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Spatial Interpolation of the Frequential Distribution of Thunderstorm and Rainfall over Balochistan, Pakistan

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Tailored digital database of the Thunderstorm (TS) and Rainfall (RF) activities have been developed to analyze and quantify their distributional impacts through suitable spatial interpolation method (i.e. Inverse Distance to a Power) over the Balochistan province of Pakistan for the period of 1961-2010. The study also incorporates the annual and seasonal analyses. Annual percentage divulge the dominance of TS over RF from April to October while the contrariwise condition is observed for rest of the year. In seasonal analysis it is revealed that in winter the rainfall activity is markedly greater than the thunders while in premonsoon and monsoon the situation is vice versa; post-monsoon unveil the comparable frequencies. The extreme activity of TS and RF is found in June (≈45%) and March (≈46%), respectively. Akin patterns have been found for the both activities in winter and monsoon while post-monsoon season also alike. Winter rainfall is most active in the western parts of the province with largest value at Nokkundi (≈ 70%) while north eastern parts acquire least RF activity in post-monsoon particularly Zhob and Kalat (i.e. ≈ 2%).

Keywords: Thunderstorm (TS), Rainfall (RF), Inverse Distance Weight (IDW), Premonsoon

1. Introduction

Thunderstorm (TS) and Rainfall (RF) are the most common characteristics of a Cumulonimbus (CB) cloud. As moisture along unstable air is the fundamental condition required for the production process of such cloud, therefore they are most likely to occur in late spring and summer seasons, though can be occur in any season throughout the year [1]. Unlike winter storms and hurricanes, thunderstorms being a meso-gamma phenomenon usually affect relatively smaller areas (typically up to 20 km in diameter) and have a life time of about half an hour [2]. Thunderstorms are very frequently occur at every moment over earth, typically more than 40,000 per day (i.e. 16 million in a year). Despite the fact that beneficial rains are associated with TS, occasionally heavy down pours cause flash floods in addition to a danger source for aviation.

Raising cool air to the point of its saturation, leading to hefty showers as well as thunderstorms.

Therefore, the summer monsoon associated with southeastern parts of Asia that persists from about June through September, implies boisterous rainfall along with gusts of wind which blow strong currents of air coming from sea to land [3]. Despite of the fact that a lot rain falls throughout the moist and wet seasonal time of year, it does not rainfall at all times. Actually, rainy durations of 15 to 40 days tend to accompanied by a few months of very hot, sun-drenched conditions.

Though TS and RF activities had been explored for many areas of different regions including India [4,5], America [6,7], Africa [8], Israel [9] etc. but a few studies have been carried out in respect of Pakistan [10-11] but these are outdated (i.e. covered the period from 1961-1990) and are confined to only TS activity. Moreover these studies are limited to the individual stations' and without the usage of any spatial interpolation technique. In general southern parts of the Pakistan and particularly west southern Pakistan (i.e. Balochistan) are very crucial in respect of these two parameters. The eastern and western parts of the province are mainly affected by the monsoon and winter seasonal rainfall activities, respectively [12].

2. Study Area and Data

The available eleven different cities of the Balochistan province subject to the data availability have been selected for this study, viz. Jiwani, Pasni, Pangur, Nokkundi, Dalbandin, Khuzdar, Kalat, Quetta, Sibbi, Barkhan and Zhob, respectively. This land of natural resources, have neighboring provinces of Punjab and Sindh to the east, Federally Administered Tribal Areas (F.A.T.A), Afghanistan to the north, Iranian Balochistan to the west and the Arabian Sea to the south. The geographic locations of stations are depicted in Figure 1. Dataset of TS and RF frequencies of 50 years (i.e. 1961 - 2010) have been utilized in the study which is obtained from the archives of Pakistan Meteorological Department (PMD). Seasonal classification has been done according to Hussain et al. [13].

