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Research Article

Logistic Regression Analysis for Spatial Patterns of Drought Persistence

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Drought is one of the natural hazards with potentially significant impacts on society, economy, and other natural resources over the globe. However, the understanding of drought characteristics and its persistence can significantly help to reduce the potential impacts of drought. Moreover, the knowledge about the spatiotemporal pattern of seasonal drought frequency and drought persistence is important for water resource management, agricultural development, energy consumption, and crop yields. Therefore, the present study is employed to examine the seasonal drought frequency and drought persistence in the region. In this regard, the standardized precipitation index (SPI) at the three-month time scale was used to determine meteorological drought. Furthermore, the logistic regression model is used to calculate the odds and probability of drought persistence from one season to the next for the selected stations by identifying the spatial pattern of seasonal drought frequency and persistence. The potential of the current analysis is validated on six selected stations of the northern area of Pakistan. The outcomes related to the current analysis provide the basis for taking more considerations on early warning systems and help to make the valuable decision for water resource management and agriculture sectors in Pakistan.

1. Introduction

Drought is a complex phenomenon and one of the greatest recurring natural disasters. It causes substantial losses in agriculture sectors [1–6], natural ecosystems [7–9], and forestry [10–12]. It is also called a creeping phenomenon with its influences gradually take in an area over a period and may persist for a long period. In severe cases, drought can last for many years and disturb many social activities, agricultural sectors socioeconomic sectors, and environmental settings [6, 13–16]. The arrival of drought occurrences is complicated; therefore, it is challenging to substantiate the onset of the drought occurrences. The complication in drought occurrence becomes a cause for new methodologies for the assessment of drought [17–19]. However, the effects of droughts have been described in several studies, and various extensive measures are proposed to hold them. However, without proper actions, drought consequences can be severe for the natural environment and sustained for a long period even after termination [20–22].

The speedy improvement in the drought monitoring policies brought several advantages to society [17, 18, 23]. To understand the complexity and improve methodologies of drought monitoring, the researchers have been grouping the

drought in several aspects including meteorological, agricultural hydrological, and socioeconomic aspects [24, 25]. Rhee and Im [26] described the meteorological drought as a lack of precipitation in a prolonged period [27, 28]. The agricultural and hydrological droughts can be defined as periods with insufficient soil moisture and river flow or groundwater, respectively [29]. The drought-related socioeconomic occurs due to a shortage in water resource systems. In this case, the water demands are not fully attained by the water supply. The water supply is unable to provide sufficient water at a particular time for society. Since last recent years, droughts cause major factors that distress the society and its economic environment sectors around the world more than other natural hazards [30]. However, the disaster can be minimized by adopting suitable approaches to assess drought occurrences. The appropriate approaches can help to mitigate drought impacts and provide significant outcomes for further drought monitoring and mitigation policies.

In the literature, researchers added several indices for the improvement of drought mentoring policy and forecasting strategies. For instance, for identifying various drought classes in the selected area, Van Rooy, [31] proposed a rainfall anomaly index (RAI) which is designed particularly for the classification of drought classes. Furthermore, a study measured the cumulative deviation of moisture supply and added new research Palmer drought severity index (PDSI) in the literature for monitoring drought more accurately [32]. Many other drought indices were added in the literature for increasing the efficiency and accuracy to determine drought occurrences more accurately and precisely. The drought indices including Crop Moisture Index (CMI) proposed in [33], Bhalme and Mooly Drought Index (BMDI) in [34], Reclamation Drought Index (RDI) introduced in [35], National Rainfall Index (NRI) in [36], Surface-Water Supply Index (SWSI) developed in [37, 38] have proposed Standardized Precipitation Index (SPI). The SPI is prevalent among other indices and frequently used for drought monitoring and forecasting [39, 40]. The obtained standardized values of SPI can be used to compare droughts in distinct climatic zones across regions. Therefore, the SPI is commonly used for assessing drought occurrences and developing new methodologies for drought monitoring and forecasting [41–43].

The current study aimed to examine the drought persistence in the selected stations. The study used logistic regression to compute odds and probability of drought persistence from one season to the next in the selected region by identifying the spatial pattern of seasonal drought frequency and persistence. The standardized precipitation index (SPI) at the three-month time scale was employed to characterize meteorological drought. Furthermore, the potential of the present study is validated on six selected stations of the northern area of Pakistan. The results associated with the present study provide the basis for taking more attention to the early warning systems and making improvements for water resource management and agriculture sectors to observe and substantiate the severity of drought in Pakistan.

