

Research Article



Identification of Precipitation Zones within Indus River Basin (Pakistan) by Global Wavelet Power Spectra

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Abstract | Water plays same role to earth as oxygen to body. In order to safe this Globe from droughts and floods, it is essential to design a strategy for the balanced usage of water resources for urban uses and agriculture. For such purpose, Precipitation regions were recognized in river Indus basin in Pakistan by examining the rainfall frequencies with the help of global wavelet power spectra. Records from 52 rain gauges were studied and the outcomes of the whole power spectra exhibited a low annual frequency all over the basin; whereas additional frequencies are present with major significance that indicate changes in the rainfall system. While, the calculated global wavelet power spectra showed variable frequencies, they presented odd patterns (symbolized by A and B) that might be used to portray the region. Therefore, three sub-regions with consistent precipitation patterns were recognized as: Region A (not apparent) and Region B (south and north part of the basin) and Transition zone (central portion of basin), having both the frequencies are identified.

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1. Introduction

Water is that natural resource which was thought to be used as long as their exist life on Earth but we run out of it very soon if we keep on using it in a way that we are doing now. Uncontrolled use of it can generate infinite social, economic and political damages.

Due to economic development and over population, the demand for water resources is continually increasing in the country. We, with the limited resources, can think of the methodologies that can aid in the application of policies for proper use of this resource together for human and agricultural purposes. This needs an understanding of the hydrological

phenomena in the main regions, and a detachment of the regions into hydrological alike sub-regions that could be valuable for various outputs to be achieved.

In order to find homogenous rainfall regions, a lot of studies have been made up till now. For example, Archer and Fowler (2005) and Tahir *et al.* (2011) in lightened the Karakoram and Himalayas region by recording about its monsoon dynamics and also determinates the pattern of rainfall over the Himalayas. The regional climate model was used by Akhtar *et al.* (2008) that observed an increase up to 16% in annual mean rainfall by the end of 21 century (2071-2100), Diolaiuti and Bocchiola (2013) founded decreases precipitation over the Upper Indus basin and growing trends over northwest Karakoram and

Chitral. Hydro-meteorological drifts in the UIB in Pakistan was analyzed by M. ShehzadKhattak (2011) using mann-kendall test.

Heike Hartmann and Hilary Buchanan (2013) analyzed trends in extreme precipitation events in the River Indus Basin and flooding in Pakistan and concluded that Western part of the Basin observed decreasing trends in extreme precipitation and increasing trends in the very high mountains region. Future flood management plan need to consider an increasing trends in extreme precipitation.

Spatial analysis of precipitation over the UIB (2016) was analyzed by Yasir Latif, Ma Yaoming, concluded that declining precipitation dominated the Upper Indus basin both spatially and temporally containing the high areas by using mann-kendall method.

In this work, the precipitation frequency over river Indus basin was analyzed with the use of "wavelet transform". The technique can provide us with the frequency of signals and the time associated to those frequencies. Wavelet transform has wide applications in image processing too. Its usage has rapidly increased as substitute to the Fourier transform. It permits the study of different scales of temporal inconsistency without the stationary series. Hence, it is appropriate for analyzing irregularly distributed measures and time series with non-stationary power of different frequencies. Wavelets, are now being used in many fields such as astronomy, nuclear engineering, neurophysiology, radar and pure mathematics; it is also used in geophysics applications, such as tropical convection, temperature variability. Lokenath Debnath presented his work on wavelet transform and its applications Nov, 1998. X Dong, in 2008, made the study on wavelets for agriculture and biology. Another research on an analysis and comparison of wavelet transform for Denoising was made in June 19, 2018, Jean-Pierre Antoine wrote about wavelet transforms and their applications.

2. Methods and Materials

2.1 Site of the study area

The region of study is the Indus River basin. Its flow begins in the locality of Mansarovar Lake in the Tibetan Plateau (China) and covers the Ladakh region of Kashmir (India). Then it makes its path to the north leading to Gilgit-Baltistan. The river then

Flows towards south covering the complete length of the country (Pakistan) and flows in the Arabian Sea nearby Karachi in Sindh.

The river has an over-all drainage area exceeding 1,165,000 km² (450,000 sq mi). Its estimated annual flow stands at around 243 km³ (58 cu mi), making it the twenty-first largest river in the world in terms of annual flow.