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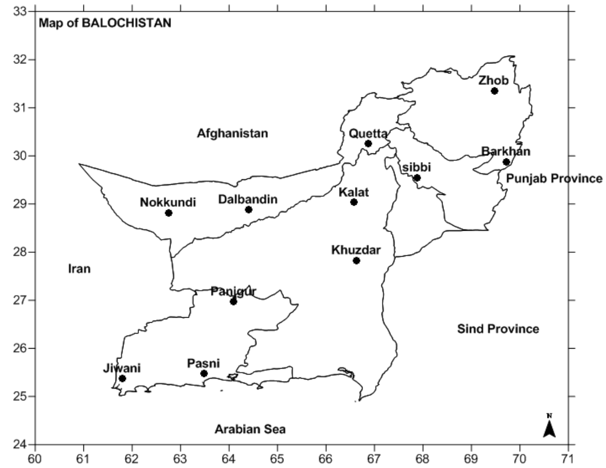

Figure 1. Map showing the location of selected meteorological station in addition to the international, provincial and district boundaries of Balochistan Province.

2.1 Geography

The area covered by the province is 347,190 km^2 which is almost 42% of the total land area of the country. The latitudinal and longitudinal range of Balochistan is 24.90^o to 32.07^o and 60.90^o to 70.26^o, respectively [14]. It is located at the Iranian Plateau's eastern edge. Though geographically it is the largest province but due to the scarcity of water and mountainous terrain the population density is very low here. Kalat is the center of the province. The capital and most immensely colossal city is Quetta; located in the northeast of the province which is also the most densely populated district. The city is near to the border of Afghanistan in a river valley. The northeast corner of the Balochistan is dominated by Sulaiman Mountains range while to the south much of the province comprises of deserted terrain structure with few inhabitants near rivers and streams.

2.2 Climate

Warm summers and chilly winters are the important climatic characteristics of the upper highlands. The attribute of lower highlands is rather different winters vary from the mild conditions near to Makran coast to very extremely cold in the northeastern districts. Summer season is dry and hot; Kharan and Chaghi districts are the hottest arid zones. Winter season in plain areas is somewhat mild in the sense that temperature never falls below 0^{o}C. In contrast summer over the plain areas are extremely sizzling and the thermometers shows up to 50^{o}C [14]. Deserted climate is typified by scorching arid conditions in addition to the occasional windstorms.

3. Materials and Methods

3.1 Spatial Interpolation

Several methods of spatial interpolation are widely used in the fields of meteorology and climatology as, it is indeed difficult to integrate the inherent highly variable spatiotemporal datasets (such as TS and RF frequential distributions), in traditional methods. Hydro-meteorological modelers are frequently encountered with a variety of deterministic methods like, Inverse Distance Weighted averaging, Polynomial Regression, Splinning, Trend Surface Analysis, Krigging and Co-Krigging for climatic interpretation of meteorological data through interpolation [15]. The chief advantage of Geographical Information System (GIS) is the power to combine different sets of parameters into one united base, *i.e*. generalizing all variables on identical scale to preview the picture of scenario as good as it is possible. Essential distinguishing attribute, quickness of action and inter-departmental cooperation or sharing, may all be substantially advanced by re-assessing approaches to take benefit of GIS capabilities. The advantages of GIS have a tendency to be positioned in quality of the decisions (in research, planning, managerial and / or operational aspects *etc*.) made-up with it, in comparison to those made-up without it.

GIS can be distinguished from other graphic and computer mapping systems by its eminent analytical capabilities and capacities in respect of geographically referenced data [16] *i.e*. unlike computer mapping, it generates and established new geographic information rather than just retrieving and regain possession of previous encoded information. The functionality of GIS completely described [17] as GIS stores spatial data with logically attribute information in a data base of GIS storage where analytical functions are controlled interactively by a human operator to produce the needed information product.

Hence, GIS is considered to be an effective and productive tool to measure and evaluate the prone areas. In this context, after examining different available methods (for example, Natural Neighbor, Spline, Krigging *etc*.) the method of Inverse Distance Weight (IDW) was found as the most appropriate classifier to observe the distribution and dispersal of TS and RF frequencies.

3.2 Weighted Overly Analysis

Gridding method is utilized for the study by employing the algorithms of weighted average interpolation. This implies that, the closer a point is to the grid node, the more weight it carries in determining the z-value at that grid node, keeping all other factors being equal.

