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Research Article

Drought assessment on barley and millet production in Karnali Province, Nepal

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Abstract

Spatio-temporal characteristics of agricultural drought and its impact on the yield of winter barley and summer millet crops in Karnali Province of Nepal were evaluated. For this purpose, precipitation data from 1988 to 2018 of 18 stations and agricultural data from 2003 to 2018 were used for the analysis. Standardized Precipitation Indices (SPI-3 and SPI-4) were used for measuring drought intensity. Based on drought intensity, SPI<-1 was considered for drought occurrence. Similarly, Standardized Residual Yield Series (SYRS) was also calculated for crop yield change, eliminating other factors responsible for crop yield. The result shows that Salyan, Surkhet, and Jumla districts have more occurrence of summer and winter drought in comparison to other districts. Similarly, 1999, 2002, 2004-05, 2008-09, 2012, and 2015 were considered as drought years in most stations. Moreover, the province experienced more winter drought events than summer and winter droughts are increasing after 2015. Concerning the impact of drought occurrence on cereal yield loss, barley seems to be more affected. SPI-3 and SYRS (barley) are significantly correlated in Jumla, Humla, Mugu, Jajarkot, Dailekh, Surkhet, and Salyan districts at 95% confidence. With the exception, drought occurrence has a larger impact on barley yield loss than drought severity in the study area. However, millet yield loss doesn't seem to be affected due to drought occurrence and intensity in all districts except Rukum, as millet is a drought-tolerant crop. Therefore, for sustainable agriculture practices, drought-tolerant crops like millet could be suitable in Karnali Province, where drought frequency is very high.

Keywords: Agriculture, drought, Karnali Province, Standardized Precipitation Index, Standardized Residual Yield Series

Introduction

Drought is commonly described as a recurrent severe climate event (Sun et al., 2006; Wilhite, 2000), mainly classified in meteorological, agricultural, hydrological, and socio-economical drought (Mishra & Singh, 2010; Wilhite, 2000) based on its intensity and frequency. Drought periods have occurred many times throughout the globe during the last 500-1000 years (Cook et al., 2007; Gianini et al., 2003; Schubert et al., 2016; Shen et al., 2007) and have substantially increased since the mid-20th century (Dai, 2013a). It is expected that the number of drought days could increase by more in the coming future (Hallegatte et al., 2016), and the situation has become more perilous due to change in the climate (Kawasaki & Herath, 2011; Prasad et al., 2012).

Drought has severe impact on various aspects of the environment, including agriculture (Du et al., 2013; Popova et al., 2014). Drop in soil moisture available for plant growth causes agricultural drought (Mannocchi et al., 2004) which leads to significant decline in crop yield (Boken et al., 2005). Several studies show that agricultural yield has decreased with a substantial increase in drought frequency and intensity (Ciais et al., 2005; Downing & Bakker, 2000; Nagaraja et al., 2011), leading to economic loss (Below et al., 2007; Ding et al., 2011). It is found that drought stress reduced the grain yield of different cereal crops (Daryanto et al., 2016; Elliott et al., 2014; Kadam et al., 2014; Maisura et al., 2014) as the change in temperatures and erratic rainfall patterns affect the crop production (Malla, 2008). Furthermore, Nath et al. (2017) mentioned an increase in temperature causes drying of agricultural land and decreases overall cereal yield. Though the drought impact depends on the degree of vulnerability of communities, agriculturally dependent farmers are more susceptible to drought (Pandey et al., 2019). In addition to this, the impact is high to the agricultural dependent countries where the agri-system is based on rain-fed (FAO, 2014). But the

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agricultural yield is found to be reduced in both irrigated and rain-fed land types (Ray et al., 2018).

Nepal, with its complex topography, drought stands as one of the natural hazards with significant impact in various aspect (Dai, 2013b). The drought is already visible in the past (Dhaubanjar et al., 2019; Ghimire et al., 2010; Hamal et al., 2020; Karki et al., 2020; Shrestha et al., 1999; Shrestha et al., 2017) and is projected to increase in the future (Dahal et al., 2016a; Hamal et al., 2020). Also, significant warming over the country is observed in recent years (Karki et al., 2020; Khatiwada et al., 2016). Drought events can affect people in any way, which could be difficult to tackle in less developed regions like western Nepal (Adhikari, 2018; Pandey et al., 2019). Due to inadequate and untimely rainfall, most of the *Khet* (shallow farm lands) might have left fallow land, decreased productivity (Shrestha et al., 2000), and also changed the replenishment of water sources nearby (Paudel & Duex, 2016). The winter drought of 2008/2009 had a 50% decrease on the output of two main winter crops, wheat and barley, compared to the previous year, 2007 (Wang et al., 2013). Moreover, drought intensity has severe impacts on Nepal's mountain communities, posing a serious threat to agriculture, crop failure, and food production (GoN, 2009; Panthi et al., 2016). Therefore, correct characterization of drought and its effect in different areas and levels need to be assessed for applying appropriate and timely response to the droughts (Pandey et al., 2019) with respect to the capacity, community, and technology (Andersson et al., 2020; Ghimire et al., 2010). But due to the lack of drought assessment (Manning & Clayton, 2018), it has created difficulties in resource conservation and adaptation strategies in geologically challenging terrain. Although some studies have been done based on the assessment of drought and agricultural impacts (Hamal et al., 2020; Khatiwada & Pandey, 2019), site-based research at a provincial level with implications for drought-tolerant crops is still lacking.

Barley is an important crop that ranks fourth in global production and cultivation (Zhou, 2009). Although barley consumption is low on a global basis, it has remained an important crop in Asia and Himalayan nations like Nepal (Baik & Ullrich, 2008). The production of barley has decreased globally by 12 % (Ullrich, 2010) and by 50% in some years in Nepal (Wang et al., 2013). Despite being one of Nepal's major crops, the study of climate impact on barley yield is still limited. Similarly, millet is one of the drought-tolerant crops with high nutritional value (Sood et al., 2015; Wang et al., 2018). Unique adaptive features of millet, (Lata et al., 2013) make it resistant to water shortage and grow with minimal resources (Habiyaremye et al., 2017). Though millet accounts for low production globally, it can be important food crop in arid to semiarid regions (Lata et al., 2013; Obilana & Manyasa, 2002). A high amount of digestible protein (Zhang et al., 2007a), along with a high energy content in grain (Arora & Srivastava, 2002; Dwivedi et al., 2012), shorter life cycles (Lata et al., 2013), and the adaptive feature of millet makes it economically viable for mountain people. But in-depth study regarding this crop is yet to be done. Therefore, this study tends to identify drought intensity using Standardized Precipitation Index (SPI) and its impact on winter barley and summer millet yield. SPI is a simple model for long time series precipitation data analysis and easy to separate the level and intensity of drought.

