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Spatial Variations in Hydro-Meteorological Parameters in the Foot-Hill Areas of Arunachal Himalayas

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Abstract

Rainfall is an important parameter for climatic study which is associated and controls other hydro-meteorological factors such as PET, soil moisture, sub-surface flow, land use etc. But the rainfall pattern, duration and its intensity directly or indirectly influenced by the atmospheric conditions. The present study tried to analyse spatial variability of hydro-meteorological parameters in Dikrong River Catchment which is located in the foot-hill areas of Arunachal Himalayas. For this purpose daily statistics of rainfall and temperature for the periods of 2003-2006 were collected from different offices and used Thornthwaite-Mather method for calculating heat index, PET and soil moisture in Dikrong river catchment of high humid areas of Arunachal Himalayas. It is found that the spatial variation of rainfall was maximum during monsoon season while it is very less during winter. The high concentration PET is found in winter and pre-monsoon period in the lower plain areas and on the other hand it is reverse during monsoon and post monsoon. The soil moisture if found highest in the plains because of high runoff in the upper hilly parts of the catchment.

Keywords: *Rainfall, hydro-meteorological, Dikrong, PET, soil moisture*

1. Introduction

Rainfall is a major element which forms complex phenomena of climate (Narkhedkar *et. al.* 2010). As a result, rainfall is defined differently by the scientists of different disciplines like meteorologists, hydrologists, soil scientists, agronomists, geographers and so on, to understand the nature of variable rainfall. Rainfall pattern are influenced by the atmospheric conditions (especially air pressure, temperature and humidity) that have implicit effects on evapotranspiration, soil moisture, surface and sub-surface flow and runoff in the river catchment (Singh 2003). But the amount of rainfall, its intensity and occurrences are greatly controlled by the orography and relief features (Starkel 1972a and 1972b, Starkel *et. al.* 2002). Therefore, relief features (elevation and surface slope) are main factors that influence rainfall. Moreover, the changes in Inter Tropical Convergence Zone (ITCZ) of atmospheric conditions for monsoonal create seasonal abnormalities and differences in the rainfall distribution pattern in general at macro-regional frame and orography at micro-conditions of rainfall (Singh and Syiemlieh 2001).

Rainfall is the key element of hydrological and water quality models because it influences the speed and volume of flow and mass transport (Chaubey *et. al.* 1999, Sangati and Borga 2009). The analysis of rainfall characteristics of a watershed/river catchment or drainage basin would be helpful for the management of water resource application as well as its effective utilization. The study of nature and characteristics of rainfall is used for mitigation of flood and drought situation, applied to the planning and engineering design such as construction of reservoir, flood control work, drainage network design, soil and water conservation (Lee 2005, Verbist *et. al.* 2010) and is also useful for determining the potentiality of crop production, farming system and pattern of agricultural productivity of a region (Barman *et. al.* 2012, Das 2012). Analysis of rainfall characteristics in context with its temporal variations has important role to play in sustainable development. Due to increasing industrialization in the world, the climate has changed globally and regionally that affects the hydrologic conditions and its responses to the runoff in watershed. That's why, the analysis of rainfall variability at regional level is important to understand its impact on regional economics (Kwon *et. al.* 2008, Beecham and Chowdhury 2010).

Rainfall is directly or indirectly related to vegetation cover of a particular watershed area because it intercepts a certain amount of rain water falling during the first part of rain storm, then it reaches to the surface and infiltrates while a significant share of rainfall evaporates. Evaporation and transpiration vary over time that create variability in total rainfall and finally determine the net precipitation (Shahin 2002).

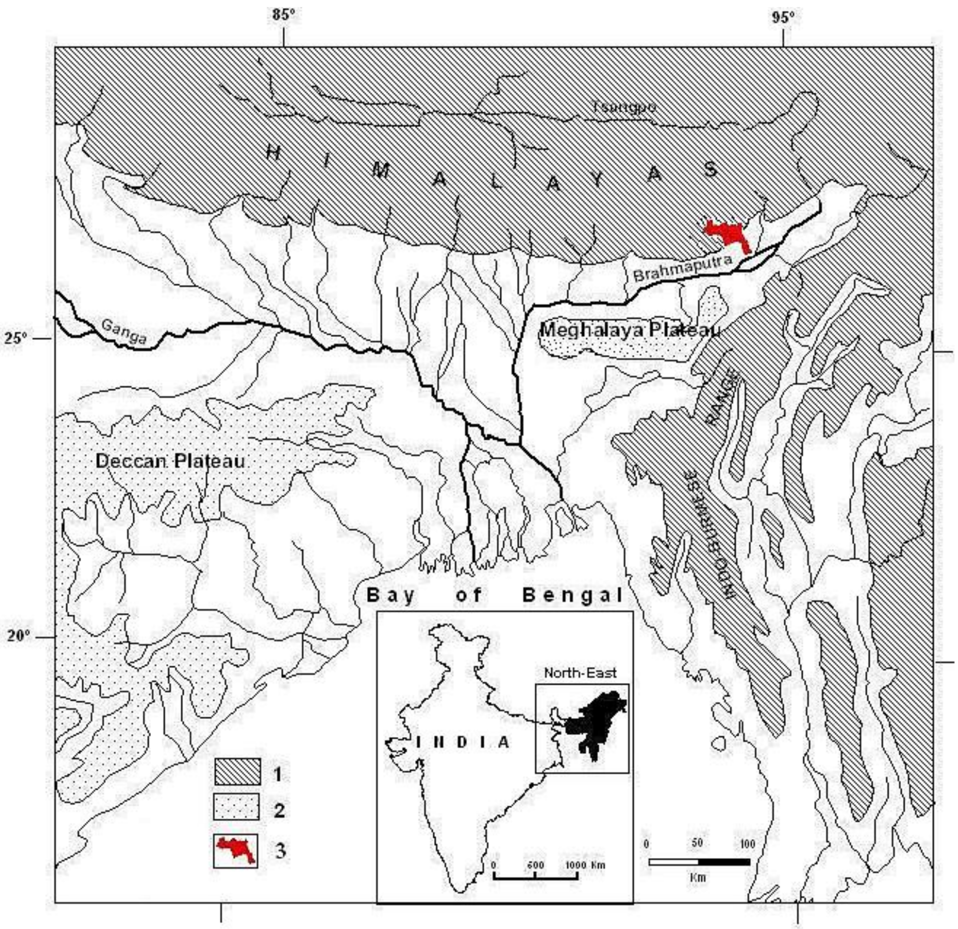
It is difficult to quantify a rainfall event that may include several dimensions i.e., the amount of rainfall, types of rainfall, rainfall duration, rainfall intensity and so on that vary over time (Lan *et. al.*.2005), while these dimensions are largely dependent on the actual availability of the rainfall data. It is highlighted that daily data of rainfall for longer period of time are significant which make possible for statistical analysis at daily, weekly and seasonal basis at temporal scale (Shamsudin *et. al.*.2010). The daily unit of the observation of rainfall is also significant temporal unit to find out the seasonal and spatio-temporal variability and the uneven distribution of rainfall for flood analysis in a particular area or region (Jianting *et. al.*.2010, Rathod and Aruchamy 2010).