To comprehend the nature of applied weighted averages, consider the following equation. For given N data values $(Z_1\ ,\ Z_2\ , \dots ,\ Z_N)$ the interpolated value at any grid node (G_j) can be computed as the weighted average for the given data values, as

$$G_j = \sum_{i=1}^{N} w_{ij}\, Z_i \tag{1}$$

where

G_j => interpolated grid node value at node j

N => number of points at each node, used to interpolate

w_{ij} => associated weight with the i_{th} data value when computing G_j

Z_i => Z value at the i_{th} point

The quality of being unlike or dissimilar between gridding methods are in the numerical calculations or mathematical algorithms used to compute the weights during grid node interpolation. Each method presents different representation of given data. Hence, to determine the most advantageous method, all the available methods are to be studied for the outcome of most satisfying data interpolation. After much cogitation, the method of IDW has been chosen among all the available interpolation techniques, as during examination this method is found more appropriate for the spatial interpolation of rainfall in perspective of floods in this study.

With IDW, during interpolation, data are weighted such that impact of one point relative to another, decline with a separation distance from a gird node. Weighting is imputed to data by means of a use of weighting power that controls the drop off factors of weighting factors as distance from a grid node increases. Effect on points far from the grid node is inversely proportional to the weighting power *i.e.* during interpolation, increasing power of the weighting power implies less effect on the far points from the grid node. Moreover, a grid node value approaches the value of a nearest point, as the power increases. Hence, for a diminutive power, the weights are impartially distributed among the neighboring data points.

In normal cases, IDW acts as an '*exact*' interpolator. During computing a grid node, the weights assigned to the given data points are in fractions, such that the sum of all the weights is equal to 1. When a particular observation is operating concurrent with a grid node, the distance between the grid node and that observation is 0; that observation is given a weight of 1, though all other observations are given the weights of 0. Hence, in this manner, the grid node is assigned the value of concurrent observation.

For buffering the kinks behavior, '*smoothing*' parameter is used. When we assign a non zero parameter, no point is given an irresistible strong weight so that no point is given a weighting factor equal to 1.

One most important characteristic of IDW is the formation of '*foci*' around the position of observations within the gridded area. During IDW interpolation, we assigned the smoothing parameter to reduce the '*kink*' effects of '*bull's eye*' by smoothing the interpolated grid. Moreover, IDW is a very fast gridding method. If points are less than 500 in numbers, the computation of the data and gridding proceeds rapidly.

3.3 Processing of Data Through Spatial Interpolation

For IDW following equation is used

$$\bar{\boldsymbol{Z}}_J = \frac{\sum_{i=1}^{N}\frac{Z_i}{h_{ij}^{\beta}}}{\sum_{i=1}^{N}\frac{1}{h_{ij}^{\beta}}} \tag{2}$$

where

$$h_{ij} = \sqrt{d_{ij}^2 + \delta^2}$$

while

$\bar{\boldsymbol{Z}}_J$ = is the interpolated value for gird node 'j'

Z_i = are the neighboring point

h_{ij} = is the effective separation distance between grid node 'j' and the neighboring point 'i'

d_{ij} = is the distance between grid node 'j' and the neighboring point 'i'

β = is the weighting power (or power parameter), and

δ = is the smoothing parameter

4. Findings and Discussion

4.1 Yearly and Seasonal Analysis

For the period from premonsoon to the beginning of post-monsoon, TS has been remains more active than the RF. While for winter season and partially post-monsoon seasons RF is found more frequent than the TS (Figure 2). Both the parameters have two apexes; one during monsoon and the other in the winter while their topmost values have been found in monsoon and winter season, respectively. Sharp step-up and step-down is noticed in the both activities from June to July and from July to September, respectively.