Materials and Methods

Study Area

The study is conducted in Karnali Province, located in the western region of Nepal and lies between 28°20'-30°41'N latitude and 80°33'-83°40'E longitude with an area of 24,453 km^2. The major crops of the province are rice, maize, millet, buckwheat, wheat, and barley (MoAD, 2017). Among all the provinces, Karnali ranks first in the production of barley (GoN/MoF, 2019). Karnali Province faces a higher probability of drought spells that can last from few months of a season to droughts lasting a year (Hamal et al., 2020). Furthermore, the study area (Fig. 1), is a geologically varied region, from dry and elevated Humla and Mugu to low elevation lands of Salyan and Surkhet with varying precipitation patterns. Karnali Province is, however, dependent upon rain-fed agriculture with year-round irrigation in only 12% of total arable land (MoLMAC/AEC, 2020). Therefore, precipitation is one of the factors contributing to the production of crops in that area (Bhandari & Kayastha, 2010), which seems to be influenced due to drought. Different meteorological stations used in this study, located at different districts are mentioned in ANNEX-I.

Data Collection

Observed monthly time-series of precipitation data from the Department of Hydrology and Meteorology (DHM) for 1988-2018 were used. For precipitation data, meteorological stations distributed across Karnali Province were taken. However, only 18 stations were selected during analysis due to missing data. Stations with <10% of missing daily precipitation data were filled with the normal ratio method from nearby stations. The annual yield of major cereal crops from 2003 to 2018 for barley (winter crop) and millet (summer crop) of various districts were taken from Agriculture Statistics available at Ministry of Agriculture and Livestock. As drought severity has increased since 2000 (Hari et al., 2020), this study is focused to evaluate the impact of drought on agriculture after 2000. However, due to the absence of agricultural data in some districts, the effects of the drought are only examined from 2003 to 2018.

Data Analysis

Calculation of drought indices is done using the SPI developed by McKee et al. (1993). This index takes at least 20-30 years of data and quantifies the precipitation deficit for multiple timescales. The negative and positive values of the SPI illustrate dry and wet criteria where drought intensity is calculated on a scale of greater than 2.0 (extremely wet) to -2.0 (extremely dry) (Svoboda et al., 2012). Drought intensity was based on agricultural drought, SPI-3 and 4, which accumulated three- and four-months precipitation respectively, for sowing and growing period of the studied crop. SPI-3 is calculated for winter (February) and SPI-4 is calculated for summer (September).

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Calculated SPI-3 and SPI-4 was then averaged for particular district. Drought frequency shows occurred drought in the study area (Tan et al., 2015) and is analyzed as the fractional frequency with SPI ≤-1. Seasonal drought frequency is calculated as ratio of drought occurrence to total drought. The estimated SPI includes data for the entire crop calendar year. Using data for the whole year may not be accurate as barley and millet have different cropping cycles. Therefore, the entire phenological periods were divided into the sowing, growing, and harvesting period (Table 1). Considering the sowing and growing period, winter drought is associated with barley (winter barley, hereafter) and summer drought with millet (summer millet).

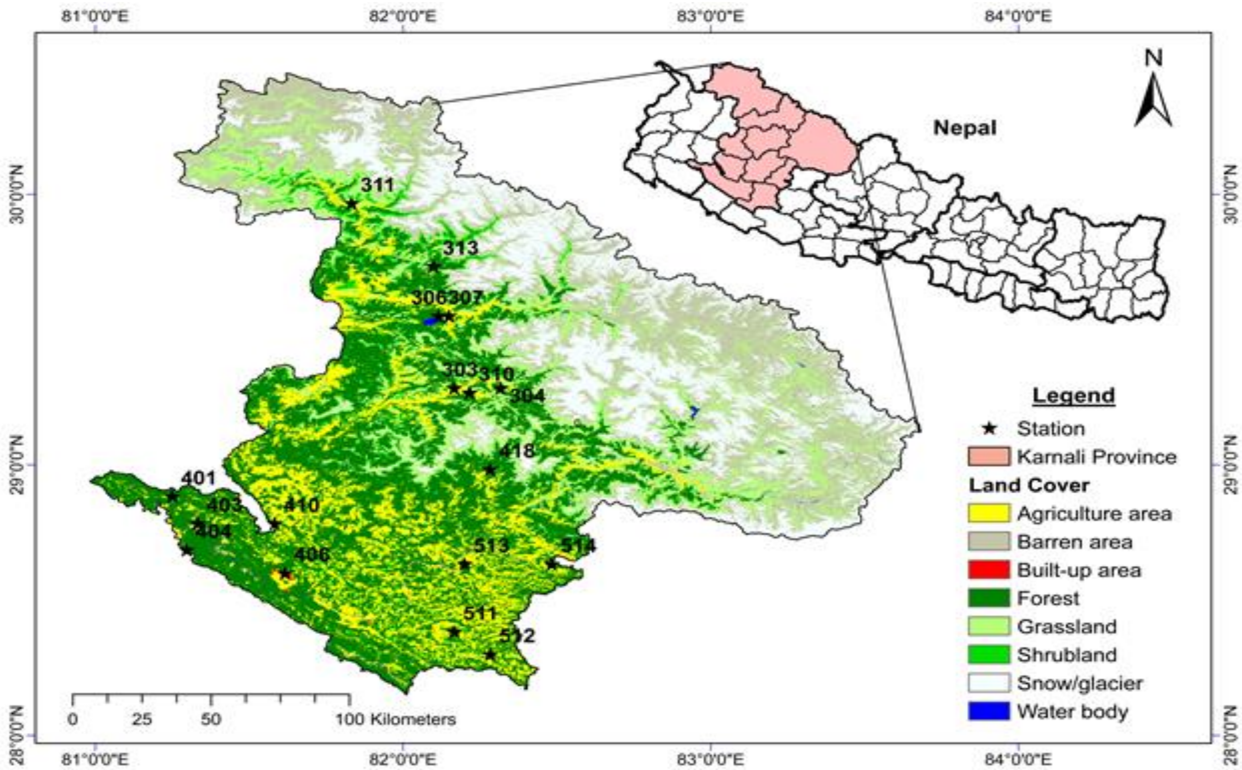
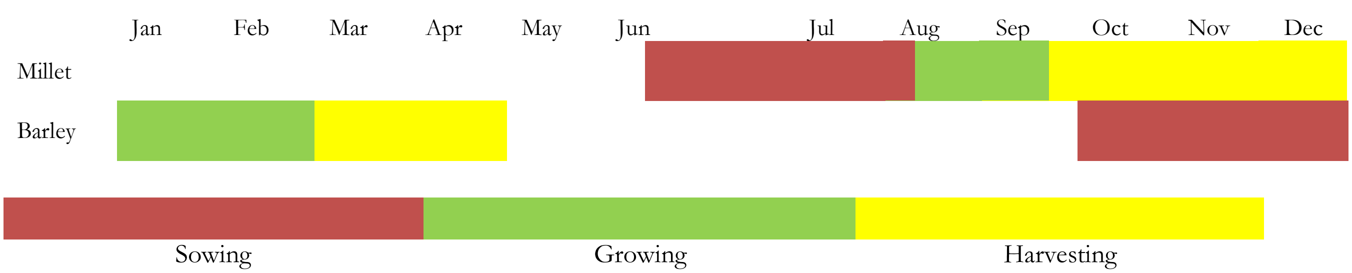


