiltration rate was highest in bunded area having 43% slope (undisturbed surface soil).

So far as distribution of soil moisture upto a depth of 0-60 cm soil profile is concerned the higher uniformity coefficients in less disturbed slopes (experimental watersheds) have been observed.

Similar to the microwatersheds, in case of runoff plots under bare fallow conditions it has been observed that daily or monthly rainfall is not linearly related with runoff and soil loss. However, there exists

good logarithmic relations in the pattern of Eq. (6.1) in which $A = 0.300$ to 1.997 for Y_{1mc} and 0.006 to 1.888 for Y_{2mc} . $B = 0.6996$ to 0.9892 for Y_{1mc} and 0.0737 to 1.3082 for Y_{2mc} . The correlation coefficients were observed to be 0.968 to 0.998 for Y_{1mc} and 0.935 to 0.990 for Y_{2mc} . Hence the relations are reasonably good.

The slope (%) in runoff plots (bare fallow) were kept as 58, 59, 62, 64, 64, 65, 67, 68, 70 and 70. Since slope is an important single parameter which is widely used for estimation of soil loss and runoff that is why an attempt was made to establish single parametric models which are as follows:

$$Y_{1a} = 291.96 - 35.0 \sin (X_2 - 64.9) / 20.66 \quad \dots (6.12)$$

$$Y_{2a} = 280.00 + 67.0 \sin (X_2 - 35.1) / 20.66 \quad \dots (6.13)$$

in which X_2 is the slope in per cent. The observed and generated data following the above two models are quite close. The parameter, slope is easily measurable in all places and hence this may be quite useful. From this point of view it may be quite realistic, though highly empirical. But the slope alone is not expected to describe erosion and runoff phenomena in real world situations, though in the past only slope has been used by Zingg (63) to express soil erosion through a parabolic relation quite different from the present one.

The effectiveness of soil conservation measures may be glanced from Table A-20. When the runoff plot is kept fallow (without any measure) the soil loss is $0.235 \text{ t ha}^{-1} \text{ yr}^{-1}$ per mm of rainfall. With measures as illustrated in Fig. 3.7 the reduction in soil loss is 12.7, 42.6, 44.7, 57.5 and 74.5 per cent in case of contour bunds, level contour strips, Trash bund, tie ridge and zero slope plot (with no measure) respectively. This gives an idea on the effect of mechanical measures (soil conservation alone).

Published and unpublished works of the present author and other workers have also been taken into considerations for the comparison purposes. It is noted that these are quite akin to the findings of the other works. This has been discussed in Article 4.4.

6.2 Conclusions

From the present investigations the following conclusions

can be drawn :

1. Eighty to hundred per cent of the annual rainfall may be retained or conserved even if the slope is quite steep and rainfall is high. The retention in case of flat land (zero slope) is 71.67 per cent.
2. In micro-watersheds with the advancement of time (say within three to four years and afterwards) runoff, soil erosion and peak rate of runoff get stabilised to a permissible limit (Fig. 4.3).
3. Land levelling alone is not an effective measure to stop runoff and soil erosion on this surface of the earth. Zero slope does not mean zero soil loss as often claimed.
4. Relationships between rainfall and runoff, rainfall and soil loss are not linear as often claimed.
5. The conception of cumulative monthly rainfall, cumulative monthly runoff, cumulative soil loss and threshold rainfall (beyond which runoff gets initiated) is meaningful so far as modelling is concerned.
6. The conception of conservation factor (Eq. 3.2) seems to be very effective in predicting annual soil loss, runoff and peak flow (Eqs. 6.5 to 6.7). This is also effective in various other ways (Eqs. 6.8 to 6.11).
7. The total rainfall (in absence of rainfall intensity, erosivity and other rainfall characteristics) may suitably be used to estimate runoff, soil loss and peak flow (Eq. 6.8 to 6.10).
8. Uniformity coefficient of soil moisture storage in soil profile is higher on undisturbed or flat slope. This suggests to restrict our actions in such a manner that the land slope is disturbed to a minimum.
9. Annual runoff and soil loss increase as well as decreases with the increase in slope follow a sinusoidal pattern (Eq. 6.12, 6.13).

6.3 Recommendations for future works

It is very difficult to establish any universal model/method in the area of soil and water resources management. But there is a need to pool the relevant data from all parts of the world and a suitable attempt may be made along these lines for universalisation of the present models/ methods.

A further probe on soil profile upto a semiinfinite depth may help to understand the cause of high infiltration rate and sinusoidal pattern of soil loss in NEH region. In order to universalisation of the "conservation factor" an effort may be made to collect the relevant information from many other parts of the world.