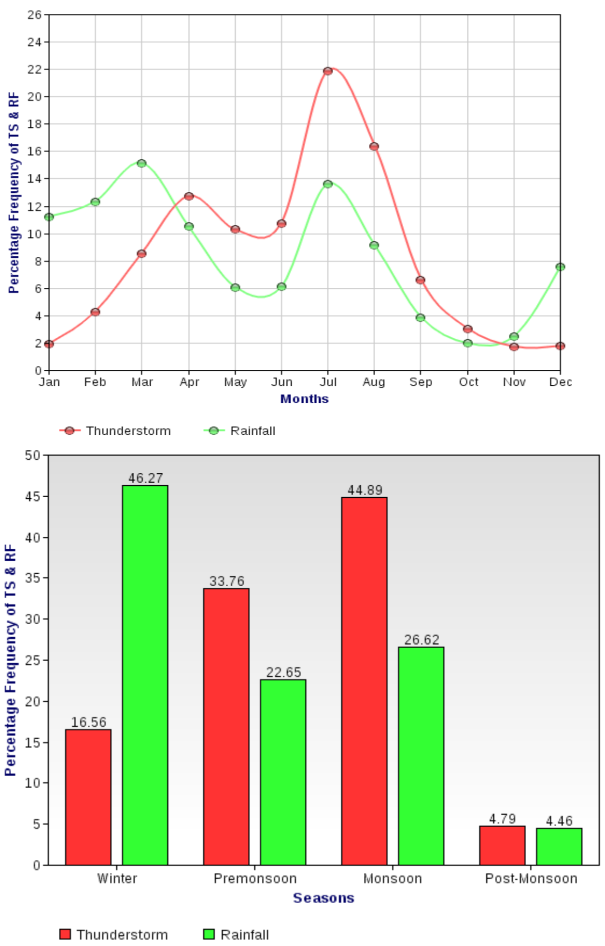

Figure 2. Monthly and Seasonal percentages of TS and RF over Balochistan.

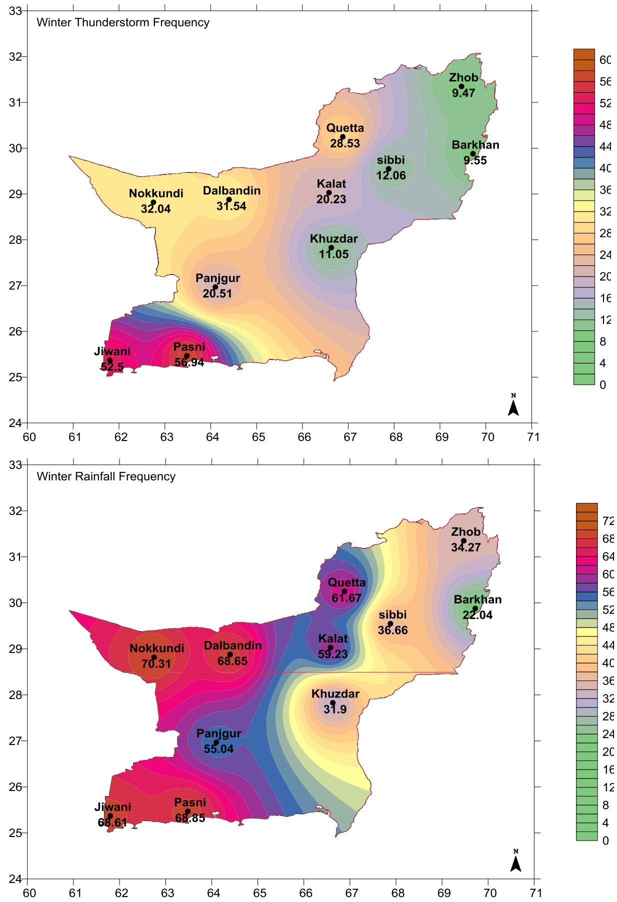

Figure 3. Spatial Interpolation of percentage frequency of TS & RF in winter over Balochistan.

Winter is the only season in which the RF frequency is found more than the TS. In winter, rainfall occurrence is 29.71% more than the Thunder one. In other seasons thunderstorm occurrence is dominating by 11%, 18.27%, and 0.33% in premonsoon, monsoon and post-monsoon season, respectively (Figure 2). The highest thunder activity is in monsoon with 44.89% and lowest in post-monsoon i.e. 4.79%. The highest activity of rains is observed in winter season i.e. 46.27% while least activity is in post-monsoon 4.46%.

4.2 *Winter Season*

In winter the highest TS frequency is found in the nethermost south western parts (like Pasni ≈56.94%) while extreme north east with some adjacent lower areas bore the lowest frequency, as for instance Zhob appears with 9.47%. The frequency shows gradually decreasing trend from western parts of the province to the eastern and adjacent areas (Figure 3). Winter rainfall has been found with its maximum occurrence as the region is more affected by the western disturbance [18]. Two-headed western arms are most frequent with the rainfalls. In the upper arm Nokkundi (≈70.36%) and in the lower-arm Pasni (≈68.85) is found with maximum activity. The occurrences of RF decrease gradually from west to eastern part though throughout values of the RF are still comparatively higher than the other seasons.

