Regionalizing precipitation characteristics of Helmand Basin in Afghanistan using TRMM Satellite Product

Regionalizing precipitation of Helmand Basin in Afghanistan

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***Abstract*— Although the total amount of precipitation in climate surveys is seen as an important factor in determining climatic conditions, and finally, ecological circumstances, but, its seasonal distribution, and to be more precise, its compliance with environmental requirements, particularly agriculture, is of great importance as well. In this study, we tried to regionalize the annual precipitation totals and the precipitation regime of Helmand basin on a regional scale, which is located in South West Asia, shared between three countries of Afghanistan, Iran and Pakistan. To this end, TRMM satellite rainfall productions with spatial resolution of 0.25 * 0.25 degrees for a 15-year period (2000-2014) have been used. To regionalize these two precipitation features in the Helmand basin, the cluster analysis by Ward linkage method was used. Performing the cluster analysis on Helmand basin annual precipitations, it was found that three rainfall areas can be identified in this basin: Eastern high precipitation region with an average annual rainfall of 256.7 mm, Central moderate precipitation region with an average annual rainfall of 171.5 mm and Western low precipitation region with an average annual rainfall of 86.1 mm. In addition, performing cluster analysis on the relative precipitation per month indicated that two different precipitation regimes, namely, winter precipitation regime and winter- spring precipitation regime can be distinguished in this basin. The winter precipitation regime prevails in the west of the basin, while the winter-spring precipitation regime prevails in the center and east of the basin. The winter precipitation regime is a regime that close to 63.4% of its total annual precipitation falls in the winter. The winter-spring precipitation regime of this basin is a regime that most of its precipitation occurs first in winter (44%) and then in the spring (30.5%).**

Keywords-c Precipitation, Regionalizing, Cluster analysis, TRMM, Precipitation regime, Helmand Basin

I. INTRODUCTION

Demarcation and separating an area to units relatively independent of each other based on one or more given criteria has always been the focus of geographers. Accordingly, individuals such as Humboldt (1817), De Martonne (1909), Penck (1910), Koppen (1918), Miller (1931), Thorenthwaite (1948), Trewartha (1954) and Strahler and Strahler (1978) have suggested some methods for climatic classification. These methods are based on preset elements and thresholds and largely rely on the biological conditions of plants. For the same reason, the boundary of climatic regions in these methods mainly matches with on the plant areas bordering. However, the climatologist geographers are now looking for using methods that are able to reveal the available facts in the climatic zones with minimum errors. One of the methods that can help the climatologists in this regard is to use multivariate statistical methods.

The use of these statistical methods has become practical for climatic classifications from the 1960s onwards with the arrival of computers into the world arena of computations. Steiner (1965) was perhaps the first researcher who has used the multivariate analysis technique for climatic classifying of a geographic area in 1965. Using 16 climatic variables, he regionalized the United States. Although the work of Steiner (1965) was a starting point in introducing a new approach to classify climate, but, he had used few variables in his work. Arguably, the researchers who had imitated his work have considered this issue (Oliver et al., 1978; Puvanswaran, 1990; Masoodian, 2004). However, in some cases, the spatial differences in an area need to be examined only in terms of a variable. Among the climate variables, due to its importance and changeable nature, precipitation may be considered as the first variable in all studies and calculations related to water resources and harnessing them. Accordingly, the climatologists such as Eklundh and Pilesjo (1990), precipitation classification of Ethiopia, Domroes and Ranatunge (1993), daily precipitation regionalizing of Sri Lanka, Basalirwa (1995), monthly, quarterly and yearly precipitations zoning of Uganda, Regenmortel (1995), daily precipitations zoning of Botswana, Sumner et al. (1995), precipitation regions zoning of Mallorca in Spain, Garcia et al. (2002), precipitation regionalizing of Iberian Peninsula have done using multivariate statistical methods. In Iran, Domroes et al. (1998) by applying principal components analysis and cluster analysis on monthly precipitations of 71 stations have identified three core components and five precipitation regime in Iran.

In climate surveys, although the total amount of precipitation is seen as an important factor in determining climatic conditions, and finally, ecological circumstances, but, its seasonal distribution, and to be more precise, its precipitation regime, meaning the ratio of incoming precipitation per month of the total annual rainfall (Masoodian, 2005) is also one of the important features of precipitation that its zoning for any planning on agriculture, water resources, land use, etc. can be helpful and leading. Zoning of this feature of precipitation by using multivariate statistical methods have been previously done by researchers such as Comrie and Glenn (1998) for the southern United States of America and northern Mexico, Johansson and Chen (2003) for Oklahoma state of America, and Darand and Mansouri Danshvar (2014) for Iran.

However, one thing in common among all these studies with a significant representation has been the use of complete and long-term data of ground stations and their appropriate spatial distribution, while these conditions are not provided in all regions of the world, especially in areas where cannot be easily accessed that have not well-timed and reliable land information as well. Helmand basin in Afghanistan, an area that has passed three decades of transboundary wars and internal conflicts, is one of the regions that lack the full, long-lasting and data and appropriate spatial coverage. Therefore, satellite productions can provide a unique opportunity for such areas to study and evaluate the temporal and spatial behaviors of environmental-climatic variables, especially the precipitation.