Broadly, it is fact that Indian subcontinent experience the summer monsoon rains during June to September (Kripalani and Kumar 2004) that brings more than 80 per cent rainfall over Indian subcontinent (Jain and Kumar 2012, Ghosh *et. al.*.2009). Summer season rainfall plays an important role in hydrological system in the north-eastern parts of India where maximum amount of rain is precipitated during summer season (May-August) that is comparatively much higher than the amount of average annual rainfall of the country (Goswami *et. al.* 2010). It is the time of frequent floods in the river basins of north-east India. Increasing the rainfall increases the fluctuation in water level and discharge in the river basin. The major causes of floods include high monsoon rainfall (Mirza 2003, Jamir *et. al.*. 2008), inadequate capacity of river banks to contain high flow, erosion, silting of riverbeds, landslides and poor drainage facility in the flood prone areas (Mohapatra and Singh 2003).

Being the study area situated in the foot-hill loop of Arunachal Himalayas, where 2,000 mm to 5,000 mm annual amount of rain received, this situation of heavy rainfall creates its fluctuating pattern is the main cause of occasional floods and sometime frequent flash floods. Such pattern of flood frequency can also be seen in Dikrong river catchment. The steep slopes of this area influence the rainfall pattern (Dhar and Nandargi 2004).

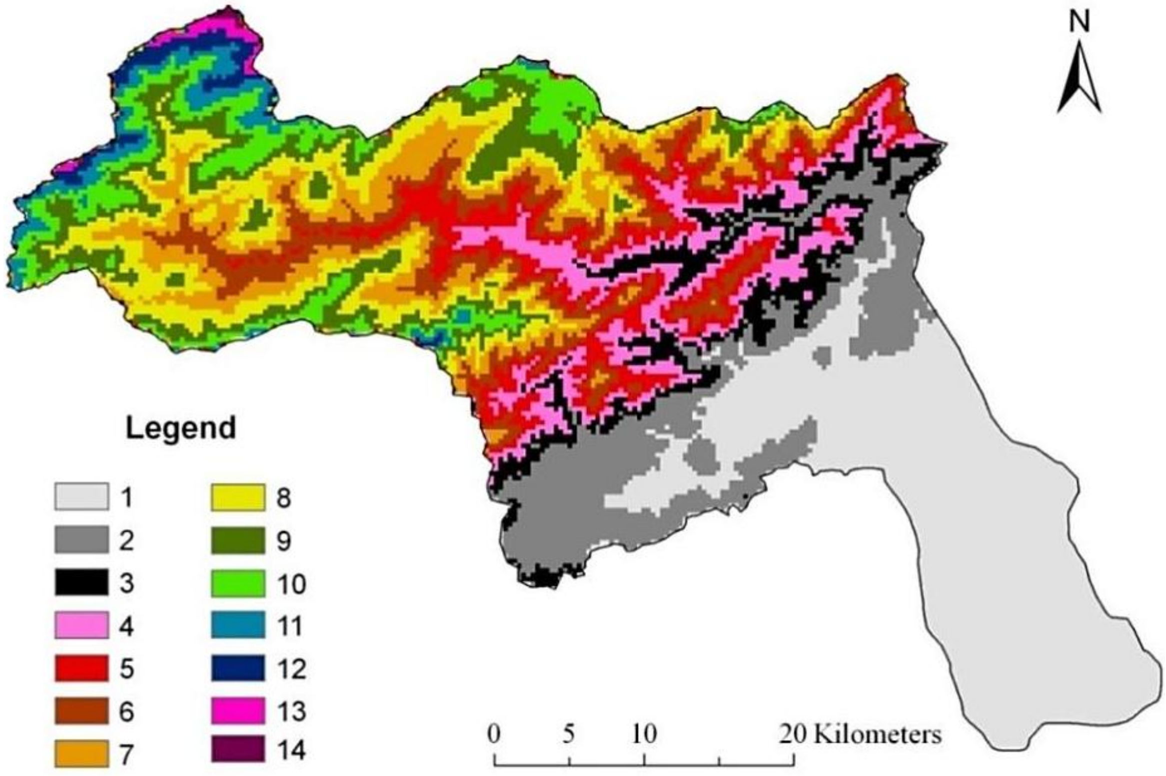
The issues of rainfall variability (regionally and temporally) and rainfall actions in the changes of Heat index, PET and soil moisture availability trends are main considerations to understand event-based spatial characteristics of rainfall. Thus, this paper is devoted to describe the general weather conditions with detail rainfall pattern of the study area.

