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Rainfall changes over tropical montane cloud forests of southern Western Ghats, India

Muthusamy Murugan[1],*,
Paddu Krishnappa Shetty[1], Auvudai Anandhi[2],
Raju Ravi[3], Subbiah Alappan[4],
Muhund Vasudevan[5] and Sreeja Gopalan[1]

[1]School of Natural Sciences and Engineering,
National Institute of Advanced Studies,
Indian Institute of Science Campus, Bangalore 560 012, India
[2]CUNY Institute for Sustainable Cities, Hunter College,
City University of New York, New York, USA
[3]Department of Materials Engineering,
Indian Institute of Science, Bangalore 560 012, India
[4]Spices and Plantation Crops Advisory Services,
Cumbum 625 556, India
[5]Department of Atmospheric Sciences,
Jawaharlal Nehru Centre of Advanced Scientific Research,
Bangalore 560 064, India

The southern Western Ghats tropical montane cloud forest sites (Gavi, Periyar, High wavys and Venniyar), which are characterized by frequent or seasonal cloud cover at the vegetation level, are considered one of the most threatened ecosystems in India and the world. Three out of four montane cloud forest sites studied in the southern Western Ghats had experienced diminishing trends of seasonal average and total rainfall, especially during summer monsoon season. The highest level of reduction for summer monsoon season was observed at Gavi rainforest station (>20 mm/14 years) in Kerala followed by Venniyar (>20 mm/20 years) site in Tamil Nadu. Average annual and total precipitation increased during the study period irrespective of the seasons over Periyar area, and the greatest values were recorded for season 2 (>25 mm/28 years). Positive trends for winter monsoon rainfall has been observed for three stations (Periyar, High wavys and Venniyar) except Gavi, and the trend was positive and significant (90%) for Periyar and High wavys. Increase in summer monsoon rainfall was observed for Periyar site and the trend was found to be significant (95%).

Keywords: Meghamalai, montane cloud forest, precipitation change.

TROPICAL montane cloud forests (TMCFs) occur where mountains are frequently enveloped by trade wind-derived orographic clouds and mist in combination with convective rainfall[1]. One of the most important direct impacts of frequent cloud cover is the deposition of cloud droplets through soil and vegetation surfaces (horizontal precipitation) which has immense hydrological importance in the cloud forest ecosystems[2]. Data collected from around the world show that horizontal precipitation can account for up to 14–18% and 15–100% of total precipitation during the wet and dry season respectively. A high annual deforestation rate in tropical mountain forests caused by harvesting fuel wood, resource logging and agricultural conversion is increasingly threatening cloud forest worldwide[3,4]. Although cloud forests provide habitats to many of the endangered species, most TMCFs are in the mountain ranges as the core of tropical biodiversity 'hotspots' that occupy approximately 0.4% of Earth's land surface while supporting about 20% and 16% of Earth's plants and vertebrates correspondingly[5]. Therefore, the conversion status of these unique ecosystems is critical and precarious as they are among the most endangered of all forest types[6].

India has only two TMCF mountain regions, which are located in north-eastern Indian states and southern Western Ghats bordering the states of Tamil Nadu and Kerala. Most of the southern Western Ghats seasonal montane cloud forests are located around the cardamom hills which are exposed to trade winds during the monsoon seasons. Among TMCF regions of the world, the Indian TMCFs are the least studied climatologically and explored biological wealth. Of all the types of tropical forest, tropical montane cloud forests are especially vulnerable to climate change[7]. The formation of cloud bank is affected not only by global climate change; there is also evidence that regional and local land-use change can have significant influence. Climatologists found that deforested Caribbean lowlands of Costa Rica remained

relatively cloud-free in dry season whilst adjacent forested regions had well-developed cumulus clouds. These forested lowlands are upwind of the Monteverde cloud forests, where reduced cloud cover had already been documented[6].