TRMM is one of the satellites that its productions can be used in the study of spatial-temporal behavior of precipitation. This satellite is a co-production of the National Aeronautics and Space Science satellites (NASA) of United States and Japan Aerospace Exploration Agency (JAXA) that has been and launched into space on 27 November, 1997, and was put in the Earth's orbit at an altitude of 350 kilometers. The satellite has started data transmission (distribution) almost simultaneously since 31 January, 2000. Its products are presented form the latitude of 50 degrees south to 50 degrees north. The satellite spatial resolution in the recording of precipitations is at least 0.25 * 0.25 degrees up to 5 * 5 degrees. The satellite passes over different regions of the planet several times a day and gathers the necessary information. The frequency of data collection and passage of the satellite varies for different regions of the Earth and depends on the latitude of the area of interest. For example, in the study area of this research, the region is on average scanned four times a day by the satellite and its specifications of rainfall are recorded. A lot of research has been done around the world to verify and compare the TRMM precipitation data with ground stations. Most researches have confirmed a high correlation between satellite and ground-based data sets (Masunaga et al., 2002; Nicholson et al., 2003; Bowman, 2004; Chokngamwong and Chiu, 2006; Villarini and Krajewski, 2007; Su et al., 2008; Nair et al., 2009; Almazroui, 2011: Li et al., 2012; Islam and Uyeda, 2012; Vernimmen et al., 2012).

In this study, we tried to regionalize different characteristics of rainfall in the Helmand basin by using TRMM satellite rainfall products and benefiting from multivariate statistical techniques such as cluster analysis. We hoped that the results of this study would provide a good knowledge regarding the precipitation behavior in this basin for policy makers of management of water resources, agriculture and etc. so that they can accordingly plan properly for sustainable development of this part of the world.

II. STUDY AREA

Helmand river basin, with 18 sub-basins has an area of about 200,000 square kilometers that is located between Iran, Pakistan and Afghanistan in South West Asia. A large part of this basin is in Afghanistan and only about 5% of its area is located in Iran (Figure 1). Helmand River with a length of 1050 km flows in this catchment area that is the origin of the rise of different pre-historical and historical civilizations. The river's water is supplied through precipitation and snow melting of in the Hindu Kush Mountains, which is finally discharged into an internal trough at the end of the basin called as Hamoon lakes (Van Beek et al., 2008).

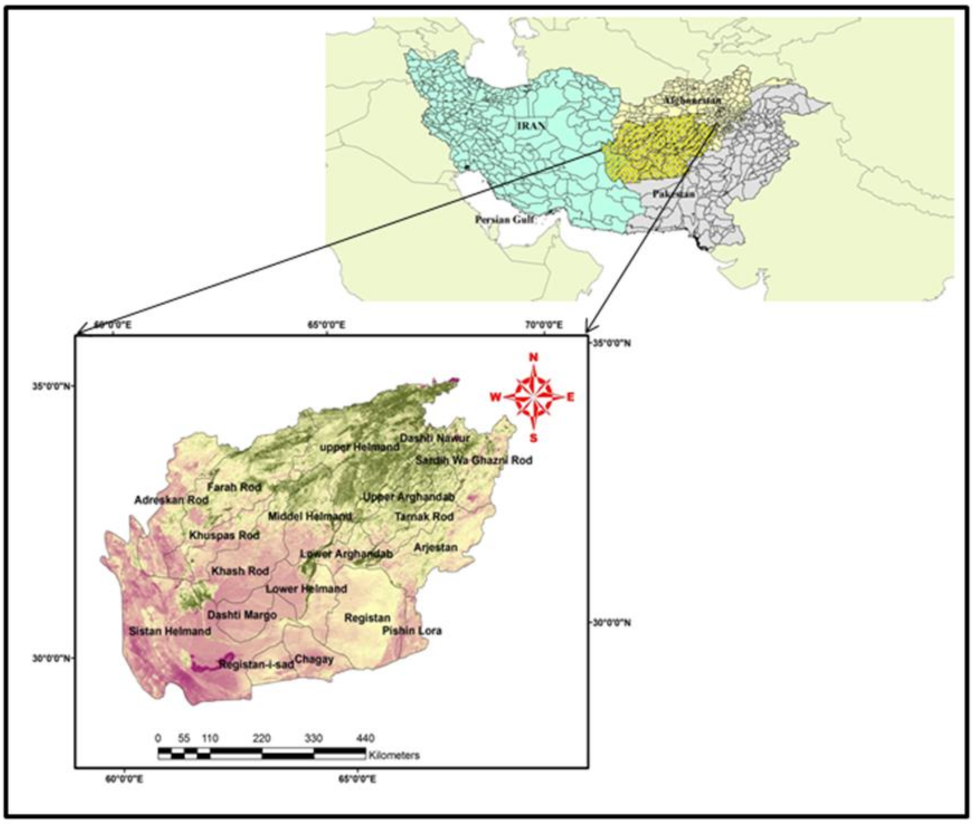

Figure 1. Geographical location of Helmand basin in South West Asia

Distribution of rainfall in Helmand basin is a function of its topographical situation and position so that these factors have caused the precipitation distribution to be non-uniform in the region. The average distribution of total annual rainfall of Helmand basin varies within the range from 29 to 567 mm. The high precipitation and low precipitation cores of the basin are located in the west and east of the basin, respectively (Figure 2). In terms of temperature, it is mild in autumn and cold in the winter; but temperature increase of 50 ° C in the summer has elevated the evapotranspiration potential up to more than 3 meters per year (Vekerdy et al., 2006).

