Geo-spatial Approach for Estimation of Precipitation over the Upper Ganga River Basin (UGRB), Uttarakhand, India

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Abstract

Background: Estimation of precipitation over hilly terrain is challenging due to its complex topography and uncertain climatic conditions. In this paper an attempt has been made to understand the potential of Remote Sensing (RS) and Geographical Information System (GIS) in estimating the precipitation over a hilly river basin of India. Methods: Precipitation data is derived from TRMM (Tropical Rainfall Measuring Mission) in Upper Ganga river basin. It is further compared and validated with ground based gauge rainfall data using following 4 statistical keys: Average Percentage Error (Avg. % Error), Root Mean Square Error (RMSE), Correlation Coefficient (r) and Mean Square Error (MSE). GIS technique is utilized to relate the three-dimensional distribution of TRMM precipitation with observed monthly precipitation products (isohyets) for rainy season. Finding: The findings have shown that TRMM sensors provide reliable information on precipitation with good accuracy for Himalayan river basins. The Correlation Coefficient (CC) is found 0.99 for the 4 rain stations. A very good agreement in addition to strong relationship is seen between the TRMM monthly precipitation and observed precipitation products. There are several studies done to validate the performance of TRMM over plain areas but for hilly Himalayan river basins more such studies are required. Application: For hilly areas where rain gauge stations are sparse, the TRMM provides reliable information on precipitation with acceptable accuracy. Therefore, the TRMM derived precipitation information can be used for various studies and applications such as disaster management, weather forecasting, environmental monitoring, water resources management etc.

Keywords: Geographical Information System, Precipitation, Remote Sensing, River Basin, Statistical Indices, Tropical Rainfall Measuring Mission

1. Introduction

Water resources management plays a vital role to tackle water related problems like flash floods, erosion, and bank shifting etc. which a very common phenomenon found in the Himalayan regions. Precipitation is a most important hydrological parameter required to study these effects. To have a low impact on livings, precipitation forecasting models plays a vital role, which is very difficult and challenging task. Although a large amount of global data is available for the precipitation with various available satellites, but to have a precise knowledge, a ground based precipitation such as automatic rain-gauges and radar network measuring equipments is required. But due to lack of ground based equipments there is no other option but to rely on remote sensing and GIS techniques. These techniques help in identifying spatio-temporal variation of the hydrological parameters and to predict the exact precipitation in the areas where the estimation of rainfall is a challenging task i.e., of the areas having complex hilly terrain or remote areas. In sustainable water resource management, precise estimation of rainfall is required for the rainfall-runoff model. It also helps in providing the knowledge for designing and operating the civil infrastructures (reservoir, dam, bridge, etc.) and also to detect and solve environmental problems related to water like
pollution, flooding and drought etc. The exact estimation of rainfall both spatially and temporally is very difficult as it is very variable and dynamic in the form of amount and magnitude for catchments. Earlier the rainfall is predicted by the ground instruments situated at a certain location for recording the precise measurement that passes over it. To study its temporal and spatial distribution is very tedious and time consuming and also required a large amount of ground based stations. To address these gaps Geomatics tools can be employed for predicting and estimating the precise value of precipitation for a certain basin. Several space missions had been employed for recording and predicting the metrological data. Among all, the Tropical Rainfall Measuring Mission (TRMM) standout the most appreciated and valuable mission to predict rainfall both spatially and temporally. The major advantage of the mission is to have a better knowledge of rainfall data over longer periods and areas. Thus this study focuses on utilizing the combined data products for TRMM. It produces 3-hourly precipitation information products at 0.25°×0.25° spatial resolutions. In this research work the (3B43) V7 product of TRMM data is utilized for determination of the rainfall variations.

2. Objective

The specific aims of the research work are:
- To assessment the reliability of TRMM (3B43) V7 rainfall products to study the precipitation distribution over the Upper Ganga catchments Uttarakhand, India.
- To evaluate a linear relationship between TRMM based rainfall products and observed rain gauge rainfall over Upper Ganga River Basin.

