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Meso Scale Hydrological Modeling for Kedarnath Flood, Uttarakhand

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Abstract- **The modeling of hydrological processes in meso-scale basins (approximately 101-103 km2; Blöschl, 1996) have become a topic of interest for hydrologists and water resources engineers in the recent past. In meso-scale basins, processes from smaller scales combine in a complex way to produce an integrated response. Heterogeneity in soil, vegetative cover, land use, etc. is present across this scale, making understanding these hydrological processes difficult. Therefore, identifying basin wide areas with the same dominating runoff generation processes is currently a major challenge in runoff generation process research in meso-scale. As this scale is crucial for water management issues, addressing several societal demands, the meso-scale studies are mainly intended for integrated water resource management and long term impact of land-use and climate change over the hydrological response at the catchment scale.**

Moreover, the linkage of a distributed hydrologic model with the spatial data handling capabilities of digital elevation models (DEMs) and Geographical Information System (GIS) offer advantages associated with the full utilization of spatially distributed data to analyze hydrologic processes.

The present study attempts to predict the catchment response to extreme floods caused by concentrated monsoon over a geographic domain. For that an extreme flood event occurred in the state of Uttarakhand, India in the year of 2013 have been selected for study. The flood was caused by concentrated cloud burst in Kedarnath in Chamoli district in June, 2013. For the hilly terrains in the upstream of river, physically-based semi-distributed TOPMODEL has been applied.

Keywords: Meso, basin, flood, GIS, TOPMODEL

I. INTRODUCTION

The mesoscale hydrologic model is a spatially explicit distributed hydrologic model that uses grid cells as a primary hydrologic unit, and accounts for the following processes: canopy interception, snow accumulation and melting, soil moisture dynamics, infiltration and surface runoff, evapotranspiration, subsurface storage and discharge generation, deep percolation and baseflow and discharge attenuation and flood routing. The model is driven by hourly or daily meteorological forcings (e.g., precipitation, temperature), and it utilizes observable basin physical characteristics (e.g., soil textural, vegetation, and geological properties) to infer the spatial variability of the required parameters. To date, the model has been successfully applied and tested in more than 300 Pan EU basins, as well as India, and USA, ranging in size from 4 to 550,000 km2 at spatial resolutions (or grid size) varied between 1 km and 100 km. Shown below is the model performance for stream flow simulations over the EU basins.

II. METHODOLOGY

Uhlenbrook et al. (2004) described the objectives of meso-scale (101-103 km2) modelling as three folds. Firstly, understanding the distributed runoff generation process is a prerequisite and the selected model must capture it. Secondly, the significant variability of atmospheric forces and runoff concentration in the spatial and temporal domain is needed to be included in the model chosen. Lastly, attention should be given to address several water management issues like societal demands as meso-scale modelling can handle it to the appropriate scale. The watershed studied here consists of rivers Alakhnanda and Bhagirathi. Figure 1.1 shows the study area with its location in the Indian map. The total basin area sums up to 1,465 km2. The total watershed was subdivided into 16 sub-basins with area varying from at minimum 121 km2 to at maximum 682 km2. Out of all the sub-basins 10 sub-basins are selected for TOPMODEL simulation and 06 sub-basins are selected for RISE simulation. The models to be used for simulation are selected based upon the land use pattern derived from NDVI product of SPOT VEGETATION sensor imageries and topography from DEM. Rice agriculture dominated areas and plain terrain areas are selected for RISE simulation.