Chapter - VII

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Appendix

APPENDIX

TABLE A - 1

Seasonal and annual rainfall (mm) at some stations in North-East India *

Seasons/ Stations	Winter (Jan.-Feb.)	Pre-Monsoon (Mar.-May)	Monsoon (June-Sept.)	Post-Monsoon (Oct.-Dec.)	Annual
Dhubri	29.7	623.8	1774.4	159.0	2586.9
Gauhati	35.6	455.4	1050.9	92.8	1634.1
Tezpur	40.9	477.0	1192.1	137.2	1847.2
Sibsagar	80.3	668.0	1613.7	177.3	2539.3
Dibrugarh	96.3	657.1	1841.3	201.7	1796.4
Haflong	56.0	708.2	1269.6	243.1	2277.8
Silchar	69.4	946.4	2082.3	249.6	3347.7
Lumding	45.0	303.5	819.2	150.3	1318.0
Imphal	51.6	341.6	867.4	151.9	1412.5
Kohima	45.2	336.3	1375.7	162.8	1920.0
Agartala	40.1	556.0	1237.5	190.8	2024.4
Pasighat	151.4	876.9	3147.8	318.0	4494.2
Tura	82.0	701.8	2289.1	270.1	3293.1
Cherrapunjee	71.6	2222.3	8016.5	558.8	10869.4
Shillong	43.2	497.9	1479.6	232.6	2253.3

* IMP (18)

APPENDIX

Table A-2

Monthly distribution of rainfall (mm) at experimental site.

Month	Year/rainfall								
	1976	1977	1978	1979	1980	1981	1982	1983	Mean
January	4.0	0.0	0.0	0.0	0.0	64.5	0.0	15.2	10.5
February	31.5	21.6	0.0	28.4	18.8	25.4	3.8	40.7	21.3
March	0.0	69.1	12.4	0.0	55.6	40.6	14.0	52.3	30.5
April	56.8	195.1	55.8	171.7	82.3	77.0	54.6	138.7	104.0
May	110.0	302.5	181.0	120.7	277.1	47.2	93.0	233.7	170.7
June	357.4	358.5	288.7	198.4	450.1	104.4	441.5	242.1	305.1
July	218.4	477.3	365.3	433.8	252.0	441.2	296.7	555.5	380.0
August	266.7	435.9	223.7	184.9	192.8	214.9	509.3	422.7	306.4
September	97.2	128.0	179.2	106.4	191.5	222.0	131.6	348.0	175.5
October	87.5	163.3	5.8	165.3	80.0	19.5	38.3	194.6	94.3
November	22.9	53.6	19.1	24.9	0.0	2.5	21.3	0.0	18.0
December	0.0	3.1	0.0	7.6	0.0	0.0	0.0	0.0	1.3
Total	1252.4	2208.0	1331.0	1442.1	1600.2	1259.2	1604.1	2243.5	1617.6

APPENDIX

Table A-3

Minimum mean temperature (°C) at some stations in North-East India.*

Seasons Stations	Winter (Jan-Feb)	Pre-monsoon (Mar-May)	Monsoon (June-Sept)	Post monsoon (Oct-Dec)
Dhubri	13.0	20.9	25.0	18.4
Gauhati	11.9	19.8	25.4	17.1
Tezpur	12.5	19.9	24.8	16.9
Sibsagar	11.3	19.3	25.1	16.4
Dibrugarh	11.5	18.9	24.2	15.9
Lumding	9.6	18.6	24.5	15.8
Silchar	12.7	20.4	24.7	17.9
Tura	13.6	21.2	23.0	16.7
Charrapunjee	9.1	14.8	18.1	12.2
Shillong	5.0	13.4	17.5	8.0

* Source IMD (18)

Table A-4

Maximum mean temperature (°C) at some stations in North-East India.*

Seasons Stations	Winter (Jan-Feb)	Pre-monsoon (Mar-May)	Monsoon (June-Sept)	Post monsoon (Oct-Dec)
Dhubri	24.1	30.5	30.2	26.4
Gauhati	25.1	30.9	32.0	27.7
Tezpur	24.5	29.9	31.9	27.5
Sibsagar	23.3	28.4	31.9	26.8
Dibrugarh	23.1	28.0	30.5	26.9
Lumding	25.1	32.1	32.7	27.2
Silchar	26.3	31.0	31.5	28.9
Tura	25.0	31.1	29.2	26.7
Charrapunjee	16.3	21.5	22.6	19.7
Shillong	16.3	23.0	23.9	19.0

* Source IMD (18)

