Meteorological Drought Analysis by Different Methods in Helmand River Basin, Afghanistan

Mohammad Musa Alami, Sardar Wali Din, and Gokmen Tayfur

Abstract—This study evaluates drought in Lashkargah, Farah, Adraskan, and Gardandiwal stations in Helmand River Basin (HRB) in Afghanistan. Thirty-seven years of monthly recorded precipitation data from 1979 to 2015 is employed for this purpose. The Standardized Precipitation Index (Normal-SPI, Log-SPI, and Gamma-SPI), Percent of Normal (PN), and Deciles were used as the drought indexes. All methods are applied to annual long term precipitation data set. Results show that all DI methods provide almost the same results for the stations. The log-SPI and gamma-SPI predict extreme drought conditions, whereas, the normal-SPI determines wet and less drought conditions. The results emphasize that the PN method predicts more moderate drought years in comparison with SPI method, however, Deciles method shows longer period of extreme and severe drought than other methods. As a result, the five methods indicate various drought intensities in 1985, 1987, 1994, 1997, 1999, 2000, 2001, 2002, 2003, and 2004 with a peak extreme drought in 2001 for the all four stations. Therefore, extreme drought conditions happened in 2001 in all stations confirm to the recorded drought reports for the same region. It is noted that normal-SPI and PN indicated less and moderate drought condition while the log-SPI, gamma-SPI, and Deciles captured the historical extreme and severe drought periods successfully, thus, these three methods are recommended to be applied to this region as drought assessment tools.

Index Terms— Afghanistan, Deciles, Drought Indexes, Helmand River Basin, PN, SPI.

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1 Introduction

Drought is complicated natural phenomenon that is usually defined as the reduction in available normal level water. It harms environment, agriculture, humans, wildlife, economic and social life [Zarei et al., 2016; Sirdas, 2003]. Various drought indexes have been developed as drought monitoring and assessment tools in different part of the world. Drought indexes are quantitative measurements that determine the drought level and intensity by integrating one or more variables of data such as precipitation and evapotranspiration into a single numerical value [Yacoub and Tayfur, 2016]. The most popular drought indexes are the Standardized Precipitation Index (SPI) which is used worldwide, the Palmer Drought Severity Index (PDSI) which is commonly used in the United State, the Deciles Index with widely usage in Australia, the China-Z Index (CZ) which is generally used in China, and the Percent of Normal (PN) which is used worldwide. Generally, most of DI methods are introduced for a specific region. Therefore, to the best knowledge of authors, there is no any related scientific research or article that recommends a specific method and analysis for the drought conditions in Afghanistan.

Although Afghanistan has suffered drought in the last two decades, there is no any published scientific research that evaluates the drought indexes in Afghanistan due to the shortage of meteorological data in the country. Nevertheless, there are some reports that mention the droughts conditions in Afghanistan. The World Bank Working Paper by Ahmad and Wasiq (2004) reported that Afghanistan experienced four consecutive years of drought from 1998 to 2001. Mayan (2015) cited that Afghanistan initiated experiencing unusual droughts beginning in 1995 and it continued until heavy snow began falling in the 2002– 2003 winter season. Another scientific project report by Asia-Pacific Network for Global Change Research [APN, 2015] stated that Afghanistan witnessed the worst drought in its recorded history in 2001 that effected the 14 out of 34 provinces of south and central areas of the country.

There is also some related research in neighboring countries (Iran and Pakistan) that have evaluated the drought in the regions, which are close to south-west part of Afghanistan. Ashraf and Routray (2015) investigated the drought in the Balochistan, they found that years 2000, 2001, 2002, and 2004 were the most severe drought duration in the province. A study by Zarei et al. (2016) in bordering city Saravan, Iran indicated extreme drought in 1987, 1998, 2000, and 2001. Morid et al. (2006) stated that the most recent drought of 1998-2001 in Iran was the worst in the last three decades.

This study aims to evaluate the historical drought in Helmand river basin of Afghanistan and compare the performance of different DI methods. The DI methods in this study include the standardized precipitation index (SPI) with three types of statistical distribution (Normal SPI, Log-normal SPI, and Gamma SPI), the Percent of Normal (PN), and the Deciles. These methods require monthly recorded precipitation data.

2 STUDY AREA AND DATA

2.1 Study Area

Afghanistan is a land-locked country with a total area of 652.000 km2 in south central Asia with the geographic location

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of (33 00 N, 65 00 E). The climate is arid to semi-arid with cold winters and hot summers [Broshears et al., 2005]. Afghanistan is divided into five major river basins as Amu Darya River Basin, Harirud-Murghab River Basin, Helmand (Hirmand) River Basin, and Kabul (Indus) River Basin as shown in (Figure 1).

The study area is Helmand River Basin (HRB) and also known as Hirmand River Basin. HRB is the largest basin among five basins in Afghanistan as shown in (Figure 1) and it has a total area of 345200 km2, from which 82.23 % is located in Afghanistan [Wolf et al., 1999]. The basin covers the catchment area for Helmand River which is the longest river in Afghanistan with 1300 km length [Thomas et al., 2016]. Helmand River rises from Hindu Kush Mountains in the north-east of Afghanistan and drains into Sistan Depression near to Afghan-Iranian border in the south-east of Afghanistan. Annual mean precipitation varies from about 50 mm in the south-west to almost 300 mm in the north-west part of the basin [Goes et al., 2015]. Precipitation mostly happens in winter months (December, January, February, and March), and falls as snow in the upper basin.

