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Influence of Elevation on Spatial and Diurnal Patterns of Orographic Rainfall: A Case Study of Uttarakhand

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Abstract—*Diurnal cycle is an important aspect of orographic rainfall. TRMM 3B42v7 3-hourly precipitation product has proved useful for the diurnal analysis of rainfall over mountainous region owing to its high spatial and temporal sampling density. Our study aims at performing statistical analysis of the diurnal signature of rainfall in context with elevation. Our findings suggest highest rainfall peak over the elevation of 500 – 1000 m which also experiences heavy rainfall during late night. The foothills receive maximum rainfall during early to late morning hours. The regions with altitude above 3000 m receive heavy rainfall usually in afternoon or evening hours.*

1. INTRODUCTION

The state of Uttarakhand, being a part of Northwest Himalaya is known for its highly varied topography with altitude ranging from 175 m to more than 7409 m above mean sea level [2]. The state experiences heavy rainfall during monsoon season with approximately 1288 mm/month which is 86% of the total annual rainfall of Uttarakhand (www.imd.gov.in/section/hydro/distrainfall/webrain/uttarakhand).
The past studies attempting to comment on the annual and seasonal rainfall patterns largely excluded Himalaya region due to non-availability of precipitation data. This lack of research is attributed to the inadequate well-distributed rain gauges networks & weather monitoring systems and absence of multi-decadal daily observation precipitation data. Additionally, the topography plays a major role in affecting the orographic rainfall which varies significantly over small spatial scales in mountainous regions. The precipitation study using remote sensing techniques has emerged as an attractive approach to conducting such research on the subject in the mountains.

In this study, we present the relationship between rainfall variability due to diurnal cycle and elevation which has been studied using satellite precipitation data.

2. STUDY AREA AND DATASET

Uttarakhand is a northern state of India which extends from 28°43` to 31°27` latitude and 77° 34` to 81°02` longitude encompassing an area of 53485 km^2. 9 out of its 13 districts are mountainous. Fig. 1 shows our study area.

The spatial variability of the rainfall of the region has been analyzed with the help of 3-hourly TRMM 3B42 v7 satellite data available from 1998-2013 with spatial resolution of 0.25° x 0.25°. TRMM 3B42 v7 is a gridded precipitation dataset having spatial coverage of 49.875 S to 49.875 N and 179.875 W to 179.875 E.

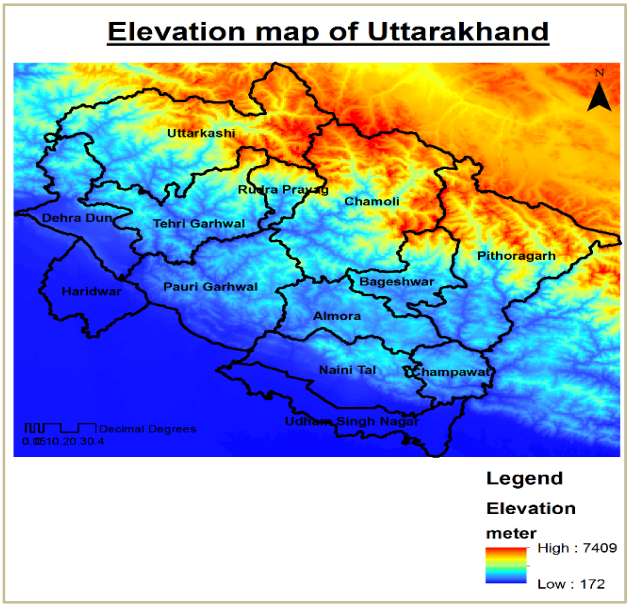


Fig. 1: Elevation map of Uttarakhand state derived from SRTM DEM version 4

The analysis has been carried out only for monsoon season (June, July, August & September months) of past 16 years i.e. 1998-2013. The Shuttle Radar Topography Mission SRTM Digital Elevation Model (DEM) with 90 m resolution has been used for the analysis of elevation which has been resampled at 0.25° x 0.25° resolution. Further information about the dataset can be obtained from the documentation available on the website of TRMM 3B42 (http://disc.sci.gsfc.nasa.gov/precipitation/documentation/TRMM_README/TRMM_3B42_readme.shtml).

3. RESULTS AND DISCUSSION

Previous analysis suggests inverse relation between average rainfall and elevation i.e. the amount of average rainfall decreases with increasing altitude over Uttarakhand region [3]. Diurnal cycle plays a major role in effectuation of orographic rainfall over Himalaya mountain region. Past studies have shown that local circulation due to heating of mountainous surface and mountain- valley breeze circulations are majorly responsible for diurnal rainfall variability over orographic regions [1, 5-6].