APPENDIX

Table A-5

Mean seasonal relative humidity (%) for the morning (6.30 A.M.)
and evening hours (5.30 P.M.)*

Seasons Stations	Winter (Jan-Feb)	Pre-monsoon (Mar-May)	Monsoon (June-Sept)	Post monsoon (Oct-Dec)
Dhubri	80/60	72/60	87/85	83/74
Gauhati	83/62	75/60	85/80	87/74
Tezpur	81/67	73/64	86/81	81/79
Sibsagar	88/76	80/73	85/81	88/83
Dibrugarh	85/75	75/75	87/83	82/81
Silchar	81/60	75/64	86/81	83/74
Tura	73/65	72/64	89/86	81/77
Charrapunjee	62/76	73/78	91/93	68/84
Shillong	61/77	55/65	81/85	66/87

* Source IMD (18)

Table A-6

Mean velocity for some stations in North-East India.*

Station	Month/wind speed (km hr ⁻¹)											
	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
Dhubri	4.4	5.1	7.0	8.5	8.0	6.8	6.1	5.4	5.3	5.0	4.5	4.5
Gauhati	2.5	3.1	4.0	4.5	4.1	3.5	2.9	3.2	3.0	2.9	2.4	2.3
Tezpur	2.4	3.2	5.0	6.7	4.5	2.8	2.5	2.3	2.3	1.9	2.1	2.1
Subsagar	2.7	4.0	5.5	5.9	5.9	5.7	5.6	5.1	4.6	3.2	2.4	2.3
Dubrugarh	1.7	2.2	2.9	3.4	2.8	2.7	2.7	2.4	2.2	1.8	1.5	1.6
Silchar	1.4	1.8	2.5	2.7	2.4	1.9	1.8	1.8	1.6	1.4	1.5	1.2
Tura	5.3	6.8	7.8	10.1	10.2	6.4	6.4	5.6	5.1	4.6	4.6	5.1
Cherrapunjee	6.7	9.3	11.8	11.9	11.7	11.9	11.5	8.5	7.0	6.1	5.3	5.4
Shillong	2.6	3.9	6.2	8.0	6.9	4.7	3.9	3.2	2.7	2.3	2.0	2.3

* IMD (18)

APPENDIX

Table A-7

Intensity of solar radiation over North Eastern Hill Region.*

Period	Energy in calories $\text{cm}^{-2} \text{day}^{-1}$
December - February	350
March - May	550
June - September	500
October - November	400

* IMD (18)

Table A-8

Numerical values of C.F. (X_3) as worked out while using Eq. 3.2 table 3.1 and 3.2 for various landuses in the present study.

Land uses	Application of Eq. 3.2	Values of C.F. (X_3)
W_1	3+1+1	5.00
W_1^*	7+1+3	11.00
W_2	$\frac{1/3(3+4+1) + 2/3(5+2+2)}{1/3 + 2/3}$	8.67
W_3	3+4+1	8.00
W_4	3+2+1	6.00
W_5	$\frac{2/3(3+4+1) + 1/3(3+2+1)}{2/3 + 1/3}$	7.33
W_6	8+1+3	12.00

* Abandoned shifting cultivation plot (fallow)

APPENDIX

Table A-9

Monthly values of runoff (mm) and soil loss
($t\ ha^{-1}$) from experimental watershed W_1 .

Month	Watershed under shifting cultivation												Abandoned watershed after shifting cultivation											
	1976		1977		1981		1982		1978		1979		1980		1983									
	Run off	Soil loss	Run off	Soil loss	Run off	Soil loss	Run off	Soil loss	Run off	Soil loss	Run off	Soil loss	Run off	Soil loss	Run off	Soil loss								
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17								
January	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00								
February	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00								
March	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00								
April	0.00	0.00	13.84	0.58	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00								
May	0.00	0.00	25.54	9.56	0.00	0.00	6.38	13.73	0.08	T	0.00	0.00	0.00	0.00	0.02	T								
June	5.48	2.98	38.55	34.76	0.00	0.00	30.70	35.06	0.66	0.02	2.31	0.55	0.63	0.02	0.66	0.07								
July	5.73	1.69	74.53	13.99	49.39	31.87	28.52	33.22	21.51	0.34	0.92	0.23	0.68	0.02	0.12	0.02								
August	1.14	0.37	59.71	17.66	0.61	0.43	3.10	1.29	4.68	0.51	2.04	0.03	0.00	0.00	0.06	T								
September	0.46	0.03	2.39	0.25	0.00	0.00	0.00	0.00	0.18	T	0.00	0.00	0.00	0.00	0.00	0.00								
October	0.49	0.03	0.24	T	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00								
November	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00								
December	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00								
Total	13.30	5.10	214.80	76.80	50.00	32.31	68.70	83.30	27.11	0.88	5.27	0.81	1.31	0.04	0.86	0.09								
Soil loss		0.4×10^{-2}		0.4×10^{-1}		0.3×10^{-1}		0.5×10^{-1}		0.7×10^{-1}		0.6×10^{-3}		0.2×10^{-4}		0.4×10^{-4}								

($t\ ha^{-1}\ yr^{-1}$)
per mm of rainfall

T - Trace (negligible); The plot under shifting cultivation without mechanical soil and water conservation measures.
Yearwise rainfall can be had from Table A-2.

