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Intra-seasonal Variation of Rainfall and Climate Characteristics in Kabul River Basin

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Abstract
In Afghanistan, spring and summertime flash floods result in 54.3% of all natural disasters with an average annual economic loss of US$92.17 million between 1990 and 2014. Knowledge of climate and rainfall periodicity are urgently needed for urban and rural land use and infrastructure planning, and their flood protection. In this study, the Thornthwaite equation was used to determine the seasonal characteristics of dry and wet periods. Spectral Analysis of precipitation was carried out to search for periodicities and intraseasonal oscillations of rainfall within the Kabul River Basin. The analysis is based on data obtained from 49 ground-base stations with three parameters (precipitation, relative humidity, and temperature) for an 8-year (2006-2013) and 5-year (2009-2013) record. Five years weather maps made from JRA-55 (55 year Japan Reanalysis data) were used to recognize the moisture trajectory in each season. The results indicated that Kabul River Basin is divided into three parts with distinct climate regions as Central, Northern, and Eastern parts. The Weather maps of relative humidity with wind arrows showed the origins and pathways of air masses leading to heavy rainfall from the Arabian Sea and the Caspian Sea approaching from the west and northwest of Afghanistan in winter and spring season, corresponding to 10-day spectral peaks. In summer and autumn, influences of South Asian summer monsoon were recognized by 6-8 days of oscillation with different density in each station, where it was much significant in the Eastern part.

Keywords: Spectral Analysis, rainfall, flood, South Asian summer monsoon.

1. Introduction

In Afghanistan, spring and summertime flash floods result in 54.3% of all natural disasters with an average annual economic loss of US$92.17 million between 1990 to 2014 [1]. The water resources in KRB had been significant issues in recent years [2] as drought and extreme flooding events have increased. To understand the climate variability better, information on precipitation and moisture sources are essential, but in Afghanistan, such an information and research are lacking due to the three-decade war and a long gap in hydro-meteorological data observation since 1980 to around 2007 [3]. Thus, the objective of the present research is to analyse the available data record from 2006.

For Afghanistan, the annual variation of rainfall is considered to be quite low, while seasonal and spatial variations are considerable. Climate differences in KRB show that temperature has increased by 0.1-1.7 °C in winter and spring season with small decreases of 0.7°C in summer and autumn, for the time periods (1962-1983) and (2009-2013). As well as precipitation has fallen by 15-25 mm in winter and spring, while it has increased in summer and autumn seasons for the time periods of (1962-1983) and (2006-2013) [4].

The main goal of this study is to analyse the current climate characteristic of the Kabul River Basin considering the most recent data and knowledge on climate variability, inter-seasonal oscillations and the large-scale atmospheric moisture transport to KRB.

2. Materials and methods

2.1. Kabul River Basin

The climate of Afghanistan varies from arid to semi-arid with cold winters (minimum temperature down to -10°C) to hot summers (maximum temperature up to 50°C). The annual precipitation ranges from less than 50 mm/year in the southwest to 1000 mm/year in the northeast high elevation areas [5]. Afghanistan has five major river basins, Amu Darya, Kabul, Helmand, Harirud-Murghab, and Western River Basin. This study focuses on the Kabul River Basin, which is located in the northeast quarter of Afghanistan (Figure 1). Kabul urban area is growing rapidly and has around 4 million people. Geographically, the North part of the basin has high mountains (about 6000 meter), whereas the south-eastern part has an elevation of 400-meter above sea level. KRB has a total area of 53830 km2; with irrigated land are estimated to be 306,000 ha. About 93% of the entire forest of the country is located on the eastern side of the basin [6].