2. Methods

2.1. Standardized Precipitation Index (SPI).
The various studies consider varying drought indices to categorize and monitor drought occurrences [39, 41, 43]. Since the last decade, the use of SPI is common for drought monitoring [41, 44]. The present study considers the SPI developed by [38] for the estimation of drought occurrences. The time-series data ranging from January 1971 to December 2017 is used for drought characterization. The consistency of SPI is significant in climatic circumstances relating to the geographical and temporal distribution [39, 40]. Furthermore, the simplicity in calculation makes SPI more prominent and recognized worldwide for characterization. The SPI can be computed for various times based on monthly data to observe the meteorological drought [39].

2.2. Logistic Regression Model.
The drought is assessed based on SPI for the selected stations. The seasonal drought is analyzed using SPI at a three-month time scale for each selected station. The seasonal drought frequency is calculated as the total number of years in which drought SPI ≤ 1 appears in each climate division of the selected station. The climate divisions are included as follows: (1) "December, January, February" (Winter); (2) "March, April, May" (Spring); (3) "June, July, August" (Summer); (4) "September, October, November" (Autumn). For instance, if the climate brings 10 years in which drought occurs in winter during the total number of 47 years, the drought frequency probability is 10/47 or 21%. Furthermore, the persistence of seasonal drought can be defined as the drought conditions staying from one season to the next. In the current analysis, drought persistence is defined as winter-spring, spring-summer, summer-autumn, and autumn-winter. For each station, the seasonal drought persistence and season combination can be expressed as the probability of persistence. The probability of persistence can be calculated as the total number of years in which drought persists from one season to season combination by dividing the total number of years in which drought appears during the first season in that climate division. For example, if the climate shows 12 years in which drought occurs in winter and drought conditions continue into spring during the 10 of those years, the drought persistence probability is 10/12 or 83%. Furthermore, in the present study, SPI for scale three is considered as a binary variable: drought occurs = 1 and drought does not occur = 0. The drought persistence can be calculated to define the impact of the influence of one season's moisture conditions on moisture conditions in the forthcoming season (Ford and Labosier, 2013). Moreover, in the current study, the logistic regression model is employed to examine the persistence of drought from one season to the coming season [45]. The logistic regression model is frequently used to examine the relationship between the binary dependent variable and one or more independent variables (Ford and Labosier, 2013). Kutner et al. [46]; stated that using an ordinary least squares regression with a binary dependent variable can lead to several issues including nonnormally distributed errors and

predicted values in which range does not occur from 0 to 1. Therefore, logistic regression is the more suitable method for analyzing a binary dependent variable. Furthermore, various studies used a logistic regression model to predict the logit transformation of the dependent variable based on the independent variables [46–49]. The logistic regression model can be considered in the following form:

$$F(t) = \frac{e^t}{e^t + 1} = \frac{1}{1 + e^{-t}}, \quad (1)$$

where t is a linear function of an explanatory variable x, and the logistic function can be written as

$$\pi(x) = \frac{e^{\alpha+\beta x}}{e^{\alpha+\beta x} + 1} = \frac{1}{1 + e^{-\alpha+\beta x}}. \quad (2)$$

The inverse of the logistic function, the logit model, is

$$g(x) = \frac{\rho}{1 - \rho} = \alpha + \beta x, \quad (3)$$

where the odds ratio of the drought occurrence is denoted by $(\rho/(1 - \rho))$, α shows the intercept, and β denotes the regression coefficient. Furthermore, the normally distributed residuals are not required in the logistic regression model. However, the error distribution between actual and predicted dependent variables follows binomial (Ford and Labosier, 2013). In the current scenario, for SPI at scale 3, the observations were perceived independently, and the binominal assumption meets [45, 47]. The use of the logistic function is beneficial as it can be considered an input with any value from negative infinity to positive infinity, whereas the output ρ is remained to values between 0 and 1 and thus is explainable as a probability. The current study employed a logistic regression model for the specific season based on a binary dependent variable which is drought occurrence (1 = drought, 0 = no drought) and the explanatory variable is the SPI value from the previous season. The outcome of the model can be described for the given season as the log odds ratio of drought occurrence, and the relationship between the dependent and explanatory variables is represented by the slope (β) of the logistic regression. For instance, when β is observed negative, for the specific season, the odds of drought occurrence are negatively related to the SPI value in the previous season. In a more precise way, it can be described that the rise in the preceding season's SPI causes to decline in the odds of drought occurring in the subsequent season.