The Indus River is approximately 3,610 km (2,243 mi) long. Through a series of dams and canals, the Indus provides much of the irrigation and power for central Pakistan. It is 2,896 km (1,800 miles) in length, having annual discharge of 6,600 m³/s. It is situated between 23°59'40" N and 67°25'51" E.

2.2 Selected data

A total of 52 rain gauges were selected, based on their geographical distribution, with data from 1964 to 2016 provided by the Bureau of Statistics Planning and development department government of Sindh and Pakistan bureau of statistics. Due to the features of the wavelet transform, it is not essential for data to be from exactly the similar period. For decision-making

Processes, it is essential to regionalize an area hydrologically. Decisions regarding agriculture, floods and droughts and hydroelectric power generation. Though, regionalization is complex because the rainfall, although within the same basin, can show different features, which are not easily measurable due to the resemblance in the hydrological system.

2.3 The wavelet transforms

Mathematical conversions are used on the original signals to find further hidden facts. Out of several transformations, the most popular one is Fourier transforms.

Wavelet decomposes or converts time series of one dimension into a time series of two-dimensions (time-frequency) image which is in a diffused state. Thus, sustains frequency and time localization in a particular signal. In this way, we can find information about an amplitude of signals that are periodic, in the particular series and its variation with time. For such transformations, wavelet analysis uses basic waves, or mother wavelets.

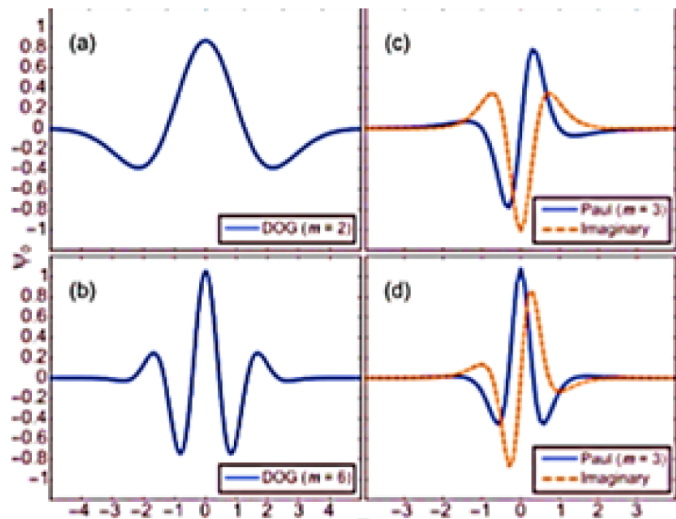


Figure 1: Mother wavelets of: (a) Derivative of Gaussian (DOG) with $m = 2$; (b) DOG with $m = 6$; (c) Paul with $m = 3$ and (d) Paul with $m = 4$. Paul mother wavelets include the imaginary part.

Some examples of mother wavelets are the Paul and the derivative of Gaussian (DOG) wavelets, as shown in Figure 1 with their respective order (m), and the Morlet wavelet (Figure 2), which is, in practice, is the product of a Gaussian envelope and an exponential function which is complex:

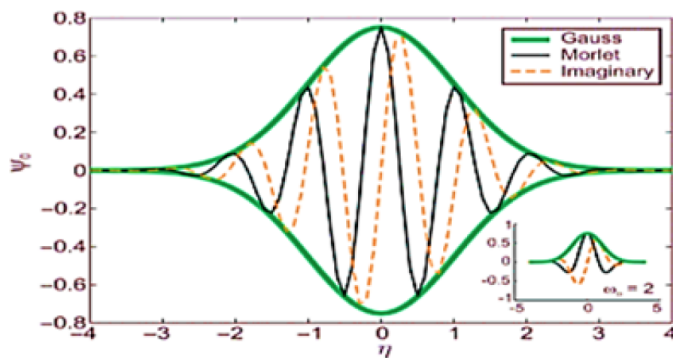


Figure 2: Example of the morlet mother wavelet including the imaginary part. Main plot: Morlet mother wavelet with $\omega_0=6$. Inset: Morlet mother wavelet with $\omega_0=2$.

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

Here $\varphi_0(\eta)$ is wavelet's value when ω_0 is the frequency (In this study, the value is 6) and time is η , (Figure 3). A new time series of the projection amplitude vs time can be constructed by sliding this wavelet along the time series. Lastly, by changing its width, the "scale" of the wavelet can be varied. Other associated physical characteristics describing all parameters and technical details can be viewed in the appropriate literature (e.g.

Torrance and Compo, 1988).

