EVALUATION OF SATELLITE – BASED RAINFALL DATA PRODUCT TRMM'S APPLICABILITY FOR LANDLSIDE RISK ASSESSMENT IN HILLY AREAS OF INDIA

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KEY WORDS: IMD, TRMM, Correlation, Elevation Profile, Statistical Analysis

ABSTRACT

With the development of more data related predictive algorithms comes a need for verification of data source. Since the major contributing factor of Indian Climatic conditions is the onset and offset of monsoon and most of the landslides occurring in the study region are deep – seated depending upon cumulative rainfall, study of rainfall data becomes imperative. The paper focuses upon comparing two major sources of rainfall data i.e. Tropical Rainfall Measuring Mission (TRMM) by NASA and Japan Aerospace Exploration Agency (JAXA) and Indian Meteorological Department (IMD). The study is conducted along the National Highway 58 due to excessive bouts of rain received by this region. Precipitation rate for the study area of latitude 30° N – 30.75° N and longitude 78.25° E – 79.75° E is extracted using both sources. The entire area is divided into seven grids of dimensional division 0.25° X 0.25° with increasing altitude. A poor positive correlation of 0.203 at best was observed when calculated for daily rainfall whereas the monthly-averaged correlation gave better results of about 0.95 at best. The month of June and September were opportune for tallying observations and giving best results. The study of elevation profile of the area ranging from 340m to 3153m was incidental in identifying that the correlation worsened with increase in altitude. TRMM data, although overestimated results, mapped a similar trend to IMD and can be used for indentifying low or high rainfall areas. Thus, both sources have pros and cons and the results can be used in an attempt to better further researches.

1. INTRODUCTION

Landslides have become a very common phenomenon in hilly areas due to factors like cloud bursts, heavy rainstorms, earthquakes, and unplanned activities of humans (Islam, 2014). The unpredictable flow of debris at precarious positions like mountain roads and hill station highways lead to damage of property, instant death or painful entrapment. Accuracy of heavy rainstorms or precipitation plays a noteworthy role in Landslide phenomenon (Bharti, 2015). The Himalayan foothill region which is taken as our study area is part of a fragile tectonic zone making it more prone to landslides. Nearly 14,000 pilgrims were left stranded at various places in Chamoli district as an aftermath of a massive landslide that blocked the Rishikesh-Badrinath highway in May, 2017. A similar situation happened in July, 2015 when the pilgrims for Char Dham Yatra were stranded due to landslides. A report published by Times of India in May 2017 suggests that over 5300 people have lost their lives due to landslides in Uttarakhand since 2001. This natural disaster has been a very recurrent phenomenon in the past decade-and-half with almost 4000 dying in the 2013 tragedy itself. The statistics are overwhelming.

With less vegetation to provide stronghold, rugged terrain, heavy rainfall and earthquakes, landslides cannot be completely avoided. Human activities like construction of roads and building of bridges in such areas also amplifies the landslide occurrences. However, its effects and aftermath can be mitigated if a proper prediction and management system is in place. Huge amount of data corresponding to the massive landslides that have occurred in Uttarakhand over a period of twenty years is available with us. This data when used in conjunction with a predictive algorithm gives an early warning system which eventually gives a general idea about the occurrence of Landslide.

