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Estimate of correlation between the meteorological drought in Ethiopia and the hydrological drought in Egypt

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Drought is one of the most complex natural phenomena and one of the main natural causes affecting agriculture, the economy, and the environment worldwide, and its global impact has become significantly evident in the level of life in recent decades. Drought happens in different regions, so assessing the intensity of the drought period is one of the most important tools for sustainable agriculture, as droughts have become observable in many parts of the world, especially in the East and North Africa region. The most important types of drought are meteorological and hydrological drought, Drought indices were used to survey drought and demonstrate its performance. Egypt suffers from water scarcity, especially in recent years. Therefore, the importance of studying Ethiopia as a research area comes due to the presence of the Blue Nile, which contributes about 85% of the Nile River's revenue. Meteorological drought was evaluated by calculating the Standard Precipitation Index (SPI), and hydrological drought was calculated by the Streamflow Drought Index (SDI) during the period of study from (1950 to 2017) based on the availability of the recorded data for meteorological stations in Ethiopia, and the streamflow for several stations. Then these data were evaluated using various methods, including homogeneity between the data for each station by considering the different time scales of periods 1, 3, 6, 9, and 12 months. As a result, there are three seasons of rain in Ethiopia. Kiremt is the main rainy season from June to September, Bega is the dry season from October to January, Belg is the lowest rainy season from February to May. Ethiopia, characterized by four precipitation regimes, was found to correlate with the meteorological index (SPI) for five stations in Ethiopia and the hydrological index (SDI) for Dongola.

1. Introduction

Drought is a major natural hazard phenomenon and its consequences can be destructive (Tigkas, 2008). Drought affects people and most sectors of society in comparison with other natural hazards (Wilhite, 2012), and it is the main natural cause for damage in agriculture, the economy, and the environment. A deficiency in precipitation is the main cause of drought (Vicente-Serrano et al., 2010). Drought is a worldwide phenomenon that is caused by the absence of precipitation. It causes damage to human lives, agriculture, and natural ecosystems (Zarch et al., 2011). Drought is classified into four types: meteorological, agricultural, hydrological, and socioeconomic. The two categories of drought concerning this paper are identified as 1) meteorological drought, which is defined as a divergence from ordinary precipitation over some timeframe, and reflects one of the essential causes of drought 2) Hydrological drought, which is defined as the insufficiencies on the surface and subsurface water supplies, and reflects impacts of drought. Meteorological drought usually appears first because of a decline in precipitation. Hydrological drought includes the shortage of water supply in the streamflow, reservoir storages, lakes, etc., and it is affected by meteorological drought management approaches (Boudad et al., 2018).

Egypt is an arid country that suffers from water scarcity especially in more recent years. Egypt depends on the Nile river as a lifeline that provides 95% of its water resources to cope with its growing population and water demands (Link, Piontek, Scheffran, & Schilling, 2012). Ethiopia has a diverse climate due to its equatorial position and the climate ranges from a semi-arid desert type in the lowlands, to humid and warm type in the southwest; the complex geographical and topographical characteristics in Ethiopia have a substantial impact on different precipitation regimes in the country (Kidanewold et al., 2014), so it is important to assess the variability of seasonal rainfall in selected areas of the region (Gebremichael et al., 2014).

One of the most common ways to evaluate drought is to calculate drought indices (Tigkas, 2008). Many indices aim to assess the severity of droughts. Some of the most popular indices that use only precipitation data are the Standardized Precipitation Index (SPI) and the Streamflow Drought Index (SDI)(Tsakiris et al., 2013). The objectives of this research are to assess the meteorological drought as well as to estimate the Standardized Precipitation Index (SPI) of Ethiopia and the Streamflow Drought Index (SDI) from the Nile River at the High Aswan Dam (HAD) downstream to Egypt and to find significant correlations between SPI and SDI.

2. Literature review

Mishra and Singh (2010) presented the essential concepts and characterization of drought, drought indices, and the relationship between droughts and climate indicators. Tsakiris et al. (2007) found that the most widely used drought indices in other countries are the Standardized Precipitation Index (SPI) and the Palmer Drought Severity Index (PDSI. Seleshi and Zanke (2004) analysed the recent changes in the annual rainfall totals for June to September, March to May, and other rainy days in 11 of Ethiopia's major stations located in five major climatic zones during the period 1965-2002. Vicente-Serrano and López-Moreno (2005) showed the main advantage of the SPI index is that it can determine and monitor drought at different time scales. From this research, for example, SPI was calculated at time scales from 1 to 24 months as an indicator of runoff in Spain. From previous literature, SPI is the most proper index for assessing the meteorological drought in humid regions.

3. Data and methods

The study area is the whole of Ethiopia, situated between 3° to 15° N latitude and 33° to 48° E longitude, with a total area of 1.13 million km2 as shown in Figure 1. The region has a highly irregular topography, characterised by the central and northern highlands, and the lowlands of the rift valley plain (Tadege, 2001). The elevation ranges from -125 m to 4620 m (Cheung et al., 2008; Dawit, 2010). The temperature increases towards the southeast region and decreases towards the central region; the climate varies mostly because of the altitude. The southwest of the country is characterized by maximum precipitation levels, while the southeast of the country has the minimum.