3. Application

The structural importance of the Northern region is important for the other regions of the country. The northern region is a geographic area that has a group of three mountain ranges, the Himalayas, Karakoram, and the Hindu Kush, which cover most of the region [50]. Many of the world's tallest peaks are found in this region, including K-2, Nanga Parbat, and Rakaposhi. The average altitude of Karakorum is 6,100 m, Hindu Kush is 7,690 m, and the Himalayas is 8,848 m [51]. These high altitudes of mountains frequently deliver a significant portion of precipitation [50–52]. The reservoirs of the other regions are also associated with the rainfall of this region. Due to the significant importance of the region for the other parts of the country, the region is selected for analysis. Furthermore, the climatic situations of the chosen region placed vast and persistent effects on climatic environments and weather conditions of several parts of the country. The current analysis is accomplished with time-series data from January 1971 to December 2017 (see [53] for the selected region of the northern area of Pakistan (Figure 1)). The weather pattern fluctuates over the varying periods within the country which brings great socioeconomic influences. These changes in the atmosphere cause disturbance for the agriculture sectors and reservoir system of the country [54, 55]. There are various climatic events related to global climate warming. These climatic events including rainstorms, high temperatures, and droughts are commonly considered for influencing global climate warming. However, the fluctuation of global warming becomes the source of wide-ranging impacts on the atmosphere and people in Pakistan [56–58]. Therefore, it is required greater considerations to recognize the drought incidents more instantly by adding improvements in the drought monitoring processes and methods. In this regard, the current study used logistic regression to evaluate the odds and probability of drought persistence from one season to the next in the selected region by recognizing the spatial pattern of seasonal drought frequency and persistence. The SPI at the three-month time scale is applied to characterize meteorological drought. The current study efficiently improves the capability of identifying the spatial pattern of seasonal drought frequency and persistence. The outcomes of the current analysis can be helpful for drought monitoring and mitigation policies in the selected region.

3.1. Results. The six stations were selected for the current analysis. These stations were chosen from the northern area of Pakistan. The climate of the stations is important for the other parts of the regions. Therefore, these stations were selected in the current analysis. The brief climatology of the selected stations for precipitation is given in Table 1. The precipitation of the selected stations is used for the calculation of the SPI index. The importance of SPI is significantly high from the drought monitoring perspective. The SPI values were standardized by using varying probability distributions. Among the various probability distributions, the distributions for the varying stations were selected based on minimum Bayesian information criterion (BIC) values. The selected distribution and their BIC values are provided in Table 2. For instance, at the three-month time scale, the gamma distribution shows suitable candidacy for the Astore station. The BIC of gamma of Astore is −1279.0507 which is minimum among other distributions. Therefore, gamma distribution is used for standardization in the Astore station. The gamma distribution is also suitable for two other stations. For Bunji station, the BIC value of gamma distribution is −824.8686 and for Gupis, it has a BIC value is −1264.9476. For the Chilas station, the BIC of 3p Weibull is minimum
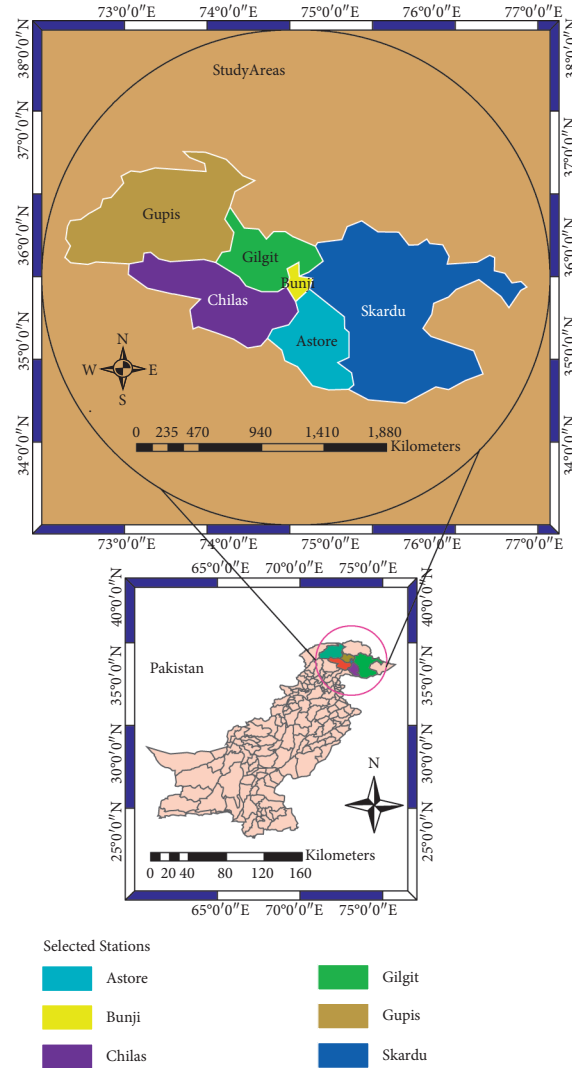
FIGURE 1: Selected geographical locations from the northern areas of Pakistan.