3. Results and Discussion

3.1 Wavelet power spectrum

Because the present data is monthly distributed, the parameters include the start scale $s_0 = 2$ months and time interval $\delta t = 1$ month, the width of the scale $\delta j = 1/4$, that generates four sub-octaves for each octave, and we have nine exponents of $2(2,4,8,16,32,64,128,256, \text{and } 512)$. For the study basin, the outcomes are alike to those in Figure 4. Figure 4(a) displays the raw data for the rainfall. Figure 4(b) shows the power (absolute value squared) of the wavelet transform for the monthly rainfalls presented in Figure 4(a), which is a record from 1961 to 2016. Here, the Morlet wavelet was used, because more accurate frequency information is given by it when compared to other mother wavelets. Figure 4(b) presents the actual oscillation of the individual wavelet, not only its magnitude, but the power concentration can easily be identified in the frequency or time, i.e. an annual frequency along the entire time series (1961-2016). The variance of power in the 8- to 16- month band displays the wet and dry years; i.e. when the power increases in this band it represents a wet year, and when the power declines it means a dry year, as discussed by Santos et al. (2001, 2003) and Santos and Ideiao (2006).

3.2 Scale-average series of time

In a certain band of a time series, the average variance is called scale-average. It is a band of 8- to 16- month in the case of Figure 4(d). We use it to observe variation of one frequency by another in the same time series. The average of Figure 3(b) is shown in Figure 3 (d) over all scales from 23 to 24 months that provides average monthly variance vs time. For example, a period of wetness can be identified between 1961 and 1967 shadowed by a dry year until the start of 1985. Another decrease in power is found amid of 1995 and 2002 and that correspond a dry period shadowed by a rainy period till 2009.

3.3 The global wavelet power spectrum

An amalgamation of exponents over the time spectrum confirms the trend in time series, assumed red noise, represented by the dashed lines (Figure 3(c)). Numerous geophysical time series are modelled either as red noise or white noise. As per Torrance and compo (1998), autoregressive process univariate lag-1 is a simple layout of red noise, he correspondence between the time series and itself is lag-1 (a_1), which is one time unit lagged. Here, it is a month's shift.