Data sets used in this study were monthly precipitation, temperature (minimum and maximum), and streamflow data collected at fifteen stations covering different parts of Ethiopia and Dongola station. These values were used to calculate the SPI and SDI index. The period of study (1950–2017) has been chosen based on the availability of recorded data for all stations.

Dongola station is viewed as a standout among other discharge estimating stations on the Nile River as its discharges are utilized to quantify the water arriving at Nasser Lake and to gauge water losses (Mohamed, 2016). Drought can be measured and analysed by different indices. In this study, SPI and SDI indices were used as described below.

SPI was developed to improve the Palmer index for representing wet and dry conditions (Guttman, 1999). SPI for any site is based on the long-term precipita-

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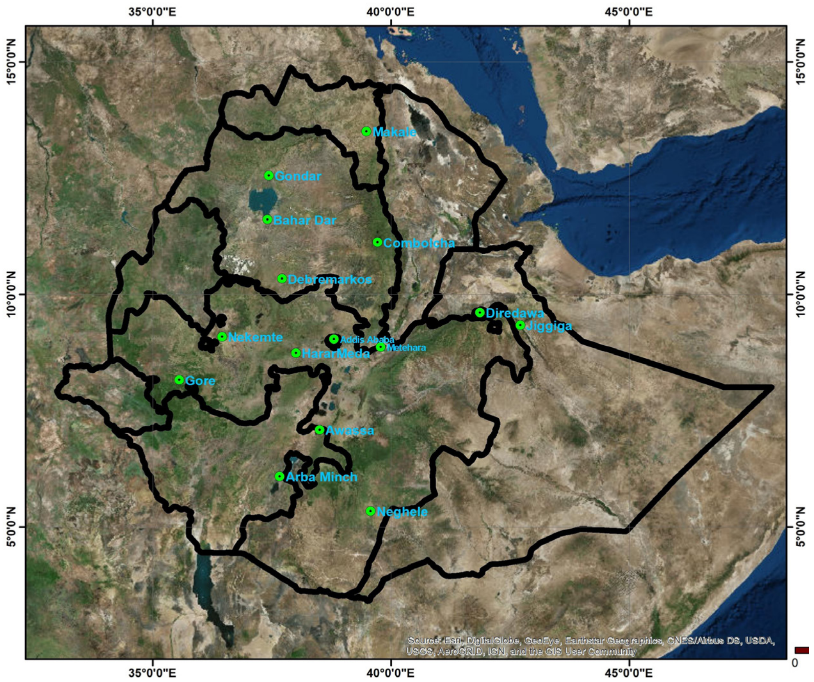

Figure 1. Location of climatic stations used in this study in Ethiopia.

tion record (longer than 45 years) and is fitted to a probability distribution (Boudad, Sahbi, & Mansouri, 2018). from 1950 to 2017, SPI was based on high cumulative rainfall (Rik) for the basis period (k) relating to (i) hydrological year and is obtained by the following equation:

$$SPI_{ik} = \frac{R_{ik} - \overline{R_k}}{S_k} \qquad i = 1,2,\ldots \qquad k = 1,2,3,4,5,6$$

$\overline{Rk}$ and Sk is the mean height of cumulative rainfall and the standard deviation cumulative rainfall, respectively, for the period k (Azareh et al., 2014). SPI values appear in Table 1.

SDI is based on monthly observed streamflow volumes at different time scales (Boudad et al., 2018) obtained from monthly precipitation and it has been used for monitoring drought and helping decision-makers assess risk (Guttman, 1999).

In this study, SDI was similar to SPI. SDI is the high cumulative flow (V ik) for the basis period (k) relating to (i) hydrological year and is obtained by the following equation:

$$SDI_{ik} = \frac{V_{ik} - \bar{V}_k}{S_k} \qquad i = 1,2,\ldots \qquad k = 1,2,3,4,5,6$$

$\overline{Vk}$ and Sk are the mean total volume flow and the standard deviation of cumulative flow volume, respectively, based on period k (Azareh et al., 2014). SDI values appear in Table 1.

To facilitate the process, a Drought Indices Calculator was used with DrinC software developed at the National Technical University of Athens Management (Tsakiris et al., 2007). The version of the software can be found at www.ewra.net/drinc.

To study the relationship between meteorological and hydrological drought, the correlation coefficients of Pearson for all series were first calculated. In the second step, and to imagine this relationship, the Pearson coefficient was calculated between each period of SPI and SDI at different time scales (for 1, 3, 6,9, and 12 months).

The correlation coefficient is a statistic used to measure the degree or strength of this type of relationship and to take on a range of values from -1 to 0 to +1 (Taylor, 1990). If r is close to 0, it means there is no relationship between variables. A positive correlation coefficient indicates a direct relationship between the variables. A negative correlation indicates an inverse relationship between the two variables (Taylor, 1990).