The Tropical Rainfall Measuring Mission (TRMM) is a collaborative effort by the two major aeronautics organisations i.e. NASA and JAXA. TRMM's objective is to measure the change in latent heat of condensation and thereby the rainfall for the subtropical-tropical region. It has a combination of instruments like TRMM microwave imager (TMI), precipitation radar (PR) and the Visible and Infrared Radiometer System (VIRS) (Kummerow, 1998). TMI is able to quantify the amount of water vapour, cloud cover and rainfall intensity by measuring amount of microwave energy emitted by Earth. Based on the design of Special Sensor Microwave/Imager (SSM/I), TMI provides five frequency channels including the new 10.7 GHz frequency channel making TMI better than its earlier instruments. The satellite involved, moves in a 350 km circular orbit having an inclination angle of 35° details of which are available at https://disc2.nascom.nasa.gov/tovas/. TRMM Multi-satellite Precipitation Analysis (TMPA) 3B42 daily data is probably the most relevant TRMM-related products for Landslide research which covers 0.25° spatial resolution, covering 50°N to 50°S from 1998 to present (Huffman, 2013). The algorithm of TMPA comprises of four steps as (i) microwave precipitation estimates are calibrated and combined; (ii) infrared precipitation estimates are created using the calibrated microwave precipitation; (iii) microwave and IR estimates are combined; and (iv) calibration against rain gauge data (Parida, 2017). In 1997, the first satellite-based precipitation radar (PR) was launched on the Tropical Rainfall Measurement Mission (TRMM) satellite which provides the first continuous precipitation measurements of the entire tropics. The TRMM PR provides better description of the vertical structure of storms than ground-based radar because of the angle at which it is able to view those although range-related problems such as variations in sensitivity or regional variations in radar calibration does not exist. The disadvantage is that the PR has a 247-km swath which can observe each location only once or twice per day. This low temporal resolution signifies that the TRMM PR must be used in combination with other observations for weather analysis and forecasting. This information on TRMM PR can be found at http://www.goes-r.gov/.

Research focuses on making use of IMD's quality rain gauge data over the country to prepare a high resolution daily rainfall data for landslide study at a spatial resolution of 0.25° × 0.25° for 10 years i.e. 2005-2015. Data set was prepared and processed using the daily rainfall data from all the rain gauge stations over the study area i.e. Rishikesh to Badrinath route available in the IMD database (Pai, 2014). The major focus area for the study is the division of the region into section based on increasing altitude. The underlying factor is the occurrence of landslide. The comparison of data sources becomes important in this terrain because of the looming danger of impending disaster. Landslides occurring in the region of Uttarakhand are mostly deep-seated, depending upon the cumulative rainfall. Many researches have been done to create models for prediction of landslides by taking rainfall as an independent variable. The holistic approach of this paper aims at understanding the advantages and disadvantages of both the TRMM and IMD data sources. Both the sources have some error balancing. Where TRMM has the disadvantage of one or two observations per day, IMD has the drawback of being only locally located and prone to damage. When used in unison, however, they give most accurate results. The aim of the paper is to depict the changes in the dataset with increasing elevation profile of the study area. The region of Rishikesh to Badrinath has the minimum and maximum altitude as 340 m and 3153 m respectively. The elevation level of Rishikesh is 372 m and that of Badrinath is 3300 m. As we move from one grid to another, the increasing altitude points to the fact that any consensus established through this study forms the basis of comparison of data with growing altitude.