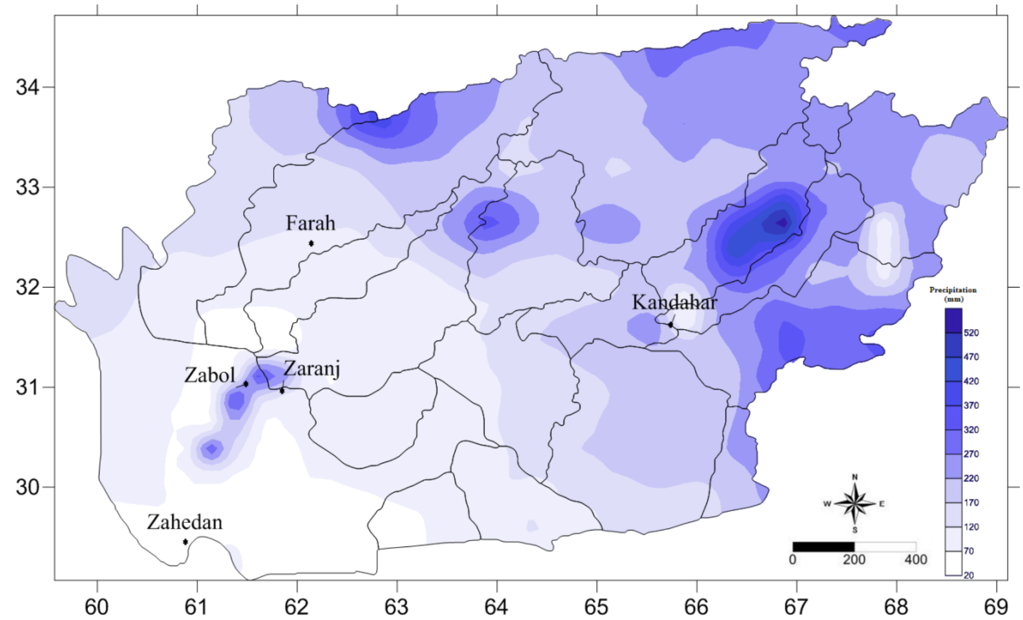

Figure 2. The spatial distribution of mean annual rainfall in Helmand basin by using TRMM satellite data for the period of 2000-2014

III. Materials and Methods

In this study, the precipitation products of TRMM satellite, called as TRMM 3B42, Ver. 7 have been used to regionalize the precipitation characteristics of Helmand basin in the South West Asia. The reasons for using the productions of TRMM satellite can be mentioned as its more accessibility and acceptable results obtained from applying them in various studies around the world (Bodian et al., 2016). The precipitation data available in this database has daily and monthly temporal resolution and spatial resolution of 0.25 * 0.25 degrees. All the TRMM data are available in ASCII text format through the website with the address below: http://disc2.nascom.nasa.gov/tovas/. More information about the types of products on the TRMM satellite is available in the sources of Huffman et al. (2007) and Huffman and Bolvin (2015). In this study, the monthly rainfall data scale from TRMM 3B42 Version 7 with spatial resolution of 0.25 * 0.25 degrees for a 15-year period (2014-2000) was used. With this spatial resolution, the total precipitation points occurring within the boundaries of Helmand basin were included 548 points (Figure 3). Therefore, from now on, these 548 basis points were considered as the basis of calculations and regionalizing the precipitation characteristics of the basin.