Overall, global land precipitation has increased by about 2% over the 20th century[8]. This increase is neither spatially nor temporally uniform. This general increase contrasts with decreases in the northern subtropics. Record low precipitation has been observed in equatorial regions in the 1990s. Small increases are observed in the southern sub-tropical landmasses[9]. Since precipitation is the main driver of ecosystem function and structure we have tried to reveal the precipitation variability and change in one of the most vulnerable tropical montane cloud forest systems so that this information on climate variation can be useful to tropical montane cloud forest conservation communities interested in addressing the climate change issues.

The location of stations studied is given in Figure 1. Daily rainfall amounts were summed up to obtain monthly, seasonal and annual values. Five statistics were analysed on these climatic variables and are reported here: (1) Arithmetic mean of precipitation at annual, seasonal (season 1 represents January to May; season 2 comprises June to September, and season 3 pertains to October–December) and monthly time-scale. (2) Temporal trends were evaluated at annual, seasonal and monthly time-scale using Mann–Kendall method. (3) Slope of each trend was identified by Sen slope method as a median of all pair-wise slopes. (4) Variation in daily temperature range Mo. (5) Significant trends were identified at annual, seasonal and monthly scale in using two tailed Z-test. (6) Locally weighted scatter plot smooth (LOESS) procedure was used to reduce the noise inherent in climate data to allow quantitative visual examination of temporal changes in these data. Temporal trends were evaluated using the non-parametric Mann–Kendall test. The advan-

tage of using non-parametric over parametric tests is that they are more suitable for non-normally distributed and censored data which are frequently encountered in meteorological time series[10]. Mann–Kendall test reliably identifies monotonic linear and nonlinear trends with outliers[11]. One of the difficulties encountered in the interpretation of the climate data is the quantification of trends (e.g. calculation of slope). To quantify the slope we used Sen's nonparametric estimator of slope[12]. This method estimates the slope of each trend as median of all pair-wise slopes. The significance of the test was evaluated using two-tailed Z-test. The significant level was varied from 1 to 10. In addition, LOESS procedure was used to reduce the noise inherent in climate data to allow qualitative visual examinations of temporal changes in these data. LOESS uses a least square regression approach to consider the user defined proportion of the data to weigh each regression point. A p-value of <0.05 was used to indicate statistical significance, using two-tailed Z-test. The data was smoothed using a five-point binomial filter. The trend values were obtained from a linear regression. The significance of the trend (at 90% and 95%) was tested using the F statistic. The geographical locations of rain gauge stations have been furnished in Table 1.

Analysis of observed precipitation data across stations of TMCFs area in southern India showed greater variations. At the rainforest site of Gavi, the average and total rainfall at seasonal scale changed downwards, which was significant for the study period 1994–2007 (Figure 2 b). Seasons 1 and 2 had a slight increase in average and total rainfall for the period (Figure 2 a). Monthly total rainfall of July, August, November, January and February registered decreasing trend while other months have reported positive values. In Periyar Tiger Reserve at Periyar station, the annual average and total precipitation showed linear positive trends for the period under study (1980–2007; Figure 3 b). Seasonal change in average and total precipitation was positively significant for season 1 while other two seasons also reported upward trends (Figure 3 a). Monthly total rainfall for July was maximum followed by October, September and June (Figure 3 a). At the high altitude Venniyar station of Meghamalai, season 2 had a decrease in average and total rainfall up to 20 mm for a period 20 years (1988–2007; Figure 4 a) and the decrease was significant, this significant increase was mainly contributed by July precipitation (Figure 4 b). With regard to monthly total rainfall, moderate increase in October precipitation was seen while little improvement in November, December and March precipitation was observed. All other months have had receding trends (Figure 4 a). At High wavys, the positive trends were observed for both seasons 1 and 3, and season 2 had decreasing pattern. However, the trends were not significant. Monthly precipitation showed up trends for eight months namely, August–December, January, February and May. Other months have reported declining values for monthly
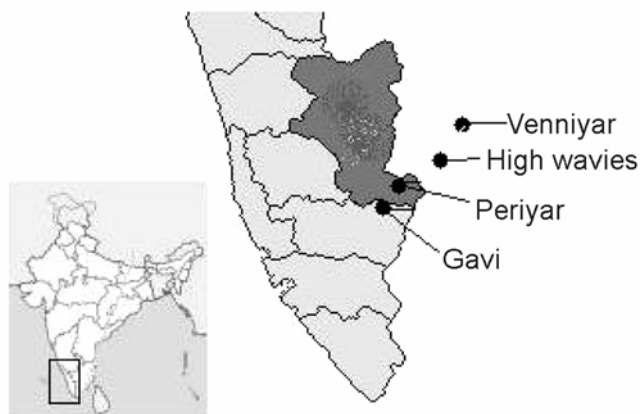