TABLE 1: The precipitation characteristics during the period 1971–2017 of six selected stations.

Variable	Station	Mean	1st quartile	Median	3rd quartile	Kurtosis	Std. dev
	Astore	39.34	10.80	25.70	52.62	3.01	41.93
	Bunji	13.56	1.30	7.10	17.10	7.55	18.90
Precipitation	Gupis	15.94	0.00	5.70	19.38	51.38	30.21
	Chilas	15.85	0.95	7.00	19.32	8.88	23.53
	Gilgit	11.75	1.10	6.05	14.72	9.93	16.57
	Skardu	19.51	2.30	9.10	26.75	5.60	25.90

among other distributions and selected for the standardization. The exponential distribution is suitable for the Gilgit station with minimum BIC (−810.2190). In Skardu station, the precipitation data is used for the standardization based on the generalized extreme value (GEV) distribution. The GEV has minimum BIC among other distributions, and therefore, selected for the standardization. Moreover, after standardization, the next step is the drought characterization which is done by the classified values of SPI.

Drought frequency is calculated by the total number of months with SPI ≤ 1 divided by the total number of months from January 1971 to December 2017. In this way for the current analysis, the seasonal drought frequency is calculated. To calculate seasonal drought frequency, the percentage of seasons in which drought SPI ≤ 1 occurs over the whole studied period for winter, spring, summer, and autumn, respectively. Furthermore, drought is a complicated phenomenon, and its impacts affect the agriculture,

TABLE 2: The selected probability distributions of SPI-3 and their BIC values for selected stations.

Index	Astore		Bunji		Gupis		Chilas		Gilgit		Skardu	
	Distribution	BIC	Distribution	BIC	Distribution	BIC	Distribution	BIC	Distribution	BIC	Distribution	BIC
SPI	Gamma	−1279.0507	Gamma	−824.8686	Gamma	−1264.9476	3p Weibull	−810.2973	Exponential	−810.2190	Generalized extreme value	−653.9913
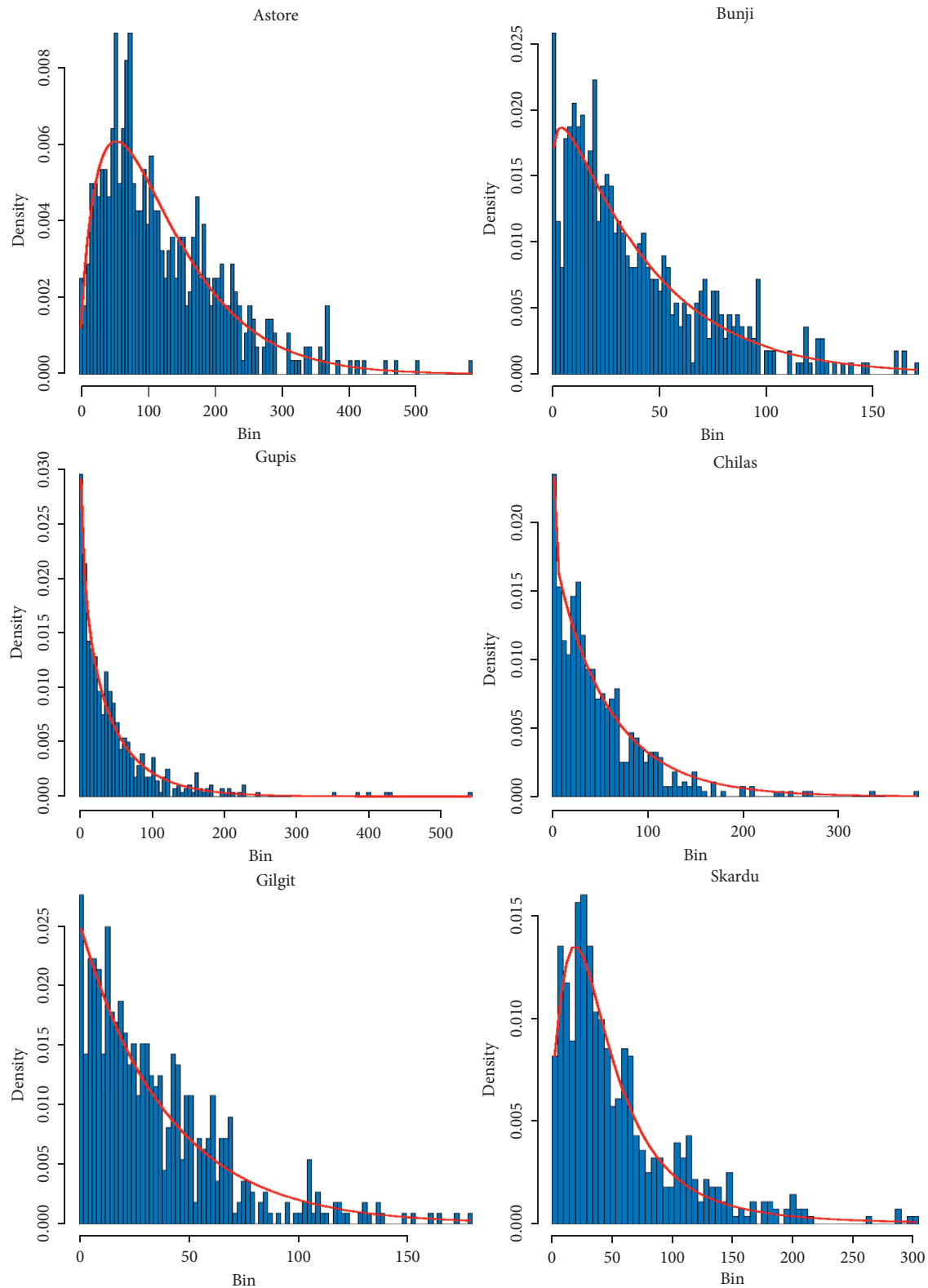
FIGURE 2: The varying distributions are selected for the six selected stations. The histograms (theoretical vs. empirical) of the selected distributions are presented for SPI-3.

