Land Degradation and Ecorestoration in the Extremely Wet Monsoon Environment of Cherrapunji Area, India

Editors

Surendra Singh
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Preface

This Volume is an outcome from the investigation carried on Ecorestoration of Natural Resources in the Extremely Wet Monsoon Area during 2005-2007 under the Second phase of Indo-Polish Joint Collaborative Research Project entitled 'Rainfall, Runoff and Soil Erosion in the Globally Extreme Humid Area of Cherrapunji, India' sponsored by the Department of Science and Technology, Government of India, New Delhi and the Ministry of Technology and Higher Education, Government of Poland, Warsawa. The main objective of the collaborative research was towards detail investigation of geo-ecological dimensions and socio-economic conditions of the degraded landscape of Cherrapunji, an area of extremely wet monsoonal conditions of the globe in which the traditional societies have been confronting for centuries. The depth and intensity of diverse issues of land degradation and ecorestoration arising out in the excessive rainfall areas of Cherrapunji, are largely dependent on the study of the operation of natural processes of landscape and the demands of traditional hill societies that are being fulfilled by the available ecosystem services and natural resources. Such issues are addressed by studying the landscape functions in connection with changes in circulation of water, energy, mineral and organic matter. . The effects of increasing demand due to population incr~ase on land and environment have been observed and the requirements of societies living in this area were assessed through inve~tigations and surveys. The analysis of the utilisation of ecosystem services received by the local people was attempted.

Most studies on land degradation are concerned with the facts of ideal conditions of landscape functions and ecosystems. However, few investigations on land degradation were conducted on fragile ecosystems and less productive functions of landscapes found in the extreme weather conditions. It was also decided at the time of discussion in the group meetings of investigators that an integrated approach of ecorestoration and recovery of natural resources in such fragile landscapes is to be adopted to interlink the human activities with land degradation and try to suggest me'asures to promote sustainable use of dwindling biological productivity of ecosystems prevalent in these extreme conditions.

This investigation was pursued by an Indo-Polish team of scientists (from North-Eastern Hill University, Department of Geography, Shillong and Polish Academy of Sciences, Department of Geomorphology and Hydrology of Mountains and Uplands, Krakow) which considered a micro-areal domain of degraded landscape at Cherrapunji. . The results of investigation were inferred by using computing tools to process spatial data, by conducting a variety of surveys and establishing a hydrological observatory in the area. In order to fulfil the basic tenets of spatial interaction, there is a need to understand landscape functions in relation to different local geological structure and existing ecosystems like grasslands and forests. We do sincerely hope that the present Volume on Land Degradation and Ecorestoration in the extremely wet monsoon area would offer an integrated view of the problems of land degradation and provide a better understanding of the processes operating in such environment and lead towards the development of an appropriate model of land degradation for the wet monsoon lands.

We are very thankful to Professor D. K. Nayak, former Head, Department of Geography, North-Eastern Hill University, Shillong not only for his generosity and permission to use department facilities, but also for valuable suggestions in preparing the Report. We also thank Professor Piotr Korcelli, Director, Institute of Geography and Spatial Organisation, Polish Academy of Sciences, Warsawa, who provided stay facilities during the time when Indian partners of the research team visited Poland and also for organisation of special lectures on the theme. We are thankful to Or. Yogendra Kumar, Department of Botany, North-Eastern Hill University, Shillong for helping us during surveys on plant species of this area. Mr Oanny M. Synnah, Incharge GIS Lab, Mr. James M. Lyngdoh, Junior Research Fellow working under the project of Department of Science and Technology, Government of India, New Delhi and Mr. Skhemborlang Marwien, Research Student, Department of Geography, North-Eastern Hill University, Shillong deserve our appreciation for their sincere help in preparing the maps and diagrams used in this Volume.

Last but not the least, our sincere thanks are due to Department of Science and Technology, Government of India, New Delhi for providing a work platform and the required financial assistance in the form of In'do-Polish Joint Research Collaboration (No. INT/POL/P-ll/2004) and the facilities to generate meteorological data by providing an Automatic Weather Station and Water Level recorder for the purpose of the present investigation under individual Project (No.ES/11 / 833/ 2004) to conduct research in Meghalaya Plateau.

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1

Land Degradation in Degraded Hills- A Concept

Surendra Singh

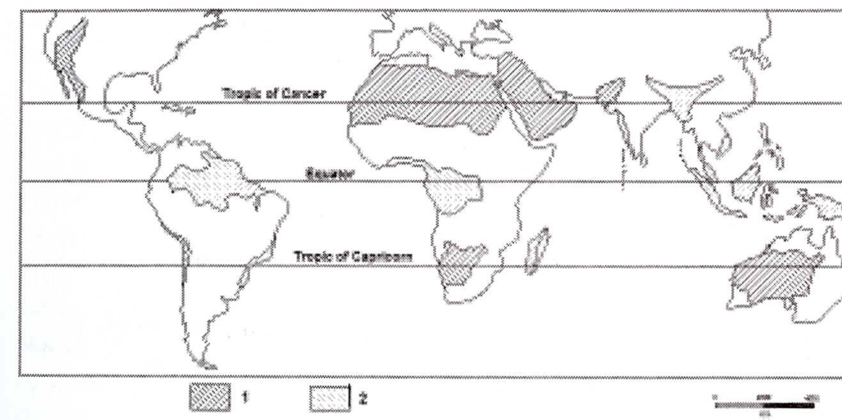
1.1: **The Land Degradation**

Land degradation can be viewed as a concept in which the value of geo-ecological environment is affected by human induced processes acting upon landscape, while landscape is a geomorphic concept in which land surface features implicitly govern the environment and alter the structure and function of prevalent ecosystems. Natural hazards, though they are causes of land degradation, are excluded as a cause. However, human activities influence natural phenomena such as mass movement over slopes, floods, river meanders and flood plains and so on. The causes of land degradation may be many such as deforestation, depletion of soil nutrients due to agricultural practices (Shifting cultivation in hill areas), livestock overgrazing, industrial activities and expansion of road network including settlements. Such expansion of area under a particular activity of land use becomes noticeable because of intensification of human activities like increasing population and wide use of technology. There are multi-dimensional effects of land degradation. For example, reduction of productivity (biological as well as agricultural) of land, increase in dwindlling resources, reduction in biodiversity, low soil fertility and leached soil nutrients are major effects. Road cutting is a major cause of increasing intensity of landslides along roads and also increasing erosion rate in river catchments (Rai 2008). In addition, the effects of land surface features such as the changes in water resources in the area due to alteration in overland flow, recharge variations of underground water and sub-surface flow, the expansion or shrinkage in water bodies and the changes in geomorphic features and resultant environmental changes are explicit effects of land degradation.

Land degradation has been a part of Global agenda under a UN Convention to combat Desertification (CCD) which considers losses of biological resources and economic productivity of major land uses arising from the forces of natural and human environment of landscape in the arid, semi-arid and dry sub-humid areas of the world. This agenda is more concerned with the mid latitudes arid regions where the hydrological cycle operates differently from the normal conditions. The habitat survival and ecosystem productivity of such areas are more concerned with extreme temperature conditions of weather where' calcification processes' of soil formation are operative resulting in the expansion of sandy topography with less productive ecosystems. On the other hand, the land degradation in the humid topics and extremely wet monsoonal environment of landscape where soil 'hydrogenisation' is prominent, leading to leaching of the soils. The gradual diminishing trends of soil nutrients due to hydrological alteration of very dry winter and extreme wet summer condition probably have a major impact on the degrading landscape leading to a semblance of desert conditions. Cherrapunji landscape is an example of operation of such processes. Both these opposing scenarios of land degradation fall under the zone of mid latitudes and basically differ each other in their characteristics of decay of the properties of land (Fig.-1.1).

Such issues of land degradation of the arid and semi-arid environment were addressed in the Commission on 'Land Degradation and Desertification' in the Sixth Meeting of the International Geographical Union (IGU) held in Perth, Australia

in September 1999. The mechanisms responsible for the land degradation and their social and economic implications were discussed (Conacher 1999). Land degradation issues of extremely wet environment were not taken up at international or even at national forums in spite of the fact that such weather extremes lead to totally different problems concerning landscape changes. However, areal extent of such events may not be as large as the arid environment issues at global scale.



1. Areas of Hot Desert
2. Tropical and Monsoonal areas of Excessive Wet Conditions
Fig.-1.1: Areal Extent of Land Degradation in Different Areas of Mid-latitudes

There are many issues relating to land degradation in extreme wet monsoon tropical environment especially in the Cherrapunji area. Intensive rainstorm changes the chemical and textural properties of soils while at the same time diminishing effectiveness of carbon cycling. Biological properties are modified under such conditiohs. Intensification of human activities like expansion of land and use of modern technology for settlements and roads including infrastructure development, increasing use of ecosystems services, pollution and sedimentation of water bodies, excessive leaching and acid rainfall and so on leads to reduction of biodiversity. In areas of excessive rainfall, ecosystem services and biological productivity are essential and are required to be maintained. This would positively help to reduce the negative effects of hydrological processes on landscape functions. Considering water circulation and land use (including changes) as important components for biological productivity, landscape functions and availability of ecosystem services to local people are as important dimensions in the contemporary deteriorating environmental scenario.

Resource scarcities in these degraded lands have mounted externalities for fulfilling the needs of increasing population while, at the same time, ecosystem development and environmental protection have become closely intertwined and necessary for sustenence. Assessment of resource availability, biological as well as physical, can be made to understand the ways and means to reduce the advancing effects due to current unsustainable demands. This issue of land degradation and ecorestoration of extremely wet degraded lands needs to be understood in the light of landscape function. Identification of ecosystem damage areas too need to be pursued in order to prioritie interventions. These issues were dealt by ecologists. However, they were not linked to landscape functioning.

Soil erosion, ecological disturbances and habitat transformation are the consequences of the changes in the cycles 6fenergy and material over landscape. The study of spatial ~rrangements of landscape functioning, identification of its degraded features and rehabilitation of degraded patches / tracts of land are now essentially linked with the information technology. Geographical Information System (GIS) and geo-statistical application of various land features (topographic, natural resources as well as clusterisation of human activities) are basic modern tools through which the processes of land degradation can be studied more accurately and its spatial features may be visualized in their real and sharp manner (Shrestha and Zinck 1998).It also provides the means of overcoming the problems of ecorestoration and rehabilitation of land resources in their right perspective.

Denudation (that creates disequilibria through removal of surface and sub- surface material with the action of natural forces over time) becomes more pronounced when natural processes are aided and intensified by human activities. In the extreme rainfall conditions, the action of water becomes too significant to alter the properties of soil and regolith through solution and displacement of surface material, while the changes in the textural and chemical properties of soils through infiltration occurs displacing the soil material through leaching. Besides, under such conditions, the role of deep weathering too is not to be disregarded.

Land degradation in the hilly areas have generally resulted out of fragile ecosystems, weak and less-productive functions of landscape (Vink 1975) not only because of the effects of geo-hydrological processes but also the advancement of traditional societies that confront the adverse conditions of ecosystems. It is true in case of extreme wet conditions at Cherrapunji area representing a degraded hilly landscape. Here the traditional human activities and culture are strong enough and people try to retain specific ecosystem by upholding traditional beliefs and practices. On the other hand, changing needs and requirements have altered landscape functions in the form of extraction of natural resources and intensification of technological uses to meet their basic needs on a sustainable basis (Ramakrishnan et al. 2003, Tripathi 1996).

Catrostophic rainfalls couched with intensive human activities of Cherrapunji may be major factors responsible for the development of a specific geo-system. The uplifted tectonic block along the Dawki fault built up of dissected margins of horizontally bedded rocks representing the degraded lands evolved because of intensive erosion processes. Such process evolved the grassland ecosystem with flat top and dense forest ecosystem in the areas of canyons. The stress due to increasing anthropogenic forces may be seen through the study of changing pattern of land cover and land uses in this area. There are two major process~s fl~c@l€ll'Ett€l by excessive rainfall and increasing human activities. Firstly, deforestation either by intensification of human activities or through the natural processes that provide leaf litters of forest/ grass plants to maintain soil status and to regulate soil organisms for plant uptake. Due to deforestation, the stream flow, slope wash, gravitational movements and several other processes are accelerated. The geo-chemical processes of rock weathering which are essentially related to sub surface systems change rocks of different forms like hard granite to sand. The second important process of ecosystem is related to top soil erosion due to excessive rainfall, cutting rock edges including exfoliation. Degradation of rock minerals and reduction of surface salts processes (Fig.-1.2) by leaching are outputs which change the physical and chemical properties of surface soils and rock material. For example, intensive rainfall has adverse effect on the plant growth through increased leaching of soils and mobilization of toxic ions (like Aluminum, Magnesium, etc.). Lime stone dominated rich structure reduces the effect of rain in the soil. However, the areas of exposed crystalline rocks like granite may be more vulnerable to excessive rainfall.

In fact, fragility of prevalent ecosystems that changes in land use / land cover is the result of two simultaneously applied forces (natural as well as anthropogenic) of landscape. There is an important issue of land degradation to address how the effects of such applied forces can be isolated to understand the nature and intensity of land degradation in different land surfaces. Greater thickness of soil and resulted biological productivities would have been degrading for long not because of the induced human activities but also due to excessive rainfall and present - day processes of atmospheric water circulation in Cherrapunji area. Keeping effects of physical factors of environment on the landscape constant (or consideration of the effects of natural forces as bench mark), the assessment of the effects of magnitudes and intensities of human activities in its spatial and temporal contexts can be made for the study of land degradation. For example, the effects of human activities on the dynamics of secondary forests

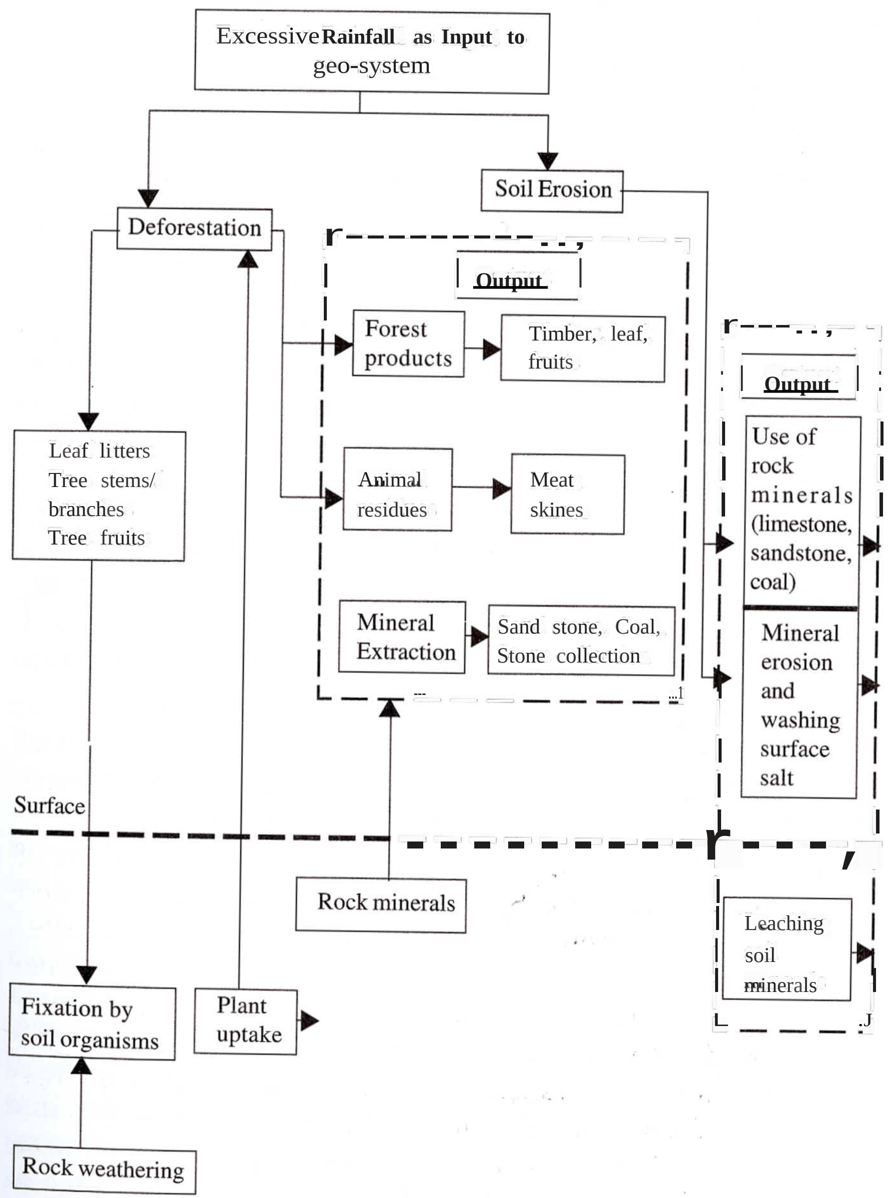


Fig.-1.2: Inputs and Outputs of geo-rock Cycle Operative at Cherrapunji Landscape (Modified from Goudie 2001) or its deforestation rate was noted three times higher than the deforestation rate of other forests of the lower Mekong basin because such secondary forests are providing ecosystem services to the demands of increasing population of the area (Heinimann et al. 2007). In such studies, the assessment of degree of biological degradation is inclusive of the effects of changes of the natural processes, while considering both (nat~ral. forces a~d hu~an activities), the assessment of land degradation ISto consIder takmg into account the effects of natural factors of landscape as spatial bench mark. Such issues of land degradation measurement are relevant in the present context also. It may be addressed to study the landscape structure and functions in which changes in land properties have been taken due place to operational natural forces and human interference continuously (Singh 2007). In order to address such issues of land-resource degradation occurring in the Indian Himalayan ecosystems varying longitudinally from Siwalik areas of 900 m elevations (the part of lower Himalayas) to the sub Himalayan zones of above 3,000 m (the greater Himalayas) with varying temperature and humidity conditions, the Departme.nt of Science and Technology, Government of India, New DelhI has undertaken a major initiative to create a bio-geo data base for spatial decision support system for the developm~nt of ecol~gical modeling and addressing issues of land degradation (MendIratta et al. 2008). The geographic approach of landscape analysis and Geographical Information System (GIS) tool were adopted for the purpose (Department of Science and Technology 2005). Addressing such issues in extremely humid areas of Meghalaya plateau like Cherrapunji, a strong geomorphologic backgro~nd and the study of water-balance budgeting which would prOVIde strong bases for the transfer of energy and material in these conditions of landscape (i.e., indicative of soil degradation and changes in physical and chemical properties of land) and chang~s in land use /land cover pattern (i.e., indicative of change In biological properties of land) are needed.

The Ecorestoration

Ecorestoration has been viewed as a systematic functioning of landscape as well as the need to restore degraded conditions arising out of the increasing anthropogenic factors on such landscape. Improvement of sustainable levels over time on the land's biological productivity may be a practical dimension towards ecorestoration which is directly linked with the physical domain of landscape and human causes of land degradation (Douglas and Lewis 2006). Degraded ecosystems and ecorestoraion are two inseparable interlinked dimensions of landscape coupled with increasing anthropogenic forces, need to be altered over time. This change would serve as a strategic basis of interpretation and analysis of degraded landscapes in an integrated manner or the benefit of mankind (Ramakfishnan et al. 2003).

A host of processes taking place in ecosystems like bioma~s production, nutrient accumulation, hydrological processes mid transfer of bio-physical elements altogether combine to produce a balanced effect. However, increasing human activities have shown dire consequences on the functioning and structure of landscapes. Hence, ecorestoration needs to address a host of processes to correct the functioning and structure of landscapes and to try to achieve sustainable levels of ec;:osystem functions (Fig.-1.3). Ecorestoration strategies for such degraded landscape require an integrated approach whereby a solution to the problems needs to be considered using a bottom-up approach reaching the community level and to correct at different decision levels.

