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Runoff Processes in Extremely Humid Areas of the Central Meghalaya Plateau

Surendra Singh and H. J. Syiemlieh

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Department of Geography
North -Eastern Hill University
Shillong 793 022

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Research Team

Surendra Singh- Principal Investigator
H. J. Syiemlieh- Co- Investigator
James Melvin Lyngdoh- Senior Research Fellow

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Preface

This Report is an outcome of an investigation completed through project entitled **'Development of Data on Rainfall, Runoff and Soil Loss Estimating SDSS for Extremely Humid Areas of the Central Meghalaya Plateau'** sponsored by DST, New Delhi. The main objectives of the research project were towards extending investigation on hydrological process and generating hydrological and meteorological data for the agencies/organizations working in the extreme humid conditions of Meghalaya plateau where rainfall varies from an average annual of 11,000 mm (in the areas around Cherrapunji) to 2,500 mm (in Byrnihat located in the northern foothills of the plateau). The whole area encompasses a variety of landscape facets and geo-ecological conditions. The investigation was carried out keeping in mind two main aspects:

(a) It covers different landscapes and three experimental watersheds of small size (below 1000 ha) from different geo-environmental and geo-hydrological zones of the plateau for inference results for the analysis of suggesting appropriate model for the assessment of water potentials of even ungauged watersheds, were selected; and

(b) The need of an appropriate model to understand rainfall-runoff relationship in one of the world's rainiest places was felt. Since there is no valid testing of rainfall-runoff modeling especially for such extreme wet conditions where the entire landscape functioning is controlled by rainfall amount and its intensity, the use of appropriate models on physically- based but distributed in nature was thought to be applicable. In this exercise, GIS-ILWIS tool for interpretation of the effects of land surface parameters like slope, soil and land use of runoff processes was used. This would help in strengthening the Spatial Decision Support System (SDSS) in assessment of water resources of a watershed for this part of the country.

It is hoped that this Report would help not only to the researchers and scientists working in this field but also to the state Government agencies and Non Governmental Organisations which are directly or indirectly involved in the execution of various programmes/schemes related to water resource management and eco-restoration of landscapes of such extreme wet conditions.

Surendra Singh

H. J. Syiemlieh

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Runoff Processes - A Concept Note

1.1 Introduction

Integration of hydrological, ecological and hydro – meteorological processes of river catchment in the hills and mountain areas of the world has emerged as general approach to natural resource development and its management. River catchment of lower levels in the hierarchy of river basin systems called watersheds are considered as ideal geo-hydrological units. They provide insights to integration of hydro-ecological parameters with land use systems and sustainability of diverse landscape functions (Sharma et al. 1998). Importance of hydrological processes of landscape has been recognized much more than the other landscape processes because these are major processes that operate in numerous systems of landscape ranging from landscape sculpturing to bio- physical and then to land use systems. Since the intensity and actions of these hydrological processes vary in different environmental conditions over the globe, it is appropriate that we should discuss the need for relevant methodological issues leading towards a better understanding of hydrological systems and towards better use of appropriate tools and techniques for their better management. It is appropriate here to discuss methodological issues of hydrological aspects for the extremely humid area of the world, the Meghalaya plateau (India) where hydrologic processes and landscape functions are inter– dependent up to some extent and largely based on extreme hydro- meteorological conditions of heavy rainfall, large duration of rainstorms confined only during summer monsoon season (Singh and Syiemlieh 2001). Runoff generation processes are controlled by geo- environmental conditions which vary over space and time. Before starting the discussion on methodological issues of runoff generation, understanding the hydrological processes of the Indian sub- continent would be appropriate.

1.2: Hydrological Processes

Hydrological processes are governed by the atmospheric water circulation and land surface characteristics of a river catchment. Rainfall, evaporative demand of atmosphere, soil retention capacity, topographical and land use/land cover patterns are major attributes controlling the runoff and discharge. Isohyets of 1000 mm divide the country into two distinct divisions on the basis of hydrological processes. In a 3,000 km long stretch of the great plains of India, there are two opposite hydrological situations of water circulation that make spatial variability of the extent and intensity of hydrological processes distinctive. It is because of weakening of the effects of South West Monsoon from East to West and the role of Himalayan barrier in this regard. The areas of the most arid conditions are called arid zones of Marusthali (Thar, Rajasthan), while the most humid conditions are prevalent in North East India. Both are located along the Inter Tropical Convergence Zone (ITCZ) near the Tropic of Cancer between 20° and 30° N latitudes. These areas are characterized as follows:

(I)A Condition of Deficit Soil Water Content: The areas of less rainfall associated with low rainfall intensity and high temperature which increase the atmospheric evaporative demand are characterized as the areas of the arid conditions of the Great Plains of India (Marusthali, Rajasthan). These are included as water deficit conditions where thick soils of 1 to 5 m and even more may be observed with porous soils of high infiltration capacity. For example, a soil column of 2.0 m thickness with high porosity (k >100 cm/day) may have retention capacity of 800 mm of water depth. The whole quantity of rain water of a storm of 250 mm can be absorbed in this soil. On the other hand, there is high evaporative demand in these areas of limited vegetal cover with high temperature. Evapotranspiration takes place from the upper layers of soil which are sandy in its texture. Soils of Thar Desert (the driest part with very high temperature of more than 50°C in the month of June) are good examples of this condition. Higher rainfall intensity than infiltration rate creates overland flow occasionally in rainy season, otherwise, during the whole year, PET is recorded higher than the rainfall. There are flash floods occasionally with seasonal drainage because of rainfall excess situation and occasional over land flow. Aquifers are very deep with deep ground water table at 15-20 m in Marusthali areas of Rajasthan. In these areas of extreme arid conditions, the ground water recharge is possible only through infiltration during summer rains. There is no case of full recharge in the Thar Desert, so there is no discharge condition through sub-surface flow.

(II) Condition of Surplus Soil Water: The areas of high rainfall (more than 2000 mm annual average), are generally defined as humid tropical environment stretching almost entire North-eastern part of the country where soil leaching processes take place along with the existence of weak aquifers and low groundwater recharge conditions because of hard and impermeable rocks. The foot hills are the areas of convergence of lateral and base flows. The sites of headwater hollows and areas below spring lines are considered as permanent water saturated areas where action of sub surface flow is significant in the process of water delivery to the river channels. On account of dense vegetal cover, the root zone of surface soil retains more water, while there is always soil moisture in the sub-surface soils which depletes during dry season (winters) in the hilly slopes. Soil retention capacity is low (200-400 mm) due to thin soils. In such conditions, macro-pores (soils porosity increases due to deep tree roots and soil cracks) on the hill-top soils and alluvial hard pans (low porosity with a receipt of hill slope lateral flow) in the lower parts of valley, the processes of overland flow are governed by two main factors: a) the low infiltration capacity of sub-surface soils because of readily available soil moisture in them and b) the frequent sub-surface flow due to hill-slopes and thin soils in which hydraulic conductivity is much higher than the normal. For example, the areas of extreme wet conditions, Cherrapunji (the wettest place over the earth, 11000 mm annual average rainfall) contain thin soils (somewhere 0.5 to1.0 m) with gravelly texture (Pawel 2010). Its retention capacity is only 1500 mm (Singh 2007). As a result, the lower water retention with good Antecedent Moisture Conditions (AMC) quickens the sub-surface flow and even controls overland flow. On account of thin gravelly root zone soils, the area is dominated by tall grasses. The grass roots cannot retain more water in root zone, so it becomes scanty during dry seasons and consequently, grasses die during winters. Hydrological environment on hill-slopes is dominated by very thin layers of soil, somewhere stony which saturates fast and allows sub-surface water to add to runoff. The saturated areas expand and contract frequently during the rainstorm within the river catchment.

The areas of dry conditions of hydrological processes (condition –I) which are operative in the deficit water conditions of soils follow a Hortonian mechanism of ‘infiltration-excess’ when rainfall exceeds infiltration contributing to overland flow. In addition, high evaporative demands of atmosphere in the tropical and sub-tropical climatic conditions of high temperature varying from 40°-50ºC in Rajasthan to 30°-35ºC in the North-East, adds another dimension in the prediction of runoff. As a result, evapotranspiration is also an important attribute of the hydrologic cycle for runoff production in tropical areas where more than 1/5 share of total annual water quantity evaporates back to the atmosphere (Singh 1999). It could not be given importance in the runoff studies conducted for the temperate environment of Europe and Northern USA.

Hydrological conditions varying the runoff processes in the extremely humid areas (condition-II), are more dependent on the receipt of lateral flow which accelerate saturation-excess processes. It is because of high humidity, shallow top soils (20-80 cm depth) with weak aquifer conditions and impervious hard bedrocks. In some areas, percolation takes place through local lineaments. As a result, there is a continued base flow with lower flow during dry periods. Top soils are so shallow that they cannot retain more water leading to restricted flow. In such conditions of extremely high rainfall intensity events, the hydrological responses are largely dependent on the saturation areas within watershed which create significant fluctuations in the discharge rate and runoff.

1.3 Methodological Issues for the Hydrology of Humid Areas

Rainfall is a major weather parameter that contributes to hydrological processes though acting as regulator of geo-system functions for water delivery in a river catchment. In excessive rainfall areas, the ecosystem functions are restricted due to excessive leaching processes and less fertile soils (Ram and Ramakrishnan 1988) associated with lower temperature. However, hydrographs are largely dependent on surface runoff and saturation excess conditions since intensive and long duration rainfall produces higher runoff ratio (Soja et al. 2010: 29-59). Fragile ecosystems also enhance the variability in the rate and volume of runoff because of inherent reduced retention capacity of soils and inappropriate land use in the watershed. In such excessive rainfall situation, saturation-excess process operative on the hill slopes and valley floors would explain the runoff phenomena. It also serves as a link between the weather parameters and ecosystem functions. It helps to understand the water delivery patterns especially in the wet monsoon areas where runoff is controlled by the availability of soil moisture and the quantity of water for evaporative demand in the hills and mountainous river catchments (called watersheds hereafter because it is micro areal level unit of catchment). The impact assessment of topography, soils and land use/ land cover on the location and extent of saturated areas in the watershed is a major methodological issue which would be discussed in the following paragraphs using physically based distributed runoff modeling.

Development of physically based distributed rainfall - runoff modeling in the last part of 20th century (Crawford and Linsley 1966, Freeze and Harlan 1969) and linking these models in relation to land surface conditions like slope, soil and land use took place when Beven and Kirkby (1979) started identifying runoff processes for different surface conditions (Beven et al. 1980, Beven 2001). More applications of these models were made towards simulation of the effects of chemical properties of soil and impurities of water of a catchment (Yang et al. 1987). In this regard, identification of hydrological processes was made to consider the land surface characteristics (stable parameters) and patterns of rainfall intensity (variables). Hortonian overland flow of surface runoff and matrix flow and macroscopic flow of sub-surface stratum are the examples of runoff processes (Schmocker- Fackel 2004).

However, Variable Source Area (VSA) hydrology and identification of saturation-excess processes of runoff generation in shallow soils were pursued by the team of the scientists of Biological and Environmental Engineering, Carnell University, Ithac (USA) (Lyon et al. 2004, Schneiderman et al. 2007). The physically based runoff generation mechanism was also developed by adding Potential Evapotranspiration (PET) component of water budgeting for Tropical areas where evaporative demand of atmosphere significantly influence the runoff processes (Mishra et al. 2008). However, no model was developed to link the parameters of land environment (physical as well as biological) with hydrograph characteristics. Such aspects of advancement in the subject would help in integrating land environment with water delivery system to resolve issues of development of land environment and toning up the ecosystem functions in eco-hydrology. In this connection, the issue of water delivery system is addressed to establish integrative links between weather variability and runoff yield in the ambit of hydro-meteorological sustainable pathway in areas of excessive rainfall monsoon environment.

Main processes of runoff are largely dependent on two flow conditions. Firstly, soil surface (i.e. overland) flow that accelerates infiltration (Hortonian) process and secondly the subsurface (lateral) flow (the water storage in the soil and the vertical flow within the soil). There are several types of sub-surface flow, namely, the matrix flow (micro and mesopore flow driven by capillary forces), the macropore flow (gravitation driven vertical flow through cracks, root channels and worm holes), the return flow (water reemerging to the soil surface after short distance) and the groundwater flow (because of deep percolation) (Schmdeker-Fackel 2004). Runoff processes vary spatially within the watershed because of different geo-ecological and geo-hydrological environment. For example, in the areas of higher elevations in watershed, the runoff is generated through overland flow. Overland flow process is accelerated when effective rainfall intensity exceeds the rate at which water can infiltrate the soil. Saturation excess runoff occurs when rainfall exceeds soil water deficit. Saturated areas vary in any watershed. It is called Variable Source Area (VSA) concept of runoff generation (Fig.-1.1). It is more related to topographic conditions (elevation and slope) soil properties (texture, porosity and depth) and land use/land cover pattern (land use/land cover properties).

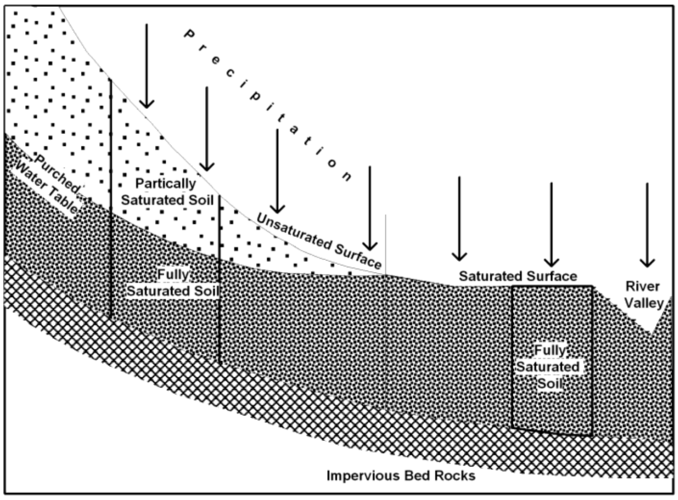


Fig.-1.1: Mechanism of Saturation on Hill Slopes

Use of SCS-CN based method for computation of the fractional areas of source runoff (Steenhuis et al. 1995), its relation with the available moisture storage and the identification of location and extent of saturation excess areas on landscape using topographic index (Beven and Krikby 1979, Schneiderman et al. 2007) are significant additions to the literature of VSA hydrology through which the areas of source runoff may be integrated with land surface parameters to isolate the effect of each of them on hydrological responses in runoff prediction and spatial pattern of source-runoff areas. Using topographic index to define the distribution of soil wetness in the traditional SCS-CN method, results of spatial pattern of saturation areas are improved towards real ones to predict accurately the runoff in the watershed (Lyon et al. 2004). Having reviewed the literature on concerned aspects of hydrologic modeling and development of tools for runoff prediction, there are two families of tools development in this context which follow two different approaches of prediction. Runoff prediction is dependent on two dimensional modeling systems in the watershed located in hill area where hard bed rock structures do not allow percolation. They are the infiltration based storage system and saturation area storage system. Details of the distributed modeling mechanism of change in storages are given below. It would be useful for development of Spatial Decision Support System (SDSS) for the humid areas such as Meghalaya plateau

(A) Saturation-Excess Runoff Model: Rainfall intensity exceeds storage capacity near the areas of soil saturation-excess in the watershed. Saturation excess runoff occurs when rainfall reaches the ground that is fully saturated due to its shallowness and poor retention capacity (Schneiderman et al. 2007). The depth of excess rainfall is called direct runoff (Qd) that is usually considered as overland flow in areas of deep macropore soil, poor vegetation cover and undulating topography. The time of initial abstraction before ponding (Ia) does not produce runoff ($P < Ia$), while the initial retention of overland flow after initial abstraction is initiated by ponding and surface hollows/roughness, is called detained rainwater (i.e., continuous abstraction, Fa) which continuously recharges the soil moisture storage, S_t, until it reaches a maximum retention capacity (Sm). The effective rainfall ($Pe = P - Ia - ET_0$) will always be more than the direct runoff as it is dependent on three parameters ($Qd = P - Ia - Fa$). Direct runoff was measured by adopting the USDA-SCS (1972) technique of Curve Number (CN) assuming that the relative share of the depth of direct runoff to the effective rainfall (Qd/Pe) is proportional to the relative share of soil moisture actually retained (detained rainwater for soil recharge) to the maximum retention capacity of soil moisture storage (Fa/Sm). Direct runoff thus increases non-linearly when maximum retention capacity of soil moisture storage decreases (Chow et al. 1988: 147-155).

(B)Physically-based Runoff Models: This family of modeling largely depends on dimensional saturated-unsaturated sub-surface flow linked with two dimensional over land flow and one dimensional channel flow (Freeze and Harlan 1969, Beven 2001: 124-127). The operational parts of such models forward the analysis of runoff yields in response to land surface parameters which are included in the model in the form of spatial distribution. Soil and Water Analysis Tool (SWAT) is a physically based but relies on Hydrologic Response Units (HRUs) which are weighted by unique soil and land use characteristics at sub-watershed level. Physically based distributed models were further developed by considering grid-system as first suggested in the *Systeme Hydrologique Eropeen* (SHE) model widely known as distributed model operative with the use of grid-based data of land surface features (Beven et al. 1980:124-127). It was intensively used for different sizes of river catchment in Europe as well as in other countries (Bathurst 1986, Jain et al. 1992, Parkin et al. 1996). Later on, a watershed analysis tool for predicting runoff volume and peak rate for single storm events was developed by Young et al. (1987) with consideration of all points of land surface as contributor to runoff. It was named Agriculture Non-Point-Source Pollution (AGNPS) model because it was developed for analyzing quality of runoff from agricultural lands located in the state of Minnesota, USA. SCS-CN method was used in this model to capture the effects of soil and land use / land cover of surface features in predicting runoff. However, it over-predicted the results of peak runoff and concentration time of runoff when it was applied in the watersheds of tropical environment (Babel et al. 2004). Physically based distributed models consider surface characteristics as variants and as well as the effects of topographic factors. GIS and RS techniques can be used for calculation of flow and energy of water in the catchment. Several general purpose catchment models of this type such as MAKE, SHE, IHDM, GNPS, SWAT (Arnold and Williams 1995, Arnold et al. 1996) are comprehensively deterministic in nature and are considered under the category of physically based modeling systems. These systems are generally based on St. Venant's equation of overland flow and channel flow. Such models primarily depend on two-dimensional modeling system (surface as well as sub-surface flows) in which water movement is the basic module of the system (Fig-1.2).

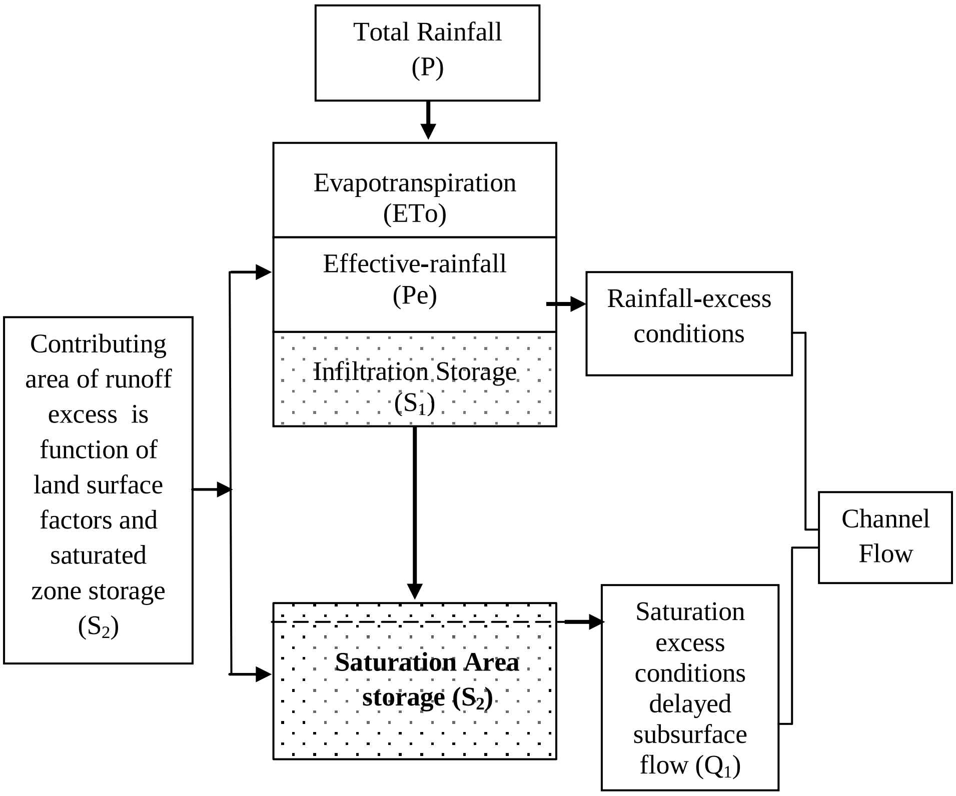


Fig.-1.2: Schematic Representation of Hydrologic Process (Modified from Beven and Kirkby, 1979)

In order to predict the runoff in humid tropical environment where hydrologic system is more controlled by atmospheric conditions and a significant share of rain water evaporates and transpires during rainy season due to high temperature ranges (Singh 1999), there is need of appropriate physically based distributed model for runoff prediction. The characteristics of saturated-unsaturated zone of land surface in the high rainfall areas of Meghalaya plateau are largely depending on the surface conditions (such as slope, soil and land use practices). Physically -based distributed modeling system may be thus useful to capture the effects of slope, soil and land use attributes on hydrographs. Variable Source Areas (VSA) technique of distribution of runoff yield is a modified version of physically-based modeling system, first developed by Beven and Krikby (1979) incorporating topographic index for identification of the fractional areas contributing runoff. It may capture the effects of land surface parameters through the calculation of the dynamics of saturated- unsaturated zones of watershed. A full branch of VSA hydrology was developed by the scientists of Soil and Water Lab, Biological and Environmental Engineering, Cornell University, USA to understand the responses of different land surface parameters as well as runoff yield (http://soilandwater.bee.cornell.edu/research/usa/links.html). Initially, the view of physically-based variable contributing area was persuaded by Bevan and Krikby (1979) by considering that flow accumulation and its direction on land surface. It is a simple method to use because it is based on the modified form of SCS-CN equation called CN-VSA approach providing solution of heterogeneous character of land surface. As emphasized by Steenhuis et al. (1995) and Lyon et al. (2006), it is more accurate to identify saturation areas and their locations in the river catchment with the use of Geographical Information System (GIS) and geo-statistical tools of grid-based approach of land surface. It is thus more suitable for well-vegetated humid areas because the process of soil saturation is largely dependent of landscape parameters and fractional depth of direct runoff with respect to increase in effective rainfall depth, Af. Af is initially a differential function of the rainfall-runoff equation developed by Soil Conservation Services-Curve Number (SCS-CN):

$$Q= [(P - Ia)^2 / (P + S-Ia)] \text{ for } P \geq Ia \text{ ; otherwise } Q= 0 \text{ for } P \leq Ia, \quad \ldots \quad (1.3)$$

where Q is the depth of direct runoff, P is rainfall, S is amount of water storage available in the soil profile or the maximum storage and Ia is initial abstraction, so effective rainfall, Pe= P- Ia and effective available storage, Se= S- Ia. The differential of the above equation with respect to effective rainfall becomes as

$$Af= dQ/dPe= 1- [S^2/(Pe + S)^2], \quad \ldots \quad \ldots \quad (1.4)$$

where Pe is effective rainfall as (P- Ia) (Steenhuis et al. 1995). In order to capture the effects of land surface parameters, a Wetness Index (WI) was prepared incorporating slope of water flow, soil depth and saturated hydraulic conductivity as surface factors which control the areas of saturation excess (Beven and Krikby 1979, Lyon et al. 2004, Lyon et al. 2006) computed as

$$WI= \ln [(a/(\tan \beta *k*d)], \quad \ldots \quad \ldots \quad \ldots \quad (1.5)$$

where a is area of the flow of upslope watershed per unit contour length (m), tan β is local surface topographic slope (m/m), d is soil depth (cm), and k is mean saturated hydraulic conductivity (cm/day).

Further modification in VSA hydraulic process was made by Mishra et al. (2008) by using infiltration component, water budgeting, sub-surface flow component and channel routing component of different land use (especially vegetated hill slope), paddy fields and semi impervious urban clusters for the study of hydrological processes in hilly watersheds of Indian tropical environment. The parameters of this model are primarily based on Thornthwaite’s equation of determining potential evapo-transpiration, Phillip’s equation of infiltration for urban clusters, two layers Green-Ampt equation for infiltration rate of the paddy field and kinematic wave approximation formula for linearized channel routing system. However in the present study, the runoff depth was predicted by using saturated area based model considering one layer condition of soil matrix due to the fact of the existence of shallow and wet soils in the central part of Meghalaya plateau.

1.4 Importance of Small Catchment

River catchments have hierarchy and spatial ordering. Through the current detailed knowledge of geomorphological, geo-ecological and geo-hydrological processes of landscape, characterisation can be possible. This would enable evaluation of natural resources and integration of these processes of landscape. Small river catchments are representatives of important elements of contemporary landscape of earth surface and are spatial units (geo-ecosystem) that are especially sensitive to natural as well as anthropogenic processes. As one moves from point pattern of hydrological events (lumped modeling when catchment characteristics are considered as homogeneous) to watershed level geo-hydrological processes (physically distributed modeling as the effect of topography of watershed is taken into account in runoff simulation processes), the importance of topographic and geomorphologic parameters for the study of hydrological events cannot be denied. As a result, International Association of Geomorphologists (IAG) formed the Working Group on small-catchments. Its first meeting was held at the Environmental Monitoring Station at Biala Gora near Miedzyzdroje in Poland during 21-23 April 2008 to discuss the problems of (a) organisation of a measuring system, (b) the small catchment monitoring and (c) the analyzing of results to regulate the use of natural resource measurement. The main theme of deliberation of the Second Meeting of the Working Group held at Palma, Mallorca, Spain during 6-8 May 2009 was to discuss sediment delivery systems and human impact in different morpho-climatic zones of the world. This theme is closely associated with the effect of topography, soils and land use/land cover patterns of the catchment with the trends of runoff and soil loss, that reflect the integrated view of the small-catchment in light of natural resource availability, human interference in the form of resource use/damage the geo-ecology and environmental monitoring. For example, calculation of contributing area to runoff is helpful for water quality as well as water availability studies in which contributing area as a function of effective rainfall and effective available soil moisture explains the variation occurring in the watershed over time during the event. The probability of runoff could be useful for estimation of soil erosion hazards and different stream pollutants used in the land use practices in the watershed.

1.5 Basis of Spatial Decision Support System (SDSS)

In the context of development of SDSS for runoff prediction of ungauged watersheds of extremely humid environment as prevalent in Meghalaya Plateau, it is appropriate to say that the analysis of spatial processes of runoff simulations are greatly attached to land surface conditions in which the topographic features, land use/ land cover pattern and soil conditions are major elements of land surface. In such conditions rainfall intensity exceeds infiltration rate and/or storage capacity on a variable area of near saturated soil for more than seven months of rainy period in the North East India (Singh et al. 2006). Horton model response of runoff may not be applicable in such excessive rainfall conditions (Beven and Kirkby 1979). The saturation excess method may be useful for appropriate prediction of runoff in such wet conditions of landscape. The methodology of the proposed SDSS has two major aspects: (a) the procedure of work for creation of inputs for the application of model and (b) its output analysis (Fig.- 1.3).

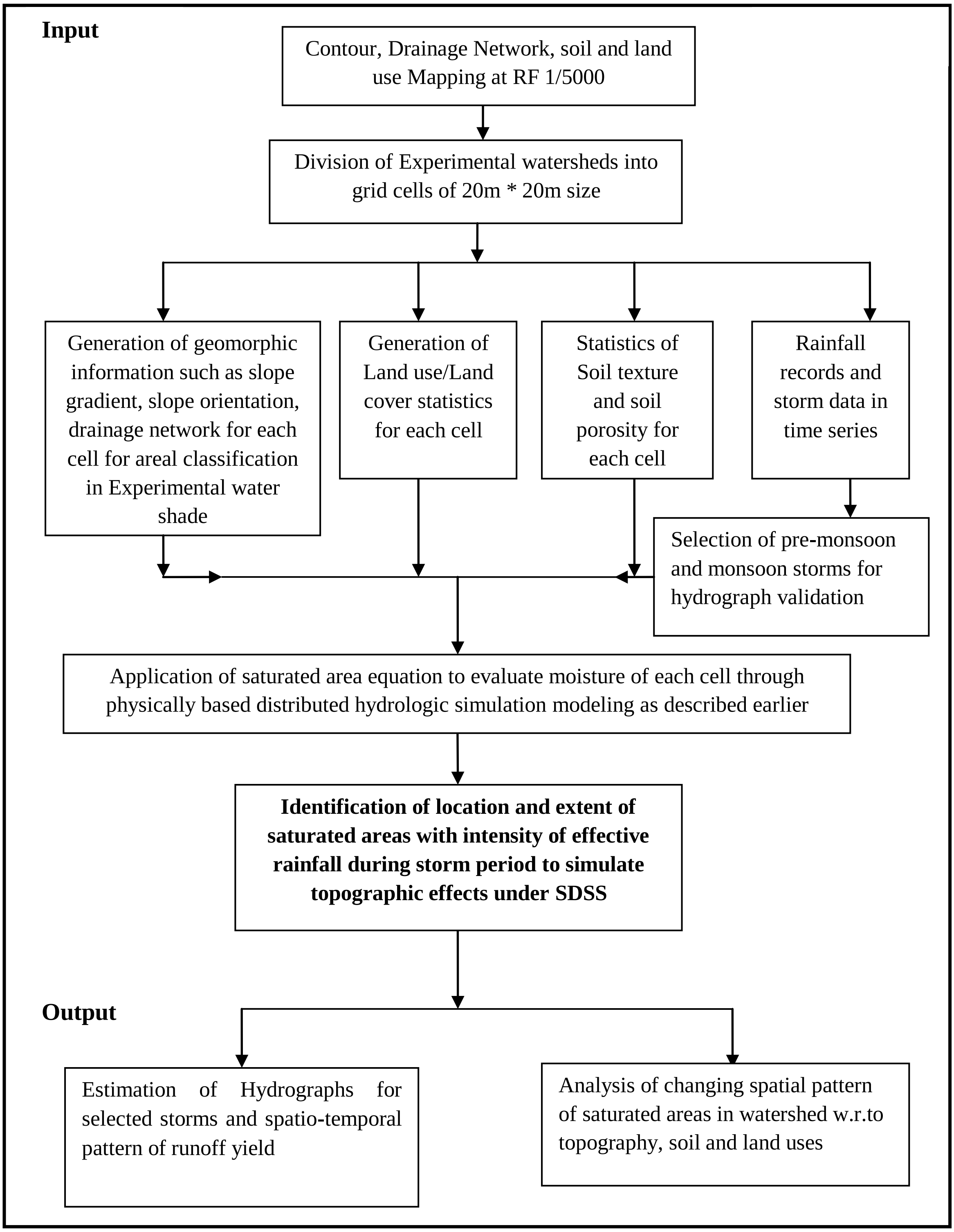


Fig.-1.3: Procedure to Develop the SDSS for a watershed following Distributed Runoff Modeling

There are four major activities for preparation of SDSS, namely, (1) the Selection of experimental/representative watersheds, (2) Physical Surveys and Geomorphological Mapping, (3) Establishment of Hydro-metrological Observatory, and (4) Application of Tools and Techniques for assessment of Coefficients and Constants of model. These aspects of watershed hydrology would be dealt with the next Section of the report separately.