economy, and other social activities. If meteorological drought sustains a prolonged time, it can be hazardous for soil moisture and evapotranspiration and lead to

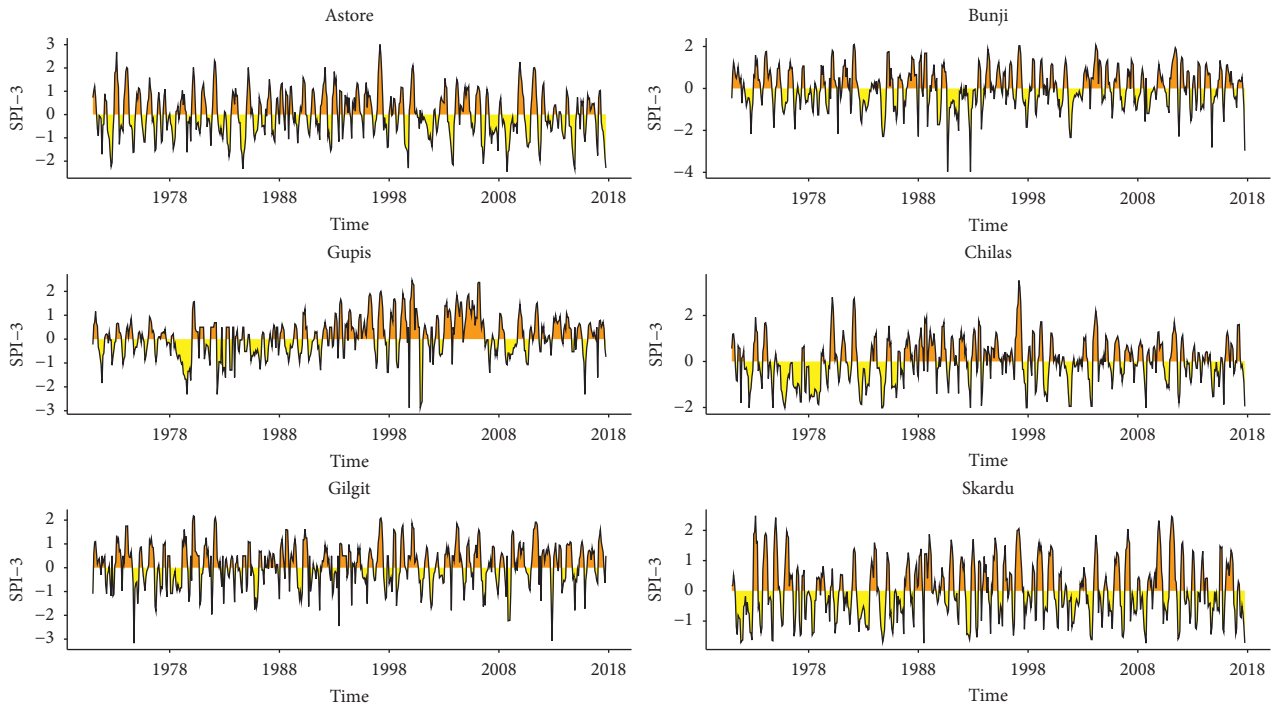agriculture and hydrological drought. Furthermore, information about seasonal drought frequency and drought persistence are essential for water resource management,