Table 1. Classification of drought according to the SPI and SDI values (Azareh et al., 2014).

Index values of drought SPI or SDI	Category
2.00 or more	Extremely wet
1.50 to 1.99	Severely wet
1.00 to 1.49	Moderately wet
0 to 0.99	Normal conditions- wet
0 to -0.99	Normal conditions - dry
-1.00 to -1.49	Moderate Drought
-1.50 to -1.99	Severe Drought
-2 or less	Extreme Drought

4. Results and discussions

Ethiopia's diverse topography contributes to the high spatial and temporal variability of precipitation in the country. Generally, the southwest of the country is characterized by maximum precipitation levels while the southeast of the country typically has the minimum precipitation levels. Ethiopia is distinguished by four seasonal precipitation systems according to the precipitation regime shown in Figure 2 that represents stations located in these regimes.

Evaluation of the Standardized Precipitation Index (SPI)

After the calculation of SPI values, Figure 3 shows the SPI distribution over Ethiopia. Results showed Kirmet as the main rain season in which extreme, heavy precipitation falls on most of the country, except for the south and south-eastern parts. Belg is the main rain season for the south and south-eastern. This agreed with the findings of Dawit (2010) and with Shang et al. (2011).

This study represented SPI at multiple time scales of 1, 3, 6, 9, and 12 months to identify the drought behaviour. The time scale refers to any number of months of accumulated SPI values. Additionally, short time scales of 3-months are important for agricultural applications, while long time scales are important in water-supply management (Guttman, 1998). When time series are small, 3 or 6 months, the SPI values

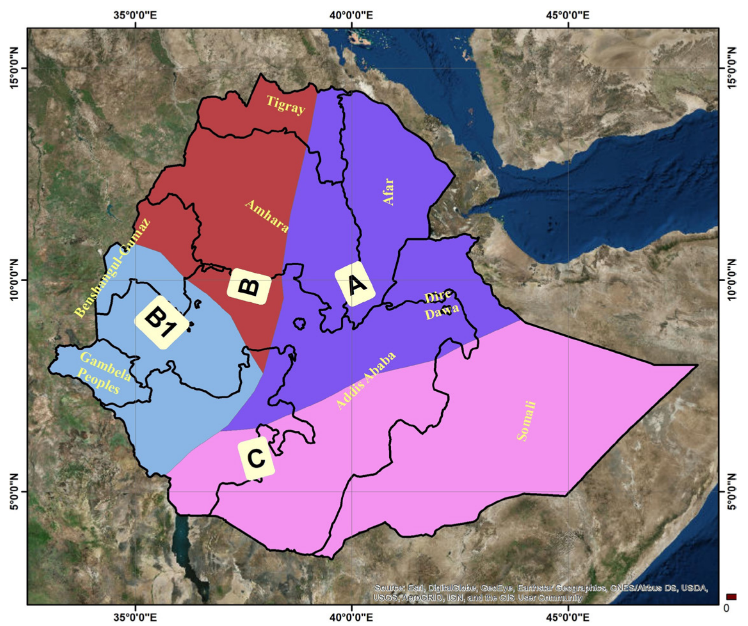

Figure 2. Precipitation Regimes of Ethiopia (A, B, B1, C) and the location of the stations (Dawit et al.,2011)

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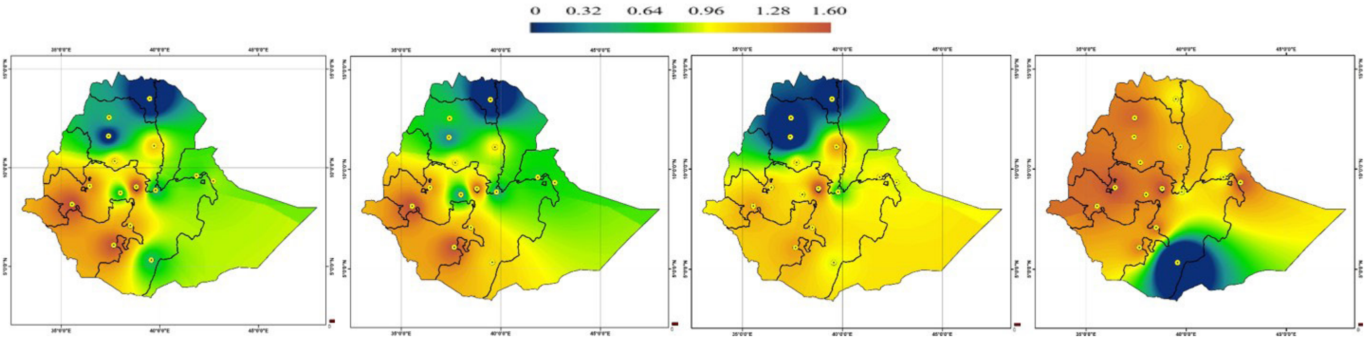

Figure 3. The distribution of annual SPI values for Ethiopia

are small, whereas for longer periods, for example, 12 months, the SPI has a slow response to changes in precipitation. After analysis SPI and SDI and calculation of annual change of the indices that describe the long term time series of precipitation observations, and according to Awulachew et al. (2009) represent climate stations, located in the or near the Blue Nile Basin (including Addis Ababa, Bahar Dar, Debre Markos, Gondar and Gore), therefore correlation coefficients had estimated for that five selected stations with Dongola at different time scale .