Not only the ecological view of restoration of ecosystem of degraded landscape prevalent in Cherrapunji area as suggested by many ecologists (Khiewtam and Ramakrishnan 1989, Tripathi et al. 1995) but also the requirements of human being and strong people's culture which sometimes retains the specific ecosystems and somewhere it stresses the landscape functions in the form of extraction of natural resources to meet basic needs on a sustainable basis (Ramakrishnan 2003: pi) are to be kept in mind. This twin concept of ecorestorl1tion and interface of landscape function and anthropogenic forces which is changeable over time, is one of the major dimensions of the study of ecosystem and its function in the form of changing pattern of land uses. The whole issue of sustainable land use as a part of landscape management and development of ecosystem prevalent in the degraded landscape is linked with the human responses. Instead of ecological dimensions of landscape like biomass and organic production, nutrient accumulation and its dynamics (nutrient cycle) and hydrological processes covering the functions of water at slopes of downstreams (transfer of matter from one place to another), the human interference (natural resource use in the form of land use intensification) and its intensity are equally important aspects of ecorestoration which would help in better understanding the man-environment relationship of habitats and causes of degradation of landscape.

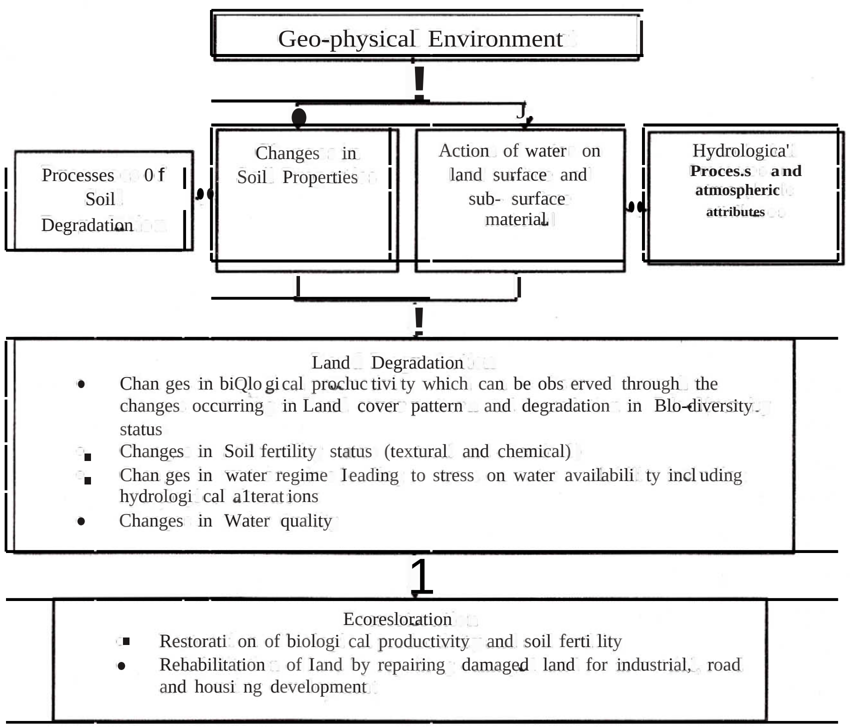


Fig.-l.3: Land Degradation and Ecorestoration in Extremely Humid Tropical and Monsoon Areas

The failure of government ecorestoration strategy especially for Cherrapunji area is an example of lacking integrated approach towards a comprehensive landscape function (Government of Meghalaya 1986-87). Therefore, basic ecorestoration strategies need to contemplate on the following aspects like the types of degraded landscapes and the restoration possibilities of such landscapes coupled with altering bio-physical and hydrological conditions in relation to land use dynamics. There are two major areas of ecosystem recovery in diverse landscape:

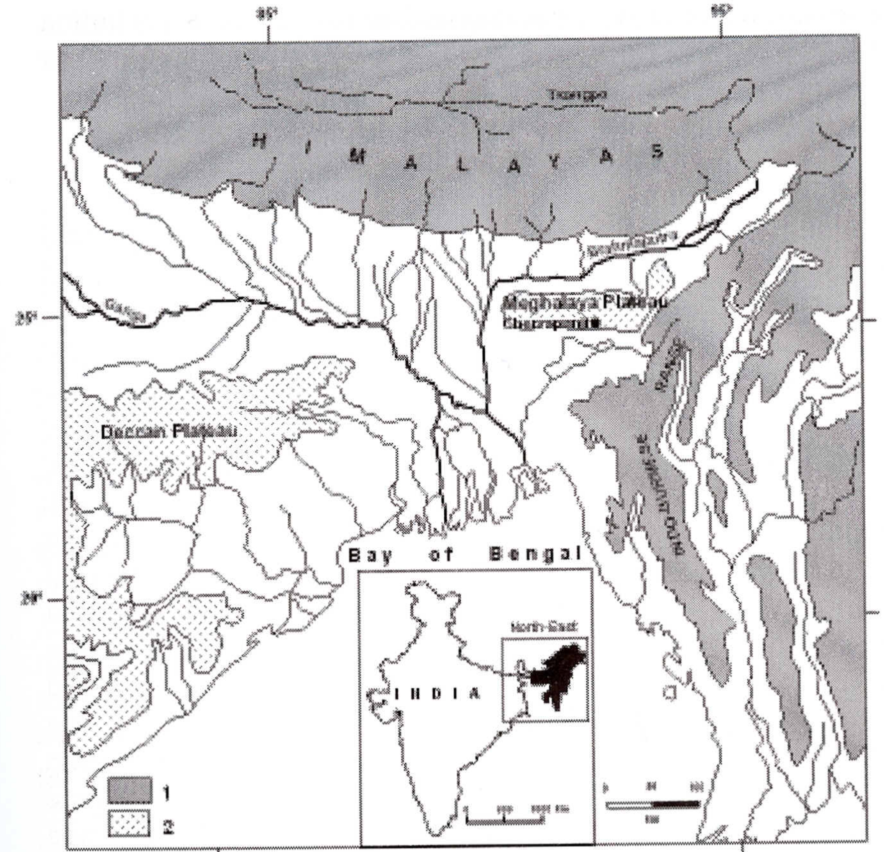
(i) The areas of least-interference: In landscape of non-interfered areas where human activities have still not altered the function of natural ecosystems, the impact of natural forces is slight and reversible ecological health can be maintained overtime in its natural recovery, and

(iD The areas of intense influence of human activities: Some places/ areas of landscape are under the threat of human forces which destroy the functioning of existing (partly endemic) ecosystems either through the use of extracting intensively the ecosystem services or altering the fabric of natural processes in his own interest.. In such conditions, the impact of such acts on biophysical environment is irreversible. Geo-ecological restoration is required along with efforts to change human activities.

Ecorestoration is a concept related to environmental quality and technological interventions aiming at achieving ecological restoration and land improvement. This would improve the hydrological regimes, stabilization of soil nutrients status and propageting afforestation as a means of water conservation and land protection. Thus, land degradation and ecorestoration are inter-dependent. . Degradation shows deteriorating conditions of land properties while restoration indicates the strategies of land reclamation and land rehabilitation to recover biophysical properties to its earlier state. For example, in extreme rainfall areas such as Cherrapunji, achieving ecological restoration is a big challange. Heavy rainstorms at Cherrapunji area drain out soil minerals directly into water bodies leading to storm runoff pollution from point and non-point sources. Untreated runoff is used for washing and drinking.

The Geo-ecological Scenario

With the extremely high rainfall conditions (annual average rainfall of 10,000-12,000 mm), the resulted intensive operation of hydrological processes on landscape, and the unique geological structure with horizontally bedded rocks resulting to a flat level surface topography in the southern slopes of Meghalaya plateau, Cherrapunji spur area is situated at an elevation of 1,200 - 1,400 m a.s.! (Fig.-1.4). There is prevalence of environmental stress which alter the function of endemic ecosystem and create a fragile forest as well as grassland ecosystems. Strong impact of water circulation on asserting landscape function and fragility of ecosystem can be seen in a variety of ways which have been studied by many environmentalists and scientists. Undoubtedly, the Cherrapunji spur area is considered under fragile and degraded grassland ecosystem which had extended its functions upon a complex rock structure of horizontally bedded with its inclination of 2-5² towards South resulting the sands tones and limestone topography (Prokop 2004:27). Evolution of geomorphic landscape and its present-day processes of transformation of slopes and channel systems in this frontal area of sandstone and shale formation are also controlled by the heavy rainfall resulting to the leached and unfertile soils (StarkeI1996). Because of heavy rainfall and long duration of rainy season, the surface of Cherrapunji spur has been exposed to heavy slope wash and, consequently, most of the part of surface cover is exposed in the form of iron-crust cover of bed rock or as armored stony layers. Such fast accelerated hydrological processes have seasonal variability and long rainy season (May-September) which receives about 80-85 percent amount of annual rainfall in this area.



1. Mountain areas of above 1,600 rn, 2. Plateau and hills of 900 to 2,000 rn of elevation

Fig.-1.4: Location of Meghalaya Plateau in North-East India

There are a few studies on the nature and pattern of monsoon variability and rainstorm characteristics of this area (Singh and Syiemlieh 2001, Starkel 2002, Soja 2004, Soja and Starkel 2007) and on the changes in soil fertility status and vegetation cover of prevalence ecosystems that have been controlled by the extreme rainfall conditions of landscape (Ram and Ramakrishnan 1988). In addition, the issues of weather variability that hampers the landscape functions, the land surface evaluation and the ecosystems fragility have been taken up by the team of scientists. working in this area under Indo-Polish Inter·Governmental

Programme. A study of measurement of rainfall trend and its fluctuations (based on Fourier analysis of periodic signal of T= 3.5 years) was pursued for extremely humid tropical environment by Prokop and Walanus (2003) and concluded that this measurement is suitable for variability measurement of rainfall in these areas. The study finds that rainfall trends in this area are highly variable in its intensity from year to year with extreme precipitation values of contrasting rainfall pattern. This analysis addresses an important issue of rainfall variability that might have had much variable trend in the changes of soil fertility status because of variable leaching conditions (seasonal as well as regional) of landscape. Forest and accompanying vegetation in this place is, therefore, fragile with short circuit nutrient cycle in shallow soils of grassland ecosystems. A detail investigation which was conducted under Indo-Polish inter Governmental Programme between the Department of Science and technology (DST), New Delhi, India and the State Committee for Scientific Research (KBN), Warsawa, Poland addressed the problem of landscape function of this area and concluded that physical processes of land surface that are concerned with its biophysical properties are themselves too weak and indifferent in their normal working to create a strong base for the rainforest ecosystems (Starkel and Singh 2004: 91-69). As a result, most of the flat lands of Cherrapunji spur are under shallow cover of soils (or soils are completely missing on some places) with fragile grassland ecosystems except debris slopes of moderately thick soils and dense forests.

Literature Review

Restoration. of ecosystems in degraded landscape of Cherrapunji had been dIscussed at length by many ecologists. However, these studies and investigations were strictly ecological in their orientation. In this connection, the available literature could not give enough information about environmental parameters and ecorestoration of this area, nevertheless it provided some basic facts and background data of what has been happening with the

environment of Cherrpunji landscape. Enough literature is available to address the issues in connection with land degradation and ecorestoration. Under these conditions, literature available could be summarised in three major directions:

1. Concerns of General Environmental Problems: Visits of William Griffith as far back as 1835 (c.£.Corrie 1995) and Oldham (1854, c.£. AlIen 1905) in this Cherrapunji area highlighted their experiences on the general problems of environmental degradation. The view on catastrophic rainfall conditions by Starkel (1972), the explanations of geomorphic features by Bandyopadhay (1972), the description on geological stucture by Mazumdar (1976) are major scientific writings on the landscape development of Cherrapunji area. It was the time when scientists and the governmental agencies realized seriously the problems related to environmental degradation in this area.
2. Studies on Environmental Degradation and Eco-restoration: During the 1980s and 1990s, the work of a group of ecologists under the supervision of Ramakrishnan pursued by considering environmental degradation as a scientific explanation of (i) the agro ecosystems with special reference to Jhum cultivation and nutrients cycling (Toky and Ramakrishnan 1981, 1982, 1983), (ii) the forest ecosystem in protected areas of Cherrapunji (Khiewtam 1986) and (iii) the grassland ecosystem (Uma Shankar 1991) are noticeable. Works done by Toky and Khiewtam were the landmark studies on the ecological approach of degraded hills of Cherrapunji. However, a publication on ecorestoration of degraded hills edited by Tiwari and Singh (1995) includes many papers on the aspects of geo-ecological, ecosystems, sodo-economic and land use of CherrapunjI landscape which are of great significance in understanding the problems of degraded landscape. Such studies were the initial stage of a scientific work when ecologists of the North-Eastern Hill University, Shillong came forward to describe the problems of degraded landscape of the extreme conditions.

Several papers and one report were published on geomorphological and meteorological aspects of this area. Such team work includes the main aspects of (i) the formation of geomorphic landscape and development of water channels and land uses in connection with geological formation (Starkel 1996, a'Hare 1997, Soja and Starkel 2007), the runoff conditions in Cherrapunji area (Prokop 1999), the rainstorm characteristics (Singh and Syiemlieh 2001, Singh 2007), soil profiles with its grain size and soil loss (Starkel et al. 2002, Froelich, et al. 2003), the micro morphological features of soil cover (Budek and Prokop 2005) and the natural hazards and impact of anthropogenic factors on environment in the river catchments of degraded Cherrapunji area (Prokop 2005, 2007). These studies were carefully compiled and coherently arranged in the form of a report on Rainfall-Runoff and Soil Loss in the Extremely Humid Area of the World - Cherrapunji, edited by Starkel and Singh (2004) under Indo-Polish Collaborative Research Program. The report describes the geo-hydrological, land use and soil conditions in order to understand the relationship among the geomorphic features (that are evolved on parallel horizontal rock formations of metamorphic and igneous rocks) (Fig.-1.5), the land uses (that are concentrated in the few dense forest patches in the valleys and the quarrying and mining) and the extreme conditions of excessive runoff because of heavy rainfall and very less infiltration (caused by very thin soil cover). What is refreshing in the same volume is a discussion of the land use and soil characteristics in its spatial context.. The offshoot publications of the report show that land use / land cover is relatively stable in the area (Prokop 2005).

3. **Institutional** Concerns **and** Commitments: In addition to studies pursued by individual scholars or team of the scientists, there has been an involvement of several institutions and governmental agencies on the problems

Source: Google Earth

Fig.-1.5: Immediate Surroundings of Cherrapunji Spur

of ecorestoration of degraded hills. Research complex for North Eastern Hill Region, Indian Council of Agricultural Research (ICAR) located at Umiam (Barapani), 20 km away from Shillong (Meghalaya) and the Regional Centre of Botanical Survey of India, Umiam (Barapani) Shillong have also been involved in the research work on this area. The Agriculture Extension Department of ICAR has conducted many studies on runoff prediction for development of agro-ecosystem and water harvesting. The integrated watershed management model was developed for the area. Agro-pastoral and agro-horticultural systems were suggested by Singh and Saxena (2002) for the hill areas in an edited volume on Integrated Watershed Management for sustainable development published by ICAR Barapani, Shillong (Sathapathy and Dutta 2002). Such aspects of scientific studies of ICAR and its experimental approach do not throw light on ecorestoration of degraded landscape prevalent in the barren lands of Cherrapunji area but provides a good literature on agro-ecosystems processes in this area.

An investigation on the tree survival rate in the social forestry plantation carried out by the Regional Centre for Social Forestry and Wasteland Development, North - Eastern Hill University, Shillong under the mandate of Ministry of Environment and Forests, New Delhi was conducted in Cherrapunjee area of degraded landscape and other areas of the state. The growth performance of different twelve tree species in different plantations was studied by collecting 20-40 percent samples of total planted areas adopting quadrant (10 m x 10 m) method of survey for different species and concluded that the mean height of *Pinus Kesiya* seedlings is comparatively satisfactory with its greater survival rate of about 73.3 percent in the Maw-ki-syiem and its other surrounding areas but growth is recorded abnormal like swelling of collar. The collar thickness is recorded much higher in this area (Tripathi, et al. 1991). This is most probably the main reason of the unsucessful *Pinus Kesiya* plantation over the barren

land of Cherrapunji spur planted by the Forest Department, Government of Meghalaya, Shillong. Selection of suitable tree species which may commercially be useful for local people is a prime aspect of any ecorestoration programme. However, ecorestoration were linked with the study of biomass productivity and conservation of gene pool as the basis of ecorestoration strategies (Tripathi et al. 1995).

Joint Forest Management (JFM) is also an integrated aspects through which public awareness about the importance of forests, raise nursery, undertake monitoring and micro-plans between forest development and village committees is imparted to villagers through various governmental as well as non-governmental agencies. A report on the status of management of plantation for the mountain and hill areas highlights that survival of native species is satisfactory (60-80%)with their quick growth provided seedlings of such species are protected from grazing and forest fire (Tiwari et al. 2006). Such programs may provide better land use and economic benefits to the local people. However, ecorestoration of forests not only in Cherrapunji area but also in the entire hill areas has been the part of tribal culture and, through the sacred forests, local people wishes to preserve the dense forests. A number of these groves are found on the spur. Of these, one is located in the barren lands near Ramakrishna Mission in the outskirts of Cherra town locally called *'Ka Law Kyntang'* of about 50 ha and second is located on the steep slopes near Nongrim village towards Thangkharang park in different ecological conditions and is known as *'Ka Law Adong'* of about 900 ha. These forests are managed by the respective village councils with the believes of the local people (Tiwari et al. 1999).There are various aspects covered in the programme, namely, the Joint Forest Management (JFM), village level participation in afforestation programme, plantation under social forestry programme, biomass and gene pool conservation and so on. The main aspects of different programmes are basically linked them with the integrated ecorestoration strategy which is more related to expansion and intensification of forests under the limitations of the fulfillment of the needs of local people (Mahlotra et al. 2004).

Watershed management seems to be an integrated approach and is comparatively better than the sectoral approaches like ecosystem approach of ecorestoration of natural resources. The attempt has been made to start monitoring and investigations of physical processes of landscape function by a team of geographers of North Eastern Hill University, Shillong and Polish Academy of Sciences, Wasawa for a correct assessment of water and soil resources in such extreme conditions of grassland ecosystems.

Realizing the problems of unscientific mining of coal (as spoils that comes out of the open cast and 'rat hole' mining), extraction of limestone (quarrying the limestone and its burning) and extreme conditions of hydrological cycle (seedling got affected), the Conservator of Social Forestry Circle, Government of Meghalaya, Shillong prepared a project on ecorestoration of Cherrapunji area in 1983-84, submitted for favour of finance to the Ministry of Environment (now Environment and Forests), Government of India, New Delhi with the objective as to develop the most appropriate technology to prevent the soil, creation of nurseries, avenues plantation of indigenous tree species with soil working to dig the pits and transport soil from the nearby forests and the construction of check dams as water harvesting devices. The Technical Report on Ecological Restoration of Cherrapunji was submitted to the Ministry of Environment and Forest, Government of India, New Delhi through the Government of Meghalaya in 1986-87. After implementing the ecorestoration program, it is found that it could neither fulfill the aspirations of the local people, nor improve the conditions of degraded landscape in spite of spending a significant amount of money sanctioned by the Central Government for the purpose.

It is realized that the strategic dimensions of restoration of natural resources should be related to both biotic and abiotic parameters of Cherrapunji landscape while at the same time considering socio-economic elements. Integrated natural resource management is essentially an approach to resolve multiple and diverse problems of ecosystem sustainability and survival of local

communities within the context of natural environment and development problems of the area. In traditional biodiversity management, the community decision and households actions are one of the human dimensions that retained many forest patches and secred groves untouched from humans. Modern concept of biodiversity conservation and natural resource utilisation emphasises the broader view of landscape environment. It considers the integration not only of the physical attributes but also the economic, socio-cultural and anthological environment with reference to Cherrapunji landscape possessing a humid tropical environment where energy and nutrient cycles have been largely dependent on the hydrological processes of landscape, the biological productivity and its conservation are more related to land degradation problems.