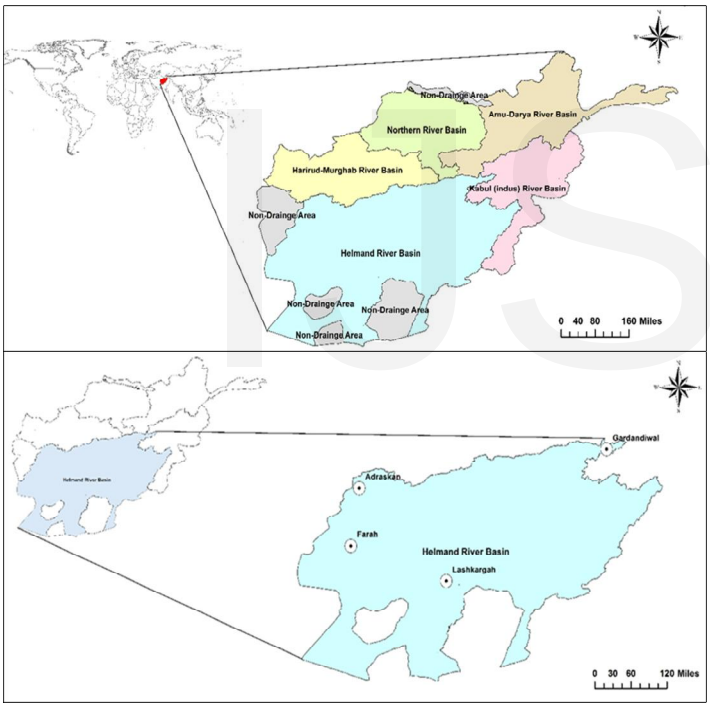

Figure 1 Five major river basins of Afghanistan (upper map) and Helmand River Basin with four precipitation stations (lower map)

2.2 Data

Due to three decades of war and conflict in Afghanistan, there is the shortage of meteorological data. Recently, the precipitation data is completed and reanalyzed for most of meteorological stations of Afghanistan by the Ministry of Energy and Water of Afghanistan (MEW). The data used in this study is collected from the Ministry of Energy and Water of Afghanistan for four stations of Helmand River Basin, namely Lashkargah (31°34'58.36"N-64°21'17.12"E), Farah (32°21'52.15"N-62°3'42.48"E), Adraskan (33°38'13.44"N-62°15'45.6"E), and Gardandiwal (34°30'1.35"N-68°12'45.56"E) as shown in (Figure 1). Thirty-seven years (1979-2015) monthly recorded precipitation data used for the stations is shown in Figure 2. The annual mean precipitation for Lashkargahm, Farah, Adraskan, and Gardandiwal stations are 94 mm, 119 mm, 199 mm, and 315 mm, respectively.

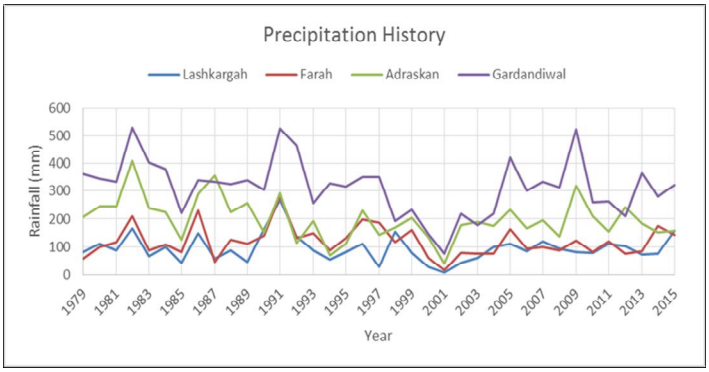

Figure 2 Monthly recorded precipitation data for the stations

3 METHODOLOGY

In this study, the Standardized Precipitation Index (normal-SPI, log-SPI, and gamma-SPI), the Percent of Normal (PN), and the Deciles methods are applied to evaluate the meteorological drought index for four stations in Helmand River Basin in Afghanistan.

3.1 Standardized Precipitation Index (SPI)

The Standardized Precipitation Index (SPI) is a widely used index to evaluate meteorological drought for a period of time. It was developed by McKee et al. (1993) using precipitation as the only input parameter. Drought classification for z-score (SPI) index is shown in Table 1. Positive SPI values indicate wet periods, conversely negative SPI values indicate dry periods.

TABLE 1
Drought classification for SPI values [Barua *et al*. 2010]

SPI value(z-score)	Drought Classification
2.00 or more	Extremely wet
1.50 to 1.99	Very wet
1.00 to1.49	Moderately wet
0.99 to -0.99	Near normal
-1.00 to -1.49	Moderate drought
-1.50 to -1.99	Severe drought
-2.00 or less	Extreme drought

Three types of widely used SPI distribution are used in this study as the Gamma Distribution SPI, the Log-normal SPI, and the Normal SPI [Cacciamani et al., 2007].