Study Area



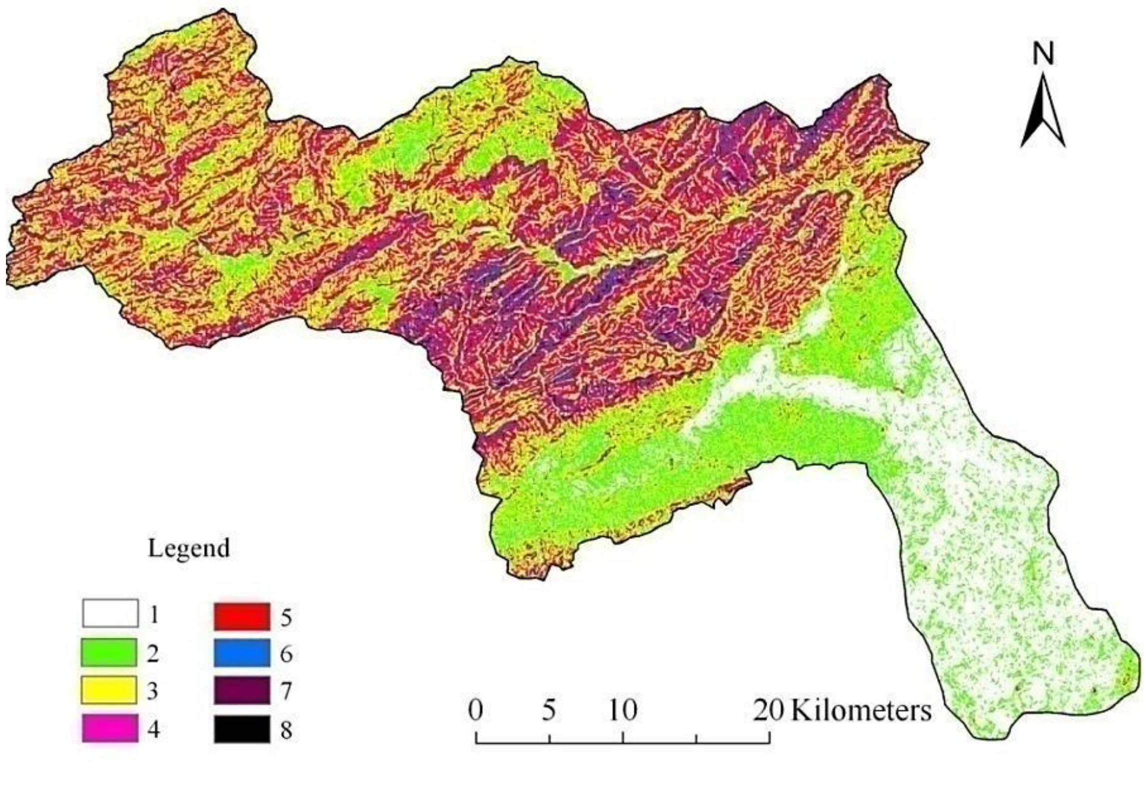
1=Areas above 1600 m a.s.l., 2= Areas of 900 to 1600 m a.s.l. 3= Study Area

Fig.1: Location of the Study Area



Abbreviations: Elevation in meters 1.0 – 200 2. 200 - 400 3. 400 - 600 4. 600 - 800 5. 800 – 1,000 6. 1,000 – 1,200 7. 1,200 – 1,400 8. 1,400 – 1,600 9. 1,600 – 1,800 10. 1,800 – 2,000 11. 2,000 – 2,200 12. 2,200 – 2,400 13. 2,400 – 2,600 14. Above 2,600

Fig.2: Digital Elevation Model (DEM) of Dikrong River Catchment



Abbreviations: Slope in percent; 1= Very Gentle (2- 4), 2= Gentle (4-10), 3= Moderate (10-20), 4= Moderately Steep (20-35), 5= Steep (35-60), 6= Very Steep (60-100), 7= Most Steep (100-175), 8= Extremely Steep (above 175).

Fig.3: Slope Variations in the Dikrong River Catchment

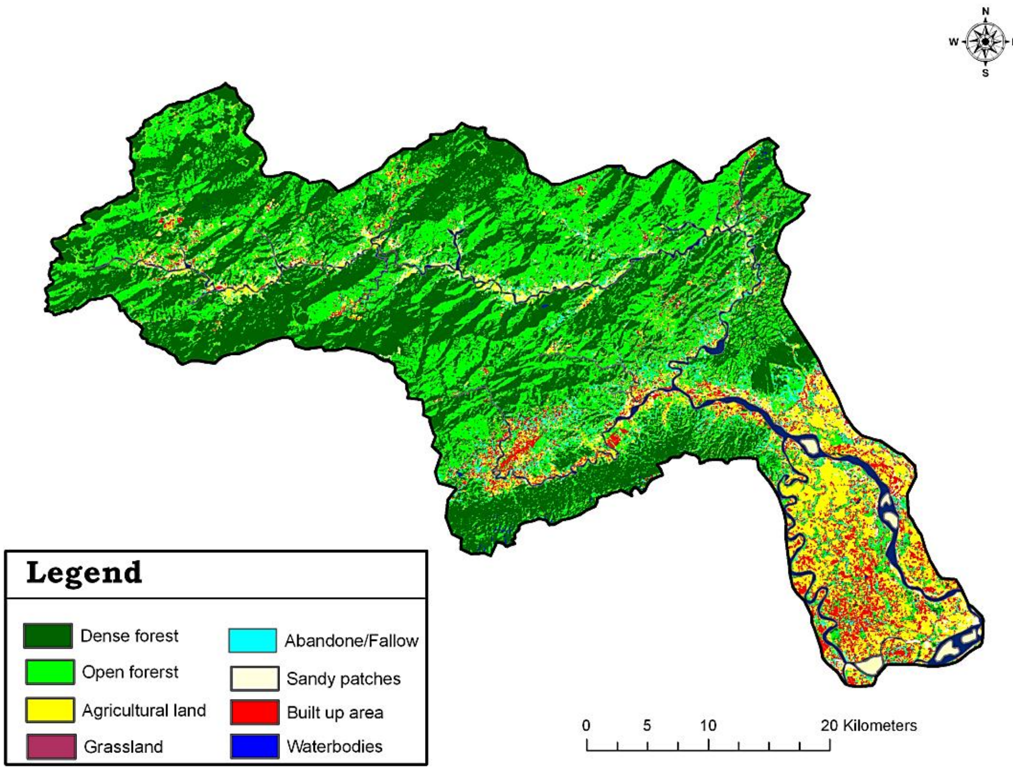


Fig.4: Land use/Land Cover Pattern (2006)