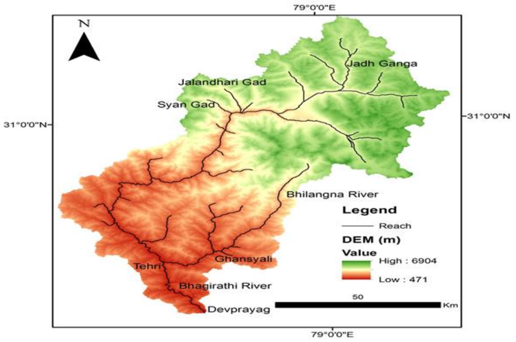


Figure 1.1: Bhagirathi River Basin

In order to reduce the effects of topography and solar illumination on the observed radiance two spectral indices are used in the profile instead of band reflectances. The spectral indices are Normalized Difference Vegetation Index [NDVI = (ρNIR – ρRED)/(ρNIR + ρRED)] and Normalized Difference Wetness Index [NDWI = (ρMIR – ρNIR)/(ρMIR + ρNIR)] (Gao 1996) respectively. The obtained profiles are joined with smooth curves, considering expected changes in the indices. Figure 1.2 shows the estimated profiles of the indices along with rainfall hyetograph, soil wetness conditions and presence of vegetation

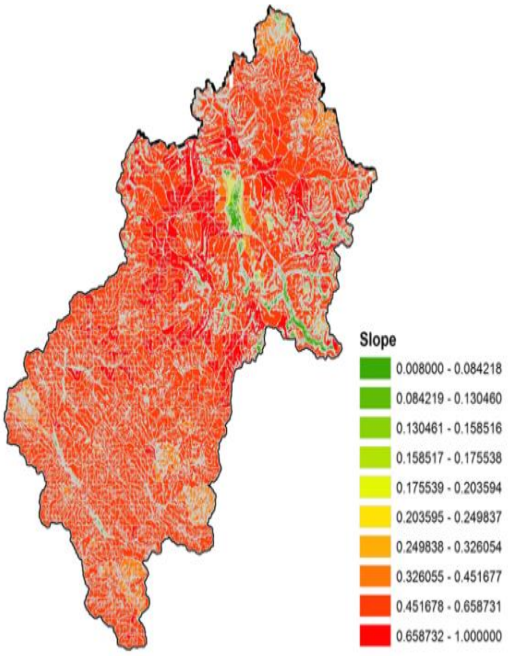


Figure 1.2: The Map shows the input data for the ArcSWAT: Slope data

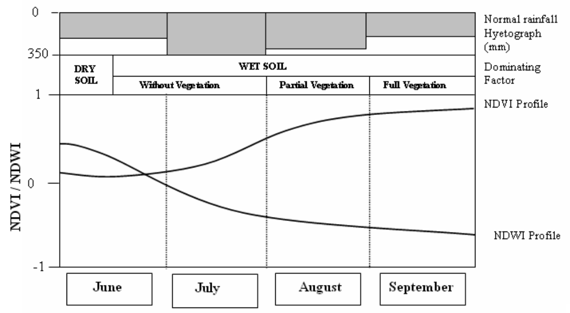


Figure 1.3: NDVI and NDWI profiles for soil wetness regions during monsoon season

In order to carry out correlation analysis, the TI map was georeferenced with the prepared image stacks. With the help of Geographic Information Systems (GIS) modules, thiessen polygons of 28 rainfall gauging stations spreading all over India were generated to calculate total monsoonal rainfall depth of each watershed. Watershed's statistics including watershed area, area covered by TI range and total rainfall depth were extracted and aggregated into river basin scale.

III. RESULTS AND DISCUSSIONS

A. *Evaluation*

In order to evaluate mapped wetness regions, hydrological simulation results reported from a distributed hydrological model study were considered. The study, based on the SCS-Curve Number method and remotely sensed data, is found to have predicted well clustered wetness regions in the the Ganga basin (Zade et al. 2005). Out of the predicted wetness regions by this model, four regions were chosen to get the temporal profile of the indices.