3.2 Gamma-SPI

Gamma-SPI is the most widely applied observational model for precipitation data. It involves fitting a gamma probability density function to a given time series of precipitation [Angelidis et al., 2012]. It is defined by its probability density function as:

$$g(x)=\frac{1}{\beta^{\alpha}\Gamma(\alpha)}x^{\alpha-1}e^{\frac{-x}{\beta}} \qquad \text{for } x>0 \qquad (1)$$

where $\alpha>0$ is a shape parameter, $\beta>0$ is a scale parameter, and $x>0$ is the amount of precipitation. $\Gamma(\alpha)$ is the gamma function, which is defined as:

$$\Gamma(\alpha)=\int_0^{\infty}\gamma^{\alpha-1}e^{-y}dy \qquad (2)$$

α and β parameters can be estimated as follows (Thom, 1958):

$$\alpha=\frac{1}{4A}\left(1+\sqrt{1+\frac{4A}{3}}\right), \beta=\frac{\bar{x}}{\alpha}, \text{ with } A=\ln(\bar{x})-\frac{\sum\ln(x)}{n} \qquad (3)$$

In Eq. (3), n is the number of observations. After estimating α and β coefficients, the probability density function is integrated with respect to x, which yields the following expression G(x) for the cumulative probability:

$$G(x)=\int_0^x g(x)dx=\frac{1}{\beta^{\alpha}\Gamma(\alpha)}\int_0^x x^{\alpha-1}e^{-x/\beta}dx \qquad (4)$$

Substituting t for x/β in Eq. (4), then it is reduced to:

$$G(x)=\frac{1}{\Gamma(\alpha)}\int_0^x t^{\alpha-1}e^{-t}dt \qquad (5)$$

As the gamma function is not defined for x=0, for possibility of zero values, the cumulative probability function becomes:

$$H(x)=q+(1-q)G(x) \qquad (6)$$

where q is the probability of zero precipitation. The cumulative probability distribution is then transformed into the standard normal distribution to yield the SPI. The approximate conversion provided by Abramowitz and Stegun (1965) is given as:

for $0 < H(x) < 0.5$

$$z=SPI=-\left(t-\frac{c_0+c_1t+c_2t^2}{1+d_1t+d_2t^2+d_3t^3}\right), t=\sqrt{\ln\left(\frac{1}{(H(x))^2}\right)} \qquad (7)$$

for $0.5 < H(x) < 1.0$

$$z=SPI=+\left(t-\frac{c_0+c_1t+c_2t^2}{1+d_1t+d_2t^2+d_3t^3}\right), t=\sqrt{\ln\left(\frac{1}{(1.0-H(x))^2}\right)} \qquad (8)$$

Where c_0 = 2.515517, c_1 = 0.802853, c_2 = 0.010328, d_1 = 1.432788, d_2 = 0.189269, and d_3 = 0.001308.

3.3 Normal-SPI

The normal-SPI uses the normal probability distribution instead of gamma distribution [Angelidis et al., 2012]. It is mathematically easier to calculate. In this case, the SPI index simply becomes:

$$SPI=z=\frac{x-\mu}{\sigma} \qquad (9)$$

Where z = SPI value, μ = population mean, and σ = standard deviation.

3.4 Log-SPI

Log–SPI distribution is non-negative and positively skewed. It is simple and just a logarithmic transformation of the data. By applying the log-normal distribution with the sample mean of logarithmic transformed data, the SPI becomes:

$$SPI=z=\frac{\ln(x)-\mu}{\sigma} \qquad (10)$$

3.5 Percent of Normal (PN)

The (PN) is a drought index for evaluation of meteorological data as the percent of the actual precipitation to the normal precipitation. It is generally applied to long-term mean precipitation where at least a 30-year mean is considered [Morid et al., 2006; Yacoub and Tayfur, 2016]. Generally monthly, seasonally, and annual PN values are calculated for drought index to be 100%, where, less than 100% of PN values indicate dry periods. However, the same PN may show different results in the different locations. Therefore, it is not a useful method to apply alone to an area [Hayes, 2006]. Drought index classification for the PN values is shown in Table 2.

TABLE 2
Drought index classification for PN [Barua *et al*. 2010]

NP values	Drought Classification
180% or more	Extremely wet
161% to 180%	Very wet
121% to 160%	Moderately wet
81% to 120%	Near normal
41% to 80%	Moderate drought
21% to 40%	Severe drought
20% or less	Extreme drought

3.6 Deciles

The Deciles approach is developed by Gibbs and Maher (1997]. In this method, the long-term precipitation data is ranked from highest to lowest to construct a cumulative frequency distribution. The distribution is divided in ten parts or deciles on the basis of equal probabilities [Barua et al. 2010]. The deciles values and drought ranking classifications are giv-

en in Table 3.