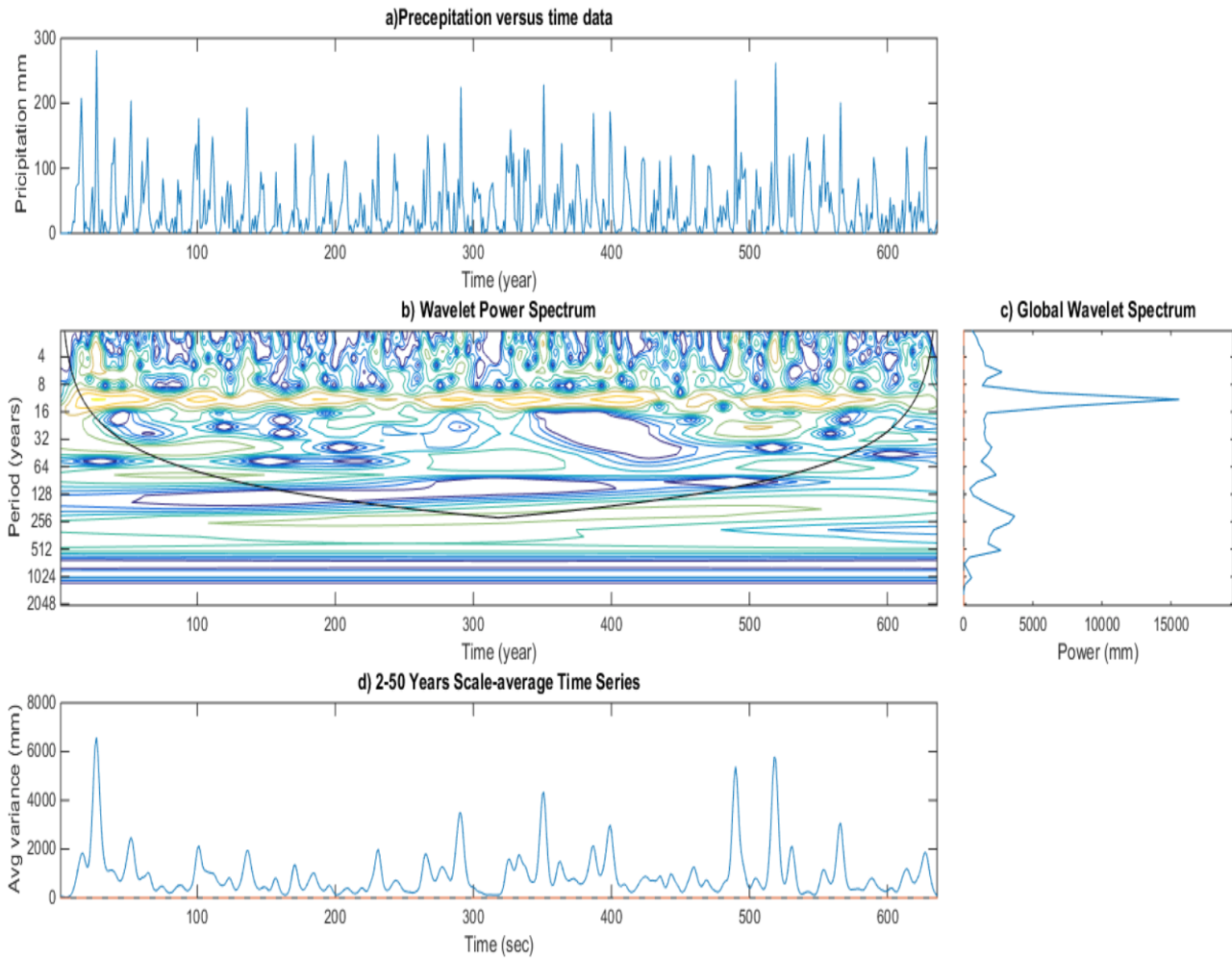


Figure 3: (a) Monthly rainfall for the 1961-2016 period; (b): The wavelet power spectrum using Morlet mother wavelet. Here thick contour encloses regions of greater than 95% confidence for a red-noise process; (c): The global wavelet power spectrum. The dashed line is the 5% significance level, using a red-noise background spectrum; (d): showsscale-average wavelet power for 8- to 16- month bandand 5% significance level is indicated by a dashed line, supposing red noise.

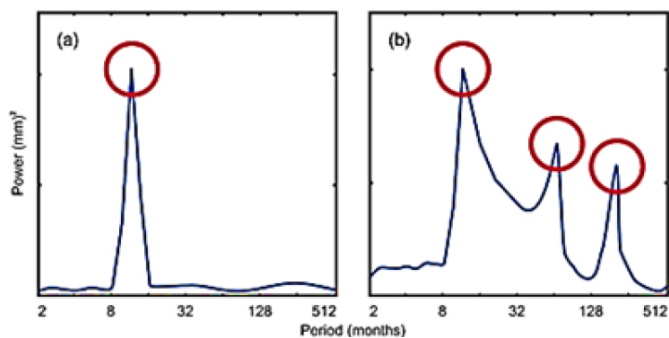


Figure 4: Global wavelet power spectrum: (a) Pattern A, characterized by only one frequency (annual), and (b) Pattern B, characterized by more than one frequency.

The lag-1 calculates that there is a glitch between two months. If $\text{lag-1} > 0.4$, it is recommended to compute the true lag-1 as $a = (a_1 + a_2 \cdot 1/2) / 2$, in which, $a_1 = \text{autocorrelation lag-1}$, and $a_2 = \text{autocorrelation lag-2}$,

lagged by 2 months instead of 1 month. The series is modelled as white noise ($a = 0$) when $a_1 < 0.4$.

The wavelet power spectrum gets its null hypothesis which states that series under examination has mean power range; so assumption can be made about the true features along with certain percent confidence. “95% confidence level” is equivalent near “significance at the 5% level”, and implication of a test contrary to certain background level is made. While “95% confidence interval” refers to the range of confidence about a given value. The 95% confidence signifies that 5% of the wavelet power should be above this level (Torrence and compo 1998).

A neutral and reliable estimation of the true power spectrum of the time series is provided by the global wavelet spectra. For example, it clearly differentiates

one peak from another, indicating the presence of an annual frequency, however other rain gauges show two or more peaks, independent of which frequencies they are, shown in Figure 4(a) and (b). Following this correspondence, Global wavelet power spectra helped to identify two main patterns: 01 with one main annual frequency referred to as pattern A (e.g. Figure 5(a), (c)) and 51 with more than one main frequency referred to as Pattern B (e.g. Figure 5(d)-(f)).

