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A Classification of Rainfall Regions in Pakistan*

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파키스탄의 강수지역 구분

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Abstract : This study is aimed to classify rainfall regions in Pakistan. Classification of rainfall regions is essential to understand rainfall patterns in Pakistan. Rainfall patterns have been investigated using a factor and cluster analysis technique by 10-days rainfall parameter. The data used here have been obtained from 32 specific weather stations of PMD (Pakistan Meteorological Department) for the period of January 1980 to December 2006. The results obtained from factor analysis provide three factors and these three factors accounts for 94.60% of the total variance. For a better understanding of rainfall regions, cluster analysis method has been applied. The clustering procedure is based on the Wards method algorithm. Overall, these rainfall regions have been divided into six groups. The boundary of the region is determined by the topology such as Baluchistan plateau, Indus plain, Hindu Kush and Himalaya ranges.
Key Words : factor analysis, cluster analysis, 10-day rainfall, rainfall patterns, rainfall regions

요약 : 본 연구의 목적은 파키스탄의 강수지역을 구분하는 것이다. 파키스탄 강수 특성의 이해를 증진시키기 위해 강수 지역을 구분하였다. 강수 형태는 순별 강수량 자료를 이용하여 인자분석과 군집분석 기법으로 분석하였다. 연구에 사용된 자료는 파키스탄 기상청에서 제공하는 32개 기상 관측소의 자료로 연구 기간은 1980년에서 2006년까지이다. 인자분석의 결과 추출된 3개의 인자는 전체 변동의 94.60%를 설명한다. 강수 지역은 강수 특성의 공간적 분포를 이해하기 위해 군집분석을 하였다. 군집분석은 Ward법을 이용하여 분석하였다. 연구 결과 강수 지역은 6개의 지역으로 구분되었다. 지역의 경계는 Baluchistan 고원, Indus 평야, Hindu Kush 산맥과 Himalaya 산맥 같은 지형을 기준으로 구분하였다.
주요어 : 인자분석, 군집분석, 순별 강수량, 강수 형태, 강수 지역

1. Introduction

Pakistan is situated in South Asian region between 24-37°N of latitude and 61-76°E of longitude. Pakistan has four Provinces namely, Punjab, Sind, Baluchistan and North West Frontier Province (NWFP). It has a more continental type of climate than the other part of sub-continent and has a great diversity of climate due to different topology and altitude. The local topology of the country, can describes such as Baluchistan plateau, Indus plain, Hindu Kush, and Himalayas ranges (Figure 1).

Pakistan has four seasons, which are

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discriminated as following groups; cold season December to March, hot season April to June, monsoon or summer rainy July to September, and autumn or post monsoon October to November (Kureshy, 1998). Most of country is arid except the southern slopes of the Himalayas and the sub-Himalayas (Shirazi *et al.*, 2006). The whole of Sind, a major part of Baluchistan, southern Punjab and central part of the northern areas have a climate as arid or semi-arid (Naqvi and Rehmat, 1962). Usually 50% of Pakistan is arid, 40% semi-arid and 10% area of the country receives the humidity (Khan, 2002).

The distribution of rainfall in Pakistan varies on wide ranges. Almost 60% of the rainfall is recorded in Punjab and Sind during monsoon. Similar, northern mountains and Baluchistan receive maximum rainfall during October to March (FAO, 1987).

In Pakistan, most of the rainfall associated with) the monsoon winds, the western disturbances and the thunderstorms, but the rainfall does not occur throughout the year. Monsoon wind is the major source of summer rainfall in Pakistan (Kureshy, 1998). In Pakistan, 50 to 75% of rainfall is associated with the monsoon (Kazi, 1951). The summer monsoon rainfall in Pakistan may vary from 17 to 59% (Luo and Lin, 1999). The monsoon rainfall is more variable than the rainfall of western disturbances and the rainfall of

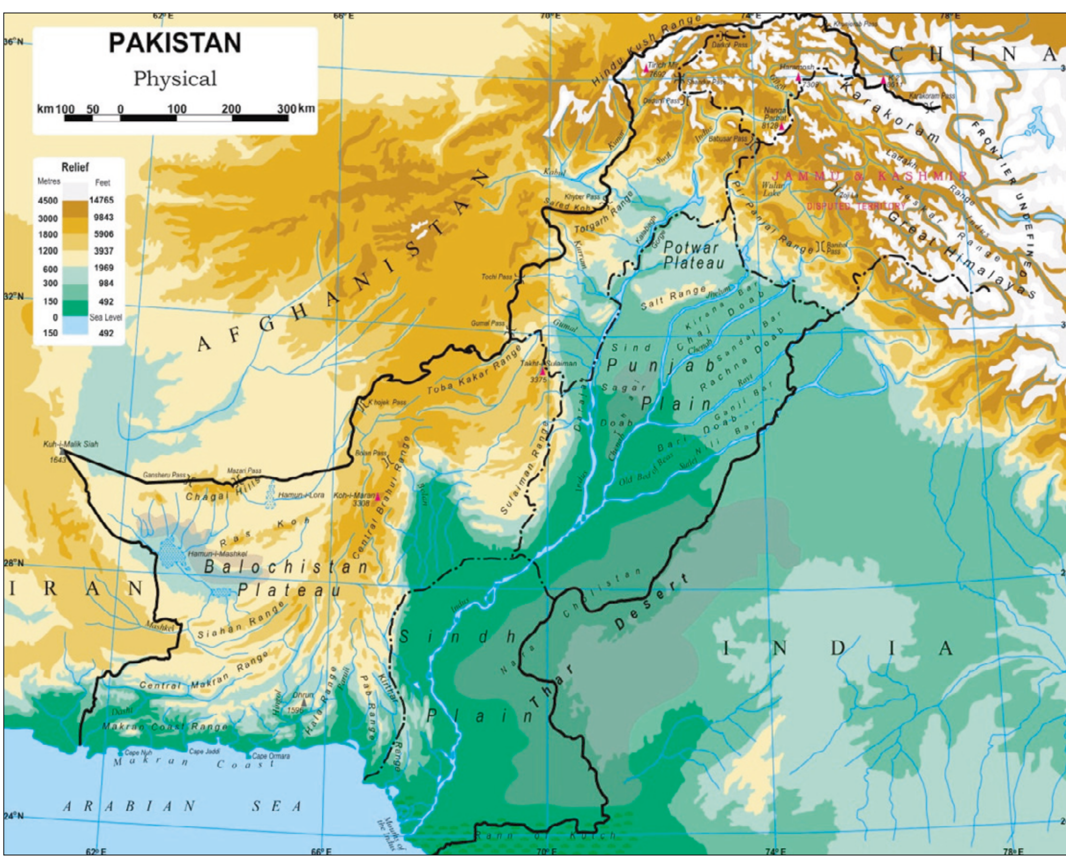

Figure 1. Physiographic features of Pakistan

Source: Orbis Atlas of Pakistan

thunderstorms (Khan, 1962). The western disturbances are the major cause of winter rainfall in Pakistan (Khan, 1993). Pakistan receives a smaller amount of rainfall, but this small amount of rainfall has a large variation. The variations of rainfall increase from north east (humid areas) to south-west (arid area) over the Indus plain (Kazi and Khan, 1951).

