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Research Article

Identification of precipitation zones in Pakistan by global wavelet power spectrum

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ABSTRACT

Regionalization for precipitation is crucial in locating the area for new dams and the area for extra supplies for both developed and urban employment. Regionalization for precipitation permits the confinement of catchment regions of related precipitation highlights and appearances of the framework elements in the zone. Precipitation areas are found inside the Indus River in Pakistan, which could be observed through precipitation frequencies by methods of Global Wavelet Power Spectrum (GWPS). The effects of precipitation zones are obtained by the method of the GWPS. It showed distinctive recurrence everywhere throughout the basin of a couple of regions; notwithstanding, different frequencies are existing with somewhat essentialness that show changes in the precipitation framework.
Our aim is to describe the area of Pakistan region into different sub regions based on cold and hot climate, mountains area, dry and coastal areas with frequency patterns A and B. In this work we found the five sub-areas as Region (1, 2, 3, 4 and 5) with frequency patterns A and B.

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INTRODUCTION

This study is the extension of the work present by using mathematical modelling for regionalization [1-2] and it is also the extension work of paper presented in the ICMAA held on June 24- 27, 2020, Istanbul, Turkey.

Pakistan is considered as a developing country and under such development phase, the need and requirement of water is increasing with respect to time which leads to uncontrolled and immeasurable economic, political and social issues in the country [3]. Five sub regions of Pakistan in terms of cold and hot climate, mountains area, dry and coastal areas had been identified in 2015 [4]. Population and economy of Pakistan are heavily dependent on annual influx into the Indus river system includes the Indus, Jhelum, Chenab, Ravi, Beas and Sutlej rivers [5]. Thus the development of new dams and reservoirs can overcome the shortage of water and fulfill the demand. According to

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the World Bank report, Pakistan is going to face drought near 2025. Which is due to steadily rising temperature and impact on cryosphere (frozen part of Earth system) due to which rainfall are disappeared in many regions around the map, changes in rainfall pattern directly affect water agriculture and disaster management sector.

The 2001–2010 decade was the warmest ever recorded around the world as mentioned in the report of WMO. The climate change have directly influenced the cryosphere and hydrological cycle of the basin. The increase river discharges due to climatic changes and the melting of glaciers is increasig the importance of regionalization the area. Regional warming is also affecting the hydrology of the Indus Basin. The region partition into hydrologically related subtantial areas can be more beneficial.The homogeneous rainfall regions have been conclude by many previous studies. For instance, Spatial analysis of precipitation is carried out using time series over the Upper Indus Basin [5]. In the ongoing work, the distribution of rain frequency in River Indus basin was contemplated by utilizing the GWPS. Whereas wavelet transform allows the workings of a non-stationary signal to be studied.

Ali (2015) states that Wavelet Transform is actually advanced and much effective method of Fourier transform [1]. Fourier Transform is a classical and non-periodic technique for analyzing stationary signals. Whereas wavelet transform allows the workings of a non-stationary signal to be studied. The goal of this paper is to identify the rainfall regions with in the Indus River basin of Pakistan by the Global Wavelet Power Spectrum Technique.

MATERIAL AND METHODS

Location of study area

Pakistan gets precipitation in three major seasons; summer, monsoon and winter [6]. The precipitation in monsoon season touches base from east and north east in the period of July to September. In this era a decent measure of precipitation occurs in the north and upper east zone of nation [6]. Pakistan gets western unsettling influence which enters from Iran and Afghanistan which cause the winter precipitation (December to March).Hussain states that the north and north western part of country receives disturbance from Afghanistan which is known as the primary western disturbance, while the disturbance received in other parts of country comes from Iran and known as secondary and covers the major area which includes Baluchistan, Punjab, Khyber Pakhtunkhwa, Kashmir, and northern areas and sometimes in Sindh [7].

In the dry season, the primary asset of water supply to the nation are those territories which get a gigantic measure of snowfall to exist in the northern zone, upper Khyber Pakhtunkhwa, Kashmir and northern Baluchistan. The water got from precipitation and snow softens assumes a critical part of the agribusiness and financial exercises.

Regional classification of Pakistan

The goal of study is to identify the variations in the precipitation, and no altitudinal variation of rainfall is observed. For this purpose, data is taken over period of 55 years from different resources (Pakistan Metrological Department and Pakistan Statistical Bureau 1961- 2016) covering the whole country. i.e. 52 stations from east to west and north to south have been considered where every station have not exactly same time period it varies station to station according to data management e.g.Chitral (1961-2016) Astor (1962-2015) and Gawader (2002- 2016)etc.The stations taken in this study are selected around them which selected on the basis of their elevation from sea level, latitudinal position, and period of record and the consistency of data that will show the view of entire country. Furthermore the data is regionalized in regions named as 1, 2, 3, 4, and 5. As shown in following figure

Wavelet Transformation

Methodology used in this paper is presented by Torrence and Compo [8]. The technique keeps up time and