TABLE 3
Deciles drought ranking classification

Deciles values	Drought Classification
Deciles 1-2 (lowest 20%)	Much below normal
Deciles 3-4 (next lowest 20%)	Below normal
Deciles 5-6 (middle 20%)	Near normal
Deciles 7-8 (next highest 20%)	Above normal
Deciles 9-10 (highest 20%)	Much above normal

4 APPLICATION OF THE METHODS

The SPI (Normal-SPI, Log-SPI, and Gamma-SPI), the Percent of Normal (PN), and the Deciles values were computed for annual (12-months) for Lashkargahm, Farah, Adraskan, and Gardandiwal stations of Helmand River Basin in Afghanistan.

4.1 Lashkargah Station

According the SPI results in Lashkargah station (Figure 3a), the normal-SPI determines wet and less drought conditions. Conversely, the log-SPI predicts extreme drought conditions. The gamma-SPI shows the results mostly between normal-SPI and log-SPI. The extreme and severe drought conditions happened in 1997, 2000, and 2001. Moderate drought years include 1985, 1989, 2000, and 2002. The extreme wet period happened in 1990, 1991, and 1992. The severe and moderate wet years include 1982, 1986, and 1998.

The deciles result and threshold ranges for Lashkargah Station are given in Table 4. According the results, the drought condition occurred when precipitation was less than 86.53 mm / year. When precipitation is less than 74.68 mm / year and 44.22 mm / year severe and extreme drought occur, respectively. Figure 3b shows the deciles ranking for Lashkargah station. To compare with SPI results, deciles ranking indicates long extreme and severe drought conditions. Extreme drought years are 1985, 1987, 1989, 1994, 1997, 2000, 2001, and 2002. The severe drought years are 1983, 1999, 2003, 2009, 2010, 2013, and 2014. According, to the deciles method, the extreme wet conditions occurred in 1982, 1986, 1990, 1991, 1992, 1998, and 2007.

Figure 3c presents results for PN method for Lashargah station. This method indicates the extreme and severe drought in 1997, 2000, and 2001. The moderate drought is happened in 1983, 1985, 1987, 1989, 1994, 2010, 2013, and 2014. This method also specifies the extreme wet period as 1990, 1991, and 1992. The severe and moderate wet years are 1982, 1986 1998, and 2007.

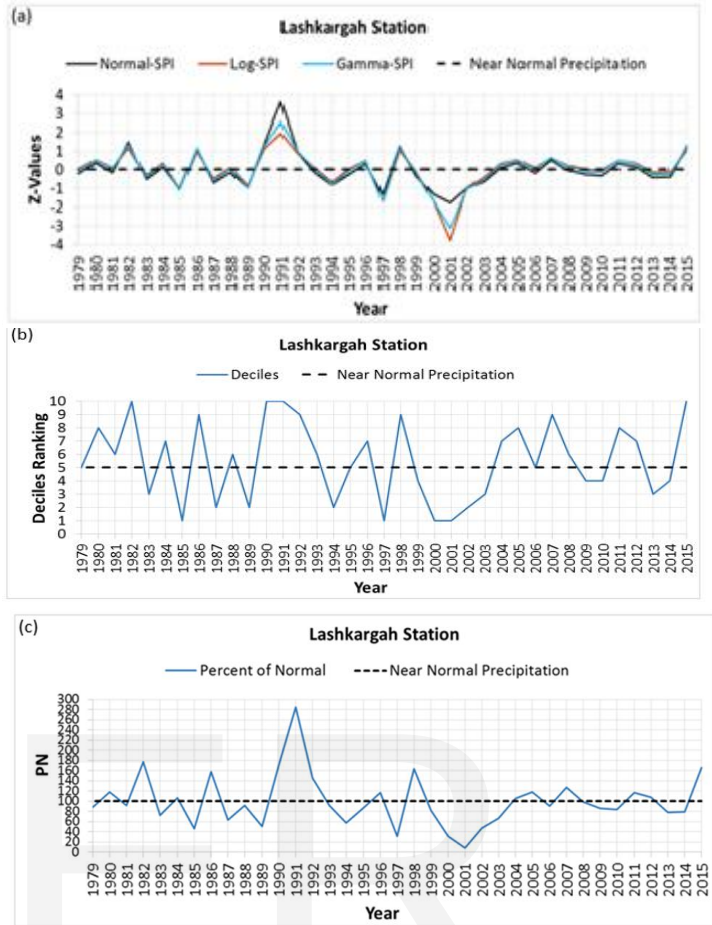

Figure 3 Results for Lashkargah station: (a) SPI, (b) Deciles, and (c) PN

TABLE 4
Deciles result for all stations

Annual Rianfall Values (mm/year)				Classification
Lashkargah	Farah	Adraskan	Grandandiwal	
44.22 - 60.19	69.45 - 79.59	121.72 - 144.59	203.97 - 224.95	Much below normal
74.68 - 81.59	87.65 - 94.68	157.44 - 176.56	262.23 - 306.81	Below normal
86.53 - 95.53	109.72 - 120.78	192.19 - 209.74	323.25 - 333.39	Near normal
110.42 - 118.01	133.75 - 158.37	232.01 - 243.67	346.92 - 365.74	Above normal
155.85 - 168.83	191.64 - 282.39	290.78 - 409.71	438.74 - 527.82	Much above normal