In 1951, Kazi has made a detailed study on the Pakistan's climate and identified the various climatic regions. For this purpose, Kazi has compared some classic climatic classifications such as, in 1931, Köppen showed, the whole of Pakistan under the group B of dry climates, except a smaller area of the extreme northern part of the country. These divisional groups of Pakistan are BShw, BWhw, BSks, Dfb and ET types of climate. Thornthwaite (1931), climatic classification indicated Pakistan as arid and semi arid excluding the northern Punjab and the adjacent Kashmir. In Blair's (1942) classification, Pakistan falls under four types. This climatic scheme indicate the arid (desert climate) and semi arid except eastern part of Punjab and Kashmir. Trewartha (1943) follows Köppen fundamentals in his classification. Trewartha made major five groups for climate recognizance as well. These groups showed Pakistan as an arid and semi arid region. Miller (1949) classified the climate into seven groups. According to him, Pakistan falls under three types, Azm, Fi and mountain climates. Moreover, Kendrew (1941) has divided Pakistan into four regions such as, arid low land, arid plateaus, northern sub-mountain and Himalayas (Kazi, 1951). Kazi has divided Pakistan into four major climatic regions those are further divided into secondary division of the micro regions. These all classifications are overall climatic classifications, but in all mentioned studies there is no solemn work which claimed the rainfall classification.

The purpose of rainfall classification may be from agriculture point of view very important, thus a rainfall classification is essential for Pakistan. With the increase in population and consequent food security, it is important to investigate the rainfall patterns and make their classification. There is not much work has been done in this area of prime importance inside the country and outside world. This paper has been conducted which is an attempt to classify Pakistan in different regions of rainfall. The main objectives of the present study are to classify the rainfall regions and identify the rainfall distributional patterns and their characteristics in Pakistan.

The classification and regionalization have a rich history in the field of climatology. That is, to understand the climatology of any country, regionalization is one of the first steps (Periago *et al.*, 1991). Anyadike (1987) has proposed rational classification and regionalization based on as many climatic elements and factors. Anyadike reported, such an approach adapted for the United States (Steiner, 1965), Australia (McBoyle, 1971), Europe (McBoyle, 1972) and South Africa (Perston-Whyte, 1974). In all such studies regionalization has been achieved by cluster analysis using factor scores. The ideal classification should not only give actual boundaries between the macro-climate regions but also generate suitable micro-climatic regions (Puvaneswaran and Smith, 1993). The classification procedures identify the spatial configuration, the patterns, the climate characteristics and the climate variability (Kulkarni *et al.*, 1992).

2. Data and methodology

Rainfall data for 32 weather stations spread over the country during the period of 1980 to 2006 has been used in this study (Figure 2). For

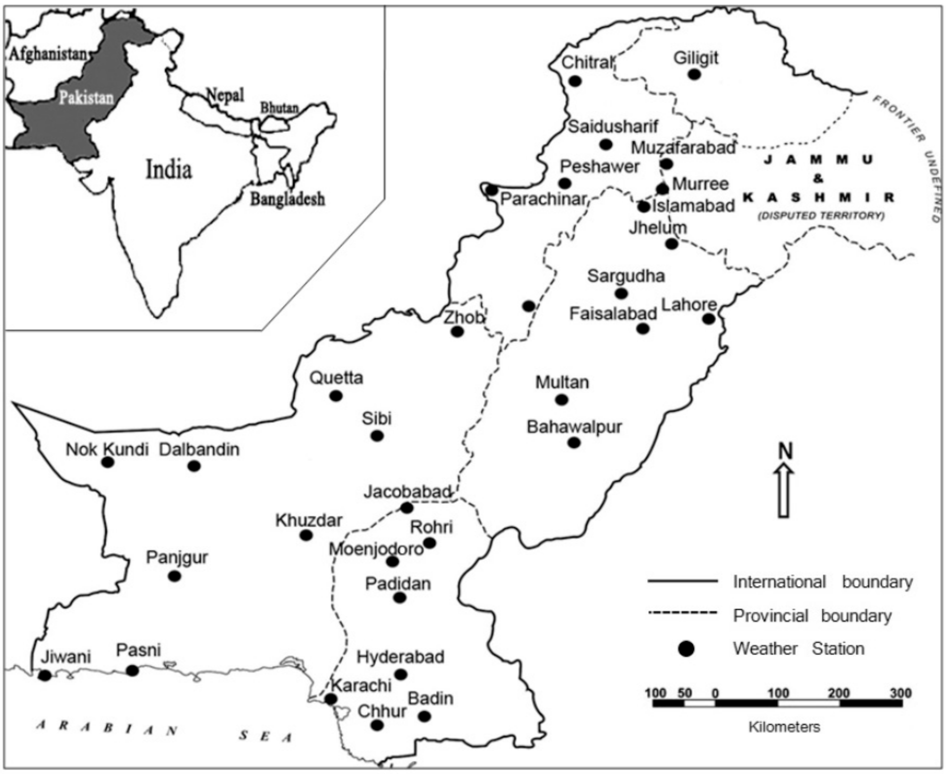

Figure 2. The location of selected 32 weather stations used in study for period of 1980-2006

this purpose, the daily rainfall data of 27 years has been obtained from PMD (Pakistan Meteorological Department). The rainfall patterns have been investigated by factor and cluster analysis technique using 10-days rainfall parameter. The 10-days rainfall is addressed as early (10-days), mid (10-days) and late (10-days) rainfall of a month. Similarly, graphs have also showed the 10-days distribution rainfall patterns. This procedure, factor and cluster analysis technique using 10-days rainfall parameters is suggested by Lee (1993).

The 10-days rainfall data is used to identify the magnitude of rainfall on short span basis. Pakistan is an agrarian country and the 10-days rainfall classification is helpful in planning the crop seasons, water management, and monsoon behavior. Besides, with the help of 10-days rainfall study, security measures can adapt easily in the sector such as emergency plans for urban sewerage, new construction and tourism.

In first step, factor statistical treatment is applied on the data and obtained 3 factors with 94.60% that explains the total variance. The factors score obtained at the final step in the factor analysis procedure have been used as an input for cluster analysis to produce rainfall regions. For clustering, the 'Equal Euclidean Distance' method is selected at first, to compute the distances between objects. This is the most frequently used method for type of distance. Similarly, for cluster of regions, the Ward's (1963) method has been chosen. This method is unique from all other methods, because this method can easily evaluate the distance between clusters for an analysis of variance approach. The Ward's method is a superior technique (Bunkers and Miller, 1996) and has the quality to minimize the sum of squares of any two clusters that can be formed on every step. Both factor and cluster methods analyzed in the SPSS statistical package. The SPSS particular has been found as the best solution to a large dataset of variables (Field, 2005). The maps of factor scores were generated with the help of software Surfer version 8.

In the present paper, factor and cluster techniques have been used to produce the rainfall regions in Pakistan. By applying these techniques one can, consider many variables and can reduce them into grouped variables (factors and clusters). In this method, the statistical procedure indicates occurrence of the most rapid changes of climate on formed boundaries. The factor analysis method was first applied by Steiner (1965) for climatic classification of USA (Ahmed, 1997). This particular method has been applied successfully to classify rainfall data in various part of the world. The application of factor analysis in meteorology and climatology research was started by the end of 1940s (Preisendorfer and Mobley, 1988). This technique is widely used in climatic research, especially, for a very large dataset. It is useful for the reduction of data with minimum loss of information, in order to have a good understanding and interpreting of the data results (Baeriswyl and Rebetez, 1997).