Dikrong river catchment is located in the foot-hills of Arunachal Himalayas and lies between 26˚55′N to 27˚22′N latitudes and 93˚13′E to 94˚0′E longitudes (Fig.-1) with its transitional characteristics of its location as it falls under Inter Tropical Convergence Zone (ITCZ) where climate is monsoonal in this part of Asian region. Being its location in the loop of Eastern Himalayas, it is more humid and has different hydrological characteristics than the other parts of North-East Region of the Country. Geologically, the catchment is located in the lower fault line which divides the river catchment into two topographic features: (i) the lower piedmont hills where erosion processes are prevalent and (ii) alluvial plains of depositional processes where frequent floods are experienced (Joshi and Shahid, 2002). However, the flood responses are more related to piedmont hill- topography and land use of its upper part that influence the water flow and discharge of river channels.

The length of the main river is recorded 145 km with an average slope of 5-15% with the perimeter of 264 km. Topographically, hill slopes are steep covering an area of about 61.54% with its narrow flat valleys located in the upper parts of the river catchment (Fig.-2 and 3). Such topography helps in accelerating the saturation processes and fast flow while the lower part is gentle plain accommodating about a quarter part of the catchment (27.01%) with sediment deposition. Average temperature is recorded 15.15°C in January (moderately cold) and 26.96°C in July (Hot). Sometimes rainfall is high during pre-monsoon period (April) but July is the peak of monsoon when it precipitates up to 602 mm to 986 mm. Post-monsoon showers which occur from October onwards are helpful for soil recharge and vegetation growth. Due to thick fertile soils (1.2 m to 1.8 m) having 200 mm of water retention capacity and high nutrient contents promote vegetal growth (NBSS & LUP, 2004).

Land use / land cover pattern of Dikrong river catchment is dominated by forest (75% areas are under dense and open forests) in the upper parts and agricultural and abandoned land (12% of total area) in the lower parts of the catchment (Fig.-4). Soils are fine loamy and coarse silty which have high faction of sand helping in retaining more water to regulate runoff. As a result, runoff has also been recorded in the dry weather of winter seasons in spite of less rainfall and moderate PET conditions (Al Huda and Singh, 2014).

Methods and Material used

Generation of Rainfall and Temperature Statistics

As we know the rainfall and temperature are main parameters to estimate PET and soil moisture availability, the spatial statistics of these parameters are not available in any Government office except the daily data of rainfall and temperature recorded at Itanagar station (which is located in the middle of Dikrong river catchment) by the state Government. However, there is fairly significant areal variation in these parameters within the Dikrong river catchment due to variability in elevation ranging from 80 m to 2,840 m and also because of implicit impact of MBT passing through the middle of the river catchment.

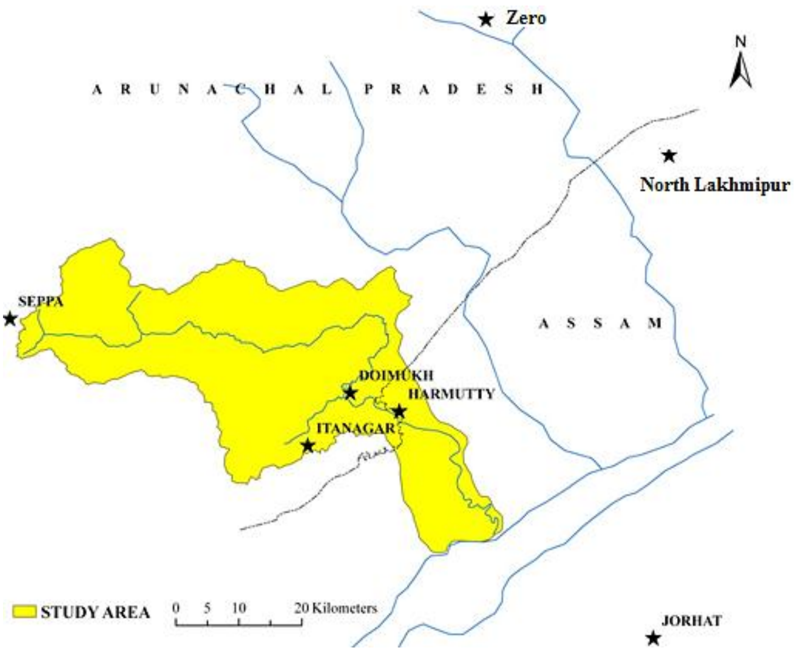


Fig.5: Locations of various stations containing Daily Rainfall and Temperature Statistics within and outside of Study Area

The spatial pattern of rainfall and temperature and its seasonal variations were shown by using extrapolation of isopleths based on collected statistics of seven station (three are located within the river catchment, one is on the upper ridges of catchment by outside and two are northern side of the catchment and Jorhat are located in the surrounding plains of Brahmaputra (Fig.-5). On the basis of monthly rainfall and temperature data of these stations the general spatial pattern of rainfall and temperature were interpreted. Seasonal variability of rainfall, temperature and PET were shown by using monthly data of four months: April as the month of Pre-Monsoon, July (Monsoon), October (Post-Monsoon) and January (Dry Season).

Calculation of Heat Index, PET and Soil Moisture: Daily detail statistics of radiation, humidity, evaporation, transpiration except rainfall and temperature are not available for the Dikrong river catchment to estimate correctly the trends of PET and soil moisture availability. Due to such limitations of data, the daily data of these meteorological parameters were generated using Thornthwaite and Mather (1957) classical procedure of calculation of Heat Index, PET and Soil Moisture availability to understand the seasonal and areal variability of hydrological processes in the study area. This method is used here because of two reasons: it is based on temperature and rainfall statistics which are available for the study area and secondly, it is simple to use.