4.2 Farah Station

As shown in Figure 4a, the normal-SPI tends to show wet and less drought conditions. On the other hand, the log-SPI and gamma-SPI predict extreme drought conditions for Farah station as well. The log-SPI and gamma-SPI indicated the extreme drought condition in year 2001, but normal-SPI did not indicate any extreme drought condition. The log-SPI and gamma-SPI showed severe drought in 1987 and normal-SPI revealed the 2001 as severe drought. The Normal-SPI showed moderate drought conditions in 1979, 1987, and 2000 while log-SPI and gamma-SPI indicated in 1979 and 2000. The extreme wet condition happened in 1986, and 1991. The moderate and severe wet years include 1982, 1996 and 1997 years.

The Deciles results and threshold ranges for Farah station are given in Table 4. As seen, the drought condition happened when precipitation was less than 109.72 mm/year. Once precipitation was less than 87.65 mm/year and 69.45 mm/year severe and extreme drought conditions occurred, respectively. Figure 4b shows the Deciles ranking for this station. Comparing deciles ranking with SPI results indicates long extreme and severe drought conditions. Extreme drought conditions include 1979, 1987, 2000, 2001, 2002, 2003, 2004, and 2012. The severe drought years are 1983, 1985, 1994, 2006, 2008, 2010, and 2013. According to Deciles, the extreme wet conditions happened in 1982, 1986, 1991, 1996, 1997, 1999, and 2014.

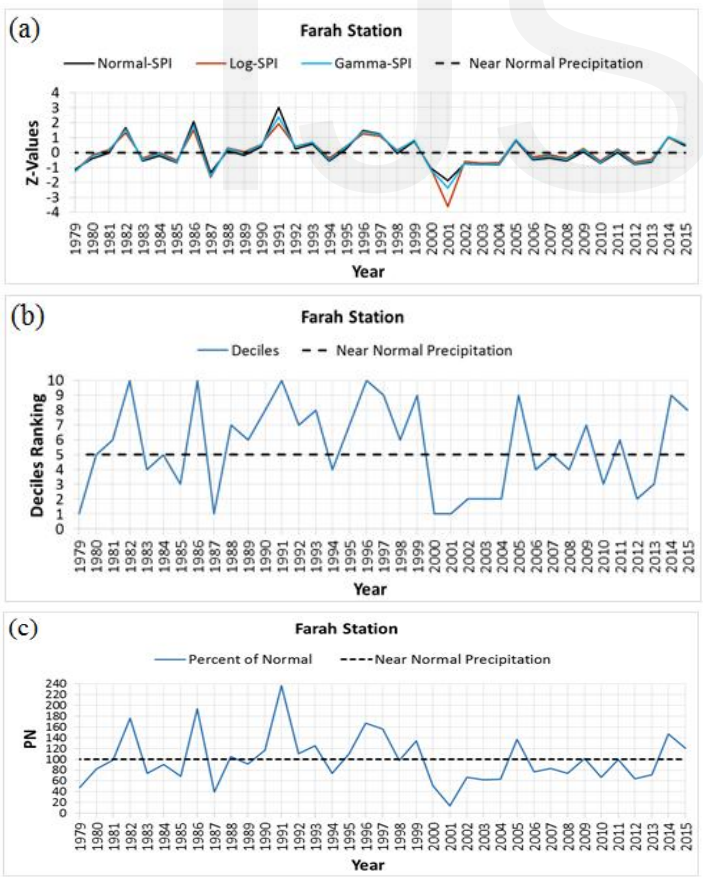

Figure 4 Results for Farah station: (a) SPI, (b) Deciles, and (c) PN

Figure 4c shows results for PN method for Farah station. This method indicates the extreme drought in 2001 and severe drought in 1987. The moderate droughts happened in 1979, 1980, 1983, 1985, 1994, 2000, 2002, 2003, and 2014. This method specifies the extreme wet period as 1986, 1991. The severe and moderate wet years are 1982, 1993, 1996, 1997, 1999, 2005 and 2014.

4.3 Adraskan Station

Figure 5a shows that normal-SPI and gamma-SPI indicated almost the same results for Adraskan station and log-SPI predicts extreme drought conditions. According the SPI results; in Adraskan station, the extreme and severe drought conditions happened in 1994 and 2001. Moderate drought years include 1985, 1992, 1995, and 2000. The extreme wet period happened in 1982 and 1987. The severe and moderate wet years include 1986 and 2009.