Figure 1 Location map of the study area with meteorological stations

Table 1 Sowing, growing, and harvesting calendar of barley and millet



Source: FAO & WFP (2007)

Although the annual trend for both crops production seems increasing, there is a loss in production considering individual years. Therefore, standardized residual yield series (SYRS) is estimated to show the crop yield's annual change. The linear regression method is used for eliminating errors in increasing crop production due to improved technology, adaptation practices, and irrigation facilities. The crop yield residual depicts the impact of weather on yield (Liu et al., 2018; Potopova et al., 2016). SYRS is calculated using equation (i). Yield loss is classified in Table 2.

$$SYRS = \frac{y_i - \mu}{\sigma} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\text{(i)}$$

Where y_i is the residual of the de-trended yield, μ is the mean of residuals of the de-trended yield, and σ is the standard deviation.

Table 2 Yield loss category with SYRS value

SYRS value	Yield loss category
-1.0<SYRS≤-0.5	Low yield loss
-1.5<SYRS≤-1	Moderate yield loss
SYRS≤-1.5	High yield loss

The correlation is analyzed between SPIs and SYRS using the t-test with 95% confidence level at different districts on seasonal scale.

Results and Discussion

Spatial and Temporal Analysis of Drought

The SPI-3 (refer to ANNEX IIA & B) and SPI-4 (refer to ANNEX IIC & D) are computed for an accumulation period of three and four months, respectively, deviated towards the near normal to an extreme dry period for individual stations. SPI value reveals that the province experienced severe to extreme drought in 1999, 2002, 2004, 2005, 2008, 2009, 2012, and 2015. The study conducted by Khatiwada and Pandey (2019) also reveals a similar survey in the Karnali River basin. Considering the spatial drought, the stations located at Jumla (Station 303), Mugu (Station 306), Dolpa (Station 312), Humla (Station 313), Dailekh (Station 410), Salyan (Station 511, 512), Surkhet (Station 403), and Rukum (Station 514) are found to have a more frequent drought in most dry years. Kafle (2015) also reported high drought in Jumla District.

Looking at the yearly drought of individual stations, we found that in station 514, extreme drought was seen in 1989 for about seven months. In 1992, stations 311, 410, and 514 showed moderate drought lasting for about eight months. At station 514, moderate to extreme drought (-2.05) was observed for six months in 1993. Similarly, in 1997 station 307 showed severe drought for seven months and three months of extreme drought (-2.41) in station 404. As the year 1999 was a drought year, almost all stations observed extreme (-3.7) to severe drought. The prolonged drought was observed from October 2001 to November 2005 for about 43 months in station 313 with extreme SPI value ranging to -3.96. In 2002, station 312 observed a long drought (Extreme, -3.14) for 17 months from February 2002 to May 2003. At station 512, continuous drought was seen from 2004 to 2005, where the maximum drought ranges up to -3.08. Similarly, continuous drought for about ten months and seven months is seen in 2007 in station 310 and 311, respectively. In 2008-09, drought was experienced in almost ten stations with a maximum drought length of 12 months. Continuous drought was seen for 12 months in 2010 in station 418 and nine months in station 406. At station 311, a full-year drought was experienced in the year 2012. In the same year, six other stations also experienced more than six months of drought. SPI values showed drought at stations 306, 307, 311, 312, 404, 418, 511, and 513 for five months in 2014. SPI shows the prevalence of drought (max. -3.14 (station 406)) in 12 stations in 2015 for continuous five months. In 2016, 2017, and 2018, drought is prevalent in December, January, and February in most of the stations. Drought indices of individual stations from the year 1988 to 2018 are given in ANNEX II.

Seasonal Drought Frequency

The longest frequency of drought reached up to >50% in the year 1992 (≤ 66%), 1999 (66%), 2002 (100%), 2003(100%) in station 313, 2005 (91%), 2008 (83%), 2009 (83%), 2012 (100%), 2015 (50%) in some stations (ANNEX II). However, all the stations were not found to have extreme dryness. The drought frequency (SPI<-1) ranges from 8% to 100%. Considering all stations from 1988 to 2018, moderate drought occurs at the frequency of 8%, severe drought 5%, and extreme drought 3%. The occurrence of moderate drought is more frequent than the other two droughts (Sigdel & Ikeda, 2010). Though the drought intensity was seen lying in near-normal condition and shows no particular pattern (Khatiwada & Pandey, 2019), drought events and frequency have increased after the year 2000 compared to the 1900s (Hari et al., 2020).

Based on seasonal drought, Karnali Province experiences more winter drought (>60%) than summer drought in most districts except Jumla (Fig. 2). The result coincides with the study done by Wang et al. (2013) in western Nepal and Khatiwada and Pandey (2019) in Karnali River Basin (KRB), where the winter drought is more prominent in most of the stations as compared to summer drought. It is mainly due to Arctic Oscillation and local Hadley circulation (Wang et al., 2013). Although climate change effects are felt throughout the year, the warming trend in the winter is greater than in the summer (Kreyling et al., 2019). Despite the westerly wind affecting the western part of Nepal, precipitation was poor in the winter (Kafle, 2015). Seasonality of drought was analyzed from 2003-2018 to show drought impact on crop yield. It is found that the occurrence of both summer and winter drought is high in higher elevated districts (Fig. 3). In Jumla, six winter droughts and summer drought are prevalent. The occurrence of winter drought is more frequent after 2015. In Mugu District, three summer and six winter droughts were experienced. Here, more winter droughts are seen after 2015. Similar to this, Humla District showed occurrence of winter drought after 2015.