3. Study Area

The Ganga basin is on of the lengthiest waterway basin of India. They have been positions among the world’s best 25 watercourses basin by the quantity of river discharge. The Ganga basin starts at the meeting of the Alaknanda and Bhagirathi tributaries, which meet at Dev Prayag location in Tehri Garhwal district surrounded by the mountains series of the Himalayas. The Bhagirathi tributary has been considered as an actual birthplace of the Ganga basin which rises at the foot of the glacier Gangotri at Gaumukh. The Ganga catchments are partitioned into 3 regions, viz. Lower Ganga River, Middle Ganga River and Upper Ganga river catchments. The river Ganga is situated in Northern India which extends over an area of about 22585 km². The altitude ranges from 7450 metre in the Himalayan foothill crests to 92 metre in the plains. Approximately 432 km² of the entire area of the watershed is under glacier land and 289 km² is in fluvial land. The Ganga basin is located in Uttarakhand state of India within geographic coordinates 30°38’ to 31°24’ N lat. and 78°29’ to 79°22’ E long. The total river basin area is 4495.52 km² up to Haridwar. The yearly average precipitation in the Upper Ganga river catchments varies minimum550 mm to maximum 2500 mm. The key parts of the rainfall are due to the south-west monsoon that overcomes from June to September. The geographic positions of the Upper Ganga catchments are given in Figure 1.

4. Data Collections

4.1 Tropical Rain Fall Measuring Mission

In this research work, TRMM (3B43) V7 data are utilized. TRMM (3B43) V7 products were taken as of the Goddard Earth Sciences Data and Information Services Center, web link (http://mirador.gsfc.nasa.gov/). These products deliver worldwide coverage of rainfall in the worldwide belt from 50°S to 50°N, at 0.25°×0.25° spatial resolution. It has been 3-hour temporal resolution. The monthly rainfall was acquired from TRMM (3B43) V7 product. Which are at the monthly temporal scales. The yearly rainfalls January 1998 to December 2012 were computed by adding the monthly TRMM (3B43) V7 rainfall product for

Figure 1. Study extent and site of the observed rainfall stations.
all month of all year. Additionally, the TRMM (3B43) V7 rainfall product was calibrated based on the correlation between the four observed gauge stations and TRMM (3B43) V7 products.

4.2 Observed Rain Gauge Stations
Rainfall data were acquired from observed gauge locations. In this research work four observed rain gauge stations were utilized for validation (Figure 1). Monthly rainfall products January 1998 to December 2012 were utilized for in this research work.

5. Methodology
The present study, month wise precipitation TRMM (3B43) V7 products were taken from TOV AS (Online Visualization and Analysis System) of GESDISC (Goddard Earth Sciences Data and Information Services Centre). TRMM produces Level-3 monthly precipitation datasets. In this research work time averaged, Lat-Long based monthly precipitation products were utilized. The factors accessible for taken, with the TRMM precipitation products are: accumulated rain, rain rate, and relative error. The month wise observed precipitation datasets were brought from Indian Meteorological Department (IMD). The detailed flow chart of methodology is expressed as in Figure 2.

5.1 Validation
Statistical methods are often applied to study spatio-temporal variations in the precipitation over a region. In this case study statistical indices are used to estimate, relate and authenticate satellite precipitation products with respect to observed precipitation products. They have helped to comprehend the present trends, co-relationships and inaccuracy action of propagating between the 2 types of products. In this research work, four statistical keys are used i.e., 1. Correlation Coefficient (r), 2. Mean Square Error (MSE, Equation (1)) 3. Root Mean Square Error (RMSE, Equation (2)) and Average Percentage Error (Avg. % Error Equation (3)).