The use of cluster analysis technique in applied climatic research is relatively uncommon compared to fields such as medical science and social sciences (Degaetano, 1996). The fundamental concept of the cluster analysis is to discover the groups in large dataset (Everitt *et al.*, 2001). Cluster analysis is one of the best multivariate techniques that can be used to accomplish climatic classifications (Gong and Richman, 1995). According to Baeriswyl and Rebetez (1997), cluster analysis is widely used for respective statistical function and this is the most popular method for classification. The multivariate technique clustering is used to identify differences and highly similar entities between individuals considering huge diversity of information (Townend, 2002).

Hierarchical clustering is the best technique for the exploratory stage of research (Stooksbury and Michaels, 1991). The most common hierarchical methods are single linkage, complete linkage, centroid, Ward's method and average linkage method (Hair *et al.*, 2005). All the hierarchical methods follow the basic four stages. In the first stage, the Euclidean distance between all variables (selected stations) are calculated. At stage second, two closest variables/entries are merged to form a new cluster. In third stage, the distance between all entries is re-calculated. In last, at the fourth stage, this is repeated until all entries are merged into one cluster. The only draw-back of this method is that an exchange of elements between the groups is impossible when 'tree structure' is developed (Gerstengarbe *et al.*, 1999).

Ward (1963) proposed a very general hierarchical cluster method known as 'Ward's method' or the 'minimum variance method' (Gong and Richman, 1995). The Ward' s method gives priority to merging clusters with fewer observations and encouraging similar sized cluster (Kalkstien *et al.*, 1987). The Ward's method has been widely and successfully used in climatic studies (Kanskar *et al.*, 2004). The Ward's method is the justified approach among the hierarchical methods (Jackson and Weinand, 1995). In the respect of grouping hierarchical method makes it easy to consider and understand relations in large collection of information (Ward, 1963). The Ward's method is the most used clustering process in climate research and has a tendency to form cluster in relatively equal size (Stooksbury and Michaels, 1991).

3. Factor analysis of rainfall classification

The objectives of the present paper are to classify the rainfall regions and to identify the rainfall distributional patterns in Pakistan. In first step, the statistical factor multivariate treatment is applied as described above for 32 weather stations. Three (3) factors are obtained using factor technique, explains of these factors is 94.60% of the total variance (Table 1). First factor loading indicates early autumn, winter, and late spring rainfall. Second and third factors are showing heavy summer and winter rainfall respectively. Interpretation of the factors makes clear our objectivity. The pattern of loadings on factor first indicates the early autumn, winter and late spring rainfall, however it generally indicates the rainfall of winter and late spring. Similarly, the factor two and the factor three indicate the loading of summer and winter rainfall.

Table 2 highlights the load quantity of 10-days rainfall, where the each factor shows rainfall significance throughout the year by 10-days monthly break up. The significance loading of 10-days rainfall is sorted by absolute value of greater than 0.5. Figures 3, 4, and 5 highlight the area by marks obtained by the distribution of 3 factors which are extracted from factor analysis.

The eigen values of the first factor is 29.835 and explains is 82.87% of the total variance. The first factor from mid of September to early of June shows a high load quantity of rainfall. From mid of June to early of September, load quantity shows the low rainfall. This factor has been given the name of early autumn, winter, and late spring rainfall factor. The first factor shows a strong correlation for the north-western sites included Saidusharif, Parachinar, Chitral, Murree and Muzaferabad. This area which starts from the Murree hills of Pir Panjal range to Swat valley and upward Hindu Kush range extreme western part of Pakistan along with the Safed Koh range. On the contrary, the loading value of the first factor is minus from east-southern (Punjab plain and Sind plain) and west-southern (Baluchistan Plateau) part of the country. In Punjab plain, Jhelum, Lahore, Faisalabad, Multan, and Bahawalpur, in Sind plain, Jacobabad, Hyderabad, Karachi and Badin and in Baluchistan plateau Quetta, Sibi, Punjgur, Khuzdar, and Pasni areas are indicate the visible low-end value below -1. The eigen value of the second factor is 3.36 and explains is 9.35% and the accumulation explained quantity with first factor is 92.22%. The load value of second factor is in June early to October mid. The second factor shows the visible negative load quantity for rainfall during October late to May late. The second factor has been given the name of monsoon rainfall factor. The second factor indicates a strong correlation for the stations of Islamabad, Murree, Muzafarabad Jhelum and Lahore. North western part of the country shows the low-end value -1. In Punjab plain, Multan and Bahawalpur, in Sind plain Jacobabd, Hyderabad and Karachi have low load quantity as well as of Zhob, Quetta, Khuzdar, Punjgur and Jiwani in Baluchistan plateau. The high value is visible from Muzafarabad to Jhelum, especially in Islamabad. This factor shows a little load also on Badin and Chhur Jamil extreme east southern part of the country.

The eigen value of third factor is 0.86, explains quantity is 2.38% and accumulation quantity is 94.60%. The positive load quantity of the third factor is from December early to December mid

Table 1. Eigen values and percent of variance explained

Factors	Factor 1	Factor 2	Factor 3
Eigen value	29.835	3.365	0.857
Explained (%)	82.87	9.35	2.38
Cum. Percent	82.87	92.22	94.6

Table 2. Factor loading of 10-days rainfall (greater than 0.5)

Months Break up		Factor 1	Factor 2	Factor 3	Extraction
Jan	Early	0.7346			0.9107
	Mid	0.7074		0.5344	0.9154
	Late	0.7034		0.5041	0.9401
Feb	Early	0.8159			0.9557
	Mid	0.7475	0.5131		0.9680
	Late	0.7492	0.5086		0.9394
Mar	Early	0.8898			0.9547
	Mid	0.8776			0.9723
	Late	0.8338			0.9724
Apr	Early	0.8628			0.9610
	Mid	0.8661			0.8855
	Late	0.9045			0.9390
May	Early	0.8879			0.9382
	Mid	0.8413			0.9524
	Late	0.8488			0.9110
Jun	Early	0.6987	0.5960		0.9013
	Mid		0.8467		0.9244
	Late	0.5244	0.7875		0.9082
Jul	Early		0.8831		0.9431
	Mid		0.9114		0.9283
	Late		0.9166		0.9389
Aug	Early		0.9161		0.8589
	Mid		0.9298		0.9336
	Late		0.9123		0.9349
Sep	Early		0.9042		0.9580
	Mid	0.5200	0.8052		0.3630
	Late	0.6963	0.6746		0.9199
Oct	Early	0.7874	0.5191		0.9064
	Mid	0.7359	0.5900		0.9192
	Late	0.8759			0.6249
Nov	Early	0.8980			0.9027
	Mid	0.8150			0.8985
	Late	0.8409			0.9017
Dec	Early	0.6925		0.6202	0.8172
	Mid	0.6736		0.6435	0.9227
	Late	0.77433			0.9415

and January mid to January late, but on the remaining whole year this factor shows the negative load quantity for rainfall. This factor has given the name of winter rainfall factor. The third factor highlights a strong correlation and high load quantity for the sites located in west-southern and northern Pakistan respectively, Quetta and Muzafarabad. In contrast, there is a very weak load quantity for the stations of Parachinar, Chitral, Saidusharif and Gilgit in west northern part and as well as for the Punjab and the Sind plain. Therefore, this factor indicates a little rainfall also in Jiwani, Pasni, Dalbandin and Panjgur in Baluchistan Plateau. This factor also