Estimation of the correlation coefficient

A comparison of SPI values for the selected stations located in the Blue Nile Basin and SDI for Dongola at 1, 3, 6, 9, 12 months was carried out. Results showed significant correlations and non-significant correlations. The frequency of a statistically significant correlation was moderate for monthly scales, where it reached its maximum at a 3-month scale, followed by a 6-month scale, and less frequently at a 9-month scale and no significance at a 12-month scale. Table 2 through Table 6 represent the correlations between SPI for the five stations and SDI for Dongola at 3-month intervals. The coloured values represent significant values at 0.01 and 0.05 level. Table 6 is illustrated in Figure 4 and shows the behaviour of the correlation between SPI for Gore and SDI for Dongola (as an example). As a result, Dongola is affected more by the drought in each of Bahar Dar, Debremarkos, and Gore.

Table 2. Correlation between SPI for Addis Ababa and SDI for Dongola

SDI3 Dongola	Oct-Dec	Nov-Jan	Dec-Feb	Jan-Mar	Feb-Apr	Mar-May	Apr-Jun	May-Jul	Jun-Aug	Jul-Sep	Aug-Oct	Sep-Nov
Oct-Dec	0.11	-0.24	-0.20	-0.14	-0.20	-0.21	-0.12	0.04	0.07	0.21	0.16	0.28
Nov-Jan	0.12	-0.21	-0.16	-0.08	-0.17	-0.20	-0.10	0.08	0.09	0.09	0.08	0.15
Dec-Feb	0.02	-0.22	-0.10	0.03	-0.08	-0.18	-0.12	0.04	0.10	0.02	0.06	0.09
Jan-Mar	0.01	-0.14	-0.12	0.04	-0.10	-0.06	-0.05	0.10	0.04	-0.06	0.02	0.01
Feb-Apr	-0.03	-0.14	-0.18	0.00	-0.10	0.02	0.04	0.16	-0.05	-0.05	0.01	0.10
Mar-May	-0.06	-0.15	-0.25	-0.01	-0.09	0.05	0.04	0.18	-0.10	0.05	0.05	0.26
Apr-Jun	0.00	-0.04	-0.28	-0.10	-0.20	0.01	-0.06	0.05	-0.11	0.17	0.21	0.33
May-Jul	0.02	0.01	-0.30	-0.14	-0.16	-0.01	0.11	0.23	0.27	0.33	0.28	0.23
Jun-Aug	0.01	0.02	-0.20	-0.09	-0.14	-0.10	-0.05	0.10	0.14	0.20	0.13	0.20
Jul-Sep	-0.02	-0.07	-0.14	-0.05	-0.10	-0.12	-0.07	0.10	0.14	0.23	0.10	0.23
Aug-Oct	0.04	-0.06	-0.11	-0.01	-0.08	-0.11	-0.14	0.02	0.03	0.12	0.07	0.22
Sep-Nov	0.10	-0.10	-0.09	0.00	-0.09	-0.11	-0.13	0.03	0.03	0.11	0.11	0.24
	SIP3 Addis Ababa											

Table 3. Correlation between SPI for Bahar Dar and SDI for Dongola

SDI3 Dongola	Oct-Dec	Nov-Jan	Dec-Feb	Jan-Mar	Feb-Apr	Mar-Ma	Apr-Jun	May-Jul	Jun-Aug	Jul-Sep	Aug-Oct	Sep-Nov
Oct-Dec	0.49	0.20	0.24	0.24	0.23	0.19	0.12	0.17	0.18	0.26	0.34	0.46
Nov-Jan	0.61	0.26	0.17	0.09	0.23	0.34	0.29	0.34	0.36	0.43	0.50	0.56
Dec-Feb	0.43	0.22	0.09	0.05	0.26	0.30	0.31	0.34	0.39	0.46	0.50	0.54
Jan-Mar	0.30	0.11	-0.06	0.03	0.19	0.30	0.33	0.25	0.30	0.31	0.31	0.25
Feb-Apr	0.26	0.03	-0.11	0.05	0.18	0.34	0.36	0.21	0.21	0.19	0.21	0.18
Mar-May	0.13	-0.01	-0.12	0.05	0.12	0.36	0.30	0.13	0.05	0.02	0.07	0.10
Apr-Jun	0.00	-0.11	-0.12	0.25	0.13	0.30	-0.09	-0.24	-0.36	-0.33	-0.23	-0.19
May-Jul	-0.01	-0.06	-0.03	0.17	0.04	0.19	-0.24	-0.37	-0.52	-0.47	-0.33	-0.22
Jun-Aug	0.02	0.08	0.15	0.06	0.01	0.10	-0.14	-0.14	-0.27	-0.27	-0.26	-0.14
Jul-Sep	0.06	0.20	0.26	0.03	0.02	0.05	-0.12	-0.06	-0.11	-0.10	-0.08	0.01
Aug-Oct	0.13	0.22	0.31	0.04	-0.02	0.14	-0.03	0.04	-0.04	-0.04	-0.04	0.05
Sep-Nov	0.25	0.27	0.34	0.09	-0.03	0.28	0.05	0.10	0.00	0.02	0.09	0.21

