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.

Key words: Wavelet, GWPS, rainy pattern, frequency pattern, climatic conditions, power spectrum, precipitation zone

1. Introduction

This study is the extension of the work present in Salma (2012), Ali (2015) and the paper presented in the International E-Conference on Mathematical Advances and Application, held on June 24- 27, 2020, Istanbul, Turkey.

According to Zerouali (2021), 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. According to Salma (2012), identified the five sub regions of Pakistan in terms of cold and hot climate, mountains area, dry and coastal areas. Latif (2016) states that 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. Thus the development of new dams and reservoirs can overcome the shortage of water and fulfill the demand. According to 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 managementsector.

According to the World Meteorological Organization (WMO) 2011 report, the (2001 -2010) was the warmest decade recorded over the globe. Global warming and climate change have directly influenced the cryosphere and hydrological cycle of the basin.

Due to climatic changes the melting of glaciers and ultimately will result in the increase

in river discharges. Regional warming is also affecting the hydrology of the Indus Basin. The hydrological phenomena within the main regions, and a partition of the regions into hydro logically related sub-regions could be beneficial. Various studies have been made in order to conclude the homogeneous rainfall regions. For example Latif, Yaoming,Yaseen.(2016) carried out Spatial analysis of precipitation time series over the Upper Indus Basin.(Li,2020). 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. Several applied elds make use of wavelets, for example, astronomy, nuclear engineering, neurophysiology, magnetic resonance imaging, radar, and pure mathematics; it is also used in geophysics applications, such as analysis of tropical convection.

Ali (2015) states that Wavelet Transform is actually advanced and much effective method of Fourier transform. 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 papers is to identify the rainfall regions with in the Indus River basin of Pakistan by theGlobal Wavelet Power Spectrum Technique.

2. Material and method

2.1. Location of study area

According to Ali (2020), Pakistan gets precipitation in three major seasons; summer, monsoon and winter. 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 (Akhter, 2021). Pakistan gets western unsettling influence which enters from Iran and Afghanistan which cause the winter precipitation (December to March).Hussain (2021) 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.

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.

2.2. 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
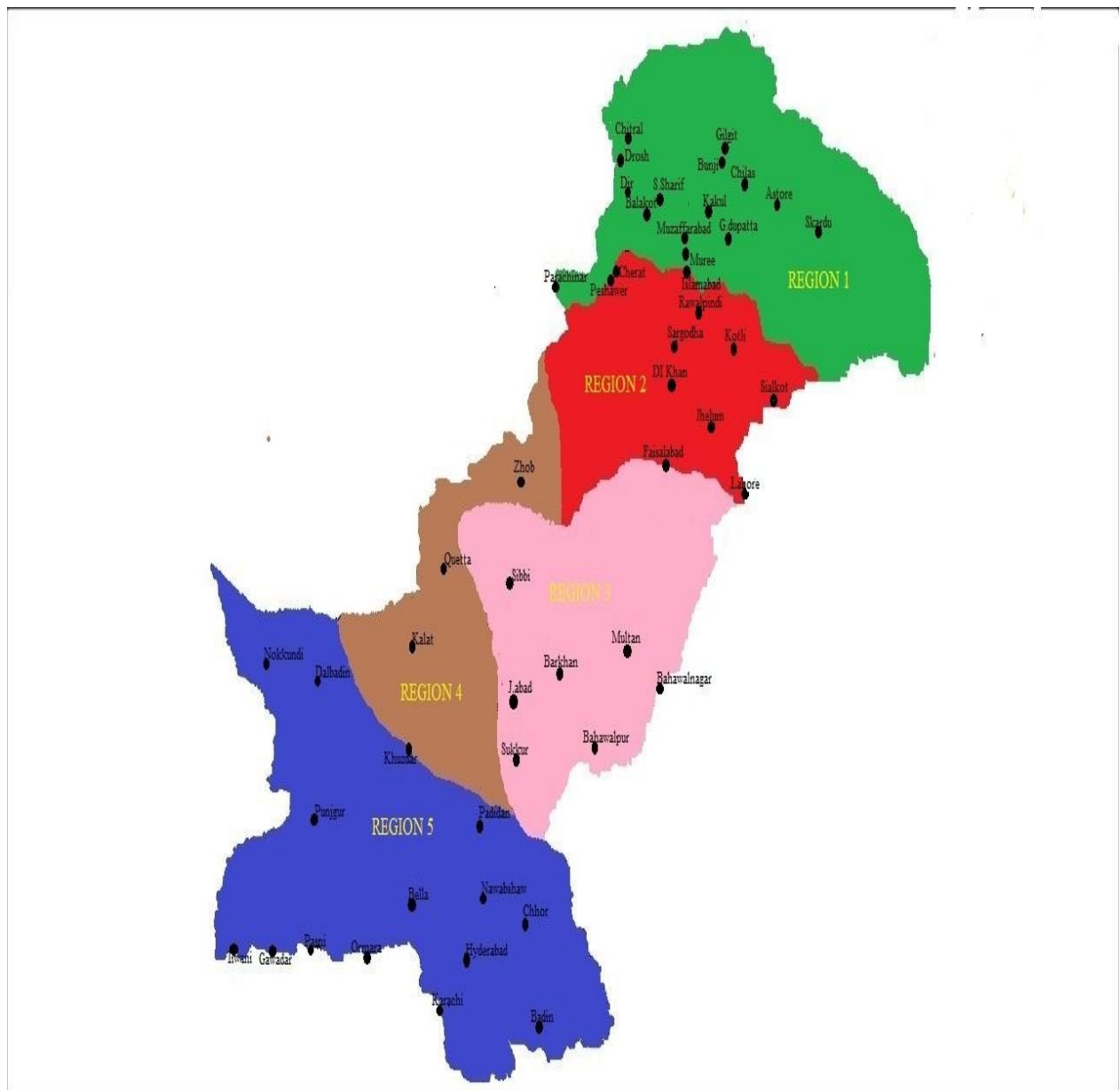
Figure 2.2: Regional classification of Pakistan