Figure 1. Geographical location of tropical montane cloud forest sites in southern Western Ghats, India.

Table 1. The observatories studied in seasonal montane cloud forest forests area in Tamil Nadu and Kerala

| Station, period of study	Geographical location of station	Land use pattern of ecosystem
Gavi, Pathanamthitta, Kerala 1994–2007	9°22′48.13″N 77°10′12.77″E 1100 msl	Tropical rainforests and grasslands
Periyar, Periyar Tiger Reserve, Idukki, Kerala 1980–2007	9°31′46.86″N 77°11′57.27″E 940 msl	Tropical ever green forests, grasslands and water bodies
Venniyar, Meghamalai Theni, Tamil Nadu 1988–2007	9°38′09.32″N 77°21′13.76″E 1750 msl	Tropical ever green forests, grasslands and plantations of tea, coffee and cardamom
High wavys, Meghamalai Theni, Tamil Nadu 1980–2007	9°38′52.05″N 77°21′39.41″E 2010 msl	Tropical ever green forests, grass lands and plantations of tea, coffee and cardamom
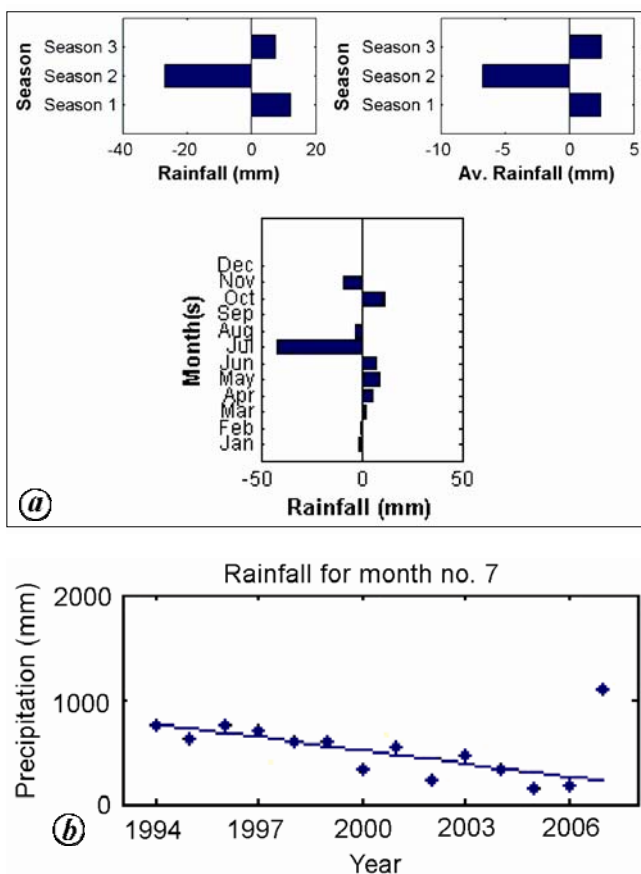
Figure 2. Senslopes of trends (*a*) and significant (*p* = 0.05) trends (*b*) in precipitation variations at Gavi tropical rainforest ecosystem, Kerala.