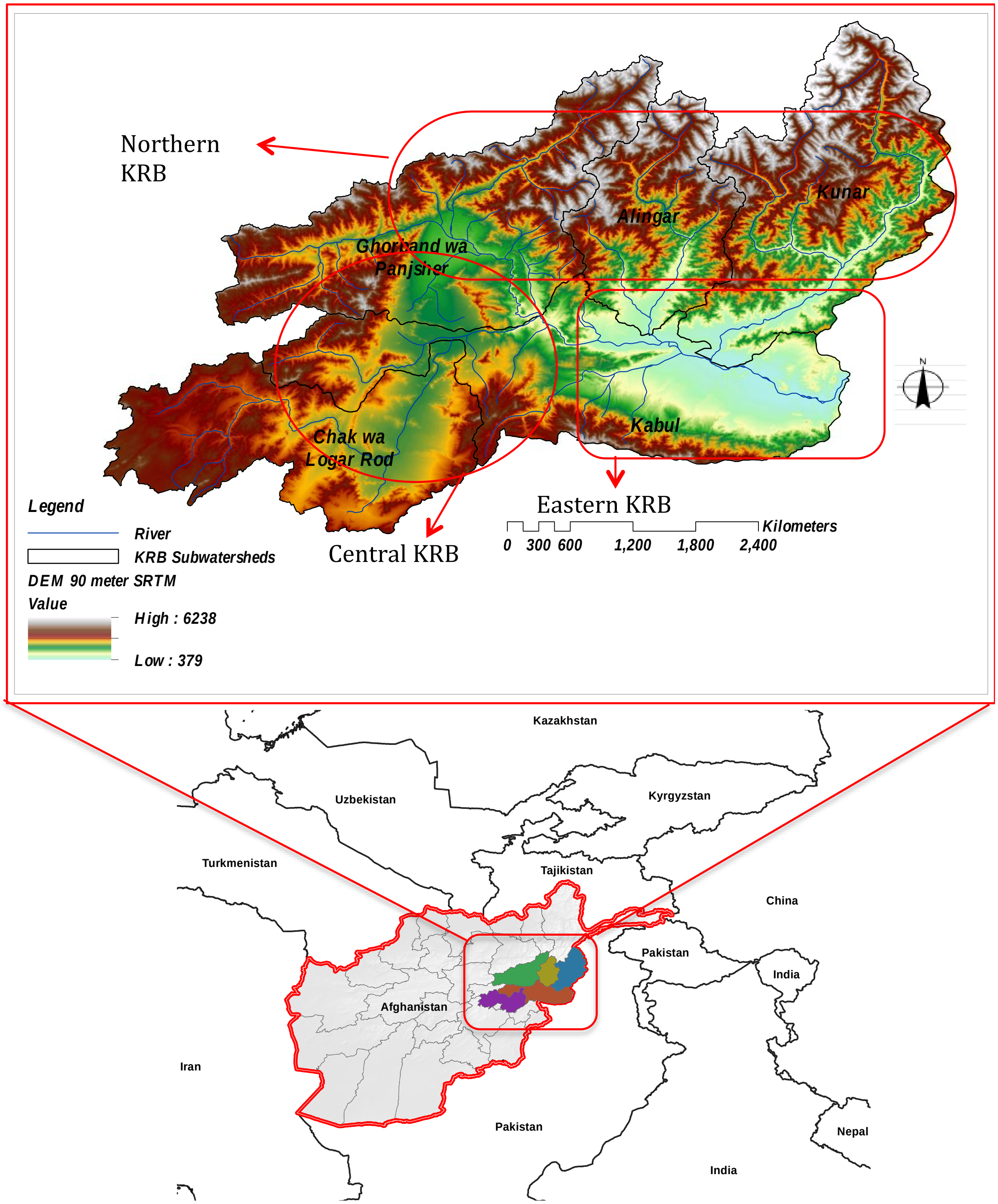


Figure 1. Global location of the Kabul River Basin and its topographic variations

2.2. Precipitation data

Daily precipitation data was used from 29 stations established in the Agromet-project (Ministry of Agriculture Irrigation and Livestock of Afghanistan, 2006-2013). Every 15 minutes data records of air temperature and relative humidity were obtained from 18 automatic hydrological stations observed by Ministry of Energy and Water of Afghanistan from 2009-2014 (Table 1). Horizontally distributed weather images were obtained from the Meteorological Laboratory in the University of the Ryukyus from 2009-2013 [7].

Table 1. Number of Hydro-meteorological Stations in each region

No	Region	Station Name	X	Y	Elevation (m)	Parameter
1	Central KRB	Badam Bagh	69.12	34.55	1803	PT
2		Darulaman	69.13	34.46	1822	PT
3		Gul Khana	69.2	34.51	1793	PT
4		Kabul	69.22	34.55	1789	PT
5		Kariz Mir	69.05	34.63	1926	PT
6		Paghman	68.99	34.58	2142	PT
7		Qargha	69.05	34.55	1934	PT
8		Sarobi	69.76	34.6	959	PT
9		Logar	69.05	33.99	1922	PT
10		Chack	68.59	34.11	2283	PT
11		Jaghatoo	68.55	33.95	-	PT
12		Qala-i-Malik	68.97	34.58	2211	AT-RH
13		Pul-i-Surkh	68.77	34.37	2216	AT-RH
14		Kabul	69.21	34.56	1980	AT
15		Shakardara	69	34.69	2168	AT-RH
16		Kapisa Agri	69.35	35.03	1471	PT
17		Kohestan	69.33	35.09	1536	PT
18		Dara Panjsheer	69.66	35.29	2330	PT
19		Dashtak	69.48	35.38	3401	PT
20		Charikar	69.19	35.04	1559	PT
21	Northern KRB	Jabulsaraj	69.25	35.13	1656	PT
22		Seya Gerd	68.86	35.00	1848	PT
23		North Salang	69.02	35.32	3586	PT
24		South Salang	69.07	35.3	2982	PT
25		Bagh-i-Lala	69.22	35.15	1698	AT-RH
26		Pul-i-Ashawa	69.14	35.09	1624	AT-RH
27		Bagh-i-Omomi	69.29	35.15	1587	AT-RH
28		Tang-i-Gulbahar	69.29	35.16	1625	AT-RH
29		Keraman	69.66	35.28	2232	AT-RH
30		Khawak	69.89	35.56	2405	AT-RH
31		Shukhi	69.48	34.94	1374	AT-RH
32		North Salang	69.02	35.32	3366	AT-RH
33		South Salang	69.07	35.3	3172	AT-RH
34		Asad Abad	71.15	34.88	875	PT

35		Asmar	71.43	35.02	1752	PT
36		Laghman	70.22	34.65	730	PT
37		Mehtarlam	70.2	34.65	751	PT
38		Agam	70.29	34.2	1205	PT
39		Farm Jadeed	70.51	34.4	554	PT
40		Ghazi Abad	70.74	34.26	552	PT
41		Jalalabad	70.47	34.47	597	PT
42		Sheshambagh	70.47	34.41	579	PT
43		Dakah	71.04	34.23	419	AT-RH
44	**Eastern KRB**	Asmar	71.2	34.92	832	AT-RH
45		Pul-i-Behsud	70.46	34.45	555	AT-RH
46		Pul-i-Qarghai	70.24	34.55	643	AT-RH
47		Naghlu	69.72	34.64	998	AT-RH
48		Pul-i-Kama	70.56	34.47	558	AT-RH
49		Pul-i-Nalyar	70.37	34.83	902	AT-RH

2.3. Methods

To characterize the climate of different regions in the Kabul River Basin, Thornthwaite's concept [8] where the precipitation effectiveness index (PE) classifies the climate from wet to arid (Table 2) based on Equation 1 was used.