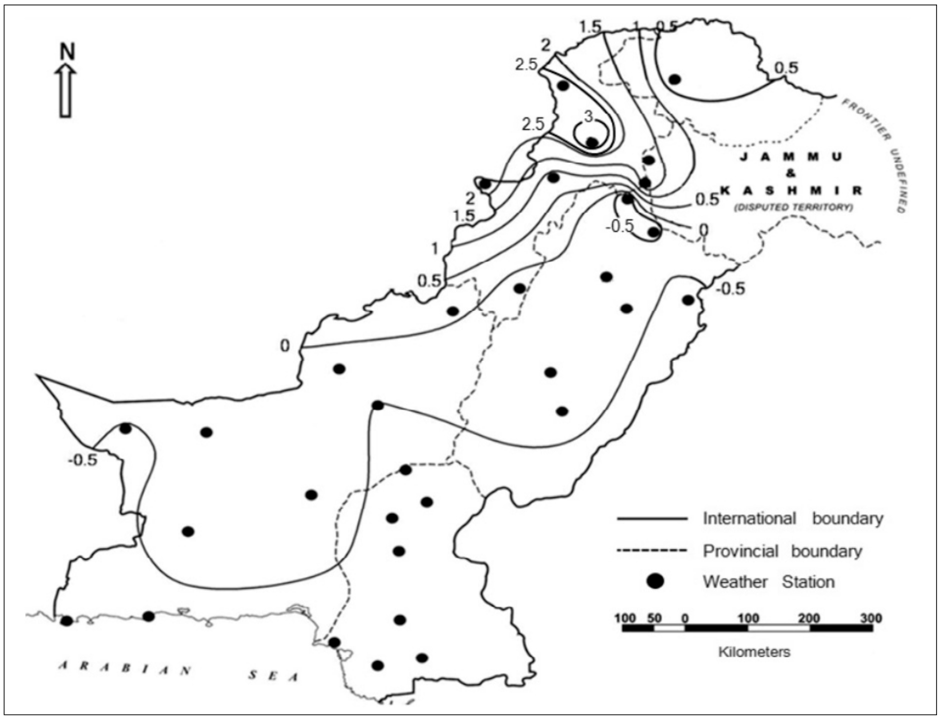

Figure 3. Scores of factor 1 at 32 weather stations in Pakistan

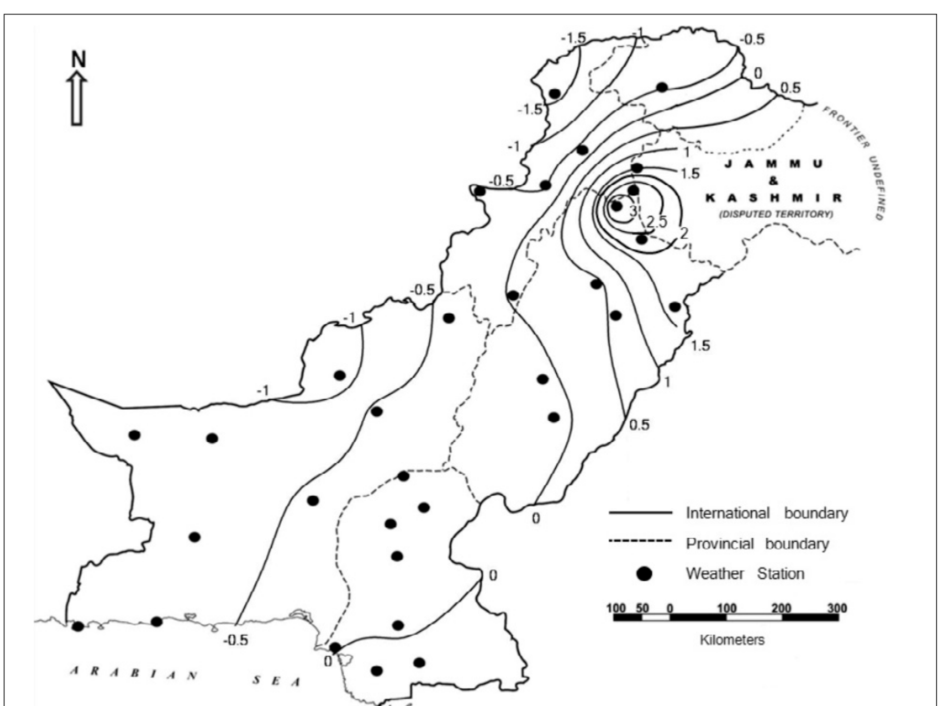

Figure 4. Scores of factor 2 at 32 weather stations in Pakistan

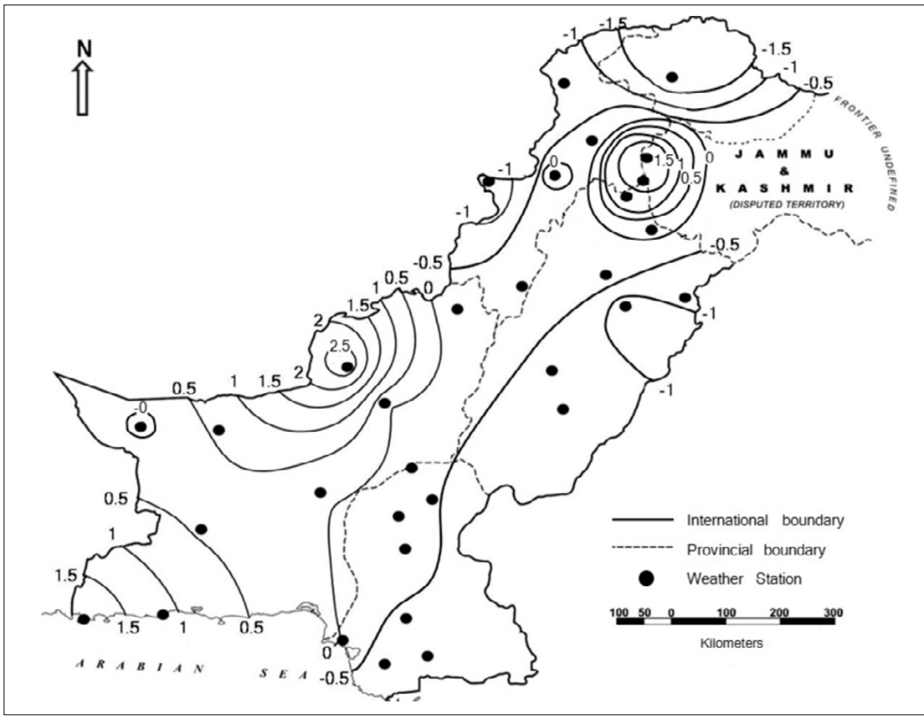

Figure 5. Scores of factor 3 at 32 weather stations in Pakistan

shows a smaller amount of rainfall at the Peshawar station.