1.6 Application of Methods:

Having reviewed the VSA hydrology, it can be said that an accurate evaluation and application of appropriate methods for prediction of runoff yield are to be dependent on the consideration of the following realities of land surface conditions and operated hydrological processes in the extreme humid tropical environment prevalent in the Meghalaya plateau.

(a) Extreme Tropical monsoon climate and less water holding capacity of soils of the Meghalaya plateau, where temperature ranging from 10ºC to 40ºC with heavy rainfall (from 2,000 mm annually in its foot hills to 11,000 mm in the windward Cherrapunji area) with different depths of shallow soils belonging to lateritic group on the hill tops, accelerate hydrological processes differently. There is no case of snow melting in these areas when daily temperature is always above 0°C. The areas of saturation are more controlled by the rainfall depth and evapo-transpiration, the detention of rainfall varying over the surface through ponding and surface depressions as well as different agricultural practices on hill slopes and the capacity of moisture retention in the soils. Evapo-transpiration, that is temperature- dependant element of water balance (Thornthwaite and Mather 1957), influences implicitly the hydrological processes in the plateau. Since soils are shallow in this humid area, the soil depth may be considered as one-layer case rather than of many-layers.

(b) In such humid tropical environment of the plateau, the land surfaces are dominant by forest and grass ecology on the hill tops; shifting cultivation on the hill slopes and permanent agriculture in the flat valleys comprising of alluvial soils. Consequently, the watersheds of small sizes also have diverse characters of land cover/ land use pattern. Due to hard bedrock, weak aquifer and shallow soils, the processes of ground water recharge/discharge are not so significant for the evaluation of runoff in these areas. The high degree of macro-porosity and highly undulating land surface increases the rate of hydraulic conductivity and saturated hydraulic conductivities of soils in such humid areas.

(c) Spatially distributed runoff areas are much accurately predicted by the use of the ‘saturation-excess’ method of landscape factors rather than by the use of the ‘infiltration excesses’ method which basically depend on soil types (Lyon et al. 2004). The changes in soil moisture storage is much more related to accumulated water loss by evapotranspiration in the dry seasons and changes in soil moisture storage during wet seasons. The saturated areas yield regular water supply in rainy season.

(d) Runoff prediction is largely based on the location and extent of saturated areas within the watersheds that are implicitly controlled by topographical features, distribution of depth and types of soil and land use/land cover patterns. Topographic Wetness Index (TWI) is much simpler and may be applicable in analyzing the dynamics of saturated excess zone in the watershed.

The prediction of runoff in humid-tropical watersheds where ecological, soil and topographic conditions vary significantly, is initially based on the analysis of saturation-excess processes operative in the watershed. A model which incorporates the parameters of evapotranspiration in addition to fully distributed model would be appropriate to capture the effects of soil, land use /land cover and topographic conditions influencing hydrological activities of the watersheds with different runoff scenarios. Therefore, the simple SCS-CN method (i.e., semi- lumped) and the Variable Source Area method (fully distributed but based on topographic wetness index) may be suitable to identify the saturated areas for simulation of runoff. Performance of the models may also be tested with some suitable validation tools which would be taken up in detail in the next Section of the present research.

Section-II

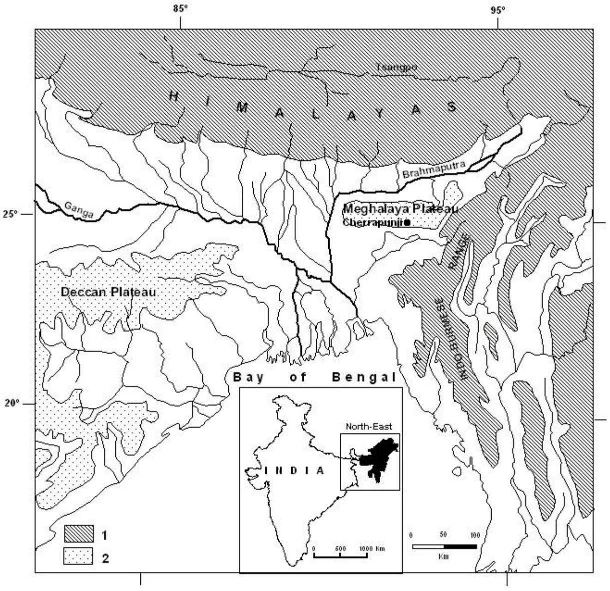
Set up of Experiments and Description of Tools and Techniques

2.1 Introduction

In the distributed physically based model, GIS and RS are two major techniques that can support this modeling approach because the runoff depth is largely dependent on topographic attributes that are now remotely sensed. VSA approach may give more correct description of hydrologic process in the watersheds located in humid environment. Several general purpose catchment models like SHE, GNPS, SWAT (Arnold et al. 1996) are comprehensive deterministic distributed and partially or fully physically-based modeling system for the simulation of land-based part of the hydrologic cycle in which Water Movement (WM) is a basic module of the system (Yang 1998, Habib-Ur-Reheman 2001). Since this approach of the modeling systems is suitable for the development of SDSS and appropriate for correct prediction of runoff in the humid environment of Meghalaya plateau, the study of locational characteristics of the area considered for experimentation is a main dimension of discussion that would provide a suitable base for selection of experimental watersheds.

2.2 Locational Characteristics and its Advantages

Analysis of hydrological processes and assessment of runoff in the conditions where ecological as well as hydrological parameters spatially vary significantly in the Meghalaya Plateau as being its location between Bay of Bengal in its South and Himalayan Ranges in the North near Tropic of Cancer (Fig.-2.1). Its (Meghalaya plateau) dissected topography has significant variation in its ecological, meteorological and hydrological set up. The undulating table-lands in its central parts of degraded-tall grasslands, the frontal areas of South-West monsoon of its southern steep slopes, the northern moderate slopes characterized by ‘leeward rain shadow’ areas and the foot hills of warmer areas with less rainfall are distinct features which provide sound bases for (i) the selection of experimental catchments, (ii) the proper understanding the real world situation for identification of runoff processes and (iii) the study the spatial variability of hydro-meteorological phenomena of this area.



N. B.: 1. Areas above 1600 m a.s.l. and 2. Areas of 900 to 1600 m a.s.l

Fig.-2.1: Location of Meghalaya Plateau in its Regional Surroundings (courtesy: Singh et al. 2010)

2.3 Spatial Variations in Geomorphologic and Hydrological Characteristics

Geological account, relief characteristics and climatic factors are main actors of hydrological events and their regional and seasonal variations. The details of rocks structure of Meghalaya plateau given by Geological Survey of India provide facts that the plateau geologically is the extensive part of Chotanagpur plateau detached from main Indian Shield (the North-Eastern part of Deccan foreland) by North-South tending Raj Mahal-Garo lineament (Mazumdar 1976). As a result, the terrain features of the Meghalaya plateau are emerging from gneissic complex of Shillong massive faults and lineament forming a block-uplifted region to its present height of about 2,000 m (Murthy 1972 c.f. Agrawal 1994).

Relief features and slopes are part of land systems and also attribute to the regional variations of the amount and intensity of rainfall which influence the regional variations in the function of hydrological cycle. There are four distinct relief features of the plateau:

- the uplifted tracts of Khasi Hills of high elevations with flat dissected top ranging from 1500 m to 2000 m elevation,
- the escarpment and eroded land features in the central parts which divide the plateau into two broad drainage systems: (a) part of Brahmaputra through Kopli North-East drainage system and (b) direct flow towards Bangladesh plains,

- the inter-piedmont flats of river valleys with depositional processes that lead to the generation of a particular type of soil, an important attribute which directly influence the surface as well as subsurface flow, and
- the foot hill flat lands of fertile soils and open-valleys.

Having conducted investigation on the assessment of surface runoff in Meghalaya plateau by considering river catchments/watersheds of lowest order (that are 235 in number) for the study of spatial variations of geo-hydrological characteristics (Appendix-I), the watershed – wise geomorphologic and hydrological statistics have been generated to study the spatial variations of runoff processes applying empirical equations. The details of such study have been given somewhere else (Singh 2007). However, the salient features of spatial variability are precisely given below.

(a) There are 17 higher order, 55 middle order and 235 lower order river catchments having average sizes of 2300 sq km, 583sq km and 136 sq km respectively. Water divide passes through East-West in the central part of plateau. Higher order catchments have much spatial variations in geo-ecological and geo-hydrological properties, so the lower order catchments are appropriate for runoff assessment (Table-2.1).

Table- 2.1: Ordering, Number and Areal Size of Geo-hydrological Units in the Meghalaya Plateau

HigherOrder	Name of the Higher Order Catchments	Area (sq.km.)	Middle Order Catchment		Lower order watershed & Inter catchments	
			Total No	Average Size (sq km)	Total No	Average Size (sq km)
I	Jinjiram	2628.65	4	657.16	19	138.35
II	Balbola	493.16	2	246.58	5	98.63
III	Dhudnai	1629.16	2	814.58	8	203.64
IV	Manki- Singram	1416.26	4	354.06	13	108.94
V	Kulsi	2204.73	4	551.18	19	116.04
VI	Umran	2702.78	3	900.93	13	207.91
VII	Borpani	1695.84	3	565.28	13	130.45
VIII	Kopili	3455.02	5	691.00	26	132.88
IX	Diyung	1161.16	3	387.05	7	165.87
X	Layang	831.30	3	277.10	3	277.10
XI	Lubhar	947.17	2	473.58	7	135.31
XII	Praog	1674.06	3	558.02	8	209.26
XIII	Umsoh – Ryngkew	1568.13	2	784.06	9	174.23
XIV	Kynshi	4560.22	6	760.04	41	111.22
XV	Simsang- Someswari	2910.80	4	727.71	25	116.41
XVI	Daring	1389.29	3	463.09	12	115.77
XVII	Marai	806.54	2	403.27	7	115.22
	Total	32074.30	55	583.17	235	136.49

Source: Singh (2007: 14)

(b) Having collected annual rainfall statistics of 14 stations located in and around Meghalaya plateau and using interpolation method for making isohyetal map, the distributional pattern of annual rainfall was shown. Precipitation is spatially concentrated in and around Cherrapunji-Mawsynram area located on the southern slopes of the plateau and tends to decrease towards foot-hills (Table-2.2).

Table-2.2: Mean Annual Rainfall of Stations Located in and around Meghalaya Plateau

Sl. No.	Name of Station (Location)	Mean Annual Rainfall (in mm)
1.	Shillong (Central Meghalaya)*	2,271
2.	Dhubri (Lower Assam)*	2,436
3.	Lumding (Upper Assam)*	1,161
4.	Gauhati (Central Assam)*	1,538
5.	Silchar (South Assam)*	3,018
6.	Charrapunjee (South Meghalaya)*	11,131
7.	Tura (Far West Meghalaya)*	3,500
8.	Williamnagar (West Meghalaya)**	3,207
9.	Nongstoiñ (Central West Meghalaya)**	3,698
10.	Baghmara (S-W Meghalaya)**	7,000
11.	Sylhet (N-E Bangladesh)***	2,432
12.	Mymensingh (North Bangladesh)***	1,524
13.	Tangail (Central Bangladesh)***	1,440
14.	Dhaka (Central Bangladesh)***	1,400

N.B. * Rainfall data based on 30 years normal (1960 – 1990)
* Data based on 5 years average (1987-1991)
**Projected through interpolation method for 5 years average
*** Data based on 30 years mean of Monsoon season (June – September) (1951-1980)

Sources: 1) Climatological Tables Part-I, Indian Meteorological department, Pune
2) District Research Laboratories of different District Head Quarters
3) Bangladesh Meteorological Division, Dhaka (BMD).

(c) The areas of extremely high annual rainfall have very low mean annual water holding capacity of soils, shallow soils with low infiltration capacity. As a result, runoff depth as well as runoff ratio were calculated which vary from very high to extremely high (above 7,000 mm annually of runoff depth and 80-95% runoff ratio) on the southern slopes of the plateau (Fig-2.2 and 2.3). The situation is different in the inter-piedmont valleys and foot-hills areas of the northern slopes where soils are much thicker with marginally high infiltration rate.

If superimposition of these maps of hydrologic parameters is made to delineate the areas of different hydrological processes, it is appropriate to say that there are three distinct hydro-meteorological areas which would help in selecting experimental watersheds to study in detail the runoff processes. They are the upper flat lands of the plateau, the steep slopes and the foot- hills of open valleys.

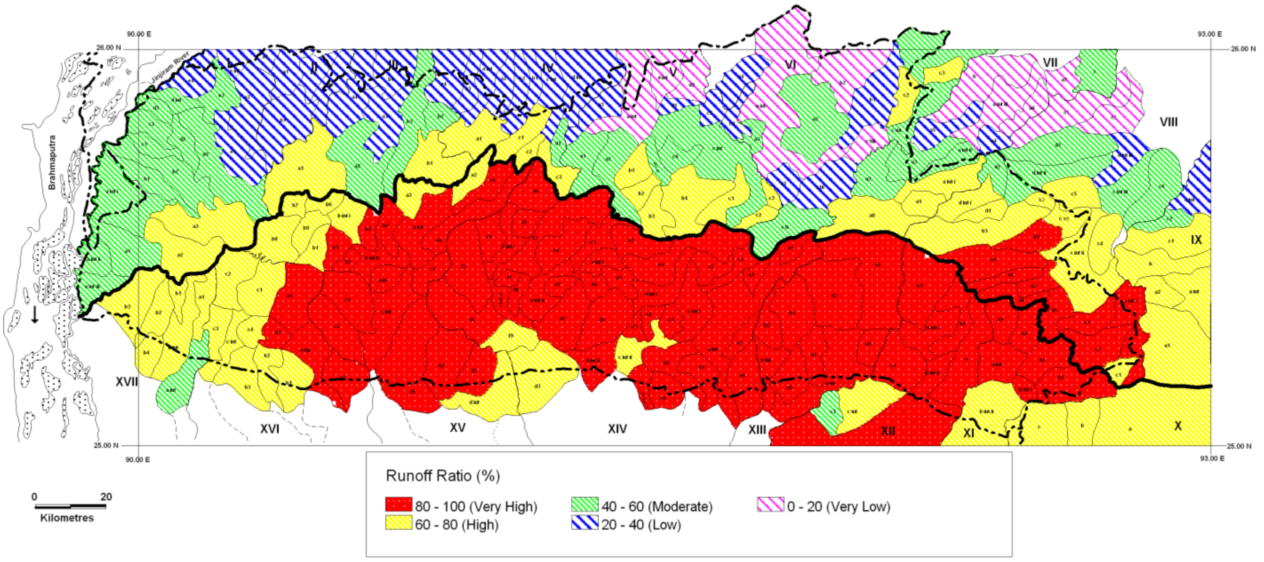
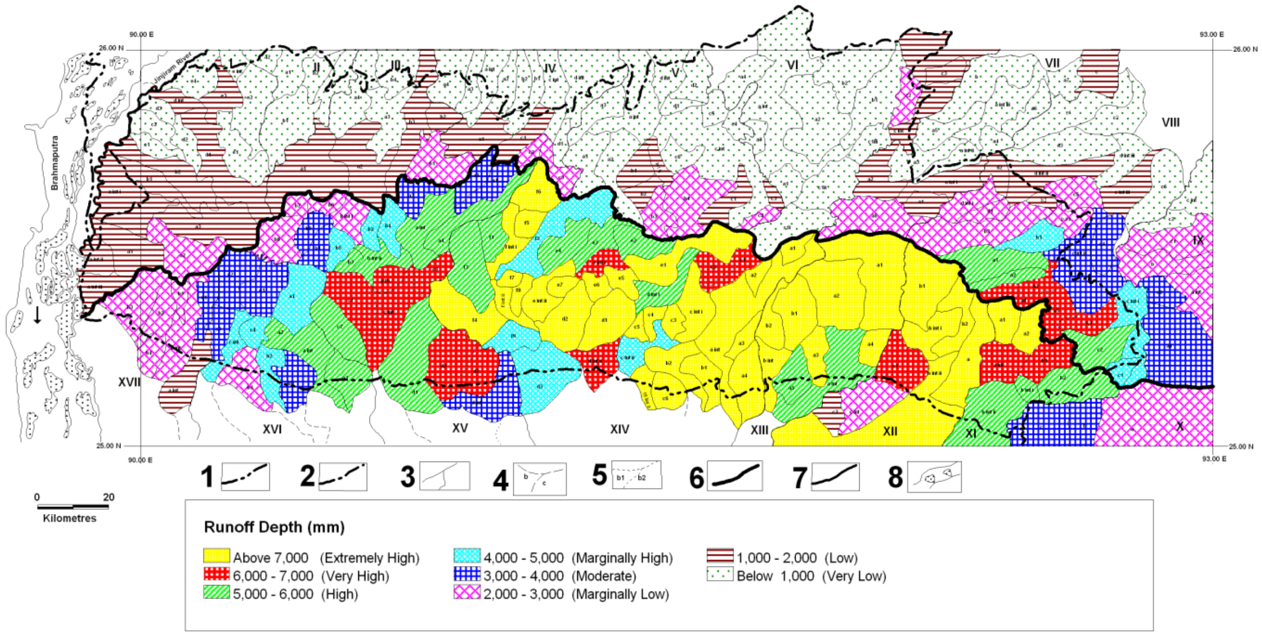


Fig-2.2: Pattern of Runoff Ratio



Abbreviations: 1=International Boundary, 2=State, 3=River Catchment, 4=Sub-Catchments, 5=Micro-Catchments, 6=Water Divide between Northern and Southern Slope, 7=Streams, 8=Rivers

Fig-2.3: Pattern of Annual Runoff Depth

2.4 Selection of Experimental Watersheds

In order to test the validity of physically distributed VSA related modeling in this unique situation of extreme wet conditions of land, and keeping in mind the spatial variability of hydrological parameters of land surface, the three experimental micro level watersheds were selected. The main task of selecting the appropreate sites for the experimental watersheds was pursued in consultation with two main agencies: one is the research organisation working on Geomorphology and hydrological aspects, the Institute of Geography, Polish Academy of Sciences, Warsawa (Poland) which has Inter-governmental Research Program with our University and also working on land degradation in Meghalaya plateau. Secondy, the two Departments (Directorate of Agriculture and Directorate of Soil and Water Conservation) of the Government of Meghalaya, Shillong which are implementing state level 'Integrated Watershed Management Programme (IWMP)' of the Ministry of Agriculture, Government of India, New Delhi. One watershed was selected from the extreme humid conditions of the southern slopes and two watersheds were selected from the rain shadow area of northern slopes of Central Meghalaya plateau for conducting the field surveys and experiments. A detail site description of experimental watersheds is given below.

2.4.1: Location and Extent of Experimental Watersheds (Fig.- 2.4)

(a) Um-u-Lah watershed which lies to the south of Cherrapunji is located on the southern slope of Meghalaya plateau (nearly 60 km from Shillong on Shillong- Sohra road) falls under East Khasi Hills District. This watershed is small in its size, covers an area of only 103.4 ha and extends from 91.715045º to 91.729592º East longitudes and 25.284860º to 25.268677º North latitudes. Um-u-Lah watershed falls under two localities of Cherrapunji (Sohra) that is Maraikaphon and Khliehshnong. The watershed is bounded by hill locks ranges from 1200-1300 m a.s.l. and also small and big rivers from all sides. The watershed has an undulating topography which comprises of small hills and depressions. The watershed area has a steep slope facing from north to south. Um-u-lah drainage flows toward south direction and change its direction towards west almost parallel with the Mawmluh Road (Fig.- 2.5A).

(b) Paham-Syiem watershed is situated on the northern slope of Meghalaya Plateau that is north of Shillong which falls under Ri-Bhoi District about 55 km from Shillong town on Shillong – Guwahati National Highway 40. It occupies an area of about 664.8 ha and extends between 25.892º-25.917º N latitudes and 91.842 º-91.885 º E longitudes. The watershed is an undulating hilly region surrounded in almost all sides by hill locks with flat tops ranging between 500-850 m a.s.l. making this area a fertile valley for cultivation. The drainage flow in west to east direction till it meets the National Highway- 40 and then flow toward south-west running almost parallel to road side from the mouth of the watershed (Fig.-2.5B).

(c) The Umpher Watershed lies to the northern part of the foot hills of Meghalaya plateau near Byrnihat which falls under Ri-Bhoi district. Byrnihat is a low lying platform region of the plateau and it gently slope towards the Brahmaputra plains. The Umpher watershed has undulating hilly terrain covering an area of 874.1 ha which extends from 26.05991 – 26.0975° N latitudes and 91.82414-91.87644° E longitudes. It is bounded by hill locks which ranges from 300 to 600 m a.s.l. making this watershed a fertile valley running from west to east direction. The drainage also flow gently from South- West and North-West to East direction and reaches the mouth of the watershed near the Conservation Training Institute (CTI) residential quarters (Fig.-2.5C).

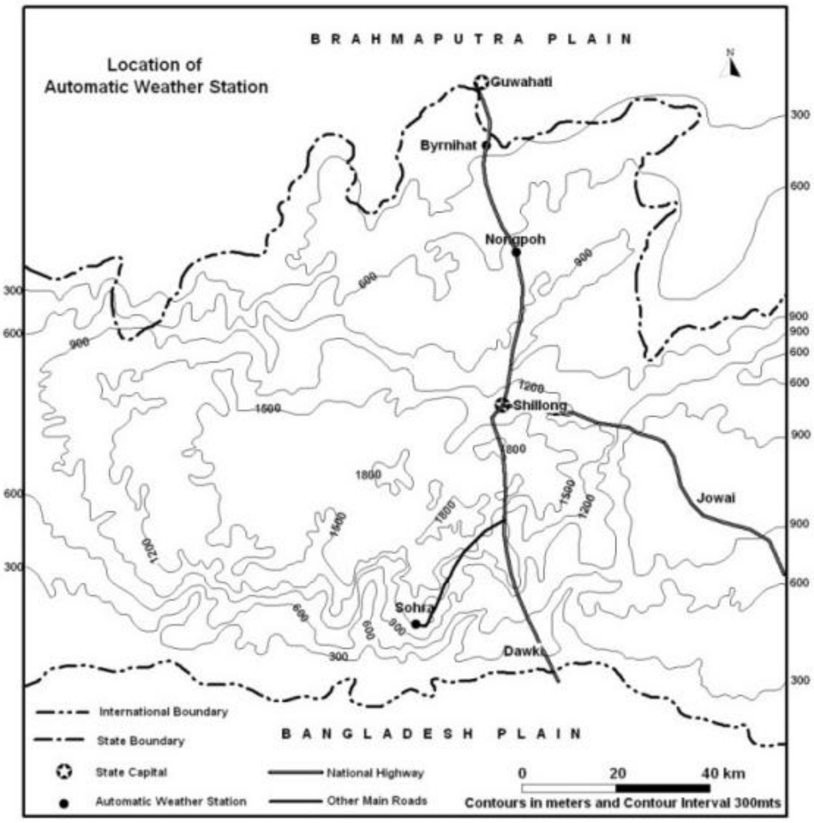
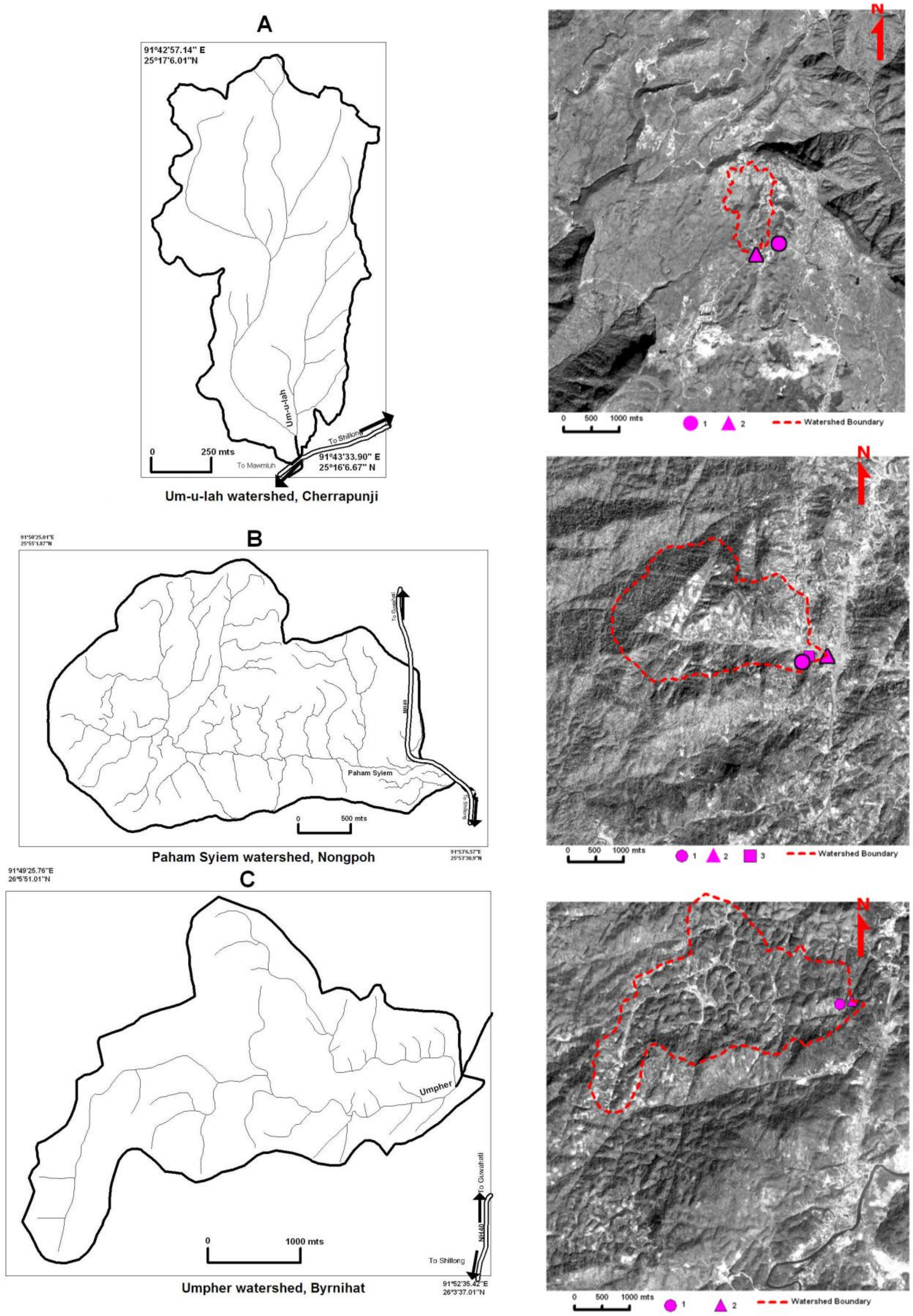


Fig.- 2.4: Location of Experimental Watersheds



Um-u-lah watershed, Cherrapunji

Paham Syiem watershed, Nongpoh

Umpher watershed, Byrnihat

N.B.: Dark colour of the image shows the dense forests, light-dark the grasses and white shade represents the establishments, settlements, roads and quarries; Source: Cartosat- II Image, NRSA Hyderabad.

Fig-2.5: Surroundings of Experimental Watersheds

2.4.2: Mapping of Dominant Runoff Processes

In fact, there is no scientific investigation conducted in this area except a few preliminary studies carried out by the scientists of Indian Council of Agricultural Research (ICAR), Regional Centre, Barapani, Shillong. However, it was decided that due to the location of experimental watersheds in the most-humid area with shallow soils, the saturation-excess processes are dominant. For application of VSA hydrology and analysis of sturation-excess process of runoff generation, the spatial data of topographic parameters and mapping of slope gradients, slope orientations (aspects), soils, drainage systems and landuse is essential requirements. The characteristic features of these paramenters would be interpreted separately in the next Section. However, the sources of their mapping are given here. The following surveys were conducted for the experimental waretsheds and experiments were carried out to apply VSA hydrological parameters in this area.

(i) **Conducting Topographic Surveys**: Since the size of experimental watersheds are small (below 1000 ha), a topo-surveys for preparing detail maps of elevation, soil and land uses are needed. Topographic surveys at R.F. 1:5000 scale were conducted to generate digital maps (DEM images) of the watersheds. In order to generate spatial features of morphometric parameters, drainage maps of its different orders were made at the same scale. Topo survey in Paham-syiem watershed (near Nongpoh) was conducted during April 2005 and contour and drainage maps were prepared with the help of using Toposheet of R.F 1:50,000 prepared by Survey of India, Dehra Dun. Likewise, topographic surveys of Um-u-lah watershed (near Cherrapunji) and Umpher watershed (near Byrnihat) were conducted on the same scale during March-April 2008 during the DST Project tenure time.

(ii) **Preparation of Soil Profiles and Mapping of Soil- Surfaces**: A total of eighteen soil samples were selected all three experimental watershed to analyse the textural properties of the soils. Soil sites were selected by following the surface parameters such as slope, elevation, topography, land use/land cover, soil depth and so on. Site description of soil samples collected from top soil (0-30 cm) is given in following Table- 2.3. With the help of these information and soil maps prepared by National Bureau of Soil Survey and Land Use Planning (NBSS&LUP) at R.F. 1:250,000 for Meghalaya state, the detailed soil surveys were conducted and mapped. This work involves analysis of soil samples collected which was done in the laboratory of NBSS & LUP, Regional Centre, Jorhat (Assam).

Table-2.3: Site Description of Soil Samples in Various Experimental Watersheds

Watershed	Sample Code	N. Latitude	E. Longitude	Slope (Degree)	Description
Um-u-lah (103.4 ha) Cherrapunji	Ch 1	26.07654	91.86414	10.34	Slope
	Ch 2	26.07654	91.8618	7.57	Hill Top
	Ch 3	26.08013	91.85757	8.47	Hill Top
	Ch 4	26.0825	91.85911	2.24	Valley bottom
Paham Syiem (664.8 ha) Nongpoh	Nong 5	26.0806	91.8614	15.00	Slope
	Nong 6	26.08142	91.8658	8.90	Hill Top
	Nong 7	26.08177	91.85918	5.67	Valley
	Nong 8	25.89973	91.85772	12.54	Slope
	Nong 9	25.90203	91.85843	13.69	Slope
	Nong 10	25.89963	91.86023	5.68	Valley
	Nong 11	25.89898	91.86274	2.87	Valley bottom
Umpher (874.1 ha) Byrnihat	Byr 12	25.90089	91.86543	4.79	Foot Hill
	Byr 13	25.8991	91.87167	3.79	Hill Top
	Byr 14	25.89709	91.88274	20.67	Hill Slope
	Byr 15	25.27935	91.71939	5.00	Valley
	Byr 16	25.2715	91.72137	25.57	Hill Slope
	Byr 17	25.27493	91.72321	6.89	Valley
	Byr 18	25.27282	91.72197	2.76	Flat Hill Top

(iii) **Requisition of Satellite Data:** Land use/land cover mapping is one of the important tasks of development of SDSS for watersheds. In order to prepare detail land use maps of the watersheds, the CARTOSAT-II (Resolution 2.5 m) satellite data were used. After identification of watersheds, data requisition were ordered to National Remote Sensing Agency NRSA (now National Remote Sensing Corporation NRSC), Hyderabad to supply the concerned data in digital form. This data were also used to compare land use pattern with developed DEM modeling for slope assessment and land use / land cover mapping.