Table 2. Thornthwaite Weather Classification

PE Index	Climate
More than 128	Wet
64 - 127	Humid
32 - 63	Sub-humid
16 - 31	Semi-arid
Less than 16	Arid

$$\text{PE index} = \sum_{1}^{n=12} 115\left(\frac{P}{T} - 10\right)^{\frac{10}{9}} \qquad (1)$$

Where, P is monthly precipitation in inches; T is temperature in °F; and n is number of months (12). Thornthwaite's concept from 1957 was used to estimate the potential evapotranspiration (PET) equation [9]. The PET and precipitation define dry and wet periods of climate over the year. PET is estimated from temperature and a heat index, which has considerable limitations, but this equation is widely used as it is simple and the temperature data is available.

Thornthwaite's equations for PET estimation are as follows:

$$PET = 16\left(\frac{10t}{I}\right)^{a} \tag{2}$$

$$I = \sum_{1}^{12} \mathrm{i}\,,\; i = \left(\frac{t}{5}\right)^{1.514} \tag{3}$$

$$a = (6.75 \times 10^{-7})\, I^3 - (7.71 \times 10^{-3})\, I^3 + (1.792 \times 10^{-2})\, I + 0.492 \tag{4}$$

Where, *t* is mean monthly temperature in °C, *I* is annual heat index, *i* is monthly heat index, *a* is a co-efficient that varies with the heat index.

Spectral Analysis

Spectral analysis was used as a method for the separation of the variance of the time series into contributions associated with different time scales [10]. For many real time series, the spectra sometimes show a decrease of amplitude with an increase of frequency that is called "red-noise". The climatic red-noise in a time series can be modelled as a first-order autoregressive process (AR1) according e.g. to Hasselmann (1976) and Schulz et.al (2002) [11, 12].

The AR (1) process equations for variable r:

$$r(t_i) = r_i r(t_{i-1}) + e(t_i) \tag{5}$$

$$r_i = \exp(-(t_i - t_{i-1}) / t \tag{6}$$

For times $t_i (i = 1, 2, ..., N)$, τ is the characteristic time scale of the AR1 process, and ε indicates "white" Gaussian noise with zero mean and variance.

$$s_e^2 = 1 - \exp\left(-\frac{2(t_i - t_{i-1})}{t}\right) \tag{7}$$

The spectrur $G_{rr}(f_j)$ $Grr(f_i)$ corresponding to the time-domain process can be calculated from the equation below:

$$Grr(f_i) = G_0 \frac{1 - r^2}{1 - 2r\cos\left(\frac{p f_i}{f_{Nyq}}\right) + r^2}, \tag{8}$$

where f_i indicates discrete frequency up to the Nyquist frequency f_{Nyq} and G_0 is the average spectral amplitude. The "average autocorrelation coefficient" ρ is calculated from the arithmetic mean of the sampling interval.

$$\Delta t = \frac{(t_N - t_1)}{N - 1} \quad as \quad \rho = \exp(-\frac{\Delta t}{\tau}) \qquad (9)$$

A Fortran90 source code was applied for all above calculations in a computer program named REDFIT that calculates above steps. This program is freely available via the link: http://www.ncdc.noaa.gov/paleo/softlib/redfit/redfit.html.

3. Results and discussion

3.1. Climate characteristics

The results show some variability of climate between regions (Figure 2). Over the course of an average year (2006-2013) precipitation is slightly higher in winter at the Central and Northern and vice versa in summer time at the Eastern part. According to the climate classification of Thornthwaite, the Central and Northern regions can be classified as a sub-humid and the Eastern region as a semi-arid climate (PE = 41, 39, 20) (Table 2). Climatic analysis of the data of 20 stations used for the Central KRB, 18 stations for Northern KRB, and 11 stations for Eastern KRB (Table 1) shows, the temperature was higher in the Eastern region than in the other regions that has affected the PE index. Relative humidity over all regions had significant peaks in spring and winter seasons but in summer and autumn there was a significant peak just in the Eastern region (Figure 2).