4. Classification of rainfall regions and 10-days characteristics of rainfall distribution

The factor analysis technique reduced the number of variables from 32 to 3. Cluster analysis has been applied (hierarchical method) on these 3 variables and divided the study area into 6 regions characterized by a specific rainfall patterns (Figure 6). A grouping of six regions, 1, 2, 3, 4, 5 and 6 (stage 1) is realistically useful for the study of rainfall classification of Pakistan. It clarifies the rainfall differences among all the regions of the country. This stage of grouping helps to identify smaller regions in this country. The technique can be further applied in grouping of smaller rainfall regions i.e. local and micro level study of rainfall characteristics (Figure 7). The regions obtained at this stage appear logical and reflect the behavior of physiographic difference of Pakistan. According to physical frame of the country, region 1 is appeared in Baluchistan plateau, region 2 consist on Indus plain, region 3 represent low hills of Baluchistan, region 4 covers the northwestern mountains, region 5 shows Murree hills and Pir Panjal range and region 6 is appeared in foothills of Pir Panjal, Potwar plateau and upper Indus plain. Similarly, the regrouping of the regions into three clusters (stage 2) A, B and C is deemed best for the purpose of simplification and generalization of rainfall patterns, where much of the information is lost. These six geographic rainfall regions are as following,

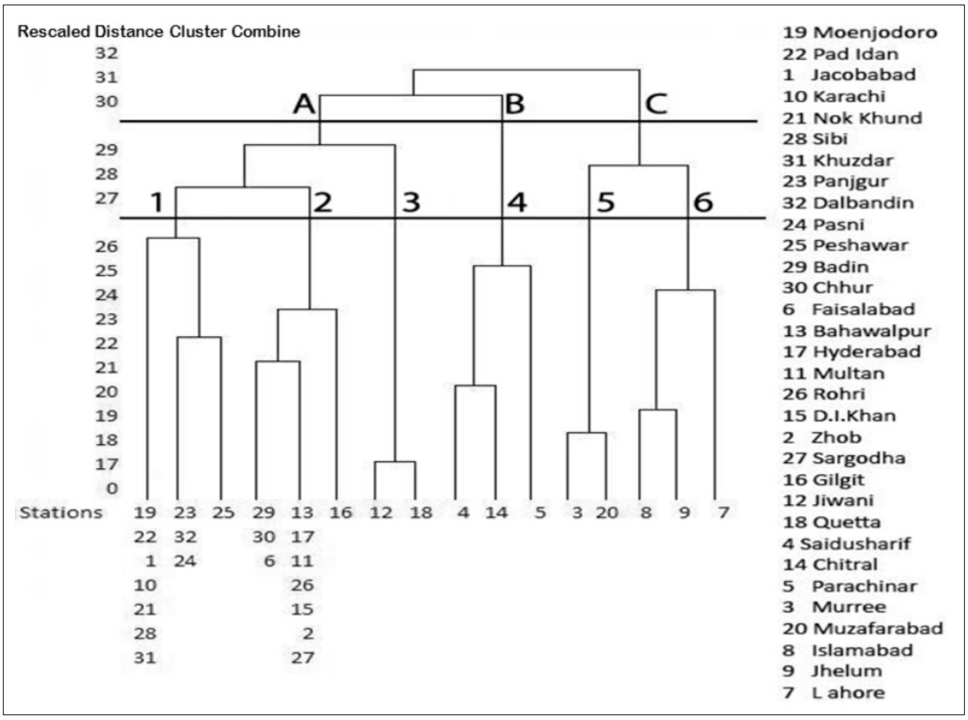

Figure 6. Hierarchical clustering of 32 weather stations in Pakistan

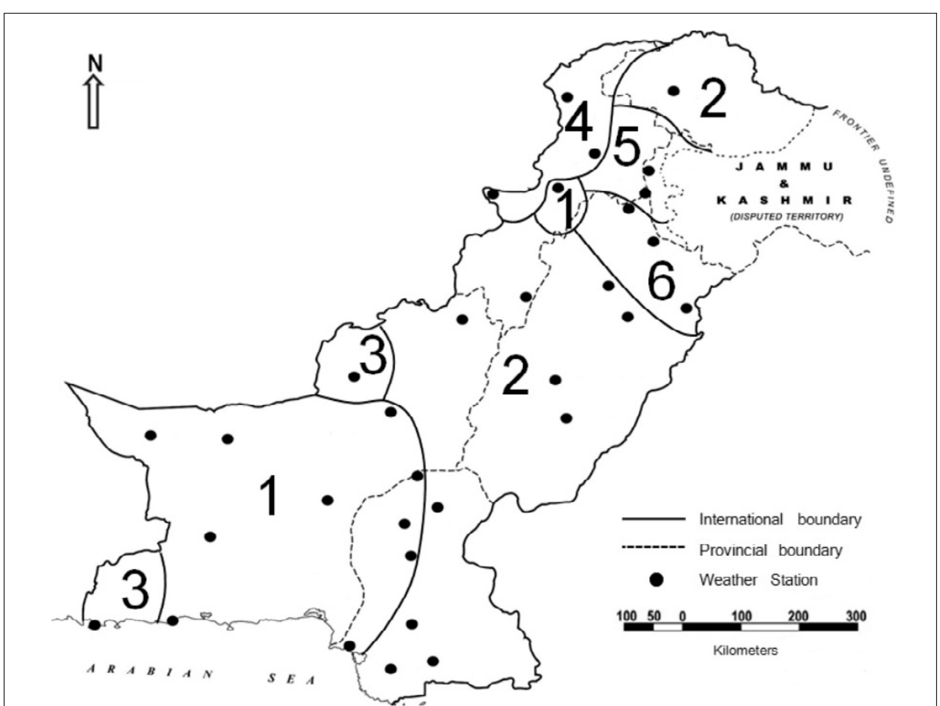

Figure 7. Six rainfall regions produced by cluster analysis

1) Baluchistan plateau and coastal rainfall region

This region covers the southwestern part of the country. Major part of Baluchistan plateau, from Sibi to coastal station Pasni and southern Sind included Karachi, Pad Idan, Moenjodoro and Jacobabad, and a smaller area (Peshawar) is located in the central part of North Western Frontier Province (NWFP). Overall this region covers almost of Baluchistan Plateau. This region collectively characterized the region by having lowest amount of rainfall. In this region visible 10 days rainfall is recorded in summer season. The stations of Moenjodoro, Pad Idan, Sibi, Khuzdar, Jacobabad and Karachi showed rainfall in June late to August late. Sibi and Khuzdar stations showed rainfall of 8mm to 12mm in January late to February mid and 10mm to 30mm during July early to August mid (Figure 8). The optimal amplitude ranges of rainfall of this region has been found between 10mm to 20mm in June mid to August late and 2mm to 10mm for the other months. Khuzdar station showed a visible rainfall in July late and August early respectively 28mm and 30mm. Overall this region has lowest amounts of rainfall, especially at Nok Kondi, in west of Baluchistan plateau. In region 1, appearance of the Peshawar station is far away from its core region. It is difficult to understand what, climatology ties to the Peshawar station with region 1. According to physiographic divisions of Pakistan, the Peshawar station localities are a valley and refer as 'Vale of Peshawar'. The altitude of Peshawar valley is 150 to 600m and the altitude of Peshawar station is 347m above sea level. Overall, Peshawar valley is far away from the monsoon winds, therefore does not receive monsoon rainfall. It seems that the immense reason of this misclassification is lack of the monsoon influence. In the presence of monsoon influence it can be emerged with nearest region, region 2.