2.5: Hydrometric Instrumentation

Hourly weather statistics at the stations located within the experimental watersheds (except station located in Cherrapunji is 775 m away from Um-u-lah watershed) were generated installing Automatic Weather Station (AWS) manufactured by Virtual Scientific Products, Roorkee (India) with 512 KB EPROM logger memory, 5 second per week clock accuracy and 5% accuracy of rain gauge recording at .25 mm of minimum count and wind speed resolution of 0.1m/s. Within the watershed in Paham-syiem, AWS was installed near its centre in the compound of Ri-Bhoi College, Nongpoh and at Byrnihat in the middle top of the flat ridge located in the central part of watershed sited in Conservation Training Institute (CTI), Government of Meghalaya, Byrnihat. The selection of AWS was made in consultation with Indian Meteorological Department officials, Government of India posted at its Regional Centre, Guwahati and Directorate of Soil and Water Conservation, State Government, Shillong. Instead of rainfall and temperature, the hourly statistics of various meteorological parameters were also collected and procured for the user agencies of this data, which are stake-holders in the project (Table-2.4). On the other hand, Automatic Gauge stations were installed at the mouths of the watersheds which are also manufactured by the same company.

Table-2.4: Weather Parameters and their Accuracy Levels

No.	Parameters	Units	Accuracy	Resolution
1	Hourly Instantaneous Air Temperature	(^{o}C)	±0.2^{o}C	0.01^{o}C
2	Hourly Maximum Temperature	(^{o}C)	±0.2^{o}C	0.01^{o}C
3	Hourly Minimum Temperature	(^{o}C)	±0.2^{o}C	0.01^{o}C
4	Hourly Instantaneous Relative Humidity	(%)	±2.0 %	0.03%
5	Hourly Maximum Relative Humidity	(%)	±2.0 %	0.03%
6	Hourly Minimum Relative Humidity	(%)	±2.0 %	0.03%
7	Hourly Wind Speed	(m/s)	2.0%	±0.1 m/s
8	Hourly Wind Direction	(^{O} from N)	±1.0^{o}	1.0^{o}
9	Hourly Total Rainfall	(mm)	5.0% of full range	0.2 mm
10	Hourly Solar Radiation	(w/m^{2})	±5.0%	-
11	Hourly Barometric Pressure	(mb)	±1.5 mb	0.1 mb

A pukk-structure of rectangular weirs was used at the mouth of each experimental watershed for generating hourly statistics of discharge rate (Fig-2.6).

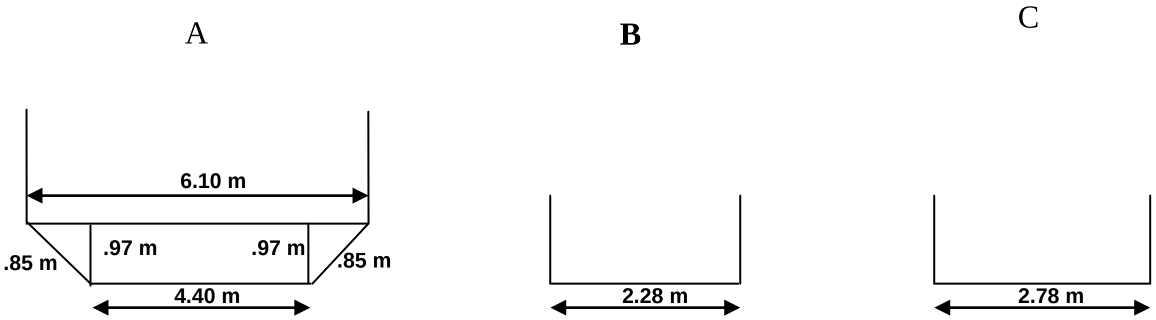


Fig-2.6: Shape and size of weirs structure used for measurement of water heads at the mouth of (A) Um-u-lah (Cherrapunji) (B) Paham-syiem (Nongpoh) and (C) Umpher (Byrnihat)

Automatic Water Level Recorder (AWLR) gauge were installed for measuring the hourly water heads which is essential for monitoring discharge of watersheds. Current-meter was used to measure flow rate and then discharge rate was evaluated by adopting 'rating curves' as given below for different weirs installed. Rating Curve Equations are given below

(a) 3.2831*(h)^1.6521 for Um-u-lah watershed (Cherrapunji)

(b) 2.28*1.83*(1.0- 0.2h)*(h)^1.5 for Paham-syiem watershed (Nongpoh), and

(c) 2.78*1.83*(1.0- 0.2h)*(h)^1.5 for Umpher watershed (Byrnihat),

Where h= head of water (m), constants 2.28 and 2.78 are length of the weires (in m) for their respective watersheds.

2.6: Data Limitations:

There were few but important problems faced by the team of investigators during the time of investigation. Firstly, the non-availability of latest-edition topo sheets of Survey of India, the old edition maps prepared at R.F. 1:25,000 (for Um-u-lah watershed) and at R.F. 1/50,000 scale (for Paham Syiem and Umpher watersheds) conducting surveys during 1972-1975, were used as basis for physical surveys of the watersheds. However, there is not much deviations of contour and drainage system from the surveys conducted by Survey of India because plateau is geologically much stable-land.

Secondly, in experimental watersheds, the regular monitoring of hourly weather and water level gauge recording were conducted from the date of installation of hydrometric instruments (August 2007 to December 2009; duration about two and a half years), however, there are data gaps in different time-slots of time-schedule and at different monitoring stations (Table-2.5). Paham Syiem watershed located near Nongpoh has less recording due to disorder of instruments, lightening problems especially during pre-monsoon seasons and sometimes mechanical problems. Fortunately, missing records of water head are of winter months when is base flow time and water head does not fluctuate much. Thirdly, Piezometer which was installed in Paham-syiem (Nongpoh) has to change the site because of problems of the farmer’s fields where it was installed. However, 70 to 99 percent observations received from AWS and AWLS were used for the present analysis.

Table-2.5: Duration of Recording of Weather and Stage Level at different Sites of Watersheds from Date of Installation to 31 December 2009

Duration	Days	Hours
(A) Um-u-lah watershed (Cherrapunji)		
(i) 12:00hrs 19 August 2007 to 13:00hrs 5 September 2008	382	9168
(ii) 12:00hrs 21 October 2008 to 10:00hrs 29 October 2009	373	8950
(iii) 10:00hrs 12 November 2009 to 23:00hrs 31 December 2009	48	1155
Total	**803**	**19273(92.84)**
(B) Paham-syiem watershed (Nongpoh)		
(i) 00:00hrs 18 August 2007 to 1:00hrs 8 February 2008	175	4200
(ii) 20:00hrs 12 August 2008 to 13:00hrs 11 November 2009	437	10481
Total	**612**	**14681 (70.72)**
(C) Umpher watershed (Byrnihat)		
(i) 10:00hrs 24 August 2007 to 12:00hrs 28 August 2007	4	94
(ii) 17:00hrs 20 September 2007 to 15:00hrs 22 September 2008	367	8806
(iii) 19:00hrs 26 October 2008 to 16:00hrs 4 May 2009	190	4541
(iv) 10:00hrs 9 June 2009 to 23:00hrs 31 December 2009	184	4606
Total	**745**	**18047 (86.93)**

Automatic Water Level Recorder (AWLR)

Duration	Days	Hours
(A) Um-u-lah watershed (Cherrapunji)		
(i) 1:00hrs 17 July 2007 to 11:00hrs 16 October 2009	821	19704
Total	**821**	**19704 (91.22)**
(B) Paham-syiem watershed (Nongpoh)		
(i) 17:00hrs 15 July 2007 to 23:00hrs 25 December 2008	518	12439
(ii) 00:00hrs 11 April 2009 to 11:00hrs 16 October 2009	189	4524
Total	**707**	**12863 (59.55)**
(C) Umpher watershed (Byrnihat)		
(i) 13:00hrs 15 July 2007 to 23:00hrs 31 December 2009	898	21552
Total	**898**	**21552 (99.77)**

N.B.: Figures in parentheses show percentages of recording time units to total span of recording.

2.7 Application of Models and Use of Tools and Techniques

There are many and varies runoff simulation models. However, a few of them are fully or partly distributed in nature. The choice of the model application would have basis that (a) the aims of the study which leads to a particular direction to choose a model, (b) the model suits to the reality of geo-hydrological processes acting in the study area and (c) the available tools and techniques for the accuracy of model. The aims and objectives of the present investigation are to analyse the spatial processes of runoff for simulation of the effects of topographic attributes on runoff processes to develop SDSS for different geo-hydrological conditions of Meghalaya plateau of most humid region of the world. For the purpose, physically distributed models of VSA hydrology can be suitable accurate predictions of runoff in such most humid areas. The saturation-excess processes of runoff generation which are part of VSA hydrology, are to be analysed not only to understand the nature of runoff generation, but also to strengthen the structure of SDSS by simulating the effects of topography (slope), soil (textural attributes) and land use (vegetal cover) on runoff processes.

Secondly the model application would predict accurate results for given specific geo-hydrological conditions.

It is interesting to note that the input requirements of these models are modest and dependent on the spatial parameters that may be generated from surveyed maps. The required parameters for further operations of the model application as given in Table-2.6 are operative through any GIS-based computer software.

Table-2.6: Parametric Requirements of Models Associated with VSA Hydrology

Spatial Attribute	Parameter	Data Source
1. Contour	(i) elevation (ii) Slope (ii)Slope orientation (Aspect)	contours digitally developed by DEM digitally developed by DEM
2. Soil	(i) Depth of restricted layer (ii) Soil type (based on texture) (iii) Saturated hydraulic conductivity (iv) Soil porosity (v) Field capacity (vi) Percent rock fragment	Field Surveys Laboratory Analysis Laboratory Analysis Laboratory Analysis Laboratory Analysis Laboratory Analysis
3. Land use	(i) Forest (ii) Grass (iii) unimproved pastures (iv) Agricultural land (v) Barren (vi) Water and road	NRSC, Hyderabad (Satellite Data) NRSC, Hyderabad (Satellite Data) NRSC, Hyderabad (Satellite Data) NRSC, Hyderabad (Satellite Data) NRSC, Hyderabad (Satellite Data) NRSC, Hyderabad (Satellite Data)
4. Weather	(i) Precipitation (ii) Air temperature (iii) Potential evapotransiration	AWS data AWS data Empirical formulation

SCS-CN method predicts runoff depending on the effects of soils and land use as its controlling factors and AMC of the soil conditions. The values of Curve Numbers are calculated ratio- based on soil and land use properties of watershed. But it does not show effects of topography on runoff prediction. The second method that is ‘topographic wetness index’ is largely dependent on topographic features like contour and slope but its map does not provide details about lateral flow processes are considered as factors of expansion or contraction of saturated areas rather than the structural components of runoff mechanism in the watershed. Accuracy and appropriate application of modeling systems for humid land conditions are the primary aim of the present investigation.

So far the application of tools and techniques of such modeling system is concerned, the SCS-CN method does not require much input data except the land use and soil texture maps. The weights of these attributes and calculation of CN are well defined and tabulated. However, for the application of later two models, that are fully distributed, the input files were created in Arc GIS to map the models parameters. Parametric relationships were established using raster- based map-algebra functions, while input files were processed by using Integrated Land Water Information System (ILWIS) software in order to get the results files and output mapping. Now, 3.6 version of this tool is available at open source and may be downloaded from Web site: http://www.itc.nl/ilwis/download/ilwis33.asp

2.8 Model Calibration

Since VSA model is process based and is fully spatially distributed, the calibration parameters are physically based which reflect topographic attributes, regional soil moisture characteristics and land use pattern for each cell of the watershed. Model calibration varies as spatial and temporal scales of the dimensions of study change. Slope, soil and land use maps provide calibration parameters to the model. The model was calibrated by using generated statistics of different events to analyse the location and extent of saturated areas in different geo- ecological environments

2.9 Performance of Model (Validation Procedures)

Model performance and good simulation results are dependent on the application of validation tool for model outcomes. There are many well-developed statistical validation tools depending on the regression analysis between observed and predicted values of model outcome. Model efficiency is somewhere measured by using absolute deviation methods of two attributes (observed as well as predicted series of outcome). The Standard Error is absolute deviation based method to evaluate the output performance. Another standard method of model performance and measurement its efficiency was given by Nash and Sutcliffe (1970) for hydrologic events. This method is statistically based on 'unexplained variation' in statistical regression analysis. The coefficient of efficiency (E) was calculated by this method using the following formula as

$$E= 1- [\sum(Qo- Qp)^2 / \sum(Qo -Qo_{mean})^2]. \quad \ldots \quad \ldots \quad (2.1)$$

If E=1.00, it shows perfect agreement between observed, Qo and predicted, Qp values when unexplained variation increases in the above equation, it must decrease the efficiency of a model. These two tests were applied to determine the level of significance of the model efficiency.

Section-III

Topographical and Hydro-Meteorological Characteristics of Experimental Watersheds

3.1 Introduction

It is appropriate to consider how topographic features affect the depth and discharge of runoff of a watershed. Undoubtedly, the size and shape, steepness, geological structure, slope orientation, hypsometry and morphometry (the drainage frequency and drainage-density) of the watershed are the major characteristic features which have implicit effects on the watershed hydrographs. Land use and soils of the watershed also have direct effect on runoff processes. For example, forest dominated land use/land cover pattern of any watershed have a high rate of evapo-transpiration that explicitly influences runoff rate (Wilson 1990:43). Likewise, soils of different types and soil depth affect porosity and infiltration capacity resulting to change in the availability of soil moisture leading to fluctuations in lateral flow and areal changes in saturated areas of the watershed. Behind these, the characteristic features of watershed provide the basis of associated spatial attributes which are used as calibration parameters in the model operation to establish their ‘cause-effect’ relationships. A detailed emphasis on topography, soil, land use and hydro-meteorological characteristics would lead us towards development of parametric generation for model application. Therefore, present discussion in this Section is devoted to the analysis of geographical phenomena associated with input attributes of model-use.

3.2 Topography and Morphometry

Steepness of slope, slope orientation and drainage system greatly influence the concentration time, infiltration capacity, surface as well as lateral flow in the watershed. More steeply the ground surface, more rapid is the runoff that will reduce concentration time. Shorter the concentration time, higher will be the flood peaks. Likewise, infiltration capacities tend to be lower as slopes get steeper. Slope orientation has direct impact on evapo-transpiration. For example, the areas under south and south-east facing slopes in the watershed have more quantity of water vapour thereby increasing rate of evapo-transpiration. Such parametric inter-dependent relationships of land surface are important to study for experimental watersheds.

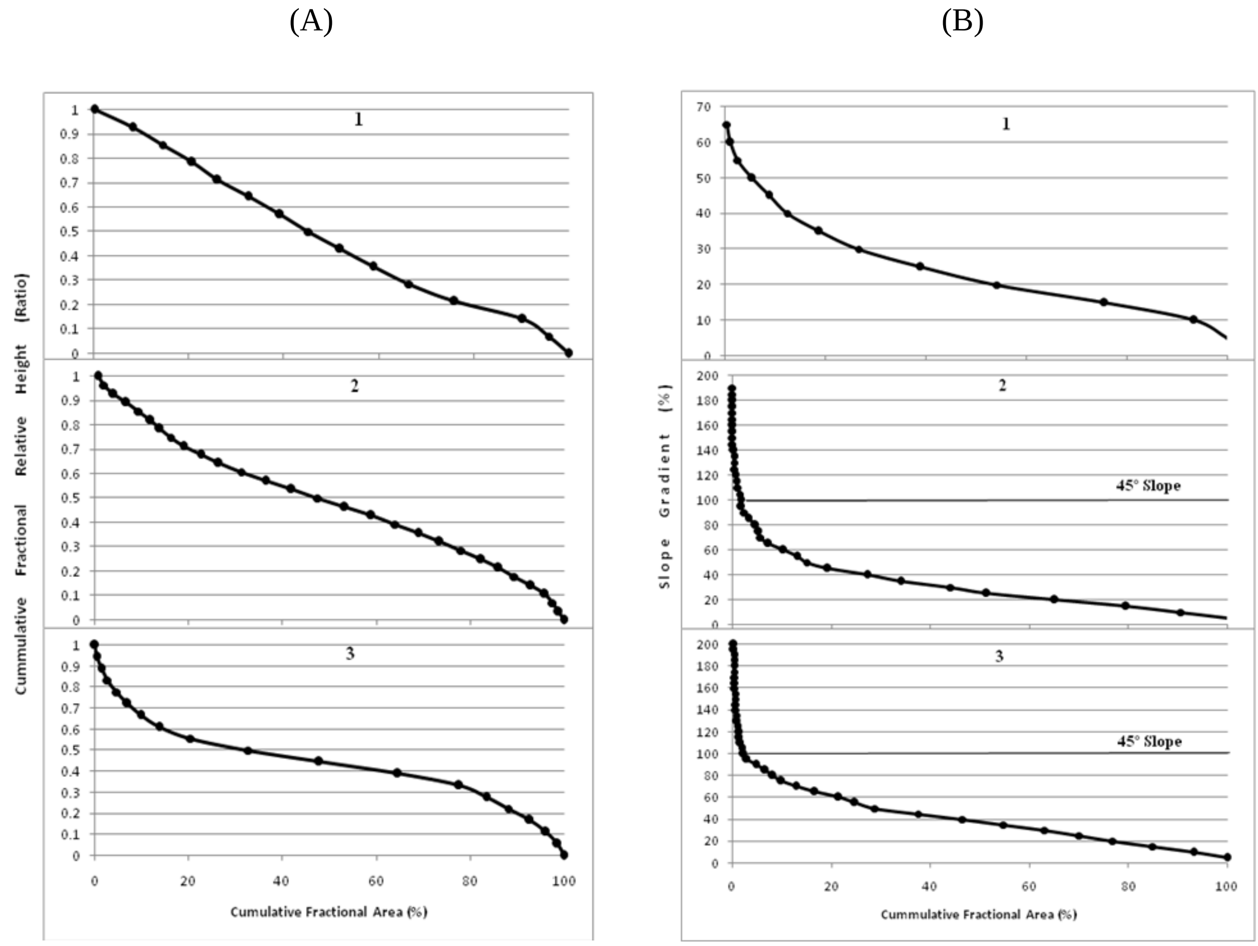
3.2(i) Area-Elevation Curves:

(a) Due to relative height of 130 m in a 1.70 km long Um-u-lah watershed (Cherrapunji), the average slope of about 8.0 percent has been noticed from the mouth of the watershed at 1,310 m to the upper reaches at 1,440 m a.s.l. Hill tops are generally flat and dissected by seasonal rivulets and depressions. Two streams are perennial and others are seasonal passing through these depressions during heavy rainfall monsoon season. Area-elevation curve of Um-u-lah shows proportionate area under each category of relative height of the watershed.

(b) Paham Syiem watershed (Nongpoh) of about 3.6 km long (straight line section) has a relative height of 277 m varying from 533 m to 830 m a.s.l. at its upper flat reaches in eastern part of the watershed. Being located in inter-piedmont valley, the surface conditions of this watershed is relatively smooth.

(c) Relative height of the Umpher watershed (Byrnihat) is recorded 360 m varying from 80 m to 440 m a.s.l. from the mouth to the upper reaches of south-western parts of the watershed. Kiling stream is the main tributary of Umpher watershed that provides regular water supply and influence the pattern of discharge rate. Undulating topography is main feature of watershed. Area-elevation curve shows that about 15.0 percent area of watershed lies at higher elevations.

From the hypsometric curves (Fig.3.1A), there is an indication that the areas of Central Meghalaya plateau display a matured plateau relief. For example, the fractional areas under each relative height are almost equal in Um-u-lah watershed which is located on flat lands of Meghalaya plateau, while Umpher watershed of foot-hills has less percentage of area under the categories of higher elevations (Fig-3.1A).

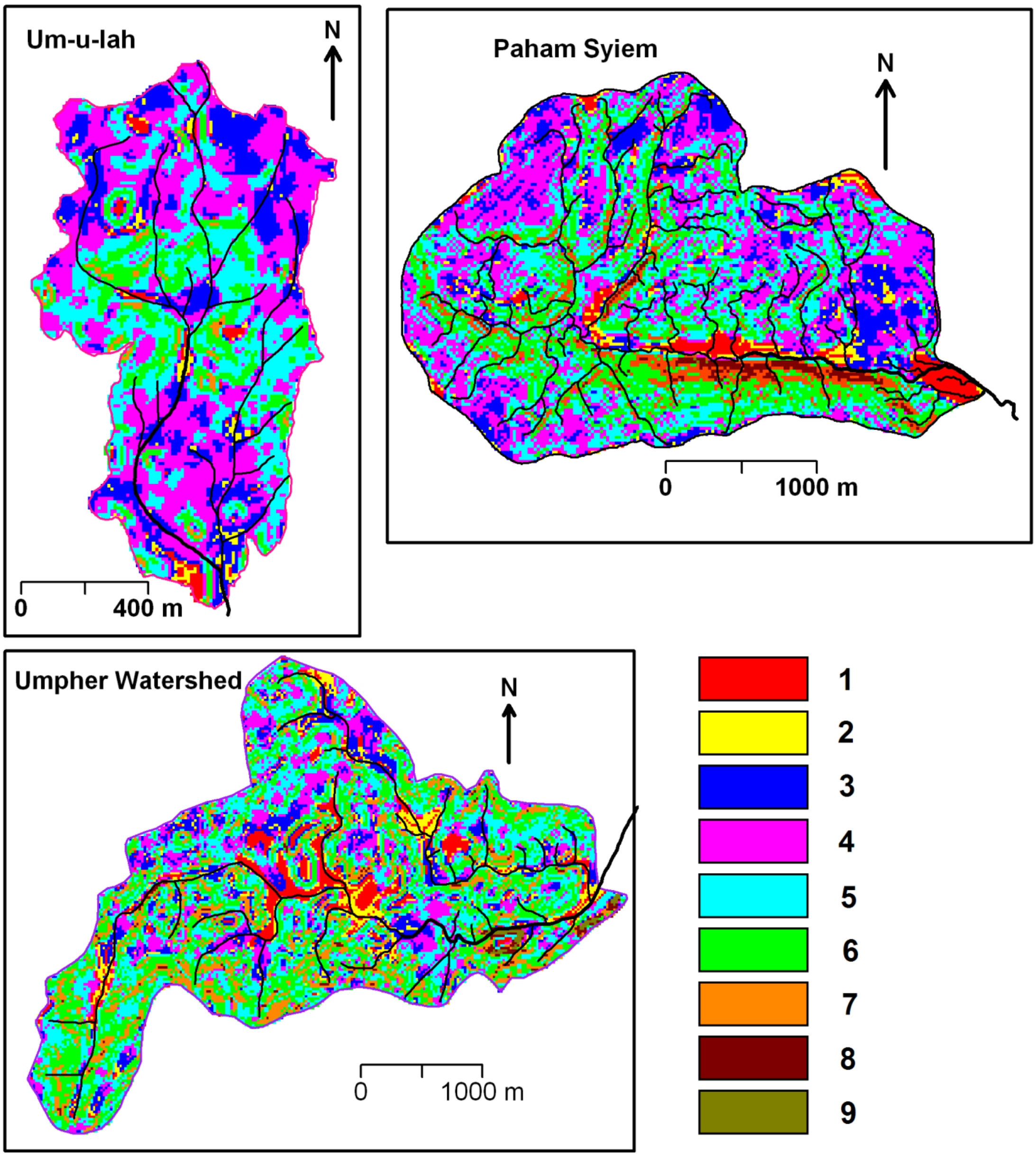


Abbreviation: 1= Um-u-lah , 2= Paham Syiem and 3=Umpher Watersheds

Fig.-3.1: (A) Hypsometric Curves and (B) Area- Slope Curves for the Experimental Watersheds

3.2(ii) Area-Slope Curves:

More than three-fourth area of Um-u-lah watershed accounts for slopes of moderate categories below 35%, while a few areas in Paham Syiem (Nongpoh) and Umpher (Byrnihat) are calculated under steep slopes of more than 100.0 percent (i.e., equal to 45^o) (Fig.-3.1B). Flat-hill tops with steep valley slopes are topographic features of these watersheds. It is indicative of higher dissection. There is a longitudinal flat land of rice cultivation along with the main stream on the mouth of of Paham Syiem watershed, while steep slopes are found either near the mouth or near the confluence areas of streams in these watersheds (Fig.-3.2).

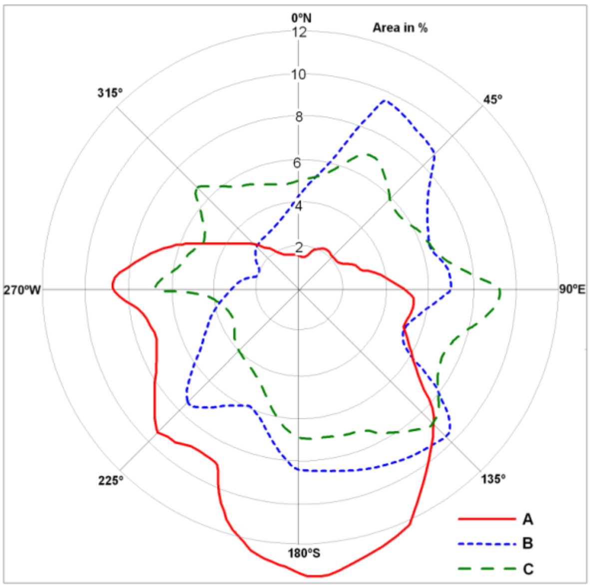


Abbreviations: Figures in parentheses are in Percent; 1= Flat (below -2%), 2= Very gentle (2- 4), 3= Gentle (4-10), 4= Moderate (10-20), 5= Moderately Steep (20-35), 6= Steep (35-60), 7= Very steep (60-100), 8=Most steep (100-175), Extremely steep (above 175%)

Fig.-3.2: Slope Variations in the Experimental Watersheds

3.2(iii) Slope-orientation (Aspects)

It is a useful parameter of topography which is closely related to the flow (overland as well as lateral) routing system in the distributed modeling for prediction of runoff. Flow movement is largely dependent on two main parameters of topography: slope gradient (steepness) and slope direction. Spatial features of slope gradient have been discussed earlier, while spatial features of slope-orientation would describe here. Slope orientation diagram shows that more than 1/3rd area of the different slopes of Um-u-lah watershed (Cherrapunji) has orientation towards South and South-East directions while the slopes of Paham Syiem (Nongpoh) are oriented East- and North- Eastwards. The slopes of Umpher (Byrnihat) are eastward facing (Fig- 3.3).



Abbreviations: A=Um-u-lah, B=Paham Syiem, C=Umpher Watersheds

Fig.-3.3: Slope Aspects in Different Experimental Watersheds

3.3 Land use/land Cover Pattern (Fig.-3.4)

Land use/ land cover of Cherrapunji area, where Um-u-lah watershed is located is dominated by tall grasses with their height of about 20 cm to 100 cm of linear leaves of about 10-65 cm thick. Such grasses belong to Poaceal family that have fibrous root system (Chakraborty et al. 2009, Kumar and Syiemlieh 2010: pp69-70) with thick netting that restricts to surface within the 5-10 cm on the top soils (Uma Shankar et al. 1991). It creates degree of macro-porosity and consequently increases porosity and infiltration rate in the area. So far as the land use/land cover of Um-u-lah watershed is concerned, it is grassland dominated with mixed forest patches situated on the upper part of watershed in its valley slopes (Fig-3.4A). Total forest land was accounted for only 16.18 percent. Barren land, land under settlements and roads are also account significant fraction of areas in which the rate of infiltration is less with high overland flow. Of course, such land use patterns do not help in retaining water in the soils and in maintaining rainfall-runoff relationship.

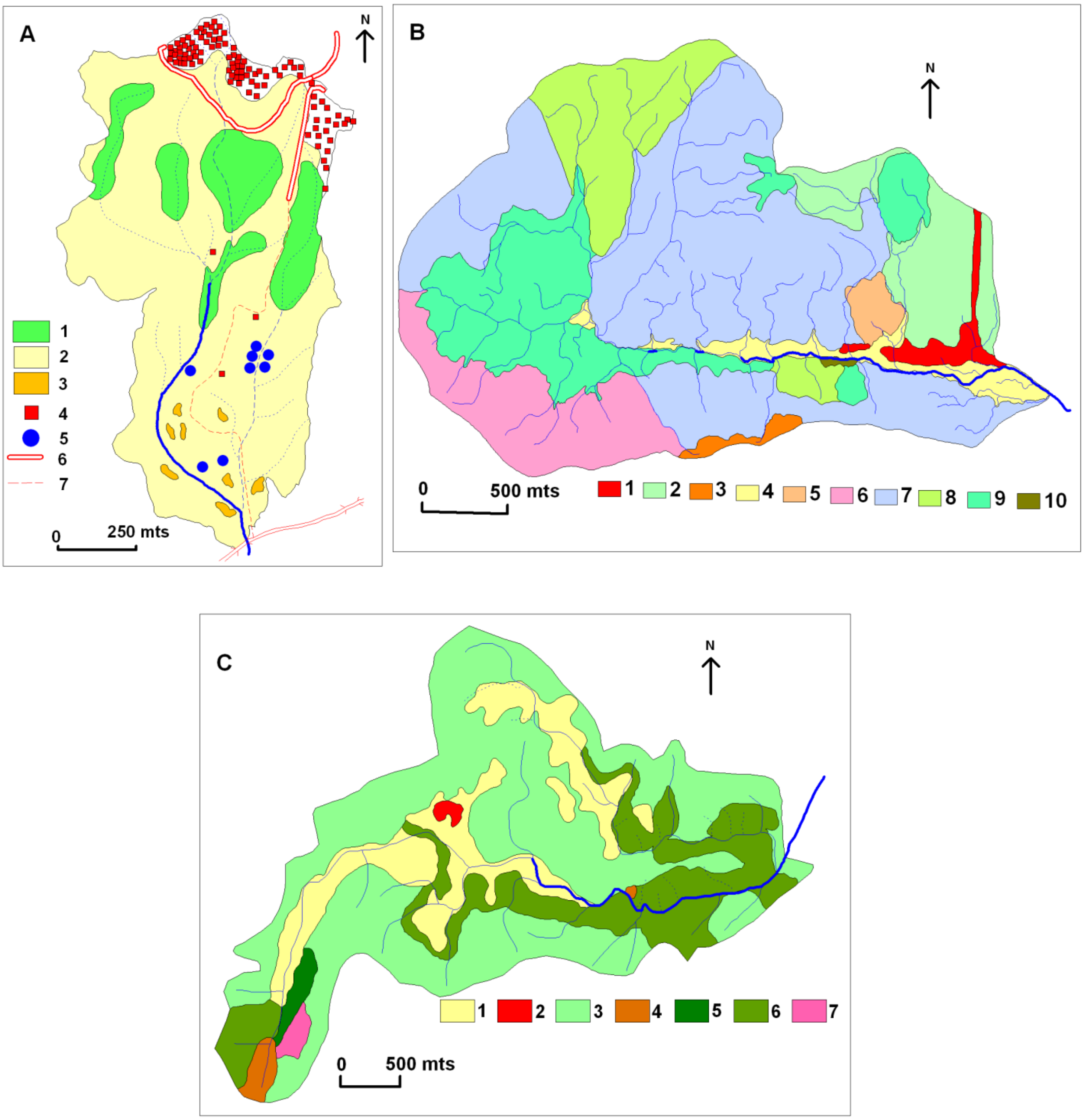
On the other hand, Pahamsyiem watershed (Nongpoh) has diversified land use pattern with ten land use categories from permanent cultivation practices (in flat valleys land) to a variety of Jhum (old with secondary forests and bamboo) and then to mixed thin forests

(Fig-3.4B). Being location of the watershed near Nongpoh town, the impact of anthropogenic forces on land use/land cover pattern is visualized in its diversification. Such pattern has spatial variability in infiltration capacity. For example, about 2.0% areas under settlement and roads have very less infiltration capacity. It may help in producing direct runoff while the moderately steep areas of jhum crops cultivation of the western slopes of watershed (19.47%) which are under seasonal flow have high infiltration capacity with high lateral flow. Further, the areas located on the steep slopes with jhum fallow practices (like broom and secondary forests) regulate runoff. In the lower level flat valley of rice cultivation has less-infiltration capacity.