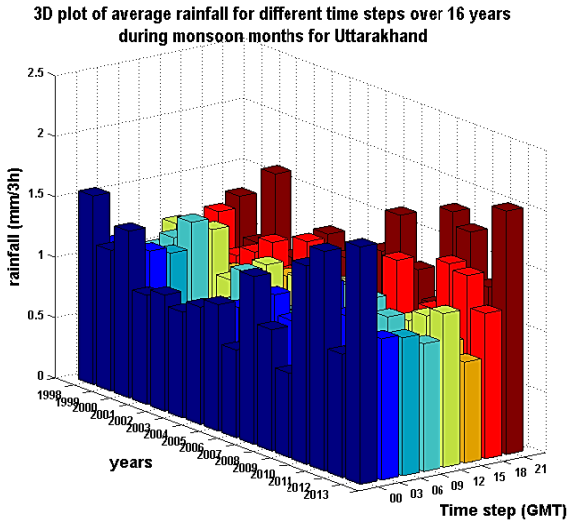


Fig. 2: 3-hourly average rainfall for different time steps year wise

Fig. 1 shows the average 3-hourly rainfall for different time steps during monsoon season over the past 16 years. Clearly 00 GMT and 21 GMT dominate the scenario while at 15 GMT the rainfall rate is usually the lowest. However, it can also be pointed out that this is not always the case as for different years the variations can be clearly seen, e.g. for year 2012 the highest average rainfall intensity was registered at 18 GMT.

Moreover, diurnal cycle and elevation suggest a relation but have not been adequately studied previously. The average daily rainfall with respect to elevation has been generated in the Fig. 3.

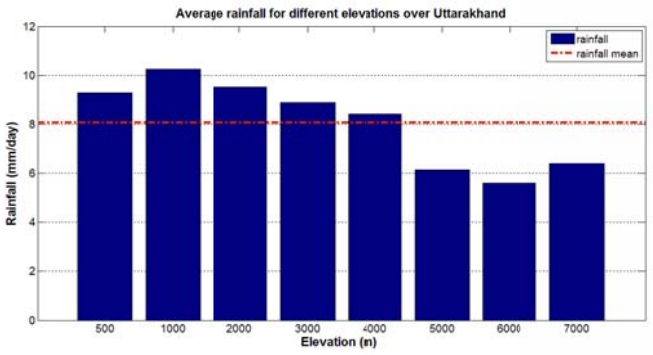
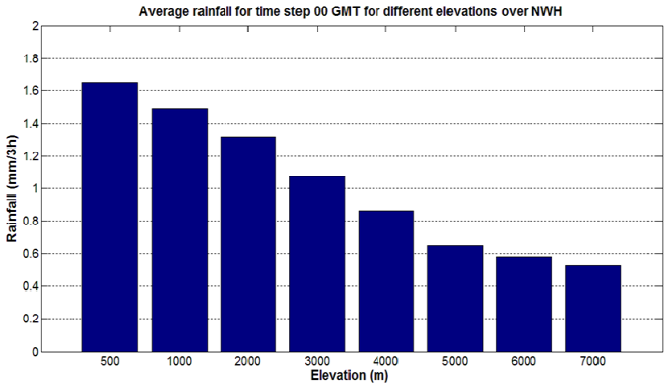
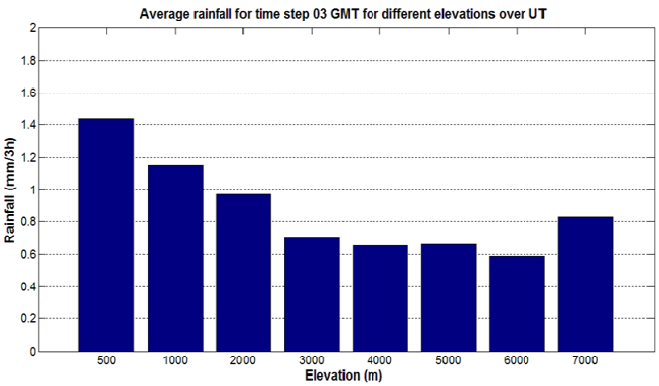