2) The central plain, southern desert and inner-Himalayas rainfall region

This region divided into two areas, one is in the east southern Sind and the central part of the country including almost Punjab, southern NWFP,

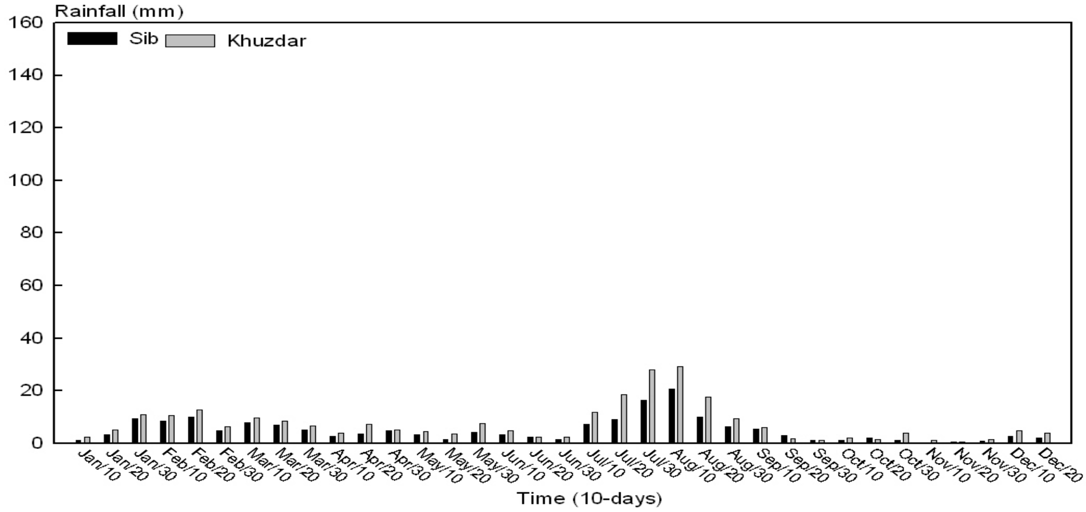

Figure 8. 10-days rainfall distribution in Baluchistan plateau and coastal region

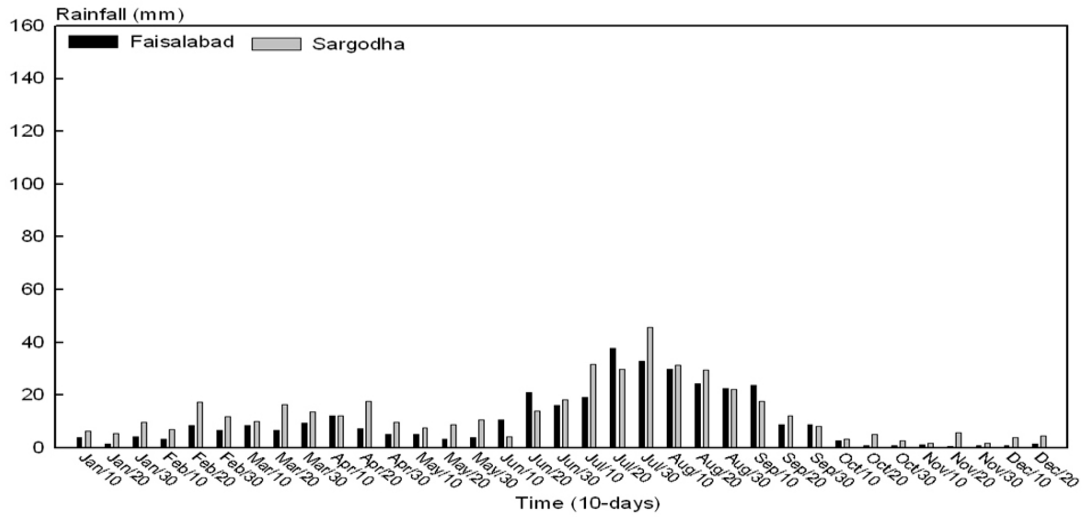

Figure 9. 10-days rainfall distribution the central plain and inner-Himalayas

and northern Baluchistan. The second part is Gilgit, which is located in the inner Himalayas (Ladakh Range), the extreme northern part of the country. This region, together with region 1, covers most land of the country. In this region the rainfall of Sargodha, Badin and Chhur is prominent. Sargodha and Faisalabad stations showed visible rainfall in July early to September early between 20mm to 40mm and 2mm to 10mm in October early to February early (Figure 9). In this region, Sargodha station shows high regime of 47mm rainfall in July late. The optimal amplitude of rainfall of this region is between 20mm to 30mm in June late to September early and 3mm to 10mm between the other months. The rain is characteristically less frequent in the western part of this region, but pronounced in the eastern part.

The reason of separation of this region from region 1 is probably the influence of monsoon rainfall. According to physiographic divisions, it feels too strange, Gilgit as part of region 2. The climatic conditions of Gilgit are dominated by its geographical location, a valley in mountainous area, southwest of Karakoram Range. The altitude of Gilgit station is 1,500m and situated among the Karakoram, Hindu Kush, and Himalayas ranges in form of a bowl. In summer season, the monsoon breaks against the southern range of Himalayas. Monsoon loose their strength while going to Gilgit, so do not get as moisture from monsoon as region 5 and region 6, whose located in southern slopes of Himalayas. Himalayas located here east to west and working as barrier in the way of east southerly monsoon. Similar in winter, western disturbances breaks against the Hindu Kush and loose their thrust while going to Gilgit. These complex physical conditions separate the Gilgit station from region 4 in west and region 5 in south. That is why it goes with region 2 and areas like south Punjab and northern Sind.

3) Northwestern Baluchistan plateau and Makran coastal rainfall region

This region occupies two smaller areas of the country one is to the extreme corner of the west

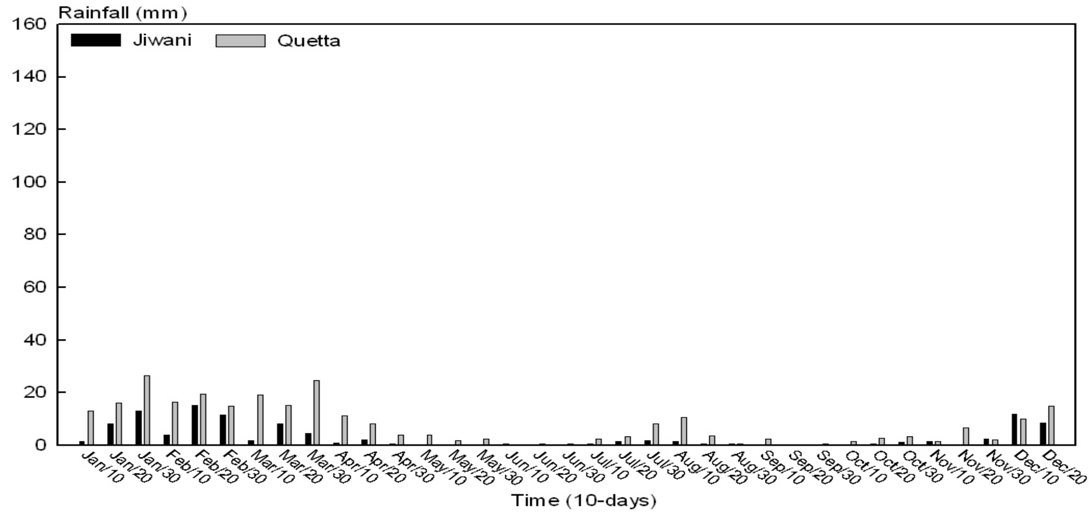

Figure 10. 10-days rainfall distribution in Baluchistan plateau and Makran region

south Baluchistan Makran coastal range and the second is Quetta, western part of central Brahui range in northwestern part of Baluchistan plateau. Basically, this region belongs to the Baluchistan plateau, but differs from region 1, because of the greater importance of winter rainfall. The reason for this winter rainfall behavior is the influence of western disturbances.

These two smaller parts of region 3, interestingly govern by physical frame of Baluchistan. Baluchistan hills working as barrier in the way of western disturbances and which divides them into two parts, one is towards northeast, the other moves towards southeast. In result, the Baluchistan plateau (Region 1) finds itself as dry region. In contrast, winter rainfall is more copious in region 3 than the region 1. This region can be distinguished by the lowest summer rainfall. It is observed that summer average rainfall drops between 3mm to 5mm, but Quetta station shows 8mm and 12mm respectively in July late and August early. The rainfall of late winter and early spring is prominent in December, January and February, March respectively. Quetta station shows rainfall of 15mm to 20mm during December early to April early. In Quetta, January late and March late showed prominent rainfall 27mm and 25mm respectively. The Jiwani station showed 13mm in January late and 15mm rainfall in February mid (Figure 10).