APPENDIX
Table A-10

Monthly values of runoff (mm) and soil loss
($t\ ha^{-1}$) from experimental watershed W₂

Month	Year/runoff and soil loss																	
	1976		1977		1978		1979		1980		1981		1982		1983			
	Run off	Soil loss	Run off	Soil loss	Run off	Soil loss	Run off	Soil loss	Run off	Soil loss	Run off	Soil loss	Run off	Soil loss	Run off	Soil loss		
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17		
January	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00		
February	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00		
March	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00		
April	0.00	0.00	11.67	0.82	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00		
May	0.00	0.00	23.27	1.97	0.15	0.002	0.00	0.00	0.85	0.30	0.00	0.00	0.00	0.00	0.77	0.04		
June	3.17	0.28	21.15	2.12	3.03	0.02	0.30	0.04	10.16	1.10	0.00	0.00	0.25	0.20	0.00	0.00		
July	3.46	0.49	28.34	2.10	3.80	0.05	0.00	0.00	0.00	0.00	1.78	1.51	0.29	0.19	0.00	0.00		
August	3.64	0.09	63.25	3.29	4.71	0.16	0.00	0.00	0.00	0.00	0.00	0.00	0.66	0.30	0.92	0.004		
September	1.00	0.04	0.00	0.00	0.21	0.003	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00		
October	3.93	0.40	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00		
November	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00		
December	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00		

Total 15.20 1.30 147.68 10.30 11.90 11.90 0.235 0.30 0.04 11.01 1.40 1.78 0.51 1.20 0.69 1.69 0.04

Soil loss 0.1×10^{-2} 0.5×10^{-2} 0.2×10^{-2} 0.3×10^{-3} 0.9×10^{-3} 0.4×10^{-3} 0.4×10^{-3} 0.4×10^{-3} 0.4×10^{-3} 0.2×10^{-4}

($t\ ha^{-1}\ yr^{-1}$ per m of rainfall).

The plot was under agri-horti laduse having mechanical soil and water conservation measures. Yearwise rainfall can be had from Table A-2.

APPENDIX
Table A-11

Monthly values of runoff (mm) and soil loss
(t ha⁻¹) from experimental watershed W₃

Month	Year/runoff and soil loss																	
	1976		1977		1978		1979		1980		1981		1982		1983			
	Run off	Soil loss	Run off	Soil loss	Run off	Soil loss	Run off	Soil loss	Run off	Soil loss	Run off	Soil loss	Run off	Soil loss	Run off	Soil loss		
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17		
January	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00		
February	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00		
March	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00		
April	0.00	0.00	14.30	0.71	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00		
May	0.00	0.00	10.40	2.22	0.00	0.00	0.00	0.00	0.68	0.03	0.00	0.00	0.12	0.09	7.95	0.39		
June	0.73	0.19	5.01	0.62	1.40	0.01	8.16	0.64	52.13	1.03	0.00	0.00	1.81	0.46	0.09	0.005		
July	0.22	0.04	20.75	3.46	14.13	0.02	2.84	0.16	0.00	0.00	0.00	0.00	0.77	0.95	0.06	0.001		
August	1.04	0.08	9.40	0.70	17.10	0.14	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00		
September	0.38	0.07	0.00	0.00	0.77	0.13	0.00	0.00	1.95	0.13	0.00	0.00	0.00	0.00	0.00	0.00		
October	2.80	0.02	0.00	0.00	0.00	0.00	0.00	0.00	21.76	0.41	0.00	0.00	0.00	0.00	0.00	0.00		
November	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00		
December	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00		

Total 5.17 0.40 60.47 7.71 33.40 0.30 11.00 0.80 76.70 1.60 0.00 0.00 1.70 1.50 8.10 0.396
 Soil loss 0.3x10⁻³ 0.4x10⁻² 0.2x10⁻² 0.6x10⁻³ 0.1x10⁻² 0.0 0.0 0.9x10⁻³ 0.2x10⁻³
 (t ha⁻¹ yr⁻¹ per mm of rainfall).