Figure 3. Senslopes of trends (*a*) and significant (*p* = 0.05) trends (*b*) in precipitation variations in Periyar tropical evergreen forest, Kerala.

precipitation (Figure 5). Among the four stations studied, a decrease in rainfall trend has been noticed for Gavi site with respect to both the monsoons as well as the annual series. However, the trend has been found non-significant (90% and 95%) for the site. Positive and significant trend was registered for Periyar site for annual and summer monsoon rainfall while the winter monsoon rainfall had increasing trend which was non-significant at 90% and 95% level. Both High wavys and Venniyar sites revealed a
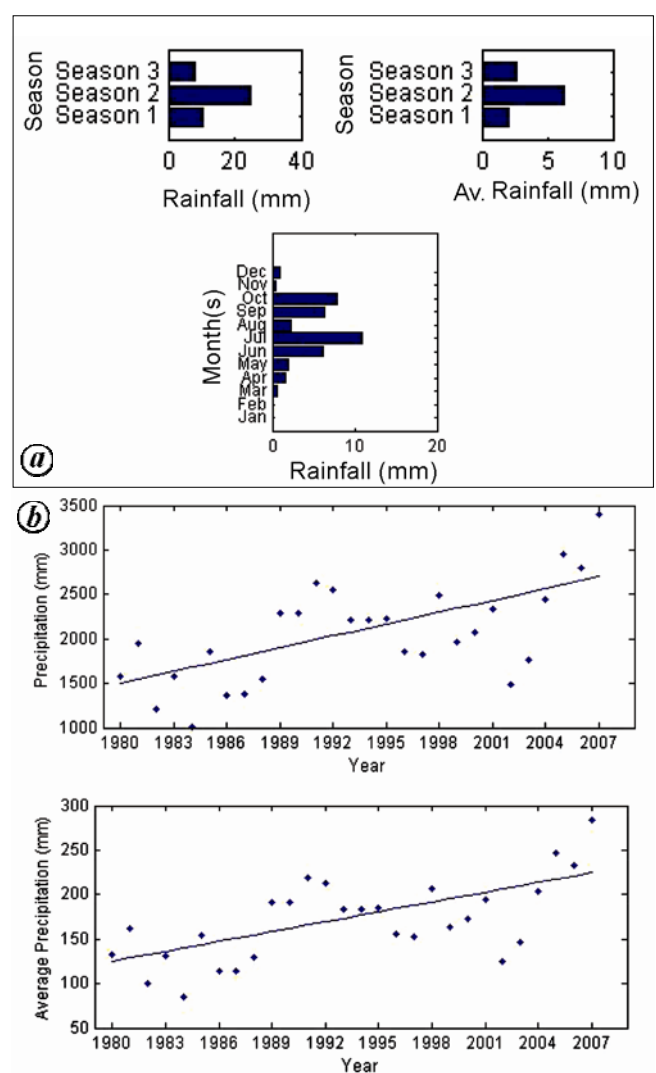
diminishing trend for summer monsoon rainfall, but the trend was non-significant at 95% level. Significant trend (90%) for winter monsoon rainfall was envisaged at High

Table 2. Trend (regression) and coefficient of determination (R^2) values of different rainfall series of montane cloud forest sites

Rainfall series	R^2	Trend	Significance (95%)	Significance (90%)
Gavi (Kerala)				
Annual	0.00083	–4.26	No	No
Summer monsoon	0.009	–10.36	No	No
Winter monsoon	0.0044	–4.24	No	No
Periyar (Kerala)				
Annual	0.41	43.5	Yes	Yes
Summer monsoon	0.21	27.3	Yes	Yes
Winter monsoon	0.1	7.81	No	No (borderline)
High wavys (Tamil Nadu)				
Annual	0.02	8.81	No	No
Summer monsoon	0.000024	–0.25	No	No
Winter monsoon	0.14	9.88	No (borderline)	Yes
Venniyar (Tamil Nadu)				
Annual	0.12	–19.57	No	No
Summer monsoon	0.29	–21.33	No	Yes
Winter monsoon	0.01	4.54	No	No