In the middle hill region, the summer drought is comparatively less than the winter drought (Fig. 4). However, in Dolpa District occurrence of summer drought is more. But this trend of summer drought is not observed in Rukum and Jajarkot. Although summer drought occurrence is more in Dolpa, winter drought is in increasing trend in recent years (Khatiwada & Pandey, 2019). Winter drought is more frequent after 2015 in Rukum District as well. In Siwalik regions, both summer and winter droughts seem to be at an equal frequency (Fig. 5). In Surkhet, the occurrence of winter drought is in increasing trend since 2015. No continuous drought has been observed (Kafle, 2015) except in 2008 (station 403), while Salyan District shows the frequent occurrence of winter drought in recent years. Winter drought was reported in Dailekh District in 2007 and 2015.

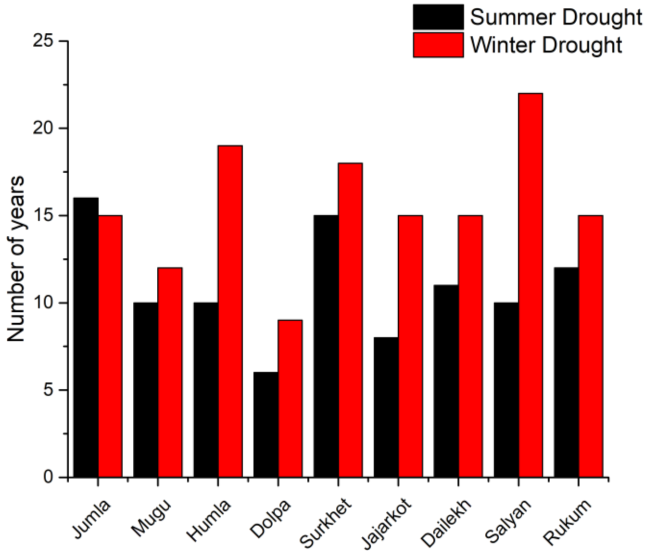


Figure 2 Number of summer and winter drought in Karnali Province over 30 years

On average, the intensity of drought is high in higher mountains (Baidya et al., 2008; Shrestha, 2000) as low precipitation is observed in western high-mountain areas (Kansakar et al., 2004). Also, the occurrence of winter drought has increased from 2015 onwards (Hamal et al., 2020) as predicted (Baniya et al.,2019).

Impact of Drought on Cereal Production

The study reveals that the value of SYRS ranges up to -3.2 for millet and -2.66 for barley from the year 2003 to 2018 with high yield loss. For millet, high yield loss was seen in 2015 (SYRS= -3.2) in Humla District. Similarly, a high yield loss for barley is found in 2007 (SYRS= -2.66) in Dailekh District. Although 2007 is not considered drought year, winter drought is experienced in Dailekh District, which affected the barley production in that region.

Impact of drought on winter barley production taking SPI-3 shows that the barley's total yield has been affected in the district where the value of SYRS is significant with SPI-3. The total yield is hence affected due to the occurrence of winter drought. Overall barley production (2003-2018) in Mugu District is significantly correlated ($r^2= 0.62, p<0.05$) with winter SPI. Similarly, such significant correlation between SYRS of barley and SPI-3 is computed in other districts, Jumla ($r^2=0.60, p<0.05$), Humla ($r^2=0.59, p<0.05$), Surkhet ($r^2=0.47, p<0.05$), Salyan ($r^2=0.37, p<0.05$), Dailekh ($r^2=0.35, p<0.05$), Jajarkot ($r^2=0.35, p<0.05$) (Fig. 6). However, in Dolpa and Rukum Districts, SYRS and SPI-3 is not significant. Considering the physiographic region, high hill region, and siwalik range significantly correlate to yield loss (SYRS) and drought intensity. But middle hill districts are not affected due to drought in barley yield loss.

The impact of drought on winter barley significantly affects yield loss although barley is considered an adaptive plant (Zeng et al., 2015). As drought intensity increases, the weight and number of barley spikes and grains per plant potentially lower the total yield (Samarah, 2005). Barley shows its loss in production when subjected to extreme drought (Ceccarelli et al., 2007). But such a trend of yield loss with increasing drought intensity is not observed in our study area where moderate, severe, and extreme drought has a similar effect on yield loss.

A similar result was found in the yield loss of barley in Lamjung District (Poudel & Shaw, 2016). Maharjan and Joshi (2013) also found high barley yield contributed due to the winter rain in Nepal. Yield loss of barley with drought stress is also dependent on the genotype (Guo et al., 2009; Nazari & Pakniyat, 2010), which may be the reason for not coinciding with the study of Ceccarelli et al. (2007). Also, yield loss of barley is moreover dependent on postanthesis drought rather than drought intensity (Samarah, 2005). In this study, more frequent winter droughts are observed in barley growing period (January-February), furthermore soil moisture is also found low during the winter season (Talchabhadel et al., 2019) which might decrease yield in Karnali Province.

Similarly, drought intensity has affected the yield of summer millet in Rukum ($r^2=0.58, p<0.05$) District only (Fig. 7). In Mugu, Dailekh, Jumla, Salyan, Humla, Dolpa, Surkhet, and Jajarkot Districts, there is no significant relation between millet yield loss and drought intensity. Like barley, millet doesn't follow such yield loss patterns according to the physiographic regions. Despite having more drought events, drought seems to have less effect on millet yield loss, as it is regarded as the drought-tolerant crop (Hadebe et al., 2017).

From the results, it can be said that drought intensity does not affect the millet yield loss. Considering the individual year, extreme loss of millet was found with extreme drought intensity, and moderate loss was seen in moderate drought intensity. However, total millet yield loss is found to be insignificant with the district. In view, millet is considered a drought-tolerant crop (Bidinger et al., 1987; Hadebe et al., 2017; Liu et al., 2013), it can grow in water shortage areas due to its physiological characteristics (Adhikari et al., 2018).

Thus, the prevalence of drought intensity has minimal impact on yield loss. The average annual yield of millet crop has also increased with rise in temperature in China (Cao et al., 2010). Millet's ability to naturally interact with a variety of rhizobacteria that exhibit high drought tolerance results in lower yield loss in drought-prone areas (Niu et al., 2018). Along with this, its water use efficiency (WUE) has also been found to be higher than maize, wheat, and sorghum (Zhang et al., 2007b).