4.3 *Premonsoon Season*

The TS frequencies above from 26.5^o latitude are more recurrent. The upper western part shows maximum TS occurrence at Nokkundi (48.54%). The lower south western part which acquires the maximum frequency in winter season, now appears with least frequent events over Jiwani (11.5%) and Pasni (12.5%). In contrast to the winter, the eastern parts are more frequent with the rain events, in this season, for example Zhob (29.34) and Barkhan (29.6%). The scenario show gradual decrease when reaches to the eastern parts. Further, The lower-arm of the province received lesser events than the upper-arm (Figure 4).

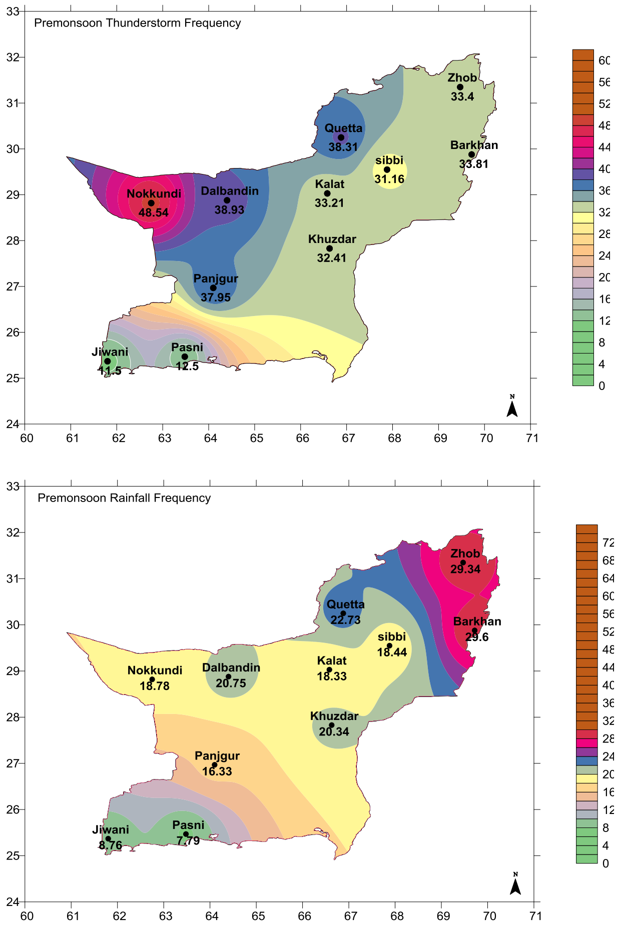

Figure 4. Spatial Interpolation of percentage frequency of TS & RF in premonsoon over Balochistan.

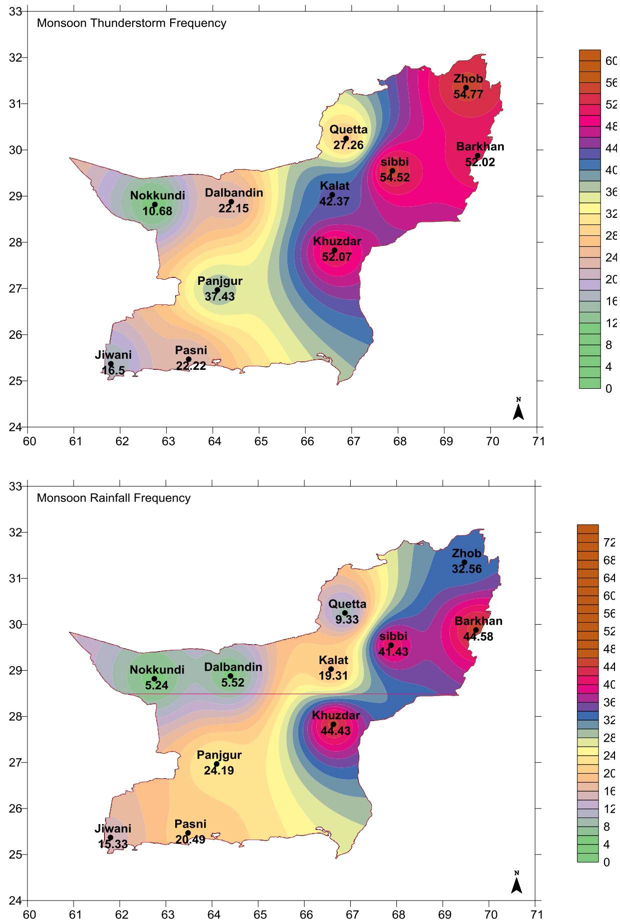

Figure 5. Spatial Interpolation of percentage frequency of TS & RF in monsoon over Balochistan.