Umpher watershed (Byrnihat) is dominated with dense mixed forests (40%) on the hillocks of water divide areas. The planted vegetation (20%) has secondary dominance. These areas are located generally on the hill slopes. On account of deep rooted vegetation of dense forests and planted trees, the infiltration capacity seems higher and evapo-transpiration processes are faster in these areas. Cultivation of paddy crop in the Umpher watershed along flat valleys in the central parts and on the flat hill tops (on the north-eastern side of the watershed) are part of the general land use practices. Quarrying is done in the southern most upper parts of the watershed and this obviously would reduce rate of infiltration and increases direct runoff. Overall, it may be said that the land use of Um-u-lah watershed is grass dominated, Paham Syiem is Jhum dominated and Umpher is Forest-plantation-cultivation dominated (Table-3.1).

Table-3.1: General Land Use/ Land Cover of Experimental Watersheds

Categories	**Um-u-lah**		**Paham Syiem**		**Umpher**	
	Area (ha)	**Area (%)**	**Area (ha)**	**Area (%)**	**Area (ha)**	**Area (%)**
Forest	16.73	16.30	-	-	502.84	57.46
Grassland	77.57	75.56	-	-	-	-
Barren land (exposed rocks)	0.87	0.85	5.47	0.82	-	-
Settlements and Roads	7.42	7.22	11.4	1.72	4.48	0.51
Ponds	0.07	0.07	-	-	-	-
Mixed thin forest	-	-	58.857	8.85	-	-
Permanent cultivation	-	-	25.795	3.88	158.24	18.08
Plantation	-	-	9.439	1.42	180.91	20.67
Jhum cultivation (Broom)	-	-	70.62	10.62	-	-
Jhum Fallow (Secondary Forest)	-	-	278.536	41.90	7.23	0.83
Jhum Fallow (Bamboo)	-	-	73.445	11.05	-	-
Jhum Cultivation (Crops)	-	-	129.458	19.47	-	-
Horticulture Crops	-	-	0.994	0.15	-	-
Quarry	-	-	-	-	11.26	1.29
Nursery	-	-	-	-	10.12	1.16



A-Um-u-lah Watershed: 1= Forest, 2= Grassland, 3= Barren land (exposed rocks), 4= Settlement, 5= Ponds, 6= Metalled Road, 7= Un-metalled Road

B-Paham Syiem Watershed: 1= Land under Settlement, 2= Mixed Thin Forest, 3= Barren Land, 4= Permanent Cultivation, 5= Rubber Plantation, 6= Jhum Cultivation (Broom), 7= Jhum Fallow (Secondary Forest), 8=Jhum Fallow (Bamboo), 9= Jhum Cultivation (Crops), 10= Horticulture Crops

C-Umpher Watershed: 1= Paddy Field, 2= Settlement, 3= Open Mixed Forest, 4= Quarry, 5= Nursery, 6= Plantation, 7= Slash and Burn

Fig.- 3.4: Land Use/ Land Cover of Experimental Watersheds

3.4 Soil Types

Infiltration capacity and porosity are key factors for identification of runoff processes (Schmocker-Fackel 2004: p17). Infiltration into the soil matrix depends on three parameters of soil use: soil texture, bulk density and soil moisture in soil matrix. Larger the size of macropores, higher is the permeability in the surface soils. Lower coefficient of permeability is experienced in high bulk density soils. In general, the soils of surrounding areas of Cherrapunji where Um-u-lah watershed is located are *Humic Dystrudepts/Typic Kanhaplohmults* under the world soil taxonomy with its sandy loam and loamy texture. The surface soils are shallow (40 cm to 80 cm in its depth) with gravelly (coarse fragments above 2.0 mm) and has sandstone bedrock (Prokop 2010: pp61-66). In the inner layers of soil, the coarse sand accounts for more than 50% share in soil texture. As a result, bulk density is found low ($1.4 g/cm^3$) with very high infiltration capacity (more than 100 cm/day) that influences the lateral flow contribution to hydrographs.

Macro-porosity agents like tree-root nets, cracks in surface soils also add the effects in increasing infiltration capacity. The texture of soils of Um-u-lah watershed is sandy-loam dominated texture with very low percentage of clay contents. As a result, permeability coefficient is very high ($k =< 100$ cm/day) in this watershed.

Soils of Paham Syiem watershed (Nongpoh) are general 150 cm thick with a moderate thickness of surface soils of 50 cm. The texture of such soils is sandy clay on hill-slopes and clayey in the lower part of watershed (Fig.- 3.5). Runoff formations are controlled by macro-porous agents like tree-roots and shifting cultivation during heavy rainfall. Lower horizon soils are gravelly and porous and help in fastening lateral flow and in maintaining confined aquifer which is weak but is available in the watershed because of local lineament in which Paham Syiem stream flows.

The soils of Umpher watershed (located in lower part of foot-hills near Byrnihat) are clayey and sandy-clay in texture with low permeability. Lateral flow is therefore confined only in the surface soils of 40 cm thick especially during heavy rainstorms of monsoon season. Confined aquifer is strong and has a thickness of about 50-70 cm which contributes to the base flow in the watershed. Plantation of trees and quarrying in the upper reaches of watershed increases macro-porosity.

On the basis of the analysis of soil samples collected from various soils of experimental watersheds, the following conclusions are drawn: (a) the soils of these watersheds have low bulk density (below $1.45 g/cm^3$) (Table- 3.2) and (b) the triangular graph depicts the distribution of soil particles of various experimental watersheds (Fig.-3.5) that indicates the soils of Um-u-lah have high to very high permeability coefficient (k = 40-140 cm/day), while the soils of watersheds located on the northern slopes, namely Paham Syiem and Umpher have low to medium permeable coefficients (k = 5- 35 cm/day) because of increase in clay contents in the soils in some parts of the watershed (Table-3.3 and Fig.-3.5).

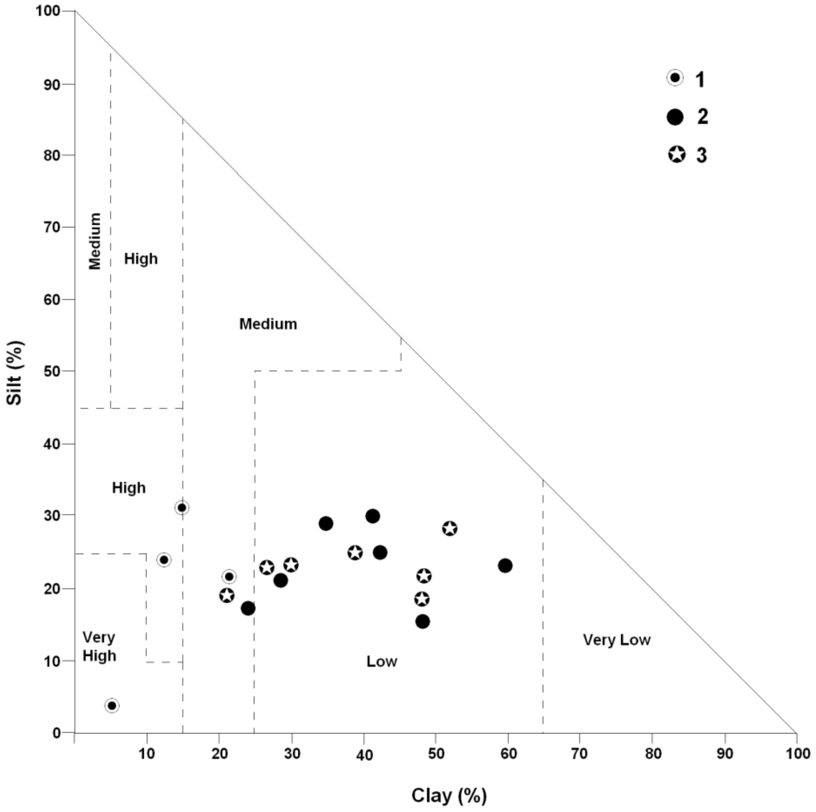
Table-3.2: Particle Size Distribution and Bulk Density

Sl. No.	Sample No.	Sand (%)	Silt (%)	Clay (%)	Texture Class	Bulk Density (g/cm³)
1	Ch-S1	54.1	30.9	15.0	sl	1.06
2	Ch-S2	90.2	4.3	5.5	s	1.25
3	Ch-S3	57.6	21.4	21.0	scl	1.07
4	Ch-S4	63.5	24.5	12.0	sl	1.04
5	ByR-S1	59.9	19.6	20.5	sl	1.11
6	ByR-S2	29.8	21.7	48.5	c	1.15
7	ByR-S3	17.7	29.3	53.0	c	1.07
8	ByR-S4	47.0	23.0	30.0	scl	1.18
9	ByR-S5	35.3	25.2	39.5	cl	1.03
10	ByR-S6	52.5	21.5	26.0	scl	1.12
11	ByR-S7	33.3	17.7	49.0	c	1.06
12	Nong-S1	28.9	30.1	41.0	c	1.10
13	Nong-S2	17.3	22.7	60.0	c	1.11
14	Nong-S3	58.0	17.5	24.5	scl	1.05
15	Nong-S4	35.5	29.5	35.0	cl	1.09
16	Nong-S5	35.3	15.2	49.5	c	1.08
17	Nong-S6	49.0	23.0	28.0	scl	1.10
18	Nong-S7	32.5	25.5	42.0	c	1.12

Source: Soil analysis was done in the Regional Office, NBSS&LUP, Jorhat, Assam

Table-3.3: Soil Matrix Permeability

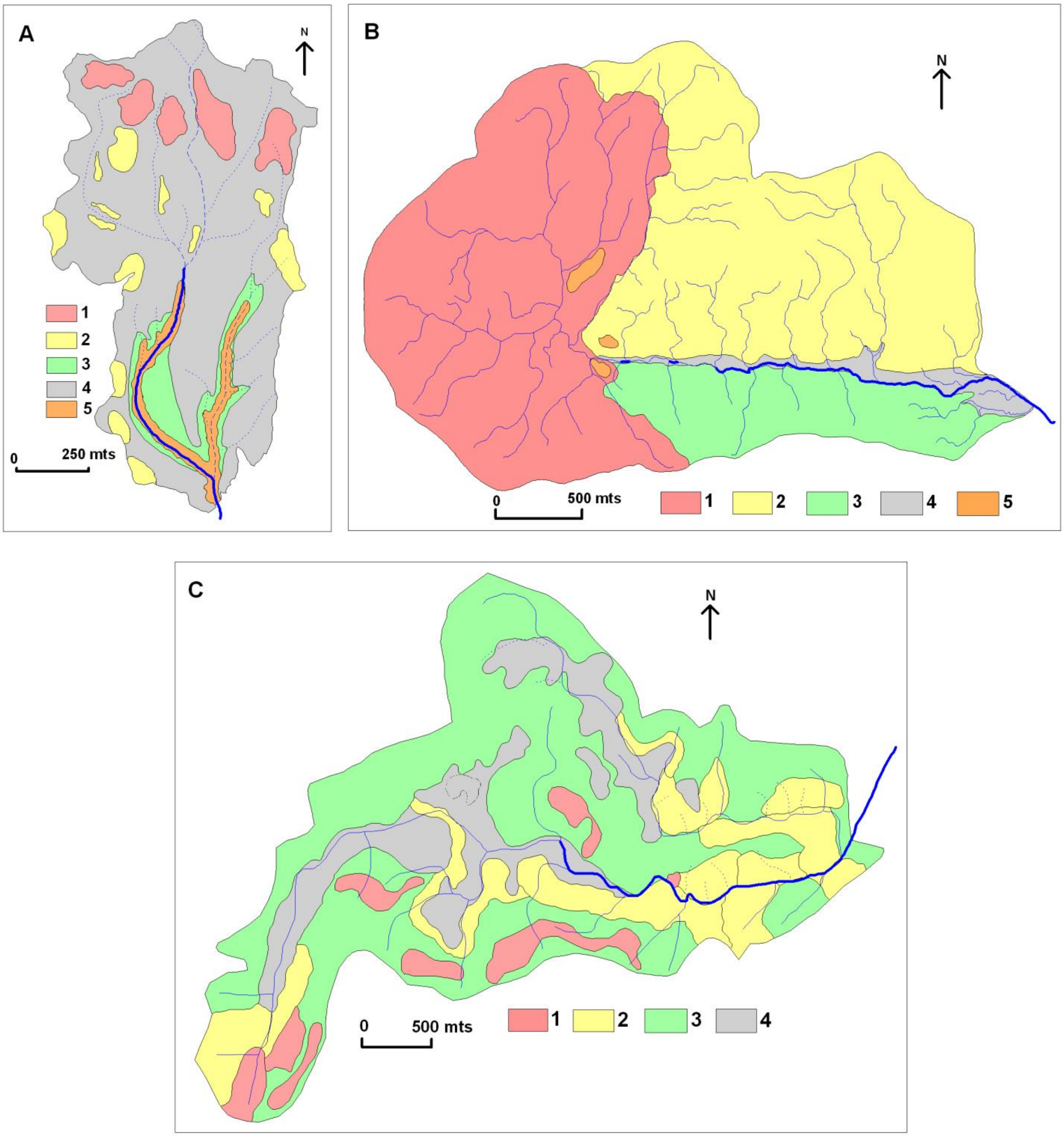
Texture Classes	Low Range of Bulk density (below 1.45g/cm^3)	
	Permeability	K (cm/day)
A	Low	<10
B	Medium	10-40
C	High	40-100
D	High	40-100
E	Very high	>100



N.B.: Soil samples of each watershed fall under low bulk density class. This class is used for calculation of porosity coefficients in the present study (see Table-3.2).

Abbreviations: Soil samples collected from 1= Um-u-lah, 2= Paham Syiem and 3= Umpher watersheds

Fig.-3.5: Soil Texture Based Permeability Classes



A-Um-u-lah Watershed: -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

B-Paham Syiem Watershed: 1= Alluvial sandy Loamy, 2= Red Colour Loamy Sandy (2-3m deep), 3= Red Colour Loamy Sandy (1-2m Deep), 4= Light Clay (2-3m Deep), 5= Stony

C-Umpher Watershed: 1= Highly Porous Sandy, 2= Sandy Loam, 3= Loam Clay, 4= Shallow impermeable (low porosity)

Fig.-3.6: Soil Types of Different Experimental Watersheds

3.5 Hydro-meteorological Characteristics (Figs.-3.7 and 3.8)

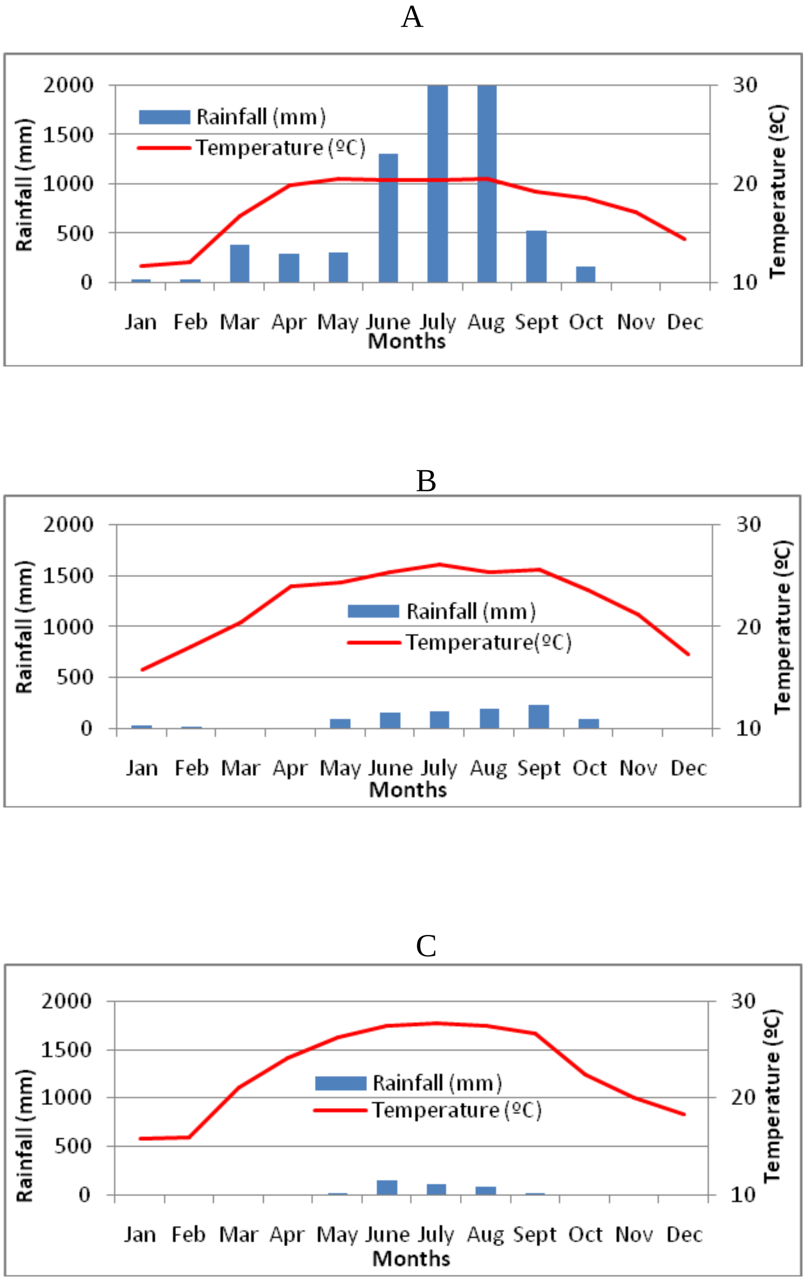
The location of Meghalaya plateau in the North-Eastern part of the country near Tropic of Cancer is characterized by most humid monsoonal conditions where more than three-fourth share of annual rainfall is precipitated in summer (May-October) while winters (November-April) are dry. Such seasonal variations in weather conditions control the runoff regime. In spite of higher evapo-transpirative demand of atmosphere, the summer rainstorms create saturated areas in watershed and, consequently, it (saturated areas) determines the time of concentration, recharge and discharge in soil layers and fluctuating trends of hydrographs. Base-flow contribution to runoff dominates in dry winters which smoothen the trends of hydrographs. No doubt, the temperature and rainfall are main drivers of controlling hydrograph trends as variations in weather parameters are depicted by taking into account the monthly rainfall and temperature of three experimental catchments:

(a) Um-u-lah watershed (Cherrapunji) which is located at fontal south facing slope, is influenced by wet adiabatic lapse rate of 2.5ºC for every 300 m of elevation (as moisture laden south-west monsoon winds have to cross the plateau barrier). It is observed between the extreme margins of the Dawki fault where Cherrapunji (on upper flat) and Thangkarang at lower parts of the fault-margins. These two stations are located at a short horizontal distance of 2,000 m with a great variation in elevation of 400 m varying from 500 m (Thangkarang) to 1,400 m (Cherrapunji) with the slope of about 48.00 percent. Due to steep slope gradient and effects of fast adiabatic lapse rate of wet winds, the monsoon precipitates with high intensity and long duration rainstorms (Singh and Syiemlieh 2001). Detail diurnal pattern of weather conditions may provide clues for rainstorm characteristics of the watershed.

(b) In the Paham Syiem watershed (Nongpoh located on the central part of northern slopes), the noon-time air pressure becomes low (950-955 mb) resulting to increase in temperature upto 35ºC. Nights are humid and calm (85-95% with below 4 m/s wind speed). Moderate wind speed (6-8 m/s) during day time attracts rainfall of low intensity and small duration rainstorms during summer monsoon. Monthly rainfall does not exceed 50 mm in the monsoon months.

(c) Umpher watershed (located near Byrnihat in the foothills) which comes under close contact with the weather conditions of Central Brahmaputra valley, has noon time moderate air pressure (993-1000 mb) with moderately high day temperature (32ºC and above) from 9:00 AM to 4:00 PM. Relative Humidity is recorded high at night (above 90%).

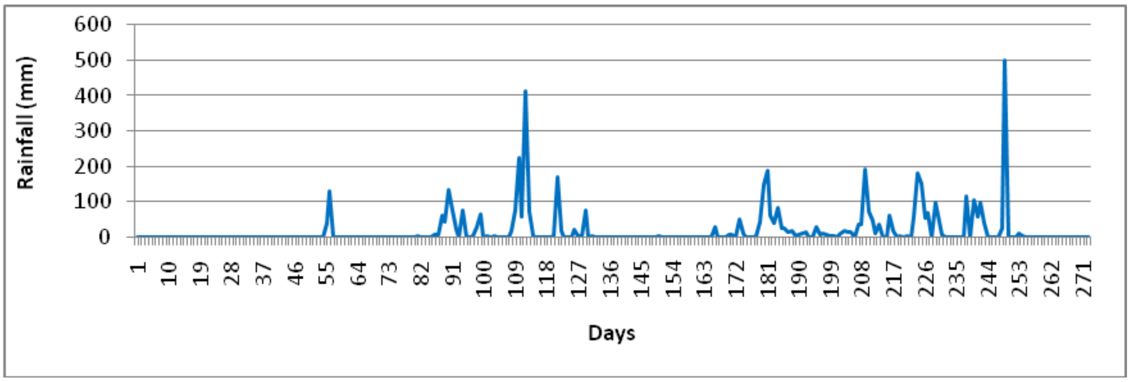
Air becomes dry during day time with moderate wind speed (4-6m/s) retarding the rainfall duration and rain intensity in the watershed. Occasional rains of short duration (less than two hours) were monitored during the month of July.



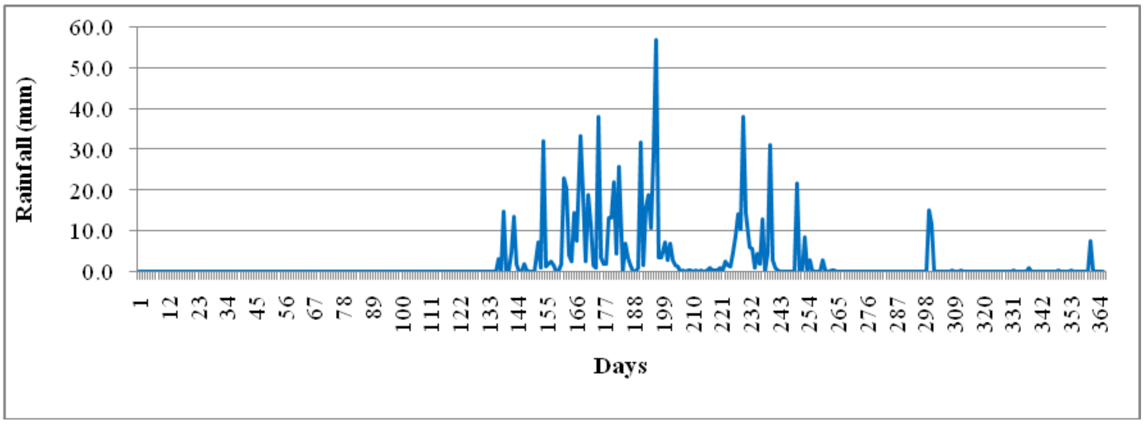
Abbreviations: A=Um-u-lah, B=Pahamsyiem and C=Umpher Watershed

Fig.-3.7: Rainfall and Temperature in Experimental Watersheds

Um-u-lah Watershed



Umpher Watershed



N.B.: Days starting from 1st January 2008

Fig.-3.8: Patterns of Daily Rainfall Intensity in Um-u-lah and Umpher Watersheds

In two different rainfall conditions of central Meghalaya plateau, the Um-u-lah watershed of intensive rainfall and the Umpher watershed of less intensive rainfall pattern, it is clear that wet summers have concentration of rainfall which might have close agreement with the pattern of daily discharge rate. It is obvious from daily pattern of rainfall intensity that it (rainfall intensity) produces low runoff yield during dry season. Most runoff fluctuations would be seen during the summer season when events of overland flow dominate the runoff processes. However, the event wise study of hydrographs would be pursued separately in the next section of the Report.

Section - IV

Hydrograph Analysis

4.1 Introduction

Two different widely recognized views of modeling runoff have been forwarded. First, the establishment of rainfall-runoff relationships is an essential tool for extrapolation of results of available statistics of watershed. This view of modeling is dependent on ‘inductive’ approach of finding out realities of such relationships of input and output products. It is closely related to transfer function of input (rainfall) to output (runoff) in linear or non-linear manner in the watershed, that is established by analyzing watershed characteristics in the study of process-description. The second view of process-description holds that there is an analogy involved in the description of the runoff processes in different watersheds while their land surface characteristics vary as depicted by changing constants and coefficients of an applied model. The faith in predictions that lies outside the range of data availability is solely based on the application of a *priori* model and its output. Such ‘deductive’ approach of process-description may be more useful for simulation of the effects of watershed characteristics and runoff prediction in ungauged watersheds. The first approach is adopted in this Section to analyse the hydrograph pattern of different experimental watersheds with interpretation of their flow characteristics.

4.2 Flow Discharge Variation

The discharge regime of Monsoon Rivers is largely dependent on the rainfall pattern. Similar rainfall patterns are found in the most humid areas of Meghalaya Plateau because it falls under the Monsoon climatic conditions. However, discharge pattern vary in different watersheds because of differentiations in landform characteristics, soil types and land use patterns. As per the recorded precipitation of the year 2008, the total annual rainfall received at Um-u-lah watershed in 273 days was 4,972 mm, out of which 2,835 mm was precipitated in four months (May to August) with high flow discharge rate. It is interesting to note that the year 2008 was dry period in the Meghalaya plateau because total rainfall precipitated in this year was recorded less than three- fourth than the normal rain. However Um-u-lah watershed (located in the highest rainfall area of Cherrapunji) received sufficient rainfall in 273 days of the year of which 4,642 mm was calculated as runoff and remaining 330 mm was assumed as evaporative demand of atmosphere.

Comparing distributional characteristics of discharge, it is fact that the annual water yield per ha was recorded the highest 4.64 m ha in Um-u-lah watershed of 103.4 ha with very high fluctuations (CV=352.4%) varying from the highest average discharge of 4.1m^3/s on 29 June 2008 to the lowest .006 m^3/s even on the 5th of August of the wet season and also in January during the dry period. Significant fluctuations in pattern have been shown in Um-u-lah watershed (Table- 4.1, Fig- 4.1).

Table-4.1: Time of Recording and Distributional Characteristics of Discharge of Experimental Watersheds

Items	Um-u-lah (Cherrapunji)	Paham Syiem (Nongpoh)	Umpher (Byrnihat)
Duration	1stJan'08-29thSept'08	1stJan'08-28thDec'08	1stJan'08-31stDec'08
No. of days	273	360	366
Total rainfall (mm)	4927	564*	827
Total runoff** (mm)	4642.3	1627.5	1163.8
Annual yield (m ha)	4.6423	1.6275	1.1638
Average discharge (m^3/s)	.15221	.3431	.3217
Maximum discharge (m^3/s)	4.103	1.5668	1.7380
Minimum discharge (m^3/s)	.006	.0021	.3217
(Max-mini) discharge(m^3/s)	4.0970	1.5647	1.4163
Standard Deviation (m^3/s)	.5364	.35041	.35178
Coefficient of variations ***(%)	352.39	102.13	109.35

NB: *Rainfall figures include duration of 151 days from August to December '08.

** Total runoff calculated dividing total discharge by area of watershed as RO=(Q/A). The conversion equation used here is RO (mm)= [{Q(m^3/s)*60*60*24*1000}/{A(ha)*10,000}].

*** Coefficient of variation (%) is the value of Standard Deviation per 100 units of average discharge as 100*(SD/Mean)

The trend of discharge rate of Paham Syiem watershed was recorded much smoother. It portrays a slowly increasing pattern during the period of monsoons and subsides gradually during post-monsoon period (Fig-4.1 B). The discharge rate is low in pre-monsoon period because of ample soil recharge period while it is moderate in post-monsoon period due to discharge when base flow contributes to the hydrograph.

Annual water yield was recorded 1.16m ha in Umpher watershed with a total runoff depth of 11,627 mm during the year 2008. This annual yield is far lesser than the Um-u-lah watershed. Undulating topography influences the flow of underground water that regulates the runoff. Of course, the location of this watershed is in the foothills of Byrnihat-Jorabat areas which have downward flow of underground water with strong aquifer discharge and fast and continuous base flow contribution to smoothen the discharge in the watershed.