Aim of the Study

The main attention in the present volume is, therefore, focussed on the dimensions of degraded landscape (1) to analyse the seasonality of hydrological processes in grasslands of Cherrapunji spur which is expected to help the understanding of rainfall-runoff conditions, (2) to describe the spatial pattern of natural resources by conducting surveys related to vegetation, soil and land use / land cover with an aim to make an inventory of dominant local vegetation species, soil conditions and to map them and (3) to assess the domestic requirements of local people who are directly or indirectly involved in changing the environment in the Cherrapunji spur.

Methods of Investigation

Survey methods used to investigate the problems of land degradation and ecorestoration of Cherrapunji area are as follows.

(1) A geomorphic survey was conducted in Cherrapunji area at R.F. 1:25,000 scale for preparation of general geomorphological maps (Starkel and Singh 2004). As the areal extent of the study area is not very large, the

geomorphic mapping was done at RP.. 1:5,000 scale to analysis and interpret the landscape characteristics in detail for the description of runoff conditions of the study area.

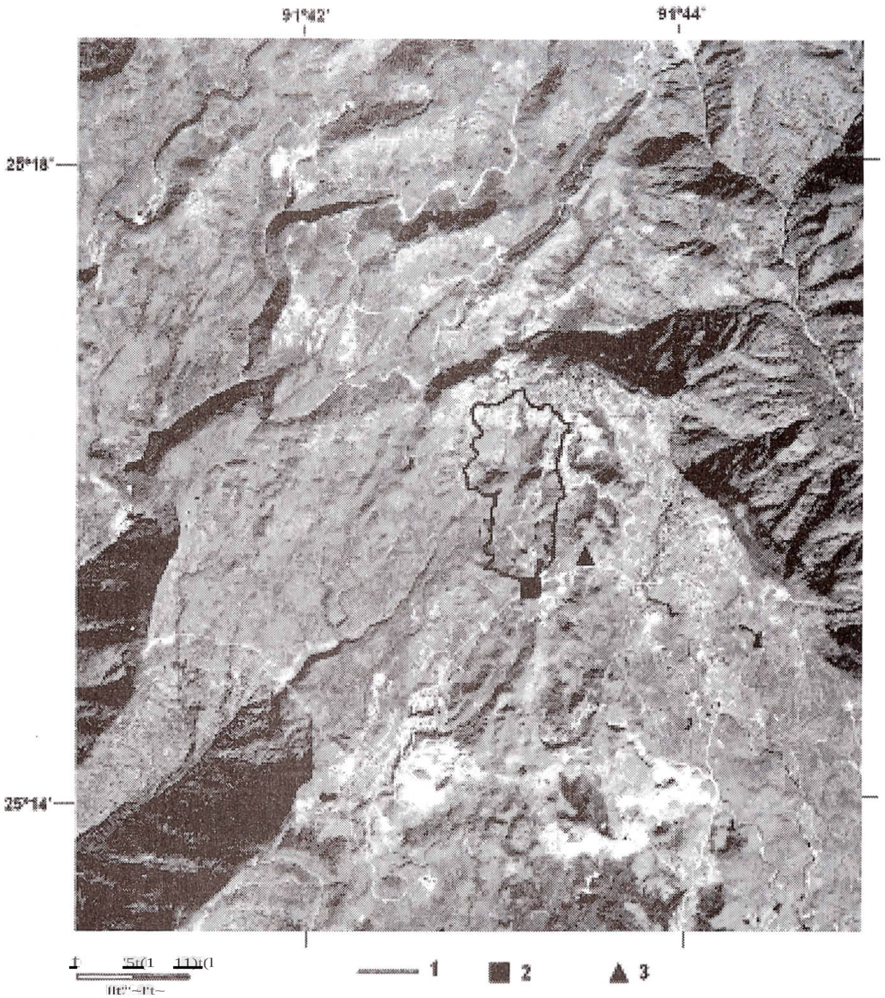
(2) Soil survey was conducted and soil samples were collected during the visit of Polish Scientists in the month of September 2005 (Prokop 2007). An investigation of soil texture was done in the soil laboratory of the Department of Geomorphology and Hydrology of Uplands, Polish Academy of Sciences, Krakow. The detail soil map of Cherrapunji was prepared by combining the soil maps prepared at a scales of RF. 1:50,000 covering part of the Cherrapunji spur (Nair et al. 2005) with a part of soil map prepared by the Regional Office of the National Bureau of Soil Survey and Land Use Planning (NBSS&LUP) at R F. 1:250,000 for the Meghalaya state (Agriculture and Soil Division 1987). Soil resource inventories were later supplemented by visual interpretation of remote sensing satellite data (Landsat 7 ETM+2002), toposheets, geological maps, along with extensive field survey and laboratory analysis.

(3) Vegetation survey of the Central part of Cherrapunji spur was conducted during December 2005 with the help of Yogendra Kumar, Department of Botany, North Eastern Hill University, Shillong following landscape criteria of the collection of vegetation samples to study plant formation and dominant plant species. This survey would provide the comparison of the topo-sequences and topo-features with vegetal cover which is also thought to be useful in preparing ecorestoration strategy. Vegetation samples would provide a sound base for the detailed analysis and determination of £1oristic composition. The areas of different vegetation were compared with topographic features and soil properties to find out the basic characteristics of vegetal cover.

(4) Hourly weather statistics have been generated at Cherrapunji station by installing an Automatic Weather Monitoring System manufactured by Virtual Scientific Products, Roorkee (India) with 512KB EPROM logger memory, S second per week clock accuracy and 5.0 percent accuracy of rain gauge recording at its full range and wind speed resolution of 0.1 m/ s (Photo-l).. The SEBA pluviometer is reinforced long life dry battery cell working up to 6-8 months. Memory card of 512KB was used to make the registration of rainfall up to 15,000 mm in a single stretch (Photo-2). The records were collected twice a year using a lap top for downloading rainfall data. The rainfall data were summed up at hourly interval of time to analyze the rainstorm characteristics.

(5) In order to study the water discharge and runoff, a watershed of small size of about 103.4 ha was chosen that is located in the Southern slope of Cherrapunji ridge representing the typical environmental conditions for the runoff in response to landscape function of the Cherrapunji spur (Fig.-1.6). Of course, it is a new watershed. In the earlier phase of landscape study, the watershed of 20 ha was chosen what is very close to the new one. The shift of watershed was necessary because of increasing population pressure in the earlier one which influenced the hydrograph pattern tremendously. The Automatic Stage-gauge manufactured by the same company was installed at the mouth of the watershed. Hourly data of discharge rate were generated with the help of Conversion of recorded level gauge data by fitting 'rating curve' of the 'base variable and power constant'. For the selected watershed, the rating curve follows the form as:

Q = 4.2831 (h)116521 where Q= discharge rate $(111^{3}/5)$ and h= water head.



N.B.: Dark colour of the image shows the dense forests and white shades represent establishments, settlements, roads and quarries; 1. Watershed boundary, 2. Water level gauge site, 3. Site of AWS

Source: Cartosat-I Image October 2007, NRSA Hyderabad

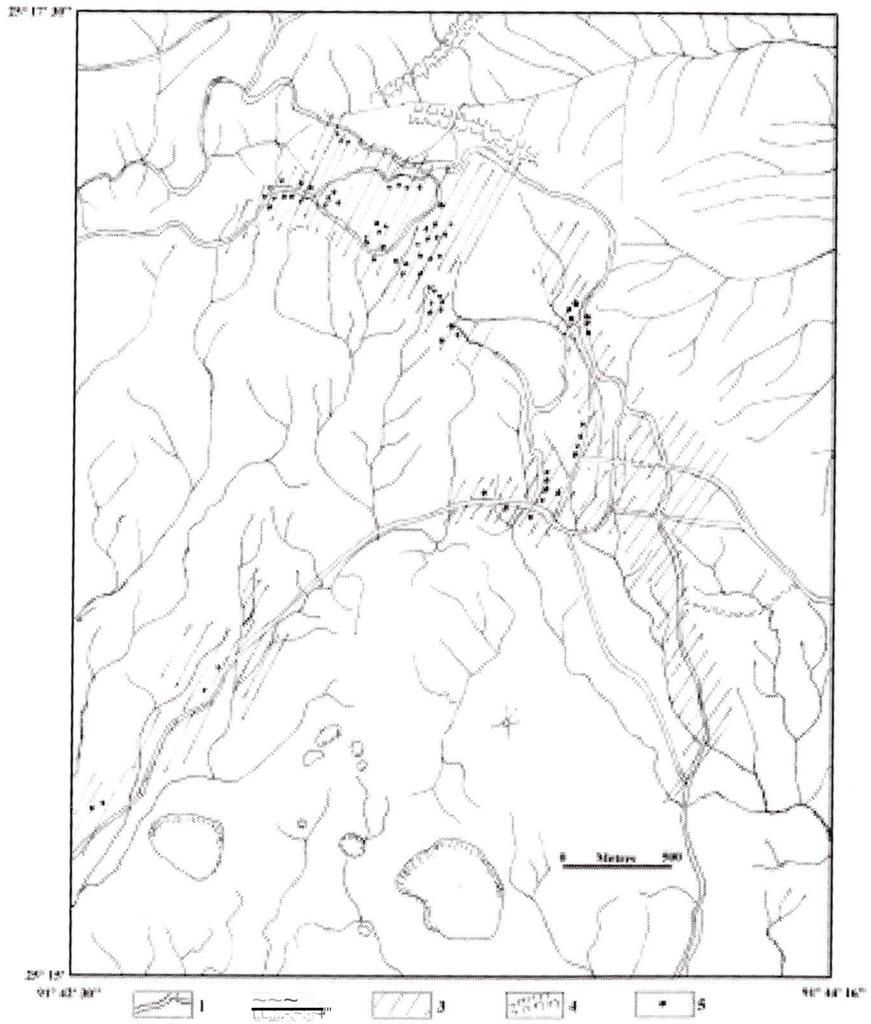
Fig-1.6: Surroundings of Um-u-lah Watershed near Cherrapunji Town

(6) The analysis of change in the pattern of land use/land cover in the Cherrapunji Spur (of an area of about 53 sq. km.) was pursued by deriving land use /land cover statistics from Survey of India Topo sheets of R.F. 1:63,360

scale for the year 1910 and also of R.F. 1:50,000 for the year 2002. The concerned statistics for the year 2002 at same scale were derived from Landsat 7 ETM+ multispectral satellite imagery, NRSA Hyderabad. The maps were created in GIS (ILWIS) environment to generate land use / land cover statistics. Visual interpretation technique was used for land cover mapping for the above mentioned three different years. The increase or decrease the areas in such land cover classes were obtained by intersecting and generating the matrices of land use / land cover changes for different years. Cartosat-I orthorectified satellite images of 2.5 m resolution scene of October 2007 were used to interpret the location of study area as well as other maps. The marginal areas of biological degradation were traced out with the help of this geocoded satellite data.

(7) Since integrated approach of ecorestoration of degraded landscape of Cherrapunji area was adopted for pursuing the present study, a socio-economic household survey was conducted in the month of November-December 2005 by the team members to assess the domestic need of population residing in the area and to analyze the effect of anthropogenic forces on land degradation and their ways and means of utilising natural resources. The survey was conducted by adopting stratified-random method of household survey based on the household size, demographic structure and socio-economic status of the households (HH). Such parameters of the HH would help in assessing the family requirements of water and fuel which are directly concerned with land degradation. Selection of localities was done keeping in mind the criteria as domestic consumption of households, concentration of population and accessibility of households from stream and forest (Fig.- 1.7). A number of 10 localities were surveyed by selecting 74 households

with population of 461 persons (3.65% to the total population) (See Table-1.1 and Appendix-I).



1= Roads, 2= Streams, 3= Settlements, 4= Bluffs, 5= Sample Households

Fig.- 1.7: Location of Sample Households for Socio-Economic Survey

Table-l.l
Name of Sample Localities, Number of HH Surveyed and Surveyed Population

Name of Locality	No.ofHH	Total Family Members	Average Family Size (persons)
Kutmadan	4	26	6
Pdeng Shnong	4	30	8
Khlieh Shnong	11	74	7
Paham Sohmen	4	20	5
Nongsawlia	3	15	5
Sait Sohpen	5	19	4
Maw-ki-syiem	22	138	6
Nongrim	4	29	7
Maraikaphon	13	91	7
Mawmluh	4	19	5
Total	74	461	6

Conducting physical as well as sodo-economic surveys in Cherrapunji area for the assessment of water, soil and forest resources was the main task of the investigation. However, the functions of landscape and its impact on natural resources were also studied in the spatial perspectives of landscape. Such material is arranged in the proceeding Chapters of the Volume.

2

Water Circulation and Availability of Water

Roman Soja
Leszek Starkel
Surendra Singh

Introduction

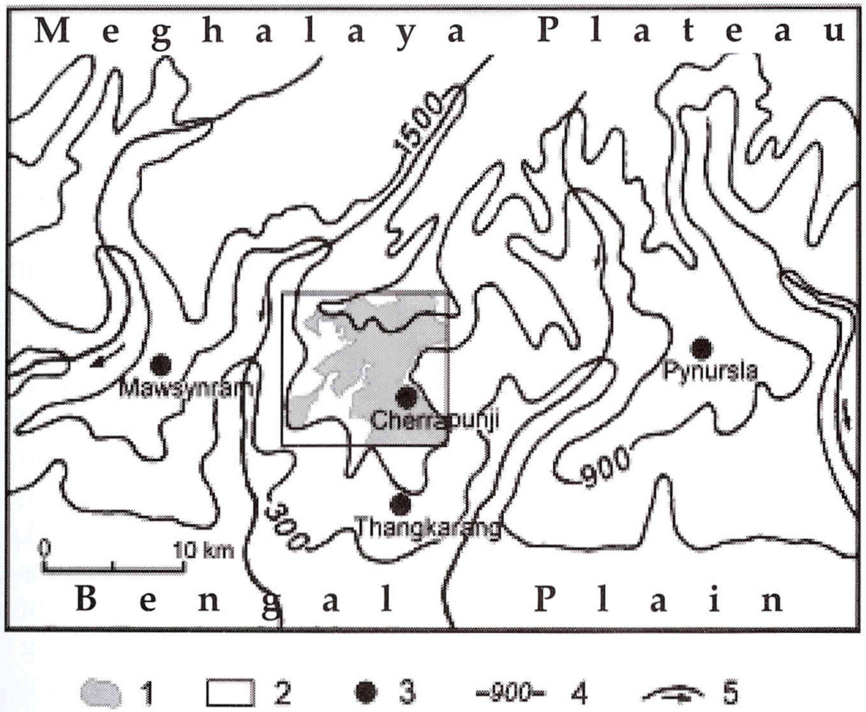
Assessment of water available in the form of surface flow and sub-surface flow is an important dimension in studying the ecosystem functions. The environmental quality which is a social priority,and the development of ecosystem and its functioning especially in such extremely humid areas where ecosystems are threatened by extreme weather conditions, are major issues of land degradation. The seasonal and regional variations of available runoff, its quality for the development of biodiversity, the rainfall runoff relationships, rainstorm patterns that produce runoff and change the land fertility due to extreme atmospheric conditions, are major aspects to be studied in the context of water circulation in environment..

Rainfall Characteristics *Roman Soja, Leszek Starkel*

Distributional pattern of rainfall and its trends over time are important attributes which influence directly and/ or indirectly the functions of landscape. These aspects of circulation of water (hydrological cycle and its action in different geo-ecosystems) need detail description. The rainfall seasonality in Cherrapunji follows m~nsoonal climatic pattern with distinct rainy summers and dry wmters. The mean annual rainfall totals during summer monsoon exc~ed sometimes 11/000 mm. Four months (June to September) whIch are part of monsoon season receives more than three-fourth share of the total annual rainfall. This share reaches in some years upto 90 percent in the extremely wet years at temporal scale of ra~nfall distribution. A significant temporal variability of annual ramfall of about 17/380 mm at Cherrapunji station has been observed ranging from a minimum of 6/283mm to a maximum of 23/663 mm (Soja 2004). However, the general trend of annual rainfall of about 100 years (1903- 2001) shows that there is slow increase in annual rainfall totals at an constant rate of 15.5 mm per year dUring first half of the century with less temporal fluctuation, while the rate of rainfall increase has been recorded fairly high (that is 43.6 mm per year) with more fluctuation during the las~.half of the twentieth century (Soja and Singh 2004). ProbabIlIty of the occurrences of heavy annual rainfall totals has less chances and *vice versa.* For example, the annual rainfall of 19/372 mm and above has only one chance of Occurrence during the century, while the rainfall of 14/797 mm has a probability of 10 percent occurrences during the same period of time.

Areal differences in the micro-relief features and variation in slope gradients in the Southern part of Meghalaya plateau, where Cherrapunji spur is located, is a major cause of spatial variation in humid air masses (Horel et al. 1989/ Matsumoto 1988/ 1992/ O/Hare, 1997). On the isohyetal map of Meghalaya plateau, the area of Cherrapunji spur and its surroundings are shown under the categories of heavy annual rainfall of more than 11/000 mm (Singh 1996/2007). However, there is a record spatial variation in the annual rainfall within this area of most humid condition. Collecting continuously rainfall records of monsoon season of the four rain gauge stations installed on E-W profile of Cherrapunji spur (Mawsynram 1,420 m a.s.l., Cherrapunji 1/320 m and Pynursla 1/340 m a.s.l.) and of two stations on its N-S transect

(Cherrapunji and Thangkharang 850 m a.s.l.), the spatial pattern of rainfall are described in the following manner (Fig.-2.1).



1. Cherrapunji Spur, 2. Undulating topography, 3. Rain gauge stations, 4. Contours (in m) 5. Streams

Fig.-2.1: Location of Rainfall Gauge Stations

It is observed that the wind speed and its direction are the major causes in spatial variations in the rainfall pattern across the micro-relief features of Cherrapunji spur. On the days of heavy rain during the monsoon season, it was observed from the rainfall statistics collected for two days of the on-set monsoon, that were 23rd and 24th June 2006/ a significant variability in daily rainfall was recorded because of change in wind directions. On the 23rd June 2006 when wind was blowing S - SW direction with a normal speed of 15 m/ s/ Mawsynram received the highest rain of the day (382 mm) followed by Cherrapunji (222 mm) and Pynursla (307 mm). On the next day when wind direction was observed changing as SE - NW, the station Pynursla received the highest daily rainfall (122 mm) followed by Cherrapunji (107 mm) and Mawsynram (64 mm). Thus, wind direction and its speed direct the wet air masses towards deep canyons across river valleys, facilitate them to rise along canyon edges and prepare them for the process of condensation. Pynursla being located on flat hills receives 20 to 30 percent less rainfall during rainstorms. The rainfall pattern on N-S transect of Cherrapunji spur is predominantly controlled by orographic effects as stated by Singh (2007).It is evident from the collected data that Thangkharang receives much lesser annual rainfall than Cherrapunji because of its location in the lower elevations in the valley. Such observations are based on the conditions of a few days and may not be generalised the results. However, there are more specific features of rainfall pattern and its seasonality which influences hydrological cycle of this area:

1. Pre-monsoon season (mid March to late May): It is characterised mainly by low intensity rains with occasional heavy downpours reaching even up to 300 mm per day. There is a significant rainfall variation ranging from 100 mm to 1,000 mm during the season.
2. The 'on-set of monsoon' period (late May to June): The rain falls in this period at an average depth of 1,500 mm for several days (Fig.-2.2).
3. The wet summer season (July to September): The daily rain fall has significant fluctuation in the season. For instance, during four months of wet summer in the year 2006, rainfall was calculated an average of more than 100 mm per day a record of 28 days. A duration of 5-days of very heavy rainfall within the same span of time of 28 days, an average rainfall of 300 mm per day was observed with the highest record of 3,017 mm of rain in 4-days continuous storm. Significant monsoon breaks were also seen during the season. More details of micro-weather features would be described separately in proceeding paragraphs of this Chapter..