3. Wavelet Transformation

Methodology used in this paper is presented by Torrence and Compo (Khattak,2015). Mathematical transformations are applied to the original raining data to obtain further information that is not apparent. There are several transformations that can be applied (Ijaz Ahmad,2015).

The technique keeps up time and 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 fundamental waves, or mother wavelets, as they are alluded to in the writing .(e.g. Torrance and Compo).

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 (Iqbal, 2013). 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 parameters utilized in various mother wavelets are given in the suitable writing (Oduro,2016). To deliver such change, the wavelet investigation utilizes essential waves, or mother wavelets, as they are alluded to in the writing. Some examples of mother wavelets are the Paul and the derivative of Gaussian (DOG) wavelets (IjazAhmad,2015). The above method is used in this work by using a software tool available at http://paos.colorado.edu/research/wavelets as shown in followingdiscussion.

A useful way to determine the distribution of energy within the data array is to plot the wavelet power spectrum, equivalent to the amplitude-squared. By looking for regions within the Global Wavelet Power Spectrum (WPS) of large power, you can determine which features of your signal are important and which can be ignored.

4. Results andDiscussion

The resolution of data is month wise with the functions of the wavelet analysis are time interval $\delta_t = 1$ 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.
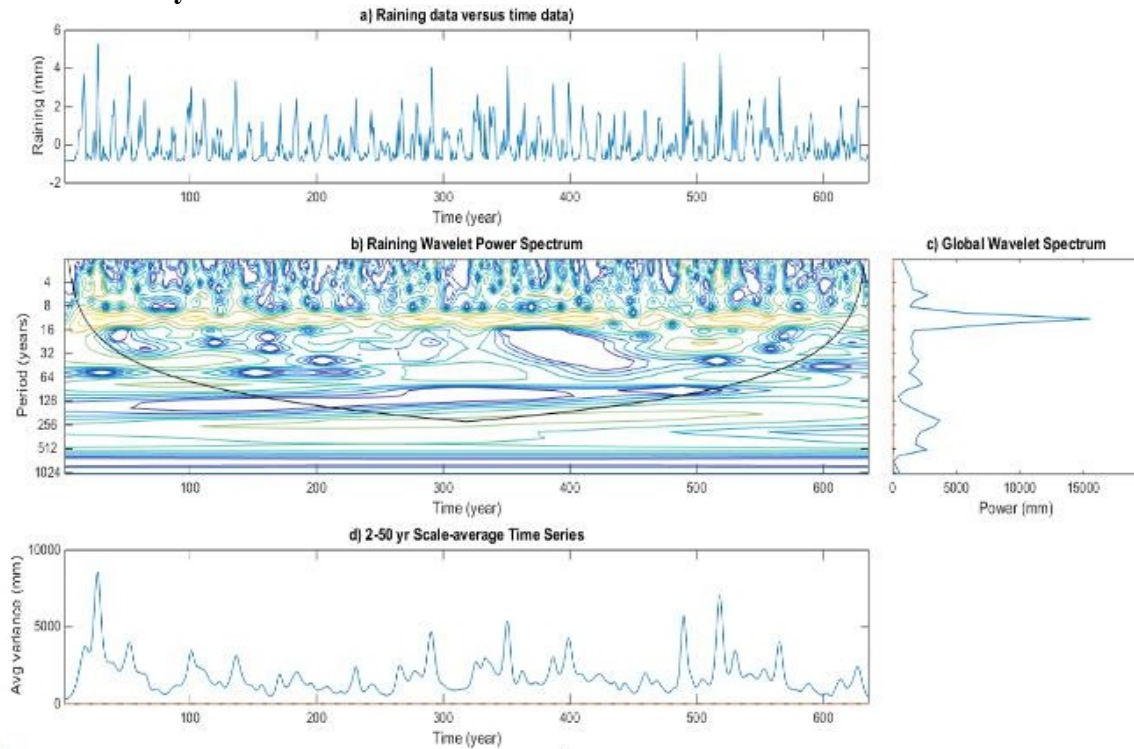
4.1. Analysis ofChitral

Fig.4

Figure 4.1: Analysis of Chitral

Fig (4.1) The monthly resolution precipitation data at Chitral stations from 1961 to 2016 and fig shows the variation in wavelet transform for total monthly rainfall. Fig (a) shows the raw data for the precipitation. This figure shows the actual oscillation of the individual wavelet relatively their magnitude (Rehman,2012). Figure (b) shows the power (absolute value squared) of the wavelet transform for the monthly precipitation; this gives information of the relative power at a certain scale and certain time. Observing this figure, the concentration of power can be easily identified in the frequency or time domain. 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).