The plot was under agricultural laduse having mechanical soil and water conservation measures. Yearwise rainfall can be had from Table A-2.

APPENDIX
Table A-12

Monthly values of runoff (mm) and soil loss
($t\ ha^{-1}$) from experimental watershed W_4 .

Month	Year/runoff and soil loss																	
	1976		1977		1978		1979		1980		1981		1982		1983			
	Run off	Soil loss	Run off	Soil loss	Run off	Soil loss	Run off	Soil loss	Run off	Soil loss	Run off	Soil loss	Run off	Soil loss	Run off	Soil loss		
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17		
January	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00		
February	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00		
March	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00		
April	0.00	0.00	43.36	2.15	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.98	0.60	9.06	0.89		
May	0.00	0.00	61.86	7.80	0.61	0.02	0.00	0.00	1.92	0.07	0.00	0.00	1.82	0.55	0.27	0.93		
June	19.37	3.73	68.27	24.23	2.46	0.07	0.35	0.08	1.48	0.03	0.00	0.00	4.50	1.24	2.17	0.02		
July	27.03	2.95	128.34	22.87	10.07	1.27	2.14	0.49	0.00	0.00	11.53	2.06	6.35	2.32	5.55	0.03		
August	23.97	2.42	120.32	11.09	9.49	3.38	0.00	0.00	0.00	0.00	0.67	0.14	0.25	0.09	0.51	0.03		
September	8.88	0.50	1.68	0.01	0.87	0.36	1.22	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00		
October	8.15	0.40	1.47	0.05	0.00	0.00	0.09	0.002	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00		
November	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00		
December	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00		

Total 87.40 10.00 425.30×10^{-2} 23.50 5.10 3.80 0.60 3.40 0.10 12.20 2.20 14.90 4.80 17.56 1.90
 Soil loss 0.8×10^{-2} 0.3×10^{-1} 0.4×10^{-2} 0.4×10^{-3} 0.6×10^{-4} 0.2×10^{-2} 0.3×10^{-2} 0.9×10^{-3}
 ($t\ ha^{-1}\ yr^{-1}$
 per mm of rainfall).

The plot was under agricultural laduse having mechanical soil and water conservation measures. Yearwise rainfall can be had from Table A-2.

APPENDIX
Table A-13

Monthly values of runoff (mm) and soil loss
(t ha⁻¹) from experimental watershed W₅ and W₆.

Month	Agriculture (Fodder crops) W ₅						Bamboo Forest W ₆					
	1978		1979		1980		1978		1979		1980	
	Run off	Soil loss	Run off	Soil loss	Run off	Soil loss	Run off	Soil loss	Run off	Soil loss	Run off	Soil loss
1	2	3	4	5	6	7	8	9	10	11	12	13
January	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
February	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
March	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
April	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
May	0.00	0.00	0.01	0.01	11.44	1.62	0.00	0.00	0.00	0.00	0.00	0.00
June	0.35	0.01	0.72	0.05	19.07	1.42	0.45	0.002	0.00	0.00	0.00	0.008
July	3.17	0.07	3.52	0.70	3.08	0.23	0.85	0.007	0.00	0.00	1.67	0.015
August	25.48	14.04	0.05	0.02	0.00	0.00	5.93	0.477	0.26	0.02	2.02	0.011
September	1.49	0.11	0.19	0.10	11.03	0.22	0.02	0.014	0.84	0.05	0.45	0.002
October	0.00	0.00	0.00	0.00	1.22	0.04	0.00	0.00	0.00	0.00	0.26	0.002
November	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
December	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Total	30.49	14.23	4.49	0.88	46.64	3.53	7.25	0.52	1.10	0.07	7.27	0.038
Soil loss (t ha ⁻¹ yr ⁻¹ per mm of rainfall).		0.1x10 ⁻¹		0.6x10 ⁻³		0.2x10 ⁻²		0.4x10 ⁻³		0.5x10 ⁻⁴		0.2x10 ⁻⁴

The plot W-5 had the support of mechanical soil and water conservation measures. In W-6 no mechanical soil and water conservation measures were used. Yearwise rainfall can be had from Table A-2.

APPENDIX

Table A-14

Peak flow from the experimental watersheds during the period under study

Experimental watersheds	Year/peakflow (mm hr ⁻¹)								Maximum
	1976	1977	1978	1979	1980	1981	1982	1983	
1	2	3	4	5	6	7	8	9	10
W ₁	24.15	50.47	16.57	4.28	0.27	65.82	74.44	3.86	74.44
W ₂	19.04	38.45	10.40	1.13	7.08	0.80	1.96	5.23	38.45
W ₃	3.98	64.09	25.10	7.02	25.01	0.00	7.66	26.40	64.09
W ₄	35.09	55.69	26.15	41.20	14.95	32.26	26.15	41.23	55.69
W ₅			33.83	28.90	1.85				33.83
W ₆			12.70	18.70	5.10				18.70

Annual rainfall can be had from Table A-2.