Figure 3: The temporal plots for SPI-3 at selected stations.

agricultural development, and energy consumption. Therefore, the study is applied to determine the frequency of meteorological drought and its persistence in various seasons in the selected stations. The seasonal drought persistence can be expressed by the probability of the persistence and computed as the total number of years in which drought remains from one season to another divided by the overall years in which drought occurs during the first season. Furthermore, the logistic regression is used to compute odds and probability of drought persistence from one season to the next in the selected stations by finding the spatial pattern of seasonal drought frequency and persistence. For example, the logistic regression model is used for winter-spring in the selected stations separately to observe odds for drought occurrences in the current season based on the SPI values of the previous season. The logistic regression model for selected stations based on spring-summer is used to observe drought occurrences. Similarly, the outcomes can be obtained from the logistic regression model for summer-autumn and autumn-winter. Moreover, the results obtained from the various seasons using logistic regression and their spatial characteristics are described by the maps, and the temporal aspects are demonstrated by the graphs.

Moreover, in Figure 2, theoretical and empirical distributions for SPI at a three-month time scale (SPI-3) are presented, and the temporal behavior of selected stations for SPI-3 can be observed in Figure 3. Figure 4 shows the temporal variation for the numbers of months/year with SPI≤1. Figure 5 represents the counts of drought occurrence in the selected stations in various seasons. It can be observed that the ND category prevails among other categories in

various seasons of the selected stations. Furthermore, SPI ≤1 specifies the drought in the selected stations and greater than 1 shows that there is no drought. The selected stations their latitude and longitude and average months of SPI≤1 is presented in Figure 6. These average months show that the overall, number of months with SPI≤1 in each year varies 6 to 12 months with an average of 10 in the Astore station from the time-series data ranging from January 1971 to December 2017. However, in Bunji station, the number of months with SPI ≤1 in each year varies from 6 to 12 months with an average of 9.8085. Furthermore, average months' SPI ≤1 for the other selected stations is also calculated based on the same rationale. Seasonal drought frequency is calculated as percentage of seasons in which drought (SPI) occurs over the whole study period for winter, spring, summer, and fall, respectively, and are presented in Figure 7. The probability maps in Figure 8 demonstrate the stations that are more vulnerable to prolonged meteorological drought. For example, 90 to 100% summer drought persistence probability in summer-autumn means that 90 to 100% of summer meteorological drought in selected stations of the northern areas of Pakistan can persist to the autumn. It can be observed that there are large spatial variations in seasonal drought persistence. A strong difference is shown in various seasons with stations. The Skardu station has a lower probability of autumn-winter drought persistence than other stations. Drought persistence probabilities in spring-summer and summer-autumn show a more similar pattern among the selected stations. This indicates that, in these seasons, the precipitation occurrences are not sufficient. Furthermore, the drought persistence probabilities in northern areas during summer to autumn are higher than in
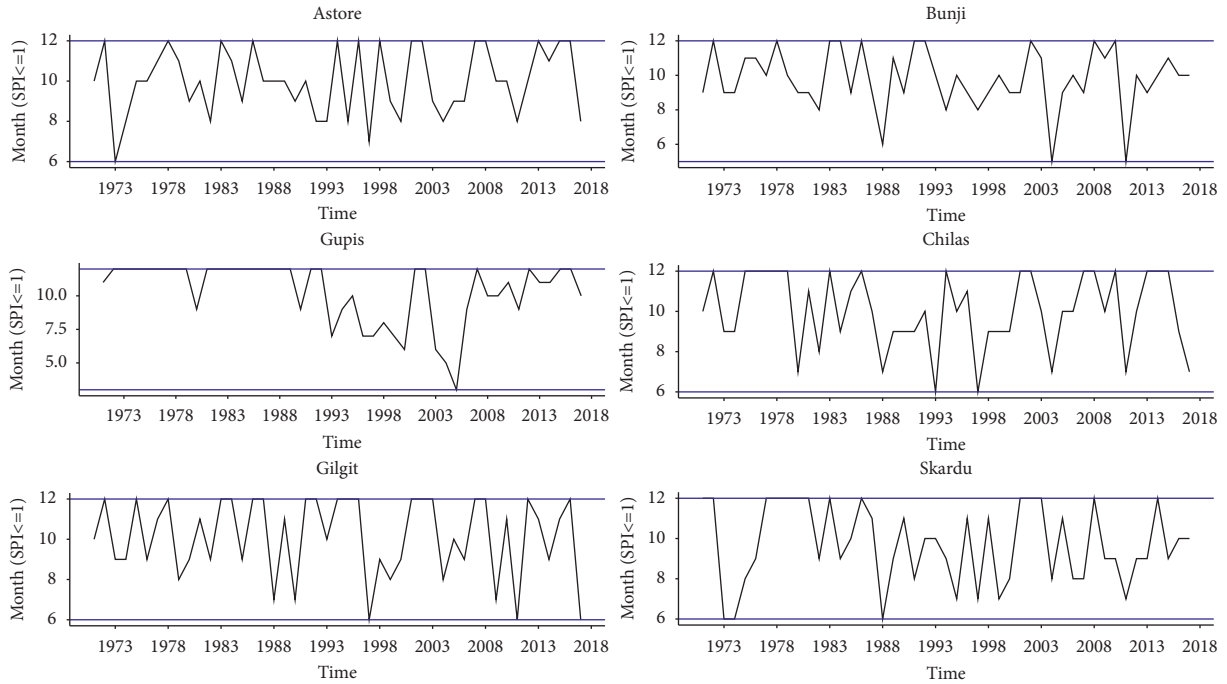
FIGURE 4: Time series plot: temporal behavior of SPI ≤1 in selected stations.