The daily statistics of rainfall and temperature for the periods of 2003-2006 were collected from the Rural Works Department, Government of Arunachal Pradesh, Itanagar (Seppa, Zero, Doimukh and Itanagar station), Harmutty Tea Estate (Harmutty station), Sub-Division Office, Water Resources Department, North Lakhimpur (North Lakhimpur station) and Toklai Tea Research Centre, Jorhat (Jorhat station).

Results and Discussion

Rainfall Characteristics and Associated Factors

(a) Temperature

Annual daily mean temperature in Dikrong river catchment was calculated 22.5o C during 2003-2006. The highest daily mean temperature was recorded 30.25o C in the mid of August and the lowest 14.25o C in mid-January. The minimum temperature ranges from 8.57o C in the winter season and it is gradually increases upto 25.57 o C in the monsoon season. Due to the seasonal variation in it, it reaches upto 35.15 o C maximum in the summers in the Dikrong river catchment (Fig.-6). It is interesting to note that during the summers when monsoon sets with its full strength in mid-July to August, the temperature variability within the day becomes the lowest, while winters have high variation in temperature. The nights become cool but days are warm with more than 230 C. It means, there is continuous evapotranspiration during the winter days with dry conditions of atmosphere.

(b) Spatial Variation in Rainfall Pattern

Seasonal and areal variations in rainfall are influenced directly by orography which is an important factor for Dikrong river catchment where elevation varies from 88 m at the mouth to 2,840 m in the upper crust of conical hills. Spatial variations in different seasons have explicit impact on the intensity and amount of rainfall and also on spatial runoff variations.

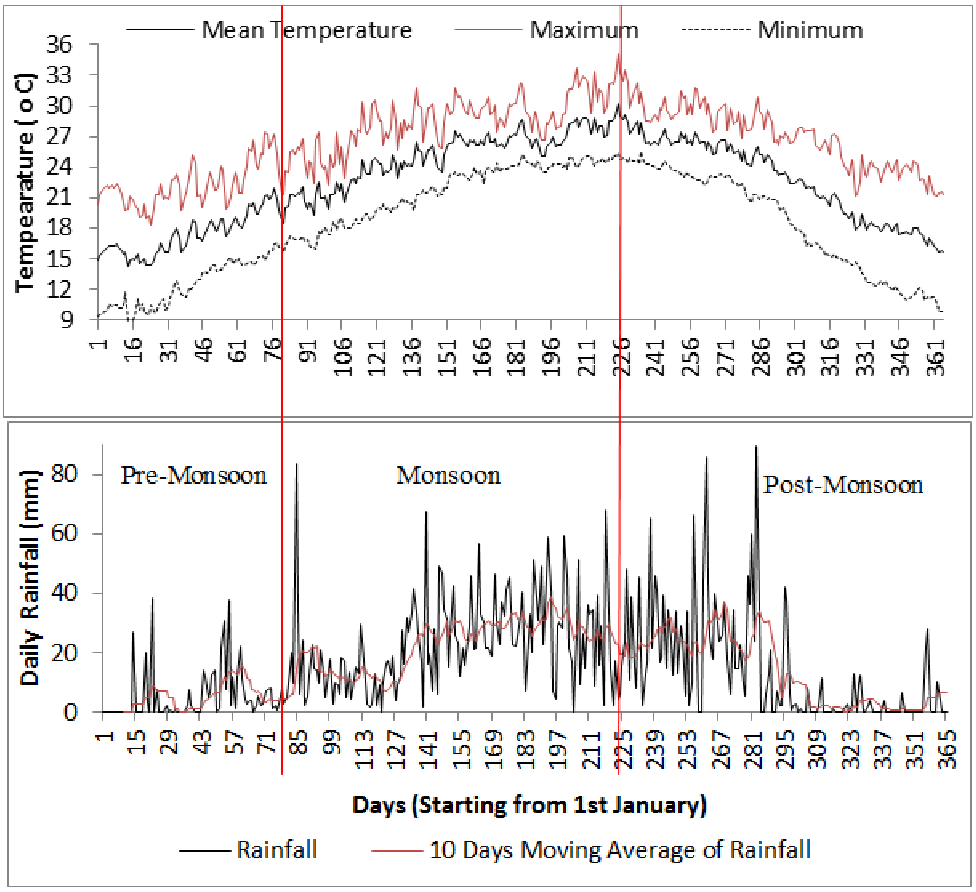
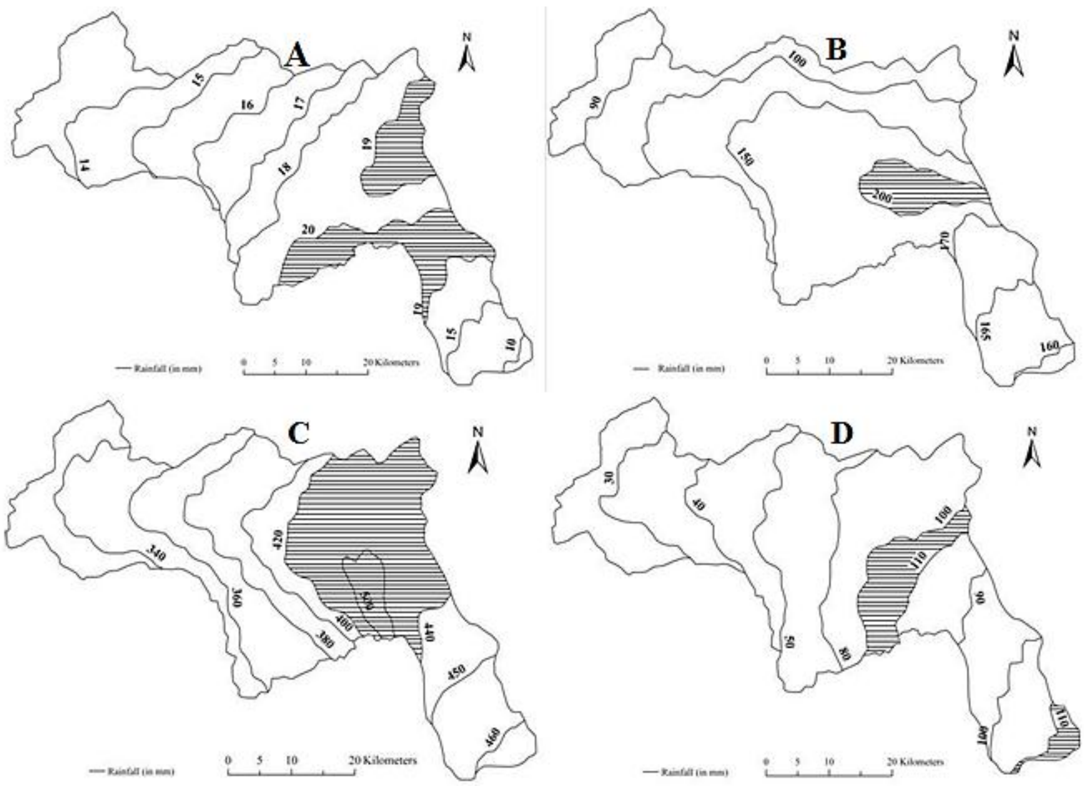