APPENDIX
Table A-15

Pooled annual values of rainfall (X_1), slope (X_2), conservation factor (X_3), compactness coefficient (X_4),
Form factor (X_5), Runoff (Y_1), Soil loss (Y_2), Peak rate of flow (Q_p) for W_1, W_2, W_3, W_4, W_5 and W_6 .

Sl. No.	Rainfall (X_1) mm	Slope (X_2) m, m^{-1}	Conservation factor (X_3)	Compactness coefficient (X_4)	Form factor (X_5)	Runoff (Y_1) (mm)	Soil loss (Y_2) ($t ha^{-1} yr^{-1}$)	Peak flow (Q_p) (mm, hr^{-1})	Experimental watershed	Year
1										
1	1252.4	0.40	5.00	1.64	0.46	13.3	5.10	24.15	W-1	1976
2	1252.4	0.44	8.67	1.15	0.65	15.2	1.30	19.04	W-2	1976
3	1252.4	0.42	8.00	1.23	0.54	5.2	0.40	3.98	W-3	1976
4	1252.4	0.43	6.00	1.11	0.64	87.4	10.00	35.09	W-4	1976
5	2208.0	0.40	5.00	1.64	0.46	214.8	76.80	50.47	W-1	1977
6	2208.0	0.44	8.67	1.15	0.65	147.7	10.30	38.45	W-2	1977
7	2208.0	0.42	8.00	1.23	0.54	60.4	7.70	64.09	W-3	1977
8	2208.0	0.43	6.00	1.11	0.64	425.3	68.20	55.69	W-4	1977
9	1331.0	0.40	11.00	1.64	0.46	27.1	0.90	16.57	W-1	1978
10	1331.0	0.44	8.67	1.15	0.65	11.9	0.20	10.40	W-2	1978
11	1331.0	0.42	8.00	1.23	0.54	33.4	0.30	25.10	W-3	1978
12	1331.0	0.43	6.00	1.11	0.64	23.5	5.10	26.15	W-4	1978
13	1331.0	0.43	7.33	1.11	0.45	30.5	14.23	33.83	W-5	1978
14	1331.0	0.45	12.00	1.38	0.20	7.3	0.52	1.85	W-6	1978
15	1442.1	0.40	11.00	1.64	0.46	5.3	0.80	4.28	W-1	1979
16	1442.1	0.44	8.67	1.15	0.65	0.3	0.04	1.13	W-2	1979
17	1442.1	0.42	8.00	1.23	0.54	11.0	0.80	7.02	W-3	1979
18	1442.1	0.43	6.00	1.11	0.64	3.8	0.60	41.20	W-4	1979
19	1442.1	0.43	7.33	1.11	0.45	4.5	0.88	9.79	W-5	1979
20	1442.1	0.45	12.00	1.38	0.20	1.1	0.07	1.13	W-6	1979
21	1600.2	0.40	11.00	1.64	0.46	1.3	0.04	0.27	W-1	1980
22	1600.2	0.44	8.67	1.15	0.65	11.0	1.40	7.08	W-2	1980
23	1600.2	0.42	8.00	1.23	0.54	76.7	1.60	25.01	W-3	1980
24	1600.2	0.43	6.00	1.11	0.64	3.4	0.10	14.95	W-4	1980

1	2	3	4	5	6	7	8	9	10	11
25	1600.2	0.43	7.33	1.11	0.45	46.6	3.53	12.70	W-5	1980
26	1600.2	0.45	12.00	1.38	0.20	7.3	0.04	5.10	W-6	1980
27	1259.2	0.40	5.00	1.64	0.46	50.0	32.30	65.82	W-1	1981
28	1259.2	0.44	8.67	1.15	0.65	1.8	0.50	0.80	W-2	1981
29	1259.2	0.42	8.00	1.23	0.54	0.0	0.00	0.00	W-3	1981
30	1259.2	0.43	6.00	1.11	0.64	12.2	2.20	32.26	W-4	1981
31	1604.1	0.40	5.00	1.64	0.46	68.7	83.30	74.44	W-1	1982
32	1604.1	0.44	8.67	1.15	0.65	1.2	0.60	1.96	W-2	1982
33	1604.1	0.42	8.00	1.23	0.54	2.7	1.50	7.66	W-3	1982
34	1604.1	0.43	6.00	1.11	0.64	14.9	1.80	26.15	W-4	1982
35	2243.5	0.40	5.00	1.64	0.46	0.9	0.01	3.86	W-1	1983
36	2243.5	0.44	8.67	1.15	0.65	1.7	0.04	5.23	W-2	1983
37	2243.5	0.42	8.00	1.23	0.54	8.1	0.40	26.40	W-3	1983
38	2243.5	0.43	6.00	1.11	0.64	17.6	1.90	41.23	W-4	1983

APPENDIX

Table 16

Infiltration characteristics of soil in various experimental watersheds - 1983.