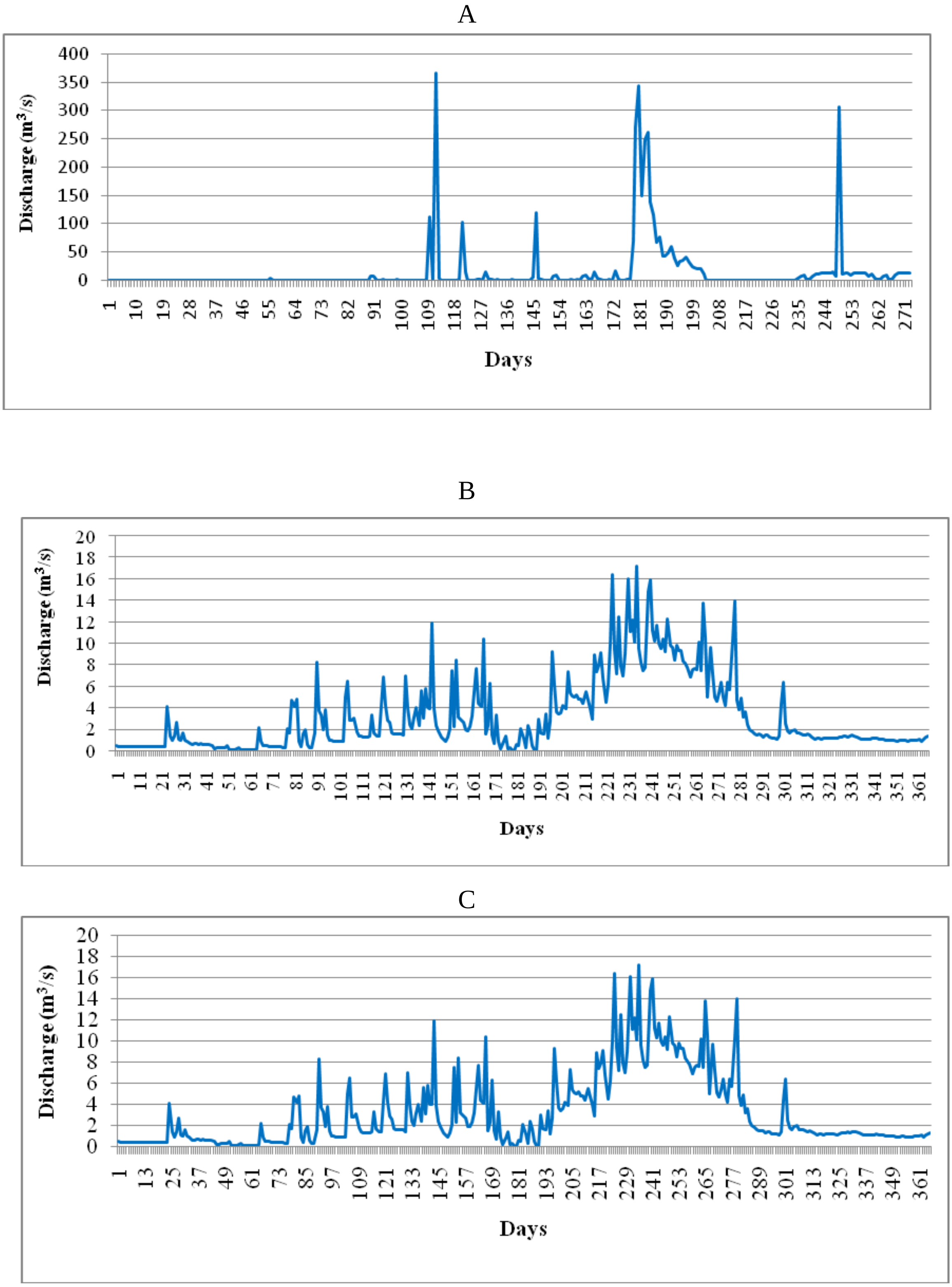


Fig.-4.1: Pattern of Daily Discharge Rate in (A) Um-u-lah, (B) Paham Syiem and (C) Umpher Watersheds

4.3 Hydrologic Characteristics of Experimental Watersheds

Selecting major hydrologic events caused by high rainfall intensities during the monsoon period an example of each watershed, the following characteristic features of these different geo-hydrologic environments was highlighted.

(a) Um-u-lah watershed (Cherrapunji landscape) Characterized by thin Soil and Heavy Rainfall:

The analysis of a long duration hydrograph of 70 hours (1:00hr 17 July to 22:00hr 19 July 2008) makes it clear that during the rainstorm of this period, it received about 920.2 mm rainfall with its average intensity of 13.145 mm/h. The storm produced a total runoff depth of 882.16 mm in 70 hours from the watershed with an average depth of 12.60 mm/h. Rainfall and runoff have almost complete agreement in its patterns (Fig.-4.2). The hourly average discharge was 3.825 m^3/s with its many peaks as it was at 8.084 m^3/s discharge at midnight between 17th and 18th July, 11.206m^3/s discharge at 11:00 hrs on 18th July 2007 and 7.96m^3/s at midnight of 18th and 19th July 2007 (Fig-4.3).

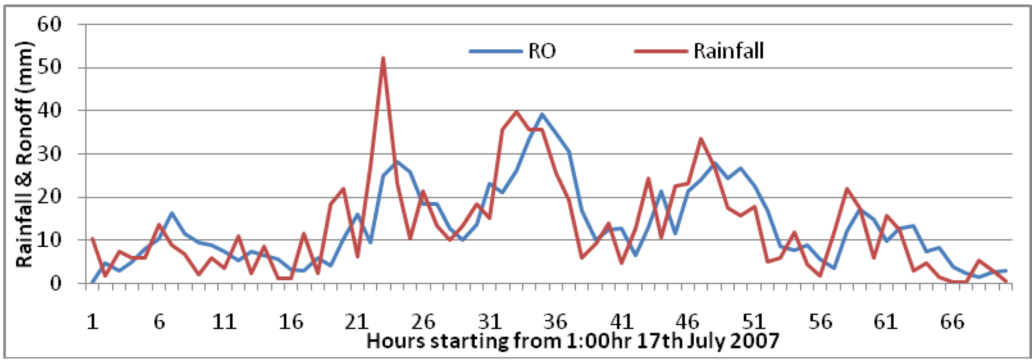


Fig.- 4.2: Rainfall and Runoff patterns in Um-u-lah Watershed

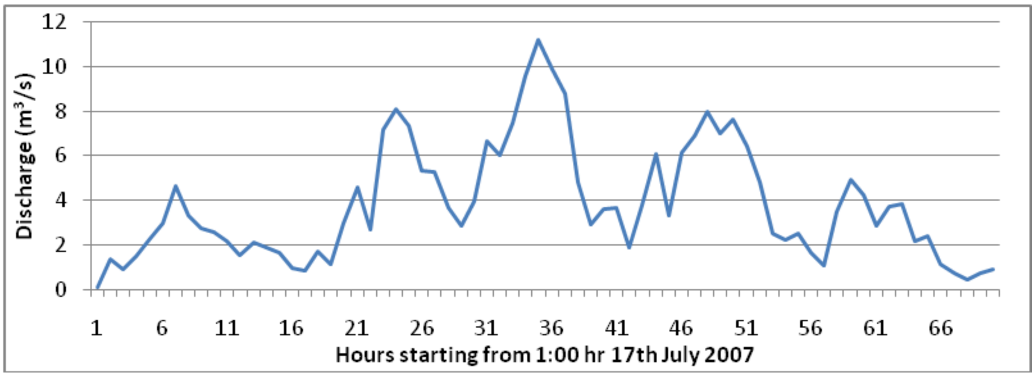


Fig.- 4.3: Pattern of Discharge in Um-u-lah Watershed

It produced an average yield of 133.17 m^3 per hour per ha form a watershed size of 103.4 ha that seems the highest in countries of wet tropical conditions (Table-4.2).

Table- 4.2: Hydrologic Characteristics of Events in Experimental Watersheds

Description	**Um-u-lah**	**Paham Syiem**	**Umpher**
Size of Watershed (ha)	103.4	664.8	874.1
Antecedent Moisture Conditions (AMC)	III	I	I
Hydrologic Event duration(hrs)	12	20	49
Total surface water (RO) produced(m^3)	279865.10	48106.8	351926.25
Average surface water produced per hour (m^3/h)	23322.10	2405.34	7182.168
Average surface water yield produce per hr/ha (m^3/h/ha)	225.552	3.618	8.2166
Total storage in channels (m^3)	20486.1	8755.4	75277.2
Share of storage of total volume per cm of Pnet (%)	7.32	18.20	21.39
Total precipitation (mm)	262.8	20.20	47.60
Total loss (mm)	10.80	12.97	7.40
Share of loss to total (%)	4.15	64.21	15.54
P net (P-loss)=(ΣQdt/A) (mm)	252.0	7.23	40.260
Travel time (hrs)	1.00	7.00	12.00
Peak flow (m^3/s)	11.206	3.50	4.474
Average discharge (m^3/s)	6.473	0.668	1.995
Minimum discharge (m^3/s)	2.9006	0.023	0.81603
Standard Deviation of discharge (m^3/s)	2.910	1.1136	1.0027
Co-efficient of variation (%)	44.956	166.70	50.260

Moreover, the specific hydrologic event of this watershed were analysed by taking into account 12 hrs duration hydrograph (4:00 hrs to 15:00 hrs on 18th July 2007) of its extremely rainfall intensity conditions (a total rain precipitated in 12 hrs was 262.8 mm with average rainfall intensity of 21.9 mm/hr). It is interesting to note that precipitation loss is observed negligible, i.e., only 3.00 mm (about 1.15% to total rainfall precipitated during the hydrologic event). It means vey less rain was absorbed by the soil since Antecedent Moisture Condition (AMC) was excessive. On account of less duration of travel time of surface runoff (i.e., 1:00 hour) and a comparatively small size experimental watershed, the rising limb of hydrograph took 7:00 hours to reach the peak flow of 11.20m^3/s from its lowest level of 3.66 m^3/s which rose at stream flow rate of 1.078 m^3/s per hour and declined faster at the rate of 2.076m^3/s per hour. The average flow was 6.557m^3/s during the hydrologic event. Because of extreme high AMC, contribution of regular base flow is 2.82 m^3/s while minimum level of base flow was .084m^3/s during winters. As a result, average direct surface flow was calculated at 3.6566 m^3/s and the unit hydrograph shows an average rate of flow per centimeter of net precipitation at 0.0145 m^3/s (Table-4.3). Trend of unit hydrograph depicted by Fig- 4.4, shows that 8th hour has the highest response of 0.32959 m^3/s per centimeter of excess rain during the event.

Table-4.3: Ordinates of Unit Hydrograph at Um-u-lah Watershed

Date	Time	Total Stream Flow(Q)	Base Flow	Regular base flow	Total Base	Direct Surface	Unit Hydrograph
DD/MM/YYYY	HH:MM	m^3/s	m^3/s	m^3/s	Flow	Flow	DSRO/Pnet)
18/07/2007	4:00	3.66095	0.084	2.81664	2.90064	0.76031	0.03017
18/07/2007	5:00	3.8123	0.084	2.81664	2.90064	0.91166	0.03618
18/07/2007	6:00	3.94609	0.084	2.81664	2.90064	1.04545	0.04149
18/07/2007	7:00	6.63465	0.084	2.81664	2.90064	3.73401	0.14818
18/07/2007	8:00	5.9967	0.084	2.81664	2.90064	3.09606	0.12286
18/07/2007	9:00	7.47882	0.084	2.81664	2.90064	4.57818	0.18167
18/07/2007	10:00	9.57593	0.084	2.81664	2.90064	6.67529	0.26489
18/07/2007	11:00	11.2062	0.084	2.81664	2.90064	8.30556	0.32959
18/07/2007	12:00	9.89279	0.084	2.81664	2.90064	6.99215	0.27747
18/07/2007	13:00	8.77933	0.084	2.81664	2.90064	5.87869	0.23328
18/07/2007	14:00	4.80251	0.084	2.81664	2.90064	1.90187	0.07547
18/07/2007	15:00	2.90064	0.084	2.81664	2.90064	0	0
Average		6.55700	0.084	2.81664	2.90064	3.6566	0.145103
Standard Deviation	---	---	---	---	---	---	0.10690
Skewness	---	---	---	---	---	---	0.22337
Kurtosis	---	---	---	---	---	---	-1.42820

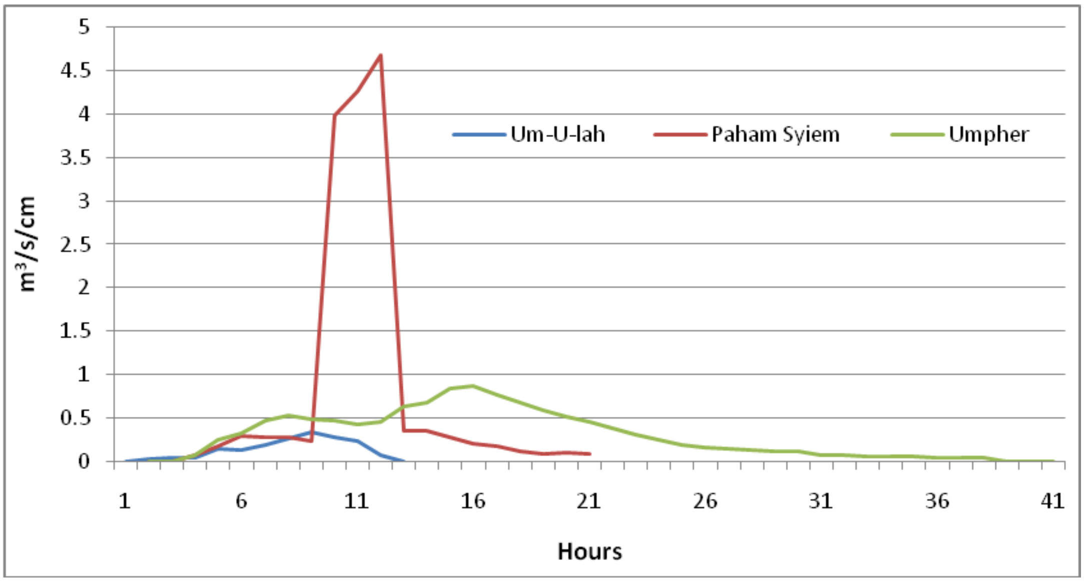


Fig.-4.4: Unit Hydrographs for Different Experimental Watersheds

(b) Paham Syiem Watershed (Nongpoh location) of Moderately Shallow Soil and Moderate Rainfall Intensity

A hydrologic event of a duration of 20 hours started at 20:00 hrs on 26th August 2007 produced a total surface water of 48,107m^3 with its average surface water yield of 3.618m^3 per hour per ha in the Paham Syiem watershed. The storm of 20 mm of rainfall precipitated in 7 hours before rising the limb of hydrograph is observed and had an average discharge rate of .668m^3/s with a noticeable variability (CV=166.70%). A slow increase in the discharge level at starting of the event was observed but suddenly rose up to 3.50 m^3/s to make the peak of hydrograph. The falling limb also had fast decline at an average rate of 0.24 m^3/s .

A total loss of rain water was calculated 12.97 mm (64.21% to total rainfall) during the event that was significantly higher than the other two watersheds (Table- 4.2). It is due to (i) porous soils of this watershed that increased infiltration capacity with good underground water reserve along the lineament located in its central part and (ii) increasing atmospheric demand of water during the occurrence of this event (monsoon period) that influences the AMC to be dry. High infiltration rate recharges the soil moisture storage at a faster rate which regulates base flow steadily. High infiltration rate influences saturation areas of the watershed, controls its extensions along main channels and stabilizes stream flow at the mouth of the watershed.

Base flow gradually increases during peak flow time which gives shape to the unit hydrograph. Of course, the hydrologic pattern of the unit hydrograph is similar to the pattern of stream flow hydrograph. However, rainfall and runoff patterns do not agree much due to regulation of base flow pattern (Fig.- 4.4). However, discharge of .467m^3/s per centimeter of excess rainfall at moderately high base flow is produced from each unit of excess rain. The average impulse response was .802m^3/s per centimeter of excess rainfall in the watershed (Table-4.3).

(c) Umpher watershed (located in Byrnihat area) of Thick Soils, Dense Forests and Plantation with Frequent Rainfall and Moderate Intensity.

A rainstorm event of 10 hours duration with its highest intensity of 20.0 mm/hr for three hours sensitized the stream flow graph for about 49 hours started at 18:00 hours on 21st September 2009 till 18:00 23rd September 2009. An amount of 47.6 mm of rain during the event produce 40.26 mm of runoff with the loss of 7.4 mm due to evapo-transpiration and infiltration losses. The losses is calculated lesser (that is 15.5%) than that of ideal for North-

Eastern Region of the country, (i.e., assessed 30 to 40%) due to dry AMC, this loss is estimated lesser being high rate of infiltration and high potential of soil moisture capacity. The total surface water produced by the watershed, recorded 351926 m^3 with a surface water yield of 8.2166 m^3 per hour per ha. The share of storage in the channels to total volume to per cm of excess rainfall is also noticeably higher. It means that the flow during the event is regulated by topographic features especially slope gradient and orientation of slopes. The shape of hydrograph follows normal distribution with its centrally located peak flow at 4.47m^3/s. The ordinates of hydrograph start from .8160m^3/s and after 15 hours of raising the flow in stream, peak flow is achieved. Rising limb started rising at an average rate of 0.2612m^3/s per hour while falling limb rate is much slower as it declined at .1057m^3/s per hour and took 32 hours to reach in its lowest level. Being the largest size and curvilinear flow directions in the watershed, the travel time of water flow is 12 hours, which also regulates the figure of hydrograph. Base flow increases slowly and reached from .816m^3/s to 1.2812m^3/s after 36 hours of hydrograph, at that level of stream flow the unit hydrograph ended after 35 hours with its maximum rate at .8629m^3/s per cm of excess rainfall precipitated over the watershed (Fig- 4.4).

4.4 Characteristics of Impulse Response Function

If one uses transfer function assuming that the system is working in linear manner in continuous time in which I(t) – Q(t) = dS/dt where S is soil storage, then it (dS/dt) is a linear transfer function. It describe the response of output Q(t) to a given input I(t) sequence. Impulse response function is an input of unit amount applied instantaneously (called a unit impulse) at a particular time, and the response of the system at later time is described by ‘unit impulse response function’. The preceding discussion describes the nature and character of impulse response to a unit input of excess rainfall in different watersheds.

Table- 4.3 depicts such characteristics of unit hydrographs of different watersheds. The impulse duration is longer in Umpher watershed (34hours) and shorter in Um-u-lah (11hours) with lower degree of maximum intensity of impulse response (average response of extent is .1583m^3/s/cm). The overall impulse response of one cm of excess rain is the highest in Paham Syiem where maximum intensity of impulse function reached up to 4.675m^3/s/cm (Fig-4.4). However the impulse response takes shorter time in Um-u-lah than Paham Syiem. It is interesting to note that the impulse response towards peak flow is indicated by the fast rising limb of the unit-hydrograph of Paham Syiem watershed followed by a fast decreasing downward trend, ultimately slowing down at last the part of recession time. Therefore, it has higher degree of its variability (CV=192.96%) and also skewed positively (Skewness= 2.1265, Kurtosis= 2.54) (Table-4.4).

Table-4.4: Distributional Characteristics of Impulse Response Functions per cm of excess rainfall

Sl. No.	Dimensions of Distributions	Units	Um-u-lah	Paham Syiem	Umpher
1	Duration of response	time unit, hrs	11	19	34
2	Duration of reaching to maximum response	hrs	6	8	11
3	Maximum intensity of response	$m^3/s/cm$	.3296	4.675	.8629
4	Increasing rate of response up to its maximum level	$m^3/s/cm$	.05000	0.5014	.07177
5	Average response of event	$m^3/s/cm$	.1583	0.802	0.3340
6	Recession time duration	hrs	3	9	22
7	Decreasing rate of response	$m^3/s/cm$	.0847	.04165	.03724
8	Minimum intensity of response	$m^3/s/cm$	.0755	.09267	.04378
9	Standard Deviation	$m^3/s/cm$	.1069	1.54760	.25194
10	Coefficient of variability	%	67.530	192.9600	75.431
11	Skewness	Unit less	.2234	2.1265	.50322
12	Kurtosis	Unit less	-1.4282	2.5401	-.91296

It can be concluded that the unit input impulse response vary in different watersheds due to differentiation in their size, shape, topographic features and land use pattern. In fact, in lumped modeling system such landscape conditions of watersheds are considered as homogeneous, which is not true. Such characteristics are important to make the analysis of hydrographs more accurate to make accurate SDSS. It is possible to isolate the effects of such factors through the use of distributed modeling which would be discussed separately in the next Section of the discussion.

Section – V

Hydrograph Prediction Using Distributed Models and Spatial Decision Support System (SDSS)

5.1 Introduction

The runoff processes based on physical dimensions of landscape leading to surface and sub-surface flow are the blue prints of hydrograph prediction of a given event for unguaged watershed. In the lumped modeling system as described in preceding Section, the hydrologic predictions are based on the assumptions that the whole watershed behaves in a homogeneous manner to transfer functions (i.e., unit impulse response in which input unit is considered as proportional to total excess rainfall and soil moisture storage also changes proportionally during the hydrologic event so it is assumed linear) in which each unit of land area of watershed gives equal response to transfer function. Relaxing these assumptions of surface (overland and channel) flow and sub-surface (soil water and ground water) flow, the physically based distributed modeling system was developed in which parametric relationships and hydrologic predictions were made to simulate the effects of different land surface parameters (topographic and land use) and atmospheric conditions. Such approach of study would be useful for SDSS for soil, water and land use management of even ungauged watersheds in given atmospheric conditions. Integrated watershed management may be suggested by applying such *a priori* hydrologic model.

In present discussion of rainfall-runoff relationship, two different physically-based models would be applied to the prediction of runoff, and their validity would be tested for accurate simulations of the effects of land surface parameters to strengthen the SDSS in decision making processes in watershed management. A classical ‘Curve Number’ (CN) method called SCS-CN and ‘Variable Source Area’ model based on saturation-excess process moisture-area relationship called VSA are main examples to be used in the present context.

5.2 Use of SCS-CN method for Runoff Prediction

Prediction of runoff through this method is initially based on the assumption that the ratio of actual soil moisture retention (P-Ia-Q) with a potential maximum retention (Sm that is greater than P-Ia-Q) equals to the ratio of actual runoff (Q) with potential maximum runoff (P-Ia that is greater than Q). SCS provides a relationship between Ia and Sm (as Ia= .2Sm) by experience of field experiments (SCS-CN 1972). It was reported Ia= 0.3 Sm by Dhruvanaryan (cf. Das 2002) for Indian conditions and also used by many scientists for India (Das 2002) (see box-5.1).

Box- 5.1: Procedure for Calculation of Runoff through SCS-CN Method

1. Choose CN from the given combination of land use and hydrologic soil cognitions (as shown by different HRU) for AMC-II and Ia= .2S of experimental watershed (Table-5.1).
2. If required as per the AMC of discharge event of watershed, calculate CN at AMC-I or AMC-III assigning conversion factor weights at AMC-II to AMC-I or AMC-III (Table-5.2)
3. Calculate weighted CN by assigning fractional area as weight for each HRU

(W_i*CN_i) $i=1,2,3,\ldots,n$ HRU's. … … (5.1)

4. Add all weighted CNs to get one figure for whole watershed that is $\sum(W_i*CN_i)$
5. Calculate effective available soil moisture within the soil profile, Se using SCS-CN formula

$Se = (25400/CN)-254.$ … … … (5.2)

6. Now finally calculate excess precipitation or direct runoff (RO in mm) that can be converted into predicted discharge (Qp in mm) for hourly rainfall of the storm by using SCS-CN formula

$Qp = [(P-.2Se)^2/(P+.8Se)].$ … … … (5.3)

It is suitable for US conditions. For Indian conditions while Ia=.3Se, the above rainfall-runoff equation may be written as

$Qp= [(P-.3Se)^2/(P+0.7Se)].$ … … … (5.4)

Table- 5.1: Runoff Curve Numbers for selected land use categories by its different Hydrologic Soil Groups (AMC-II, Ia=.2Se)

Code	Land use/Land Cover Description	Hydrologic Soil Groups			
		A	B	C	D
L6	Cultivated land (fallow, Row crops, small grains,				
	(i) without conservation treatment	72	81	88	91
	(ii) with conservation treatment	62	71	78	81
L2	Grassland and pastures				
	(a) Poor conditions	68	79	86	89
	(b) Good condition	39	61	74	80
L5	Jhum (good conditions)	30	58	71	78
L3	Wood or forest land				
	(i) Poor cover	45	66	77	83
	(ii) Dense cover	25	55	70	77
L4	Plantation	30	55	65	75
L1	Roads, settlements, dirt and hard surface	74	84	90	92

NB: (i) Land use classes are modified as per required classes, (ii) Soil Groups refer to A=deep sandy, aggregated silts highly porous , B=Sandy loam with porous conditions, C=Clay loam, shallow loam with less porous, D= Soils that swell significantly when wet, heavy plastic clays, shallow hard surfaces (impervious).
Sources: USDA-SCS (1972), Chow et al. (1988) pp.149-151 and Das (2002) pp:74-75.

Table-5.2: Conversion of CN from AMC-II to AMC-I and AMC-III

CN at AMC-II										
Multiplier factor to convert CN at AMC-II to	10	20	30	40	50	60	70	80	90	100
AMC-I	.40	.45	.50	.55	.62	.67	.73	.79	.87	1.00
AMC-III	2.22	1.85	1.67	1.50	1.40	1.30	1.21	1.14	1.07	1.00

Source: Das (2002) Table-5.3 p.74

Of course, the whole gamut of SCS-CN method is based on the value of the maximum amount of rainfall that the watershed can absorb is known as potential maximum retention or soil moisture deficit called here as effective available storage (Se). The value is altered as CN changes. Curve Numbers (CNs) are shown rainfall-runoff relationship and determine CN for different combinations of land use and hydrologic soil types called Hydrologic Response Unit of land surface (HRU) that have been defined in Table-5.1 given in Box. The fractional area of different HRU's of watershed is weighted to CN for calculation of maximum retention of different antecedent soil moisture conditions (AMC) namely, the dry AMC (I), normal AMC (II) and Wet AMC (III) (see Table-5.3).

5.3 Analysis and Results

The present analysis is based on hydrologic events of monsoon season chosen from each experimental watershed. The dates and duration of events are (a) 12:00 hours starting from 4:00 hours on 18th July 2007 for Um-u-lah (Cherrapunji) watershed, (b) 20 hours starting from 20:00 hours on 26th August 2007 for Paham Syiem water watershed and (c) 49 hours starting from 18:00 hours on 21st September 2009 for Umpher watershed as considered events for preceding Section of the discussion. The weights as per given AMCs of soils for the experimental watershed were considered. The experiments in these watersheds were conducted during extreme rainfall time (monsoon), so CN-III AMC were assigned to make calculations of Weighted Curve Number(WCN) for each Hydrologic Response Unit (HRU) (Table-5.3 and 5.4). The HRU's were delineated by multiplying the land use map of the watershed with its hydrologic soil types (Figs.- 5.3). After summing up WCN for each HRU and using equation- 5.2, the value of available soil moisture retention (Se) have been calculated for the watershed. Main inferences from the analysis are as follows:

(i) Table-5.3 depicts that more than half of the watershed area under the HRU is grass covered and barren in Um-u-lah watershed. The high value of ΣWCN reaching upto 92.18 shows very less absorption of rainfall of about 21.55 mm in the soil in this watershed. Moisture absorption in the soils of Paham Syiem (Nongpoh) and Umpher (Byrnihat) watershed are higher.

Table-5.3: Hydrological Response Units (HRU) and Values of their Weighted Curve Numbers (WCNs)

HRU	Area(sq m)	Fractional Area	CN II	Conversion-Factor III	CN III	WCN
(A) Um-u-lah watershed (Cherrapunji)						
L1*S1	10600	0.010364721	74	1.14	84.36	0.874368
L1*S2	3600	0.003520094	84	1.07	89.88	0.316386
L1*S4	67200	0.065708419	92	1.00	92.00	6.045175
L2*S1	127200	0.12437665	68	1.21	82.28	10.233710
L2*S2	67000	0.065512858	79	1.14	90.06	5.900088
L2*S4	580600	0.567712917	89	1.07	95.23	54.063300
L3*S1	20300	0.019849418	45	1.40	63.00	1.250513
L3*S2	2200	0.002151168	66	1.21	79.86	0.171792
L3*S4	144000	0.140803755	83	1.14	94.62	13.32285
Total	1022700			**Weighted CN**		**92.17819**
				Se		**21.55327**
(B) Paham Syiem Watershed (Nongpoh)						
L1*S2	54800	0.008266457	84	1.07	89.88	0.742989
L1*S3	109600	0.016532915	90	1.09	98.1	1.621879
L1*S4	22800	0.003439329	92	1.07	98.44	0.338568
L3*S3	585200	0.088276112	77	1.14	87.78	7.748877
L4*S2	2672400	0.403125566	55	1.35	74.25	29.932070
L4*S3	1627200	0.245459482	65	1.25	81.25	19.943580
L4*S4	11000	0.001659325	75	1.17	87.75	0.145606
L5*S2	1046800	0.15790744	58	1.30	75.40	11.906220
L5*S3	234000	0.035298377	71	1.21	85.91	3.032484
L5*S4	10000	0.001508478	78	1.14	88.92	0.134134
L6*S2	43200	0.006516623	81	1.13	91.53	0.596467
L6*S3	49600	0.007482049	88	1.07	94.16	0.70451
L6*S4	173600	0.026187172	91	1.07	97.37	2.549845
Total	6629200			**Weighted CN**		**79.39723**
				Se		**65.91039**
(C) Umpher Watershed (Byrnihat)						
L1*S1	114400	0.013117461	74	1.2	88.8	1.164831
L1*S4	34800	0.003990277	92	1.06	97.52	0.389132
L3*S1	461600	0.052928496	45	1.45	65.25	3.453584
L3*S3	4552800	0.522038252	77	1.14	87.78	45.82452
L4*S2	1803600	0.206806403	55	1.35	74.25	15.35538
L5*S1	71200	0.008164014	30	1.67	50.10	0.409017
L6*S2	98800	0.011328716	81	1.14	92.34	1.046094
L6*S3	44800	0.005136908	88	1.07	94.16	0.483691
L6*S4	1539200	0.176489474	91	1.05	95.55	16.86357
Total	8721200			**Weighted CN**		**84.98981**
				Se		**44.85935**

Abbreviations: L1=Roads, settlements, dirt and hard surface, L2= Grassland and pastures, L3= Wood or forest land, L4= Plantation, L5= Jhum (good conditions), L6= Cultivated land (fallow, Row crops, small grains), S1=deep sandy, aggregated silts highly porous , S2=Sandy loam with porous conditions, S3=Clay loam, shallow loam with less porous, S4= Soils that swell significantly when wet, heavy plastic clays, shallow hard surfaces (impervious).

(ii) In fact, this method predicts event-based depth of runoff. However, it is applied here by using hour as a time-unit of a longer duration of hydraulic events for extremely high rainfall area. A total rain of 920.2 mm precipitated in 70 hours with an average intensity of 13.14mm/hr starting from 17th July 2007 at 1:00 hr during monsoon season. Runoff predictions were carried out by fitting the line between observed runoff (Q_o) and rainfall intensity (P) as Q_o= f(P) and then calculating interception value which is used as effective available soil storage (Se) to operate basic equation of rainfall-runoff predictions (eqn- 5.4). So, runoff predictions are made to be used at Se= 5.789 mm. Calculation of Se by the used of T-M procedure is almost similar as Se= 5.88 mm.