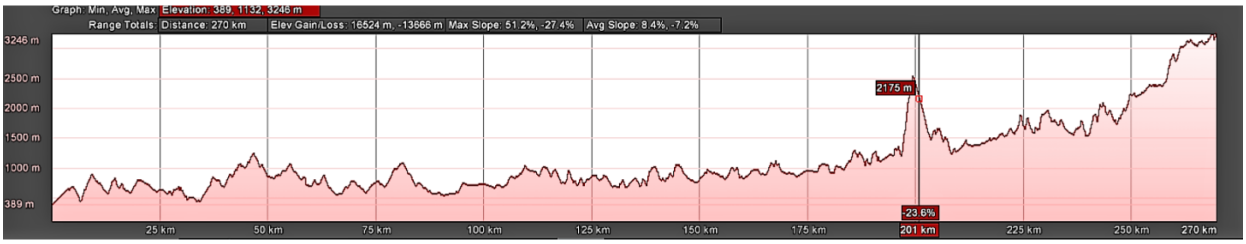


Figure 1 Elevation Profile of the Rishikesh – Badrinath Route: Google Earth

2. RESEARCH BACKGROUND

Comparison between satellite precipitation data and ground based data has been an ongoing field of research in many parts of the world. A tropical country like India provides a ripe conditioning for such researches. Study by Nair, Srinivasan and Nemani (2009) compares the multisatellite TRMM data with extensive gauge station data over diverse rainfall prone region of Maharashtra. While the data held strong correlation for moderate rainfall, there was a sharp reduction in correlation in regions with sudden and heavy bouts of rainfall. An Indian land mass study for data comparison by Narayanan et al. (2005) concluded that the then used version 5 of 3B42 (3B42V5) was not able to detect very low i.e. less than 1 mm or very high i.e. greater than 80 mm rainfall. This suggested that the daily temporal correlation would come out to be poor between the two sources. R. Harikumar (2008) portrayed extensive understanding of TRMM vs. Micro Rain Radar and Disdrometer in Thiruvananthapuram city of Kerala, India showing erratic results with good and poor correlation with varying climatic conditions. S. Rahman (2009) talks about the variability of monsoon rainfall by comparing satellite and gauge data sources involving TMPA, IMD and GPCP over Western Ghats and Himalayan Foothills. A general underestimation of data by TMPA is hinted upon but good inter-seasonal variations are seen. Chokngamwong and Chiu (2008) study of about 100 rain gauges in Thailand showcase a day-to-day correlation coefficient of 0.44 for satellite vs. ground data which is not on the higher side. Evaluation of error in TRMM 3B42V7 by V. Bharti (2015) exhibits the most relevant results for the current study. Working on Himalayan region as the study area, the research gives conclusive results based on elevation profile of the terrain. The study offers poor correlation of 0.23 for daily variance and 0.67 correlations for averaged data set. It also makes the revelation of 3100m as the altitude breakpoint which curtails the functioning of satellite data. Although the individual data comparison may envision the disparity of datasets, spatiotemporal study of extreme rainfall events (ERE) by V. Bharti (2016) proclaims the ability of TRMM data to predict the occurrence of EREs. All these researches come to a touch upon the fact that both ground and satellite sources vary in the performances with respect to change in terrain and only through better study of both, a greater understanding can be established.

3. DATA AND METHODOLOGY

For the present study, the daily precipitation has been derived from 3B42 research version dataset, the algorithm being Version 7 TRMM Multi- Satellite Precipitation Analysis given at https://pmm.nasa.gov/TRMM/TMI. The TRMM data product is a combination of the information received by the three instruments TMI, PR and VIRS. The 3B42V7 provides us with a much calibrated global rainfall product over the latitude of 50°S – 50°N with spatial resolution of 0.25°X0.25°. The study area also known as National Highway 58 lies in the foothills of Himalayas. It has been divided into seven grids with altitude in the increasing order incrementing with each grid. The seven grids comprises of latitude of the range 30° N – 30.75° N and longitude ranging from 78.25° E - 79.75° E. Since, the TRMM provides data between 50°S – 50°N; we shall extract the required data for our latitude and longitude values. The rain gauge local data available for this study was provided by the Indian Meteorological Department for thirty years i.e. 1985-2015. The study on the other hand has been carried out for 11 recent years i.e. 2005-2015. Figure 2 showcases the holistic approach of handling the data including steps of extraction and analysis.

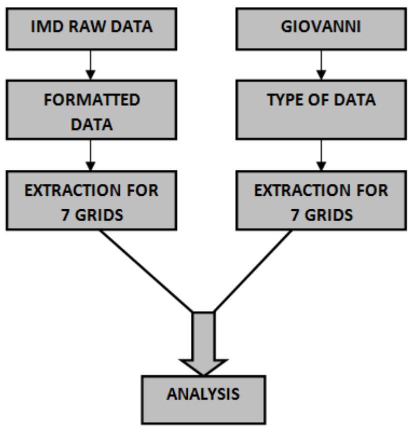


Figure 2 Flow Chart depicting Methodology

All the data pre-processing is done in steps as shown. The entire region of the NH-58 has been divided into seven regions or grids based on the rainfall received and altitudes of the areas. Table 1 gives the start and end points of the seven gridded sections. Our National Highway 58 gets heavy rainfall every year. The entire path cannot be taken as points, hence the path was divided into section of squares and each square was defined as a grid of seven pairs. The guiding points when taken together formulate a complete square.