Land use systems	Time interval (min)	Depth infiltrated cumulative (cm)	Infiltration rate (cm hr ⁻¹)	Soil Moisture content (%)	
				Range	Mean
Abandoned Jhum (W ₁)	2	4.49	134.70	19.82-43.64	27.15
	5	9.24	110.88		
	15	15.72	62.88		
Agri-Horti	2	4.56	136.80	16.28-27.49	25.57
	5	8.34	100.10		
Bund+Terrace (W ₂)	15	13.43	53.72	16.28-27.49	23.57
	2	4.56	136.88		
Agriculture bench terrace (W ₃)	5	8.13	97.56	20.41-29.34	24.31
	15	11.63	46.52		
	2	5.24	157.20		
Agriculture contour bund (W ₄)	5	10.39	124.68	25.42-47.19	33.20
	15	16.15	64.60		
	2	5.03	150.90		
Forest (Bamboo) (W ₆)	5	8.91	106.90	N.A.	N.A.
	15	N.A.	N.A.		
	2	N.A.	N.A.		

N.A. Not available. The values are mean of six sets replicated thrice and distributed between August to December, 1983.

APPENDIX

Table A-17

Monthly values of runoff from runoff plots under bare fallow condition - 1982

Month	Runoff (mm)/Runoff plots										Mean
	1 (58)	2 (59)	3 (64)	4 (65)	5 (64)	6 (62)	7 (67)	8 (68)	9 (70)	10 (70)	
January	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
February	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
March	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
April	24.02	41.00	41.75	49.47	41.40	24.20	25.15	26.52	8.48	21.42	30.34
May	32.07	33.02	30.18	35.39	40.78	16.06	23.88	24.60	13.04	17.35	26.64
June	80.17	73.01	65.45	74.66	81.10	73.86	61.03	40.68	48.33	50.29	64.85
July	64.56	51.78	45.70	51.22	55.53	67.06	53.63	57.42	50.80	48.18	54.59
August	88.92	86.97	90.86	81.29	89.44	106.41	100.83	85.34	77.24	82.60	88.99
September	7.51	4.11	3.42	3.38	4.30	6.84	7.22	4.11	2.39	4.14	4.74
October	14.89	15.48	13.03	13.86	15.03	17.61	17.20	13.17	10.54	11.77	14.26
November	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
December	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total	312.14	305.37	290.39	309.27	327.58	312.04	288.94	251.84	210.82	235.75	284.41

Values in parentheses indicate per cent slope of runoff plots. Rainfall details can be had from Table A-2.

APPENDIX
Table A-18

Monthly values of soil loss from runoff plots under bare fallow condition - 1982

Month	Soil loss (t/ha)/Runoff plots										Mean
	1 (58)	2 (59)	3 (64)	4 (65)	5 (64)	6 (62)	7 (67)	8 (68)	9 (70)	10 (70)	
January	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
February	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
March	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
April	10.30	38.90	31.47	42.69	42.56	22.26	45.76	23.67	4.51	19.99	28.21
May	26.15	26.32	22.02	14.83	43.53	12.98	15.15	19.53	14.16	18.71	21.34
June	32.10	28.77	31.13	69.29	34.41	43.59	25.75	23.60	27.26	89.53	40.54
July	32.90	12.77	27.86	30.42	55.08	188.87	58.63	15.27	15.80	49.78	48.74
August	125.52	155.72	165.79	155.90	235.09	236.43	231.42	146.35	178.42	185.82	181.65
September	20.42	9.69	9.17	10.73	8.25	14.91	19.22	13.82	5.06	10.11	12.14
October	11.32	30.34	17.73	37.68	35.18	24.65	17.88	32.20	20.87	33.17	26.10
November	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
December	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total	258.71	302.51	305.17	361.54	454.10	543.69	413.81	274.44	266.08	407.11	358.72
Soil loss, t, ha ⁻¹ per mm of rainfall.	0.16	0.19	0.19	0.23	0.28	0.34	0.26	0.17	0.17	0.25	0.22

Values in parentheses indicate per cent slope of runoff plots. Rainfall details can be had from Table A-2.