Fig.6: Trends of Daily average **A.** Temperature and **B.** Rainfall at Itanagar in Dikrong River Catchment, 2003-2006



N.B. Shaded area is high rainfall area

Fig.7: Spatial Variation of Rainfall **A.** January**, B.** April**, C.** July and **D.** October

On the basis of available rainfall statistics of 7 stations located in and around the Dikrong river catchment, isohytal map was prepared for the month of January (dry Season), April (Pre-monsoon), July (Monsoon) and October (post-monsoon) following topographic features of the catchment (Fig.-7). It is seen that the monthly rainfall is highest in the Brahmaputra plains comparing to the foot-hills of Arunachal Himalayas. Three stations, Jorhat (25 mm in January, 147 mm in April, 444 mm in July and 144 mm in October), Harmutty (20 mm in January, 170 mm in April, 438 mm in July and 85 mm in October) and Doimukh (19 mm in January, 204 mm in April, 516 mm in July and 101 mm in October) which are located in the plain areas received maximum amount of rainfall. As we move towards the northwards the higher ranges of Arunachal Himalayas, rainfall decreases sharply. The main causes of low rain in the northern part of river catchment may be the less moisture availability in the high altitude of Himalayas. Due to this effect, moisture holding capacity of the air decreases in high range of elevation in the Arunachal Himalayas (Dhar and Nandargi 2004). However, a slight difference in the seasonal pattern of rainfall is seen. For example, the monthly rainfall varies from 14 mm to 20 with spatial variation of 6 mm in the month of January; it has highest spatial variation from 340 mm to 500 mm in the monsoon season. The central longitudinal belt started near MBT has high rainfall in all the season.

Rainfall and Hydrological Parameters

As there is no availability of the data of meteorological parameters like radiation, humidity, evaporation, transpiration except rainfall and temperature for few stations located in the Dikrong river catchment, the daily data of main hydrological parameters were generated using Thornthwaite and Mather (1957) procedure (T-M) of calculation of PET and soil moisture availability. In-fact, T-M procedure based on "Water Balance Equation' as given in the earlier chapter. This method is used here due to two reasons: it is based on temperature and rainfall statistics which are available for the study area and secondly, it is simple to use. The main features of these generated hydrological parameters are given below:

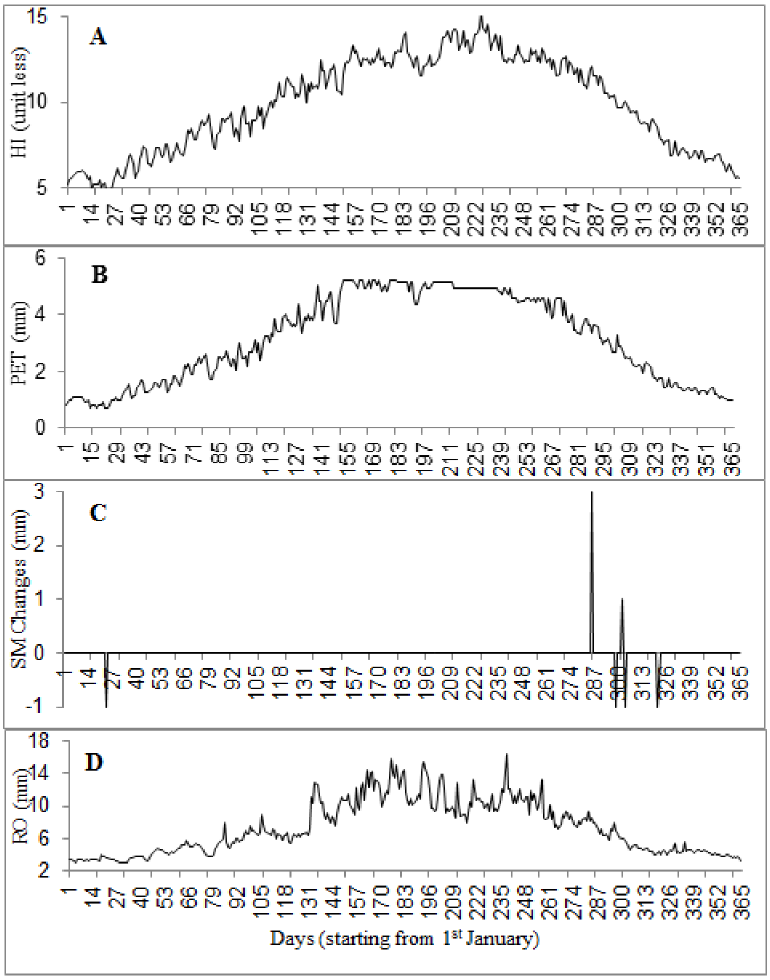


Fig.8: Trends of daily **A.** Heat Index, **B.** PET, **C.** Changes in Soil Moisture and **D.** Runoff

(i) Increasing heat index increases PET especially during pre-monsoon period when daily rainfall is lesser than the PET. However, during the monsoon season when atmospheric conditions are wet (relative humidity becomes more than 90%), the process of PET becomes slower. PET reaches to its maximum level that is assessed 5.00 mm/day when PET curve becomes flat during monsoon season, despite of fluctuation in heat index (Fig.-8 A and B).