Table 1 Gridded Dimensions of the Study Area

PAIR	START POINT	END POINT
1	**30°N – 78.25°E**	**30.25°N – 78.5°E**
2	**30°N – 78.5°E**	**30.25°N – 78.75°E**
3	**30°N – 78.75°E**	**30.25°N – 79°E**
4	**30.25°N – 78.75°E**	**30.5°N – 79°E**
5	**30.25°N – 79°E**	**30.5°N – 79.25°E**
6	**30.25°N – 79.25°E**	**30.5°N – 79.5°E**
7	**30.5°N – 79.5°E**	**30.75°N – 79.75°E**

After understanding the latitude and longitude pairs, data has to be extracted according to the above mentioned table. Using KDB+ and Q query, IMD data is extracted. KDB+ is a database manager which is usually used for data which is too large for excel. Excel has a limitation of rows and it could not show the complete data at a time because of the huge amount of data that was used. KDB+ on the other hand efficiently handled the data by Q language queries typed directly in the command prompt. The data which is extracted by both IMD and TRMM sources were put into proper acceptable format by using python for data pre-processing. The Python code converts raw data into the format of DATE, LATITUDE, LONGITUDE and RAINFALL. NASA has an official web interface in the form of Giovanni which helps in the analysis and extraction of gridded data. Researchers can explore the various fields offered by Giovanni under disciplines and measurements like Evaporation, Latent Heat, Aerosol and Water and Energy Cycle (https://giovanni.gsfc.nasa.gov/giovanni/). This ability of Giovanni to handle excessive data and display it under numerous subjects adds variations to the studies that can be carried out on this data. The TRMM data taken from Giovanni is in the form of area-averaged value; hence it gives a singular value for the entire squared area of each grid. These values are then extracted for monsoon seasonal months of JUNE, JULY, AUGUST and SEPTEMBER of 2005 to 2015. The IMD data, on the other hand, is completely tabulated from increasing latitude and longitude values with an increment of 0.25° with each value. IMD data on extraction provides point-to-point geographical rainfall value i.e. four individual values for four corners that the grid consists of; which is different from the TRMM area-averaged value. With proper calculations and systematic calibration, the four IMD values are compensated to give one singular value like TRMM so that further tests can be carried out without any hindrance.

Once the data extraction is complete, entire dataset is separated into different sections for analysis. Four types of analysis are ensued upon the data: 1. Daily Temporal Correlation, 2. Monthly analysis (Four months containing 11 values pertaining to each year), 3.Inter-Annual seasonal analysis (2005 – 2015), and 4.Inter-Grid analysis. One of the major pointers of this study is to evaluate the ability of TRMM in correctly classifying the region and its climatic conditions. This comparison when done in lieu to the local rain gauge data will be strong enough to substantiate any further research or study on this topic in this area.

3.1 Daily Temporal Analysis

The TRMM Precipitation Radar (PR) can provide better understanding of storms than ground radars because of its viewing angle but it has a swath path of 247 km raising the disadvantage that it can observe regions and locations once or twice a day (http://www.goes-r.gov). Because of this disadvantage TRMM may not be able to correctly predict the rainfall at places which get sudden bouts of heavy rainfall; at least not on daily basis. However, when the same pattern is encountered over and over again, the overall prediction by TRMM and IMD show certain amount of correlation. Daily Temporal Correlation study substantiates the claim that observing the daily rainfall values of TRMM and IMD may not provide us with concrete study conclusions.