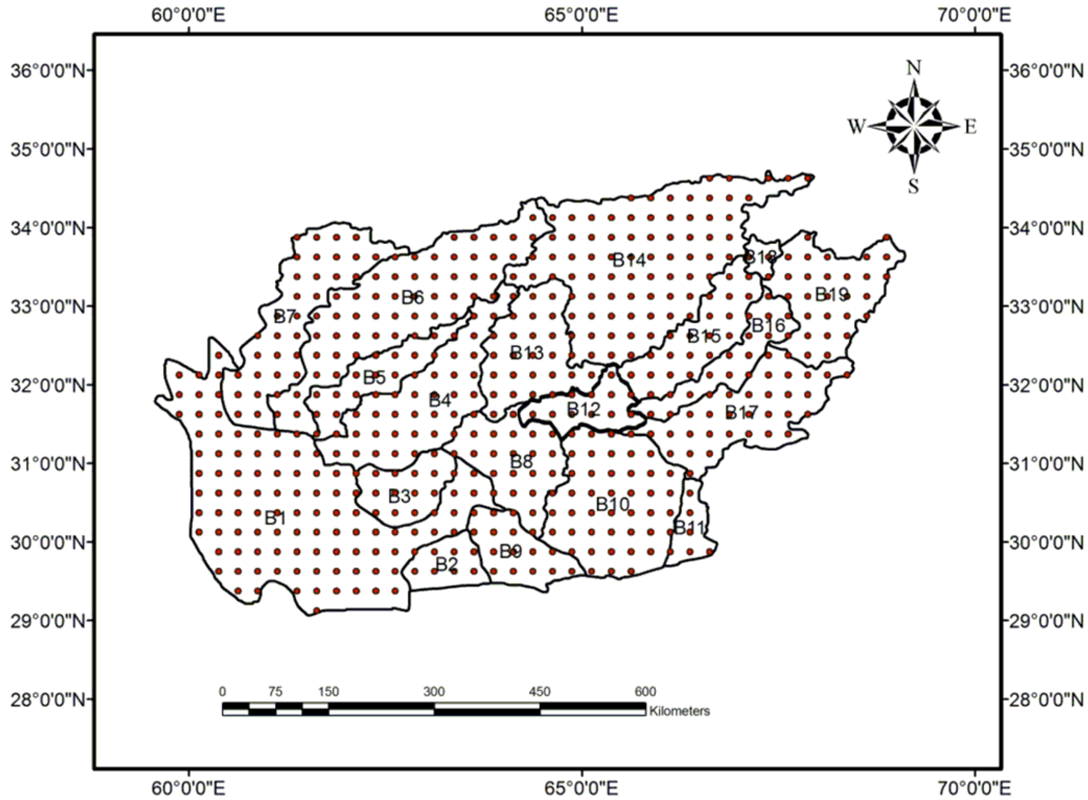

Figure 3. Number and geographical positions of monthly precipitation points taken from TRMM satellite

To regionalize the total annual precipitation of the studied basin, first, the total annual precipitation (October-September) of all 548 points within Helmand river basin was calculated for the whole 15-year period of study. In the second step, for identifying and zoning the precipitation regimes regulations, i.e., the pattern of ratio of rainfall per month to the total annual rainfall, the precipitation in each month was divided by the total annual rainfall of the same year to obtain the relative rainfall of each month for the entire studied points (548 points). Then, the cluster analysis was used to regionalize these two precipitation features of Helmand basin. Cluster analysis is a statistical method that is used in the context of reducing data and finding the actual groups. The main objective of this method is to generate groups and classes that their diversity and dispersion within the group would be less than the diffraction and dispersion between groups (Alijani, 2002). To do this, two key steps should be taken:

- Step 1: Calculating the degree of similarity of stations with each other
- Step 2: Linkage of stations based on their degrees of similarity

A variety of methods have been suggested to measure the degree of similarity that each has their own specific efficiency proportional to the nature of the studied subject. In climatic studies, the Euclidean distance is often used to calculate the degree of similarity. However, the squared Euclidean distance was used in this study, since in this index; the observations with larger distance from each other are given more weight. Having m: the number of variables, Xij: the value of variable j for the ith subject, the squared Euclidean distance between K and I will be as follows:

$$D_{KI}^{2} = \sum_{j=1}^{m} \left(X_{kj} - X_{Ij} \right)^{2} \tag{1}$$

After measuring the degree of similarity of stations, a method should be used to link and interstate the stations with highest degree of similarity. Ward method is an approach that was used at this stage. In this method, the groups "r" and "s" are integrated if the variance increase resulting from their integration than to their integration of each of them with other groups would be minimal; in mathematical terms:

$$d(r,s) = \frac{n_r n_s d_{rs}^{2}}{(n_r + n_s)} \tag{2}$$

Here, d_{rs}^{2} is the distance between group "*r*" and group "*s*".

The method has the advantage that each station occurs in a group to minimize the sum of squares deviations within group. The stations fitting in a cluster in this way are located adjacent to each other on the map spatially (Masoodian, 2005). Finally, variance analysis (Scheffe, 1999) and Scheffe analysis (Scheffe, 1999) were used to test the significance of differences of precipitation zones and the resulting precipitation regime from two previous methods.

IV. Results

Performing cluster analysis on the Helmand river basin annual precipitation matrices, which results are shown as a Dendrogram (Figure 4), indicates that three precipitation areas can be identified in this basin: Eastern high precipitation region, central moderate precipitation region, and western low precipitation region (Figure 5). The eastern precipitation area is considered as the largest precipitation zone in terms of area in Helmand basin, which encompasses about 35.6% of the basin. The average annual rainfall of this precipitation region is equal to 257.7 mm. The central moderate precipitation zone is the second largest precipitation region of the basin, located in the west of the Eastern high precipitation area, approximately includes 34.1% of the basin area. The average annual precipitation in this region accounts for 171.5 mm. The region with the minimum area and precipitation of Helmand basin, which approximately covers 30.3% of the basin area, is the Western low rainfall area with 86.1 mm of rainfall in the west of the basin.