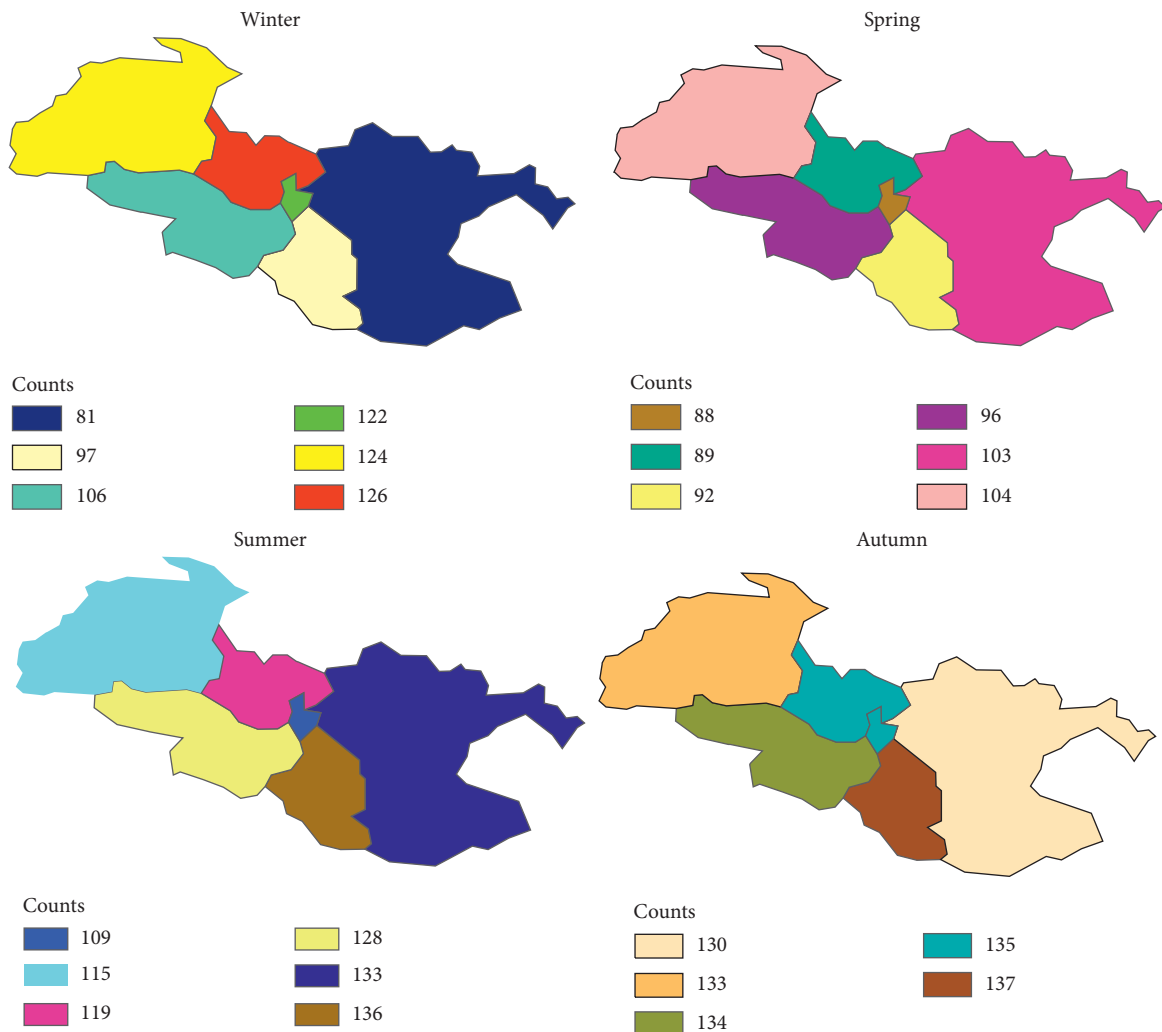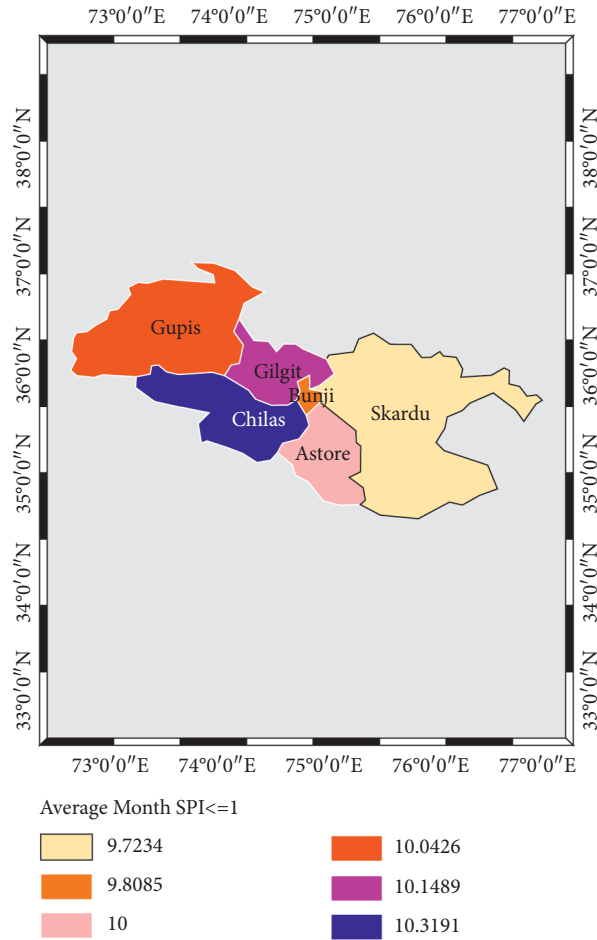FIGURE 5: The total number of counts with SPI ≤1 in the selected stations for SPI-3 in various seasons.