Table 2 Correlation values for daily variation

	GRID 1	GRID 2	GRID 3	GRID 4	GRID 5	GRID 6	GRID 7
DAILY TEMPORAL CORRELATION	**0.203**	**0.261**	**0.234**	**0.222**	**0.161**	**0.135**	**0.003**

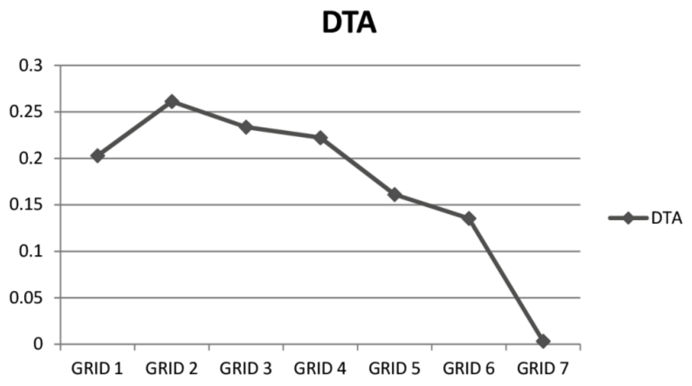


Figure 3 Daily Temporal Correlation graph for seven grids

The correlation values for four monsoon months (June, July, August, September) for 11 years have been summed up in the Table 2. The line graph in Figure 3 showcases the trend line bending downwards as the plot moves forward with the grids. Grid 1, 2 and 4 have better correlation values while grid 7 results are very low for DTA (Daily Temporal Analysis). The graph does suggest the decrease in the correlation between the IMD and TRMM values with successive grid areas; however, it also suggests that the highest correlation too comes out to be 0.261 for grid 2 which in itself is a very low constant. Correlation of such low magnitude points to the fact that the comparison between the two sources over day-to-day values is not significant enough to draw inferences. Hence, the daily relationship mapping of the satellite and local sources provides evidence to the disadvantage of TRMM discussed earlier.

3.2 Monthly Analysis: June, July, August, September

Table 3 Seasonal Correlation Values

	JUNE	**JULY**	**AUGUST**	**SEPTEMBER**
GRID 1	**0.904364**	**0.593418**	**0.705504**	**0.756634**
GRID 2	**0.923284**	**0.56365**	**0.660005**	**0.85508**
GRID 3	**0.843043**	**0.708942**	**00543675**	**0.76233**
GRID 4	**0.953032**	**0.725622**	**0.811311**	**0.890301**
GRID 5	**0.832406**	**0.405175**	**0.367965**	**0.482254**
GRID 6	**0.784197**	**0.196684**	**0.369004**	**0.555491**
GRID 7	**0.716307**	**0.334986**	**0.242542**	**0.286073**

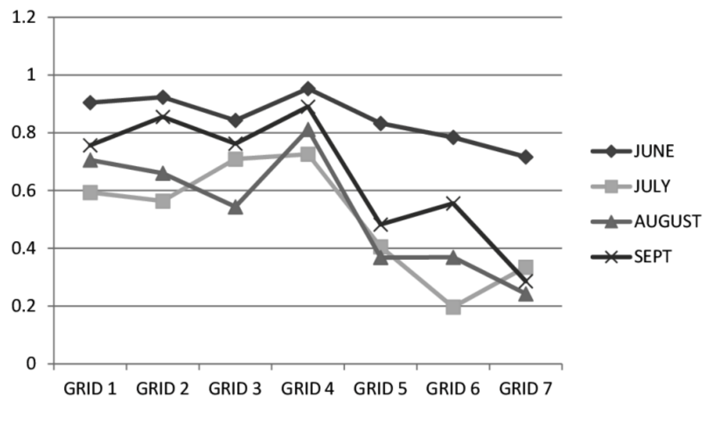


Figure 4 Monthly Relationship Graph

In the previous test environment, we established that experimenting on day-to-day values provides a general piece of information that correlation is deteriorating as the altitude is increasing. For the present test series, the four months have been separated with each month having all the values of that particular month for eleven years. To improve upon the daily temporal testing, IMD and TRMM values for each month of each year is summated into two different sections giving total of 22 test values for each month of June, July, August and September. The study on the monthly data can be ensued in two ways. The individual correlative bias values of the four months for every grid are given in the Table 3. The four months of June, July, August and September are considered the wettest monsoon months in the tropical region of India. Major part of our study area lies in Uttarakhand which gets heavy bouts of rainfall in these four months. Hence, the study has been restricted to the seasonal months. Usually under many studies it is witnessed that the months of June and July give better results as these are the months of heavier rainfall as compared to August and September. However, for the period of 2005-2015 there is a general trend of June, September, August and July (correlation in the descending order). The line graph of four months plotted against seven grids showcased in Figure 4 gives a sizeable window of opportunity to understand the relation that the data is hinting at. The result could mean that TRMM and IMD are not able to provide similar results for the month with the heaviest rainfall even when taken as a sum and not daily findings. This approach is able to judge with definitive measure that for a terrain like this, TRMM and IMD are not able to correlate their values when heavy rainfall occurs.