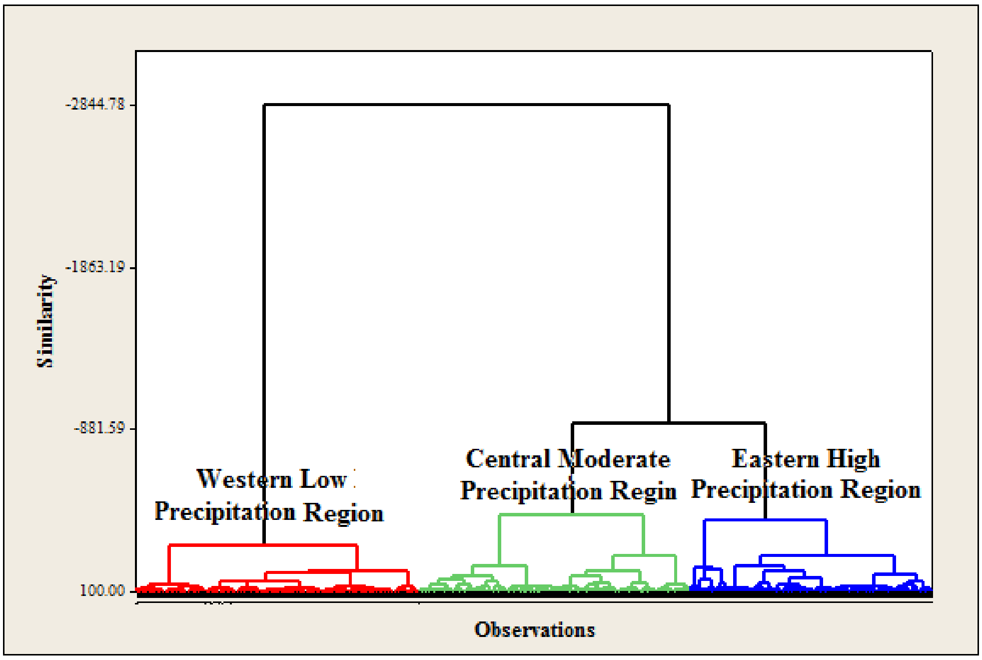

Figure 4. Dendrogram resulting from cluster analysis on the matrix of annual rainfalls of Helmand basin

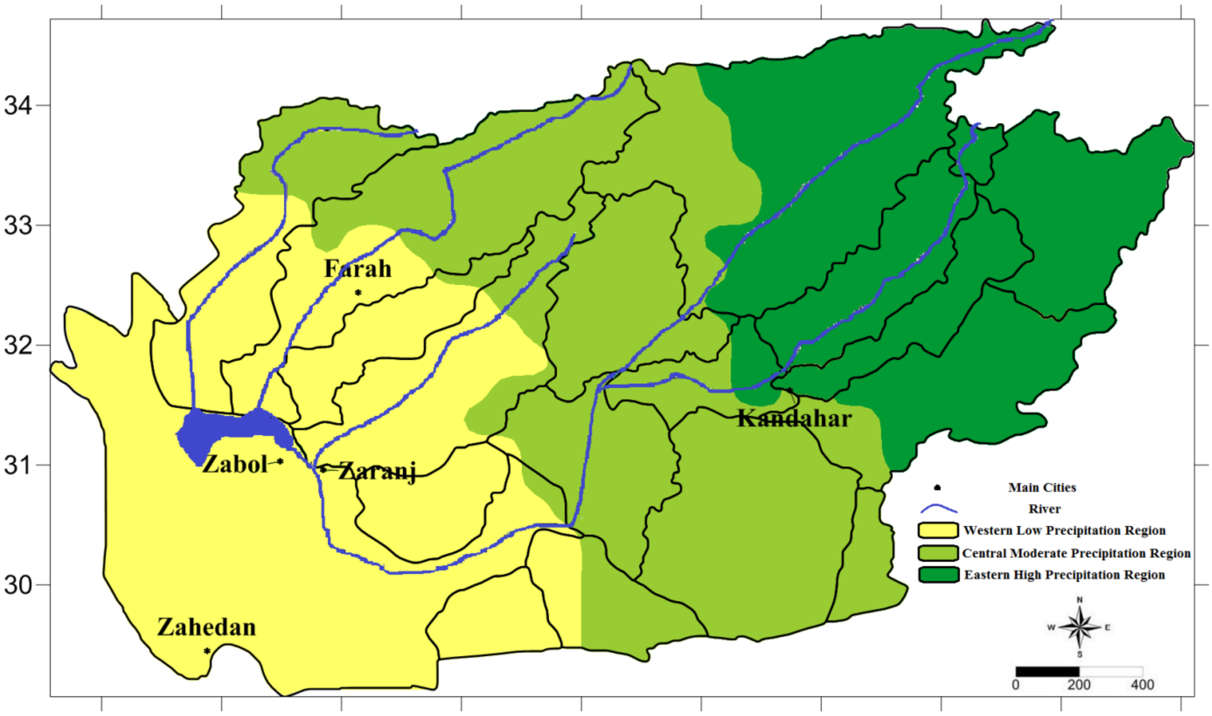

Figure 5. Precipitation zones of Helmand basin

The variance analysis of average annual rainfall in three areas obtained from cluster analysis at the probability level of α = 0.05 shows a significant difference between the average annual precipitation of these three areas (Table 1). However, the variance analysis does not clearly show a difference between the three zones. That is, the analysis does not indicate which area has had a significant difference with other areas. Thus, the post hoc Scheffé's analysis was used to answer this ambiguity. Table 2 Shows the results of Scheffe analysis of precipitation at a yearly scale. Based on the results of this analysis, it was found that there is a significant difference between all three regions at probability level of α = 0.05. Therefore, separation of Helmand basin area into three zones is acceptable.