4. The transitional season of Post- monsoon (September to November): T.t1e occasional rainstorms of shorter duration especially in the month of October have been experienced with the start of dry winter. Soils become fully saturated and retain water for dry season.

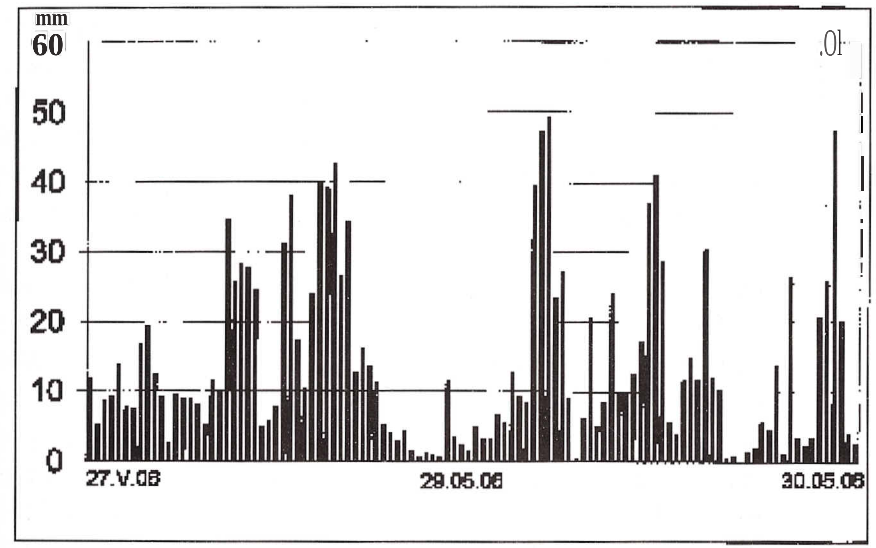


Fig.-2.2: Distribution of Hourly Rainfall at Cherrapunji

Hydro-meteorological Characteristics of Rainy Season

Surendra Singh

The hydro-meteorological features of Cherrapunji area were studied in detailed by taking in to account daily rainfall statistics of 13 years (1986-1998)and hourly weather data of monsoon period of the recent year 2007.The following rain storm patters are to emerge.

(a) The long duration rain storms (more than 8-days), though they are few in number, follow a normal pattern with their peak of 620 mm per day, while short duration storms (2-days) are more in number but they produce an average rainfall depth of about 364 mm per storm with its intensity of 132 mm per day at Cherrapunji station (Singh and Syiemlieh 2001).

(b) A significant amount of rainfall (5,210 mm, i.e., nearly a half of the amount of average annual total) was precipitated during intensive rainfall period of 65 days (about two months duration) in the monsoon season (16th July to 18th September 2007). This amounts to an average rain of 84 mm per day during the period of intensive rainfall. The distribution of rainy days during theintensive rainfall period which was arranged by taking in to account an increasing series of their class- intervals, shows a logarithamic increase in the concentration of rainfall. The highest concentration of rainfall (about a half amount of the total rainfall of the intensive rainfall period, i.e., 55.5 percent) is recorded in excessively stormy rainy days when rainfall intersity ranges from 200 mm/ day up to 500 mm/ day. This rainfall amount of 55.5 percent is precipitated in only 12.3 percent time duration of total duration of 65 days. It means that the concentration of rainfall in this distribution is recorded in few days (Fig.-2.3 and Table- 2.1). Temporal variation of rainfall during this period shows that about 40 percent days of the total number of days of intensive rainfall period (23 days out of total 62) has been considered stormy (the days received rainfall more than 85.9 mm as identified by Singh and Syiemlieh (2001) using' Z' score criterion for Cherrapunjee station (Box-2.1).Such stormy days account for more than 85.0 percent concentration of the total rainfall during this intensive rainfall duration of 65 days (Fig.-2.3).

(c) The temporal variability of rainfall for a duration of 65 days period of intensive rainstorm occurred during monsoon season in 2007 was observed fairly high as 136.91 percent being higher value of Standard Deviation (109.8 mm per day) than the mean (80.2 mm of daily rainfall) of the distribution of daily rainfall. It shows greater fluctuation of rainfall during the extreme events. Three types of distribution of excessive rainfall are noticed for the extremely stormy events.

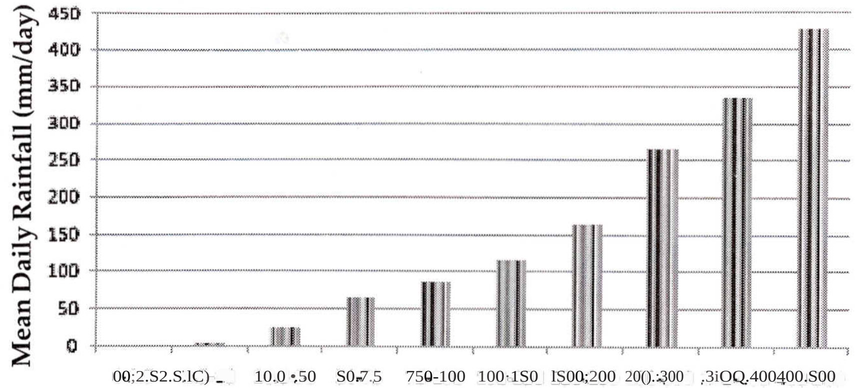


Fig.-2.3: Concentration of Rain in Different Rainfall Classes

Table-2.1
Frequency Distribution of Rainy Days (65 days; 16 July -18 September 2007)

Rainfall Class (mm)	No. of days		Total rainfall (mm)	Concentration of rainfall (%)	Mean daily rain (mm/day)
	Total	%			
Dry day (0.0 - 2.5)	18	27.69	7.0	0.13	0.39
Normal (2.5-10.0)	7	10.77	31.6	0.61	4.15
Wet (10.0-50.0)	11	16.92	281.6	5.40	25.60
Very Wet (50.0-75.0)	6	9.23	388.8	7.46	64.80
Slight Stormy (75.0-100.0)	5	7.70	428.6	8.22	85.72
Stormy (100.0-150.0)	6	9.23	690.1	13.24	115.01
Very Stormy (150.0-200.0)	3	4.16	488.6	9.38	162.86
Excessively Stormy (200.0-300.0)	3	4.16	792.4	15.21	264.13
Very Excessively Stormy (300.0-400.0)	5	7.69	1674.1	32.13	334.82
Extremely Stormy (400.0-500.0)	1	1.53	428.0	8.21	428.00
Total	65	100.00	5210.8	100	80.16

(d) Three major and one minor but significantly heavy rainstorms of different durations and intensities have been identified by following the criteria given by Singh and Syiemlieh (2001) (Fig.-2.4 and Box-2.1). Following this criterion developed for identification of the severity of storms occurring at Cherrapunji station, the intensive rainfall period of 65 days starting from 16th July 2007 has been studied for characterising the duration, intensity and pattern of rainstorms as given below:

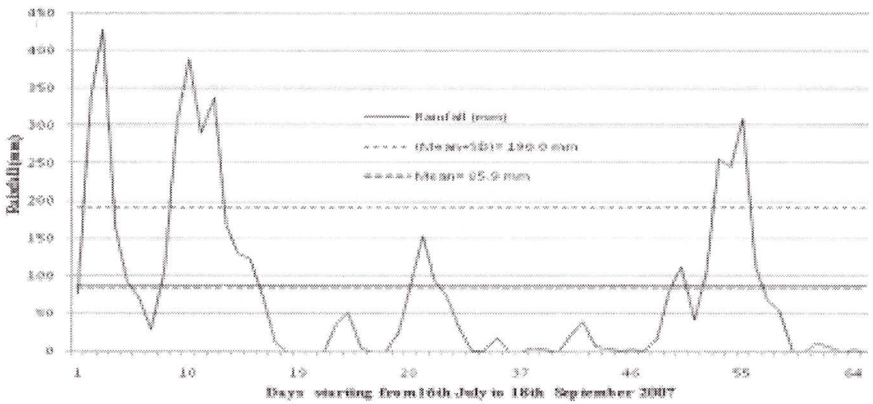


Fig.- 2.4: Extreme Events of Rainstorms during Intensive Rainfall Period of 65 Days in Monsoon Season 2007

(i) Longer duration rainstorms have higher fluctuations with moderate intensity and *vice-versa.* However, the greater severity of rainstorms is observed during the period when monsoon starts in the month of July.

(ii) In the distribution of hourly rainfall of four identified rainstorms, a short duration of 97 hrs rainstorm occurred at the starting of monsoon season in the middle of July 2007, supplied more than 1,000 mm depth of rain with high average intensity of 10.5 mm/hr. . It followed 'two-peaked' normal distribution with its severe intensity of 52.2 mm/hr at its peak time. The rate of increase of rainfall intensity was recorded 1.41 mm/hr on rising side of the storm. On the other hand, the storm event of the September month had long duration of 207 hrs with its moderate mean of 6.6 mm/hr, and higher temporal fluctuations (CV= 109.1%). It had an intensity of 36 mm/hr at its peak time which occurred in the last part of the storm (Table-2.2 and Fig.-2.5).

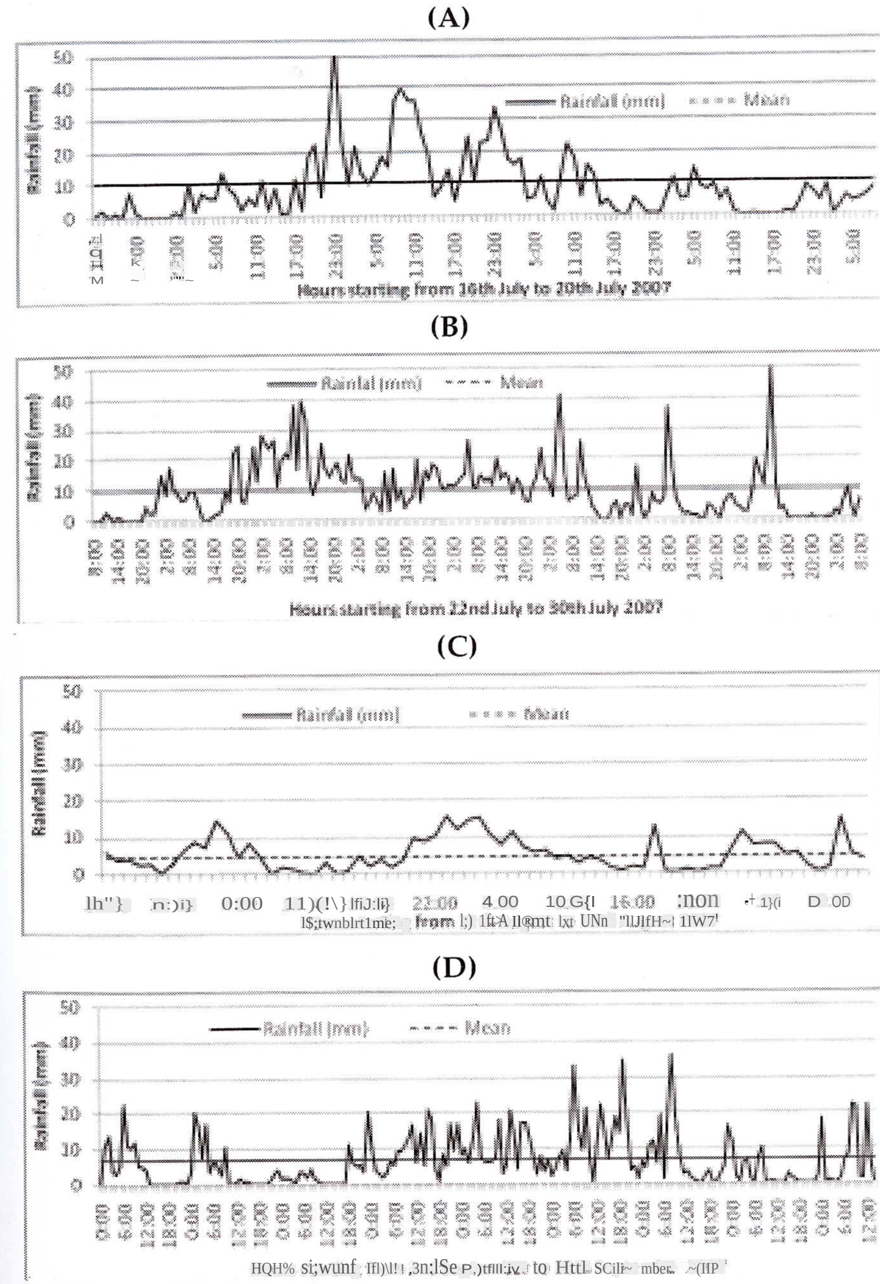


Fig. -2.5: Rainfall Patterns of Four Identified Rainstorms of Different Durations (A) 97 hrs in mid July, (B) 185hrs during late July, (C) 91 hrs in August and (D) 207 hrs in September 2007

Table-2.2
Characteristic Features of Identified Rainstorms at Cherrapunji

Duration in hrs (Period of Time)	Total rainfall (mm)	Variations in Rainfall Intensity			Intensity at peak time (mm/hr)	Duration until peak reaches (hr)	Ratio of peak duration	Rate of rising rainstorm (mm/hr)
		Mean (mm/hr)	SD (mm/hr)	CV (%)				
1	2	3	4	5	6	7	8	9
97 (11:00; 16th July to11:00; 20th July07)	1019.5	10.5	10.4	99.04	52.2	37	0.3814	1,41
185 (21:00; 22nd July toI4:00; 30th July 07)	1828.0	9.9	9.1	91.92	49.6	108	0.5837	0,46
91 (16:00; 12 August tol0:00; 16th August 07)	421.4	4.6	4.2	91.30	15.4	32	0.3516	0,48
207(00:00;3'd September to 14:00; 11th September 07)	1382.0	6.6	7.2	109.10	36.0	153	0.7319	0.23

N.B. :(1) Coefficient of Variability (CV%) = [(SO 1Mean)*100) where 50= Standard Deviation.
(2) Ratio of Peak duration (col 8) = (duration until peak *timel* total storm duration) that is (col 7/Col 1)
(3) Rate of rising rainstorm (col 9) = (col 6/col 7)

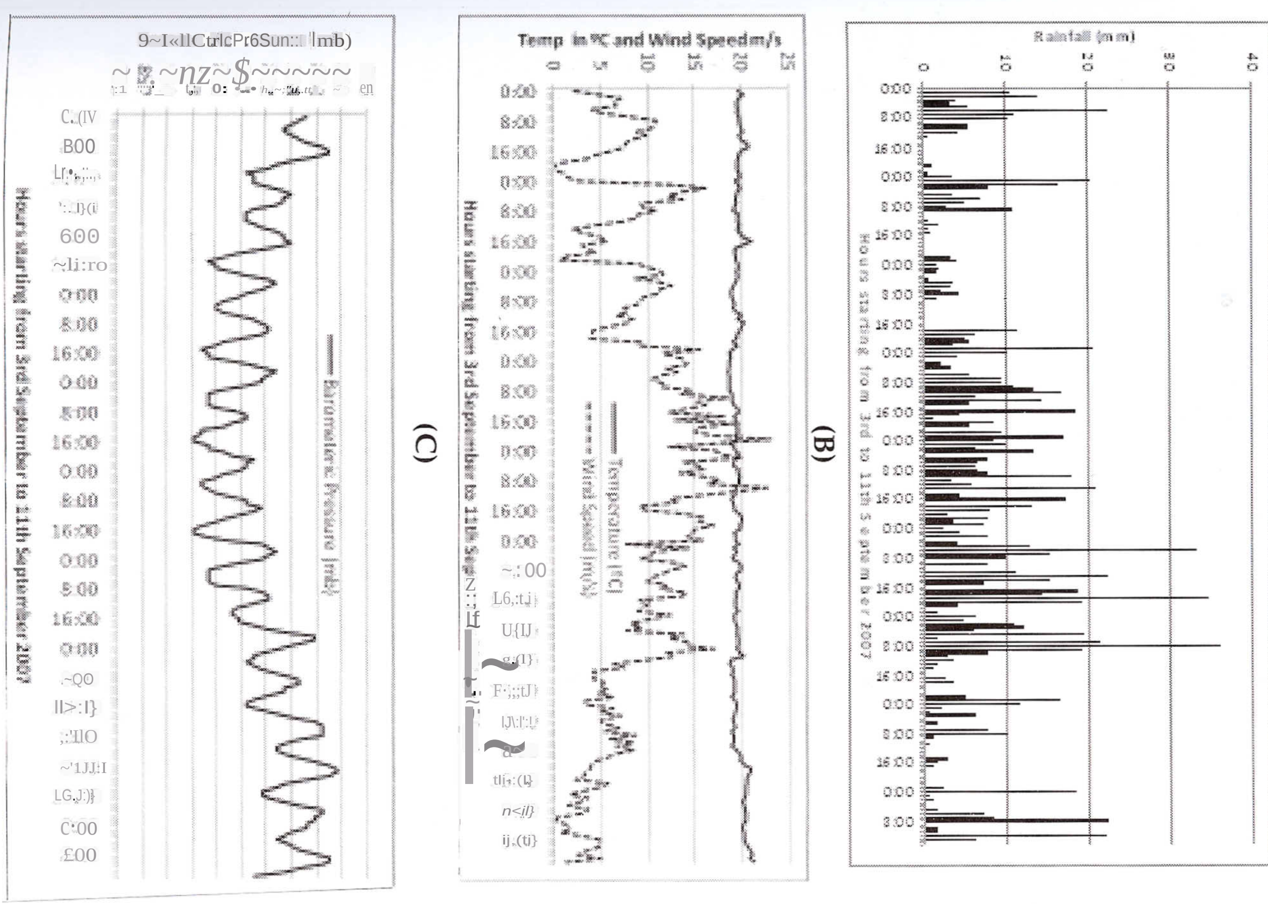


Fig.-2.6: Comparison of (A) Rainfall Pattern with (B) Pattern of Wind Speed and Air Temperature and (C) Air Pressure for Long Duration Rainstorm (3-11 September 2007)

(iii) An hourly pattern of this long duration rainstorm occurred in the month of September 2007 was negatively related to hourly pattern of wind speed and atmospheric air pressure while temperature became constant. During the peak time of rainstorm (after 127 hrs from starting the storm), wind speed was recorded 10 to 15 m/ s sometimes more than 20 m/ s with low atmospheric pressure of 860 mb while air temperature of 19.5°C was recorded. It means that the hours of low pressure with slow speed of wind have intensive rainfall during the peak time of storms (Fig.- 2.6). This is only the example showing causes of rain in relation to the atmospheric conditions. It may not be considered as general a rule for which long period of time data is needed.