3.3 Inter – Annual Seasonal Analysis (2005-2015)

The third approach adopted for testing data is the Inter – annual analysis. In the last approach, the data was divided on the basis of months. It also gave us the result that the month of July is giving the lowest level of correlation between IMD and TRMM data. Now, the present approach is undertaken with a fresh understanding of the problem statement in mind. By taking the four months as whole we can look at it as an entire monsoon season for each year. This methodology tries to study the data from a different perspective. This perspective goes as such: by understanding the trend of monsoon months over a span of 11 years we can completely judge the relation between the two sources. To follow up with the required methodology, data corresponding to four months are divided under 11 sections; one for each year from 2005 to 2015. A summation procedure is undertaken which finally gives two columns of IMD and TRMM data for 11 years. This procedure is followed for all the seven grids giving the final line graphs as we see them. The 7 line graphs obtained outline a diverse opinion when it comes to the ongoing issue of data reproducibility of the sources.

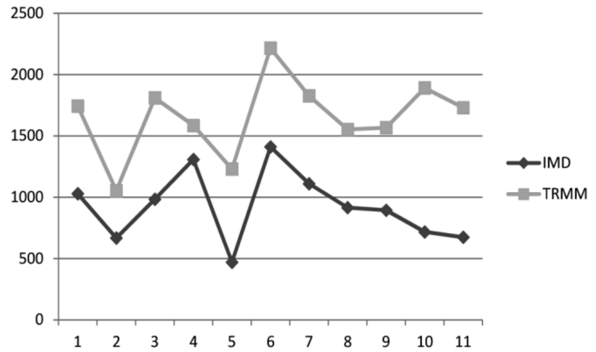


Figure 5(a)

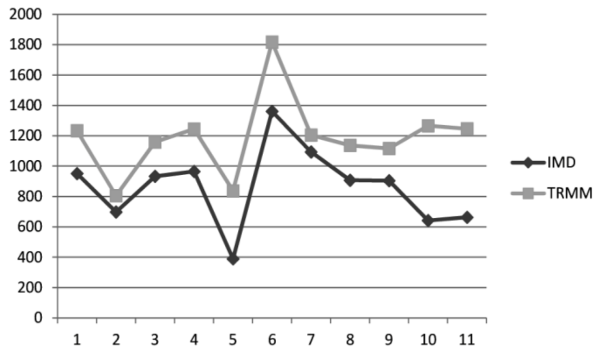
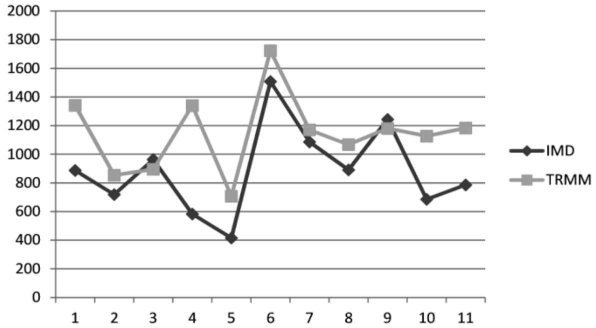


Figure 5(b)



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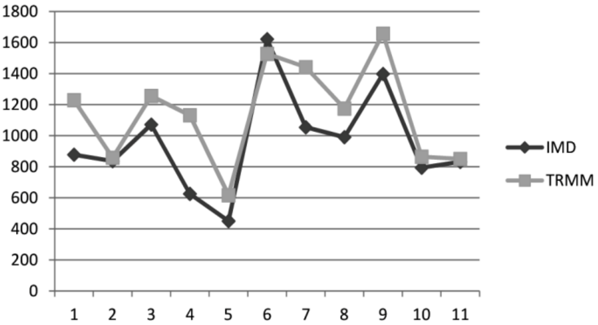