It is interesting to note that total depth of predicted runoff (Q_p) is 591.13 mm from Um-u-lah watershed of 103.4 ha in size, while observed runoff (Q_o) was 897.15 mm. There are cases of under-estimation of runoff usually at higher rainfall intensities peaks and *vice-versa* (Fig.-5.1A). Predicted and observed relationship is strong with marginally slow regression of predicted runoff (b=.7046, Fig-5.1B). It may be said that SCS-CN method predicts well when very low values of Se are used in it especially for shallow soils of excessively high rainfall areas such as Cherrapunji where soils are almost fully saturated during wet moisture conditions (AMC-III). It does not predict well for Paham Syiem and Umpher watersheds (Fig.-5.2)

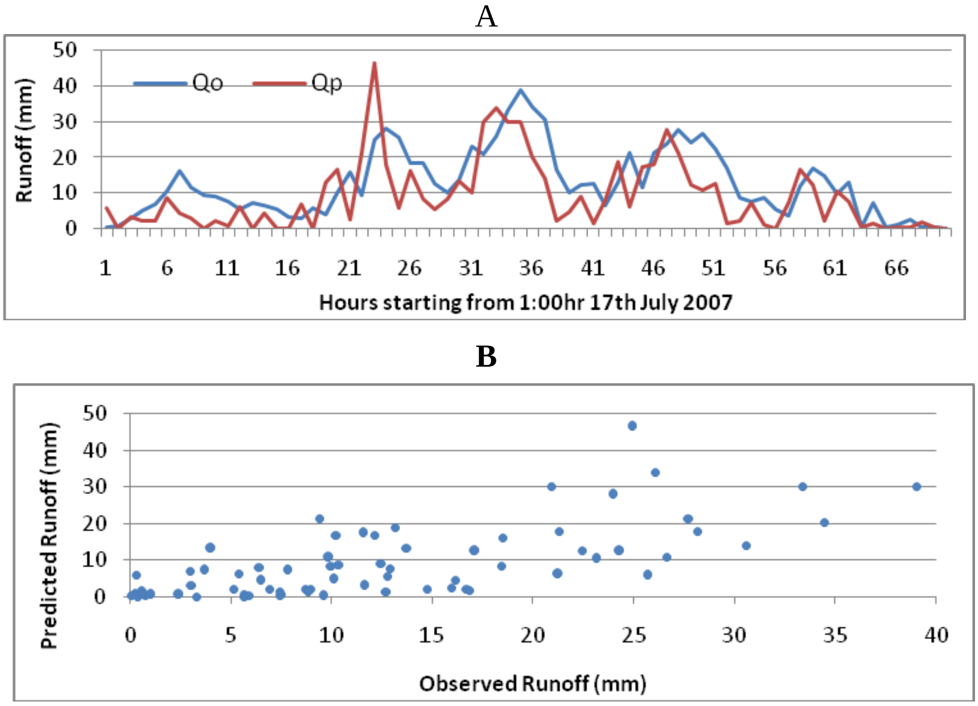


Fig.- 5.1: Um-u-lah Watershed: (A) Pattern of Observed and Predicted Runoff Depth and (B) Scatterness between Observes and Predicted Runoff Depth at Se= 5.88 mm.

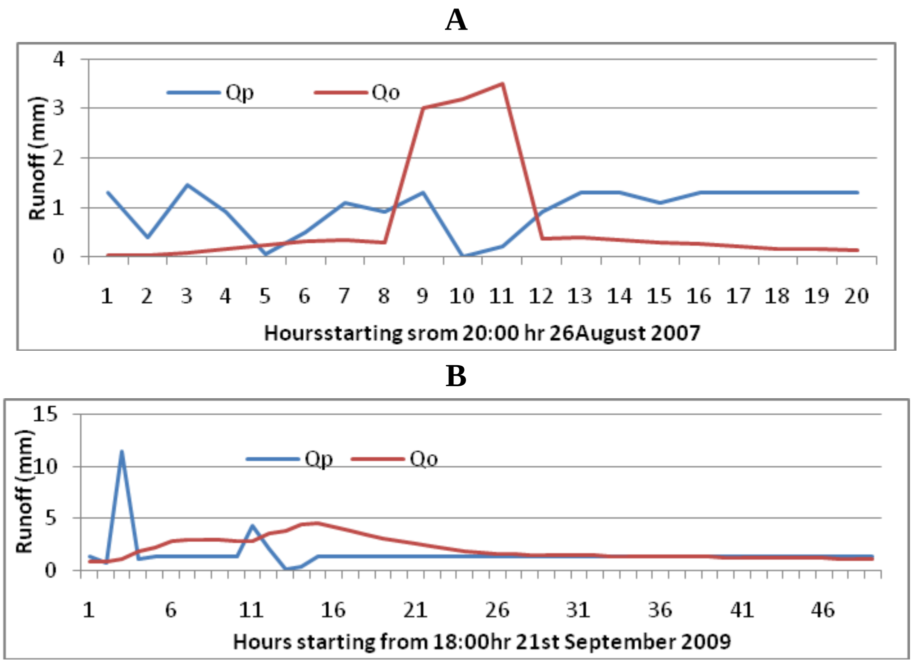


Fig.- 5.2: Pattern of Observed and Predicted Runoff Depth in (A) Pham Syiem Watershed at Se=10.00 mm and (B) Umpher watershed at Se=15.00 mm

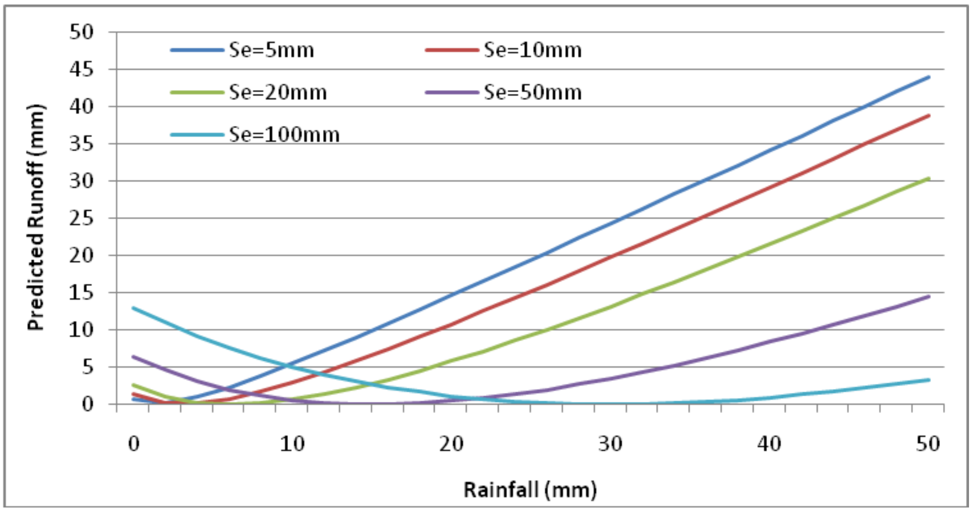


Fig.- 5.3: Pattern of Predicted Runoff subject to Rainfall for Different Effective Soil Moisture Levels in Um- u-lah Watershed

(iii)The runoff prediction through SCN-CN method is greatly controlled by the numerator of the rainfall-runoff fraction rather than its denominator (because numerator acts in its power function). However, this method over estimates at lower intensity of rainfall till (P-.3Se) reaches upto zero in equation-5.4; it again increases as rainfall intensity increases (Fig.-5.3).

Therefore, runoff prediction is basically dependent on Se; when rain is equal to 30% share of effective available soil storage as (P-.3Se) =0, then Q= 0. Therefore, increasing value of Se must result increasing intensity of over-estimation of runoff at starting of rainfall intensity as logically shown in Fig.-5.3. On the other hand, SCS-CN method does not estimate runoff well for no-rain condition during the event. As P= 0 is used in rainfall-runoff equation (5.4), it predicts the highest runoff which is not correct in ideal situation. Avoiding extreme conditions of rainfall, it predicts well as shown in preceding discussion taking into account the example of Um-u-lah watershed of Cherrapunji.

5.4 Effect of Land use / Land Cover Change on Runoff

After developing ideal scenarios of land use /land cover changes in different experimental watersheds, the following changes have been observed in runoff depth.

(A) Um-u-lah watershed (Cherrapunji): It comprises grass-dominated land cover/ land use with increasing land under settlements, because of its location near Cherrapunji town. Two changing scenarios of land cover/ land use were analysed. A conversion of grassland growing in barren impervious soils of 58.06 ha to forest land in the same soil type (L2*S4 to L3*S4) does not have significant impact on effective available soil storage (Se). As a result runoff depth decreases negligible as 1.15 mm. However, there is significant increase in the depth of runoff (15.7%) as conversion of grassland to settlements (L2*S1 to L1*S4) is suggested (Table-5.4)

(B) Paham Syiem watershed (Nongpoh): If jhum lands are proposed to change to plantation from 1.0-2.0 ha in impervious soils (L5*S4 to L4*S4) and land under settlement are increased form the same (L5*S4 to L1*S3), then there seems to be no change in runoff depth.

(C) Umpher watershed (Byrnihat): A significant decrease to 2.77 percent in runoff is shown when 8.0 ha (1.0%) of jhum land in Umpher watershed is proposed to change to forest lands in loamy soils (L5*S1 to L3*S3).

Table- 5.4: Effects of Changing Scenarios of Land Cover/Land use on Runoff

		ΣWCN	Se (mm)	Rainfall events*	Q (mm)	Changes in Q	
	Description					Q (mm)	%
A	**Um-u-lah watershed (Cherrapunji)** **Scenario-I: Conversion of grasses to forest lands**						
L2*S4	Grasses in barren impervious soils	92.18	21.55	262.8	236.45		
L3*L4	Forest in barren impervious soils	91.83	22.59	262.8	235.30	-1.15	
	Scenario-II: Conversion of grasses to Settlement land						
L1*S4	Settlement in barren impervious soils	92.18	21.55	262.8	236.45		
L2*S1	Grassland in barren impervious soils	93.39	17.99	262.8	240.60	+ 4.15	+15.69
B	**Paham Syiem Watershed (Nongpoh)** **Scenario-III: Increasing Plantation from Jhum**						
L5*S4	Jhum in impervious soils	79.23	66.58	20.2	.008	-	-
L4*S4	Plantation in impervious soils (from 1.0 ha to 2.1 ha)	79.23	66.57	20.2	.008	-	-
	Scenario-IV: Increasing land under settlement from Jhum						
L1*S3	Settlement in shallow soils	79.23	66.50	20.2	.008	-	-
L5*S4	Jhum in shallow loam	79.25	66.50	20.2	.008	-	-
C	**Umpher Watershed (Byrnihat)** **Scenario-V: Conversion of jhum to forest**						
L5*S1	Jhum in deep sandy soil	84.30	43.78	47.6	15.18	-	-
L3*S3	Forest in loam soil expanding from 455 ha to 462.2 ha (52.2 to 53.2%)	85.30	44.86	47.6	14.76	-.42	-2.77

NB.: Effects of land cover/land use changes are calculated from the existing scenario of HRU's in watersheds.
*Rainfall events specified earlier in preceding parts have been considered for the present purpose.

5.5 Use of CN-VSA method for Runoff Prediction and SDSS Development

This method is an extension of SCS-CN method in order to achieve the saturated incremental fraction contributing runoff depth, Af (Steenhius et al.1995) (see eqn. 1.4 for more detail) that is linked with the topographic map through the use of wetness index (λ) to determine the areas of relative propensities for saturation within the watershed (Lyon et al. 2004). Thus, there are two main aspects as to find the location and extent of saturated areas to predict the runoff depth.

5.5.1 The Wetness Index (λ) which is largely dependent on topographic factors to measure the contributing area per unit of contour length (α), slope-gradient (tan β), hydraulic conductivity of saturated soil (k) and soil depth (d) for each areal unit of watershed to map wetness index. In present case, grid-cell of 10m*10m size was considered for Um-u-lah because it is comparatively small in size, 20m*20m size for Paham Syiem and Umpher watersheds to prepared λ-maps. However, wetness index is considered as temporally constant because topographic factors are assumed unchanged overtime during the event under consideration; it is used as a spatial constant while calculating the location and extent of saturated areas for different depth of effective rainfall. A digital elevation model (DEM) is needed to determine λ-maps (Fig-5.4). Since λ is dependent on the contributing area of flow direction and flow accumulation parameters of landscape, the grid-cell frequency of each λ-class multiplied with its areal size, must show the contributing area (Ac) of respective wetness classes which have been converted to its fractional form (Ac/A) for further analysis.

Two wetness index maps were prepared: the first, considering transmissivity as 'un-controlled' variable ($\lambda_t = \ln(\alpha/\tan\beta*t$, where $t=k*d$)) and secondly, keeping transmissivity as homogeneous to avoid spatial effects as 'controlled' variable when k*d is considered as an average value ($\lambda_{avg} = \ln(\alpha/\tan\beta*t_{avg}$). It is obvious that there is a significant effect of soil moisture on runoff processes in experimental watersheds.

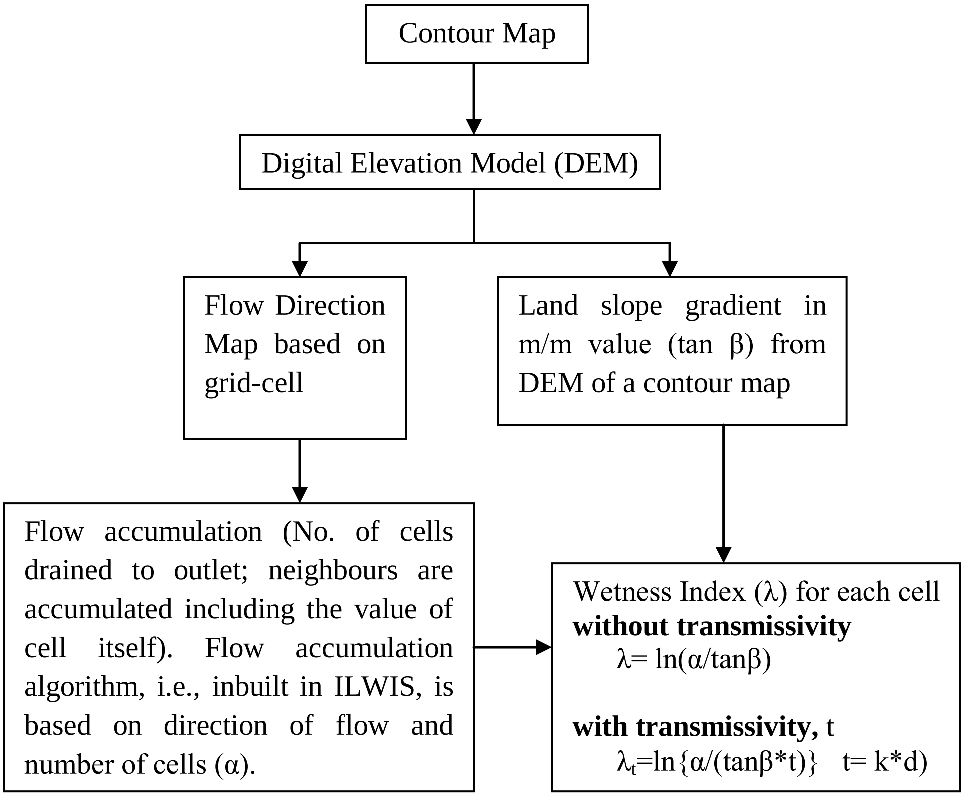


Fig-5.4: Development of Wetness Index (λ) for Estimating Effects of Topographic Factors on Runoff in Watershed (Bevan and Krikby 1979)

5.5.2 The Location of Saturated Area (As) is based on the incremental fraction contributing runoff depth (Af). Assuming that saturated fraction equals to fractional contributing area {Af = (Ac/A)}, a critical value of λ has been achieved to locate saturated areas within the watershed. When the value of λ is lower, higher is the soil wetness and consequently lesser is the extent of saturated area and *vice-versa*. As a result, the graph of cumulative fractional contributing area with λ (ogive) shows 'S' type of relationship (Fig-5.5).

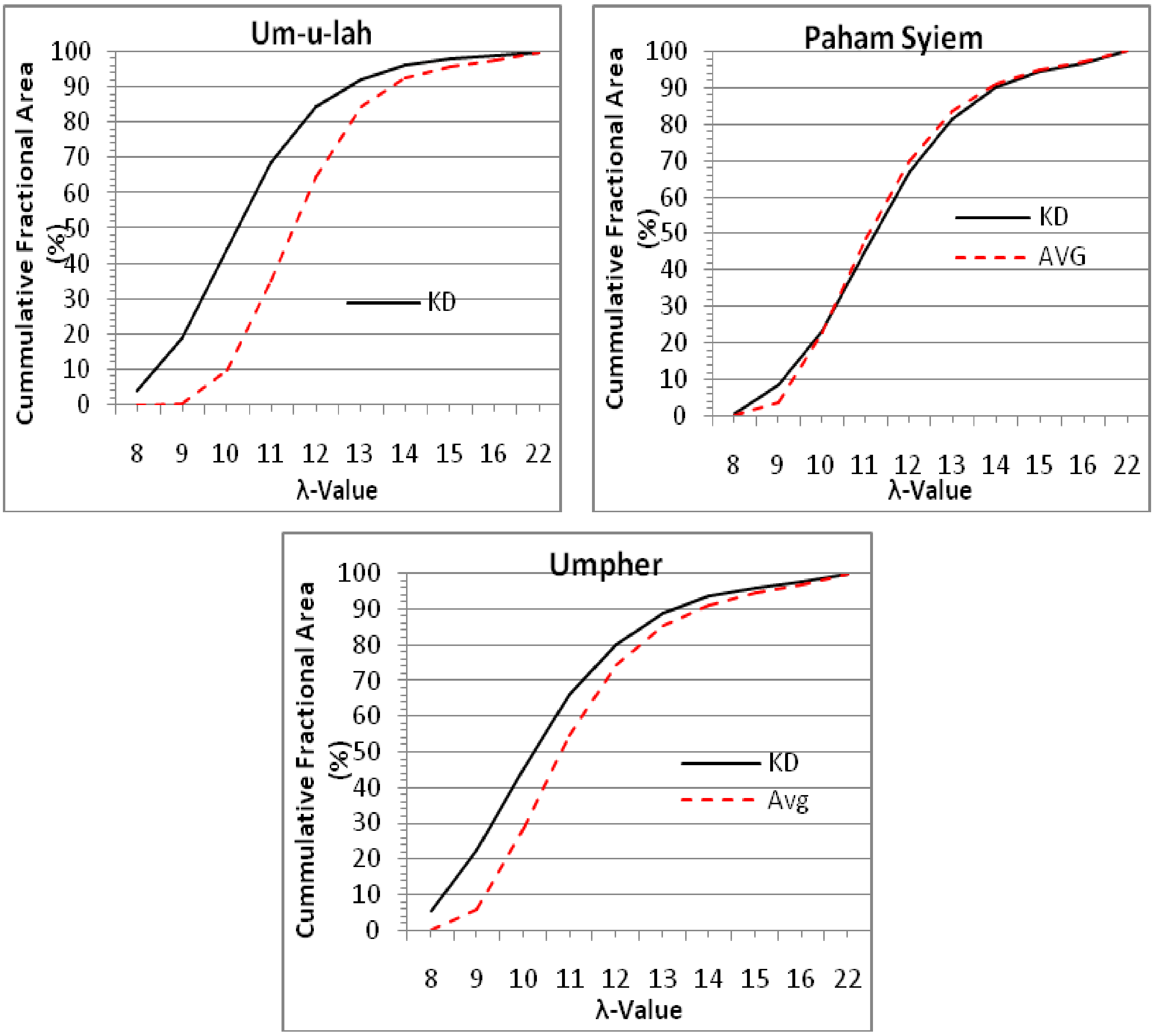


Fig.- 5.5: Ogives for Uncontrolled as well as Controlled Soil conditions in three Experimental Watersheds

It is to be noted here that since intensity of effective rainfall (Pe) varies overtime, the location of saturated areas contract or expand subsequently; they are variable over a constant wetness index-map because each grid-cell of concerned watershed shows a relative propensity of becoming saturated and producing saturation excess runoff. Runoff depth of each cell (q) is

$q = Pe - Se$ for $Pe > Se$, otherwise $q = 0$. … ... …(5.5)

A total quantity of discharge (Q) is then the multiplication factor of runoff depth with area of saturated cells as

$Q = \sum(q_i * ac_i)$, $i=1,2,3,\dots, n$ cells falling within saturated area … … …(5.6)

5.6 Effects of Soil Tranmissivity (k*d) on Wetness Index (λ)

Two maps of wetness index of each watershed were prepared; first to show the effect of natural conditions of soil transmissivity with its spatial variation (λ_t) giving weight of k and d factors of soil parameters to each grid cell (Table-5.5) and secondly, to assume soil transmissivity as a spatial constant using its weighted mean (λ_{avg}) that were calculated at 5500 cm^2/day for Um-u-lah, 4333 cm^2/day for Paham Syiem and 4500 cm^2/day for Umpher watersheds. Comparisons of these maps would provide a sound base of SDSS development to simulate the effects of saturated hydraulic conductivity and soil depth on spatial features of wetness in the watershed. Categorising distribution of wetness into ten classes (Table-5.6), mapping the area under each category would show the effects of soil transmissivity on wetness.

Table- 5.5: Values of Soil Transmissivity Used for different Experimental Watersheds

Code	Type Description	Saturated Conductivity (K in cm/day)	Soil depth (D in cm)	Soil Transmissivity (K*D in cm^2/day)
S1	Shallow but Highly porous gravelly sand	100	50	500
S2	Sandy loam	70	150	10500
S3	Loam clay	10	150	1500
S4	Clayey Deep and Shallow impermeable	5	200	1000

The main features of changing spatial pattern of wetness are given as:

(i) Overall, most of the areas of all three experimental watersheds fall under moderately wet to moderately dry classes with λ values varying from 9.00 to 13.00. In uncontrolled set of distribution (consideration of natural soil transmissivity conditions) the range of λt values are counted towards low values of distribution (Table-5.6).

Table-5.6: Percentage Share of Contributing Areas in Various Wetness Classes in Different Watersheds

Wetness Class (λ value)	Um-u-lah		Paham Syiem		Umpher	
	λt (%area)	λ avg (%area)	λt (%area)	λ avg (%area)	λt (%area)	λ avg (%area)
Extremely wet (Below 8)	3.83	0	0.53	0.01	5.48	0.25
Very wet (8 to 9)	14.77	0.22	7.8	3.79	17.14	5.72
Moderately wet (9 to 10)	25.58	9.3	14.97	18.92	22.78	22.71
Wet (10 to 11)	24.47	25.44	22.28	25.96	20.55	26.14
Dry (11 to 12)	15.78	29.75	21.26	21.44	14.23	19.71
Moderately dry (12 to 13)	7.87	19.74	14.68	13.61	8.76	11.05
Very dry (13 to 14)	3.69	8.2	8.54	7.42	4.67	5.6
very very dry (14 to 15)	2.17	3.08	4.41	3.71	2.39	3.38
Extremely dry (15 to 16)	0.95	1.93	2.35	2.11	1.65	2.24
Driest (Above 16)	0.89	2.34	3.18	3.02	2.35	3.19

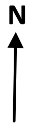


Fig.-5.6: Pattern of Wetness Index for Uncontrolled (λ_t) and Controlled (λ_{avg}) Soil Conditions in Different Experimental Watersheds

It does not seem much difference in frequency distribution especially in Paham Syiem and Umpher watersheds located in moderately wet areas of rain shadow when controlled soil transmisssivity index (λ_{avg}) is used for (Table-5.6). There is a significant deviation in the distribution of controlled and uncontrolled soil conditions in Um-u-lah watershed of extremely wet conditions (Fig- 5.6). Soil transmissivity contributes significantly in the most humid areas of shallow soils rather than less humid areas of thick soils because such soils have more moisture retention capacity. Higher degree of soil transmissivity decreases the value of wetness that indicates a lesser extent of saturated areas and consequently it reduces runoff depth in the watershed.

(ii) So far as spatial pattern of wetness index is concerned, the areas of central flat lands and hill tops of Um-u-lah watershed are having lesser degree of wetness under uncontrolled conditions of soils while the same areas are considered moderately dry in controlled transmissivity map. Spatial pattern of wetness index also vary in the Paham Syiem and Umpher watersheds of thick soils. Most of the areas of Paham Syiem watershed fall under the category of moderately dry when controlled transmissivity conditions are applied. Ogive of the distribution of uncontrolled soil conditions has steeper gradient than the ogive of the distribution of controlled transmissivity condition especially in Um –u lah watershed. In may be said that since porosity and depth of soil have effects on the soil moisture storage system, the uncontrolled transmissivity maps have limited wet areas in the watershed. So soil transmissivity has significant effects on saturated areas.

(iii) Statistical parameters of wetness distribution show that (a) frequency distribution of grid-cells seems closer to normal distribution in all three experimental watershed for both cases controlled as well as uncontrolled distributions, (b) the range of frequency distribution is calculated lesser for Um-u-lah watershed in both the cases of controlled as well as uncontrolled soil conditions with lower coefficient values of variability (CV=17.114% for uncontrolled and 14.60% for controlled soil conditions), (c) the coefficient of Kurtosis and Skewness of distributions are normal and very close to unity in almost all cases of experimental watershed, and (d) the ogives of such distribution are ‘S’ types with slightly greater degree in case of controlled (natural) soil conditions for Um-u-lah watershed because of its geomorphic peculiarity and low soil depth associated with dominant grass-cover (Table-5.7).

Table-5.7: Characteristics of Wetness Distribution in different watersheds

Description	Um-u-lah	Paham Syiem	Umpher
(A) Wetness Index with soil transmissivity effect (uncontrolled soil conditions λt)			
No. of Cells	10166	16511	21512
Minimum	7.1	7.13	5.95
Maximum	19.34	22.18	21.37
Mean	10.6	11.84	10.76
Range	12.24	15.05	15.42
Standard Deviation	1.8141	2.23	2.2416
Coefficient Variation	17.114	18.8344	20.8327
Kurtosis	1.3511	0.8467	1.4317
Skewness	0.911038	0.8028	1.0868
(B) Wetness Index with Soil transmissivity homogenous (controlled soil conditions λavg)			
No. of Cells	10483	16505	21572
Minimum	8.8	7.7	7.02
Maximum	20.6	21.14	20.57
Mean	11.88	11.98	11.5
Range	11.8	13.44	13.55
Standard Deviation	1.7341	2.1152	2.1687
CV	14.5968	17.9632	18.8583
Kurtosis	1.8315	1.2081	1.3583
Skewness	1.1082	1.0139	1.1705

N.B.: Lower values of grid-cells indicate more wet and *vice-versa*
*range is calculated subtracting minimum values from maximum ones

5.7 Simulation of Rainfall Effects on Spatial Pattern of Saturated Area

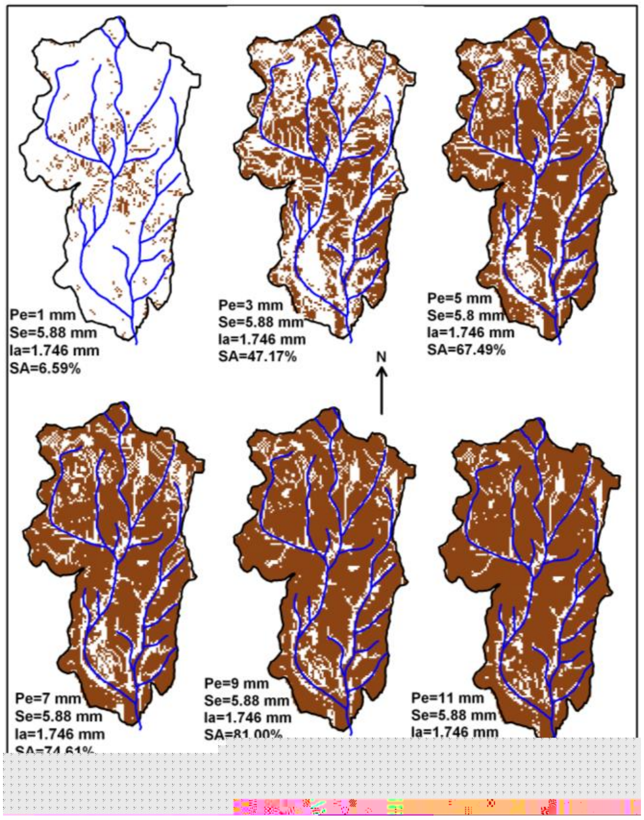
In this analysis, rainfall simulations were conducted to calibrate the VSA-model at Se=5.88 mm for Um-u-lah watershed, at Se=10.00 mm for Paham Syiem and 15.00 mm for Umpher watersheds. These values were calculated by using T-M procedure of soil water availability in water balance sheet for AMC-III as wet soil conditions. Simulations were made to consider uncontrolled (natural) soil conditions (λt). Initial abstraction is counted 1.746 mm only for Um-u-lah and 3.00 mm for Paham Syiem and 4.5 mm for Umpher watershed. Input of model is effective rainfall depth which varies at interval of 2.00 mm from 0 to 25 mm to visualize the changes in wetness index (λt) and accordingly in the location and extend of saturated areas within the watersheds, that vary in the following manner:

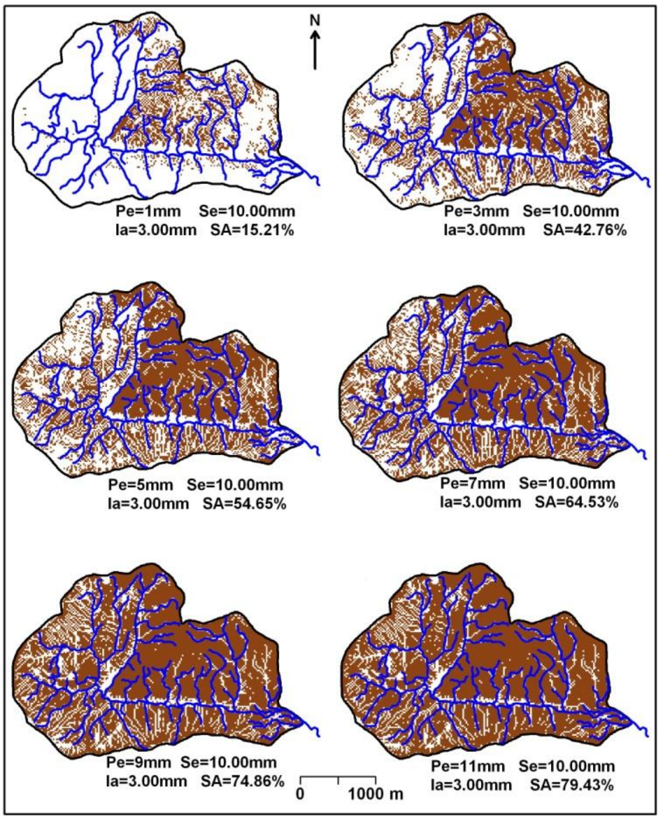
(i) In Um-u-lah watershed under most wet soil conditions, by increasing depth of effective rainfall results to fast increase in the extent of saturated areas. Saturated area was observed to be only 6.58% when effective rainfall was 1.00 mm. The saturated area increased to 47.17%, when effective rainfall is increased by 3.00 mm. Accumulation of water in the flat lands of the central part of the watershed contributed to saturated areas. Such areas are increased to 67.49% (20% additional areas including flat tops of hills and settlement areas) when the depth of Pe is increased by 2.00 mm ie., from 3.00 to 5.00 mm). Likewise, 81.00% areas become saturated at the depth of 9.00 mm of effective rainfall (Fig.-5.7, Table-5.8)

(ii) On account of relatively deep soils and higher porosity in Paham Syiem watershed, the saturation areas are concentrated towards southward facing slopes even at low intensity of effective rainfall. It was observed that saturated areas covered 15.21 percent when effective rain was recorded 1.00 mm. Increasing the intensity of effective rainfall by 2.00 mm initially, saturated areas expanded by 27.55 percent covering an area of 42.76 percent including the flat land of hill tops. Further, the expansion of saturated areas along inter-streams flats accounted for about 75 percent at a depth of 9.00 mm of effective rainfall (Fig-5.7A).

(iii) Due to the existence of flat hill tops between streams in Umpher watershed, the process of expansion of saturation areas starts from hill-tops. At 1.00 mm of effective rainfall, only 9.50 percent area of hill-tops are saturated, while by increasing 2.00 mm depth of effective rainfall from 3.00 mm to 5.00 mm, an increase of more than 20.00 percent area under saturation from 14.83 to 35.30 percent was observed. An additional depth of 2.00 mm of effective rainfall from 7.00 mm to 9.00 mm creates an expansion of about 7.00 percent area over hill-slopes (Fig-5.7B). It means that saturation area expands faster at initial stage of intensification of effective rainfall. As a result, the rising limb of hydrographs becomes steeper than the falling limbs in this watershed.