Box-2.1: Criteria of Identifying Rainstorm of Different Intensity and Duration at Cherrapunji

Considering the definition given by Indian Meteorological Department (IMD) for the wet days for general Indian weather conditions as a day is considered rainy day when it receives an amount of rainfall equal to or more than 2.5 mm, the applicable criteria for identifying stormy days for the extreme rainy weather of Cherrapunji area is dependent on the Daily Average Effective Rainfall (DAER) as developed and adopted by Singh and Syiemlieh (2001). It is based on two parameters of rainfall distribution: (i) the mean rain per rainy day of the year (X*) and its fluctuation which is measured by calculation of its Standard Deviation (SO) and (ii) coefficient of variation (CV= ratio of SD with X*). After transforring rainfall amount of considered wet days (Xi) of the year(s) into Standard Scores (Z) as

$$Z= \{(Xi- X^*)/SD\},$$

the days above mean rainfall when Z= 0 with daily rainfall of 80.12 mm (that is based on 13 years of daily rainfall data of Cherrapunji station from 1986 to 1998) are considered as normal wet days. The range of positive Z values have been classified in the following categories:

Class	Standard Score (Z)	Category of daily rainfall (mm)
1. Wet days	0.0-0.05	80.12-85.88
2. Stormy	0.05-0.50	85.88-137.78
3. Heavy Stormy	0.50-1.50	137.78-253.11
4. Very Heavy Stormy	1.50-2.50	253.11-368.45
5. Extremely Heavy Stormy	2.50 above	368.45 above

Trends of Water-budget Parameters:

In order to understand the temporal trend and available runoff and its use, the estimation of potential evapotranspiration (PET) which is one of the important parameters of water-budget equation, is required. Quantity and depth of Runoff (Ra), changes in soil moisture storage due to infiltration (~ST) and rainfall (P) are other parameters of this equation as

$$P= PET + \sim ST + Ra.$$

The nature and characteristics of hydrological regimes, seasonality of runoff deficit/ surplus and runoff yield of land surface are main dimensions which are associated with the assessment of PET. It becomes more important parameter especially for humid tropical environment of this area where a significant share of total annual water is lost through evapotransiration specially in the North-Eastern part of the country (Singh 1999).

(a) The Measurement:

In spite of available different equations of the estimation of potential evapotranspiration, the trends of daily PET and soil moisture availability were estimated adopting Thornthwaite and Mather (T-M) procedure of water-budget estimation which is simply temperature based and is ideal for assessment of PET in Tropical environments (Box-2.2).

The statistics of temperature (TQC), rainfall (P) as variables and water storage capacity of soil (STm) as a constant are used to operate the T-M procedure. In order to use this procedure of discriminating the parameters of water budget such as PET, ~ST and Ra, the trends of these parameters have been analysed to understand the weather conditions for survival of plants, plants growth rate and also the functioning of ecosystems.

(b) The Daily Trends of Water-budget Parameters:

Daily data of temperature and rainfall for one year (January-December 2008) were used with consideration of maximum water storage (Le, field) capacity of 92.00 mm as estimated earlier elsewhere by Singh (1996) and National Bureau of Soil Survey and L.and Use Planning (NBSS&LUP),Jorhat based on thickness, poroslty an~ textural properties of soils of Cherrapunji area (it V'as over e~tlmated by Froehlich (2004) as 180 mm by conducting fIeld expenments). The T-M procedure was applied for estimation of daily PET and resultantly the other parameters of water-budget.

(i) In extremely humid tropical environment of Cherrapunji spur where daily average value of heat index was recorded moderate with comparatively less fluctuation (9.195 ± 2.586, i.e., unitless) due to moderate mean annual temperature of 21.5°C ± 4.0°C, a total amount which was potentially evapotranspired was estimated 1,565.0 mm, that was calculated 19.78 percent to total annual rainfall. However ratio of actual evapotransiration to total rainfall was calculated 18.48 percent (Table-2.3).

(ii) The degree of variability was significantly higher in the daily trend of rainfall whereas trends of effective rainfall (potential evaI:0transiration subtracting from total rainfall) becomes mucn more fluctuating (CV= 216.62%). There were least occurrences of rainfall during the dry winter (November-February) with significantly high PET fl~ctuations ~hat added the degree of rainfall variability in thIs area. HIgher degree of variability in daily rainfall during rainy season (May-September) was observed due to its greater range from 2 mm to 357 mm rainfall of a day of extensive rainstorm.

(iii) Wit~ fully saturated root zone soils after its recharge during Apnl to September (about 156 consecutive days, that is nearly a ~alf of t~e year), the months of July and August were notIced as mtensive runoff period with its higher degree of fluctuation. Daily runoff varies from 5 mm to 356 mm in the rainy season. On the other hand, deficient so~l moisture conditions were observed in the dry winter (FIg-2.7). However, an amount of 87.00 mm of water in the soil (field capacity minus deficient water) always retained in the soils of Cherrapunji. It feeds water to streams

even during dry winter time. As a result, main streams are perennial and springs are regular in this area.

Table-2.3

Mean, Standard Deviation and Coefficient of Variability of Hydrological Parameters (2007-2008)

Parameters	Annual Total/ Average	Standard Deviation	Coefficient of Variation (%)
1. Mean Temperature (TQC)	21,45	4.06	18.39
2. Total Rainfall (mm)	7912.60	45.25	209.91
3. Mean Heat Index (unitless)	9.19	2.58	28.12
4. Total Potential evapotransiration (mm)	1565.10	1,91	44.78
5. Total Effective rainfall (P-PET) (mm)	6347.50	45.24	261,62
6. Available average soil moisture (mm)	80.72	17,58	21,77
7. Total Actual Evapotransiration (mm)	1462.39	2.01	50.60
8. Share of Actual Evapotranspiration (%)	18,48	-	-
9. Total Runoff (mm)	7131,85	59,49	116,79
10. Runoff Ratio (%)	90.13	-	-

(iv) A substantial amount of rainfall (i.e., more than 90%) runs off due to heavy rains, less retention capacity of soil and season variations in rainfall trend. However, rainfall-runoff relationship in Cherrapunji area obviously states that runoff has perfectly direct relationship with rainfall with its very high coefficient (r=0.9996). Runoff depth has complete agreement of rainfall intensity following its linear form as runoff increases at unitary rate with its insignificant standard error of 1.63 mm (Fig.-2.8). However, after recharge of soil moisture runoff starts when rainfall of 5.16 mm is precipitated in a day as interception a= -5.16 in the rainfall-runoff equation, that depends on the maximum capacity of soil moisture storage and shows its recharge. Owing to less capacity of soil recharge, it appears to be less fluctuation in changes in soil storage(~ST). High runoff ratio is thus observed in such conditions of weak aquifer and groundwater storage. Similar result of rainfall-runoff relationship was also drawn somewhere else (Singh 2007: 34-39).

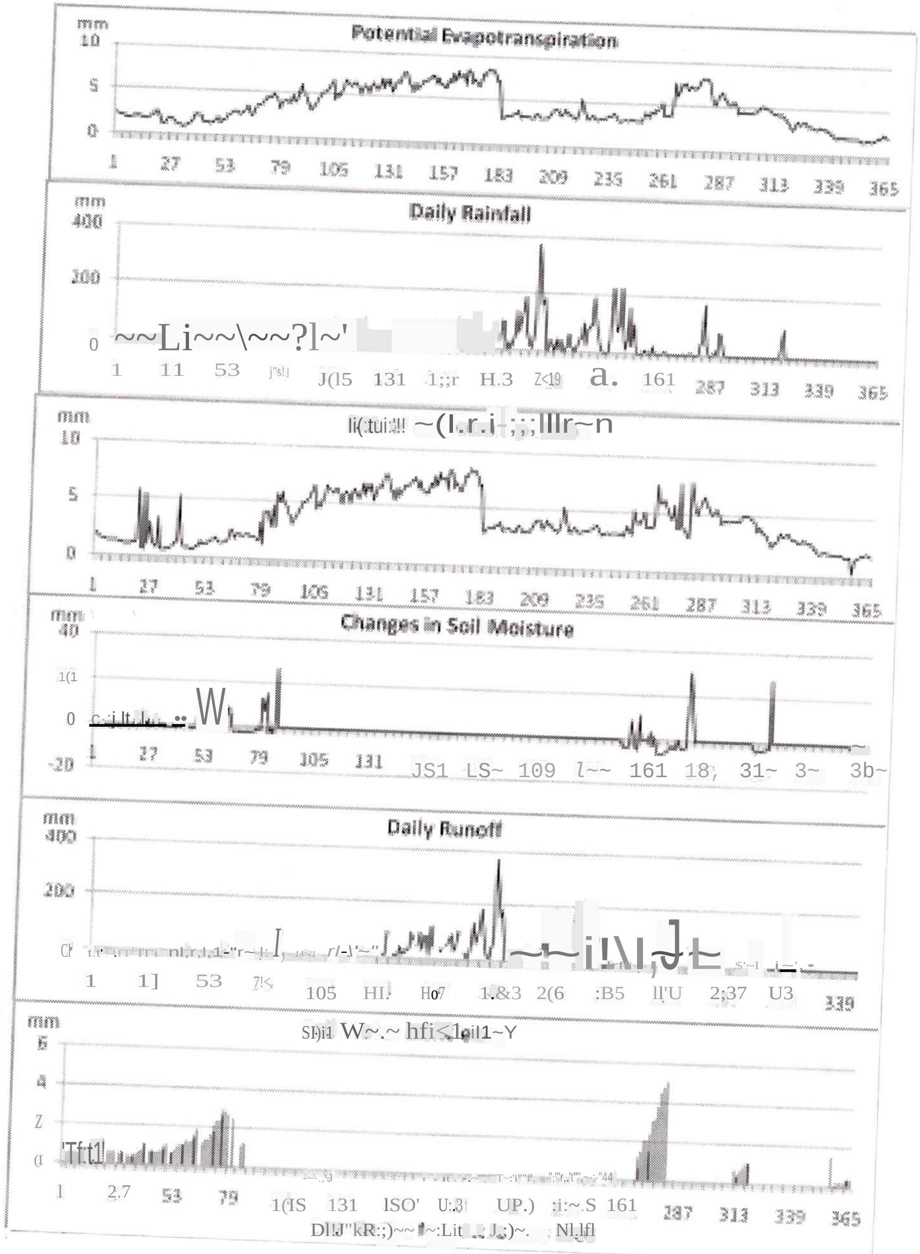


Fig.-2.7: Trends of Daily Rainfall, Potential Eva[illegible] Evapotranspiration, Changes in Soil Moisture, Runoff and Soil [illegible] at Cherrapunji

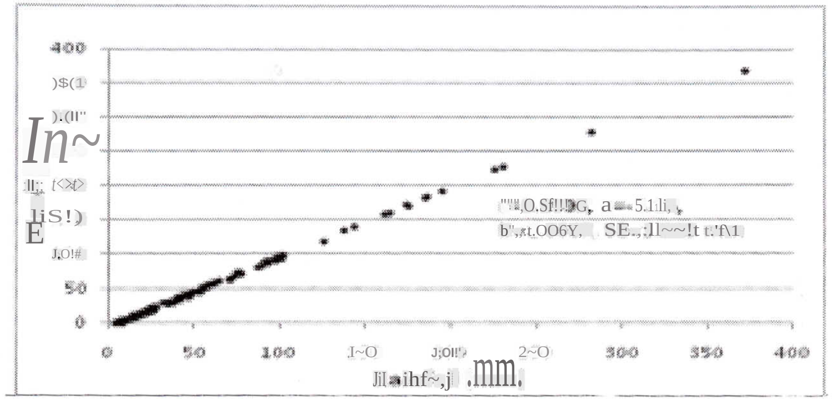


Fig.- 2.8: Rainfall- Runoff Relationship at Cherrapunji (based on daily data)

(v) Since PET is direct function of temperature and solar radiation, it does not follow any form with rainfall. Coefficient of correlation between PET and rainfall is therefore too weak (r=.0255) to perform any relationship (Fig. -2.9).

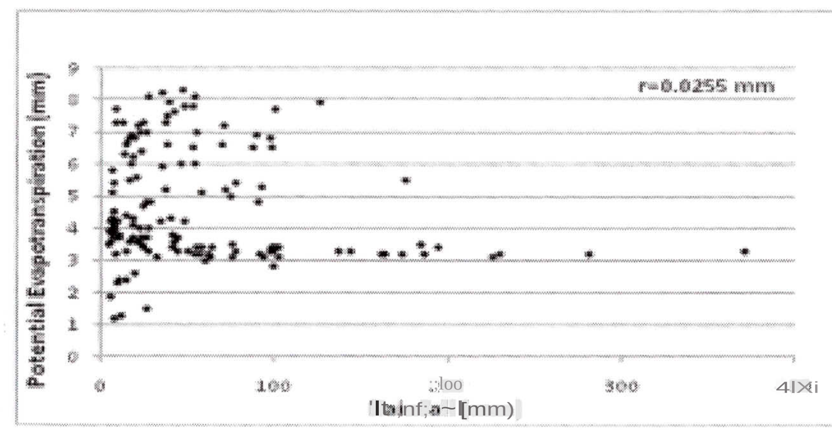


Fig.-2.9: Rainfall - Potential Evapotranspiration Relationship (based on Daily data)

Undoubtedly, the excessive rainfall and the seasonal trend of heavy rainstorms have implicit impact on land surface to generate more runoff available for its use but it is in the form of flash floods with its extremely high temporal variability. Analysing water circulation in the environment of Cherrapunji area through the use of water budget equation, the study of rainfall runoff relationship is found ideal. It is obvious to conclude that the temporal variability of rainstorms is fairly high and more fluctuating during the extreme rainstorm events.

In general, the daily trend of potential evapotranspiration (which is more controlled by temperature) and relative humidity conditions of the atmosphere, do not follow rainfall pattern, so they do not have significant co-relationship with each other. Contrary to it, the runoff is implicitly regulated by the surface conditions and the availability of water in sub surface soils.

Box-2.2: Computation of Daily Potential (or Reference) Evapotranspiration (ETo)

ETo is the loss over land surface with no limitation of water, so it becomes the function of atmospheric demand which depends largely on the net radiation energy to convert liquid water to vapour, the humidity gradient in the lower atmosphere that influence the rate of conversion of water to vapour, the wind speed which helps to circulate evaporised air from one place/area to the other ones and the surface roughness that creates spatial variability in the vaporization process as well as in the distribution of vapourised air (Beven 2001). Such factors were included in different forms in different equations for the estimation of ETo as given below:

Contd...

Slno.	Method	Equation	Basis and requirement for computation
1	Simple Annual sine curve Penman (1956)	ETo = ET [1 + sine ((360i/365) -90}]H = Rn-A-G-SH = C +eAE	Based on mean daily Evapotranspiration and energy balance (incoming and outgoing radiation) Referred by Colder et a1. (1983) and saturated deficit Referred by Papadakes (1975) and Beven (2001)
2	Thornthwaite and Mather	HI = L(Tm/ 5)1514and ETo = 1.6[(10Tm/HI)~ where a = 67.8*10-8* (HI)3 -7.71 *10-S*(HI)Z +0.01792* HI +0.4923	Thermal Efficiency Critarian Temperature-based computation of heat index given by Thornthwaite (1948) quoted from Patel and Endang (2003)
3	Papadakis (1957)	ETo = 5.625(e_{ma} - e_{avg})	Saturation deficit based
4	Hargreaves - Samani (1982)	ETo = 1/ A[O.0023Rn (Tm+ 17.8)(Tx-Tn)5]	Radiation balance and temperature variation
5	Panman-Monteith (FAO-56)	ETo = (Ro+Ao) where Ro =((1 / A)t(Rn-G)}/ *{MY(l* +0.34U_Z)} Ao = [Y{900/ (Tm+273)}U_Z(e_a-e_d)}J Simplified from: ETo= {.408t(Rn-G}+{Y*(900/Tm+ 273)*Uz_2*(e_a-ed)} / {MY(1+0.34U_Z)}	Referred from Allen et a1. (1998) quoted from Kothari et a1. (2007) Data required on net radiation, air temperature, humidity and wind speed and calculation of two resistance terms:- (i) Ro= radiation term (ii) Ao= aerodynamic term which is an expression of roughness of canopy and canopy (surface) resistance Le. effective parameter of surface for movement of vapour.
6	Turc - Wendling (DVWK 1996)	ETo = ({2.3(Tm+22)} / ((Tm+ 123)* (O.71(R_n/ A)+0.72)}J	Heat flux and temperature variation referred by Dirnbock & Grabherr (2000)

Contd ...

Notations:

ETo= Reference Evapotranspiration (mm Day-I)

HI= Heat index

i= days of the year

ET= mean daily potential Evapotranspiration (mm)

H= Total energy available for evaporation (wm^{-2})

Rn= Net radiation (wm^{-2})(about 500 wm^{-2} in noon summer)

A= Heat loss due to advection (wm^{-2})(about 1wm^{-2})

G= Heat loss due to ground (G=owm^{-2})

S= energy flux in physical and biological storage (15wm^{-2} in a day time and 3wm^{-2} in night time)

C= Sensible heat flux

AE=Latent heat flux, A = constant of latent heat of vaporization, i.e. $2.47*10^6$ J Kg-I(Le. 1/1l.=00408 MJKg-I)and E= Evapotranspiration rate(Kg-2S-I=mmS-I)

Tm= mean daily temperature (0C);Tm= $(T_x-T_n)/2$

ema=saturated vapour process at maximum temperature T_x

e_{mj}•saturated vapour pressure at minimum temperature T_n

e_a= saturated vapour pressure at temperature T(hpa); ea = 6.1121e(I7.s02t!(240.97+t) as given by Buck (1981).

E_{avg}= Average saturated vapour pressure of the day or month whatever unit of time is taken (hpa)

T_x= Maximum daily temperature (0C)

T_n= Minimum daily temperature (0C)

U_2= Average daily wind speed (m/s)

Do= Slope of saturation vapour pressure curve (hpa °CI); Do={4099(e_a)/ (T_n+237.3?}

y= Psychometric constant (in hpa/°C); y= 0.00163~/A where 1/1l= 00408 MJKg-Iand ~= barometric pressure (in hpa) as a function of elevation (El) in meters, ~= 101.3{(293-0.0065 El)/ 29W[26]

e_d= saturation vapour pressure (hpa) at mean dew point temperature from daily maximum (TJ and minimum (T_n)in °C and maximum (RHJ and minimum (RH_n) relative humidity (%) as:

e_d= [{(e_{ma}RHn/100)+(emtRH) 1OO)}2]

It is to be noted that Panman-Monteith (FAO-56) combination equation is based on energy balance and heat index due to radiation but complicated to use and even not practically applicable for the present case when required statistics are not available. The most simple temperature -based equation given by Thornthwaite and Mather (1957) predicts better results as it is initially based on water balance equation. The T-M procedural steps of estimating ETo are given below:

Contd...

Step-I: Estimation of annual Heat Index (HI, unitless) using 'base variable and power constant' equation as

$$HI= \Sigma(T^0C/5)^{1.514}, \quad i= 1,2,3,\dots,12 \text{ months}$$

Step- 11:(a) Direct empirical calculation of ETa in respect to temperature can be made by using following formula as suggested by Thornthwaite (1948)

$$ET_O=1.6[(10*TOC/HI)a]$$

Where a is constant but calculated as curve-linear third degree (i. e., 4-terms) polynomial function of Heat Index as

$$a= 67.5*10^{-5}(HI)^3-7.71*10^{-5}(HI)^2+ 0.01792(HI) +0.4923$$

(b) For sake of simplification, ETo calculations can be done by using Conversion Tables prepared by Thornthwaite and Mather (1957) applying above given formula. Unadjusted ETo is a conversion factor of Heat Index. Location specific day duration is considered as weight to Unadjusted ETo to estimate finally the ETo values. In this connection, an algorithm was made by Singh (2005) for the purpose of ET_O calculation for biophysically based crop yield estimation.

Step-Ill: Accumulation Potential Water Loss (AccLoss) that is the function of water demand when ETo exceeds rainfall (P). Soil moisture storage changes accordingly. This step of calculation AccLoss is essentially required for further procedure for the estimation of soil moisture (ST). AccLoss is accummulated difference of (P- ET_O) over time when this value is -ve and the atmospheric demand is filled partially by available soil moisture especially in root zone surface soil.