The variance of power in the 8 to 16 months band (also confirmed in Fig (c)) reveal the dehydrated and rainy years; i.e. the decreased power represents in this band a dehydrated year, and maximum power represents rainy year. The scale-average wavelet power is a time series of the average variance in a certain band (Latif,2016). In the case of Fig (d) it is the 8- to 16-months band. This can be used to examine modulation of one frequency by another within the same time series (Santos,2003). Figure (d) is the average of Fig (b) over all scales between 8 and 16 months, which gives a measure of the average monthly variance vs time. Fig shows the variation in precipitation which is high rainfall pattern from 0 to 80 month and then a moderate wet period at 90- 480 months then followed by high rainfall pattern. In short the above fig shows the rainfall pattern of Chitralwhich explains the heavy rainfall behavior.
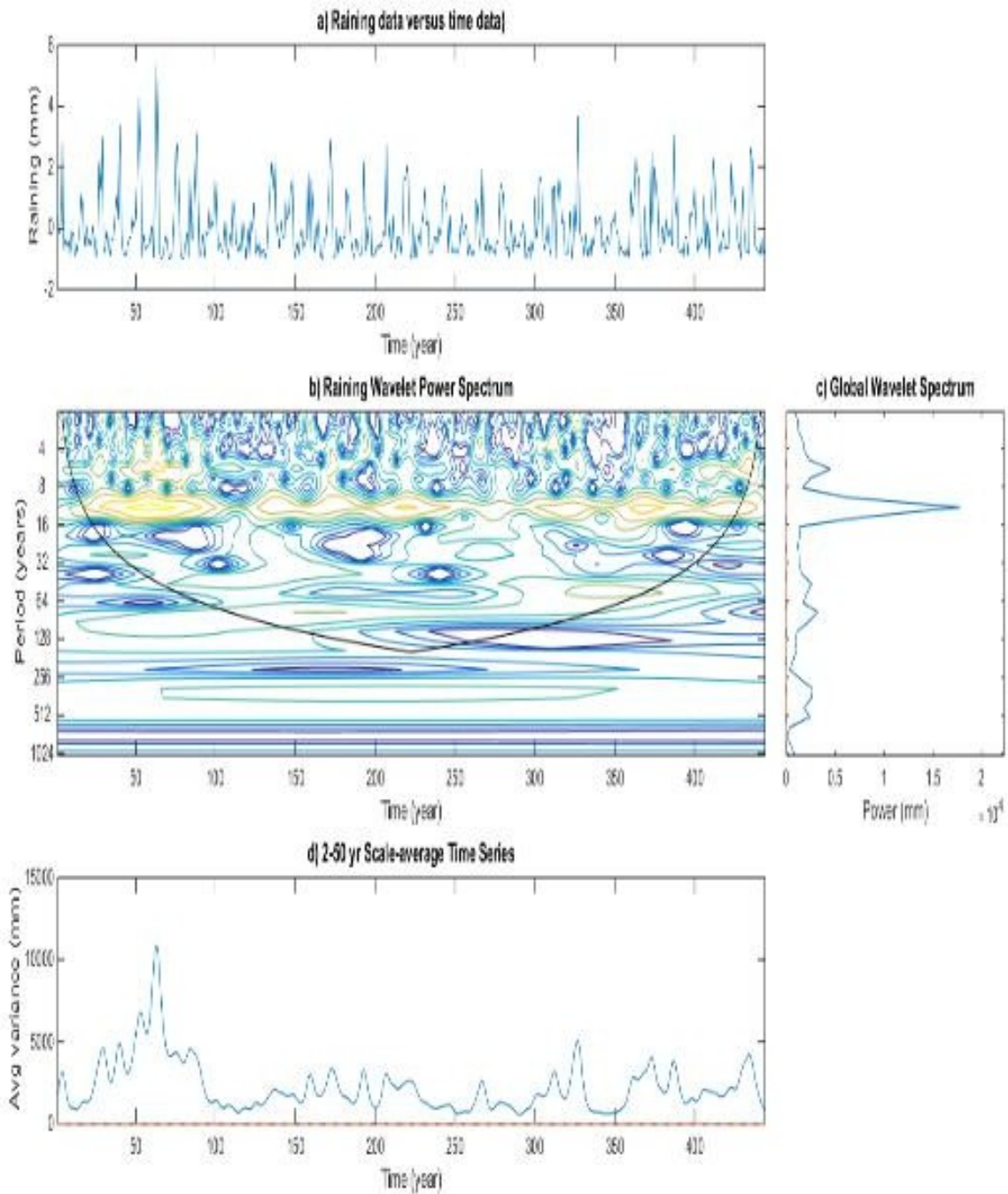
4.2. Analysis of Darosh