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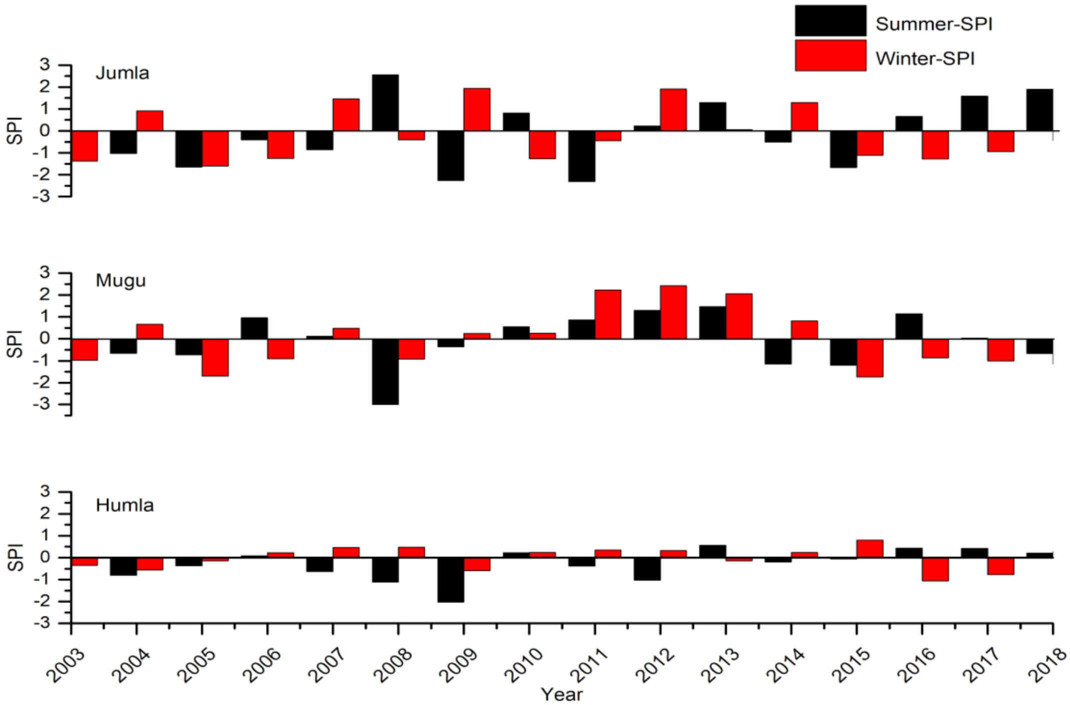