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MSE = \sum_{i=1}^{N} \frac{(Obs - TRMM)^2}{N} 
\]

\[
RMSE = \sqrt{MSE}
\]

\[
Avg. \% Error = \frac{100 \times Abs(Obs - TRMM)}{Obs} \frac{N}{N} 
\]

Figure 2. Flow chart of methodology.

Initially, the co-relation coefficients (r) were computed concerning the observed rainfall and TRMM satellite datasets. A value of one agrees to a perfect correlation and a significance of zero shows gauge observed and estimated rainfall data are uncorrelated. The Avg. % Error gives a percentage amount of the dissimilarity in the middle of the assessed versus the observed gauge datasets. The validation is estimated outstanding when Avg. % Error is <10%, great if the Avg. % Error is in the middle of 10% and 20%, satisfactory if the Avg. % Error is in the middle of 20% and 30%, and poor if >30%. The Avg. % Error test gives significance for the forecast model error level by employing weight on a high level of errors. Finally, the RMSE, lesser values show best performance.

6. Results and Discussion
TRMM products determined monthly precipitation datasets over the dated of January 1998 to December 2012 is related to observed precipitation product of four rain gauge stations viz. Chamoli, Tehri Garhwal, Uttarkashi and Rudraprayag in the Upper Ganga basin (UGB) cover in Uttarakhand state, India. Statistical keys viz. CC, RMSE, Avg. % Error, and MSE evaluated for four observed locations are brief in Table 1. This one can be understood
from Table 1 that entirely the four locations, TRMM (3B43) V7 precipitation datasets are considerably correlated with observed monthly precipitation datasets. The CC of 0.99 is established for four locations viz. Chamoli, Tehri Garhwal, Uttarkashi and Rudraprayag. An extreme average % error of 6.8 % is estimated for Rudraprayag gauge location. Subsequently, a strong spatial trend is not detected between the CC and average % error in the study region. But, the measurement appears to increase with the aggregate precipitation. The levels of RMSE and MSE are straightforwardly correlated to one and all. An overall perception for the four gauge locations is that both the average % error and CC increase with aggregate precipitation. The monthly statistical keys are calculated for monsoon period i.e., June, July, August, September and October months in Upper Ganga river basin. It can be found from Table 2 that yet again maximum CC of 0.90 is noticed for four gauge locations during June, July, August, September and October months i.e., monsoon period (Figure 3). A maximum average % error of 5.3%, 5.5%, 4.5% and 5.5% is calculated for four gauge locations respectively. Hence, it is marked from Table 2 that during monsoon period high agreement occurs between the TRMM and observed rainfall datasets. To authenticate the TRMM precipitation with observed precipitation products, a study of the existing correlation in the middle of them is required. A decent correlation is estimated between the 2 types of precipitation data (Figure 4). For supplementary proof and to require a superior depiction of the correlation GIS based investigation are utilized.

Figure 3. Co-relationship between TRMM and observed monthly precipitation products for stations in Upper Ganga river basin. (a) Rudraprayag. (b) Tehri Garhwal. (c) Chamoli. (d) Uttarkashi rain gauge stations.
Figure 4. Time series monthly TRMM satellite and observed precipitation products for stations in Upper Ganga river basin. (a) Rudraprayag. (b) Tehri Garhwal. (c) Chamoli. (d) Uttarkashi rain gauge stations.
Evaluation of the spatial distribution of TRMM satellite with observed monthly gauge precipitation product (isohyets) for the following monsoon period. (a) June. (b) July. (c) Aug. (d) Sept. (e) Oct.

An evaluation of the three-dimensional distribution of TRMM precipitation with rain gauge monthly observed precipitation products (isohyets) is prepared for the monsoon period i.e. June, July, August, September, and October (Figure 5). In these figures isohyets lines denote the observed precipitation products for months of the monsoon period.