Step-IV: Estimation of soil moisture (ST) which changes according to variation in AccLoss computed as

$$ST= STm (e) [Acc(P-E)/STm]$$

Where STm= maximum storage (or field) capacity of root zone soil, DoST=variation in ST during the time of AccLoss. Note that the -ve term in the power function indicates soil moisture discharge and +ve term shows soil moisture recharge to the level of STm. This exponential function for estimation of soil moisture storage has been intensively used for cop planning (Kothari et a1, 2007).

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S~ep-V: The estimation of actual evapotranspiration (ETa) is now the dIfferential function of P and i1.ST at the time of AccLoss, otherwise ETa = ETa when P exceeds ETa' It can be written as

ETa = (P- i1.ST) at AccLoss time.

Otherwise

ETa = ETo when P > ETo.

The entire hydrological regime and runoff availability can be expressed and estimated through the use of this procedure.

3

Watershed Characteristics and Hydrograph Pattern

Surendra Singh

The Location and Extent of Um-u-Iah Watershed

The Um-u-lah watershed of an area of about 103.4 ha selected for the purpose is located between *25°17'00"N* latitude and *91°42'30"E* longitude. The South facing watershed lying over the Southern slopes of Cherrapunji rolling topography starts from the ridge to the confluence of stream near the bridge located on Cherrapunji-Mawmluh road. This area receives excessive rainfall (annual average of 11, 490 mm). This part of spur acts as local water divide and generate many local streams (Fig.-1.6 in earlier Chapter-I). The Um-u-lah watershed has elevations varying from 1,300 m a.s.l. (at its mouth) to 1,450 m a.s.l. (at the top of the ridge where Cherrapunji town is located).

Watershed Land surface Characteristics

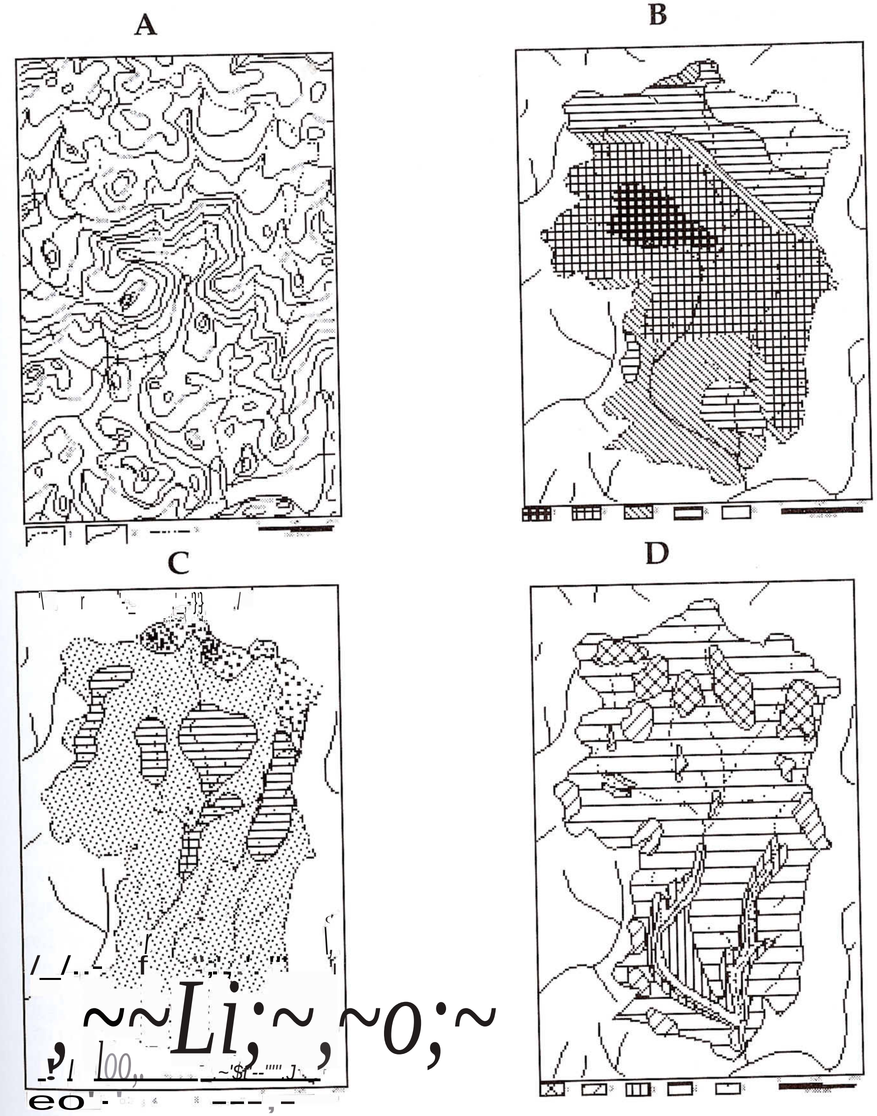
Water resource assessment and its management are largely dependent on the uniqueness of landscape of this area that is dominated by fragile grass ecosystem (Photo-3) with different hydrological regimes and large seasonal variations in runoff. Runoff yield is thus a direct function of the rainstorm events and hydrological behaviour of varying elements of landscape. A small watershed of about 103.4 ha size, namely the Um-u-lah located

Table-3.t
Relief, Soil and Land Use Conditions of Um-u-Iah watershed (Cherrapunji)

Parameters	Unit	Value	%
Total area	ha	103.4	-
A. Relief			
1. Elevation maximum	m	1,450	-
2. Elevation minimum	m	1,300	-
3. Relative height	m	150	-
4. Average slope	%	8.79	-
5. Drainage length	m	7,914	-
6. Drainage density	m/ha	76.54	-
B. Area under different soil types			
1. Alluvial sandy loam	ha	-	-
2. Deep red sandy loam (2-6m)	ha	8.43	8.15
3. Shallow gravelly (O-lm)	ha	72,80	70,41
4. Stony	ha	6.13	5.93
5. Thick (0-30 cm)	ha	6.77	6,55
6. Very thick soil with stony and edge surface	ha	9.26	8.96
C. Area under different Land Use/Land Cover			
1. Forest	ha	16.68	16.13
2. Grasses	ha	79.32	76.71
3. Shifting (Jhum) cultivation	ha	-	-
4. Permanent cultivation	ha	-	-
5. Plantation	ha	-	-
6. Roads and settlements	ha	7.40	7.16
7. Quarry	ha	-	-

Source: Self Surveyed in February 2007

on the Southern slopes of about its 8.8 percent gradient with variety of soils and land use / land cover, has been chosen for the purpose of estimating runoff yield and for detail hydro graph analysis (Photo-4). Selected watershed varies in its elevation from its mouth elevated at 1,300 m a.s.l. (towards Cherra-Mawmluh road) to the highest elevation of 1,450 m at which the southern extension of Cherrapunji town (Cherra settler houses) is located. Watershed is dominated by shallow gravelly soils, with grass of 30-50 cm tall on the hill slopes and barren with rocky near the edges of streams in its lower part (Table-3.1, Fig-3.1 A through 3.1 D) (Photo-5). Flat hill tops located in the Northern side of watershed are under settlements with isolated ponds located along the



A . Contours (in m, contour interval in 10 m), B. Slope (in degrees, 1. Strong 18° above, 2. Moderately Strong 15-18°, 3. Moderate 12-15°, 4.Moderate Undulating 9~12°,5. Gentle-undulating <9°), C. Soil Types (1. Deep soil with less slope, 2. Thick with stony edge surface, 3. Thick soil, 4. Shallow soil with grass dominance, 5.Very shallow with rocky exposed), D. Land cover /land use (1. Forests. 2. Grass lands, 3. Settlements, 4. Water bodies and Ponds, 5. Roads, 6. Unmetalled roads)

Fig. 3.t: Land Surface Characteristics of Um-u-Iah Watershed (Prepared under DST- Sponsored Project by Skhemborlang Marwien)

unmetalled road passing through the watershed. This road connects Cherrapunji town to Mawmluh road which intensifies an impact of human activities on the watershed ecosystem. There are a few patches of dense forests in the upper part of the watershed with comparatively thick soils. Soils are moist and, resultantly, main streams produce water even in dry winters (Soja et al. 2004). In such conditions of different hydrologic regime, the rainfall-runoff relationships and trend of runoff yield become most remarkable and exciting.

Rainfall-Runoff Relationship

On account of weak monitoring system of hydrological events in the area, much detailed phenomenal analysis of rainfall runoff relationship could not be pursued in the earlier part of this Chapter.. The runoff analysis in the earlier part was based on water budget technique for daily rainfall and temperature data. However, some preliminary observations of rainfall-runoff relationship were highlighted by Soja et al. (2004) in collecting manually daily runoff / discharge data of the specific watershed for two hydrological regimes (the saturated landscape conditions of 8-days rainstorm of June 2002 and the recharge period of November 1999) and observed a very high degree of fluctuations of discharge and water level. It shows low rate of infiltration and less water holding capacity of soils. After installation of regular automatic monitoring system of gauge-level for calculation of discharge rate and weather conditions that has been generating data at hourly time unit for the last one and a half years, a detail investigation of rainfall-runoff relationship was carried out for different hydrological regimes.

Having been investigated hourly pattern of rainstorms of three different hydrological regimes: (a) the 6-days storm of early monsoon period when there are surface-flow and sub-surface recharge conditions of land surface, (b) the 5-days storm of late monsoon period of excessive surface flow and sub-surface discharge and (c) the 4-days storm of the recession period and base-flow contribution to runoff, a detailed analysis of hydrological system working in the selected watershed was carried and silent

features of rainfall relationship of the system were highlighted in the following manner.

(1) A heavy 6-days storm of early monsoon occurred in mid July 2007 with a total rainfall of 1,250 mm yielded 851 thousand cubic meters of water with its total depth of 823.42 mm following runoff ratio of 0.659. The average runoff yield of 6.588 m^3 per ha per mm of rainfall was calculated for the storm. It appears that about one-third share of water was either got evapo-transpirated or infiltrated during soil recharge period. On the other hand during the late monsoon time of fully saturated soil conditions, a heavy rainstorm of almost same magnitude and intensity produced 978.36 thousand cubic metres of water (runoff yield of 13.433 m^3 per ha per mm of rainfall) with very high runoff ratio. It shows that there is a condition of complete saturation excess and intensive outflow from sub-surface soil which added sub-surface flow directly to the surface runoff. The third case that represents recession period of 159.8 mm rainstorm produced only 54.46 cubic meters of water because of soil recharge. The average daily discharge of 0.158 m^3/s is due to contribution of base flow to runoff during this recession period. (Table- 3.2)

(2) Runoff depth which is lower than the rainfall intensity in most of the time during early monsoon period, increases as rainstorm becomes longer and stronger. It is obvious that after the condition of soil moisture recharge, runoff trend follows the rainfall fluctuations. However, higher the intensity of rainfall, the greater is the runoff volume that reduces the time of concentration of running off water towards mouth of the watershed. As a result, runoff trend crosses sometimes the rainfall curve showing excessive runoff during heavy rainstorm as the case of rainstorms occurred during late monsoon saturation-excess regime and produced 1,425 thousand cubic metres of water in 103.4 ha. of watershed in 123 hours (Fig-3.2).

Table-3.2

Runoff Yield of the Selected Rainstorms in watershed: (a) 6-days storm of early Monsoon Recharge Period (17-22 July 2007) with 15 mm rainfall in 5-days during Antecedent Moisture Conditions, (b) 5-days Storm of late Monsoon Discharge Period (5-10 September 2007) with fully saturated AMC and (c) 4-days Dry Season Rainfall Recession Period.

Date	Rainfall (mm)	Discharge Rate Q (m^3/s)	Daily RO yield *** (thousand m^3/day)	Runoff Depth+ (mm)	Runoff Ratio
(a) 6-days earlyMonsoon Rainstorm (144 hrs duration) starting from 17.07.07 at 1:00 hrs					
17 July 07	235.0	1.81±6.20	156.64	151.51	0.6447
18 July 07	476.4	4.88±7.73	421.67	407.81	0.8560
19 July 07	209.6	1.81±1.97	156.85	151.72	0.7238
20 July 07	103.8	.67±1.13	57.60	55.71	0.5367
21 July 07	174.0	.53±.92	45.54	44.05	0.2532
22 July 07	49.0	.15±.63	13.07	12.63	0.2577
Total	1249.8	-	851.37	823.42	-
Hourly Mean	8.68	1.64±2.35	5.91	5.72	0.6588
(b) 5-days late Monsoon rainstorms (123 hrs duration starting from 5.9.07 at 00.00 hrs)					
5 Sep 07*	51.6	0.75±1.22	32.39	31.42	0.6098
6 Sep 07	219.4	2.55±3.53	221.18	213.91	0.9765
7 Sep 07	234.8	2.66±3.71	230.63	223.05	0.9532
8 Sep 07	289.8	3.09±4.82	266.97	258.21	0.8906
9 Sep 07	181.8	2.06±3.23	178.15	172.38	0.9482
10 Sep 07**	48.0	0.91±1.64	49.03	47.42	0.9880
Total	1025.4	-	978.36	946.31	-
Hourly Mean	8.33	2.00±3.29	7.95	7.69	0.9232
(c) 4-days dry season rain (96 hrs duration starting from 15.11.07 at 00:00 hrs)					
15 Nov 07	59.8	.0400±.06	3.461	3.340	0.0558
16 Nov 07	99.0	.5889±1.53	50.881	49.208	0.4971
17 Nov 07	00.8	.0007±.001	0.060	0.058	0.0725
18 Nov 07	00.2	.0007±.001	0.060	0.058	0.2900
Total	159.8	-	54.463	52.673	-
Hourly Mean	11.66	.039±.02	0.560	0.550	0.3296

N.B.: * Total/average figures of 12hrs; ** Total/average figures of 15 hrs. ***Daily RO Yield= Discharge*60*60*24; + RO Depth= Q/ A

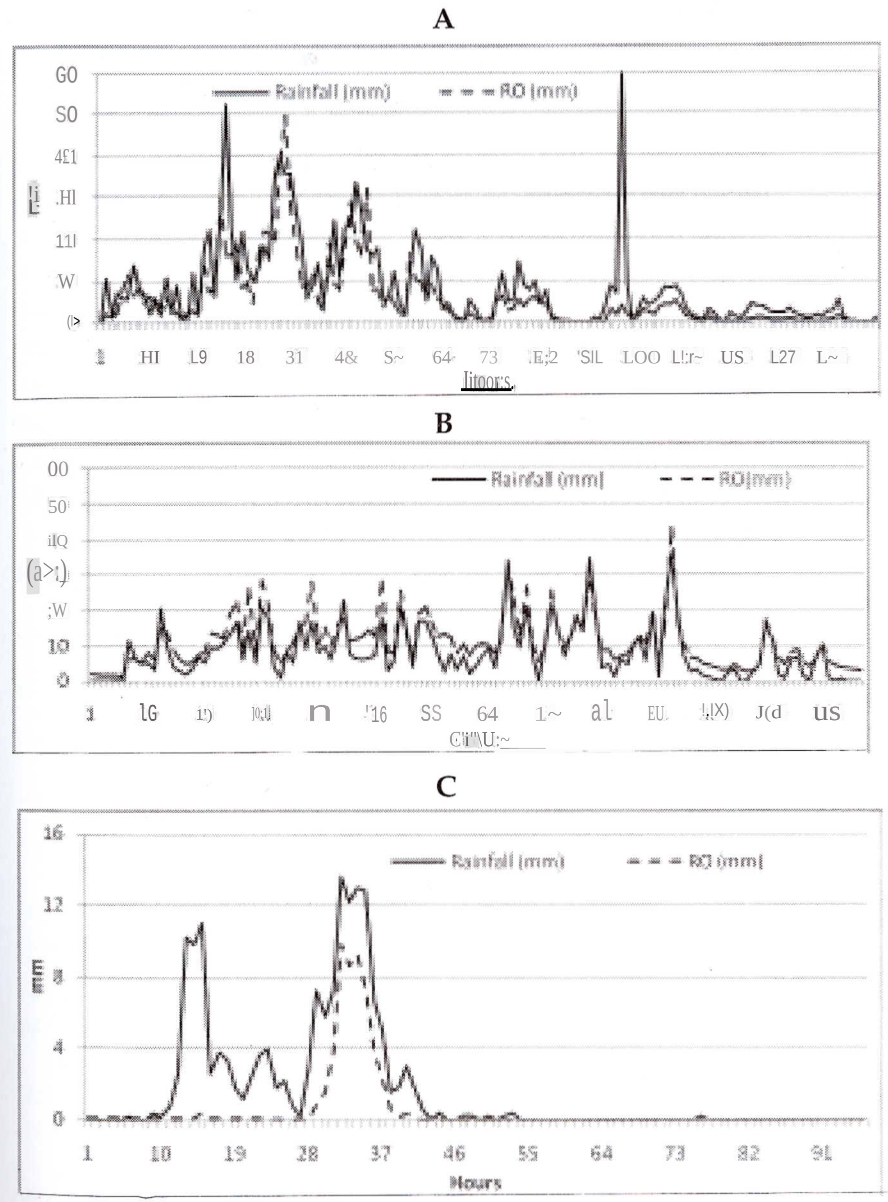


Fig-3.2: Rainfall- Runoff Trends of Three Rainstorms: (A) Early Monsoon 17th JUly 2007 (B) the Late Monsoon 5th September 2007 and (C) the Recession Period 15th November 2007

(3) Runoff depth is recorded higher than rainfall intensity in most of the time during the storm occurred in saturation-excess regime. The sub-surface flow generally has direct impact in the depth, intensity and volume of runoff in watersheds. Runoff trends happen to be more fluctuating rather than rainfall. As a result, runoff ratio is observed some times higher than unity. This is the time of flash flood with its high flow in the watershed. This situation of flash flood occurs only for few hours and again runoff discharge becomes very low. However, runoff depth becomes always lower with very low value of its ratio during the recharge period hydrologic regime which starts from October in this area (Fig.-3.3). Small duration rainstorm with its less intensity occurring during the dry season often fluctuates runoff curve. Most of the share of rainwater acts to increase the soil moisture

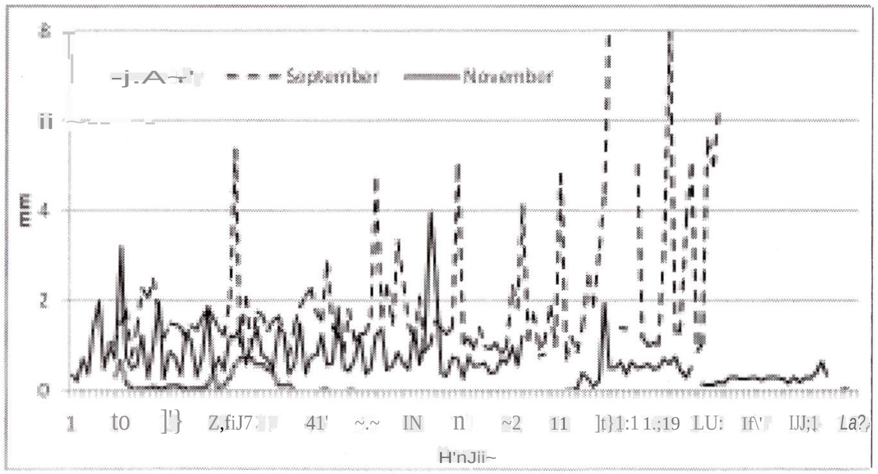


Fig.-3.3: Hourly Trends of Runoff Ratio of three Rainstorms

Concluding Remarks

Average intensity of rainfall during extreme events reached up to 109.00 mm/h at its peak with an average rising rate of 0.63 mm/h in the one-tenth part of the total duration (15-20 hrs) of the

rainstorms. The rainstorms have significantly long durations ranging from 100 to 100 hours in this area.