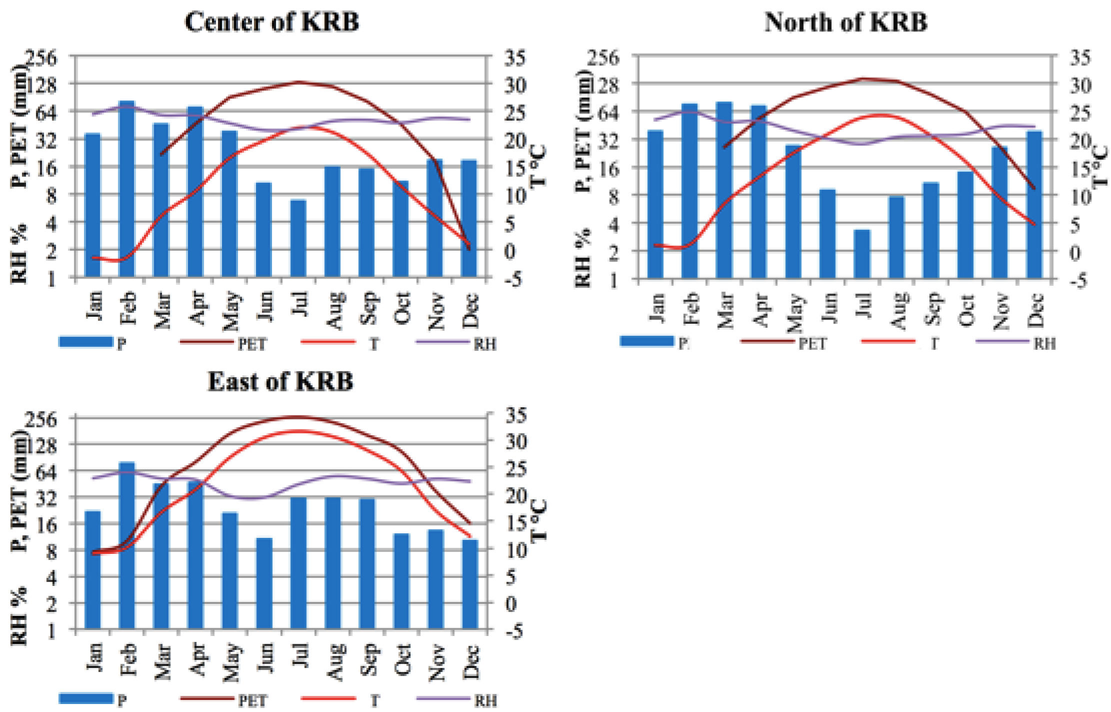


Figure 2. Monthly mean climate characteristics in three regions of KRB. (P =Precipitation, T = Temperature, PET = Potential Evapotranspiration, RH = Relative Humidity)

Weather maps during heavy rainfall events from 2009 to 2013 show that spring and winter peaks of precipitation corresponded with large-scale humidity that passes through the Caspian Sea and the Black Sea, which is approaching from north and northwest of Afghanistan (Figure 3) In summer and autumn seasons, the climate is influenced by South Asian summer monsoon. Summer monsoon is noticed only in the eastern parts of Afghanistan with high rainfall events (Figure 2). The South Asian summer monsoon was approaching from the Arabian Sea, the Bay of Bengal, and the Indian Ocean, crossing India, passing Pakistan and affecting the Eastern part of the Kabul River Basin (Figure 3). Temperature showed spatially different fluctuation patterns. Daily fluctuation of temperature did not show below zero values in the eastern part, while it was below zero in other regions. The maximum daily temperature was higher in the eastern part, especially in July and August. The wet period over the Northern and Central parts occurs in winter and early spring seasons, while it exists just in winter in the Eastern part (Figure 2). Summer is almost dry over all regions, and heavy rainfall could cause flooding over these regions.