Table 1: ANOVA for comparison of the mean annual rainfall in three precipitation zones of Helmand basin

	Sum of Squares	**Df**	**Mean Square**	**F**	**Sig.**
Between Groups	2617895.071	2	1308947.535	823.955	0.05
Within Groups	865795.165	545	1588.615		
Total	3483690.236	547			

Table 2. Results of Scheffe post hoc analysis on mean annual rainfall of three precipitation zones of Helmand basin

(I) Region	(J) Region	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval Lower Bound	95% Confidence Interval Upper Bound
West region	**Centeral region**	-85.44504*	4.07946	0.05	-95.4580	-75.4320
	East region	-170.67197*	4.20912	0.05	-181.0032	-160.3407
Centeral region	**West region**	85.44504*	4.07946	0.05	75.4320	95.4580
	East region	-85.22693*	4.25032	0.05	-95.6593	-74.7946
East region	**West region**	170.67197*	4.20912	0.05	160.3407	181.0032
	Centeral region	85.22693*	4.25032	0.05	74.7946	95.6593

The process of cluster analysis was conducted on the relative monthly precipitation of 548 precipitation points within the Helmand river basin with the aim to identify and zone of the precipitation regimes of Helmand basin. It was observed that Helmand basin has two different precipitation regimes called as winter precipitation regime and spring-winter precipitation regime. The results of this analysis, shown as a Dendrogram, are given in Figure 6. On this chart, the clusters related to each of these two precipitation regimes are marked. Finally, the rainfall regimes determined by cluster analysis were converted to a zoning map of the precipitation regime of Helmand basin by using Kriging geostatistical method. Based on this map, one can see that the winter precipitation regime and the winter-spring precipitation regime are located in the west and center and east of Helmand river basin (Figure 7).

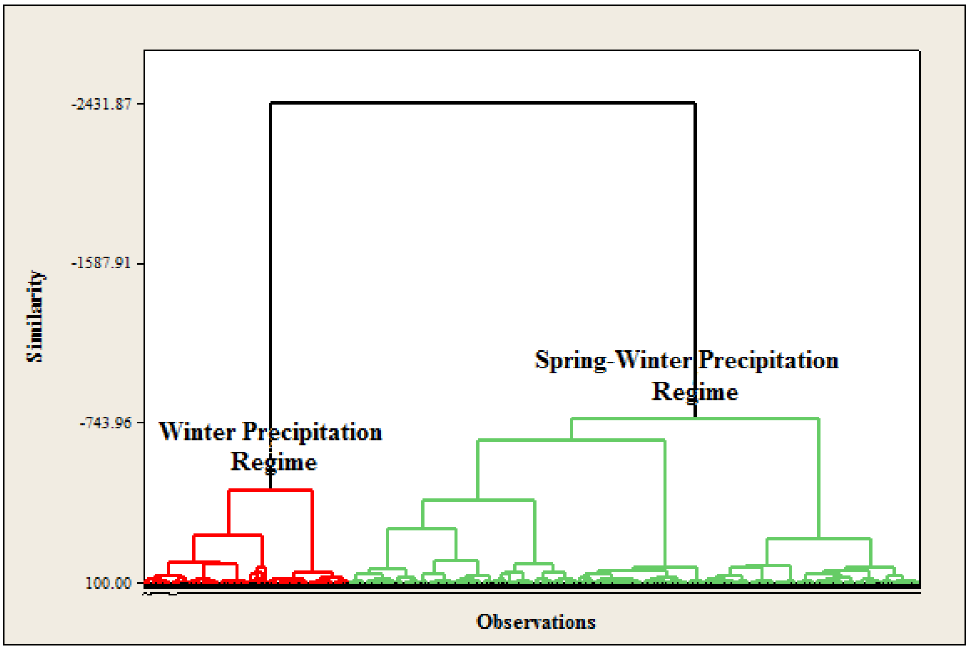

Figure 6. Dendrogram resulted from cluster analysis on monthly relative precipitations of points taken from TRMM satellite for Helmand basin