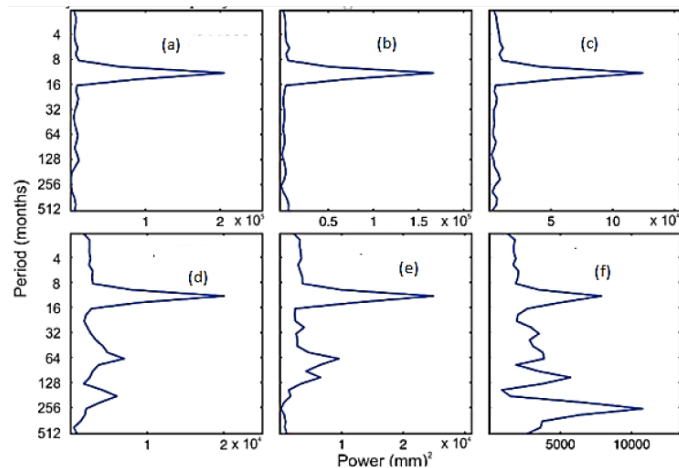


Figure 5: Global wavelet power spectra: (a), (b) and (c) classified as frequency Pattern A, characterized by one main frequency, at the 8- to 16-month band; and (d), (e) and (f) classified as frequency Pattern B.

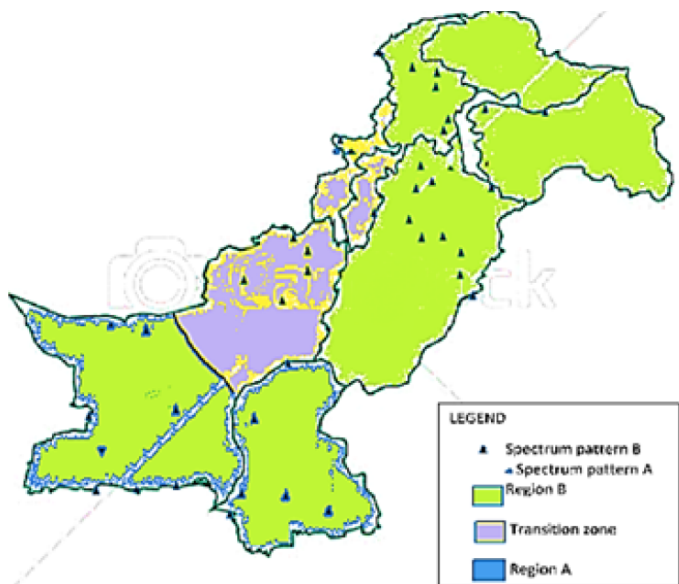


Figure 6: Three regions in Pakistan indicating Pattern (A, B and Transition zone) of the global wavelet power spectra over river Indus.

From this result, three distinct hydrological zones (generally named here, Section A, Section B and Transition zone) were recognized, illustrated in Figure 6. Region A intends to show Pattern A, Region B shows frequency Pattern B and Transition

region displays frequency Patterns A and B. Frequency Pattern A signifies the presence of only an annual frequency and, therefore, the shape of its global wavelet spectrum is different from those of Pattern B. Smith *et al.* (1998) also characterized time series using such global spectra, because a neutral and reliable approximation of power spectrum is obtained with it.

Thus, the characterization of river Indus basin in Pakistan into three hydrological regions, based on rainfall frequency, could enable the implementation of plans that is benefited for the agriculture and misuse of water in affected vicinity.

Conclusions

It is possible to bring this discussion to an end that the wavelet transform is an active device in regionalizing any zone through precipitation as we done for the Indus river basin. Records from 52 rain gauges were analyzed. The outcomes of the global power spectra showed a low yearly frequency all over the basin; whereas additional frequencies exist in major impact that signifies changes in the precipitation regime. Through global wavelet power spectra, we found peculiar patterns of rainfall data that might be used to portray the region. Hence, three sub-regions with homogenous precipitation patterns were recognized as: Section A with frequency pattern A (not apparent), Section B with frequency pattern B (the south and north part of the basin), and a Transition zone in the central part. A neutral and reliable estimation of true power spectrum is obtained by means of global wavelet spectrum. This is considered as simple and robust way to portray the time series variability of Indus river basin. More studies are suggested with a larger amount of rain gauges together with more hydrological variables to depict the entire basin.

Author's Contribution

The idea of research, calculations and plotting were completed by Kamran Zakaria. Noreen Munawar manipulated the whole text. Shafqat Ejaz provided the expert view of the paper.

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