APPENDIX

Table A-19

Monthly values of run off from bare fallow runoff plots having mechanical soil conservation measures - 1983.

Month	Runoff (mm)/Soil conservation measures										
	No measure (59)	(70)	Trash bund (64)	(70)	Contour strip (65)	(68)	Tie ridge (64)	(67)	Bunds (58)	(62)	Level plot(O)
January	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
February	2.59	3.58	3.80	2.87	3.68	4.37	3.36	4.72	6.08	7.40	0.00
March	17.65	20.01	13.15	13.00	9.95	8.64	4.88	4.26	15.67	7.38	20.00
April	25.01	39.85	10.29	13.52	15.69	17.35	0.51	3.96	12.13	21.35	29.05
May	67.43	61.64	41.54	56.74	62.27	65.18	9.52	18.74	68.12	61.96	104.47
June	43.22	53.26	47.86	42.66	43.66	44.39	26.03	45.63	65.36	57.30	76.03
July	104.13	109.78	90.30	81.77	107.07	110.90	87.30	104.24	124.42	117.63	164.33
August	80.70	68.92	68.10	55.47	76.93	75.94	66.79	88.65	84.95	81.26	122.32
September	76.39	10.40	74.26	4.70	77.40	14.05	66.45	65.69	95.32	77.79	125.82
October	12.88	2.66	12.22	1.87	15.55	3.62	8.60	4.43	15.63	9.36	14.60
November	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
December	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total	430.00	370.10	369.52	272.60	412.20	344.44	273.44	340.32	487.68	441.43	656.62

Values in parentheses indicate per cent slope of runoff plots. Rainfall details can be had from Table A-2.

APPENDIX
Table A-20

Monthly values of soil loss from runoff plots under bare fallow having mechanical soil and water conservation measures - 1983.

Month	Soil loss ($t\ ha^{-1}$)/Soil conservation measures										
	No measure (50)	(79)	Trash bund (64)	(70)	Contour strips (65)	(68)	Tie ridge (64)	(67)	Bunds (58)	(62)	Level plot(O)
January	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
February	1.27	1.42	15.25	5.83	6.10	3.55	0.30	5.72	1.07	20.55	0.00
March	8.96	22.71	13.02	8.23	2.84	3.97	5.46	4.05	61.51	4.20	0.00
April	49.33	129.57	5.26	7.20	16.92	5.98	0.20	4.10	3.29	8.87	4.37
May	167.45	157.27	29.75	65.45	23.31	55.62	2.32	14.13	42.15	41.69	4.25
June	50.59	124.19	81.94	121.86	103.61	83.78	72.47	30.72	151.04	83.35	15.17
July	136.58	31.42	14.79	36.88	49.46	38.11	105.58	37.76	65.02	106.25	37.55
August	91.72	0.52	91.80	57.49	100.35	80.59	91.37	54.83	119.82	66.42	35.87
September	58.46	0.30	11.66	0.79	31.88	1.79	15.68	2.98	141.19	6.05	21.67
October	15.33	0.20	1.82	0.19	3.74	0.31	0.75	0.55	2.60	0.59	6.11
November	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
December	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total	579.69	467.60	265.29	303.92	338.21	273.70	294.13	154.84	587.69	337.97	124.99
Soil loss $t\ ha^{-1}\ yr^{-1}$ per mm of rainfall.	0.26	0.21	0.12	0.14	0.15	0.12	0.13	0.07	0.26	0.15	0.06

Values in parentheses indicate per cent slope of runoff plots. Total annual rainfall (2243.5 mm) for the year 1983 has been taken from Table A-2.

APPENDIX

Table 21

Annual values of runoff and soil loss from steep slopes (32-50 per cent) at other locations*

Land use systems	Slope (mm ⁻¹)	Soil conservation measures used	Rainfall retained within the area (%) of total	Soil loss (t ha ⁻¹)	Length of record (Yr)
Agriculture (fodder)	0.32	Contour trash	99.97-100.00	T-0.004	1984-85
Agriculture (Food crops)	0.32	Bench terrace contour bund	99.47-99.77	0.07-0.150	1984-1985
Agri-horti-silvi-pastoral	0.42	Bench terrace contour bund half moon terrace	99.73-99.99	T-0.120	1984-1985
Horticulture	0.53	-do-	99.50-99.58	0.14-0.370	1984-1985
Natural fallow	0.46	Nil	99.97-100.00	T-0.050	

* The data are from Singh (52). The symbol T stands for trace.