SIP3 Bahar Dar

Table 4. Correlation between SPI for Debre Markos and SDI for Dongola

SDI3 Dongola	Oct-Dec	Nov-Jan	Dec-Feb	Jan-Mar	Feb-Apr	Mar-Ma	Apr-Jun	May-Jul	Jun-Aug	Jul-Sep	Aug-Oct	Sep-Nov
Oct-Dec	0.28	-0.07	0.08	0.06	0.07	0.04	0.12	0.16	0.06	0.11	0.28	0.46
Nov-Jan	0.50	0.13	0.18	0.20	0.26	0.24	0.37	0.42	0.29	0.31	0.41	0.59
Dec-Feb	0.42	0.25	0.21	0.23	0.34	0.36	0.47	0.55	0.47	0.47	0.41	0.53
Jan-Mar	0.33	0.25	0.13	0.09	0.22	0.36	0.39	0.47	0.36	0.34	0.17	0.29
Feb-Apr	0.35	0.16	0.04	0.03	0.13	0.37	0.37	0.38	0.25	0.27	0.17	0.32
Mar-May	0.24	0.05	-0.08	-0.09	-0.03	0.27	0.19	0.10	-0.05	0.01	0.07	0.30
Apr-Jun	0.08	-0.17	-0.32	-0.35	-0.32	-0.07	-0.23	-0.32	-0.50	-0.44	-0.36	-0.13
May-Jul	-0.16	-0.30	-0.39	-0.32	-0.39	-0.24	-0.36	-0.47	-0.60	-0.60	-0.43	-0.32
Jun-Aug	-0.12	-0.36	-0.24	-0.28	-0.28	-0.18	-0.25	-0.33	-0.38	-0.34	-0.24	-0.18
Jul-Sep	-0.13	-0.33	-0.15	-0.17	-0.21	-0.14	-0.20	-0.24	-0.24	-0.18	-0.05	-0.03
Aug-Oct	-0.02	-0.27	-0.10	-0.11	-0.15	-0.05	-0.13	-0.16	-0.20	-0.13	-0.06	0.03
Sep-Nov	0.08	-0.14	-0.04	0.01	-0.10	0.04	-0.06	-0.08	-0.16	-0.10	0.01	0.16

SIP3 Debremarcos

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Table 5. Correlation between SPI for Gondar and SDI for Dongola

SDI3 Dongola	Oct-Dec	Nov-Jan	Dec-Feb	Jan-Mar	Feb-Apr	Mar-Ma	Apr-Jun	May-Jul	Jun-Aug	Jul-Sep	Aug-Oct	Sep-Nov
Oct-Dec	0.33	0.22	0.45	0.27	0.11	0.20	0.18	0.18	0.23	0.26	0.33	0.37
Nov-Jan	0.58	0.41	0.47	0.29	0.26	0.41	0.38	0.41	0.43	0.46	0.53	0.53
Dec-Feb	0.47	0.41	0.36	0.34	0.35	0.53	0.41	0.40	0.38	0.41	0.45	0.52
Jan-Mar	0.37	0.25	0.20	0.25	0.29	0.47	0.23	0.22	0.19	0.25	0.33	0.39
Feb-Apr	0.33	0.18	0.18	0.20	0.20	0.29	0.02	0.01	0.00	0.07	0.17	0.25
Mar-May	0.14	0.07	0.08	0.14	0.13	0.11	-0.11	-0.18	-0.19	-0.18	-0.10	0.02
Apr-Jun	-0.06	-0.11	-0.12	0.19	0.08	-0.08	-0.23	-0.37	-0.39	-0.40	-0.31	-0.21
May-Jul	-0.09	-0.17	-0.10	0.12	0.05	-0.07	-0.02	-0.17	-0.21	-0.25	-0.15	-0.09
Jun-Aug	0.04	-0.03	0.11	0.06	0.01	-0.04	0.12	0.08	0.14	0.08	0.05	-0.06
Jul-Sep	0.06	0.02	0.19	0.05	0.00	0.00	0.18	0.20	0.28	0.23	0.17	0.05
Aug-Oct	0.14	0.08	0.21	0.05	-0.02	0.05	0.18	0.19	0.26	0.22	0.16	0.02
Sep-Nov	0.23	0.15	0.21	0.06	-0.02	0.16	0.20	0.19	0.20	0.17	0.18	0.15
	SIP3 Gondar											