4.4 *Monsoon Season*

Monsoon shows its clear influence over the eastern parts, like, zhob (54.77) and Sibbi (54.52), of the province. Though over all west bore the least thunder activity but western upper- arm appears with least occurrence (Nokkundi ≈10.68% and Dalbandin ≈22.15) than the western lower-arm (Jiwani ≈16.5 and Pasni ≈22.22). Alike to TS activity, RF activity is also found more frequent in the eastern parts. Barkhan appears with maximum occurrence with 44.43%. In the similar fashion, upper western parts receive less rainfall than the lower one. Nokkundi appears with least RF (5.24%) activity. The entire situation is depicted in Figure 5. The movement of contours of TS and RF activities pointing the invasion of the activity from the provinces that are mainly affected by the monsoon times.

4.5 *Post-Monsoon*

The pattern of interpolation for the post-monsoon season is similar to the premonsoon season. The foremost lower western arm receives the highest occurrence as for instance, Jiwani ≈19.5%. The eastern region appears with least values (as for instance, Sibbi ≈2.26% and Zhob ≈2.37%). The overall values are less than any other season (Figure 6). Similar to TS, RF activity is also least in this season throughout the province, in contrast to monsoon season the lower western-arm bore more activity (for example, Jiwani ≈7.3%) than the eastern parts (for example, Zhob 3.83%) of the province.

5. Conclusion

The occurrence of thunderstorm and rainfall has been interpolated through geo-spatial tool-set which is a mature information technique. During post-monsoon and winter season RF activity is found more frequent than TS while premonsoon and monsoon season dominated through TS activity. It is also notable that rainfall activity is highest in winter while TS activity is greatest in the monsoon. TS and RF frequencies in winter season seems more dominated in western parts of the province. In premonsoon both activities shifted/inclined towards eastern parts and on the other

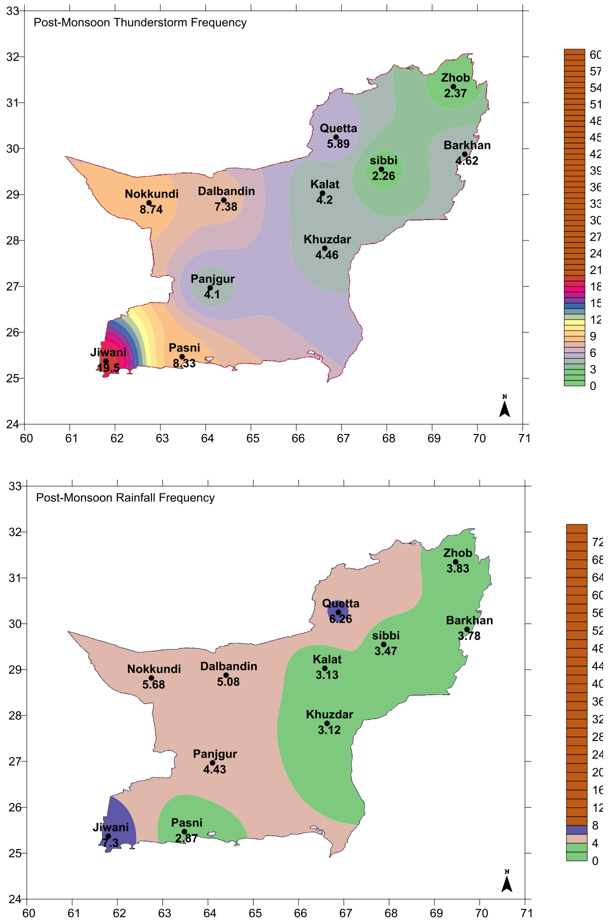

Figure 6. Spatial Interpolation of percentage frequency of TS & RF in post-monsoon over Balochistan.

hand south western areas like Jiwani and Pasni become less frequent in this season. During monsoon, eastern parts of the province is dominated by both frequencies because of the monsoon invasion from the east, while over all thunder activity is found more than TS activity. In post-monsoon season western part of the province again begin with raising values specially in lower south areas (as for instance Jiwani).

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