4) The northwestern mountain rainfall region

This region represents the north western areas of Pakistan from Hindu Kush range to Sfed Koh. This region is characterized by receiving the high amounts of late winter and early spring rainfall. In Saidusharif, January late to February mid average rainfall is between 40mm to 50mm. In March mid to March late this amount of rainfall is increased between 60mm to 70mm. In summer season, Saidusharif has high amplitude of rainfall in this region. Saidusharif showed rainfall of 38mm to 60mm in July early to September early and 60mm rainfall in July late. In this region Parachinar station received rainfall of 20mm to 40mm from January late to May late. Similarly, in summer season, it showed 25mm to 50mm

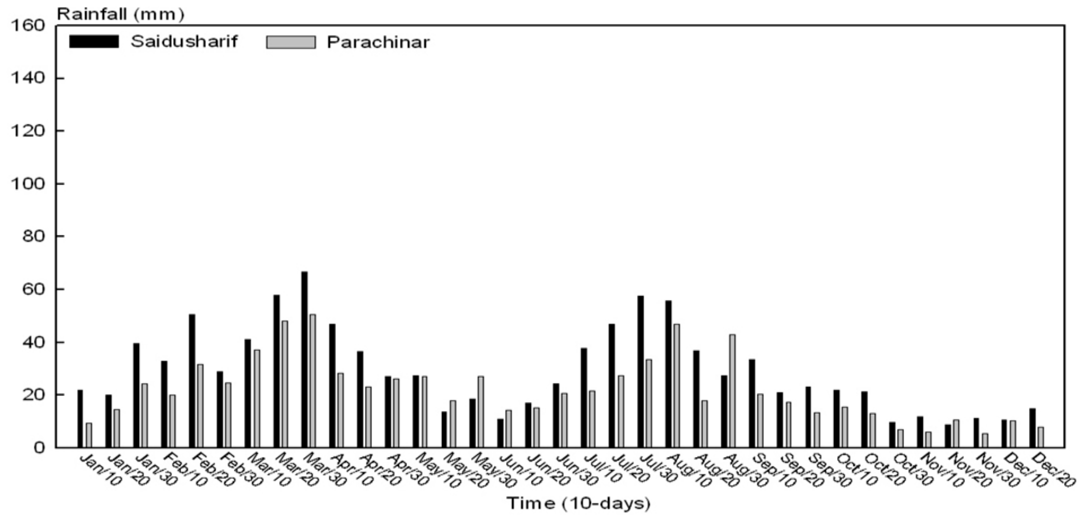

Figure 11. 10-days rainfall distribution in northwestern mountain region

rainfall in Jun late to September early. In Parachinar, March mid and March late showed high regime of rainfall that is 50mm and 53mm, respectively (Figure 11). Chitral station received low rainfall in this region; therefore, spring rainfall is considerable between 25mm to 43mm during February mid to April early. But there is a visible rainfall decline between Jun early to October early. March mid showed high regime of rainfall 43mm in Chitral. In this region, a large amount of winter rainfall is associated with western disturbances. The north western mountain i.e., the Hindu Kush range has an average height between 3,500m to 5,500m and the direction of this range is from north to south. The western mountains act as barrier in the way of western disturbances. In result, western slopes of the Hindu Kush and Safed Koh range receive orographic rain. The eastern slopes of western mountains also get monsoon rainfall, however monsoon does not penetrate into interior of the region 4.

5) Murree hills and Pir Punjal mountain rainfall region

This group is formed by north of Potwar Plateau to Lesser Himalayas. This region covers the Galliat area of the Murree hills and Pir Panjal range. The direction of the sub-Himalayas (Murree hills) and the Lesser Himalayas (Pir Panjal) is east to west along with the Great Himalayas. The elevation of this region is varies between 1,500m to 7,500m from south to north. This region is wettest part of the country. Region 5 received the rainfall in both, cold and monsoon seasons. Winter rains come from western disturbances, and a few thunderstorms also occur in same season.

In summer, the monsoon from Bay of Bengal, move towards north and east where they are being blocked by Assam hills in India where they are orographically lifted and then after giving rains to Cherapunji move towards west into main land Indo-gangetic plain. Obviously as they move towards west, their moisture content got lesser and lesser therefore Pakistan has experience the tail end of these monsoons. In Pakistan, the

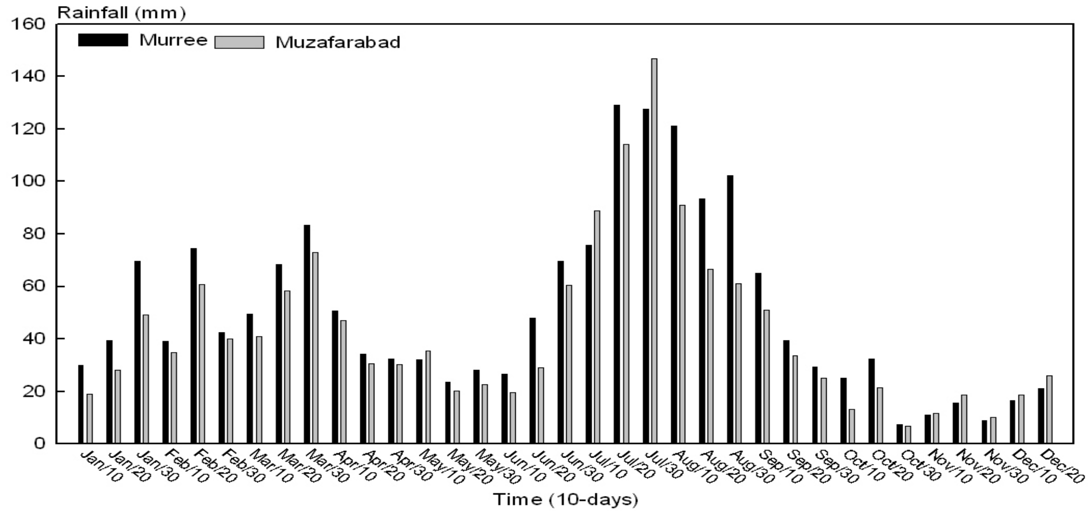

Figure 12. 10-days rainfall distribution in Murree and Pir Punjal mountain region

influence of monsoon does not go beyond the south of the country. The topographical barrier such as Margalla hills, Murree hills, and Pir Panjal range are received high rainfall on southern slopes in monsoon season. The elevation of Murree and Muzafarabad stations are 2,291m and 3,000m respectively. In this region Murree and Muzafarabad receive high rainfall because of their high altitude. The region 5 is the ending area of the monsoon strength, now they become week and do not penetrate into the Great Himalayas. The main feature of this area is raininess. The highest rainfall in the year occurs during monsoon season. In winter, January late and February mid showed visible rainfall respectively 70mm and 75mm. During spring, the average rainfall of March mid and late is 70mm and 83mm respectively. Murree station showed high regime of rainfall during July mid to August early between 120mm to 130mm. Therefore, a noticeable decline in Murree is observed during October late to November late.

In Muzafarabad, the optimal amplitude of rainfall is always greater than 20mm apart from October late and November late. In winter, February mid average rainfall is 60mm, similar, in spring, March late average rainfall is 77mm. In contrast, June late to August late showed the high rainfall between 80mm to 140mm (Figure 12).