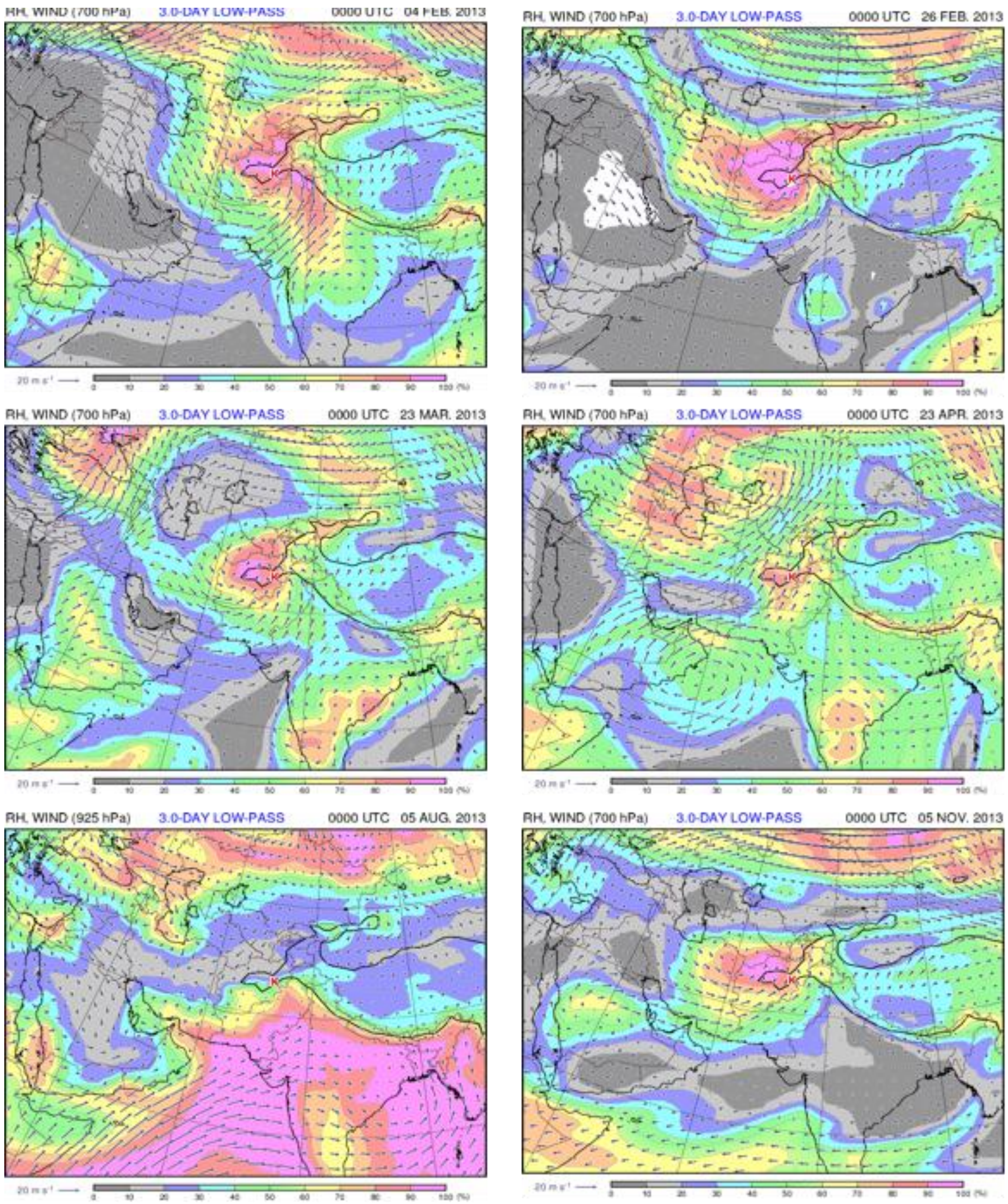
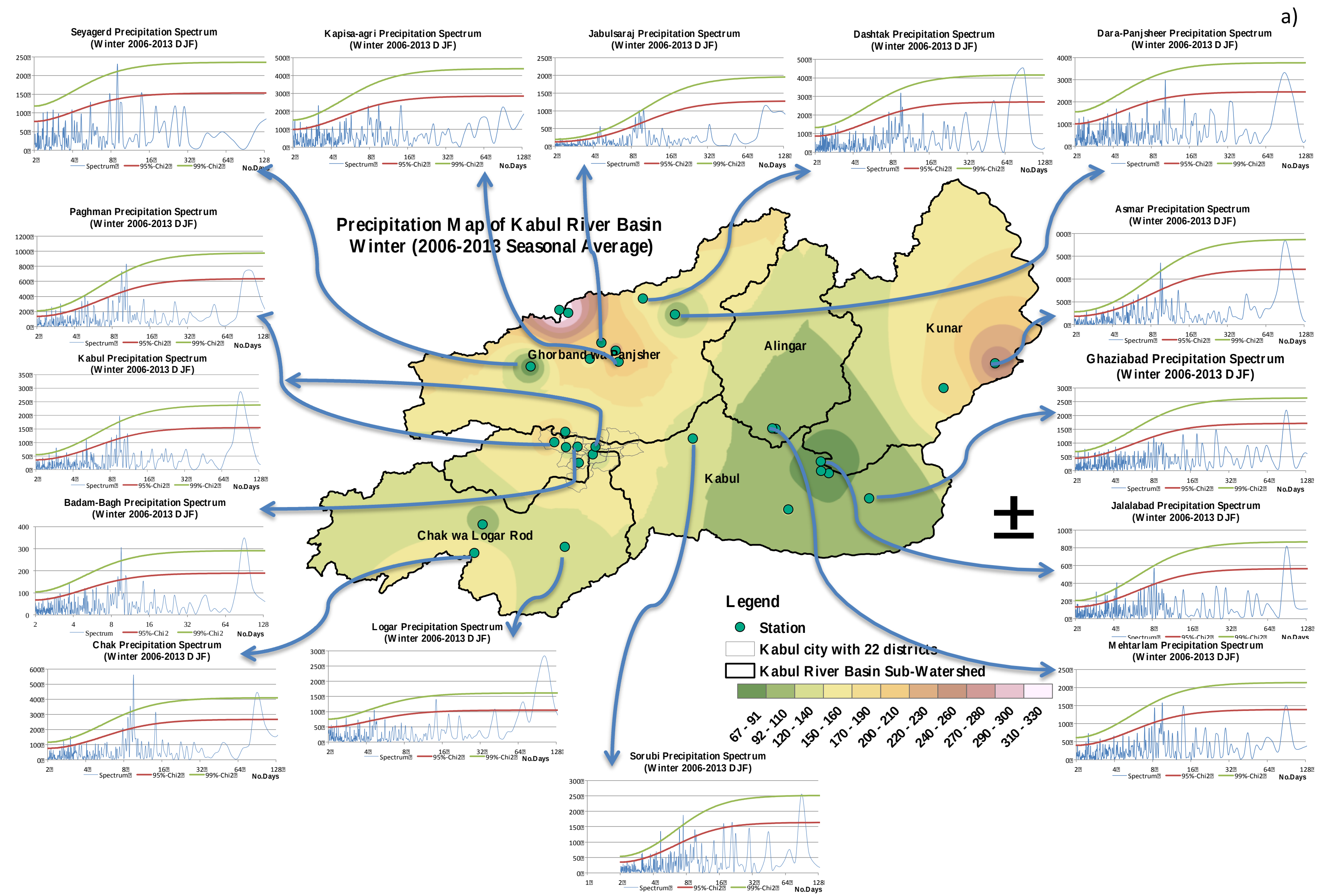