B. *Comparison with Topographic Index (TI) distribution*

Brief description of Topographic index

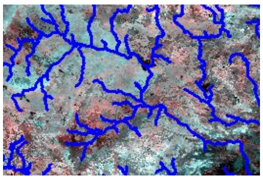
Topography defines the effects of gravity on the movement of surface and subsurface runoff in a watershed, and, therefore influences many aspects of the hydrologic system. It is parameterized as the statistical distribution of the Topographic Index TI = ln (a / tan β), where ln is the Naperian logarithm, a is the upslope area per unit contour length, and tan β is the surface slope gradient. The topographic index has been proven to be an important hydrologic modelling component because it reflects the spatial distribution of soil moisture, surface saturation, and runoff generation processes (Beven and Kirkby 1979).

Comparisons

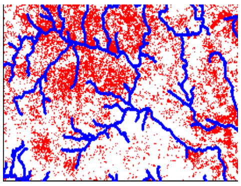
Figure 1.4 shows a set of imageries including the FCC [False Colour Composite; red = NIR, green = B3 (red) and blue = B3 (red)] , TI distribution, normal total monsoonal rainfall and retrieved wetness regions for selected three years in and around the Naye River Basin, India. All images are overlaid along with the river. From the maps of wetness regions, it can be clearly observed that the wetness regions were formed mainly in the upstream of the river due to favourable topography and in the downstream due to coastal plain environment. In figure 1.5 it can be seen that area covered by TI range between 6 and 8 are well matching with the monsoonal wetness regions. However, yearly variations of the wetness regions are observed and are also expected due to annual variation of monsoonal rainfall. Average area of the wetness regions in the selected years is found to be in close agreement with the area covered by the selected TI range. A scatter plot showing fractional area of the wetness regions and TI ranges of 41 watersheds in the Naye River is shown in Figure 1.5. Interestingly, a good correlation between them is found up to total rainfall depth of around 1400 mm.

Monsoonal soil wetness regions in Naye River Basins

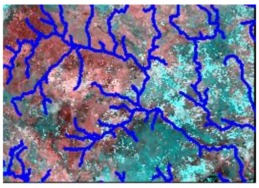
To understand spatial distribution of the wetness region, yearly area fraction of wetness regions of all watersheds were extracted for all the three years i.e. 1999, 2000 and 2001. This shows yearly variation of the fractions for Naye River Basins.



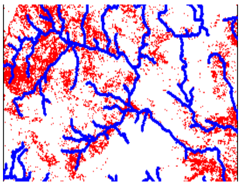
FCC IMAGE (2001)



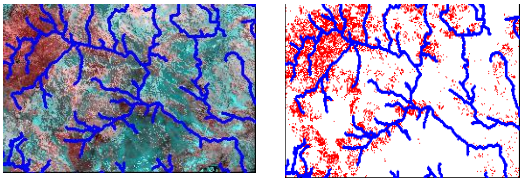
SOIL WETNESS REGIONS (2001)
WETNESS FRACTION = 28.49 %



FCC IMAGE (2000)

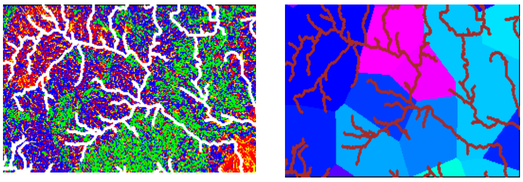


WETNESS REGIONS (2000)
WETNESS FRACTION = 23.96 %



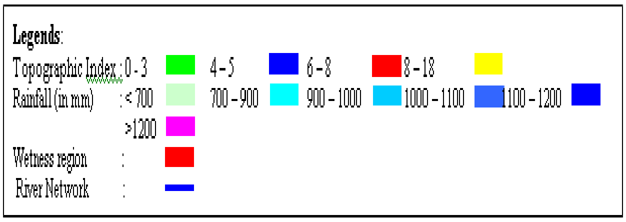
FCC IMAGE (1999)

WETNESS REGIONS (1999)
WETNESS FRACTION = 21.31 %



TOPOGRAPHIC INDEX (TI) MAP

NORMAL MONSOONAL RAINFALL MAP (THIESSEN POLYGON)