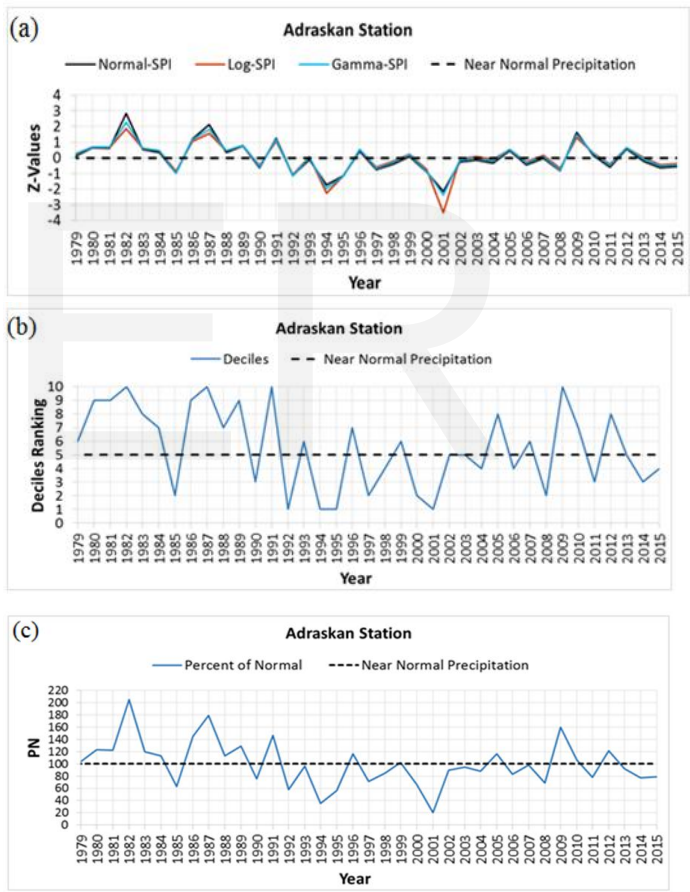

Figure 5 Results for Adraskan station: (a) SPI, (b) Deciles, and (c) PN

The Deciles results and threshold ranges for this Station are given in Table 4. As seen, the drought condition occurred when precipitation was less than 192.19 mm/year. When precipitation is less than 157.44 mm/year and 121.72 mm/year severe and extreme drought occur, respectively. Figure 5b shows the Deciles ranking for Adraskan station. To compare with SPI results, the Deciles ranking indicates long extreme and severe drought conditions. Extreme drought years are 1985, 1992, 1989, 1994, 1995, 1997, 2000, 2001, and 2008. The

severe drought years are 1990, 1998, 2004, 2006, 2011, 2014, and 2015. Deciles method shows that the extreme wet conditions occurred in 1980, 1981, 1982, 1986, 1987, 1991, and 2009.

PN results for Akraskan station are given in Figure 5c. PN method indicated the extreme drought condition in 2001 and severe drought in 1994. The moderate drought conditions are happened in 1985, 1990, 1992, 1994, 1995, 1997, 2000, 2006, 2008, 2011 and 2014. This method specifies the extreme and severe wet period in 1982 and 1987. The moderate wet years occurred in 1980, 1981, 1986, 1989, 1991, 2009 and 2012.

4.4 Gardandiwal Station

Figure 6a shows the results of SPI method for Gardandiwal station. According to the results, the normal-SPI tends to show wet and less drought conditions. Conversely, the log-SPI and gamma-SPI predict extreme drought conditions. The log-SPI and gamma-SPI results in this station indicate the extreme drought conditions in years 2000 and 2001, but normal-SPI shows extreme drought condition only in 2001 and severe drought in 2000. All the SPI methods show the same moderate drought conditions in this station that occurred in 1985, 1998, 1999, 2002, 2003, 2004 and 2012. The extreme wet condition happened in 1982, 1991, and 2009. The moderate and severe wet years include 1992 and 2005 years.