Figure 5. Senslopes of trends in precipitation variations in High wavys tea ecosystem, Tamil Nadu.
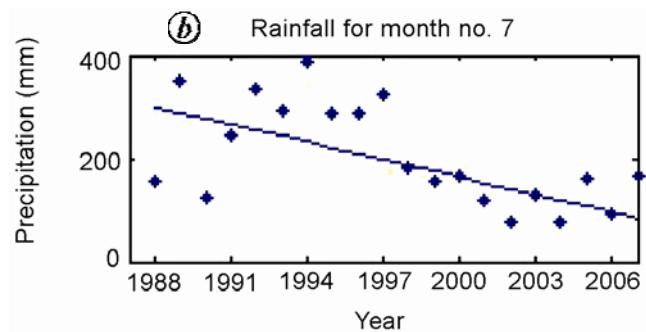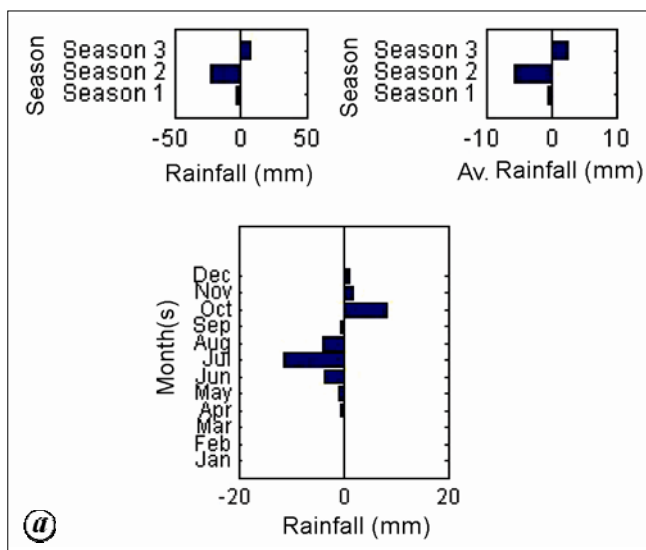

Figure 4. Senslopes of trends (*a*) and significant (*p* = 0.05) trends (*b*) in precipitation variations in Venniyar high-altitude tea ecosystem, Tamil Nadu.
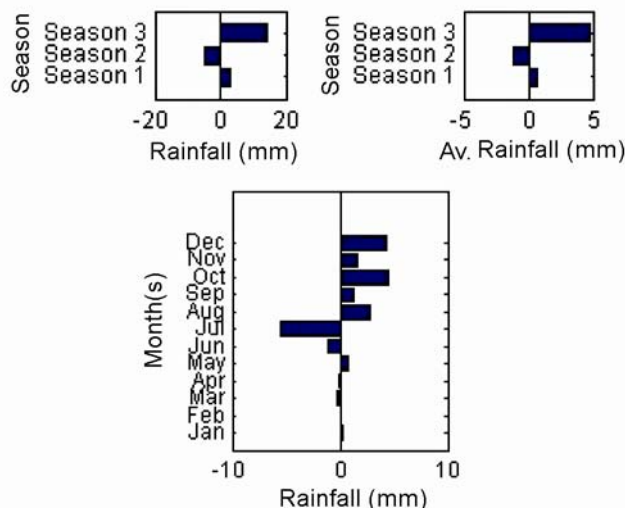
wavys site. The site Venniyar had registered negative trend for summer monsoon rainfall and the trend was found to be significant at 90% level (Table 2, Figure 6).