Figure 3 Winter and summer SPI of Jumla, Mugu, and Humla Districts

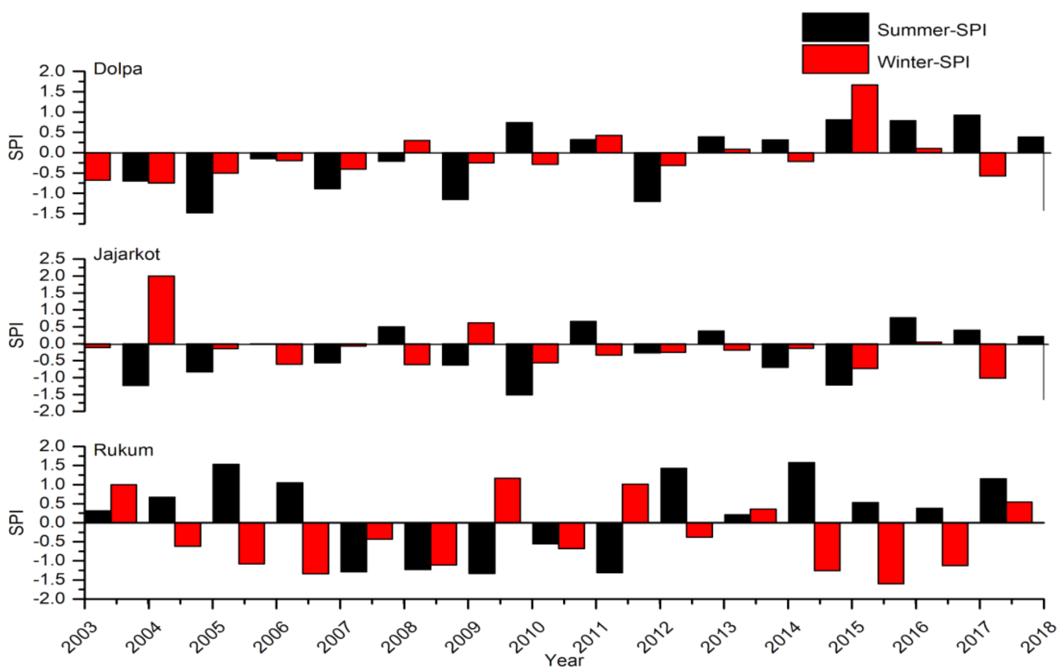

Figure 4 Winter and Summer SPI in Dolpa, Jajarkot, and Rukum Districts

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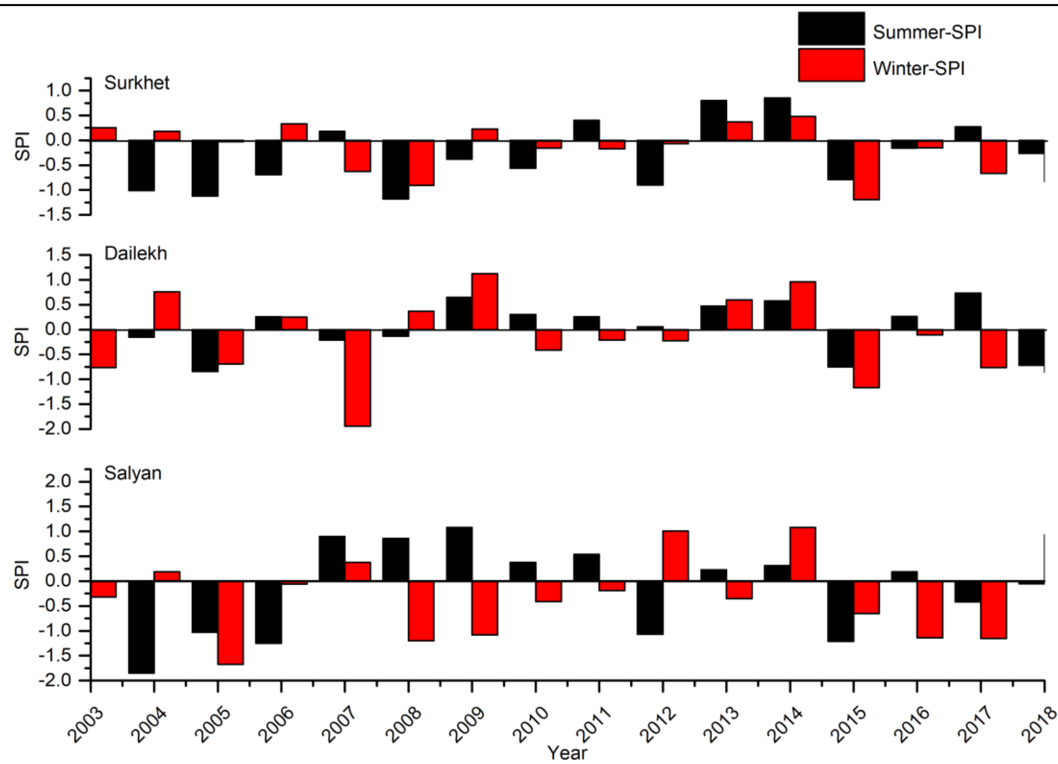

Figure 5 Winter and Summer SPI in Surkhet, Dailekh, and Salyan districts

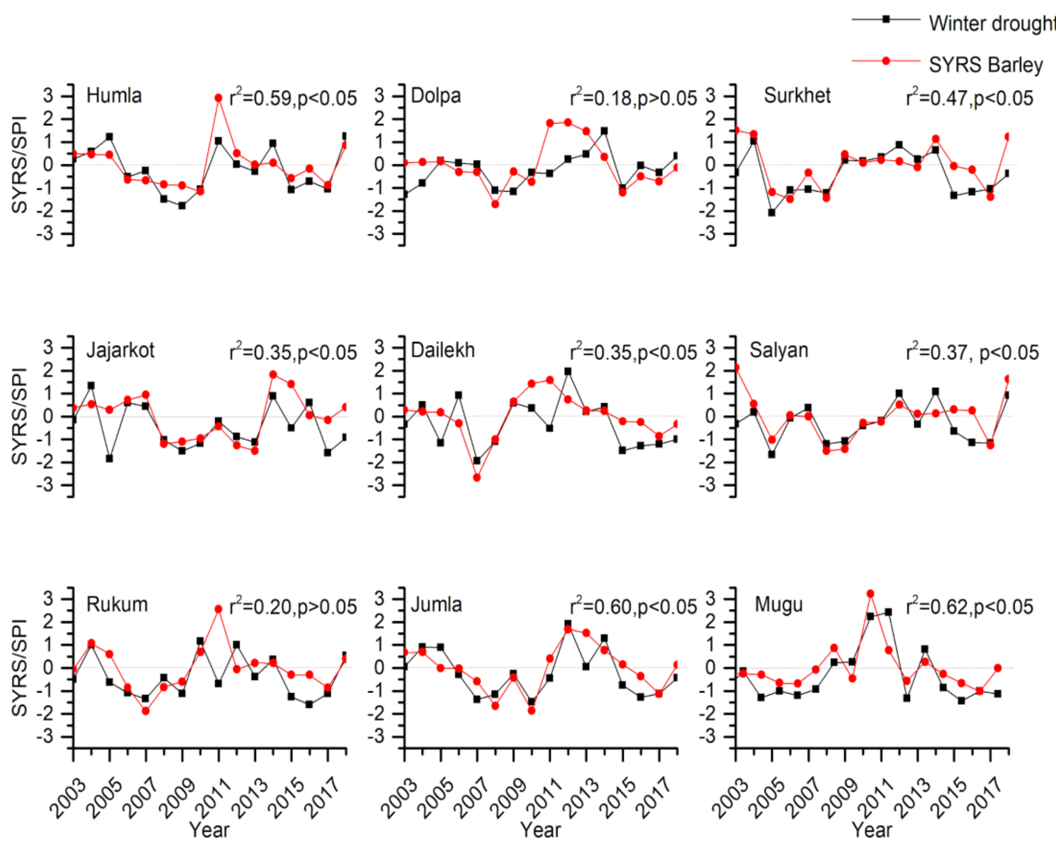

Figure 6 Correlation between Winter SPI-3 and SYRS (Barley)