Legends:
Topographic Index : 0-3 🟩 4-5 🟦 6-8 🟥 8-18 🟨
Rainfall (in mm) : < 700 🟩 700-900 🟦 900-1000 🟦 1000-1100 🟦 100-1200 🟦
>1200 🟪
Wetness region : 🟥
River Network : ▬

Figure 1.5 FCC and monsoonal wetness area in years a) 2001, b) 2000, c) 1999; d) TI and e) Normal rainfall in and around the Naye River Basin, India with river network basins. A suitable range of TI values have been found out for each river basin by comparing spatial distribution of TI and soil wetness region pattern. In case of the Naye, Mahanadi, Godavari and Narmada Rivers, area fractions of wetness regions and TI range are found to be in close agreement. In these basins, the average normal monsoonal rainfalls are more than 900 mm. The major exception occurs in the Brahmaputra River Basin where temporal and spatial pattern of monsoon storm events are different than that of the other river basins. It is expected that the expected temporal profile of the indices of the monsoonal wetness regions may not represent the same in this basin. Therefore, even through parts of watersheds' area are covered by high range of TI index indicating prone to wetness, but for lack of sufficient rainfall depth, the regions are found to be dry.

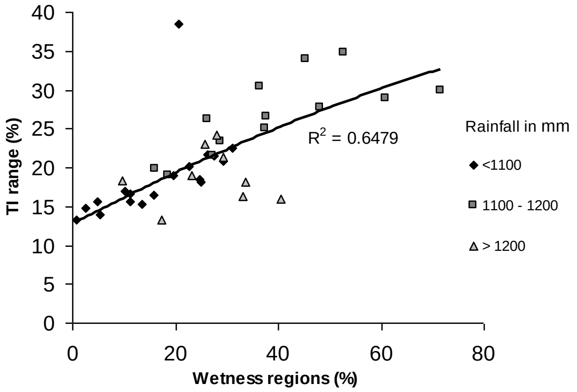


Figure 1.5: Relationship between fractional watershed area covered by the obtained wetness regions and that by the TI range in 41 watersheds of the River Mahanadi for year 1999

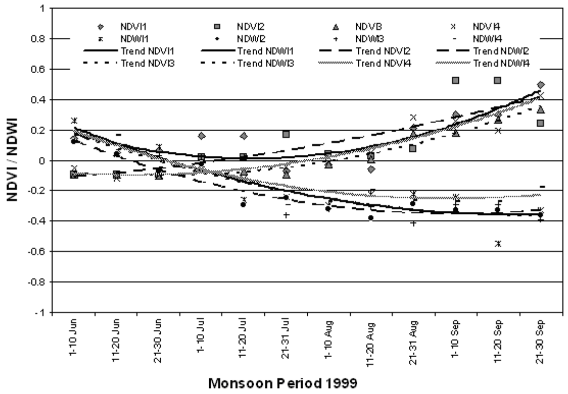


Figure 1.6: Temporal profile of NDVI and NDWI of the soil wetness regions located in the Naye River basins

This table shows the fraction of monsoonal wetness regions in major Indian River basins, in comparison with corresponding area covered by TI range and total monsoonal rainfall

River Basins	Estimated soil wetness regions (%)			Average % of 3 years	Suitable Range of TI	% of basin area covered by TI range	Total normal monsoonal rainfall (mm)
	1999	2000	2001				
Naye	15.62	17.27	9.91	14.27	8-10	15.32	947.69

IV. CONCLUSIONS

This chapter has demonstrated a mapping approach by which the retrieval of monsoonal soil wetness region can be feasible using high temporal satellite data in optical range. The derived soil wetness regions are found to have a significant correlation with the topographic index range and total rainfall depth which are the prime control factors in their formation. From correlation analysis, a significant proportion of the mapped wetness is observed in naye river basins .Therefore, the wetness region can be used for calibration and validation of Meso-scale hydrological models in these river basins.

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