In general, it can be said that effective rainfall expands saturated areas within the watershed faster in Um-u-lah watershed located in the extreme wet conditions (Cherrapunji) and as a result the watershed produces much more runoff with higher runoff ratio. The runoff yield is lesser in Umpher watershed located in the foothills because of high degree of porosity and thick soils that retains more water before saturation (Fig.-5.8).





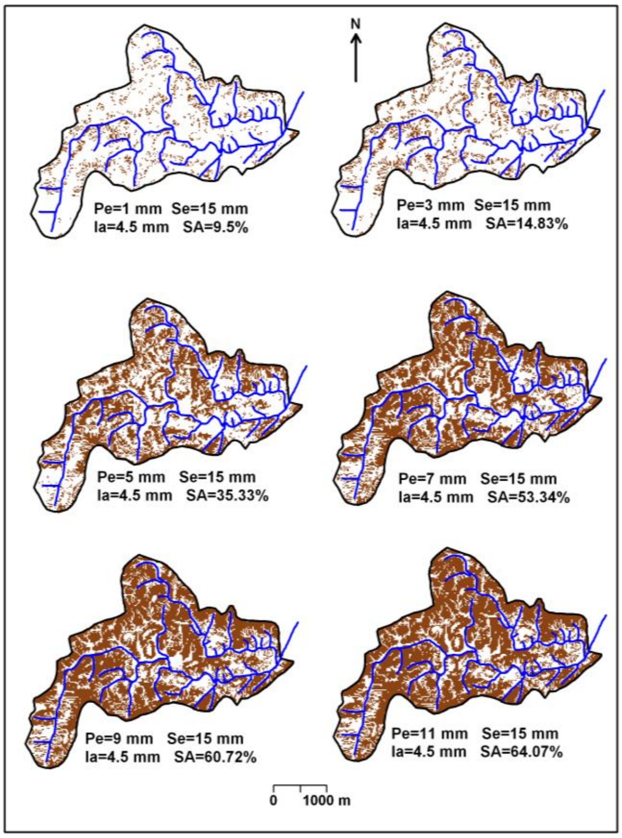


Fig.- 5.7: Patterns of Saturated Areas at Different Effective Rainfall Intensities in Different Watersheds

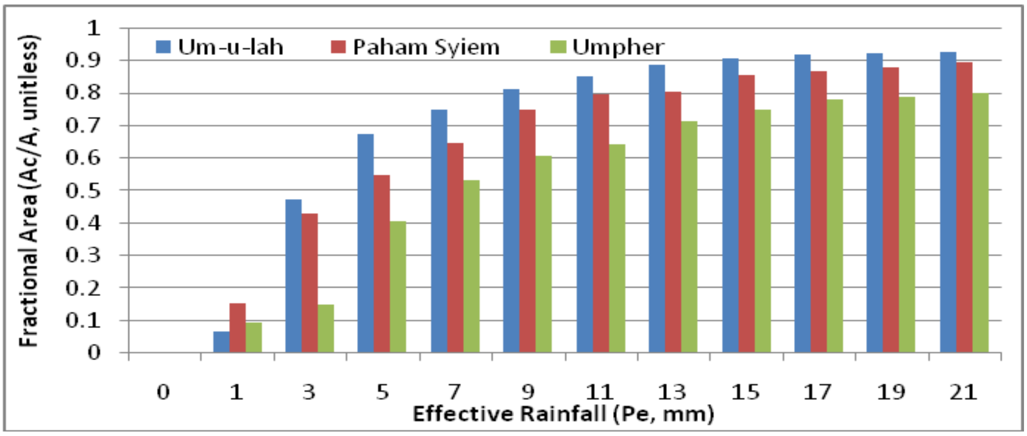


Fig.- 5.8: Trends of Fractional Saturated Areas at Different Effective Rainfall Intensities in Different Watersheds

(c) Model Validation

Validity testing was pursued to analyse the result of an extreme event of 12 hours starting from 4:00 hr 18th July 2007 in the Um-u-lah watershed (located in Cherrapunji) with a total rainfall of 262.8 mm (an average intensity of 21.99 mm/h). Calculating location and extent of saturated area for observed hourly rainfall of this event and finally predicting runoff depth, it is found that there is significant agreement of observed and predicted values of runoff. In later period of the event, it was found that the model over estimated runoff. This may have happened because of non-inclusion of the effect of concentration time (i.e. considered 1:00 hour) for this watershed (Fig-5.9). Nash and Sitchiff Coefficient of efficiently is calculated at .65716 with standard error of 5.68 mm. It shows good agreement of these two distributions of runoff (Fig.- 5.9B).

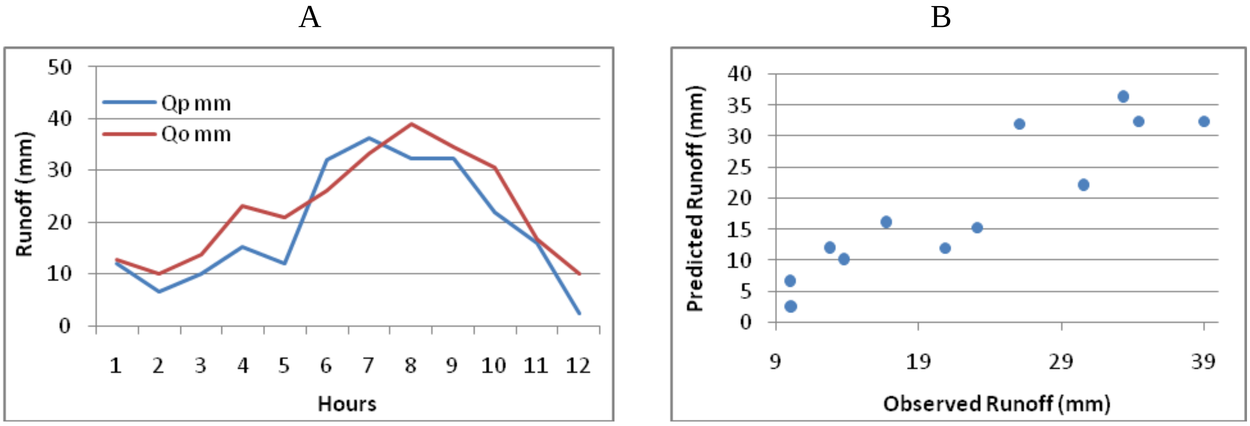


Fig.- 5.9: Um-u-lah: (A) Trends of Predicted and Observed Runoff and (B) Scatterness between Predicted and Observed Runoff

Section – VI

Summary and Conclusions

6.1 Introduction

Spatial Decision Support System (SDSS) for the management of water resources in the extreme humid conditions of land as prevalent in the central part of Meghalaya plateau with significant variations of its weather conditions is largely dependent on the investigations of rainfall and runoff processes. Taking into account the three experimental watersheds of different ecological conditions, the experiments on topographic characteristics and runoff processes were conducted. The experimental watersheds are located at and characterized by:

a. The extremely wet south slope of plateau, namely, Um-u-lah watershed covering an area of 103.4 ha is characterized by shallow soils and heavy rainfall with high intensity;
b. On middle part of the plateau over the northern slopes where the weather conditions are moderate, namely Paham Syiem watershed with an area of 664.8 ha is charcaterised by moderately shallow soils and moderate rainfall amount and intensity; and
c. The Umpher experimental watershed of about 874.1 ha located in the foot-hills of Meghalaya plateau with moderately humid with warmer temperature characterized by deep soils, dense forests and plantation with frequent rainfall of moderate intensity.

6.2 Methodology

Physical surveys for preparing detail contour, drainage and soil maps of the watershed were conducted at R.F. 1:5000 scale, while the land use maps of the watersheds were generated from IRS-Cartosat II data with spatial resolution of 2.5m. Soil samples were collected from each soil type and were analysed in the soil laboratory of NBSS&LUP, Regional Centre Jorhat. On the other hand, hourly statistics of weather parameters and water level gauge were collected by installing AWS and AWLR at the mouth of each watershed. However several technical limitations curtailed the collection of continuous data set of input and output variables for detail investigations of rainfall runoff system.

Spatial features of land use and soils of experimental watersheds were highlighted to obtain an overview of physical conditions. This was done with the help of soil map provided by NBSS&LUP, Regional Office Jorhat. The detailed land use mapping was done by digitizing land cover land use features from Carto Sat-II data supported with adequate field checks. Slope gradient maps of the experimental watersheds were obtained from DEM. The geo-spatial data of the watersheds were processed in the following manner (Fig.- 6.1).

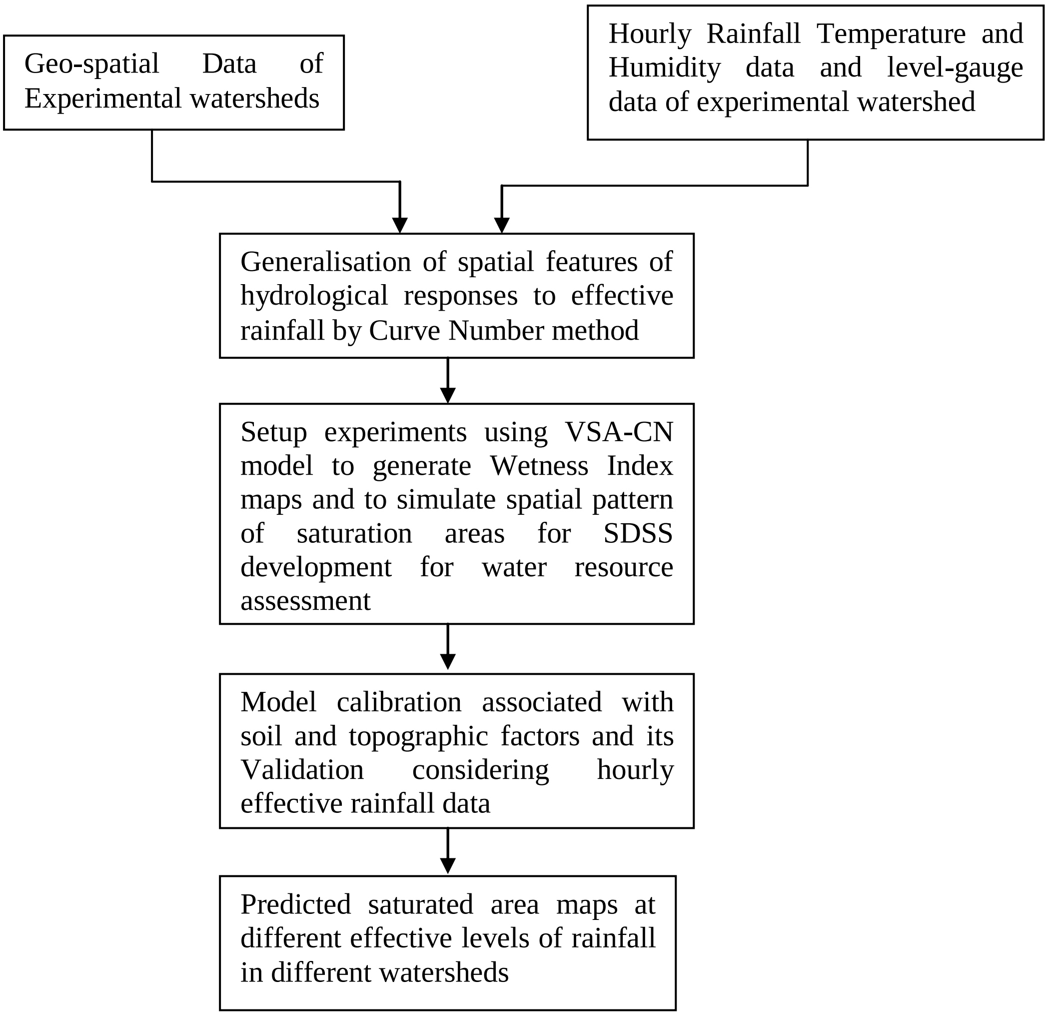


Fig.-6.1: Methodology Used for Simulation of Rainfall and Development of SDSS

6.3 Model set up for Experimental Watersheds

VSA-CN Model is basically dependent on preparation of Wetness Index map. Setting up grids at spatial resolution of 10x10m for Um-u-lah watershed and 20x20m for Paham Syiem and Umpher watershed because the latter two watersheds are large in size, the Wetness Index map were prepared to consider uncontrolled (natural) as well as controlled (average) conditions of soil of soil transmissivity to understand the effects of soil depth and soil porosity on runoff prediction. Bevan and Krikby's (1979) Method of calculation of Wetness Index (λ) was used for this purpose as given below:

$$\lambda = \ln (\alpha/\tan\beta * t), \quad \ldots \quad \ldots \quad \ldots \quad (6.1)$$

where α = contributing area per unit of contour length i.e. inbuilt in ILWIS software in the form of flow accumulation logarithm based on direction of flow and number of grid cells, tanβ = land slope gradient (unitless) and t = soil tranmissivity which is a function of soil depth (d) and saturated hydrologic conductivity of soil (k).

Rainfall response to runoff was approximated by preparing Wetness Index map and calculating distribution of contributing area to each category of Wetness Index. Further, calculation of fraction incremental runoff depth subject to effective rainfall (Af) to show the saturated area response to different depth of effective rainfall was done.

6.4 Main Findings

(1) There are a few generalizations based on the hydrograph analysis that show clearly the complete agreement of rainfall and runoff curves during the hydrologic events with its high fluctuations and very high average runoff yield in the Um-u-lah watershed (Cherrapunji) located in extremely high rainfall areas. For example, an average water yield of 225.5 m^3 per hour per ha was calculated from Um-u-lah watershed of 103.4 ha during an extreme event of 262 mm of rainfall precipitated in 12 hours with wet AMC. This average yield was recorded far higher than the other experimental watersheds located on the northern slopes of Meghalaya plateau.

(2) Paham Syiem watershed exhibited a maximum hydrologic impulse response. The average impulse response was 0.802m^3/s per centimeter of excess rainfall in this watershed. A discharge of 0.467 m^3/s per centimeter of excess rainfall at moderately high base flow time was produced. This figure of impulse response is far higher than the impulse response rates of other two watersheds.

(3) In most wet areas of the plateau, increasing land use under settlements increases land under impervious soils leading to the decrease in the storage of effective soil moisture (soil moisture deficit). It results to increasing runoff depth. When 5.0 percent grassland area is proposed to be converted to settlements under general land use of the watershed, it was found that runoff depth increased to 15.69 percent in Um-u-lah watershed. However, change in other categories of land use does not have significant effect on runoff.

(4) More specifically, the findings which are related to development of SDSS for the geo-hydrological conditions prevalent in experimental watersheds, are derived from the use of VSA –based methods.

‘S’ type of ogives of wetness index distribution have fast rising nature in uncontrolled soil conditions. It means increasing depth as well as porosity of soils limits the saturation areas in the watershed and consequently, checks the discharge rate of runoff at mouth of the watershed. Such soil parameters also have impact of spatial processes of saturation in the watershed. Shallow soil of Um-u-lah watershed in extreme wet conditions has faster rate of filling up the storage deficit leading to full saturation of soil and thereby saturated areas expand faster. Consequently, more areas may be saturated even at low depth of effective rainfall in thin soil cover. In such conditions, the runoff ratio increases fast and contribute to direct runoff. Therefore, there is a negative relationship between soil transmissivity and wetness index.

(5) Considering uncontrolled (natural) condition of soils of the experimental watershed, and calibrating VSA-CN Model at effective soil moisture level at Se=5.88 mm for Um-u-lah, Se=10.00 mm for Paham Syiem and Se=15.00 mm for Umpher watershed as calculated by using T-M procedure of water budget balance equation for wet weather condition as prevalent in the watersheds during experiments, the location and extent of saturation areas vary at different effective rainfall depth in the following manner:

(a) Increasing depth of effective rainfall quickly expands the saturated areas in Um-u-lah watershed. At 8.25 mm of effective rainfall depth about 85.03 percent area of the watershed becomes saturated. In Paham Syiem watershed of moderate wet weather conditions, about 80.00 percent area becomes saturated at 11.00 mm of the depth of effective rainfall and about 66.68 percent area of Umpher watershed of foot-hills topography was calculated as saturated area at same depth of 11.00 mm of effective rainfall. In general, saturated areas expand fast in less porous and shallow soils. Contrary to it, watersheds having highly porous deep soil with more saturation capacity have less fractional areas under saturation.

(b) The distribution of contributing areas to wetness index follows the trend of normal distribution in all topographic and soil conditions. However, the steepness of cumulative distribution (ogive) varies for different watersheds.

(c) Increasing soil transmissibility (porosity as well as depth) concentrates the areas of wetness index and there by limits the saturated areas within the watershed. As a result, it checks the runoff discharge as it has been observed in Umpher and Paham Syiem watersheds.

(d) Saturated areas are controlled by surface gradient. Saturation starts initially at the flat hill-tops and then expands towards low slope areas within the watershed. So surface gradient has the negative impact on saturation processes.

In the end can be concluded that the location and extent of saturation areas which are greatly related to the prediction of runoff within the watershed, are directly influenced by the expansion of accumulating water location, and inversely related to surface gradient as well as soil transmissibility. Such factors of topography limit the wetness index and saturation processes in the watershed.

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Appendix- I: Geo-hydrological Characteristics of Watersheds of Meghalaya Plateau

Sl.	Catchment		Area	Runnoff Depth	Total Runoff	Runoff Ratio	Precipitation	PET	W.H. Capacity	Infiltration	Infiltration	Bifurcation	Maxi-Eliv	Mini-Eliva	R Height	Stream Length	Slope
No.	Order	Name	(sq. km)	(mm)	(m ha)	(RO/P)	(mm)	(mm)	(mm/m)	Rate (mm/m)	Depth (mm)	Ratio(I/II)	(in m)	(in m)	(in m)	(L in m)	(%)
1	Ia1	Damu	182.3	1708.96	311543.408	0.569653333	3000	1250	180	0.228	41.04	4.5	153.01	70.2	82.8096	4506.163	1.837696506
2	Ia2	Rongkhon	205.1	2128.52	436559.452	0.646966565	3290	1125	160	0.228	36.48	3.4	273.41	76.2	197.2056	9024.6528	2.185187667
3	Ia3	Ganol	262.7	1958.52	514503.204	0.627730769	3120	1125	160	0.228	36.48	2.75	473	76.2	396.7984	3218.688	12.32795474
4	Ia int i	Kalo	277.6	1304.4	362101.44	0.501692308	2600	1250	200	0.228	45.6	2.25	914.4	234.696	679.704	13518.49	5.027958153
5	la int ii	Chhota	81.34	1696.68	138007.9512	0.56556	3000	1260	190	0.228	43.32	3	91.44	64.008	27.432	6437.376	0.426136364
6	la int iii	Rongkha	97.31	1946.68	189431.4308	0.598978462	3250	1260	190	0.228	43.32	3	88.392	60.96	27.432	12231.014	0.224282297
7	Ib1	Singwii	106.1	1206.68	128028.748	0.482672	2500	1250	190	0.228	43.32	1.14	100.28	51.2064	49.0728	8368.5888	0.586392774
8	Ib2	Gatwang	189.2	1216.68	230195.856	0.486672	2500	1240	190	0.228	43.32	1.85	304.8	51.2064	253.5936	10299.802	2.462121212
9	Ic1	Kacha	59.18	914.4	54114.192	0.415636364	2200	1240	200	0.228	45.6	1.2	190.8	76.2	114.6048	4506.1632	2.543290043
10	Ic2	Gime	82.58	924.4	76336.952	0.420181818	2200	1230	200	0.228	45.6	1.6	143.87	76.2	67.6656	3218.688	2.102272727
11	Id1	Ringgi	271.5	1529.4	415232.1	0.546214286	2800	1225	200	0.228	45.6	2.9	680.92	118.2624	562.6608	30577.536	1.840111643
12	Id2	Rom	68.73	904.4	62159.412	0.411090909	2200	1250	200	0.228	45.6	1.6	333.45	76.2	257.2512	15449.702	1.665088384
13	Id3	Chota Rom	49.93	890.98	44486.6314	0.404990909	2200	1260	215	0.228	49.02	2.5	100	76.2	23.8	1287.4752	1.848579297
14	Id int	Burha Rom	59.06	1586.664	93708.37584	0.547125517	2900	1265	212	0.228	48.336	1	114	76.2	37.7952	7081.1136	0.533746556
15	Ie1	Diti	157.4	716.68	112805.432	0.35834	2000	1240	190	0.228	43.32	2	187.15	76.2	110.9472	4506.1632	2.462121212
16	Ie2	Atagar/Didak	198.5	849.4	168605.9	0.395069767	2150	1255	200	0.228	45.6	3	447.45	152.4	295.0464	10299.802	2.864583333
17	Ie3	Bhagua	103.7	1890.98	196094.626	0.59093125	3200	1260	215	0.228	49.02	3.2	420.01	96.012	324.0024	14162.227	2.2877927
18	Ie4	Jhingiram	127.6	785.296	100203.7696	0.373950476	2100	1265	218	0.228	49.704	4	112.17	76.2	35.9664	8368.5888	0.429778555
19	le int	Lower Didak	48.82	683.7	33378.234	0.34185	2000	1265	225	0.228	51.3	3	152.4	89.916	62.484	12874.752	0.48532197
20	IIa1	Rongi	102.3	638.7	65339.01	0.327538462	1950	1260	225	0.228	51.3	5	569.06	76.2	492.8616	7081.1136	6.960227273
21	IIa2	Upper Rongi	48.26	638.7	30823.662	0.327538462	1950	1260	225	0.228	51.3	0	320.04	76.2	243.84	4699.2845	5.188875052
22	IIb1	Didiram	228.5	548.016	125221.656	0.296224865	1850	1250	228	0.228	51.984	2.3	431.6	68.58	363.0168	6437.376	5.639204545
23	IIb2	Lower Didiram	114.1	489.4	55840.54	0.271888889	1800	1265	200	0.228	45.6	2.87	367.28	87.7824	279.5016	12231.014	2.2851874
24	IIb3	Jlhar	80.84	589.384	47645.80256	0.310202105	1900	1260	222	0.228	50.616	4	569.06	50.292	518.7696	7402.9824	7.007575758
25	IIIa1	Damring	335.2	1836.24	615507.648	0.61208	3000	1125	170	0.228	38.76	3.6	387.4	53.9496	333.4512	4506.1632	7.399891775
26	llla2	Rengri	254.5	1461.24	371885.58	0.584496	2500	1000	170	0.228	38.76	1.14	386.18	193.548	192.6336	10299.802	1.870265152
27	llla3	Chidrang	170.8	708.96	121090.368	0.35448	2000	1250	180	0.228	41.04	2.28	477.62	86.868	390.7536	10299.802	3.793797348
28	llla4	Damring	187.9	504.4	94776.76	0.280222222	1800	1250	200	0.228	45.6	1.72	547.12	160.02	387.096	6437.376	6.013257576

29	lllb1	Chichara	183.6	2465.8	452720.88	0.704514286	3500	1000	150	0.228	34.2	1.23	305.71	53.6448	252.0696	34761.83	0.725133277
30	lllb2	Chil	61.52	1336.24	82205.4848	0.534496	2500	1125	170	0.228	38.76	1.27	440.44	301.752	138.684	7724.8512	1.795296717
31	lllb3	Dhudnai	222	1211.24	268895.28	0.484496	2500	1250	170	0.228	38.76	1.09	568.45	86.868	481.584	7081.1136	6.800964187
32	lllb4	Lower Dhudnai	132.8	524.4	69640.32	0.286557377	1830	1260	200	0.228	45.6	2.33	446.84	52.1208	394.716	10299.802	3.832267992
33	lVa1	Upper Iideek	167.3	1873.08	313366.284	0.618178218	3030	1125	140	0.228	31.92	1.66	780.9	188.0616	592.836	9012.3264	6.578057359
34	IVa2	Lower Iideek	85.63	600.54	51424.2402	0.316073684	1900	1255	195	0.228	44.46	2	581.86	48.1584	533.7048	14162.227	3.768508953
35	IVa3	Thokhol N	75.06	600.54	45076.5324	0.316073684	1900	1255	195	0.228	44.46	1.33	457.2	50.5968	406.6032	7081.1136	5.74207989
36	IVa4	Chota Thokhol	146.6	604.4	88605.04	0.318105263	1900	1250	200	0.228	45.6	3	304.8	76.2	228.6	6115.5072	3.738038278
37	IVa int	Manki	107.4	552.12	59297.688	0.298443243	1850	1250	210	0.228	47.88	1.66	457.2	48.1584	409.0416	9656.064	4.236111111
38	IVb1	East Singra	96.76	554.4	53643.744	0.299675676	1850	1250	200	0.228	45.6	1.5	344.42	67.3608	277.0632	5149.9008	5.379971591
39	IVb2	West Singra	67.61	584.4	39511.284	0.310851064	1880	1250	200	0.228	45.6	0	181.97	41.148	140.8176	8368.5888	1.682692308
40	IVc1	Gijang N	107.1	1963.976	210341.8296	0.654658667	3000	1000	158	0.228	36.024	1.5	692.81	76.2	616.6104	6437.376	9.578598485
41	IVc2	Umlaju	44.32	2168.08	96089.3056	0.677525	3200	1000	140	0.228	31.92	2	830.28	518.16	312.1152	5793.6384	5.387205387
42	IVc3	Umtynseng	81.27	2048.08	166447.4616	0.682693333	3000	920	140	0.228	31.92	1.5	1407.3	518.16	889.1016	10299.802	8.632220644
43	IVc int	Singram	135.1	599.22	80954.622	0.318734043	1880	1250	135	0.228	30.78	0	440.44	146.9136	293.5224	7724.8512	3.799715909
44	IVd1	Umsynthi	44.04	839.66	36978.6264	0.41983	2000	1125	155	0.228	35.34	2	914.4	844.296	70.104	2574.9504	2.722537879
45	IV d int	Boko N	258.1	504.4	130185.64	0.280222222	1800	1250	200	0.228	45.6	1.6	604.11	51.816	552.2976	11587.277	4.766414141
46	Va1	Umsir	143	972.25	139031.75	0.486125	2000	1000	150	0.185	27.75	1.75	1201.5	762	439.5216	7724.8512	5.689709596
47	Va2	Umngi	167.8	972.25	163143.55	0.486125	2000	1000	150	0.185	27.75	1.66	1693.8	609.6	1084.174	14162.227	7.655389118
48	Va3	Doiang N	107.7	491.7	52956.09	0.298	1650	1125	180	0.185	33.3	1.28	3599.1	96.9264	3502.152	2574.9504	136.0085227
49	Va int	Kulsi	255.2	316.7	80821.84	0.1979375	1600	1250	180	0.185	33.3	3	503.22	52.4256	450.7992	17380.915	2.593644781
50	Vb1	Umkanrem	80.68	1597.25	128866.13	0.6389	2500	875	150	0.185	27.75	1.16	1576.7	609.6	967.1304	9656.064	10.01578283
51	Vb2	East Syana	53.83	1899.1	102228.553	0.67825	2800	875	140	0.185	25.9	2	1764.2	1075.944	688.2384	9656.064	7.127525253
52	Vb3	Umsohlans	91.4	2794.47	255414.558	0.793883523	3520	700	138	0.185	25.53	1.75	1922.7	1327.0992	595.5792	10299.802	5.782433712
53	Vb4	Umtynsung	235.1	2073.175	487403.4425	0.727429825	2850	750	145	0.185	26.825	1.62	1773.9	1345.9968	427.9392	5793.6384	7.386363636
54	Vb int	Syanu	47.08	1097.25	51658.53	0.548625	2000	875	150	0.185	27.75	2	914.4	609.6	304.8	5149.9008	5.918560606
55	Vc1	Umrina	99.92	1732.25	173086.42	0.6929	2500	740	150	0.185	27.75	4	1792.5	1685.2392	107.2896	5149.9008	2.083333333
56	Vc2	Umdan	42.41	2261.695	95918.48495	0.753898333	3000	710	153	0.185	28.305	7	1600.2	1524	76.2	6437.376	1.183712121
57	Vc3	Umnongkrem	27.21	1421.325	38674.25325	0.661081395	2150	700	155	0.185	28.675	0	1219.2	990.6	228.6	1931.2128	11.83712121
58	Vc4	Umrit	63.66	668.55	42559.893	0.393264706	1700	1000	170	0.185	31.45	1.4	632.46	152.4	480.06	9334.1952	5.143025078
59	Vc5	Umshail	56.66	492.625	27912.1325	0.298560606	1650	1125	175	0.185	32.375	1.5	609.6	304.8	304.8	643.7376	47.34848485
60	Vc6	Uming	69.02	980.4	67667.208	0.510625	1920	910	160	0.185	29.6	1.5	1075.3	487.68	587.6544	2896.8192	20.28619529