Figure 4.2: Analysis of Darosh

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) shows power of the wavelet transform for the monthly rainfalls, observing this figure above the cone of influence the yellow contour shows the continuously precipitation occur during 1961 until 2014 (Santos,2013).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 a measure of the Average monthly variance vs. time. Above fig shows that wet period can be identified between 1961and 1969.
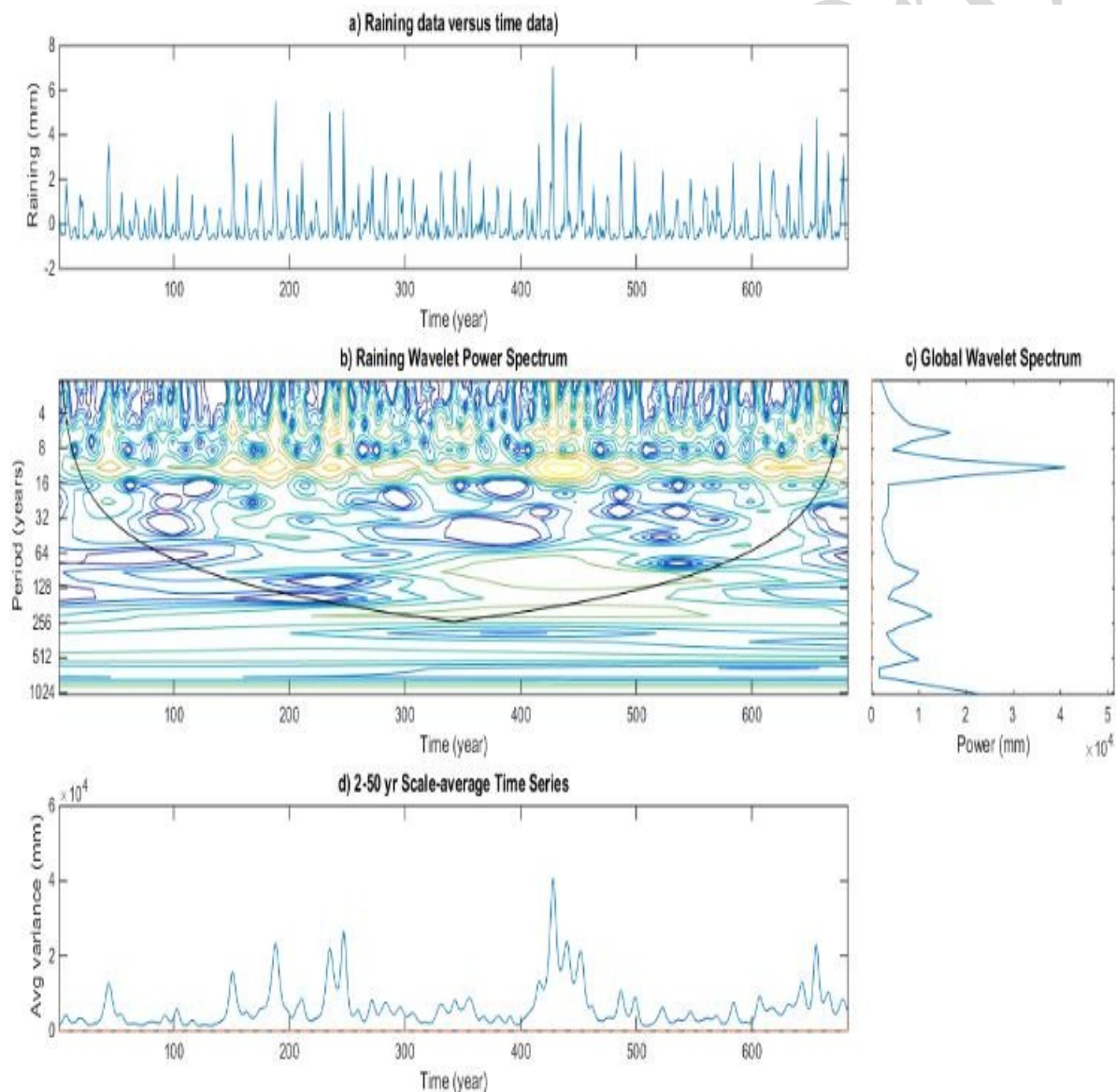
4.3. Analysis of Lahore

Figure 4.3: Analysis of Lahore

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. Fig (b) the wavelet power spectrum, using the Morletwavelet.Wavelet location along x-axis taken in time and along y-axis the wavelet period in years. The yellow contours shows the