Alternatively spatial distributed precipitation surface is created from TRMM data of months of the monsoon period. Then both isohyets and spatial distributed precipitation surface are superimposed to get the similar agreement in the middle of the datasets. The outcomes demonstrate a brilliant matching in the middle of the sat-
ellite and observed precipitation datasets. Subsequently, validation of TRMM products with observed precipitation datasets shows a great overall agreement.

7. Conclusions

In this case study used 4 statistical indices viz. Correlation Coefficient (r), Avg. % Error, MSE, and RMSE. They were utilized to relate and authenticate the TRMM estimated precipitation data with observed precipitation products of Upper Ganga catchments which comes underneath sub-tropical region. For all four locations, the CC of 0.99 is calculated and the maximum average percentage error 6.8% is calculated for Rudraprayag location. The isohyets, prepared using observed precipitation datasets in line well with and the spatial disseminated precipitation surface arranged by TRMM products for months in the monsoon period of the study region. However, entirely chose locations come in the sub-tropical region, a similar pattern is seen in their relationship charts. The CC appears to increase with the aggregate precipitation in the catchments.

A noble relationship and agreement is seen on matching the TRMM precipitation with observed monthly precipitation datasets. The deviation in satellite based precipitation and observed precipitation might be as a result of the limited spatio-temporal analysis of TRMM products over a specific area. The TRMM satellite may slip few precipitation occasions. Further causes can be the ambiguity and errors while sensing the precipitation factors from the TRMM satellite and during the raw satellite factors processing using algorithms. These errors might influence the final precipitation datasets. Geomatics tools such as remote sensing and Geographical Information System are encouraging technologies for satellite based precipitation calculation. TRMM datasets utilized in this case study has demonstrated that satellite-derived precipitation can be utilized to supplement ground-based estimations. In cases where ground estimations are not accessible and it is strongly suggested that the TRMM precipitation products did not perfectly match with the ground estimations but it can be utilized to supplement ground estimations of evaluating precipitations in un-gauged basins. They can give spatio-temporal distri-

Table 1. Locations of the observed gauge stations and TRMM satellite monthly precipitation product for validation parameters from Jan 1998 to Dec 2012

| Stations       | Long. | Lat. | r      | MSE  | RMSE | Average % Error |
|----------------|-------|------|--------|------|------|-----------------|
| Rudraprayag    | 30.3  | 78.9 | 0.99   | 10.1 | 3.1  | 6.8             |
| Tehri Garhwal  | 30.3  | 78.5 | 0.99   | 8.3  | 2.8  | 6.8             |
| Chamoli        | 30.4  | 79.3 | 0.99   | 14.2 | 3.7  | 5.4             |
| Uttarkashi     | 30.7  | 78.4 | 0.99   | 8.1  | 2.8  | 6.1             |

Table 2. Statistical keys for validation of the TRMM products with respect to observed monthly precipitation for the monsoon period in Upper Ganga river basin

| Stations       | June | July | Aug. | Sept. | Oct. |
|----------------|------|------|------|-------|------|
|                | A    | B    | C    | D     |     |
| Rudraprayag    | 0.9  | 16.7 | 4.0  | 4.0   | 0.9  |
|                |     | 0.9  | 18.2 | 4.2   | 1.3  |
|                |     | 0.9  | 19.0 | 4.3   | 1.6  |
|                |     | 0.9  | 14.2 | 3.7   | 2.4  |
|                |     | 0.9  | 12.9 | 3.6   | 1.2  |
|                |     | 0.9  | 24.7 | 4.9   | 3.5  |
|                |     | 0.9  | 26.6 | 1.6   | 1.6  |

Where, A = r, B = MSE, C = RMSE, D = Average % Error
bution of precipitation datasets which is not possible with simple ground based precipitation estimations. TRMM precipitation products to be well utilized as inputs to the hydrological and stream runoff models for different watershed developing associated activities. The outcomes furthermore recommend that TRMM precipitation products could be utilized for hydrological runoff simulation for the ungauged basin.

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9. References

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