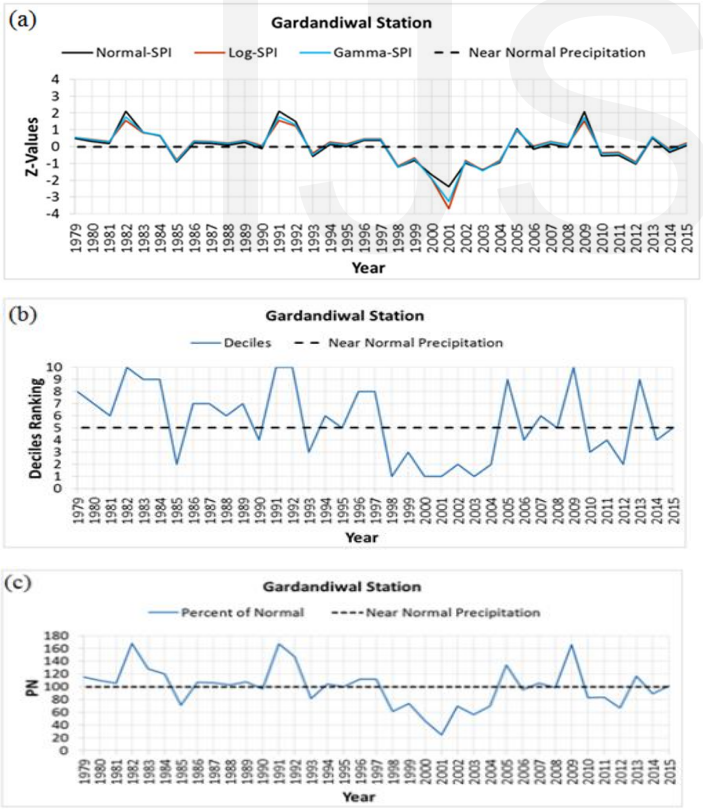

Figure 6 Results for Gardandiwal station: (a) SPI, (b) Deciles, and (c) PN

The Deciles results and threshold ranges for Gardandiwal station are given in Table 4. As a result, the drought condition happened when precipitation was less than 323.25 mm/year. Once precipitation was less than 262.23 mm/year and 203.97 mm/year severe and extreme drought conditions occurred, respectively. Figure 6b shows the Deciles ranking for this station. Extreme drought conditions include 1985, 1998, 2000, 2001, 2002, 2003, 2004, and 2012. The severe drought years are 1990, 1993, 1999, 2006, 2010, 2011, and 2014. Based on the results of the Deciles, the extreme wet conditions happened in 1982, 1983, 1984, 1991, 1992, 2005, 2009, and 2013.

Results for PN method are given in Figure 6c for Gardandiwal station. PN has not indicated the extreme drought condition for this station. PN shows severe drought in 2001. The moderate drought conditions happened in 1985, 1993, 1998, 1999, 2000, 2002, 2003, 2004, and 2012. This method specifies the very wet period as 1982, 1991, and 2009. The moderate wet years occurred in, 1983, 1984, 1992 and 2005.

5 DISCUSSIONS ON THE RESULTS

Table 5 summarizes the drought intensities for the stations. The extreme, severe, and moderate drought intensities are listed for normal-SPI, log-SPI, gamma-SPI, and PN methods. The moderate drought intensity is not listed for the Deciles method this is because this method just indicates extreme and severe droughts.

According, to the results of all methods, the common extreme drought year is 2001 for all the stations. The 2000 year was also predicted as generally extreme drought for Gardandiwal station and 1994 for Adraskan station. 1997 and 2000 years were predicted as severe drought for Lasskargah station and 1987 for Farah station. The common moderate drought conditions occurred in 1985 and 2002. As discussed before in Figures (4, 5, and 6), the extreme wet conditions are also generally common for all stations in 1982, 1991, and 1992. Therefore, all stations have experienced almost the same occurrences of drought and wet conditions in the same period. The results point out that the PN method tends to overpredict the number of moderate drought years as opposed to the SPI method. The Deciles ranking indicates two drought intensities as below normal (severe drought) and much below normal (extreme drought) as given in Table 4. Therefore, the Deciles method shows more years of extreme and severe drought than other methods.

In summary, Lashkargah station experienced the drought conditions frequently from 1997 to 2002 with a peak extreme drought in 2001, also, in 1983, 1985, 1987, and 1989. Farah station experienced droughts 1979, 1987, 2000, and 2001. The drought for Adraskan station is predicated to be in 1992 50 1995 with a peak in 1994, also extreme drought in 2001. Gardandiwal station experienced the drought conditions continuously from 1998 to 2004 with a peak extreme drought in 2001, same as other stations.

These results confirm the reports about Afghanistan's droughts during the last three decades. As discussed earlier the central and south-west parts of Afghanistan and neighboring regions of the study area in Iran and Pakistan experienced the extreme drought mostly between 1998 and 2002 years with peak in 2001.

TABLE 5
Summary of indicated historical drought by five DI methods

Stations	Methods													
	Normal-SPI			Log-SPI			Gamma-SPI			Percent of Normal			Deciles	
	Drought Intensity													
	Exreme	Severe	Moderate	Exreme	Severe	Moderate	Exreme	Severe	Moderate	Exreme	Severe	Moderate	Exreme	Severe
Lashkargah	–	2001	1985 1989 1997 2000 2002	2001	1997 2000	1985 1989 2002	2001	1997 2000	1985 1989 2002	2001	1997 2000	1983 1985 1987 1989 1994 2010 2013 2014	1985 1987 1989 1994 1997 2000 2001 2002	1983 1999 2003 2009 2010 2013 2014
Farah	–	2001	1979 1987 2000	2001	1987	1979 2000	2001	1987	1979 2000	2001	1987	1979 1980 1983 1985 1994 2000 2002 2003 2004	1979 1987 2000 2001 2002 2003 2004 2012	1983 1985 1994 2006 2008 2010 2013
Adraskan	2001	1994	1985 1992 1995 2000	1994 2001	–	1985 1992 1995	1994 2001	–	1985 1992 1995 2000	2001	1994	1985 1990 1992 1994 1995 1997 2000 2006 2008 2011 2014	1985 1992 1994 1995 1997 2000 2001 2008	1990 1998 2004 2006 2011 2014 2015
Gardandiwal	2001	2000	1985 1998 1999 2002 2003 2004 2012	2000 2001	–	1985 1998 1999 2002 2003 2004 2012	2000 2001	–	1985 1998 1999 2002 2003 2004 2012	–	2001	1985 1993 1998 1999 2000 2002 2003 2004 2012	1985 1998 2000 2001 2002 2003 2004 2012	1990 1993 1999 2006 2010 2011 2014

6 CONCLUSIONS

This study explored the performances of five popular drought indexes (normal-SPI, log-SPI, gamma-SPI, PN, and deciles) in four stations of Helmend River Basin in Afghanistan.