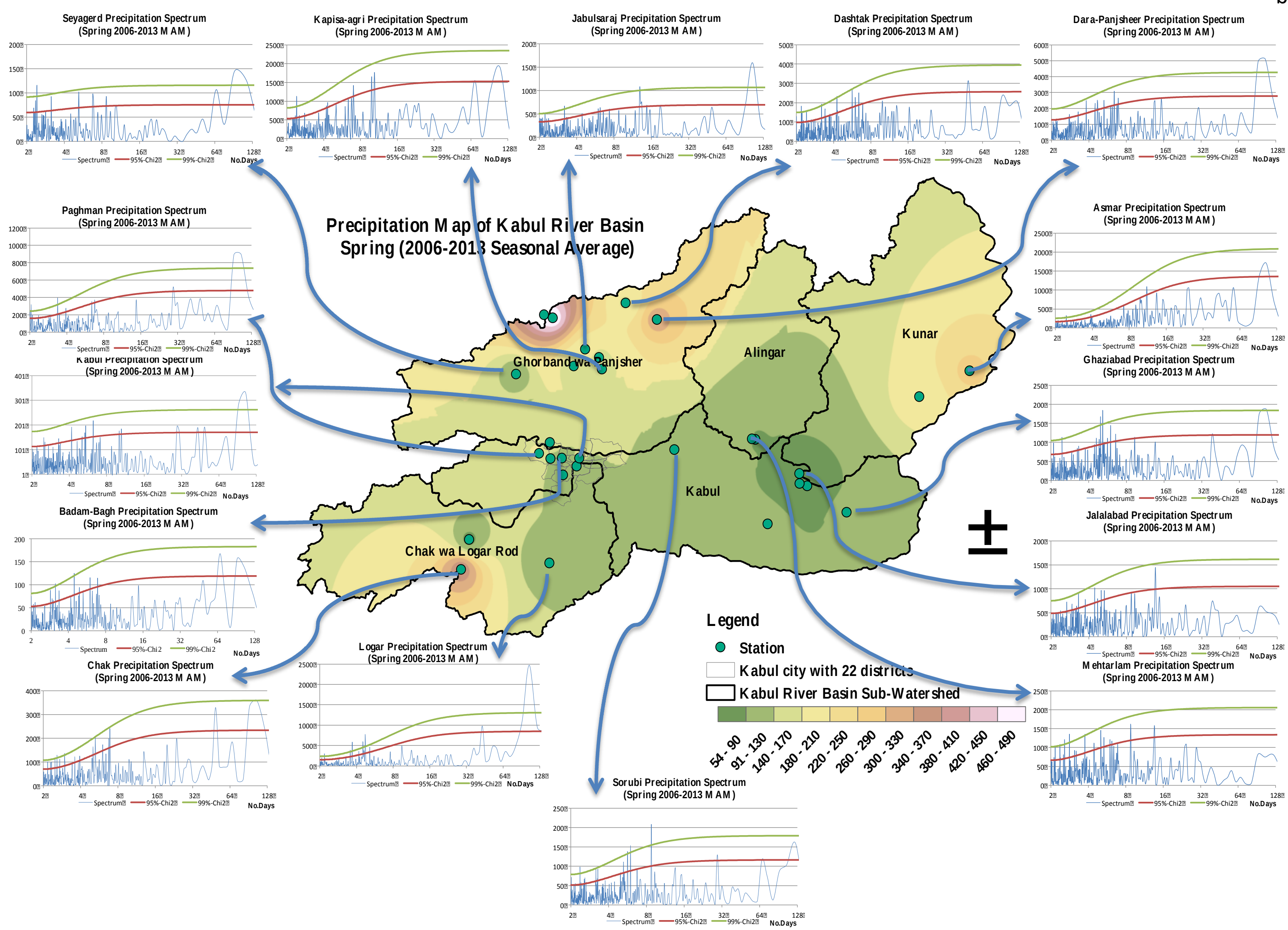
Figure 1. Weather maps in different rainfall events, **(**shaded colors are relative humidity distribution, arrows are wind vectors considering 3-days low-pass filter)

3.2. Spectral Peaks

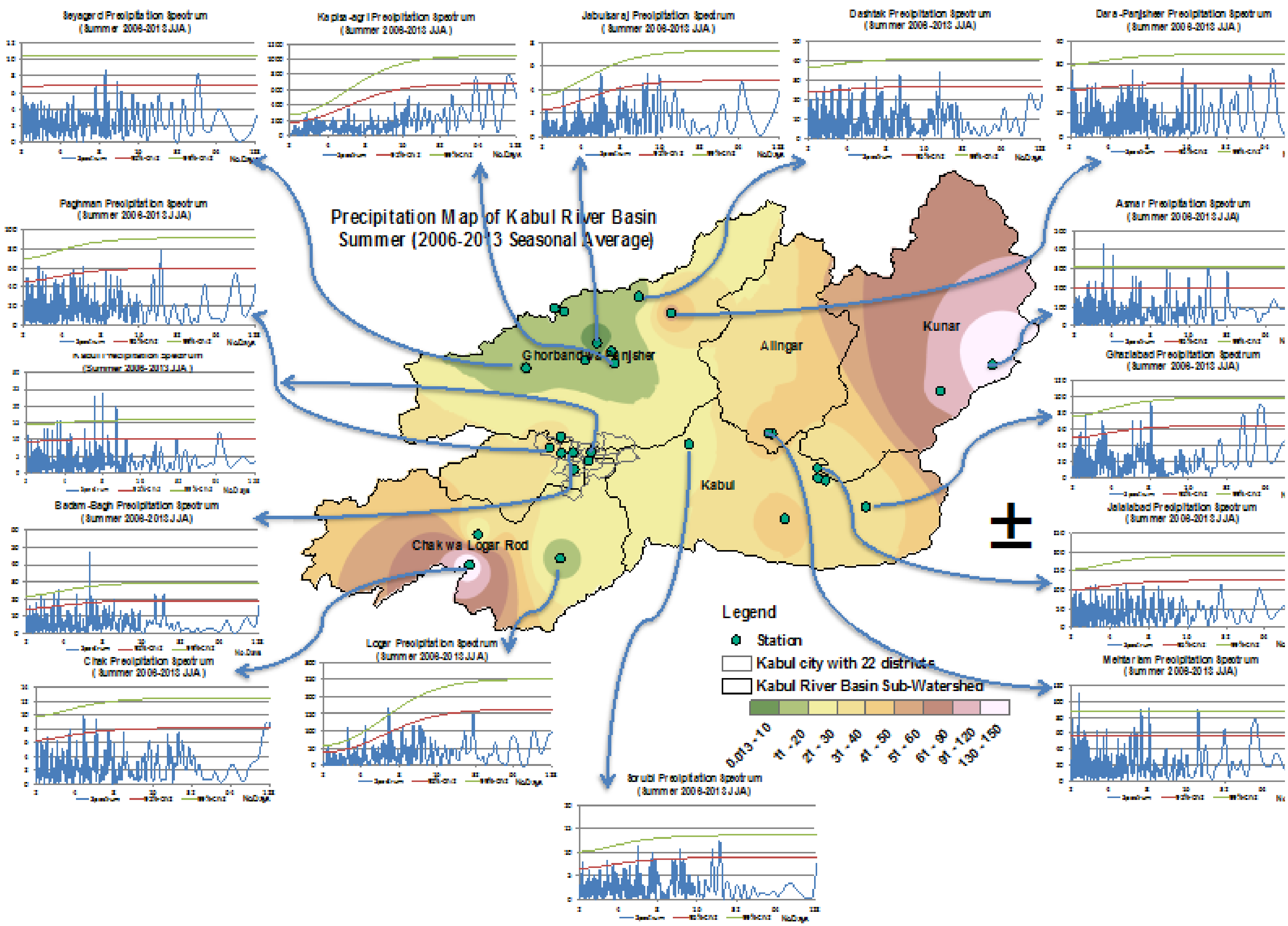
Spectral peaks of rainfall in each meteorological station from 2006to 2013 were calculated with 90% and 99% confidence interval of red-noise. The seasonal cycle of rainfall (for 2006-2013) over all regions showed ten days oscillation in the winter season. The winter spectral (Figure 4a) shows nearly 10-day peak considering 95 and 99 % confidence level (smooth curves) in all stations; it corresponds with existence of large-scale air mass (Figure 3). Spectral peaks in the spring season (Figure 4b) shows nearly 7-10 days peak in most of the stations with addition of 14-16 days oscillation in the Eastern part. The summer and autumn (Figure 4c and4d) spectral peaks show 6-8 days peaks with a high density in the Eastern part. This information would help to manage agriculture rainfed areas considering each period of rainfall as well as for flood events determination.