continuous precipitation occur during 1970-1990 and 1994-2002 while the dryness period occur 2003-2011. .Fig(c) shows the dry and wet years; i.e. when the power decreases substantially in this band it represents a dry year, and when the power is maximum it means a wet year. 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. Figure (d) is the average of Fig (b) over all scales between 8 and 16 months, which gives a measure of the average monthly variance vs time. For example, a dry period start from 1961 to 1973, 1982 to 1994 and 2001 till present followed by a wet period until the beginning of 1974 (Sarfaraz,2014).

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:
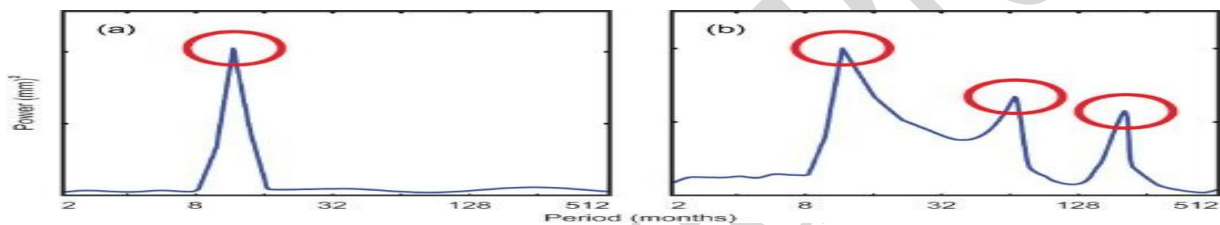

Figure 4.4: Annual Frequencies

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.