The following conclusions can be drawn:

1) The five DI methods provide almost the same results for Lashkargah, Farah, Adraskan, and Gardandiwal stations of Helmand River Basin.

2) All four stations experienced more droughts from the end of 1990s to the beginning of 2000s with the extreme drought conditions in 2001 which confirm to the reported worst drought in the region.

3) When precipitation is less than 44.22 mm/year, 69.45 mm/year, 121.72, and 203.97 mm/year extreme drought occurs in Lashkargah, Farah, Adraskan, and Gardandiwal stations, respectively.

4) It is noted that normal-SPI and PN indicated less and moderate drought condition while log-SPI, gamma-SPI, and Deciles captured the historical extreme and severe drought periods successfully, therefore, these three methods (log-SPI, gamma-SPI, and Deciles) are recommended to be applied to this region as drought assessment tools.

REFERENCES

[1] Abramowitz M., and Stegun A. 1965 Handbook of mathematical formulas, graphs and mathematical tables, *Dover Publications Inc, New York*.

[2] Ahmad, M., and Wasiq, M. 2004 Water resources development in Northern Afghanistan and its implications for Amu Darya Basin (No. 36). *World Bank Publications*.

[3] Angelidis P., Maris F., Kotsovinos N., Hrissanthou V. 2012 Computation of Drought Index SPI with Alternative Distribution Functions. *Water Resour Manag*, 26(9), 2453-2473.

[4] APN. 2015 An International Geosphere-Biosphere Programme Synthesis Theme on Global Environment Change and Sustainable Development: Needs of Least Developed Countries. *A project report by Asia-Pacific Network for Global Change Research*. 16-17.

[5] Ashraf M., and Routray J. K. 2015 Spatio-Temporal Characteristics of Precipitation and Drought in Balochistan Province, Pakistan. *Nat Hazards*, 77, 229-254.

[6] Broshears, R.E., Akbari, M.A., Chornack, M.P., Mueller, D.K., and Ruddy, B.C. 2005 Inventory of ground-water resources in the Kabul Basin, Afghanistan: *U.S. Geological Survey Scientific Investigations Report*.

[7] Bura S., Ng A., Perera B. 2010 Comparative Evaluation of Drought Indexes: Case Study on the Yarra River Catchment in Australia. *Water Resour Plan Manag*. 137, 215-226.

[8] Cacciamani C., Morgillo A., Marchesi S., and Pavan V. 2007 Monitoring and forecasting drought on a regional scale: Emilia-Romagna region, Methods and tools for drought analysis and management. *Springer,* 29-48.

[9] Goes, B. J. M., Howarth, S. E., Wardlaw, R. B., Hancock, I. R., and Parajuli, U. N. 2015 Integrated water resources management in an insecure river basin: a case study of Helmand River Basin, Afghanistan. *International Journal of Water Resources Development*, 32(1), 3-25.

[10] Hayes M. J., 2006 Drought Indices, Willy Online Library Center. (Online). < https://drought.unl.edu/whatis/indices.htm

[11] Mckee TB., Doesken NJ., and Kleist J. 1993 The relationship of drought frequency and duration to time scales. Proceedings of the 8th Conference on Applied Climatology. *American Meteorological Society Boston, MA, USA*, 179–18.

[12] Miyan, M. A. 2015. Droughts in Asian Least Developed Countries: Vulnerability and sustainability. *Weather and Climate Extremes*, 7, 8-23.

[13] Morid S., Smakhtin V., and Moghaddasi M. 2006 Comparison of Seven Meteorological Indices for Drought Monitoring in Iran. *International Journal of Climatology*, 26, 971-985.

[14] Oxfam. 2011 Afghanistan Drought Will Become Disaster without Aid. *Oxfam Says by Jack Phillips for Epoch Times*. September20. ⟨http://en.wikipedia.org/wiki/Drought_in_Afghanistan⟩.

[15] Sirdas S., and Sen Z. 2003 Spatio-temporal drought analysis in the Tarakya region, Turkey. *Hydrological Sciences Journal*, 48(5), 809-819.

[16] Thom HCS. 1958 A note on the gamma distribution. *Mon Weather Rev,* 86, 117–122.

[17] Thomas, V., Azizi, M. A., and Behzad, K. 2016. Developing transboundary water resources: What perspectives for cooperation between Afghanistan, Iran and Pakistan? Afghanistan Research and Evaluation Unit, Case Study.

[18] Wolf, A. T., Natharius, J. A., Danielson, J. J., Ward, B. S., and Pender, J. K. 1999 International River Basins of the World. *International Journal of Water Resources Development*, 15(4), 387-427.

[19] Yacoub E., and Tayfur G. 2016 Evaluation and Assessment of Meteorological Drought by Different Methods in Tazara Region, Mauritania. *Water Resource and Management*, DOI: 10.1007/s11269-016-1510-8.

[20] Zarei A. R., Moghime M. M, and Mahmodi M. R. 2015 Parametric and Non-Parametric Trend of Drought in Arid and Semi-Arid Regions Using RDI Index. *Water Resource and Management,* 30, 5479-5500.