Table 6. Correlation between SPI for Gore and SDI for Dongola

SDI3 Dongola	Oct-Dec	Nov-Jan	Dec-Feb	Jan-Mar	Feb-Apr	Mar-Ma	Apr-Jun	May-Jul	Jun-Aug	Jul-Sep	Aug-Oct	Sep-Nov
Oct-Dec	0.27	0.01	0.06	-0.01	0.14	0.41	0.39	0.25	0.07	0.07	0.11	0.14
Nov-Jan	0.48	0.30	0.30	0.25	0.36	0.63	0.58	0.53	0.38	0.38	0.43	0.43
Dec-Feb	0.46	0.41	0.42	0.35	0.42	0.65	0.57	0.55	0.48	0.49	0.47	0.43
Jan-Mar	0.50	0.33	0.30	0.23	0.31	0.52	0.49	0.47	0.45	0.44	0.37	0.28
Feb-Apr	0.46	0.19	0.15	0.05	0.18	0.48	0.49	0.44	0.36	0.32	0.22	0.13
Mar-May	0.14	-0.03	-0.05	-0.16	0.00	0.34	0.31	0.20	0.06	0.01	-0.05	-0.07
Apr-Jun	-0.20	-0.34	-0.34	-0.27	-0.07	0.12	0.05	-0.13	-0.31	-0.38	-0.32	-0.27
May-Jul	-0.28	-0.25	-0.31	-0.30	-0.25	-0.13	-0.20	-0.36	-0.49	-0.54	-0.36	-0.31
Jun-Aug	-0.16	-0.23	-0.24	-0.29	-0.24	-0.09	-0.12	-0.26	-0.40	-0.41	-0.37	-0.30
Jul-Sep	-0.11	-0.18	-0.15	-0.20	-0.18	-0.04	-0.09	-0.20	-.334*	-.300*	-0.29	-0.23
Aug-Oct	-0.04	-0.22	-0.21	-0.21	-0.18	0.02	-0.02	-0.10	-0.25	-0.21	-0.26	-0.18
Sep-Nov	0.03	-0.14	-0.17	-0.12	-0.11	0.12	0.06	0.04	-0.13	-0.09	-0.10	0.02
	SIP3 Gore											

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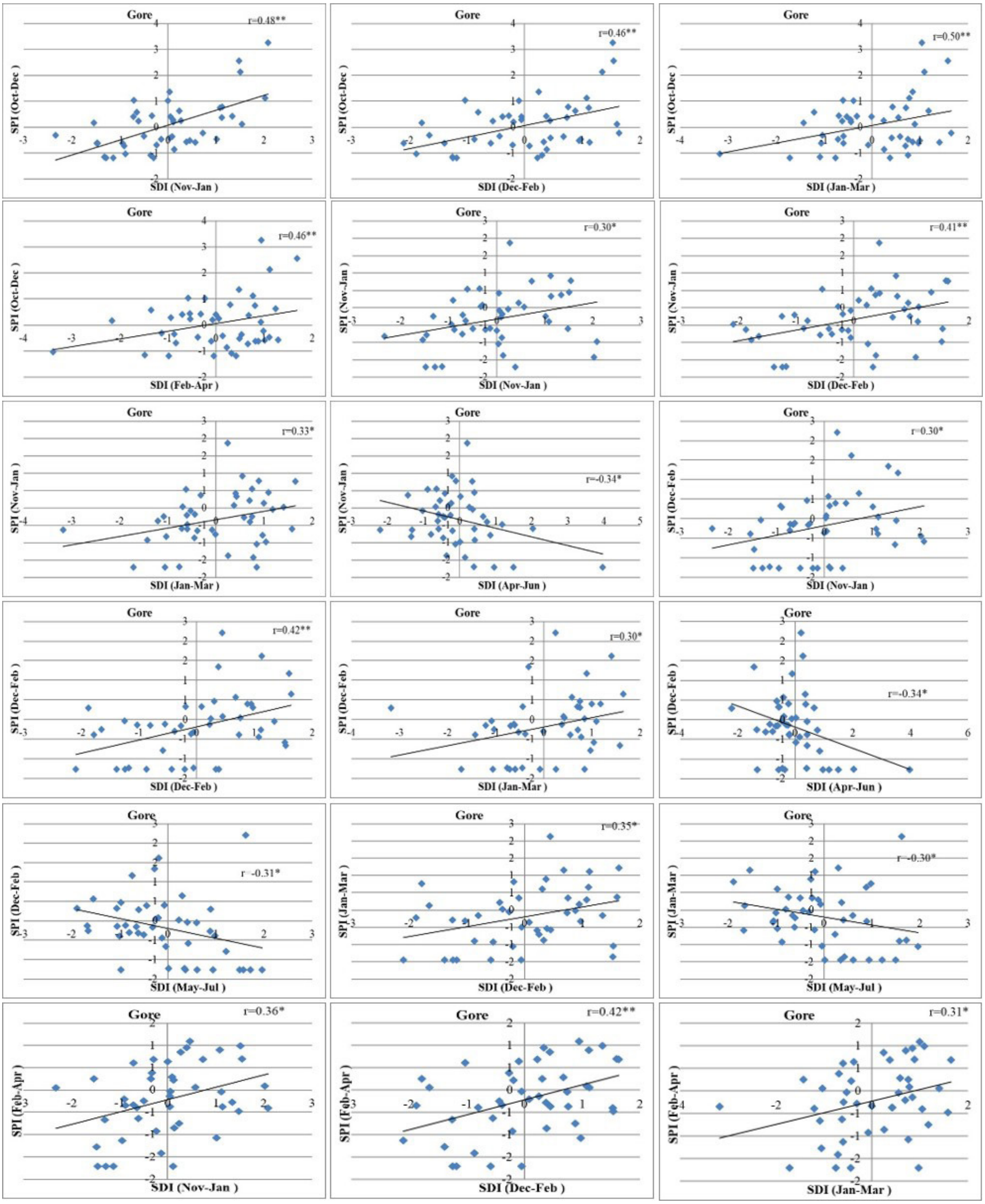