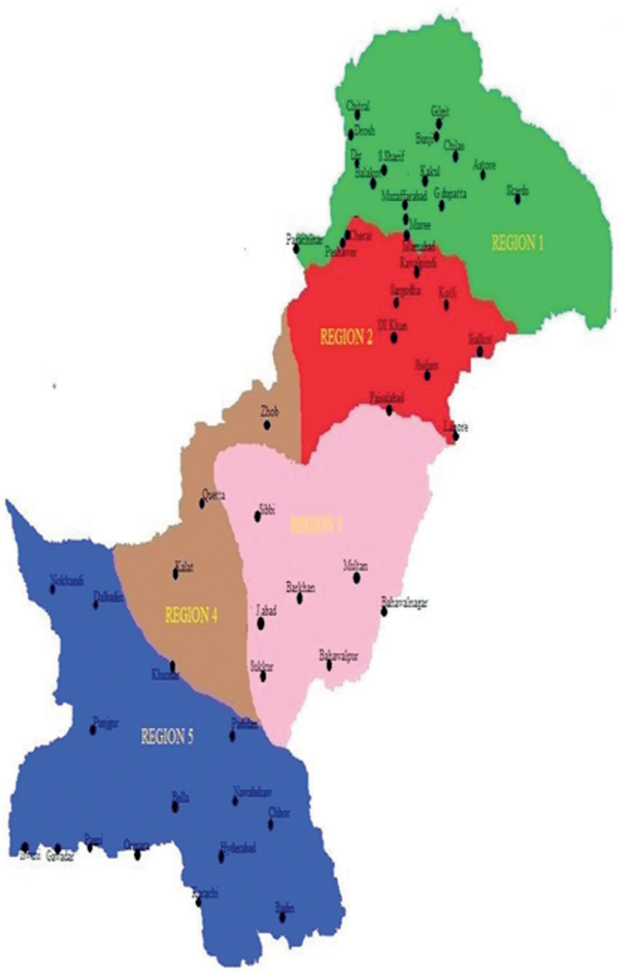


Figure 2.2. Regional Classification of Pakistan.

frequency localization in a time series data to give a two-dimensional time-frequency picture at the same time. So as to deliver such change, the wavelet analysis utilizes mother wavelets [8-10].

In the past two decades the wavelet transform has been applied in many branches of science and engineering. The continuous wavelet transforms decomposition can be used as an unconventional methodology to the short time Fourier transform decomposition to stun this resolution problem [8]. In the continuous wavelet transform as in the short time Fourier transform

$$\varphi_0(\eta) = \frac{1}{\sqrt[4]{\pi}} \exp(i\,\omega_0\,\eta)\exp(-\eta^2/2)$$

Where $\omega_0(\eta)$ is the wavelet value at non-dimensional time η, and w_o is the non-dimensional frequency [6]. The wavelet functions then apply to next points to develop other time series of the projection amplitude with time. Specialized points of interest and related physical attributes depicting all frameworks utilized on many mother wavelets are given in the suitable writing [9]. To deliver such change, the wavelet investigation utilizes essential waves, or mother wavelets, as they are alluded to in the writing. The Paul and the derivative of Gaussian (DOG) wavelets are the some examples of mother wavelets. The above method is used in this work by using a software tool available at http://paos.colorado.edu/research/wavelets as shown in following discussion.

A useful way to determine the distribution of energy in a data set is to plot the WPS(Wavelet power spectrum) corresponding to the square of the amplitude. High-power regions can be searched in the global wavelet power spectrum (WPS) to determine which features of the signal are important and which are negligible.

Results and Discussion

The resolution of data is month wise with the functions of the wavelet analysis are time interval δt = 1 month that scale start from s0 = 2 with lags of power of 2 i.e. (2, 4, 8, 16, 32, 64, 128, 256, 512 and 1024). To study the Indus basin precipitation of different cities of Pakistan has been under observed, which show results as shown in following figures.

Figure (4.1) The monthly resolution precipitation data at Chitral stations from 1961 to 2016 and fig shows the