61	Vc int	Khri	401.3	786.7	315702.71	0.432252747	1820	1000	180	0.185	33.3	1.9	1685.2	304.8	1380.439	31543.142	4.376352814
62	Vd1	Khuna Khemdi N	36.56	541.7	19804.552	0.318647059	1700	1125	180	0.185	33.3	1.5	358.44	152.4	206.0448	3218.688	6.401515152
63	Vd2	Umshroor	110.4	314.85	34759.44	0.19678125	1600	1250	190	0.185	35.15	1.75	727.86	228.6	499.2624	6759.2448	7.386363636
64	Vd int	Bhata N	115.8	213	24665.4	0.142	1500	1250	200	0.185	37	0	377.95	49.9872	327.9648	7724.8512	4.245580808
65	VIa1	Umryleng	72.84	718.55	52339.182	0.359275	2000	1250	170	0.185	31.45	2.66	914.4	838.2	76.2	643.7376	11.83712121
66	VIa2	Umran	316.9	967.625	306640.3625	0.552928571	1750	750	175	0.185	32.375	3.25	990.6	609.6	381	1931.2128	19.72853535
67	VIa3	Upper Umrew	43.95	750.4	32980.08	0.421573034	1780	1000	160	0.185	29.6	4.5	685.8	457.2	228.6	1287.4752	17.75568182
68	VIa4	East Umrew	111.7	588	65679.6	0.392	1500	875	200	0.185	37	3	914.4	228.6	685.8	1931.2128	35.51136364
69	VIa int	Lower Umrew	563.3	314.85	177355.005	0.19678125	1600	1250	190	0.185	35.15	3	1066.8	152.4	914.4	3218.688	28.40909091
70	VIb1	Umsniang	216.7	467.07	101214.069	0.31138	1500	1000	178	0.185	32.93	3.14	914.4	609.6	304.8	3218.688	9.46969697
71	VIb2	East Umsniang	230.6	161.15	37161.19	0.111137931	1450	1250	210	0.185	38.85	2.62	914.4	762	152.4	643.7376	23.67424242
72	VIc1i	Upper Umiam	184.1	895.4	76404.482	0.497444444	1800	875	160	0.185	29.6	2.33	1752.6	914.4	838.2	3218.688	26.04166667
73	VIc1ii	Middle Umiam	175.5	388.55	68190.525	0.273626761	1420	1000	170	0.185	31.45	2.66	1752.6	838.2	914.4	1287.4752	71.02272727
74	VIc1iii	Lower Umiam	80.86	10.225	826.7935	0.007865385	1300	1250	215	0.185	39.775	1.66	1066.8	762	304.8	643.7376	47.34848485
75	VIc2	East Umswai	85.33	2059.1	118789.479	0.748763636	2750	665	140	0.185	25.9	3.5	1219.2	685.8	533.4	3218.688	16.5719697
76	VIc3	Umswai	57.69	1221.88	224948.108	0.61094	2000	750	152	0.185	28.12	2	838.2	609.6	228.6	1287.4752	17.75568182
77	VIc int	Umiam Interfluve	310.5	1066.7	331210.35	0.484863636	2200	1100	180	0.185	33.3	0	838.2	304.8	533.4	643.7376	82.85984848
78	VIIa1	Upper Umkhan	70.07	1424.1	99786.687	0.647318182	2200	750	140	0.185	25.9	2.66	1255.2	873.8616	381.3048	5793.6384	6.581439394
79	VIIa2	Umlew	139.2	1023.175	142425.96	0.568430556	1800	750	145	0.185	26.825	3.5	1086	914.4	171.6024	1287.4752	13.32859848
80	VIIa3	Mynlen	130.3	696.325	90731.1475	0.435203125	1600	875	155	0.185	28.675	3	1241.5	758.3424	483.108	10943.539	4.414549911
81	VIIa4	Mynshrehn	56.49	570.4	32221.896	0.3565	1600	1000	160	0.185	29.6	4	997.92	857.0976	140.8176	7081.1136	1.988636364
82	Vlla5	Ummat	115.5	570.4	65881.2	0.3565	1600	1000	160	0.185	29.6	3	1210.1	1000.9632	209.0928	5793.6384	3.609006734
83	VIIa6	Umud	81.71	116.7	9535.557	0.083357143	1400	1250	180	0.185	33.3	3	914.4	609.6	304.8	7402.9824	4.117259552
84	VIIa7	Sonaidong	79.27	161.15	12774.3605	0.107433333	1500	1300	210	0.185	38.85	3.66	559	457.2	101.8032	4184.2944	2.432983683
85	VIIa8	Sonai	237.8	2264.85	538581.33	0.75495	3000	700	190	0.185	35.15	3	1676.4	873.8616	802.5384	22530.816	3.561958874
86	Vlla int i	Upper Umkhen	139	1222.25	169892.75	0.611125	2000	750	150	0.185	27.75	2.25	1340.2	889.4064	450.7992	4506.1632	10.00405844
87	Vlla int ii	Middle Umkhen	80.8	770.4	62248.32	0.428	1800	1000	160	0.185	29.6	2	1090.9	433.1208	657.7584	31865.011	2.064202632
88	Vlla int iii	Lower Umkhen	184.6	213	39319.8	0.142	1500	1250	200	0.185	37	2	435.86	161.544	274.32	26393.242	1.039356984
89	Vllb	Myntriang	248.2	211.15	52407.43	0.140766667	1500	1250	210	0.185	38.85	3.6	1066.8	161.544	905.256	63086.285	1.43494898
90	Vllc	East Sonai	132.9	1659.3	220520.97	0.5531	3000	1300	220	0.185	40.7	3.33	388.92	137.16	251.7648	6115.5072	4.116826156
91	Vllla1	Umlurem	190.5	5100.95	971730.975	0.850158333	6000	875	130	0.185	24.05	2.5	1357.3	791.2608	566.0136	19955.866	2.836326979
92	Vllla2	Umtarang	67	5600.58	375238.86	0.861627692	6500	875	132	0.185	24.42	1.5	1295.4	1014.6792	280.7208	17702.784	1.585743802

93	Vllla3	Khanker	58.04	6099.285	354002.5014	0.871326429	7000	875	139	0.185	25.715	2.66	1034.8	914.4	120.396	2253.0816	5.343614719
94	Vllla4	Rashu N	71.6	6977.43	499583.988	0.87217875	8000	1000	122	0.185	22.57	2	1270.7	975.0552	295.656	10299.802	2.870501894
95	Vllla5	Umpawat	93.48	6851.875	640513.275	0.856484375	8000	1125	125	0.185	23.125	1.66	1254.3	883.3104	370.9416	3218.688	11.52462121
96	Vlllb1	Mynsan	104.2	4099.1	427126.22	0.81982	5000	875	140	0.185	25.9	1.5	1283.8	914.4	369.4176	7724.8512	4.78219697
97	Vlllb2	South Myntang	28.39	1898.175	53889.18825	0.677919643	2800	875	145	0.185	26.825	1.5	944.88	838.2	106.68	965.6064	11.0479798
98	Vlllb3	Myntang	299.4	2425.58	726218.652	0.75799375	3200	750	132	0.185	24.42	1.66	1389.3	914.4	474.8784	7081.1136	6.706267218
99	Vlllb int	Myntang	73.34	2298.175	168548.1545	0.718179688	3200	875	145	0.185	26.825	3	863.5	762	101.4984	1287.4752	7.883522727
100	Vlllc1	Dikisim	47.34	4724.47	223656.4098	0.787411667	6000	1250	138	0.185	25.53	1.71	1524	1019.556	504.444	9334.1952	5.404258098
101	Vlllc2	Wahkhynriam	157.9	5850.025	923718.9475	0.835717857	7000	1125	135	0.185	24.975	2.125	1219.2	953.4144	265.7856	3540.5568	7.506887052
102	Vlllc3	Umphung	91.72	6850.95	628369.134	0.85636875	8000	1125	130	0.185	24.05	2	1219.2	1021.08	198.12	6115.5072	3.239633174
103	Vlllc4	Umrang	108.9	3597.25	391740.525	0.799388889	4500	875	150	0.185	27.75	1.9	831.49	609.6	221.8944	3218.688	6.893939394
104	Vlllc5	Dinar Umphar	117.6	2595.4	305219.04	0.741542857	3500	875	160	0.185	29.6	1.66	861.97	771.7536	90.2208	5793.6384	1.557239057
105	Vlllc6	Langkni	192.6	966.7	186186.42	0.48335	2000	1000	180	0.185	33.3	1.16	355.4	140.208	215.1888	5149.9008	4.178503788
106	Vlllc int i	Upper Kopili	175.6	4974.1	873451.96	0.829016667	6000	1000	140	0.185	25.9	1.33	914.4	754.38	160.02	9012.3264	1.775568182
107	Vlllc int ii	Middle Kopili	304.1	3972.25	1207961.225	0.79445	5000	1000	150	0.185	27.75	2.08	1133.9	762	371.856	3862.4256	9.627525253
108	Vlllc int iii	Lower Kopili	141.4	1470.4	207914.56	0.58816	2500	1000	160	0.185	29.6	1.6	717.8	253.8984	463.9056	13196.621	3.51533629
109	Vllld1	Myntang N	55.54	2224.1	123526.514	0.741366667	3000	750	140	0.185	25.9	2.5	1275	914.4	360.5784	8368.5888	4.308712121
110	Vllld2	South Mynniang	62.87	1096.695	68949.21465	0.5483475	2000	875	153	0.185	28.305	1.14	1042.7	876.9096	165.8112	2896.8192	5.723905724
111	Vllld3	Mingla	221.7	844.475	187220.1075	0.4222375	2000	1125	165	0.185	30.525	3	881.18	304.8	576.3768	6437.376	8.953598485
112	Vllld int i	Upper Mynniang	100.5	2024.1	203422.05	0.722892857	2800	750	140	0.185	25.9	1.25	1143	914.4	228.6	4828.032	4.734848485
113	Vllld int ii	Middle Mynniang	199	1170.4	232909.6	0.532	2200	1000	160	0.185	29.6	1.66	975.36	558.6984	416.6616	8046.72	5.178030303
114	Vllld int iii	Lower Mynniang	113.6	641.7	72897.12	0.3565	1800	1125	180	0.185	33.3	2	640.08	152.7048	487.3752	4506.1632	10.81574675
115	Vllle1	Kalanga N	233.3	233.925	54574.7025	0.153898026	1520	1250	195	0.185	36.075	3	1069.2	258.1656	811.0728	30899.405	2.624881629
116	Vllle2	Dera juri	145.4	231.15	33609.21	0.152072368	1520	1250	210	0.185	38.85	1.6	560.83	152.4	408.432	7081.1136	5.767906336
117	lXa1	Dalaimar	390.4	3224.1	1258688.64	0.716466667	4500	1250	140	0.185	25.9	2	1036.3	323.088	713.232	17059.046	4.180960549
118	lXa2	Dihamlai N	74.97	3847.25	288428.3325	0.76945	5000	1125	150	0.185	27.75	1.75	777.85	671.7792	106.0704	9656.064	1.098484848
119	lXa int	Diyung	143.6	2970.4	426549.44	0.7426	4000	1000	160	0.185	29.6	2.5	609.6	188.976	420.624	9334.1952	4.506269592
120	lXb	Langlair	168.8	2971.88	501653.344	0.74297	4000	1000	152	0.185	28.12	4	611.12	291.9984	319.1256	4184.2944	7.626748252
121	lXc1	Didarbi N	191	2470.4	471846.4	0.705828571	3500	1000	160	0.185	29.6	1.5	559.61	228.6	331.0128	12552.883	2.636946387
122	lXc2	Longku N	61.69	970.4	59863.976	0.4852	2000	1000	160	0.185	29.6	1.5	431.6	230.4288	201.168	7724.8512	2.604166667
123	lXc int	Lower Diyung	130.7	588	76851.6	0.336	1750	1125	200	0.185	37	1.5	316.38	34.1376	282.2448	8368.5888	3.372668998
124	Xa	Kayang	535.9	2188	1172549.2	0.625142857	3500	1300	160	0.075	12	1.25	1314.9	82.9056	1232.002	10943.539	11.25779857

125	Xb	Larang	109.1	3187.625	347769.8875	0.708361111	4500	1300	165	0.075	12.375	2.5	1219.2	304.8	914.4	11587.277	7.891414141
126	Xc	Gumra	186.3	3186.5	593644.95	0.708111111	4500	1300	180	0.075	13.5	1.33	1322.5	304.8	1017.727	4506.1632	22.58522727
127	Xla1	Saipung	88.85	7491.75	665641.9875	0.881382353	8500	1000	110	0.075	8.25	2.2	1143	914.4	228.6	7081.1136	3.228305785
128	Xla2	East Saipung	92.87	7366.75	684150.0725	0.866676471	8500	1125	110	0.075	8.25	1.5	1254.3	733.9584	520.2936	9012.3264	5.773133117
129	Xla int	Umlunar	128.5	6741.375	866266.6875	0.842671875	8000	1250	115	0.075	8.625	1.5	872.03	84.1248	787.908	10299.802	7.649739583
130	Xlb1	Umphung	123.1	6741	829817.1	0.842625	8000	1250	120	0.075	9	1.66	1626.7	239.268	1387.45	6759.2448	20.52669553
131	Xlb2	Dikisim	190	5540.25	1052647.5	0.814742647	6800	1250	130	0.075	9.75	2	1583.4	510.54	1072.896	6437.376	16.66666667
132	Xlb int i	Lukha	38.05	5238.75	199334.4375	0.805961538	6500	1250	150	0.075	11.25	0	1040.3	304.8	735.4824	257.49504	285.6297348
133	Xlb int i	Lubhar	285.8	5085.75	1453507.35	0.794648438	6400	1300	190	0.075	14.25	1.5	1322.5	304.8	1017.727	4184.2944	24.32255245
134	Xlla	Praog	221.3	7238.75	1601935.375	0.851617647	8500	1250	150	0.075	11.25	3.5	976.27	304.8	671.4744	5149.9008	13.03858902
135	Xllb1	Myntdu	256	7891.375	2020192	0.886671348	8900	1000	115	0.075	8.625	6.5	1404.8	1199.388	205.4352	13518.49	1.519660895
136	Xllb2	Umrpong	122.5	8191.75	1003489.375	0.890407609	9200	1000	110	0.075	8.25	4	1097.3	762	335.28	13518.49	2.48015873
137	Xllb int i	Upper Hari	130.4	8367.5	1091122	0.880789474	9500	1125	100	0.075	7.5	2	1159.2	597.1032	562.0512	7081.1136	7.937327824
138	Xllb int ii	Lower Hari	528	7038.525	3716341.2	0.84801506	8300	1250	153	0.075	11.475	0	812.6	762	50.5968	1287.4752	3.929924242
139	Xllc1	Umtyrngai	168.9	6039.875	1020134.888	0.827380137	7300	1250	135	0.075	10.125	3	862.28	506.2728	356.0064	8046.72	4.424242424
140	Xllc2	Nayapara	70.36	1893.5	133226.66	0.59171875	3200	1290	220	0.075	16.5	2.5	14.63	14.3256	0.3048	3862.4256	0.007891414
141	Xllc int	Lower Goyain	176.6	2735.6	483106.96	0.6839	4000	1250	192	0.075	14.4	2	11.887	8.8392	3.048	4506.1632	0.067640693
142	Xllla1	Umgot	396.8	7239.5	2872633.6	0.9049375	8000	750	140	0.075	10.5	2.25	1676.4	1066.8	609.6	17380.915	3.507295174
143	Xllla2	Umdon	280.2	8241.75	2309338.35	0.91575	9000	750	110	0.075	8.25	2.75	1911.7	272.1864	1639.519	14162.227	11.57670455
144	Xllla3	Umngi	89.61	8863.75	794280.6375	0.886375	10000	1125	150	0.075	11.25	1.5	1347.2	39.9288	1307.287	10621.67	12.30773646
145	Xllla4	Umkrem	69.4	8869	615508.6	0.8869	10000	1125	80	0.075	6	2	914.4	616.6104	297.7896	5149.9008	5.782433712
146	Xllla5	Dhamalia	109.1	5736.5	625852.15	0.8195	7000	1250	180	0.075	13.5	1.6	1064.4	845.2104	219.1512	3540.5568	6.189738292
147	Xllla int	Piyaingang	272.5	5736.5	1563196.25	0.8195	7000	1250	180	0.075	13.5	2.3	918.06	490.728	427.3296	5471.7696	7.809714795
148	Xlllb1	Umrew	173.5	9993.25	1733828.875	0.908477273	11000	1000	90	0.075	6.75	1.66	1894	535.5336	1358.494	7724.8512	17.58601641
149	Xlllb2	Umpyn	84.77	10994	931961.38	0.916166667	12000	1000	80	0.075	6	1.5	1662.4	1034.796	627.5832	5793.6384	10.83228114
150	Xlllb int	Dhalai	92.25	9864.5	910000.125	0.896772727	11000	1125	140	0.075	10.5	2.5	1310.6	572.4144	738.2256	6437.376	11.46780303
151	XlVa1	Upper Umiew	46.89	7240.25	339495.3225	0.90503125	8000	750	130	0.075	9.75	0.5	1963.2	1960.7784	2.4384	3218.688	0.075757576
152	XlVa2	Mosingi	38.3	9241.6	353953.28	0.92416	10000	750	112	0.075	8.4	1.25	1828.8	1524	304.8	4570.537	6.668800683
153	XlVa3	East Bagra	51.81	10992.5	569521.425	0.916041667	12000	1000	100	0.075	7.5	2	914.4	609.6	304.8	643.7376	47.34848485
154	XlVa4	Sonai	161.6	7738.75	1250582	0.859861111	9000	1250	150	0.075	11.25	1.66	1358.5	304.8	1053.694	4506.1632	23.38338745
155	XIVa int	Umiam	421.6	10991	4633805.6	0.915916667	12000	1000	120	0.075	9	2.55	1870.9	675.132	1195.73	14805.965	8.076004611
156	XIVb1	Umktung	96.55	7738	747103.9	0.859777778	9000	1250	160	0.075	12	1.71	678.48	304.8	373.6848	9012.3264	4.146374459

157	XIVb2	Umparsumal	130.4	7738	1009035.2	0.859777778	9000	1250	160	0.075	12	1.8	848.87	304.8	544.068	3218.688	16.90340909
158	XIVc1	Umngi	69.65	6240.25	434633.4125	0.891464286	7000	750	130	0.075	9.75	4	1764.5	1676.4	88.0872	7081.1136	1.243973829
159	XIVc2	Umnongspung	69.19	6239.5	431711.005	0.891357143	7000	750	140	0.075	10.5	1.5	1885.5	1663.5984	221.8944	11587.277	1.914983165
160	XIVc3	East Mukai	46.25	7994	369722.5	0.888222222	9000	1000	80	0.075	6	1.75	1616	1219.2	396.8496	2574.9504	15.41193182
161	XIVc4	Umsrow	38.88	9993.25	388537.56	0.908477273	11000	1000	90	0.075	6.75	3	1525.2	304.8	1220.419	4184.2944	29.16666667
162	XIVc5	North Mukai	31.3	8868.1	277571.53	0.88681	10000	1125	92	0.075	6.9	3	914.4	304.8	609.6	3862.4256	15.78282828
163	XIVc6	Lower Dhamalia	84.21	10695	900625.95	0.89125	12000	1290	200	0.075	15	1.75	270.05	42.3672	227.6856	3540.5568	6.430785124
164	XIVc int i	Umngi	145	9994.15	1449151.75	0.908559091	11000	1000	78	0.075	5.85	2	1772.4	539.496	1232.916	16415.309	7.510769459
165	XIVc int ii	Mukai	104.7	4739.5	496225.65	0.789916667	6000	1250	140	0.075	10.5	1.125	1155.8	609.6	546.2016	4828.032	11.31313131
166	XIVc int iii	Dhamalia	49.58	8195	406308.1	0.862631579	9500	1290	200	0.075	15	0	304.8	76.2	228.6	1287.4752	17.75568182
167	XIVd1	Umrilang	175.6	7743.25	1359714.7	0.860361111	9000	1250	90	0.075	6.75	1.4	1573.4	257.2512	1316.126	10299.802	12.77817235
168	XIVd2	Kynchiang	181.9	7742.875	1408428.963	0.860319444	9000	1250	95	0.075	7.125	3.25	1340.2	609.6	730.6056	8368.5888	8.730332168
169	XIVd3	Baul	257.4	4685	1205919	0.780833333	6000	1300	200	0.075	15	2.5	598.63	277.6728	320.9544	8046.72	3.988636364
170	XIVd int i	Upper Dukatja	118	5238	618084	0.873	6000	750	160	0.075	12	5	2048.3	1584.96	463.296	19312.128	2.398989899
171	XIVd int ii	Lower Dukatja	114.5	6739.5	771672.75	0.8424375	8000	1250	140	0.075	10.5	2	928.42	516.0264	412.3944	4506.1632	9.151785714
172	XIVe1	Khynshi	239.4	7241	1733495.4	0.905125	8000	750	120	0.075	9	2.6	1815.7	1507.236	308.4576	27036.979	1.140873016
173	XIVe2	North Kynshi	108.3	5240.25	567519.075	0.873375	6000	750	130	0.075	9.75	2.25	1641	1524	117.0432	3540.5568	3.305785124
174	XIVe3	Umkyrtha	93.35	5115.25	477508.5875	0.852541667	6000	875	130	0.075	9.75	2	1524	1307.2872	216.7128	9656.064	2.244318182
175	XIVe4	Umlang	133.6	5115.85	683477.56	0.852641667	6000	875	122	0.075	9.15	2.33	2667	1219.2	1447.8	1931.2128	74.96843434
176	XIVe5	Nongpathar	57.71	7116	410664.36	0.8895	8000	875	120	0.075	9	1.5	1538.6	1388.364	150.2664	3862.4256	3.890467172
177	XIVe6	Umsingsong	46.67	7115.625	332086.2188	0.889453125	8000	875	125	0.075	9.375	2	1562.7	1219.2	343.5096	4506.1632	7.623106061
178	XIVe7	Umphyrphra	40.27	7116.15	286567.3605	0.88951875	8000	875	118	0.075	8.85	1.5	1020.8	944.88	75.8952	6437.376	1.178977273
179	XIVe int i	Kynshi	65.85	6116	402738.6	0.873714286	7000	875	120	0.075	9	2	1524	1388.364	135.636	3540.5568	3.830922865
180	XIVe int ii	Lower Kynshi	112	7492.5	839160	0.881470588	8500	1000	100	0.075	7.5	2	1219.2	802.8432	416.3568	16415.309	2.536393345
181	XIVf1	West Umwasan	77.86	5115.25	398273.365	0.852541667	6000	875	130	0.075	9.75	1.5	798.58	609.6	188.976	3540.5568	5.337465565
182	XIVf2	East Umwasan	234.3	4615.1	1081317.93	0.839109091	5500	875	132	0.075	9.9	2.4	1598.7	609.6	989.076	32830.618	3.012663399
183	XIVf3	Wanlaw	219.1	5991	1312628.1	0.855857143	7000	1000	120	0.075	9	2.4	661.72	304.8	356.9208	10621.67	3.360307622
184	XIVf4	Wahlytet	211.7	7366.75	1559540.975	0.866676471	8500	1125	110	0.075	8.25	1.16	570.28	272.1864	298.0944	13196.621	2.25886918
185	XIVf5	Wahblei	55.1	7115.625	392070.9375	0.889453125	8000	875	125	0.075	9.375	1.33	1066.8	996.696	70.104	6759.2448	1.037157287
186	XIVf6	Upper Wahblei	124.1	7115.1	882983.91	0.8893875	8000	875	132	0.075	9.9	1.6	1141.2	914.4	226.7712	9334.1952	2.429467085
187	XIVf7	East Wahblei	26.98	7616.6	205495.868	0.896070588	8500	875	112	0.075	8.4	1.6	609.6	304.8	304.8	5149.9008	5.918560606
188	XIVf8	Riangmaw	39.8	7792.275	310132.545	0.885485795	8800	1000	103	0.075	7.725	1.5	727.25	304.8	422.4528	5793.6384	7.291666667

189	XIVf9	North Riangmaw	92.52	4742.5	438776.1	0.790416667	6000	1250	100	0.075	7.5	2	564.79	487.3752	77.4192	6115.5072	1.265948963
190	XIVf int i	Upper Wahblei	87.27	7616	664648.32	0.896	8500	875	120	0.075	9	2	998.52	914.4	84.1248	3862.4256	2.178030303
191	XIVf int ii	Lower Wahblei	61.03	7491.75	457221.5025	0.881382353	8500	1000	110	0.075	8.25	2	382.83	304.8	78.0288	643.7376	12.12121212
192	XVa1	Rengshi	92.83	3614.875	335568.8463	0.803305556	4500	875	135	0.075	10.125	2	1141.2	886.6632	254.508	9656.064	2.635732323
193	XVa2	Ronga	75.7	3514.65	266059.005	0.798784091	4400	875	138	0.075	10.35	2.33	780.9	609.6	171.2976	7724.8512	2.217487374
194	XVa3	Rongit	92.95	3314.5	308082.775	0.789166667	4200	875	140	0.075	10.5	1.66	431.9	336.4992	95.4024	4506.1632	2.11715368
195	XVa4	Riangdhr	157.9	5615.4	886671.66	0.863907692	6500	875	128	0.075	9.6	2	896.42	609.6	286.8168	7724.8512	3.712910354
196	XVa int i	Rongdi	180.5	5115.625	923370.3125	0.852604167	6000	875	125	0.075	9.375	1	717.8	252.984	464.82	14805.965	3.139410408
197	XVb1	Rongni	67.11	3863.9	259306.329	0.77278	5000	1125	148	0.075	11.1	2	609.6	304.8	304.8	7081.1136	4.304407713
198	XVb2	Rompli	50.46	4114.5	207617.67	0.8229	5000	875	140	0.075	10.5	1.28	695.25	608.076	87.1728	6437.376	1.354166667
199	XVB3	North Rompli	30.79	5989.5	184416.705	0.855642857	7000	1000	140	0.075	10.5	2	433.43	304.8	128.6256	1931.2128	6.660353535
200	XVb4	Rongtham	82.11	4614.275	378878.1203	0.838959091	5500	875	143	0.075	10.725	2.5	304.8	233.7816	71.0184	3218.688	2.206439394
201	XVb5	Wahbyt	60.54	4989.35	302055.249	0.831558333	6000	1000	142	0.075	10.65	1.66	433.43	304.8	128.6256	1931.2128	6.660353535
202	XVb6	Simsang	44.75	2488.9	111378.275	0.711114286	3500	1000	148	0.075	11.1	1.5	687.93	488.5944	199.3392	6759.2448	2.949134199
203	XVb7	Riangmaw	44.42	2463.75	109439.775	0.684375	3600	1125	150	0.075	11.25	1.33	715.67	609.6	106.0704	3218.688	3.295454545
204	XVb8	Simsang	147.6	2863.375	422634.15	0.71584375	4000	1125	155	0.075	11.625	2.4	995.78	304.4952	691.2864	4506.1632	15.34090909
205	XVb9	Someswari	66.38	3063.225	203336.8755	0.729339286	4200	1125	157	0.075	11.775	2	609.6	304.8	304.8	5149.9008	5.918560606
206	XVb10	Nongriang	57.09	6366	363434.94	0.8488	7500	1125	120	0.075	9	1.33	1010.7	132.588	878.1288	7402.9824	11.86182477
207	XVb int i	Middle Simsang	89.51	2988.9	267536.439	0.747225	4000	1000	148	0.075	11.1	2.5	687.93	250.5456	437.388	11265.408	3.882575758
208	XVb int ii	Lower Simsang	90.42	5490.475	496448.7495	0.844688462	6500	1000	127	0.075	9.525	2	436.78	233.7816	202.9968	2896.8192	7.007575758
209	XVc1	Chebe	175.3	6365.4	1115854.62	0.84872	7500	1125	128	0.075	9.6	2.5	609.6	304.8	304.8	8046.72	3.787878788
210	XVc2	Rongpha	160.2	5740.1	919564.02	0.820014286	7000	1250	132	0.075	9.9	2.5	367.59	76.2	291.3888	5793.6384	5.029461279
211	XVc3	Ranghi	74.14	6991	518312.74	0.873875	8000	1000	120	0.075	9	2	381	304.8	76.2	643.7376	11.83712121
212	XVc int i	Lower Someswari	210.9	6741	1421676.9	0.842625	8000	1250	120	0.075	9	1.75	530.05	304.8	225.2472	3862.4256	5.831755051
213	XVd1	Rongva	352.5	5687.4	2004808.5	0.812485714	7000	1300	168	0.075	12.6	1.42	1025.7	76.2	949.452	11587.277	8.19391835
214	XVd2	Mahadeo	198	6715.975	1329763.05	0.839496875	8000	1273	147	0.075	11.025	1.5	909.83	405.0792	504.7488	12874.752	3.920454545
215	XVd3	Karnoi	119	6706.825	798112.175	0.838353125	8000	1282	149	0.075	11.175	4	628.5	76.2	552.2976	12231.014	4.515550239
216	XVd int	Kharnoi	189.7	3885.6	737098.32	0.747230769	5200	1300	192	0.075	14.4	1	628.5	302.0568	326.4408	6115.5072	5.33791866
217	XVla1	Daring	186.3	4843.08	902265.804	0.80718	6000	1125	140	0.228	31.92	1.42	1196.3	50.292	1146.048	14162.227	8.092286501
218	XVIa2	Bolmagi	51.21	5216.94	267159.4974	0.802606154	6500	1250	145	0.228	33.06	1.66	272.19	152.4	119.7864	1931.2128	6.202651515
219	XVIa3	Ramshali	125.1	5213.52	652211.352	0.80208	6500	1250	160	0.228	36.48	1.6	367.59	152.4	215.1888	3218.688	6.685606061
220	XVIa int	Nitai	151.4	5314.66	804639.524	0.805251515	6600	1250	155	0.228	35.34	2	274.93	76.2	198.7296	7081.1136	2.806473829

221	XVIb1	Romkhali	129	3711.24	478749.96	0.742248	5000	1250	170	0.228	38.76	1.75	261.52	94.488	167.0304	6437.376	2.59469697
222	XVIb2	East Romkhali	92.95	4692.38	436156.721	0.782063333	6000	1270	165	0.228	37.62	2	152.4	76.2	76.2	5149.9008	1.479640152
223	XVIb3	Upper Ramkhali	139.9	2664.4	372749.56	0.6661	4000	1290	200	0.228	45.6	2.66	153.01	76.2	76.8096	5149.9008	1.491477273
224	XVIc1	Bugi	150.9	3840.8	579576.72	0.76816	5000	1125	150	0.228	34.2	1.62	580.34	76.2	504.1392	6437.376	7.831439394
225	XVIc2	Norang	145	3340.344	484349.88	0.742298667	4500	1125	152	0.228	34.656	1.75	1410.6	249.3264	1161.288	7724.8512	15.03314394
226	XVIc3	Chapera	77.31	3713.52	287092.2312	0.742704	5000	1250	160	0.228	36.48	2	167.34	76.2	91.1352	643.7376	14.15719697
227	XVIc4	Ragu	56.2	4718.08	265156.096	0.786346667	6000	1250	140	0.228	31.92	2.2	266.7	167.3352	99.3648	12874.752	0.771780303
228	XVIc int	Bhugai	84.02	4208.96	353636.8192	0.765265455	5500	1250	180	0.228	41.04	1.66	266.7	46.0248	220.6752	4506.1632	4.897186147
229	XVIIa1	Thalang	80.99	3710.1	300480.999	0.74202	5000	1250	175	0.228	39.9	2	152.4	147.828	4.572	1609.344	0.284090909
230	XVIIa int	Lower Thalang	148.7	1634.4	243035.28	0.5448	3000	1320	200	0.228	45.6	2	152.4	76.2	76.2	3862.4256	1.972853535
231	XVIIb1	Bangdra	40.22	2514.204	101121.2849	0.661632632	3800	1250	157	0.228	35.796	1.33	261.52	94.488	167.0304	6437.376	2.59469697
232	XVIIb2	Sanda	97.4	2693.52	262348.848	0.67338	4000	1270	160	0.228	36.48	2.33	113.08	76.2	36.8808	1287.4752	2.864583333
233	XVIIb3	Daring	192.6	2178.96	419667.696	0.62256	3500	1280	180	0.228	41.04	2.2	153.01	76.2	76.8096	6115.5072	1.255980861
234	XVIIb4	Malijhi	71.53	2144.4	153388.932	0.612685714	3500	1310	200	0.228	45.6	1.5	152.4	76.2	76.2	1931.2128	3.945707071
235	XVIIb int	Marisi	175.1	2564.4	449026.44	0.657538462	3900	1290	200	0.228	45.6	1.66	242.62	76.2	166.4208	2574.9504	6.463068182
	Mean Values		**135.4106**	**3652.129698**	**480566.9873**	**0.654044367**	**4757.787234**	**1080.34**	**156.753**	**0.15317872**	**25.31711**	**2.0975**	**887.04**	**472.38204**	**414.6572**	**7891.4536**	**9.596930273**
	Standard Deviation		**91.22508**	**2878.175023**	**577961.4487**	**0.227572304**	**2846.689973**	**183.283**	**33.4356**	**0.06555732**	**13.83823**	**0.9811**	**543.51**	**419.43993**	**386.006**	**7040.4817**	**22.63323023**
	Coeffi of Variatioan (%)		**67.36924**	**78.80812735**	**120.2665734**	**34.79462789**	**59.83222521**	**16.9653**	**21.3301**	**42.7979311**	**54.65959**	**46.775**	**61.273**	**88.792522**	**93.0904**	**89.216537**	**235.8382273**