Figure 4. The Correlation between SPI for Gore and SDI for Dongola at 3 months

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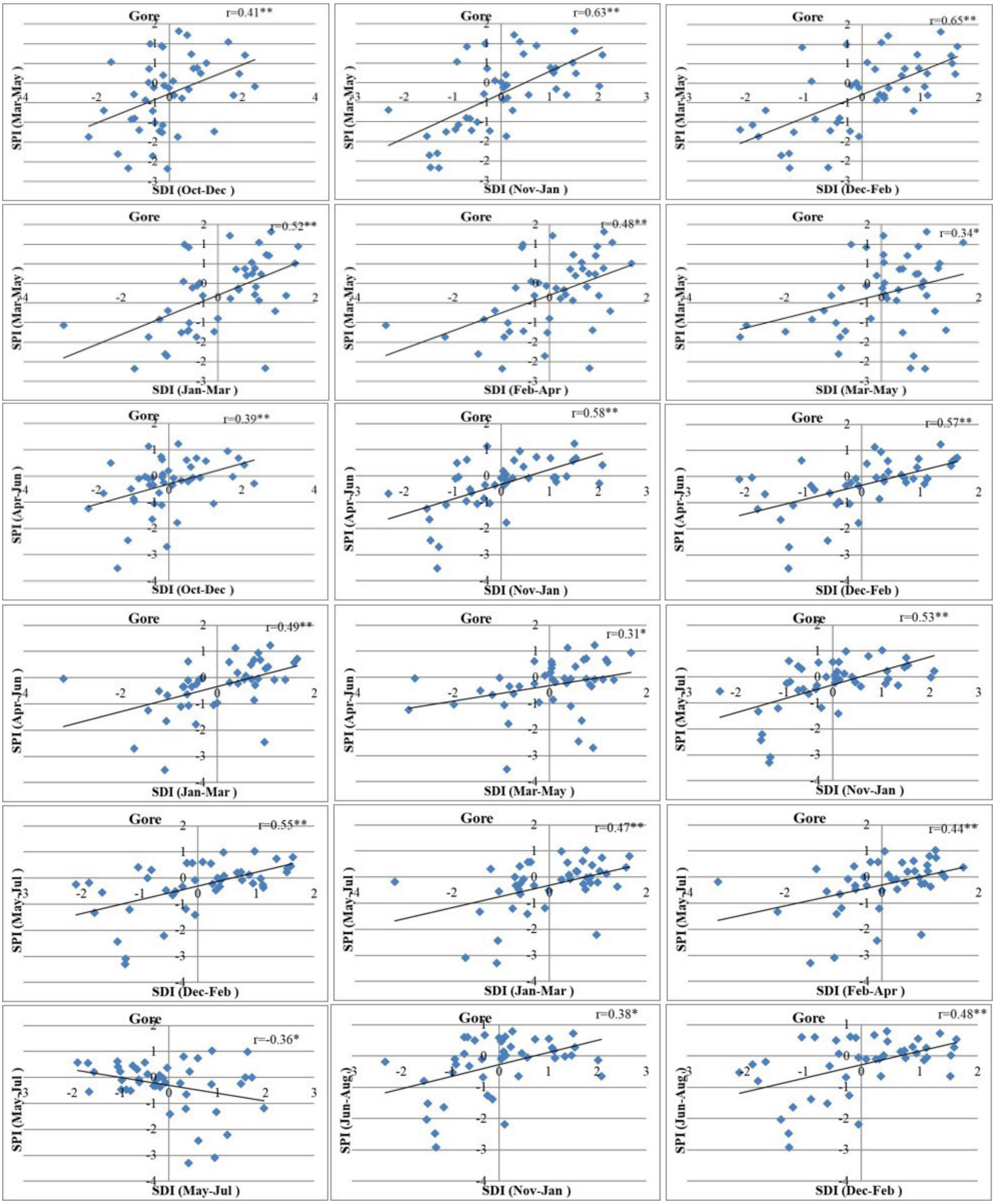

Figure 4. continued. The Correlation between SPI for Gore and SDI for Dongola at 3 months