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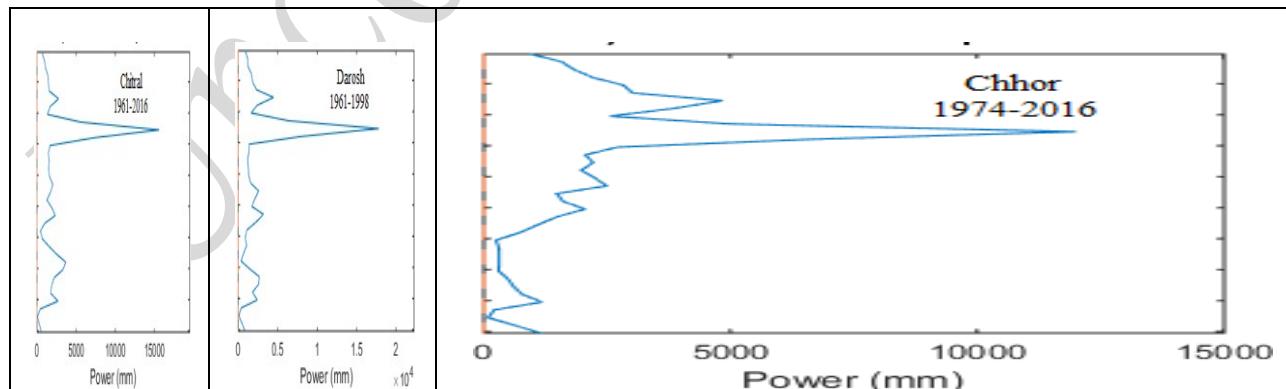

Figure.5: Global wavelet spectrum categorized only one frequency
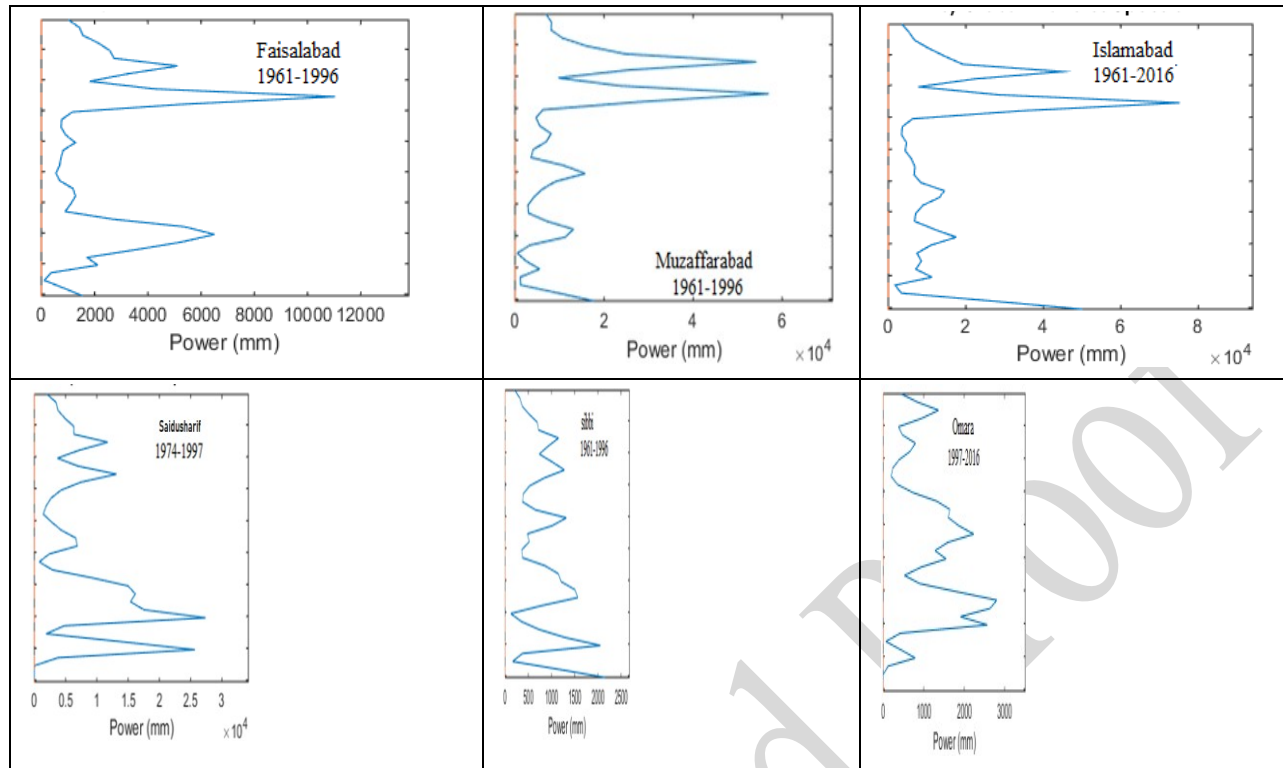
Figure .6 Global wavelet spectrum categorized more than one one frequency