a)
Precipitation Map of Kabul River Basin
Winter (2006-2013 Seasonal Average)
Seyagerd Precipitation Spectrum (Winter 2006-2013 DJF)
Kapisa-agri Precipitation Spectrum (Winter 2006-2013 DJF)
Jabulsaraj Precipitation Spectrum (Winter 2006-2013 DJF)
Dashtak Precipitation Spectrum (Winter 2006-2013 DJF)
Dara-Panjsheer Precipitation Spectrum (Winter 2006-2013 DJF)
Paghman Precipitation Spectrum (Winter 2006-2013 DJF)
Asmar Precipitation Spectrum (Winter 2006-2013 DJF)
Kabul Precipitation Spectrum (Winter 2006-2013 DJF)
Ghaziabad Precipitation Spectrum (Winter 2006-2013 DJF)
Badam-Bagh Precipitation Spectrum (Winter 2006-2013 DJF)
Jalalabad Precipitation Spectrum (Winter 2006-2013 DJF)
Chak Precipitation Spectrum (Winter 2006-2013 DJF)
Logar Precipitation Spectrum (Winter 2006-2013 DJF)
Mehtarlam Precipitation Spectrum (Winter 2006-2013 DJF)
Sorubi Precipitation Spectrum (Winter 2006-2013 DJF)
Spectrum
95%-Chi2
99%-Chi2
No.Days
Ghorband wa Panjsher
Alingar
Kunar
Kabul
Chak wa Logar Rod
Legend
Station
Kabul city with 22 districts
Kabul River Basin Sub-Watershed
67 - 91
92 - 110
120 - 140
150 - 160
170 - 190
200 - 210
220 - 230
240 - 260
270 - 280
290 - 300
310 - 330

b)


Precipitation Map of Kabul River Basin
Spring (2006-2013 Seasonal Average)
Seyagerd Precipitation Spectrum (Spring 2006-2013 MAM)
Kapisa-agri Precipitation Spectrum (Spring 2006-2013 MAM)
Jabulsaraj Precipitation Spectrum (Spring 2006-2013 MAM)
Dashtak Precipitation Spectrum (Spring 2006-2013 MAM)
Dara-Panjsheer Precipitation Spectrum (Spring 2006-2013 MAM)
Paghman Precipitation Spectrum (Spring 2006-2013 MAM)
Asmar Precipitation Spectrum (Spring 2006-2013 MAM)
Kabul Precipitation Spectrum (Spring 2006-2013 MAM)
Ghaziabad Precipitation Spectrum (Spring 2006-2013 MAM)
Badam-Bagh Precipitation Spectrum (Spring 2006-2013 MAM)
Jalalabad Precipitation Spectrum (Spring 2006-2013 MAM)
Logar Precipitation Spectrum (Spring 2006-2013 MAM)
Chak Precipitation Spectrum (Spring 2006-2013 MAM)
Mehtarlam Precipitation Spectrum (Spring 2006-2013 MAM)
Sorubi Precipitation Spectrum (Spring 2006-2013 MAM)
Spectrum
95%-Chi2
99%-Chi2
No.Days
Ghorband wa Panjsher
Alingar
Kunar
Kabul
Chak wa Logar Rod
Legend
Station
Kabul city with 22 districts
Kabul River Basin Sub-Watershed
54 - 90
91 - 130
140 - 170
180 - 210
220 - 250
260 - 290
300 - 330
340 - 370
380 - 410
420 - 450
460 - 490

c)



Precipitation Map of Kabul River Basin
Summer (2006-2013 Seasonal Average)
Ghorband wa Panjsher
Alingar
Kunar
Kabul
Chak wa Logar Rod
Legend
Station
Kabul city with 22 districts
Kabul River Basin Sub-Watershed
0.013 - 10
11 - 20
21 - 30
31 - 40
41 - 50
51 - 60
61 - 90
91 - 120
130 - 150
Paghman Precipitation Spectrum (Summer 2006-2013 JJA)
Asmar Precipitation Spectrum (Summer 2006-2013 JJA)
Ghaziabad Precipitation Spectrum (Summer 2006-2013 JJA)
Jalalabad Precipitation Spectrum (Summer 2006-2013 JJA)
Logar Precipitation Spectrum (Summer 2006-2013 JJA)
Badam-Bagh Precipitation Spectrum (Summer 2006-2013 JJA)
Dara-Panjsher Precipitation Spectrum (Summer 2006-2013 JJA)

d)