Analysis of Chitral

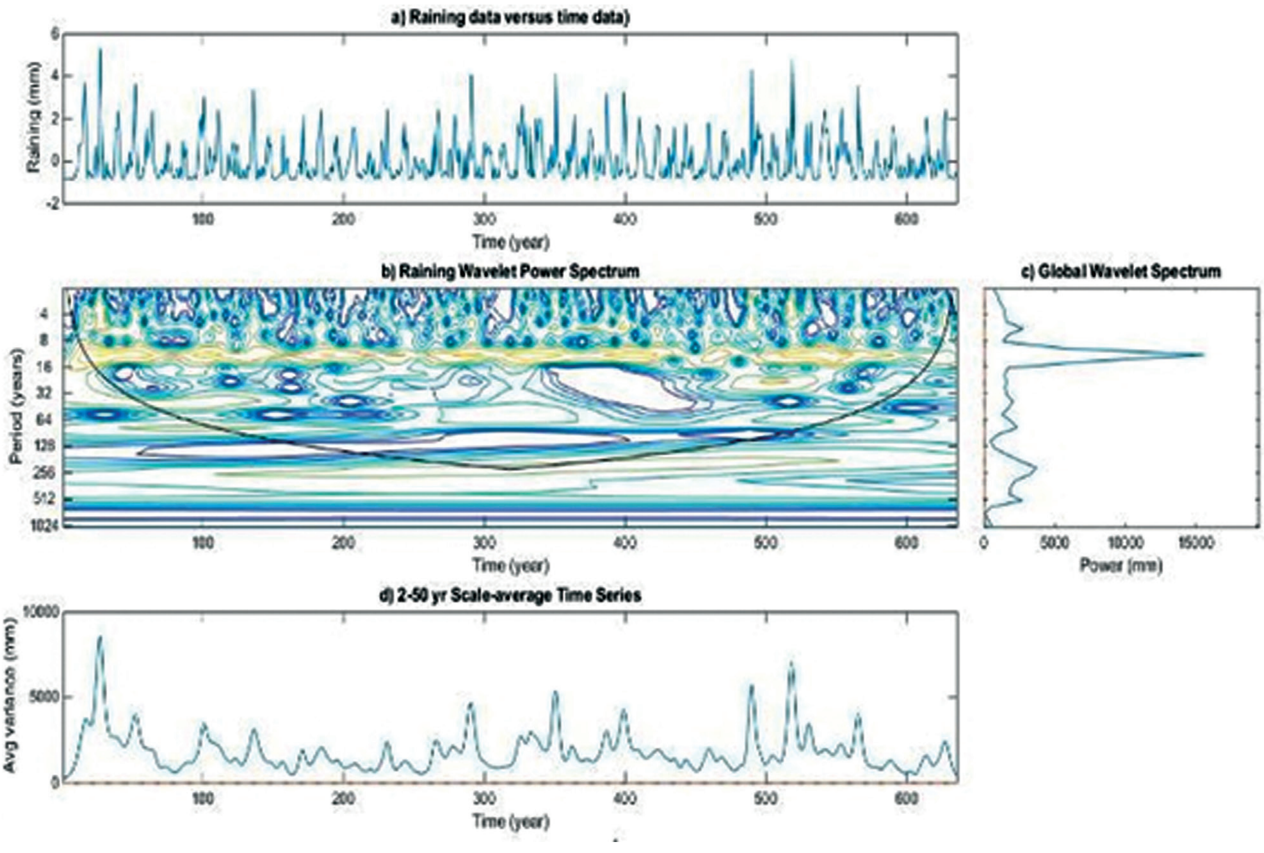
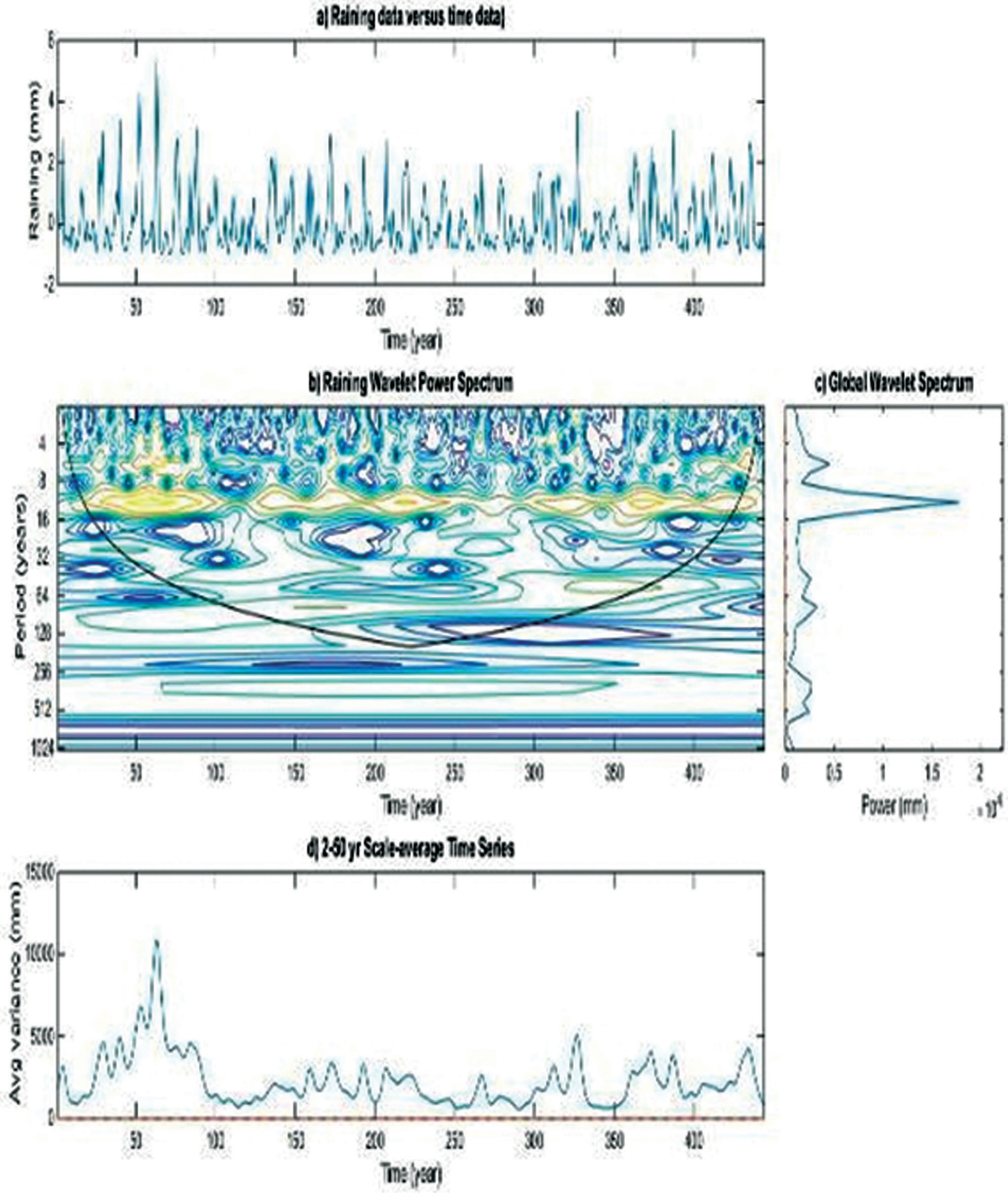