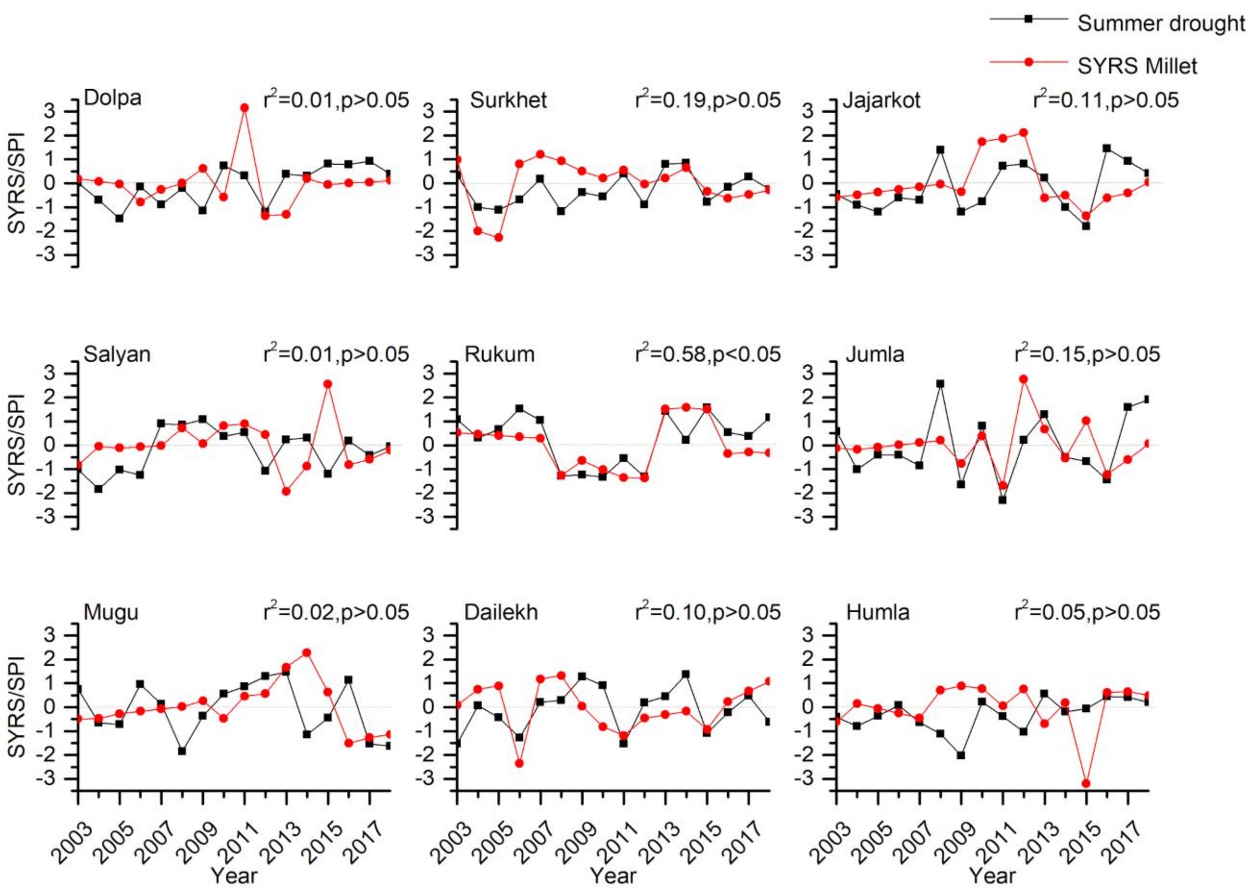

Figure 7 Correlation between summer SPI-4 and SYRS (Millet)

The frequency and intensity of drought events experienced in Karnali Province have negative consequences for soil properties, agricultural practices (Bhandari & Kayastha, 2010; Bhandari & Panthi, 2014), livestock production (Dahal et al., 2016b), socio-economic patterns, and the psychological well-being of the people living in that area (Ghimire et al., 2010; Hallegatte et al., 2016; Khatiwada & Pandey, 2019; Passioura, 2007). Various drought studies and impacts on other cereal crops (rice, maize, wheat) show a more negative effect due to drought severity (Hamal et al., 2020; Khatiwada & Pandey., 2019). As a result, cultivation of drought tolerant crop should be encouraged in such area where extreme drought occurs.

Conclusion

This study presents the spatio-temporal analysis of drought in the cropping season of two major cereal crops (barley and millet) in Karnali Province, which shows the frequent drought occurrence in 1999, 2002, 2004-05, 2008-09, 2012, and 2015. Moreover, the frequency of winter drought is more than summer drought in most of the districts. Regarding the crop type, winter barley has a significant impact due to drought intensity for yield loss. However, the yield loss of barley is independent of drought severity rather than drought occurrence. In contrast, millet, standing as the drought-tolerant crop, has minimal impact on yield loss due to drought and has no significant relation except Rukum District. Nevertheless, the occurrence of drought has a potential effect on agriculture-dependent mountain people. Therefore, for better livelihood and agricultural practices, drought-tolerant crops like millet should be promoted with more interventions in irrigation and adaptive management strategies.

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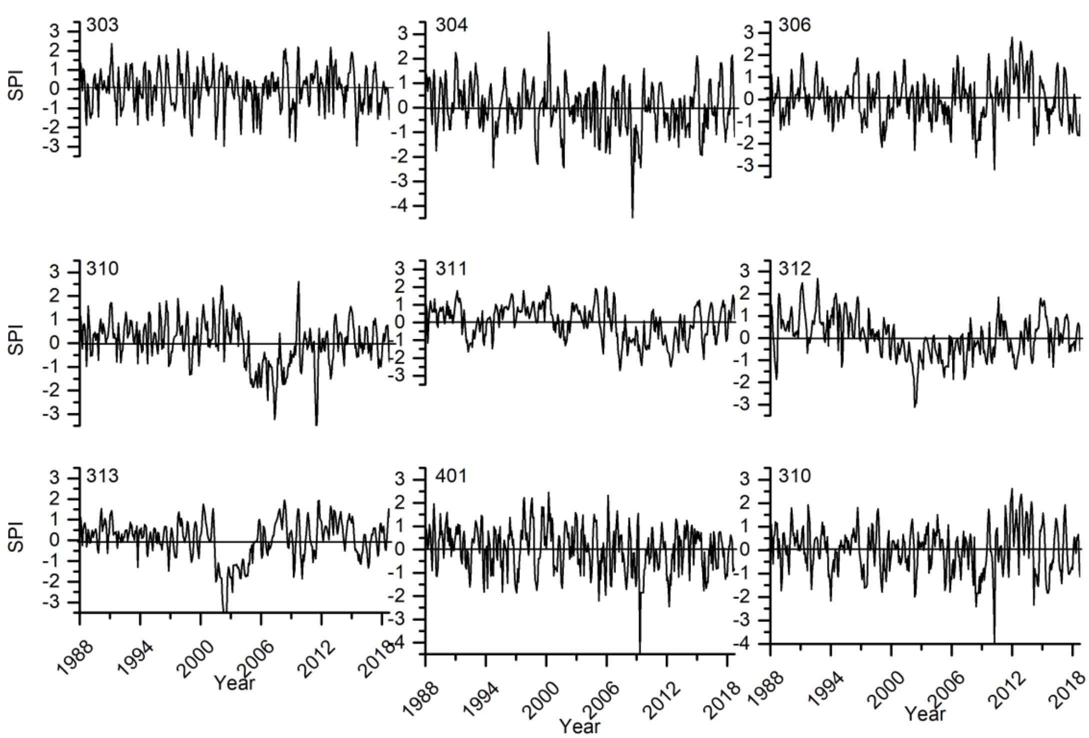
ANNEX-I Meteorological Stations and districts wise details