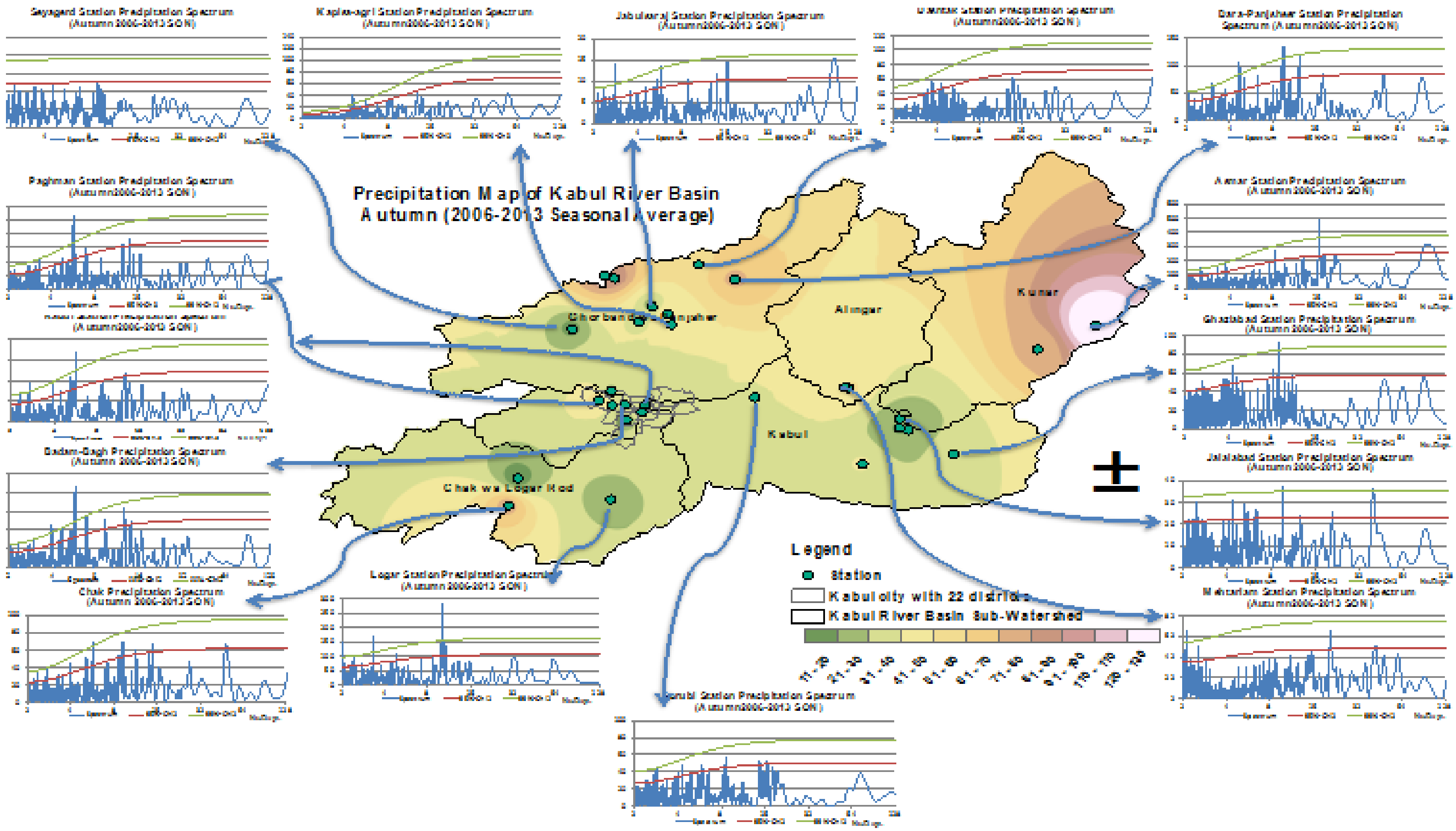


Figure 2. Spectral peaks of daily rainfall in four seasons based on 810-days, for the period 2006-2013, considering 95 and 99 % confidence level (smooth curves) in all stations; a) winter season, b)spring season, c) summer season, d) autumn season, period in days on x-axis.

3.3. Uncertainty

In this research, the authors tried to provide a first assessment and a general overview of the seasonal weather characteristics in the Kabul River Basin considering the newly available data. Considering the complex topography of Afghanistan, it is recommended that a further work should be undertaken in detailed explanation and investigation of seasonal variations of climate in KRB for each extreme event.

4. Conclusion

This paper determined the three different climate characteristics in Kabul River Basin at each region; Central, Northern, and Eastern, and the moisture source in each season of the year. A time domain of rainfall analysed by spectral analysis method was used to find the periodicity of the rainfall in each season. The climate was classified with Thornthwaite's concept. The main conclusions are:

1. Winter and spring seasons were determined as wet periods in all three regions.
2. Summer and early autumn were classified as dry due to high temperature, but precipitation was quite high in the Eastern part.
3. Winter rainfall spectral analysis showed 10-days peaks in all parts this corresponds to the existence of large-scale air mass.
4. There were summer spectral peaks shown in eastern part, which accompanied with South Asian summer monsoon.
5. Weather maps in winter and spring showed the moist source mostly coming from the Caspian Sea, Black Sea, Gulf of Oman, and Gulf of Persian approaching from west and northwest with anticyclonic circulations.
6. Weather maps in summer and autumn showed the source of moisture is mainly from South Asian summer monsoon that the Eastern part was mainly under effect. That is why the summer precipitation is high in the Eastern part.

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