On account of weak water retention capacity of surface and sub-surface soils, the pattern of daily runoff follows the rainfall patterns. However, runoff yield and runoff ratio which are variable over time, have been observed to raise increasingly fast from early monsoon recharge period (6.588 cubic meter runoff yield produced by 1 ha of land per mm of rainfall in 103.4 ha of watershed with 0.66 runoff ratio during the heavy storm of July 2007) to late monsoon period of excessive discharge (13.43 cubic meter runoff yield produced by 1 ha of land per mm of rainfall in the same watershed with very high runoff ratio that is, 0.923 due to saturation-excess conditions of surface soils). Towards the end of the monsoons, during the month of September, flash floods usually occur in the plains of Bangladesh due to short duration and high intensity rainstorms leading to high discharge. Such dimensions of land-degradation are to be studied separately in the next Chapters.

7

Assessing Water and Fuel Requirements of the People

Surendra Singh
Hiambak Janes Syiemlieh

Introduction

Preceding Chapters of the volume have given emphasis on the characteristic features of hydrological cycle and changes in the soil properties because of excessive and intensive rain and available rock material to be weathered and soils to be leached. Land use / land cover changes and their causes were also interpreted in details. However, it is realised from the changing pattern of land uses that there has been continuously increasing interference of man-dominating activities for the changes of land uses. The requirement of human beings and the efficiency of providing services through ecosystems are main issues that can be addressed in the context of water and fuel requirements of traditional societies living this area for centuries. Thus, the main attention in this Chapter is focussed on the requirement of natural resources for the maintenance of socio-economic status of the population living in this area.

Socio-economic Status of Population

Figures of the Sodo-economic status of population which were gathered by conducting population survey, show that unmarried children who are generally below 18 years of age dominate in the family structure (57.04% to total family size). The children and adolescents account for 29.93 per cent share of total population. Infants (0-5 years) are recorded nearly 10.0 percent in the survey (Table-7.1). It indicates a heavy base age-sex pyramid that shows the water consumption and utility is more towards children and adolescents who use more water for cleanliness the cloths, houses and kitchens and water requires for maintaining kitchen gardens and fruit trees in the courtyard of houses.

Generally, the half of the members of family are accounted for in the primary to middle primary (up to 8th class) levels, while illiterates are nearly 14.5 percent. A small section of family (about 12.2%) is obtained higher education level (graduates and above). However, the percentage share of the population who obtained a level of professional courses is only 1.0 percent. Mainly the workforce of the family is engaged in primary activities like agriculture, horticulture, grass cutting, hunting, mining and quarrying. A major share of workforce is engaged in tertiary activities like petty jobs working on shops, transport activity, marketing because Cherrapunjee is a growing town of this area and the cement factory where the labour force of the surroundings are employed.

Socio-economic status of the surveyed population shows that unmarried children below 18 years of age dominate in the family structure (57%). The children and adolescents account for about 30 percent and adults (19-60 years) about more than half (52%) of the total HH population. Infants (0-5 years) are recorded nearly 10 percent.. The sample population sex ratio is counted 1,075 females per 1,000 males. An age-sex pyramid shows that children's and adolescents' use more water for cleaning clothes and kitchens. The water requirement for maintaining kitchen gardens and trees in the courtyard has also been observed.

Mainly the one- third share of workforce of the HH population was recorded engaged in primary activities like agriculture, horticulture, grass cutting, hunting, mining and quarrying. A major share of about 60 percent of the workforce is engaged in tertiary activities like petty jobs, trade, transport and allied services.

Table-7.1
Social, Demographic and Economic Status of Sample Households (2005)

Items	Total	Percent
Number of Localities Surveyed	10	-
Number of Households	74	-
Total Population included in Household Surveys	461	-
Average Household Size	6	-
(A) Family Structure: Relation with Head of Family		
1. Head of Family	62	13.80
2. Spouse of Head	39	8.82
3. Married Child	4	0.68
4. Spouse of Married Child	9	2.04
5. Un-married Child	263	57.24
6. Others	84	17.42
(B) Demographic Structure		
1. Total Male	222	48.19
2. Total Female	239	51.81
3. Sex Ratio	-	107.51
4. Age Structure		
Infant (0 - 5 years)	43	9.95
Children and Adolescence (6 - 18 years)	138	29.41
Young Adult. (19 - 30 years)	132	28.51
Adult. (31 - 60 years)	107	23.07
Old (60 + years)	41	9.06
(C) Socio-Economic Structure		
1. Educational Status		
1. Non Literate	69	14.48
2. Literate through attending NFEC/ AE	-	
3. TLC	-	-
4. Others	1	0.22
5. Below Primary	42	8.60
6. Primary	97	20.59
7. Middle Primary	77	18.78
8. Secondary	53	11.54
9. Higher Secondary	58	12.67
10. Graduate and above	60	12.22
11. Professional	4	0.90
2. Occupation		
Total	152	
1. Basic Primary	3	2.05
2. Primary	51	34.93
3. Secondary	8	4.79
4. Tertiary	90	58.22

Source: Self-Surveyed

~herrapunjee is a trading centre and growing town and has an Impact on occupational structure of this area.

Pattern of Fuel Requirement

The evaluation of domestic requirement of fuel and water in the family .is a major aspect to understand the interacting nature of ~an wIth the resource use and the provision of ecosystem services m the degraded lands of Cherrapunjee spur. There are two main sources of domes:ic fuel (wood and charcoal) which are directly relate~ ~othe. avaIlable forest and vegetation. The people also use electnCIty, hquefied petroleum gas (LPG) and kerosene as alternative sources of domestic fuel. These sources dominate in the domestic fuel consumption pattern of the families (Fig.- 7.1).

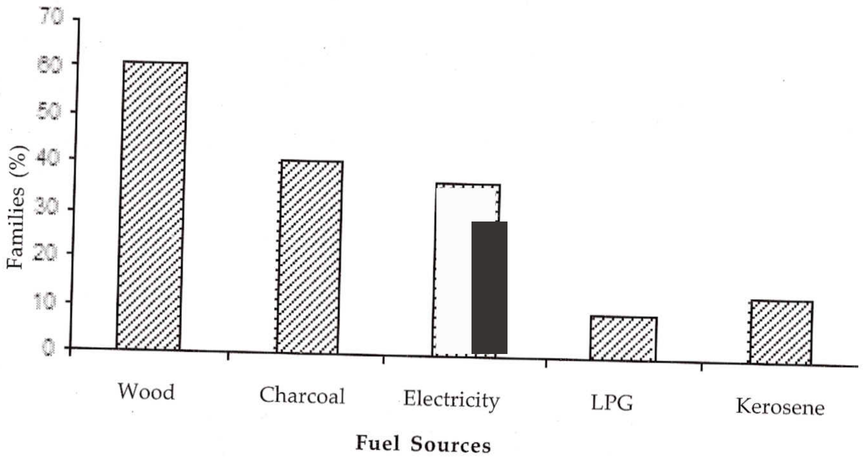


Fig.-7.1: Domestic Fuel Consumption

Converting the source-wise domestic fuel consumption into monetar: te~m.sto understand the share of fuel consumption in the fam~ly, It IS marked that wood is used more in quantity. Con~ertmg the same to per capita fuel consumption, the costs of the fIrewood and charcoal are costlier in its money term but they use th~se tradit~onal s~urces regularly because of their highly accessIble, eaSIly avaIlable and reliable use in the houses

(Table-7.2). They collect firewood from nearby forest places and use it without com.idering its money value.

Table-7.2
Source-wise Consumption of Domestic Fuel

Fuel Source	No. of HHs	Consumption per *capital* day	Price per unit of (Rs)	Consumption (Rs/ person / day)	Fuel source used by HHs (%)
Fire Wood	45	1.45 kg	1.30/kg	1.88	60.81
Charcoal	30	0.330 kg	6.00/kg	1.98	40.54
Electricity	27	369.763 W	*1.421* kW	0.52	36.46
LPG	7	0.007 kg	23.00/kg	0.16	09.46
Kerosene	10	0.027 lit	18.00/lit	4.86	13.51

(a) Causes of Spatial Variations in the Use of Domestic Fuel

Having assigned arbitrary weightings for (a) the different levels of educational status of the HH members as 0.25 for non-literates, 1.0 for Primary level, 2.0 for Secondary 3.0 for Higher Secondary and 5.0 for Graduates and other Professional educational levels and (b) the different occupations performed the surveyed HHs as 1.5 for Primary, 3.0 for Secondary and 5.0 for Tertiary occupations, the composite indices for educational and occupational status of the HH were prepared separately to correlate and statistically treat them as 'independent variables' and traditional fuel sources as ,dependent variables' for the analysis of the understanding the nature of variations in the use of traditional domestic fuel.

An average use of firewood for domestic purpose was counted 1.5-2.5 kg / person/ day while the consumption of charcoal was calculated at 2-3kg/ person/ day. Out of four main sodo-economic attributes, namely, the family size, educational level, occupation and non-workers dependent on the family, it is found that the family size is the most influential attribute for the use of firewood ($R2$ = 0.9405) as well as charcoal ($R2$ = 0.5466). However, there is a moderately increasing rate in the use of firewood (i.e., 0.41kg/ day) and higher increasing rate in the consumption of charcoal (i.e., 0.90 kg/ day) with the increase of one member to the family size (Table-7.3).

Table-7.3

Fir~wood, ~ha~coal and Wate~ Use as Dependent Variables (Y) Regressing with Family Size (X_1), Education (X_2), Occupation (X_3) and Non-Workers' Dependency (X_4)

Regression Parameters	Family Size (X_1)	Edcation Index (X_2)	Occupational Index (X_3)	Non-Workers' Dependency (X_4)
A. Firewood (dof =43, Ymme,n=14.38kg/day/HH)				
Standard Error (SE)	0.9531	5.1697	4.4349	1.4266
Gradient (b)	0.4100 *	0.4695 **	0.2634	0.0903
Coefficient of Determinant (R^2)	0.9405	0.5091	0.2316	0.2552
Coefficient of Correlation (r)	0.9698	0.7135	0.4812	0.5052
B. Charcoal (dof =28, Ymme,n3.40kg/day/HH)				
Standard Error (SE)	2.2702	5.0089	3.7503	0.9898
Gradient (b)	0.8998 **	1.6875	0.7332	0.2547**
Coefficient of Determinant (R^2)	0.4566	0.4655	0.2268	0.3369
Coefficient of Correlation (r)	0.7393	0.6823	0.4762	0.5804
C. Water Use (dof =72, Y_{mean}207.70 lit/day/HH)				
Standard Error (SE)	1.0230	6.5739	5.7631	1.6611
Gradient (b)	0.0284**	0.0248	0.0040	0.0073
Coefficient of Determinant (R^2)	0.8260	0.0809	0.0030	0.1072
Coefficient of Correlation (r)	0.9088	0.2844	0.0548	0.3274

N.B.: * at 0.01 and ** at 0.05 level of significance by using 't' test for two-tailed distribution with two samples of unequal variance, dof=degree of freedom

Education and occupation do not show much effect on the use of traditional sources of fuel. In fact educated people of the society would use modern means of domestic fuel simultaneously with the traditional sources. As a result, the relationship between the use of firewood and education levels as well as charcoal and education levels are noticed insignificantly. It was hypothesized that non-workers dependency on working population in the family (children, teenagers, old and very old persons per unit of adult members) might have influenced the consumption of traditional domestic fuel because more number of non-working people of the family who stay at home and use kitchen services frequently in the day time increase the consumption of traditional domestic fuel. In the present regression analysis, the hypothesis is not significant

for the study area, though the correlationships between the traditional sources of domestic fuel and non-workers dependency are marked positive but insignificant (Table -7.3).

Table-7.4

Effect of Forest Accessibility on Fuel Consumption

Distance from Forest (km)	No.of HH	Domestic Firewood Consumption (kg/ day / HH)
Highly Accessible		
0-0.5	11	22.10
0.5-1.0	11	18.07
Fairly Good Accessible		
1.0-1.5	12	21.00
1.5-2.0	11	19.20
Moderately Accessible		
2.0-2.5	6	6.50
2.5-3.0	6	9.00
Less Accessible		
3.0-3.5	9	8.00
3.5-4.0	5	7.50
Least Accessible		
4.0-4.5	3	7.00

(b) Pattern of Forest Use

Forest is an important source of firewood and charcoal. HHs living in the close vicinity of forests (up to 2.0 km) use fairly higher quantity of fire wood (18-22kg/ day / HH) as domestic fuel (Table-7.4). People collect/ cut wood from the jungle located on valley slopes (excluding sacred groves) for domestic purpose especially in dry winters; carry it on foot from jungle to home every day, for using them in wet summers (Photo-23). This is usu~l w.ork of women in winters. As a result, the fire wood consumption is very high in the areas accessible to forests. After most accessible zone of upto 2 km, the fire wood consumption diminishes mor~ than three times. The HHs living near forests are female dominated with higher degree of dependency of non-working people and less educated. The economy of such HHs is more dependent on forest activities. As a result, wood collection and use it at home for domestic purpose increase the firewood consumption. On the other hand, HHs living far from forest areas and close to road side have higher degree of educational and occupational indices with low dependency ratio and less use of firewood for domestic purpose (7-8 kg/ day /HH) because they would have more interaction of market area of non forest activities.

Domestic Water Consumption

The surveyed central part of the Cherrapunji spur is characterised by the strong water deficit during at least 6-7 months and by heavy pollution even in the uppermost headwater areas. Average estimated annual use of water for domestic purpose in the Cherrapunji area in 2005 was recorded 208 lit/ day per **HH** consisting of an average of 6 persons. It worked out to be 35 lit/ person/ day that is very low at the scale of the use of water for domestic purpose in developed countries (i.e., 120-150lit/person/ day) (c.f. Brassington 1988). There are many causes of lesser use of water for domestic purpose as (i) the effect of seasonality when very less water is available to retain at home from the streams during dry winter, (ii) the social traditions that the members of the households go to the nearby streams to wash clothes and also take bath which reduces the domestic consumption, (iii) the low storage capacity of rain water at home and (iv) the non-use of the modern domestic appliances like flushing lavatories, washing machines, shower baths etc. However, watering the trees and plants in the courtyards is an activity which consumes more water because Khasi community is generally fond of maintaining a small courtyard with flowering plants.

Family size is undoubtedly a main explanatory variable which shows high correlation with the use of water for domestic purpose (r = 0.9088). The rate of water consumption varies with family size. The rate of increase per person is almost 30 lit/ day in the increasing family size.

Pattern of water consumption for domestic purpose is perhaps more influenced by the sources of water availability. Classifying

surveyed HHs as per available source of water, namely, water available at spring, from the stream, by tap and other sources as well, hand pump etc, it is observed that water use is recorded higher (295-327 lit/ day /HH) in the HHs having tap facilities at home or nearby. The consumption of water in the HHs who has been using spring / stream water for domestic purpose, is significantly lower 240-241 lit/ day /HH in the Cherrapunji.. This category of HHs is dominated by females, higher degree of dependency of non-workers with lower degree of education index (Table-7.5).

There are, in fact, prevalence of the effects of two distinct ecological scenarios of the domestic use of fuel and water.. The HHs residing in the forest dominated ecological scenario, use forest firewood as source of domestic fuel and stream/ spring water with its very low consumption. They bring water from the far off streams by their traditional methods of tin containers with bamboo balance. On the other hand, the HHs living far off places from the forests and nearby road side have more mobility and use LPG Gas with less quantity of firewood as a substitute of petroleum gas. They use generally tap water of Public Health Engineering (PHE) department (Photo-24).

Table-7.S
Domestic Water Consumption and Source of Water Availability

Sl. No	Source of Water	No. of HH	Domestic Water Use	
			Lit / day / HH	Lit / person / day
1	Spring	15	240	40
2	Stream	11*	241	35
3	Tap (PHE)	20	295	49
4	Spring and Tap	18	327	47
5	Others	10	225	45

N.B.:*Three out of a total 11 HHs use spring and stream water sources in this category

The people of this area are still highly dependent on the use of traditional source of domestic fuel especially firewood and charcoal which directly affect the eco-restoration of such degraded

·hil~s. Cutting trees for firewood is common primary activity which mcreases the degree of degradation.

Concluding Remarks

1. Low percentage share of workers to the total surveyed population (32.97%) shows a high non-working class dependency (i.e., 2.033). In a scenario of such strong base of adolescents and adults with higher educational levels (where working class of adults is not fully employed), more people including adolescents can be trained for the ecorestoration programme in the area.
2. The people of this area are still highly dependent on the u.se of traditional source of domestic fuel especially fIrewood and charcoal which directly affect the ecorestoration of such degraded hills.
3. Cutting trees for firewood from the fields /jungles is common primary activity which increases the degree of forest degradation.
4. Forest fires and grass burning in the later part of the dry season (February - April) are common practices which increase the ecological degradation.
5. Supply of domestic water from the bigger tanks and pipe leakages diminish the water supply to the households.
6. The extensive mining of limestone in the captive mines of Mawmluh Cherra Cements Limited and the lime kilns surrounding Mawsmai are the major sources of water and air pollution. The use of weathered soils and clays for the purpose of cement manufacturing would hasten the degrading processes this area. Remedial measures of these aspects of land degradation are to be suggested seprately in the next chapter of the volume.

8

Land Degradation and Possibility of Restoration of Natural Resources

Surendra Singh

Leszek Starkel

Introduction

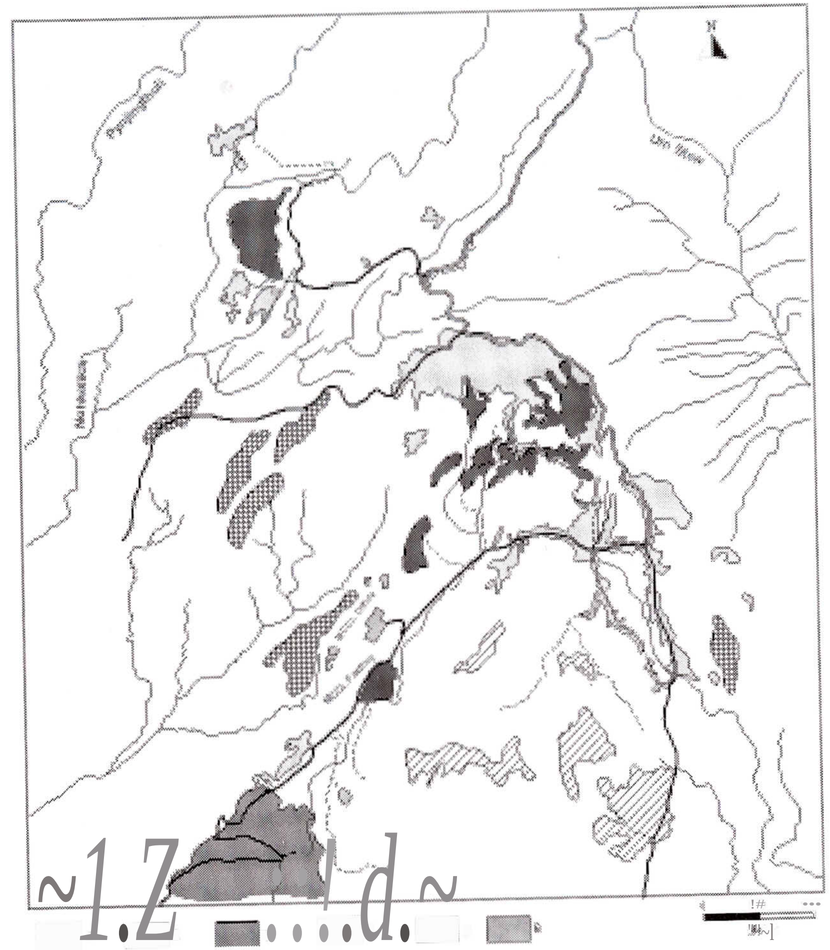
The environmental conditions of Cherrapunji spur on the Meghalaya Plateau are specific and extreme from various points of view. Hummocky relief over horizontally bedded sedimentary rocks (predominantly sandstones) exposed to the highest rainfalls at the global scale with very distinct rainy and dry season underwent even total deforestation in last several centuries.