Figure 4.1. Analysis of Chitral.

Analysis of Darosh



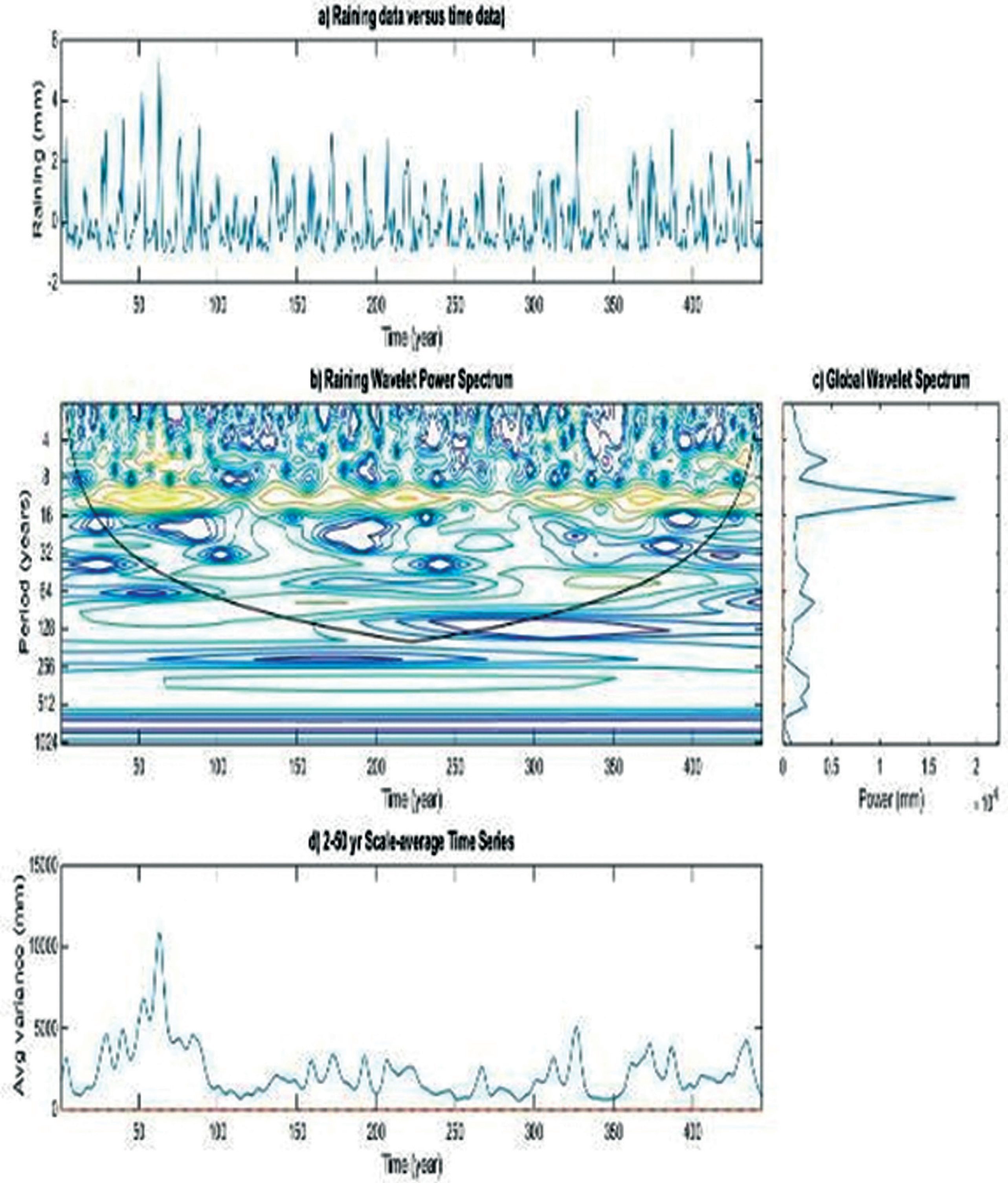

a) Raining data versus time data)
Raining (mm)
Time (year)
b) Raining Wavelet Power Spectrum
Period (years)
c) Global Wavelet Spectrum
Power (mm)
d) 2-50 yr Scale-average Time Series
Avg variance (mm)

Figure 4.2.

variation in wavelet transform for total monthly rainfall. Fig (a) presents precipitation raw data. This figure shows the actual oscillation of the individual wavelet relatively their magnitude. Figure (b) includes The monthly precipitation's power(squared value) of the wavelet transform; this gives information of the relative power at a certain scale and certain time. Observing this figure, Frequency or time domain can be idntified by power concentration. Moreover plainly there is more centralization of intensity between the 8-16 months bands, which demonstrates that this time series has a strong yearly signal (2010) .