In the light of above results and observation, we report that three out of the four montane cloud forest sites located in the southern Western Ghats had experienced diminishing trends of seasonal average and total rainfall especially during summer monsoon (SM). The highest level of reduction for SM season was observed at Gavi rainforest station (>20 mm/14 years) in Kerala and Venniyar site (>20 mm/20 years) in Tamil Nadu. Annual and average precipitation increased during the study period
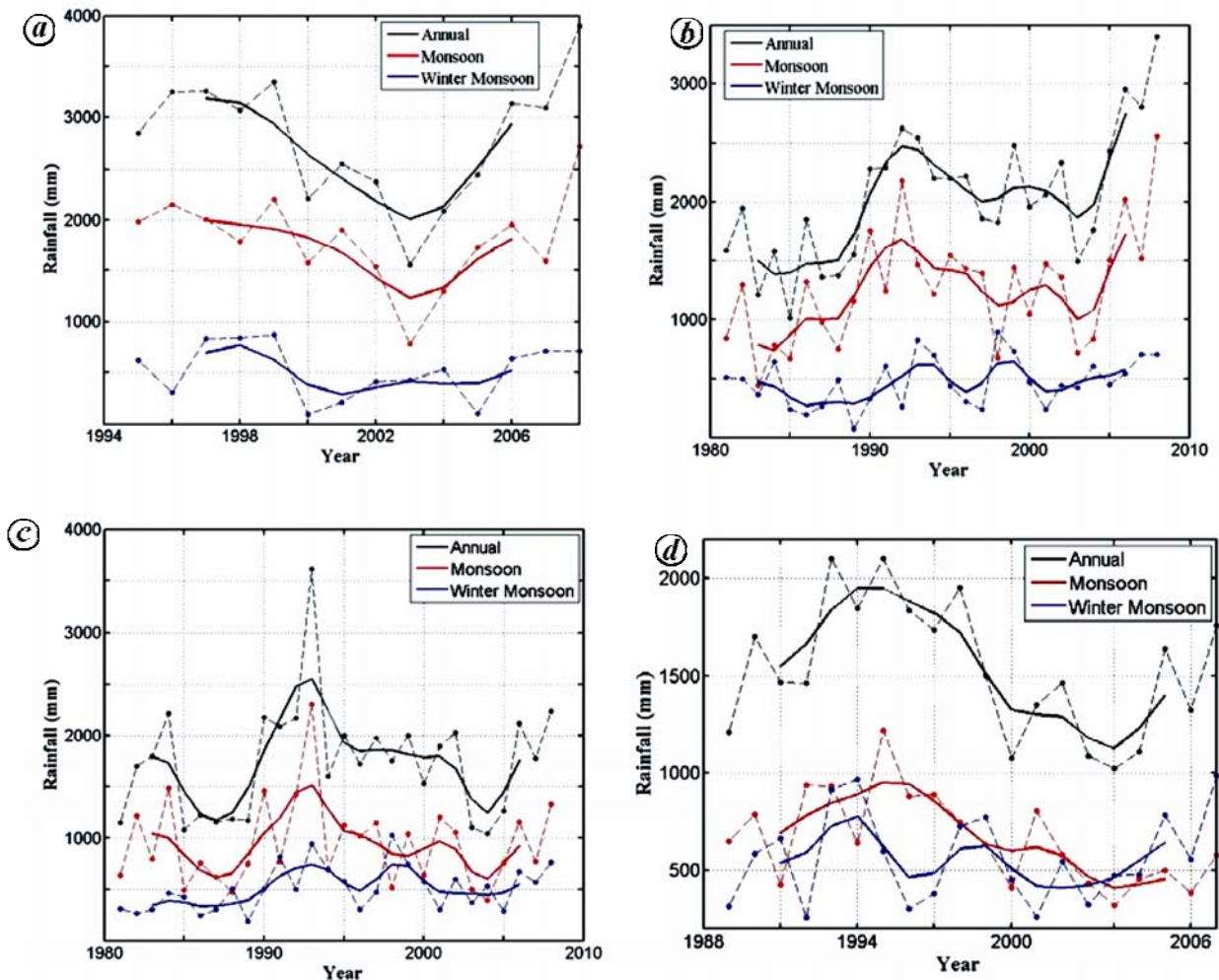
Figure 6. Time series (smoothed by 5 point binomial filter) of annual and seasonal (summer and winter monsoon) rainfall of (*a*) Gavi, (*b*) Periyar, (*c*) High wavys and (*d*) Venniyar sites.