The effect of that was the acceleration of runoff and soil erosion and formation of new secondary soil profile characterised by stony surface cover overlying thin loamy soil of low permeability and water capacity. The slopes were overgrown by exothermic grasses deeply rooted adapted to long dry season. The density of vegetation cover is permanently reduced by overgrazing, annual burning practices as well as by open cast coal mining connected with removal of upper soil layer with pavement. These practices are against aforestation experiments locally undertaken. In the mean time we observe the population growth and growing demand on water and energy.

Habitat Changes **and** Resource **Depletion**

There are many evidences of stress on land resources and ecosystems in the form of soil degradation, destruction of fragile hill ecosystem as highlighted is the earlier part of the Volume. The habitats of Cherrapunji area are threatened by intensification of quarrying and mining activities, expansion of land use under settlements and roads, exploitation of ecosystem services and changing the gaseous composition of atmosphere through induction of gaseous pollutants because of increasing production capacity of Cherra Cement Factory (Photos-25,26,27). The forest damage survey conducted by the team of scientists during their visits in 2005 and 2006 states that there are declining symptoms of growth of forest ecosystem because the forests of the central part of Cherrapunji spur are under the stress of habitat changes and, consequently, forest trees have been losing gradually their leaves, feeder root - biomass and leaf-aging of needles before time. On the other hand, the seasonal grasses are also under the threat due to disturbances of their natural habitat which is fragile in nature and further has been threatened by the construction of new houses and expansion of roads. Declining grass height, death of small grasses and herbs and resultantly the changes in biomass composition and biodiversity. are the consequences of such changes. The accelerated land degradation discriminates destruction of vegetation and changes in land uses of the area (Fig.-8.1).

Assessment of spatial and temporal changes in land use / land cover pattern and habitat changes is an effective tool for the evaluation of the changes occurring in and the extent of the environmental degradation (Raju and Kumar 2006). Fragility of environment that is based on the extreme physical processes of land, itself restricts the growth of organism in the ecosystem and the human forces add more stress on it. Due to excessive rainfall and its seasonal variability, degradation of natural resource has reached up the extent when ecosystems of this area have adapted lack of fertile soil and reduction of biodiversity. As a result, geo-system produces non-arboreal species in the valley bottoms. In



1 Forests damaged by quarrying, 2. Forests damaged by expansion of settlements, 3: Forests damaged by air pollution, 4.Grasses damaged by grazing and fire,S. Forests and grasses damaged due to soil erosion, 6. Areas under settlements

Source: Surveyed, March 2007

Fig.-8.1: Forest and Grass Land Damages in Cherrapunji Spur

such scenario of weak biotic potential and greater environmental resistance in the hills of Cherrapunji, the plant growth is constant and even the number of plant species and biodiversity have been reduced up to a minimum extent because of limited growth and development of several species (Box-8.1). Both forces of gr~wth processes of plant species are changing over time because of eIther the decrease of biotic potential (owing to decreasing survival rate of plant species in grasslands as well as forest ecosystems in the area as there is fast changes in forest and grass land habitat changes) or increasing anthropogenic stress on physical environment which is already fragile and weak in these extreme humid conditions of landscape. For example, traditional societies, which are in contact with such degraded geo-system and ecosystem for centuries, may help in ecorestoration by alternation of land use practices and adoption of Traditional Ecological Knowledge (TEK) following traditions of the maintenance of secred forests. Traditional Societies may help in plantation and survival of suitable plants for biodiversity development (Photo-28).

Atmospheric Pollution and its Effects on Ecosystem

On account of regular emission of sulphur dioxide and other gaseous pollutants through smoke of Mawmluh Cherra Cements Limited and burning of lime stone in quarries in the lower marginal part of Cherrapunji spur, there is a zone of intensive gas pollutant concentration which cover half of the southern part of the spur including the parts with dense forests located on the slopes of Umiew river and isolated patches of forests including grasslands and small ponds and lakes. These water bodies which supply water to the residents of Cherrapunji town and the adjoining areas. Such gaseous pollutants react in environment with atmospheric moisture to produce acid solution. Acidification of rainfall affects the ecosystems in four ways in this area:

(a) It increases soil leaching and decreases soil pH (reaction) and affects soil productivity which is recorded moderately low. Consequently, the plant growth is also moderate in spite of strong growth components like higher ET-PET ratio, high rate of photosynthesis process and also the higher value of heat Index (Table-8.1).

(b) Acid rainfall seems to affect tree leaves and arrests the growth of young leaves in the forests located in the Western parts of the spur near the factory site and the forests located on the Eastern slopes and Central parts of the spur.

Table-S.l
Monthly ET-PET Ratio and Heat Index at Cherrapunji Station

Months	PET (mm)	ET (mm)	ET/PET	Heat Index (HI)
January	57.70	28.18	0,488	4.95078
Feburary	64.40	47.38	0.736	5.52610
March	74.99	74.99	1,000	6,43450
April	83.64	83.64	1,000	7.17636
May	98.80	98.80	1,000	7.69112
June	104.62	104.62	1,000	8.16046
July	107.15	107.15	1,000	8.35728
August	107.92	107.92	1,000	8,41788
September	105.01	105.01	1,000	8.19074
October	98.02	98.02	1,000	7.64570
November	82.88	64,56	0.779	6,46478
December	68.13	34.31	0,503	5.31414
Total	1053.25	954.58	0.906	84.32980

N.B.: Figures are based on 10 years average (1985-1995)
Source: Singh 1996; Table - 4 P 53

(c) The main cause of weak grass root mat is the thin acidic soils built on hard resistant rock that slows down the growth of secondary roots. It affects the swards growth and fastens the decay of dry- swards of grasses in winter season.

(d) Due to excessive rainfall, there are many ponds and water deeps developed in the area which serve as water sources for the domestic and drinking purposes of the residents of Cherrapunji town and nearby villages without any treatment. Acid rain especially in the pre-monsoon season increases acidity of pond water which results to limited the natural growth of fish (aquaculture), while at the same time affecting human health (Fig.-8.2 and 8.3).

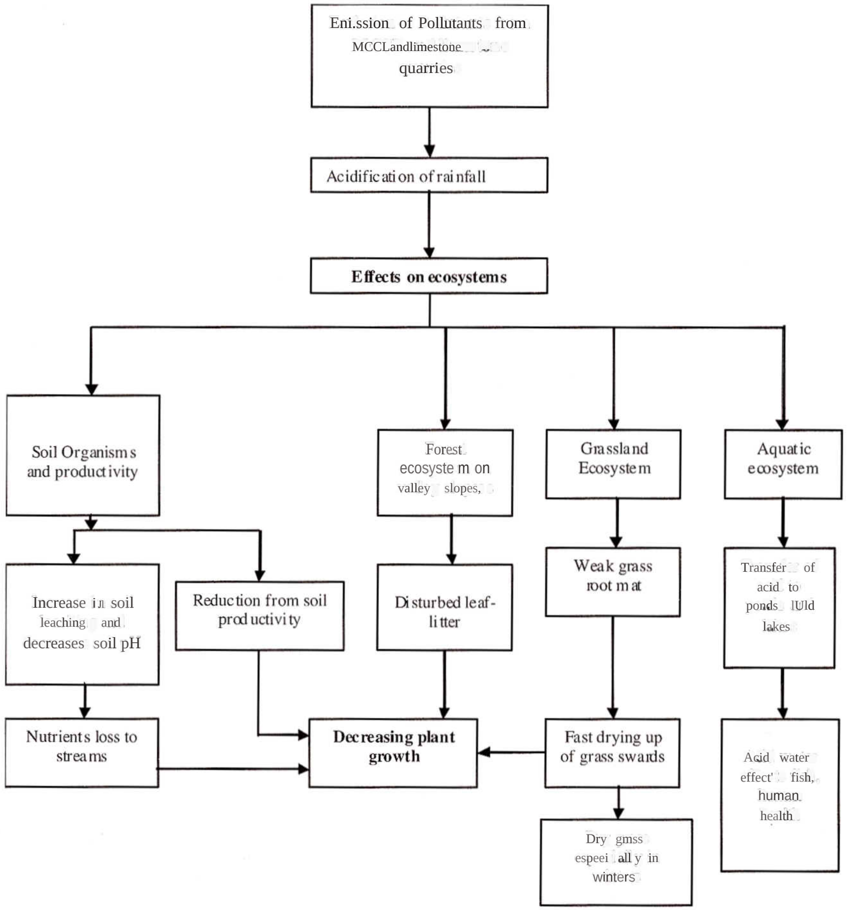
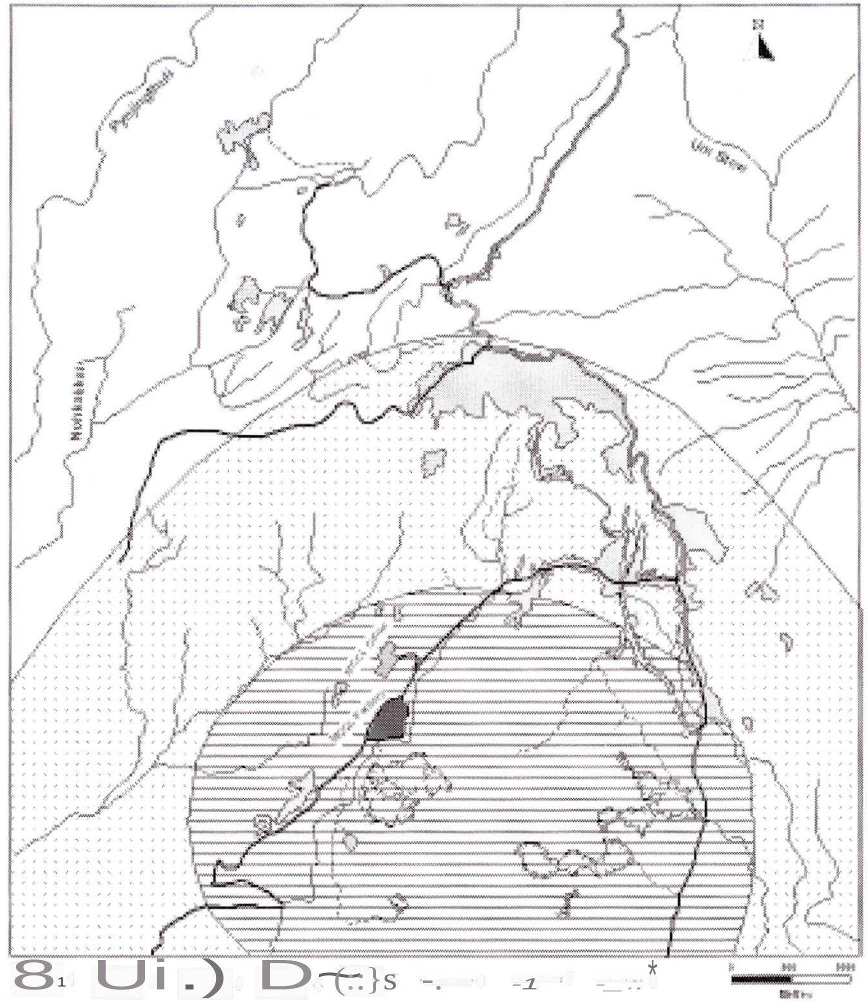


Fig.-8.2: Effects of Smoke on Ecosysytem of Cherrapunji



1. Zone of Intensive Effects of Emission of pollutants 2. Moderate effect of Emission of Smoke from Cement Factory, 3. Location of Cement Factory, 4. Settlements, S. Quarries, 6. National Highway, 7. Metalled roads, 8. Unmetalled roads

Fig.-8.3: Effects of Cement Factory and Lime Stone Quarrying on Ecosystems in the Cherrapunji Area

Box-S.l: Plant Growth and its Regulation

There are two opposing forces operating in the process of plant growth and plant survivorship in a given ecosystem. One is related to the inherent capacity of each species in the ecosystem enabling it to produce at a given rate that is called' reproductive potential rate' (r). The inherent capacity of ceasing to exist is another opposing force which indicates the physiological longevity of plant survival.. If this factor is considered for assessment of plant growth then the difference between reproductive potential and death rate is net reproductive rate. However, reproductive potential (or what can be called the maximum reproductive rate) is considered for growth measurement, maximum reproductive rate varies temporally as well as in different ecosystems because of its changing areal nature. However, the maximum reproductive potential rate of plant organisms is noticed in the moderate temperature conditions between 20°C and 34°C. If this rate of reproductive potential is multiplied by the total producer plants (N) as rN, which is referred to as 'biotic potential' by Kormondy (1996), it shows a total population of a particular species in ecosystem. The force that opposes biotic potential is a physical and biological environment in which the organism exists. It is called 'the environmental resistance'. Environment is a dynamic phenomena and limited to its varying degrees. It has maximum limit to produce plant population called carrying capacity (K) of a given ecosystem. When the population of a species, N, approaches to maximum, K, more resistance is encountered because the thinning process starts and fewer unoccupied space would be available to grow more number of plants in the system (K-N). The resistance effects may be expressed quantitatively as [(K-N)/K] called 'resistance factor' in the plant growth (Singh 2000).

Now, the growth rate of a plant species (LlN/ Llt) which follows logistic law of increase (cf. Kormody 1996), is the interaction of two forces of the growth processes expressed as

(LlN/ Llt)=rN[(K-N)/K].

In this equation, increasing N would mean increasing the biotic potential to produce more and diminishes simultaneously the environmental resistance. It means that at the initial stage of growth biotic potential will operate marginally faster until the effects of environmental resistance becomes greater than the earlier one.

The effects of factors of plant growth and its regulation was shown by adopting another quantitative form called 'exponential growth' of biotic potential at a particular rate of increasing plant population, r, for a time span, t, in which carrying capacity of habitat (i. e., maximum limit to produce plant population, K) shows environmental resistance. It is represented by the following expression (Simmons 1981) as

$$N = [K/(1 + e^{rt})]$$

where e is constant (2.1714) and exponential base for the rate of increase of population and K stabilises the growth rate at its later stage, so the growth follows 'S' type of curve (Fig.-8.4).

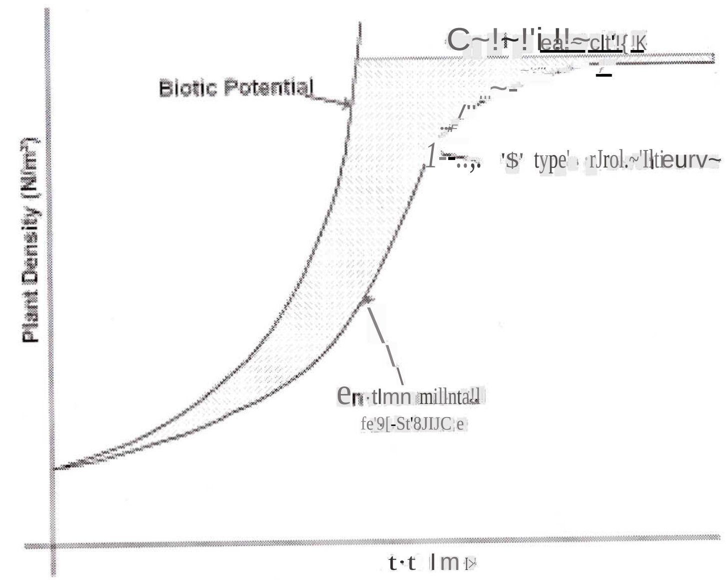


Fig.-S.4: Plant Growth and its Regulation

The Ecorestoration

The problem of restoration of natural resources includes the regulation of water circulation and conservation of soil and vegetation cover.

In case of water management it is needed to reduce the rapid runoff and soil erosion while at the same time building a system to protect water for the dry season necessary for the household use and eventually for irrigation. The strategy to reduce erosion should be focused on re-vegetation of gullies in headwater areas and protection against lateral erosion by flood waves during heavy downpours. There is a need of water management by transporting water from non-polluted source by pipelines as well as establishing of water treatment units to clean polluted surface and ground waters.

To recover the soils and tropical vegetation it is postulated to immediately restrict and to stop practices with overgrazing, annual burning and open cast mining. The process of natural recovery is also long. It can be accelerated by planting trees in the pits and irrigating them during dry season but this is again an expensive affair. The same is related to costly soil conservation measures over slopes, but the construction of terraces or irrigation channels may be easily damaged during frequent heavy downpours. Therefore, the gradual re-vegetation combined with restricted human activity seems to be the most prospective method. As suggested by Uma Shankar et al. (1991),*rhoizome* derived plans are more successful on nutrient-poor soil than plants establishing from seeds.

It is suggested that the mixed local species both from xerothermic grasses as well as from evergreen, mixed evergreen and shola type of vegetation can suitably be grown and suggested for further plantation (Photo-13). Choice of non-arbored plants is limited due to rainfall scarcity during dry winter.. *Arundinella bengalensis* is a prominent grass in the area which survives in degraded soils and may be propagated in other barren lands of Cherrapunji. *Ligustrum robustum* is a most common local tree species in the area, which is found in evergreen and mixed forest area dispersed in river valleys, may be utilized for afforestation programme along with other local species like *Litsea, Symplocos* spp. and *Exbucklandia populnea.* It is realized that this discussion is largely based on the floristic composition of different species growing in different ecosystems. However, more scientific explanations of the suitable species may be given by developing the experimental plots of similar conditions with different species to observe their growth and performance for eco-restoration and especially for afforestation in this area.

The observations at the time of vegetation survey show that the mixed composition of local flora (comprising of the fast as well as slow growing species with their deep root system like *Duabanga, Quercus* and *Ligustrum)* may be suitable for the valley

depressions and later on may be expanded towards ~he entire barren slopes and flat lands of higher altitudes. Such species sho~ld also help in increasing rate of infiltration, maintaining the aqUifer and stabilizing the water circulation of the area.

Parallel with above mentioned, a more scientific socio-economic policy should be undertaken to s~ve t~e ~etoriora~ing environment including the settlement planrung, fmdmg new Jobs for the growing population and especially im~ortant the diversification of energy sources aiming the reduction of local demand depending on charcoal and wood as well ~he creation of storage facilities of surplus of water to be used dunng dry season in small tanks and other small scale reservoirs. To realise these ideas the local population including adolescents should be trained for the eco-restoration programme in the area. The local schools and functional Non Governmental Organisations may be helpful in this connection.

The Strategic Aspects

The investigation of Regional Centre National Afforestation Eco-development Board, Shillong (Tripathi et al. 1991) and an observation of Corrie, the Ex Deputy Conservator of Forests posted at Shillong (Corrie 1995) suggested an action plan based on checking the processes of soil erosion, afforestation and the control of fire hazards and grazing in the grass ecosystem.

In order to regulating the present functions of present ecosystem of this area, there is a need of chec~ing the increa~ing extensive mining of lime stones in open quarnes, supply of hme and burning of coal in cement factory. Such activities, though providing employment opportunities to the local people have increased air pollution in the area manifold in recent years and resultantly degrade the ecosystem explicitly.

Selection of indigenous tree / grass species which survive and grow fast in such disturbed conditions and to identify the areas where such species are to be planted.

Rehabilitation of barren patches of land through establishment of recreation facilities and promoting eco-tourism in the area are major dimensions of ecorestoration strategies. Improvement of touris~ facilities near natural lime stone caves, development of recreatIOnal parks by maintaining lands as per the requirement of lan.d .s~rface are to be thought of serously. Such location specific activIties may help in restoring the ecology of this area.

. Environmental awareness programmes pertaining to dIsadvantages of over grazing and forest fires are to the conducted for local people make them aware about ecosystems functions and the uses of its services. Over exploitation of such services may damage the ecosystem and create more imbalances the landscape functions.

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