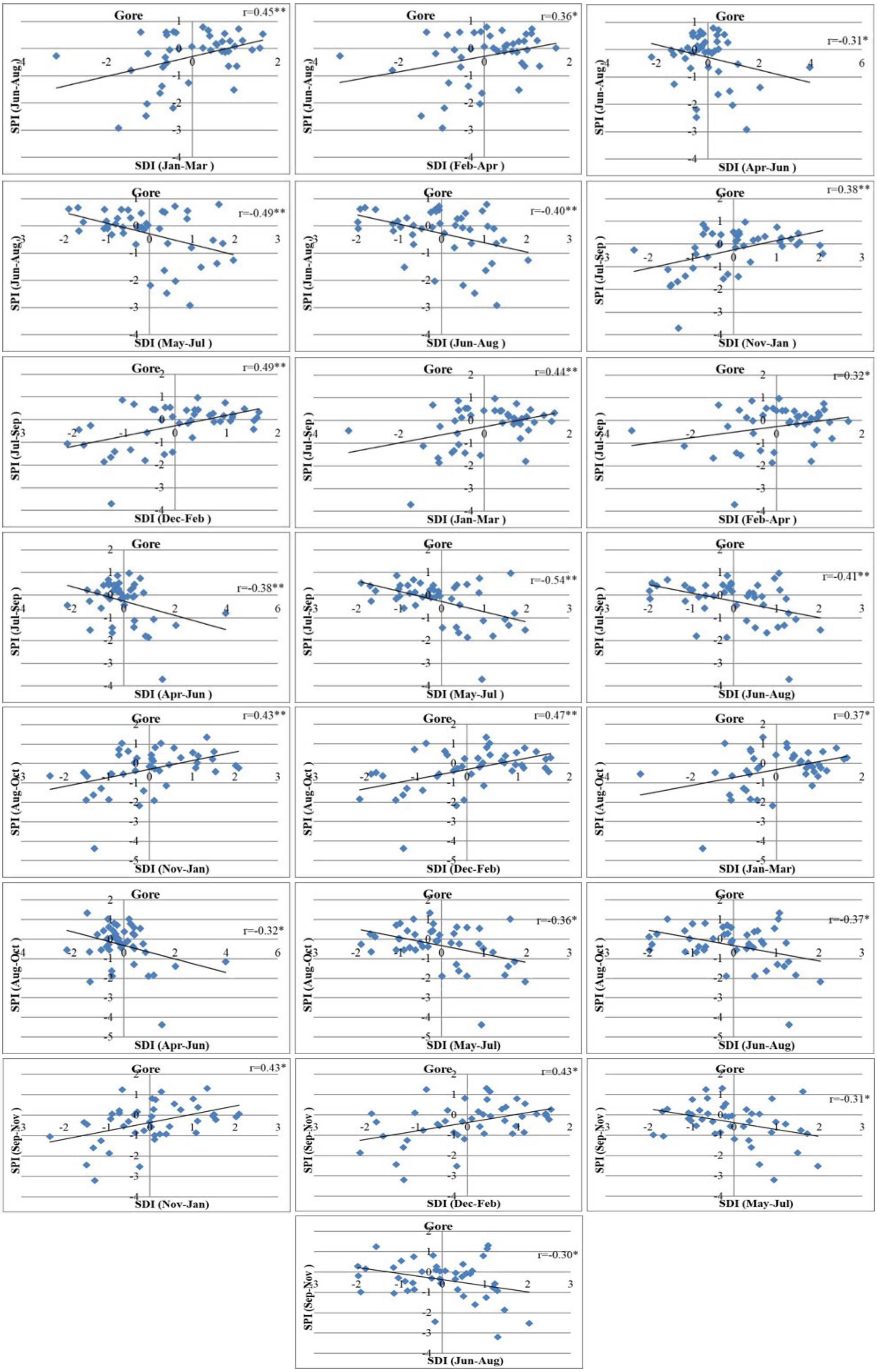

Figure 4. continued. The Correlation between SPI for Gore and SDI for Dongola at 3 months

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5. Conclusions

- Ethiopia has a climatology that varies from hot, semi-desert to mild and humid. According to the distributions of temperature which vary from north to south and increases towards the southeast region and decreases towards the central part, the climate varies mostly because of the altitude.

- There are three seasons in Ethiopia for precipitation distributions: Kiremt is the main rain season from June to September, Bega is the dry season from October to January, and Belg is the minor rainy season from February to May.

- After analysis of SPI and SDI from monthly values of SPI collected from the five stations located on the Blue Nile Basin (Addis Ababa, Bahar Dar, Debre Markos, Gondar and Gore) and SDI of Dongola, Dongola is more affected by the drought in Bahar Dar, Debre Markos and Gore.

- Pearson's correlation coefficients between each SPI and SDI intervals at different time ranges (for 1, 3, 6, 9, and 12 months) found some significant correlations (at 5% and 1% level of significance) while some were non-significant.

- The frequency of a statistically significant correlation is moderate in case of a monthly scale, where it reaches its maximum at 3 months scale, followed by 6 months scale, and less frequently at 9 months scale and not significant at 12 months scale.

- Results demonstrated a correlation exists between SPI, as a meteorological index, and SDI, as a hydrologic drought index.

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