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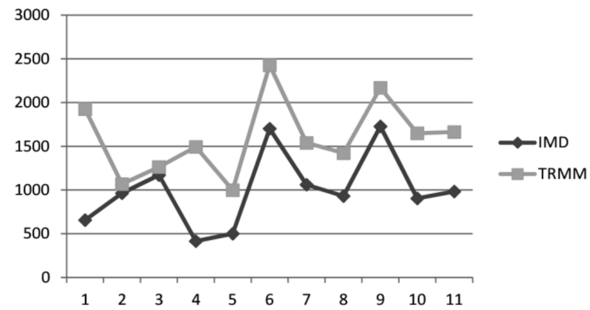

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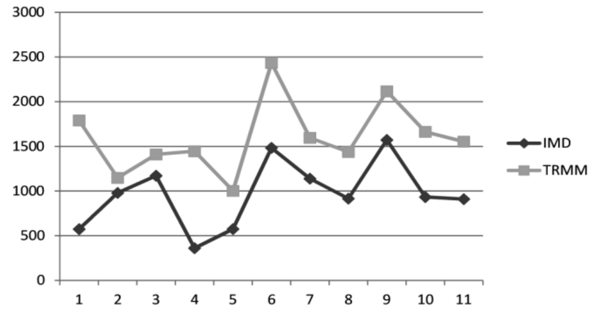

Figure 5(f)

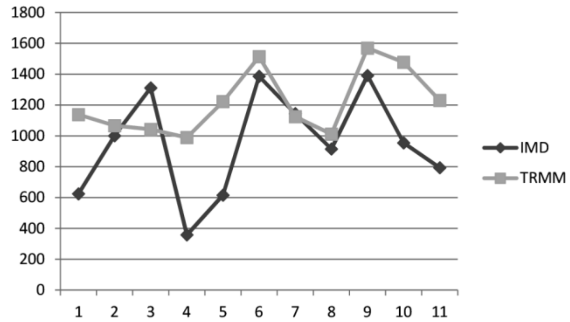

Figure 5(g)

Figure 5(a-g) IMD vs. TRMM gridded plots

Graph of grid 1 follows the path of two lines as they reproduce the general trend of data. It is clearly visible that in the first four grid outputs graphs the IMD and TRMM lines follow a similar trend. Grids 5, 6 and 7 do not relate to grid 1, 2, 3 and 4 in terms of trend endearment. The two source lines do not show a much similar trend. However, a constant attribute witnessed in all grid graphs is the difference in the values of the two sources. It points to the case where the correlation exists with a certain amount of general variance between the satellite and local data. Figure 5 (a-g) refers to line graph of grid 1till grid 7.