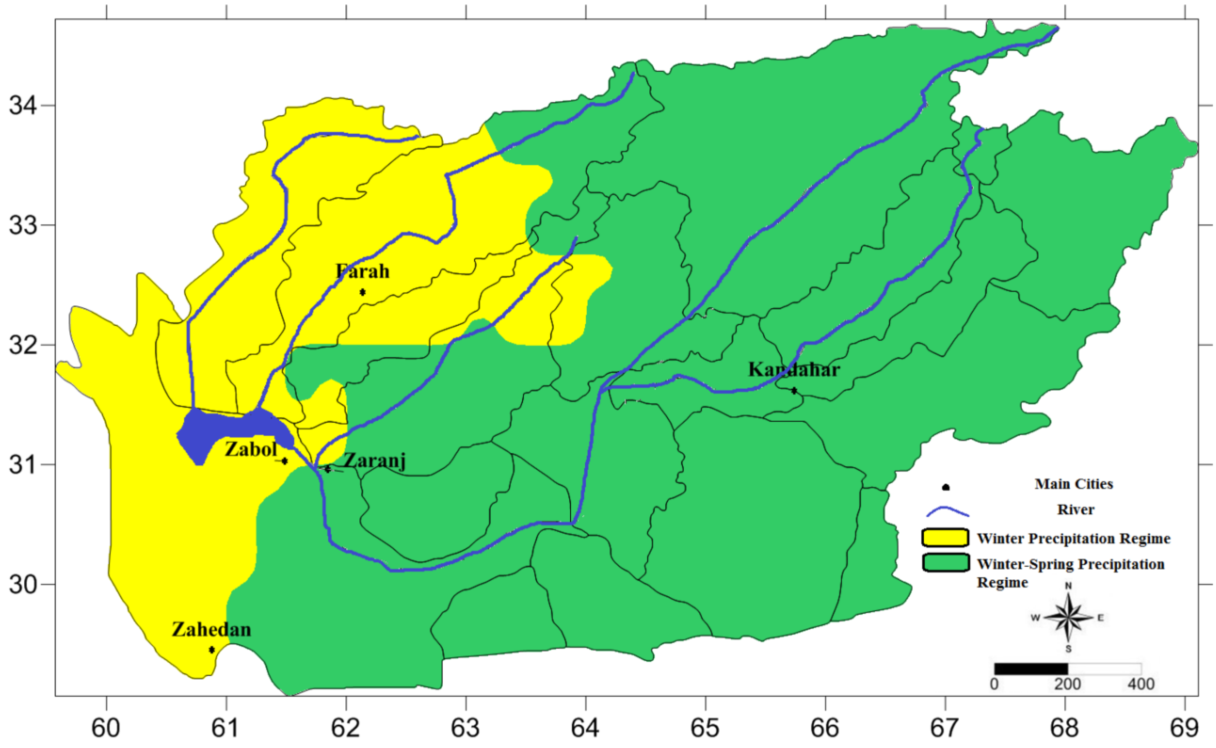

Figure 7. Zoning of precipitation regimes by using points taken from TRMM satellite for Helmand basin

Winter rainfall regime, which almost includes 26% of the catchment area in the West, is a regime that close to 63.4% of its total annual rainfall occurs in winter. Two seasons of autumn and spring, each with 21.6% and 13.3% of the total annual rainfall, are placed in the next rankings (Table 3).

The highest rainfall month of this precipitation regime is February, while the lowest rainfall is in October, which respectively will receive 22.7% and 0.3% of the total annual rainfall. In this regime, summer is considered as the driest season of the year (Figure 8).

Table 3. Relative distribution of rainfall in precipitation regimes of Helmand basin

regimes	Fall	Winter	Spring	Summer
Winter rainfall regime	**21.6**	**63.4**	**13.3**	1.6
The winter-spring precipitation regime	16.7	44	30.5	8.7

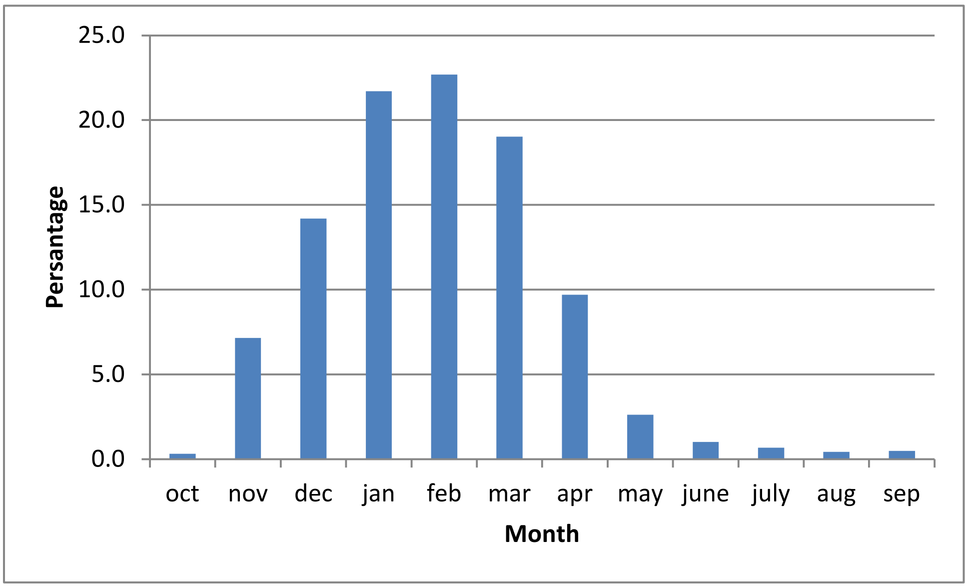

Figure 8. The pattern of monthly relative rainfall of precipitation regime of Helmand basin

The winter-spring precipitation regime of this basin, which is the second precipitation regime and at the same time, its largest precipitation regime, covers the eastern and central parts of the basin. The majority of this regime precipitation falls in winter and spring; thus, the precipitation in winter and spring are respectively about 44% and 30.5% of the total annual precipitation. It is then autumn that includes 16.7% of total annual precipitations received in this region (Table 3). The month with highest and lowest rainfall rates of this precipitation regime are February and September, respectively, with 18.9% and 0.8% of the total annual rainfall (Figure 9).