(ii) It is observed from the Fig.8 C that there is fast fluctuation in soil moisture availability during pre and post-monsoon seasons when there are cases of occasional rains that infiltrate almost its total amount and fluctuate the soil moisture availability through the operation of discharge and recharge processes simultaneously. In the monsoon period, the soils of the river catchment become fully saturated and not have much change in Antecedent soil Moisture Conditions (AMC). Soils produce more surface and sub-surface runoff.

(iii) The runoff trend increases gradually from pre-monsoon period to monsoon period with increasing rainfall trends. The runoff recorded very high during the monsoon period because of the fully saturated soil and wet AMC in the area. The highest runoff of 16.45 mm/day was observed on 26th August and the lowest of 3.02 mm/day on 29th January when PET is moderately low with low rainfall but there is no change in soil moisture because of its more retention capacity and slow flow of sub-surface water with gradual release of water to river channels (Fig.-8, D).

Spatial Variations in PET and Soil Moisture

Since PET is the direct function of temperature and availability of daily temperature averages of seven stations located in and around the Dikrong river catchment, the seasonal variations and their spatial patterns were shown and interpreted by preparing isoline map of PET for the months of January, April, July and October taking into account of catchment topography (Fig.-9). It is noticed that the average monthly amount of PET gradually decreases from 35 mm in the lower plains to 22.08 mm in the upper hilly topography in the months of January. Due to increase in temperature during the pre-monsoon and monsoon season, the amount of PET increases with amount of 110 mm in the lower parts of the catchment in April and it is decreases to 86.67 mm in the upper parts of the catchment. In the month of July, it is calculated equal amount of PET of 159.30 mm for all the stations because of high temperature throughout the region with high moisture condition in the air. Due to moisture air effect, the PET for the month of October was calculated fairly low as 120.25 mm in the lower parts rather than high amount of PET as 133.65 mm in the upper parts of the catchment.

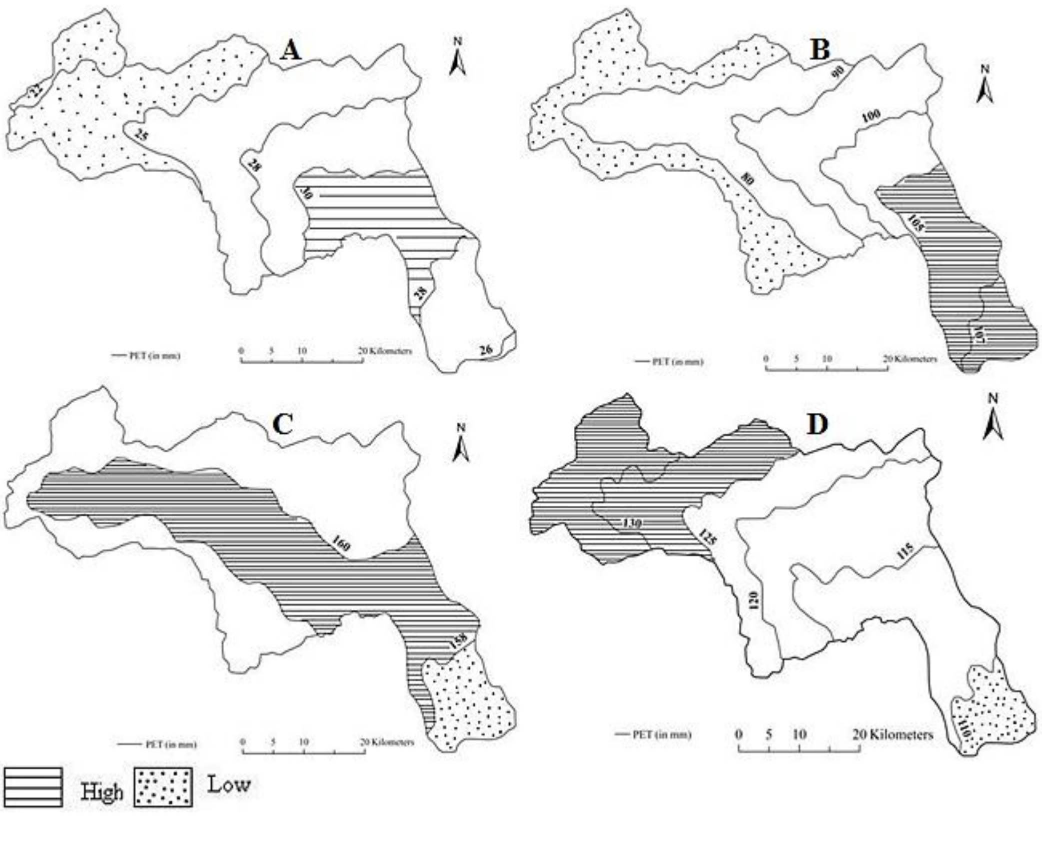


Fig.9: Spatial Variation of PET for the month of **A.** January **B.** April **C.** July and **D.** October

It is surprise to note that in the dry winters, the range of areal variations in PET was very low (30-22=8 mm) with the decreasing trend from lower reaches to the upper hill areas. During monsoon period of heavy rains the areal variations becomes lesser (almost uniform throughout the river catchment).