3.4 Inter – Grid Analysis

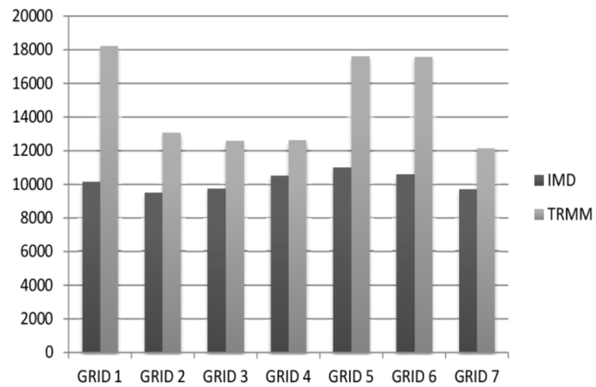

Figure 6 IMD vs. TRMM Total Precipitation Rate

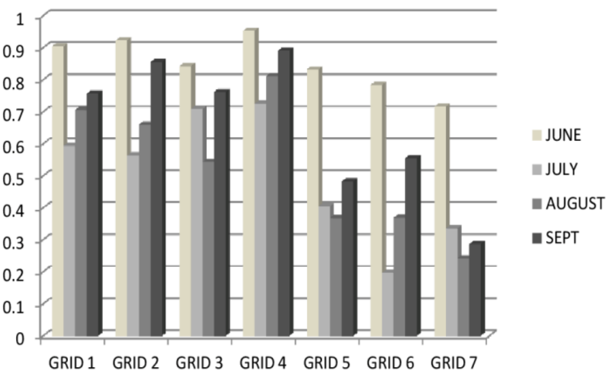

Figure 7 Comparison of monthly trends

The final level of analysis is the Inter – Grid analysis which focuses on creating an understanding of each individual grid section.

Figure 6 shows the column graph of the IMD and TRMM extracted data for the 7 different grids. The actual data was extracted has been summarized to obtain the total rainfall value of four months of 11 years. This graph gives the complete overview of the problem at hand. It is clearly visible that the satellite and local rain gauge data are quite unlike. This comparison offers the disposition that the entire study area gets almost the same amount of rainfall if the IMD source is to be confirmed. Observation of TRMM source points offers a different opinion as the precipitation rates predicted by TRMM are higher than the ones predicted by IMD. The trend followed by both the sources however is mirrored. Grid 1, 5 and 6 receive the highest amount of rainfall. The actual amount predicted by the two sources maybe different but both IMD and TRMM values point out that grids 1, 5 and 6 are heavy rainfall zones. Grid 2 and 7 receive the lowest amount of rainfall as compared to the other gridded sections. However, if seen overall, the entire area receives plenty of rainfall.

Figure 7 compares the correlation values of the four months over the seven grids. The column bar graph takes into account the correlation values of June, July, August and September to give the final plot and consolidate the already existing notion that the correlation goes on decreasing with increase in the altitude i.e. successive grids. The overall best month of correlation is the month of June. This month gives the best results for the seven grids. July, however, comes out as the worst performer by accounting the lowest correlative factor for 4 out of 7 gridded sections. September comes second after June in being a better month for results. The grids were divided in a way to cover the entire land slide prone belt of Uttarakhand.

4. CONCLUSION

The performance of satellite data varies when compared on averaged and non-averaged basis. The result for daily temporal correlation was 0.203 at best even for grid 1 whereas it went as low as 0.003 for grid 7. With such poor results for individual comparison, the second analysis of monthly-averaged dataset shows great promise. This analysis gives a better understanding of comparison between the four monsoonal months. Contradictory to the general notion that the month of July gives best results for comparison, our study stated with enough evidence of trends over 11 years that July gave the least associative results out of the four months. Monthly comparison championed the months of June and September with maximum correlation of 0.953 and 0.89 respectively. The Inter-Seasonal Analysis was an eye opener in terms of the difference in the plotted values. It suggested that although a correlation exists, but the TRMM data still provides an overestimation of the actual precipitation rates. This suggestion is further proclaimed by the simple comparison of the amount of total predicted rainfall by TRMM and IMD which clearly shows that for each grid IMD predicted lower precipitation rates than TRMM. If we are to compare all the conclusions in light of the elevation profile of the Rishikesh-Badrinath route with maximum and minimum elevation as 340m and 3153m, we can very well say that the correctness of prediction at higher altitudes worsens.

The difference in terms of individual rainfall between the two sources can be due to the drawbacks arising from the satellite orbit and swath path. Also TRMM measures the precipitation rate based on energy released and hence this factor is prone to changes. The very evident breakpoint at higher altitudes and also overestimation generate from certain errors related to measurement of rainfall in areas with heavy bouts and monsoons. However, if we are to study the graphs between IMD and TRMM in the inter-seasonal analysis, we see that the path followed in the graphs come out to be following the same trend. Thus, although TRMM does not predict the right amount but then it comes very close to the overall trend and prediction of rainfall or no-rainfall days. Surely the dataset in itself cannot be used for modelling predictive algorithms for landslides but it can be used in accordance with the local data to fill in the blanks and give a strong set for establishment of early warning systems.

5. ACKNOWLEDGEMENTS

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