irrespective of the seasons over Periyar area, and the greatest increases were recorded for season 2 (>25 mm/28 years). Precipitation trends were similar for high altitude High wavys and Gavi station. Venniyar has experienced receding trends in total and average rainfall for the first two seasons during the period of our study. Therefore, spatial and temporal variation in precipitation pattern over these study areas had occurred. The overall trend in India for different rainfall series indicates a declining trend in the monsoon circulations which caused large-scale decrease in the monsoon rainfall over the country (www.tropmet.res.in). The rainfall climatology of montane cloud forest and Kerala plains as well as southern Western Ghats is more comparable with each other than those of other eco-climatic regions, for example, rain shadow semi-arid ecosystem of Tamil Nadu. The observed variation in annual and seasonal rainfall series for Kerala plains and southern Western Ghats does not match with the rainfall fluctuations reported in this study for the same period. For instance, in Periyar and Gavi where the variations among monthly (June, July and August) and

seasonal (summer and winter monsoon patterns) rainfall were opposite to the observed rainfall trend reported for Kerala plains as well as other southern Western Ghats site (Punalur) (www.tropmet.res.in). As in the case of other TMCF, the obvious reason for precipitation change over these important cloud forests could be global warming and local land-use change. Land-use change can modulate both air and dew point temperatures, because of changes in surface energy fluxes. Therefore, deforestation raises the air temperatures and lowers the dew point temperatures in the atmosphere over montane and premontane regions. Consequently this results in precipitation changes[13,14]. The average global warming coupled with degradation of forests can accelerate evapotranspiration, which along with increased levels of relative humidity can increase precipitation amounts in forested mountain environments. However, the influence of surface warming on the probability of cloud formation at current cloud forest altitudes is not straightforward[15]. Overall, the current precipitation changes in these pristine montane cloud forest areas can have negative impacts on

crops and plants as well as ecosystem hydrology because cardamom, coffee, tea and native forest plants are highly sensitive to precipitation changes.

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Satellite-based geomorphological mapping for urban planning and development – a case study for Korba city, Chhattisgarh

Arindam Guha*, K. Vinod Kumar and A. Lesslie

Geosciences Division, National Remote Sensing Centre, Indian Space Research Organisation, Hyderabad 500 625, India

Geomorphology is an important aspect which guides immensely in urban planning. Mapping of geomorphology not only gives an idea about the variations in landscape but also indirectly facilitates in evaluating the resources of an area. Present study shows the capability of satellite data in delineating major geomorphological units in an industrial area like Korba city. It has also been observed that geomorphological maps along with other relevant terrain-related information such as lithology and geological structures can delineate few important zones; each of these zones is suitable for specific type of urban development and planning. This communication highlights how a simplistic approach like logical integration of geomorphological and geological information can provide valuable inputs for urban planning and development.

Keywords: Geomorphology, land use, lithology, urban planning.

GEOMORPHOLOGY is the scientific study of landscapes and the processes that shape them[1]. The science of geomorphology has two major goals; one is to organize and systematize the description of landscapes by intellectually acceptable schemes of classification and the other is to recognize in landscapes, the evidences for changes in the processes that are shaping and have shaped them[1]. Landforms or geomorphological units are usually clearly displayed to the field observer or on remote sensing imagery. Geomorphological studies therefore can provide a basis for regional classification of terrain. Moreover, other environmental variables of interest are often controlled by geomorphological units. Therefore, geomorphology has a unique role in management and planning for urban area development. Techniques of geomorphological mapping is a fundamental tool for resource appraisal not only because they provide an effective and relatively cost effective means of generating valuable environmental data, but also because it can be adapted to surveys at different scales of enquiry. The resulting maps can be used as a basis for other environmental surveys for specific problem such as surface hazards, etc. Secondly, geomorphological studies dealing with the identification, monitoring and analysis of contemporary geomorphological processes may

*For correspondence. (e-mail: arindam_iit@rediffmail.com)