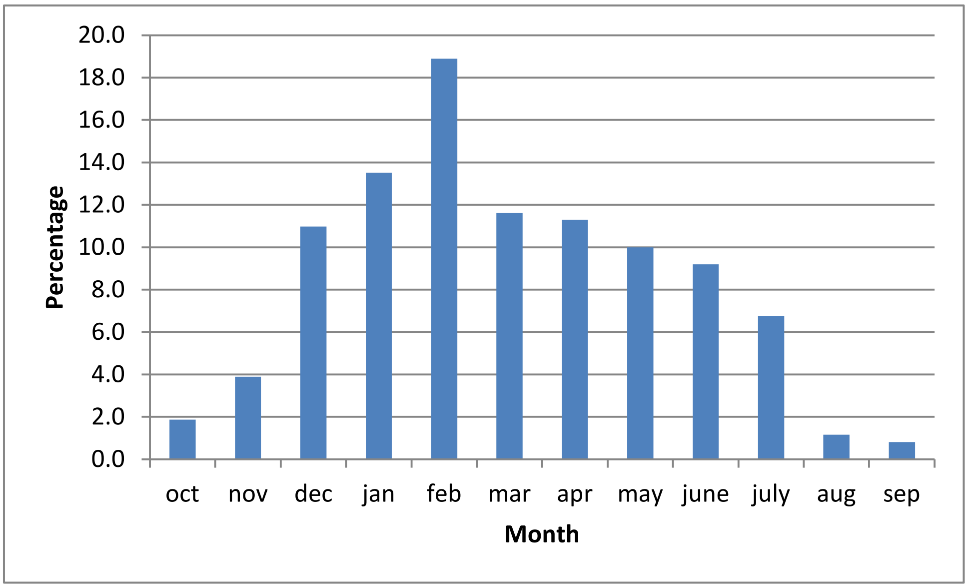

Figure 9. Monthly relative rainfall pattern of winter-spring precipitation regime Helmand basin

The ratio of each month precipitation to the annual total precipitation is used for regionalizing the precipitation regimes of Helmand basin. Also, the total relative rainfall of each region will be one hundred percent at the end. Thus, the analysis of variance or similar analyses cannot be used to examine the significance of the separation of these two areas from each other. Hence, due to high capability of Cluster Analysis in the separation of precipitation areas, we rely on the principle of accepting this zoning without using analysis of variance or other similar analyzes.

V. Conclusion

Precipitation is a climatic phenomenon that its amount continuously varies temporally and spatially. Thus, the isorain maps are in the group of contour maps that the amounts of rainfall variable are displayed on them as isorain lines. However, the precipitation regime encompasses zones of a location with different sizes, and therefore, the precipitation regimes territory are displayed by choropleth maps (zoning maps). This difference in the nature of these two climatic characteristics suggests that the precipitation regime has a higher spatial reliability compared to the amount of rainfall. It should not be forgotten that the precipitation regime is independent from the amount of precipitation, and in Helmand basin, this situation is apparently a function of longitude and the posture of elevation and relief direction.

According to the output from cluster analysis and determination of precipitation region of each point, the results were implemented on a map and it was found that Helmand river basin has three different precipitation regions. These three precipitation region were named as eastern high precipitation region, central moderate precipitation region and western low precipitation region.

Accurate examining the Figure and spatial distribution of three precipitation zones of Helmand basin, it can be seen that the three zones have an almost West-East extension, which is in fact, a function of the orientation of the Hindu Kush mountain range in the same direction. In addition, moving from the eastern high rainfall zone towards the western low rainfall zone, the precipitation rate will decrease so that the average rainfall in the eastern high precipitation area is equal to 256.7 mm, while the value is about 171.5 mm and 86.1 mm for the central moderate precipitation region and western low precipitation area, respectively. Therefore, given that the Helmand basin is much far away from the entry path of Mediterranean pluvial cyclones to the Middle East, and considering that the South Asian summer monsoon systems have the least impact on the entire catchment area, it is realized that the elevations have a greater role in reducing the amount of precipitation from east to the west of the basin. Thus, two factors of direction and height of the elevations have had the largest contribution in the formation of these three precipitation regions in this basin.

Doing cluster analysis on the relative precipitation of 548 points located at Helmand basin, it was observed that the analysis, together with squared Euclidean distance index and Ward linkage method have a very high potential for separation of precipitation regimes in Helmand basin. Thus, based on this method, two different precipitation regimes can be distinguished called as winter precipitation regime and winter - spring precipitation regime. The winter precipitation regime is in the west of the basin, while the winter-spring precipitation regime occurs in the central and eastern parts of the basin.

Finally, we can conclude that these type of studies, especially on this scale, can be worthwhile to reveal the characteristics of precipitation regions implantation. In other words, they show that smaller precipitation areas always occur at the heart of a major rain zone that their formation depends on smaller players.

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