Dehydrated and rainy years have been revealed by the variance of power in the 8 to 16 months band(In figure C this concept is already confirmed). For instance, A dehydrated year can presents the decreased power and rainy year can presents maximum year. The average variance in a certain band is depiction of the scale-average wavelet power [5] . When we come to figured, it shows eight to sixteen months band. Modulation of one frequency can be examined by this method by staying in same time series [10]. The average of figure is presented in figure d where it covers total scales among eight to sixteen months, where it gives

Analysis of Lahore

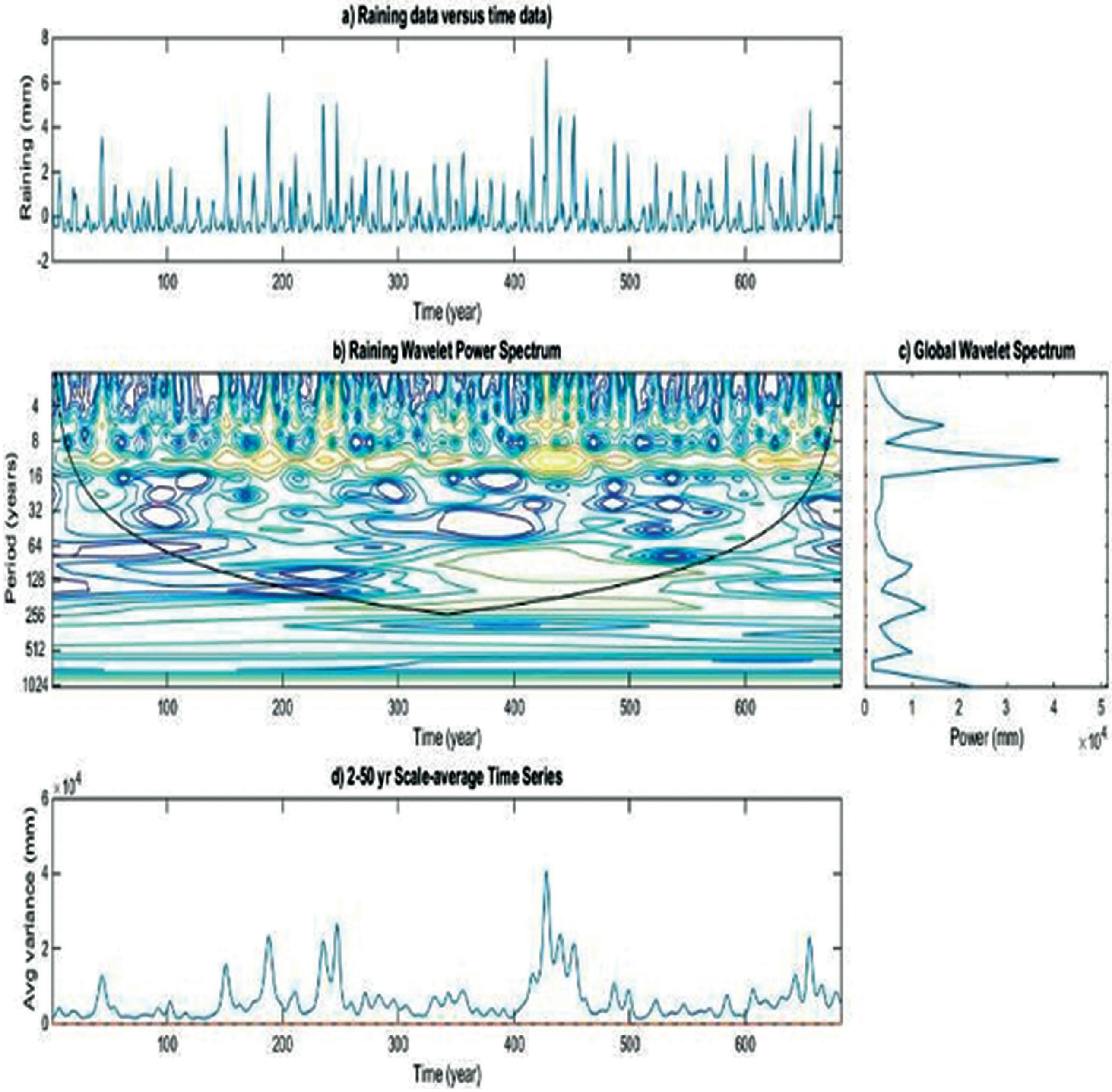


Figure 4.3. Analysis of Lahore.