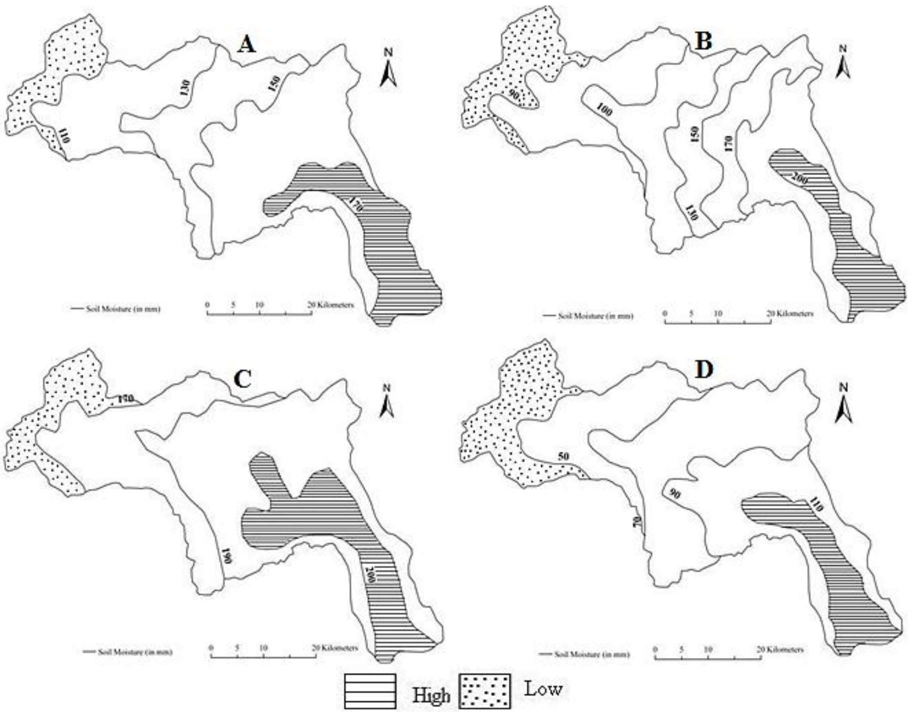


Fig.10: Spatial Variation of Soil Moisture for the month of **A.** January**, B.** April**, C.** July and **D.** October

But the range of areal variability of PET increases with its increasing trends from lower reaches to the upper parts during post-monsoon period when rainfall pattern fluctuates with discharge conditions of surface soils.

The spatial pattern of soil moisture for the same seasons shows that it is gradually decrease of soil moisture variability from the lower parts to the central and upper parts of the river catchment throughout the year. In the month of January, the soil moisture was available 172 mm for the lower reaches while it is decreases to 129 mm in the upper parts with areal variations of 43 mm. The soil moisture was calculated 129 mm for the Itanagar station and it is increase to 200 mm for Doimukh station and decline to 84 mm for the Seppa station which is located in the upper parts of the catchment in the month of April. But in the month of July, whole catchment is fully saturated with its maximum capacity of 200 mm in the lower parts and 150 mm in the upper parts, while in the month of October it is calculated 111 mm for the lower reaches and decline to 61 mm for the upper parts of river catchment (Fig.-10). It is happened due to its variation in topography and different soil types. However, there are not much areal variations in the soil moisture availability with similar patterning throughout the year.

Relationship of Rainfall with Hydro-meteorological Attributes

(a) As heat index is power function of temperature, the relationship between rainfall and heat index follow almost same trend and, hence, it follow logarithmic relationship (Table-1).

(b) Polynomial is best fit function of PET as it has moderate degree of its determinant (R^2=0.431). It shows that increasing rainfall intensity increases fast the amount of PET especially during pre-monsoon when rising temperature and increasing rainfall increases the amount of evapotranspiration (Table-1).

(c) Change in soil moisture does not influence much the hydrologic parameters as it has steadily slow effect in the water cycle in the river catchment throughout the year. Soil types and porosity of soil may be factors soil moisture variability with in the river catchment.

Table1: Relationships between Rainfalls with Hydro-Meteorological Factors

Mathematical Function	Y	Degree of Determinant (R^2)
Rainfall-Temperature		
Linear	Y=3.124x-32.31	0.278
Polynomial	$Y=0.036x^2+0.521x-15.37$	0.279
Logarithmic	Y=44.91ln(x)-123.5	0.271
Rainfall-Heat Index		
Linear	Y=3.291x-17.05	0.280
Polynomial	$Y=-0.029x^2+3.858x-19.57$	0.280
Logarithmic	Y=29.66ln(x)-51.24	0.271
Rainfall-PET		
Linear	Y=0.051x+2.334	0.323
Polynomial	$Y=-0.001x^2+0.115x+1.965$	0.431
Exponential	$Y=1.998e^{0.019x}$	0.294
Rainfall-Soil Moisture		
Linear	Y=-0.016x+199.3	0.126
Polynomial	$Y=-0.000x^2+0.039x+199.2$	0.180
Exponential	$199.3e^{8E.05x}$	0.126

Conclusion

Fluctuation in rainfall intensity varies from year to year. It is clear from the four years (2003-2006) rainfall statistics that the highest rainfall recorded 4166 mm in the year 2004 with highest rainfall intensity. Rainfall intensity increases from 6.85 mm/day in extremely low magnitude to 39.67 mm/day in extremely high magnitudes events during 2003-2006. The average rainfall depth of storm and its total share to stormy rainy are inversely related to the storm duration. The rate of rainfall increases with the increasing rate of temperature from pre-monsoon to monsoon period and again falls down during the post-monsoon period. More than 65% of total rain precipitated during the monsoon period in the Dikrong river catchment in the four years duration (2003-2006). The highest share of total rain (about 27%) precipitated in the stormy events starching during 6-7 days mostly in the months of June to September.

The fluctuation of heat index, PET and runoff increases with the increasing temperature and rainfall from pre-monsoon to peak monsoon and again decreases in the post-monsoon period. On the other hand, fast fluctuation in soil moisture availability is observed during the winter season when the amount of rainfall was recorded less and whole the amount of rain infiltrated in these days. Polynomial is found best-fit form to establish rainfall-PET relationship because it follows the higher degree of determinant. Spatial pattern of these hydrological parameters are interesting as PET processes are smooth throughout the year and do not have much variations spatially. However, soil moisture availability is high in lower reaches in the river catchment.

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