S.N.	Station name	Station ID	Measuring type	District	Latitude	Longitude	Altitude
1	Jumla	303	Synoptic	Jumla	29.17	82.1	2300
2	Guthi Chaur	304	Precipitation	Jumla	29.17	82.19	3080
3	Gam Shree Nagar	306	Precipitation	Mugu	29.33	82.09	2133
4	Rara	307	Climatology	Mugu	29.33	82.07	3048
5	Dipal Gaun	310	Climatology	Jumla	29.16	82.13	2310
6	Simikot	311	Climatology	Humla	29.58	81.5	2800
7	Dunai	312	Climatology	Dolpa	28.56	82.55	2058
8	Darma	313	Precipitation	Humla	29.44	82.06	1950
9	Pusma Camp	401	Climatology	Surkhet	28.53	81.15	950
10	Jamu (Tikuwa Kuna)	403	Precipitation	Surkhet	28.47	81.2	260
11	Jajarkot	404	Precipitation	Jajarkot	28.42	82.12	1231
12	Surkhet (Birendra Nagar)	406	Synoptic	Surkhet	28.36	81.37	720
13	Bale Budha	410	Precipitation	Dailekh	28.47	81.35	610
14	Maina Gaun (d.bas)	418	Precipitation	Jajarkot	28.59	82.17	2000
15	Salyan Bazar	511	Climatology	Salyan	28.23	82.1	1457
16	Luwamjula Bazar	512	Precipitation	Salyan	28.18	82.17	885
17	Chaur Jhari Tar	513	Climatology	Rukum	28.38	82.12	910
18	Musikot (Rukumkot)	514	Climatology	Rukum	28.38	82.29	2100

ANNEX II-A Individual stations (303 to 401) with SPI-3 of Karnali province



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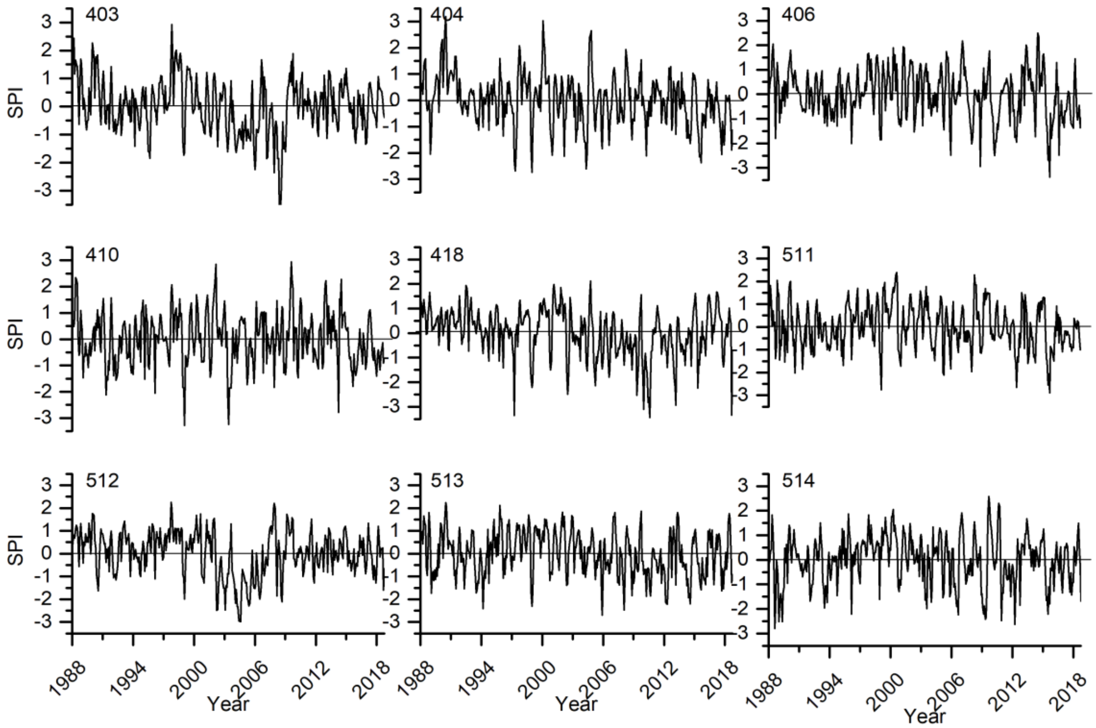
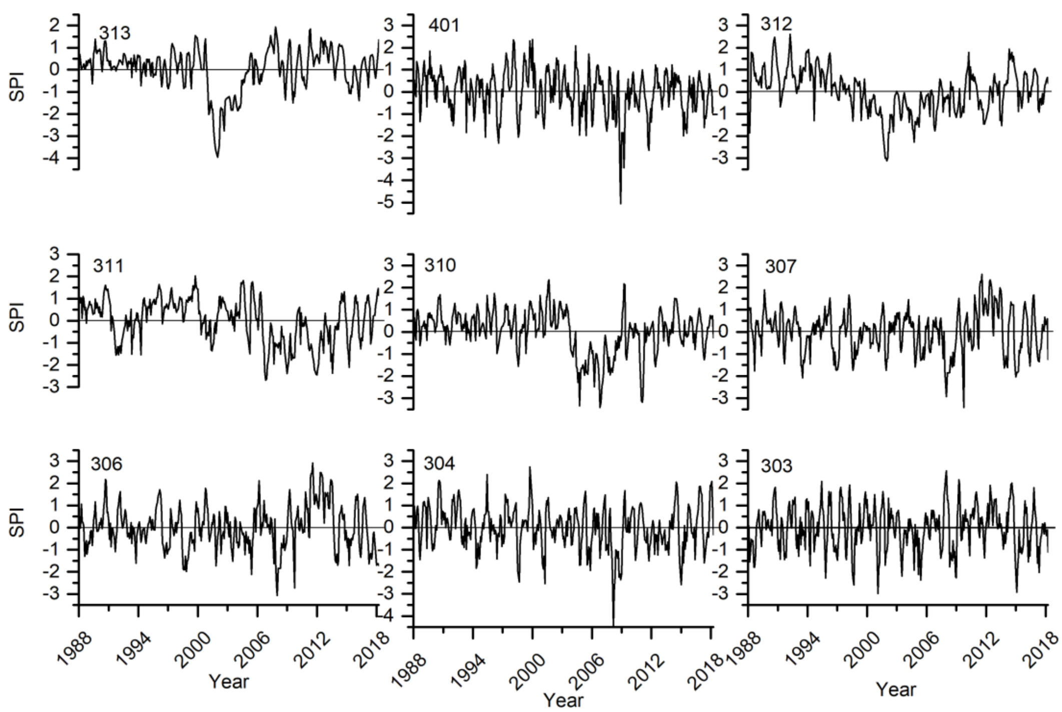
ANNEX II-B Individual stations (403 to 514) with SPI-3 of Karnali province



ANNEX II-C Individual stations (303 to 401) with SPI-4 of Karnali province



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ANNEX II-D Individual stations (403 to 514) with SPI-4 of Karnali province