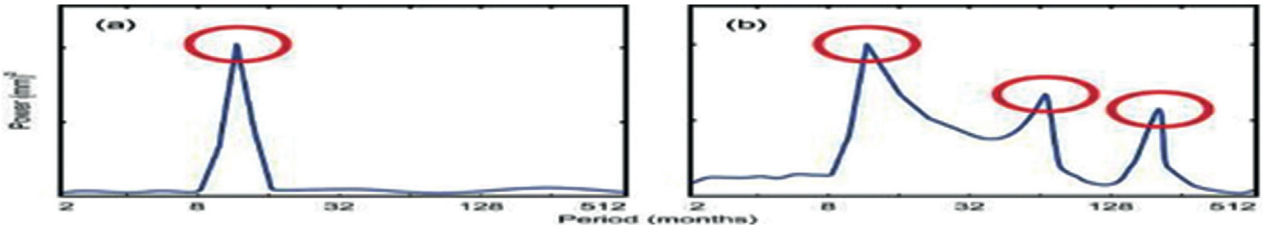


Figure 4.4. Annual Frequencies.

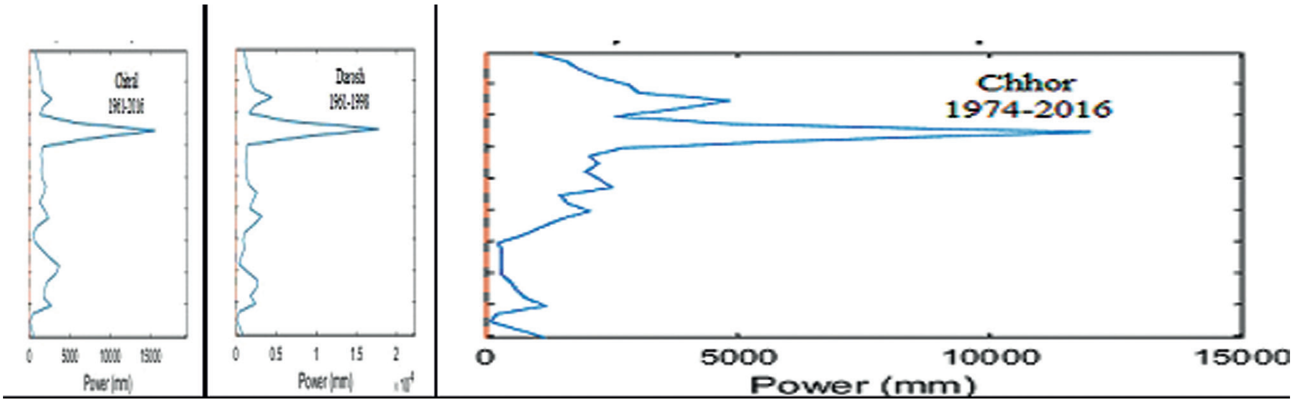


Figure 5. Global wavelet spectrum categorized only one frequency.

the measurement of mean of monthly variance vs time. The variation in precipitaion is presented in figure in which it shows the thick rainfall pattern from zero to eighty months and then in ninty to four eighty months, a moderate wet period followed by rainfall pattern which is high. Heavy rainfall behavior is presented in the above figure where it shows the high rainfall.

Fig (4.2a) The total monthly rainfall at Darosh from 1961 to 2014 and fig shows the power of the wavelet and also show the actual oscillation of the individual wavelet relatively their magnitude. Fig(b) presents monthly rainfalls includes power of the wavelet transform, observing this figure above the cone of influence the yellow contour shows the continuously precipitation occur during 1961 until 2014 [10].Which shows that this time series has a strong annual signal. Fig(c) shows the power of decrease and increase it represent a dry or wet year. If the peak increases the frequency of precipitation will be high. By observing the above fig the peak formed between 8-16 period(year). Fig(d) overall scales between 2-50 years, which gives the degree of normal month to month change vs time. Above fig shows that wet period can be identified between 1961and 1969.

Fig 4.3 (a) show the total monthly rainfall at Lahore from 1961 to 2014.This fig shows the raw data for the precipitation and also show the actual oscillation of the individual wavelet relatively their magnitude. The wavelet power spectrum presented in Figure (b) using the Morlet wavelet.Wavelet location along horizontal-axis taken timely and along vertical-axis the wavelet period yearly. The yellow contours shows the continuous precipitation occur during 1970-1990 and 1994-2002 while the dryness period occur 2003-2011.The dry and wet years presented in figure C; for instance, dry year can be observe by decreasing power when the power, and wet year can be observed by maximed power.By observing above fig, the global wavelet shows a peaks at period 4-8 and 8-16 .4-8 shows a low frequency while 8-16 shows a high frequency of rain fall. The mean of figure b is shown in figure d and it covers the graph among eight to sixteen months. where the output includes the mean of normal month to month variance vs time.For instance, a period that is dry start from 1961 to 1973, 1982 to 1994 and 2001 till present a wet period until the starting of 1974 [11].

We classify the two main pattern of global wavelet spectrum that is pattern A and pattern B. Pattern A follows one peak annual frequencies and Pattern B shows more than one peaked frequencies:

Following three stations follows the pattern A and 6 stations follows pattern B in the following diagram.