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 (Salma,2012).

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 (Torrence,2001). Remaining figures of Saidusharif, Sibbi and Ormara showing the same pattern as Muzaffarabad, Islamabad and Faisalabad.

5 .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
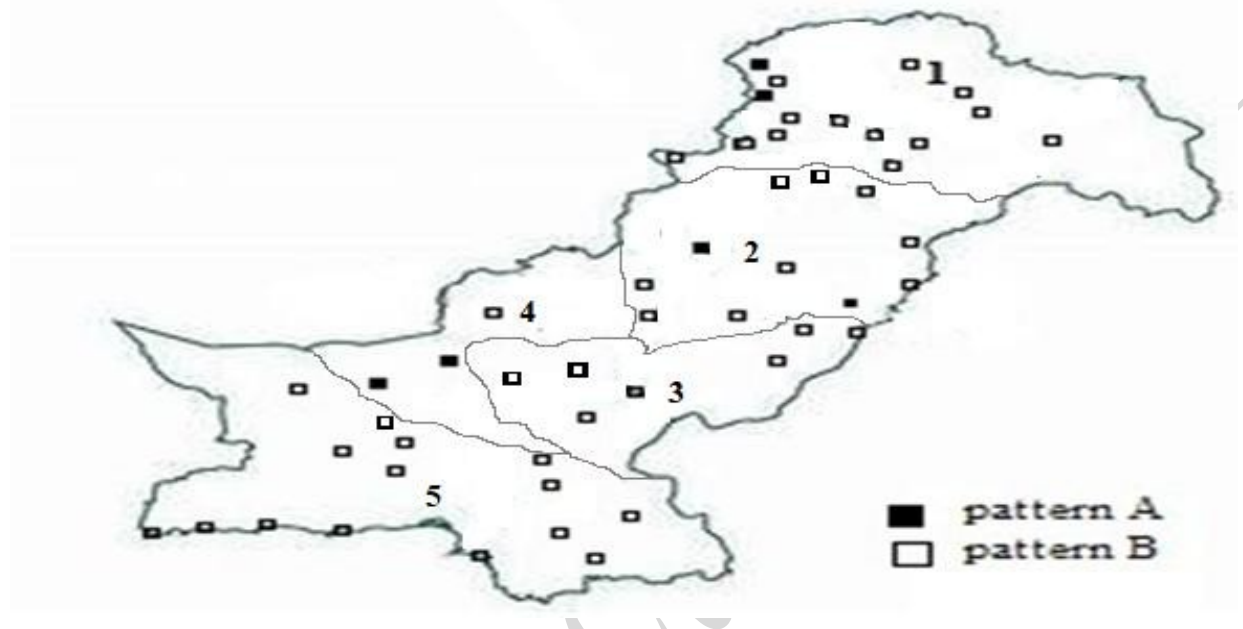

Figure 6 1: Frequency of Precipitation in Pakistan

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 regionalizedthe Indus basin of Pakistan and examine the effect of precipitation of five different regions. 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. This result reflects that the wavelet transform is an effective 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 .The mentioned method provides an unbiased and consistent estimation of the true power spectrum of the rainfall time series, and could be considered as a simple and robust way to characterize the time series variability of regions around Indus River basin. 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.

Acknowledgment

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