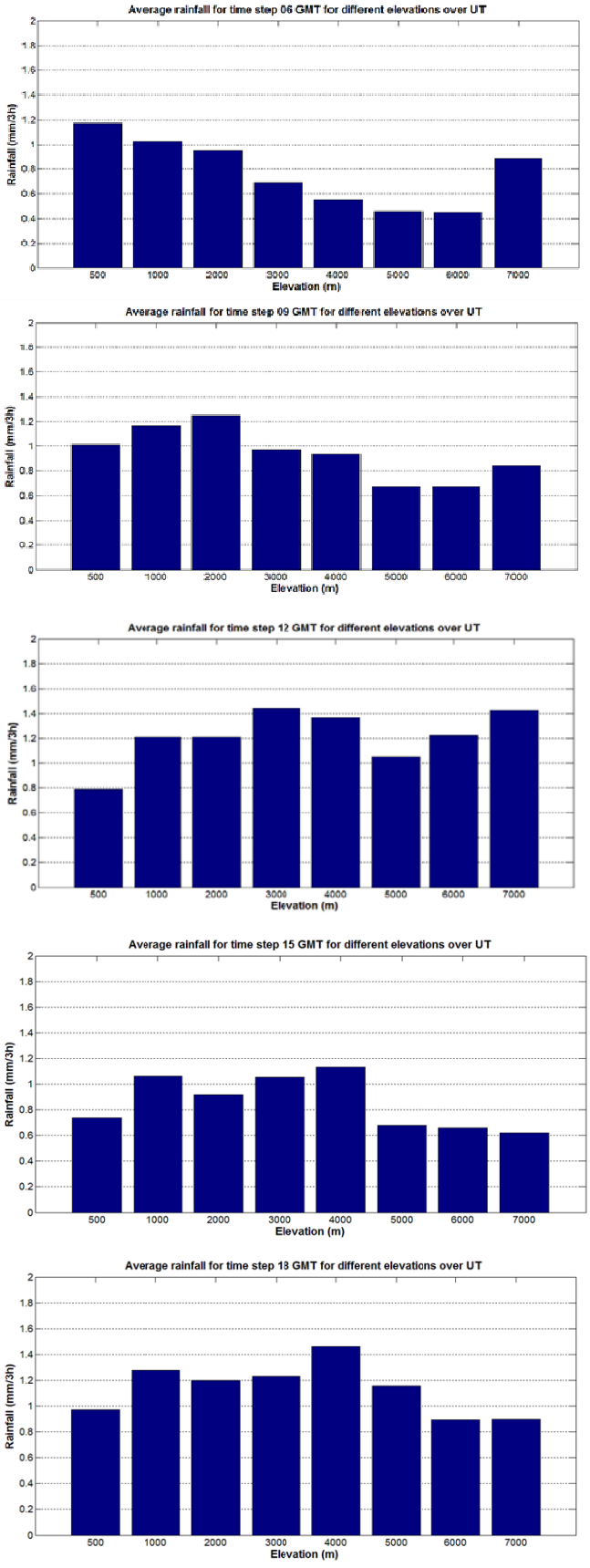
Fig. 3: Average daily rainfall for different elevations over Uttarakhand

It can be clearly seen in the Fig. 3 that the regions having elevation between 500 to 1000 m receive highest average daily rainfall indicating strong orographic capture at this elevation. Up to 4000 m there is high average rain rate which exceeds the mean, further it decreases significantly for higher elevations.

The 3-hourly accumulated rainfall for 8 time steps for 00, 03, 06, 09, 12, 15, 18 and 21 GMT corresponding to 0530, 0830, 1130, 1430, 1730, 2030, 2330 and 0230 IST respectively has been calculated and their relation with elevation has been plotted and visualized.







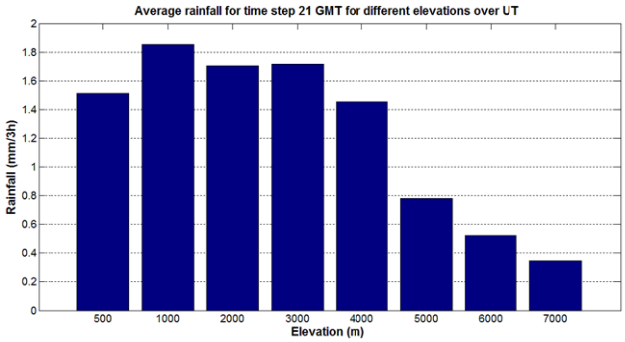


Fig. 4: Average rainfall for different time steps for different elevation ranges over Uttarakhand

It has been found that the foothills of the Himalayas receive heavy rainfall mostly during early to late morning hours which is in agreement with previous studies by Bhatt *et al*.(2005), Bhate *etal.* (2012) and Verikoden *et al.* (2012) but in disagreement with Sahany*et al.* (2010) [4-5, 7-8]. As the day progresses, the high rainfall intensity peaks shift towards higher elevations indicating convection due to convergence and the role of daytime upslope winds responsible for orographic rain. The most intense rainfall is received at 500 – 1000 m elevation during late night hours (0230 IST). The mountainous areas with 7000 m elevation also experience afternoon/evening showers. Usually plains receive high rainfall peak during late night due to shifting of convergence belt over plains and downslope winds. It is well known that convective processes are accountable for orographic rainfall and the amount of precipitation depends largely on degree of atmospheric instability and moisture supply. Himalaya Mountains due to their steep topography act as barriers and assist in mechanical uplifting of warm moist air within the atmosphere thereby promoting free convection and generating cumuliform clouds. This process often occurs during afternoon when mountain surface becomes warm enough to give rise to atmospheric instability and create convergence zone over it. However, as the night progresses and the mountain surface cools down, this convergence zone is shifted towards lower altitudes and foothills.

4. CONCLUSION

Our analysis suggests that regions having elevation between 500 m – 1000 m receive highest average daily rainfall during monsoon season over Uttarakhand state. Moreover, this region experiences heavy rainfall mostly during late night hours whereas the foothills of the mountains receive heavy rainfall during early to late morning hours. The higher elevated areas receive heavy rainfall during afternoon or evening hours.

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