Figure 4.1 (c), Figure 4.2. (a) both shows the annual frequency pattern but Fig 4.3 shows two or more peaks instead of one.

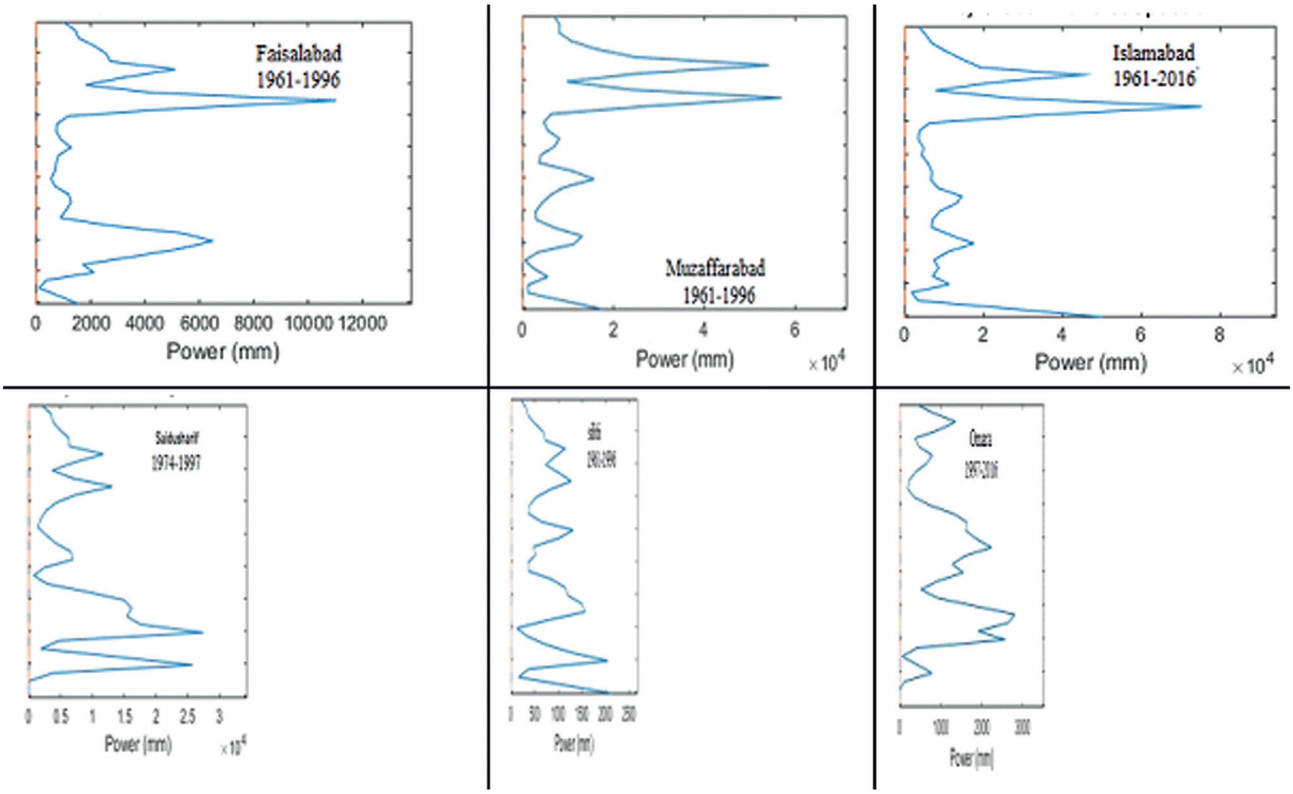


Figure 6. Global wavelet spectrum categorized more than one one frequency.

Following figure 5 Global wavelet power spectrum categorized only one frequency (annual) and figure 6 categorized more than one frequency.

First three figures show GWPS. characterized as frequency trend A which shows main frequency at 8-16 months. Remaining figures characterized as frequency pattern B which shows more than one frequency band. The first three figures Chitral, Darosh, Chore shows the one peak. It means that in these cities the strong precipitation occurs. In Chitral the total monthly rainfall from 19961-2016 calculated. Observing the figure the power reduction from 1973 to 1982 and the wet region from 1961 to 1972 which also follows 1983 to 2009.In Darosh the total monthly rainfall from 1961-1998 with the wet period from 1961-1969 and the power reduction from 1971 to 1986. In Chore the total monthly rainfall from 1974-2016 from 1961 to 1974 shows the arid period. In 1975-2016 the rainy period arises [12-15].

In this figure Faisalabad, Muzaffarabad and Islamabad shows more than one peaks. These cities lies in plain region and having less precipitation occurs as compare to upper region so the precipitation period of Faisalabad ,Muzaffrabad and Islamabad is lesser than the Chitral, Darosh and Chore. In Faisalabad a dry period can be identified from 1961-1976 and 1981-1996, While in Muzaffarabad 1966-1974 and 1982-1988 and in Islamabad 1961-1971. A wet period occur in Faisalabad from 1977-1981, in Muzaffarabad 1975-1981 ad second wet period start from 1988- 1990, and in Islamabad a wet period start from 1980-1986 and 1994-1996 [14-18]. Remaining figures of Saidusharif, Sibbi and Ormara showing the same pattern as Muzaffarabad, Islamabad and Faisalabad.