The behavior of this region is similar to the region 4. Nevertheless, difference appear in the months of July August, when rainfall is significantly higher than that of region 4. For example, in this region, July late showed rainfall regime of 150mm at Muzafarabad station and 130mm in Murree, but in same season the stations of region 4 Parachinar and Saidusharif showed the precipitation of 35mm and 58mm respectively. This region specially can be pointed out to be the most copious rainfall in summer. Summer rainfall is associated with orographic rainfall from south easterly deflected monsoon stream moving along foothills of Himalaya.

6) Upper-Indus plain and Potwar plateau rainfall region

Region 6 appears in the map as a belt running along part of the Pir Panjal foothills and the Potwar plateau towards east boarder with India

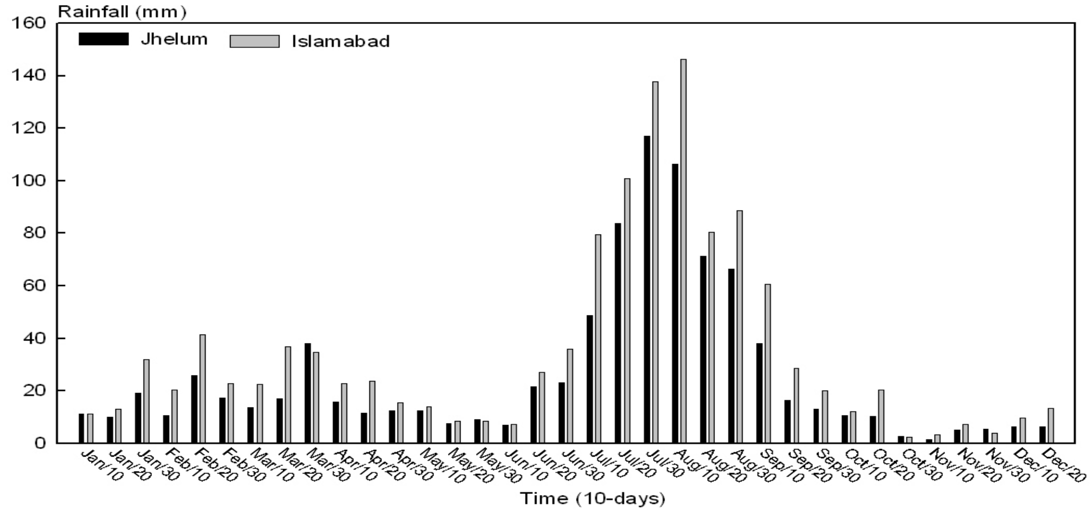

Figure 13. 10-days rainfall distribution in upper-Indus plain and Potwar plateau region

included Sialkot vicinity and Lahore. The direction of Pir Panjal range is east to west north. As reported earlier in the description of region 5, south easterly monsoon move along Pir Panjal range and the monsoon breaks against the topographic barrier such as Margalla hills and Salt range. The elevation of Salt range and Margalla hills is 1,122m and 1,580m respectively. Similarly, the stations of Islamabad and Jhelum have the elevation of 610m and 236m respectively.

The direction of Salt range and Margalla hills is from north to south. Salt range and Margalla hills act as barrier and break the strength of monsoon, in result high rainfall in Islamabad near Margalla hills and in Jhelum near Salt range. The main feature of this region is high raininess in summer season.

This region being the next neighboring region of the region 5, has registered as the next highest rainfall region. This group differs from region 5 because of the greater importance of summer rainfall. The optimal amplitude ranges between 5mm to 20mm for September mid to January mid and April mid to June early. By contrast, optimal range is between 80mm to 140mm for July mid to August late. According to obtained results, Jhelum and Islamabad stations have shown outstanding correspondence to rainfall. The Jhelum station showed the average rainfall 3mm to 20mm during September mid to June early apart from February mid and March late, when the rainfall amplitude is 28mm and 40mm respectively. In summer season, there is an apparent increase rainfall in Jhelum. Average rainfall in July late and August early is 120mm and 110mm respectively. Similarly, the Islamabad station has same distributional patterns of rainfall throughout the year. Average rainfall of Islamabad station is between 5mm to 40mm during September mid to June late. The increasing trend of rainfall is visible in summer season, where rainfall amplitude is between 60mm to 150mm during July early to September early. In this region, the Islamabad station is showing the highest regime of rainfall 150mm in August early (Figure 13).

5. Conclusions

In this study, the identical rainfall regions are identified by using the factor and cluster multivariate technique over Pakistan. The analyses have shown that the factor and cluster technique is very useful for the regionalization of rainfall regimes in Pakistan. This regime of rainfall is linked to regional factors, and the analysis of this research confirms the similarities in rainfall regions. This classification has been achieved by hierarchical cluster method of rainfall 10-days data set of 32 weather stations previously reduced by factor analysis. For this study 3 factors have been obtained with 94.60% that explains the total variance for three factors. The first factor is associated with the rainfall of early autumn, winter and late spring. The second factor is related with the rainfall of summer monsoon, and the third factor showed deep relationship with winter rainfall. The study areas are divided into 6 rainfall regions by clustering hierarchical method, which have specific rainfall patterns.

This study provides a detailed perspective upon the nature of rainfall regions across Pakistan. The 10-days rainfall span gives us a clear distributional rainfall patterns i.e. early, mid, and lat 10-days rainfall behavior of the all months. Concerning the clusters, the obtained analysis, which are strongly conditioned by the orographic complexity. These orographic features can be considered as basis of rainfall regions in Pakistan. The northern mountains, sub-Himalayas, Pir Panjal, Ladakh and Karakoram ranges located in north of Pakistan directionally from east to west. According to the general climate of Pakistan, this part of country has the wet conditions comparatively. Western highlands, Baluchistan plateau and central part of the country have a dry climate. These general climatic features of the country support the results of the present study. All obtained regions can be distinguished a set of dry and rainy region. For example, region one appears in Baluchistan plateau and can be found as lowest rainfall region. The region 5, consists on Murree hills and Pir Panjal range, and can be recognized as heavy rainfall region. In short, according to the current study, region 1, 2 and 3 is a set of lowest rainfall and regions 4, 5 and 6 another set of high rainfall.

Using this study, the authors have found factor and cluster multivariate procedure as the helpful method over the recognized techniques. This technique permits the grouping of stations with the same characteristics of rainfall regions in diverse landmass of the country. Thus, the factor and cluster multivariate technique presents an admirable option of rainfall classification in Pakistan. The obtained results were further supported with the help of seasonal rainfall distributions at selected stations. In the present research work, the authors performed a pilot attempt of performing research on the rainfall classification and distributional characteristics over Pakistan. One of the reservations that could be raised in clustering of region 1. The Peshawar station which belongs to region 1, thus it has characteristics near to region 2. The immense reason of this difference is the large empty distance between Peshawar station and nearest stations of region 2. This is considered as misclassified zone in rainfall regions of Pakistan. Further research in this area is needed in more detailed and improved study in future. Investigated 32 weather stations seem to be very small number for such research work.

Moreover, it is expected that obtained results of rainfall regions can lead to further investigations of similar nature and scope with emphasis on rainfall changes in future. The rainfall changes is a hot issue, particularly for the agriculture sector, food security and one of the major concerns for scientists working in the field of climate change, for there still many more needs to do research work to understand the changing behavior of rainfall. Consequently, next study will present the rainfall changes in identified rainfall regions in Pakistan.

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