CONCLUSION

Based upon above discussion and analysis, it is concluded that the Global Wavelet Power Spectrum has been applied on the fifty six cities rain gauge data which shows different patterns of precipitation. The fifty six obtained GWPS presents the annual frequency that showsan irregular pattern time series. On the basis of result of wavelet analysis, Pakistan is regionalized according to the frequency of precipitation in the following figure as follows;

The use of Global Wavelet Power Spectrum has allowed us to hydrologically regionalized the Indus basin of Pakistan and examine the effect of precipitation of five different regions[16-20]. In the above figure, it is mentioned clearly that region 1 and region 5 are strong frequency pattern and the remaining (regions 2, 3, 4) are weak frequency patterns. The hydrological regionalization process for river

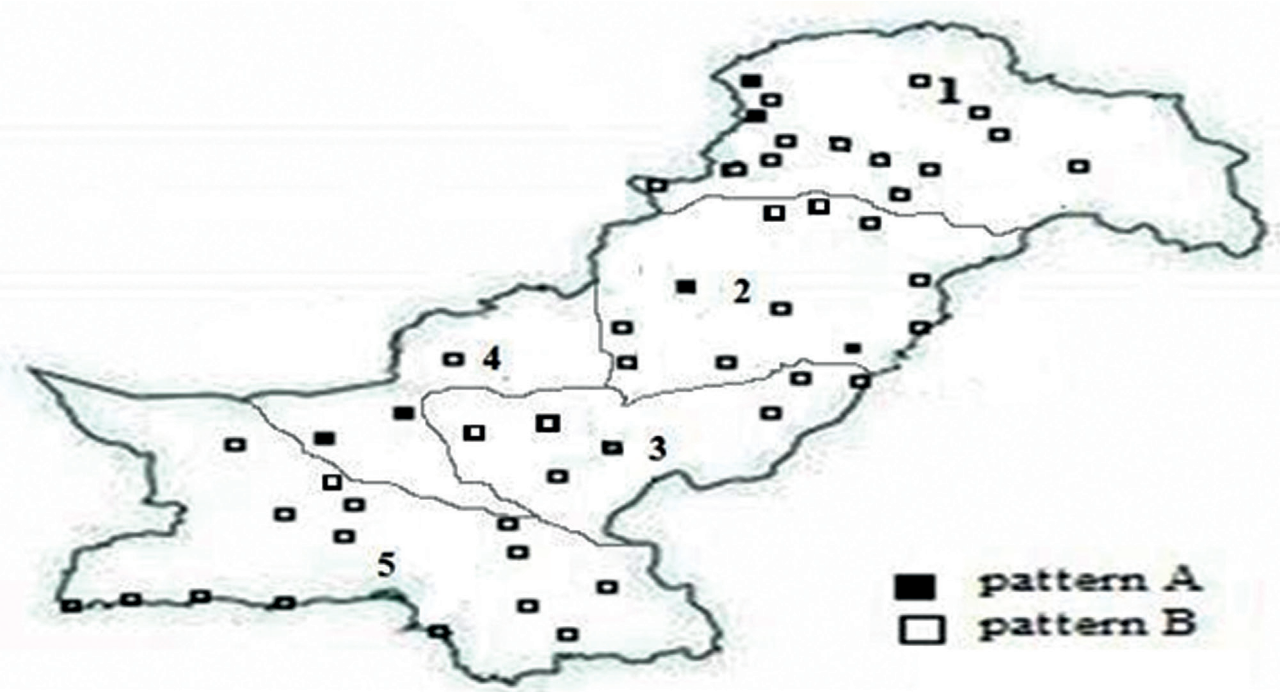


Figure 6 1. Frequency of Precipitation in Pakistan.

indus basin is reflected by thismethod.This result reflects that the method is an excellent tool in the hydrological regionalization process for river Indus basin. Thus five sub-regions with the non-homogeneous rainfall pattern may be identified with different frequency pattern as given in above diagram. Region 1 with frequency high pattern (northern region b/w 320 and 340 N and long 700 and 740 E) Region 5 with high frequency pattern (southern region b/w 230-350 and 280-300 N latitude and long 660-420 E and 710-10E) and a transition region in the central part just between Region 1 and 5. This procedure gives an good calculations of the true power spectrum of the data and may be judged as a simple method to classify the data variablity of area of land. This could allow us to take critical decisions regarding formation of dams and other civil construction work. This would allow help in taking strategic and smart decisions for agricultural and farming units of the country which would leads to increment in economic development of the country on local as well as on international basis.

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AUTHORSHIP CONTRIBUTIONS

Authors equally contributed to this work.

DATA AVAILABILITY STATEMENT

The authors confirm that the data that supports the findings of this study are available within the article. Raw data that support the finding of this study are available from the corresponding author, upon reasonable request.

CONFLICT OF INTEREST

The author declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

ETHICS

There are no ethical issues with the publication of this manuscript.

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