FIGURE 6: The latitude and longitude of the selected stations and their monthly averages for SPI ≤1.

other seasons. Seasonal drought persistence odds ratios output from the logistic regression model presented in various maps of Figure 9. This shows drought occurrence odds ratio changes as a function of a 1 unit increase in the previous season's SPI. The stations with an odds ratio <1 indicate a decreased odds ratio of drought occurrence in the given season when the SPI of the previous increases while those stations with odds ratio >1 showing that a positive increase in the odds ratio of drought occurrence in the given season when previous season's SPI increases. Furthermore, the significant odds ratio can be observed in the maps. The stations outline bolded are those at which the logistic regression fit is statistically significant at $\alpha < 0.05$. For instance, on Gupis station in spring to summer, the odds ratio is significant and shows that as increases 1 unit in the SPI of spring the odds of drought occurrence are decreasing in summer by 0.20 to <1%. Furthermore, the relationship between various seasons and SPI is negative in selected stations. This means for increases 1 unit in the SPI, the odds of drought occurrence are negatively influenced. Similarly, the odds ratio of drought occurrence can be observed for other stations and seasons. Based on the obtained results drought early warning policies should be prepared in the selected stations accordingly. Moreover, the obtained results from the recent evaluation about seasonal drought frequency

and drought persistence can be helpful to water resource management, agricultural development, energy consumption, and crop yields.

3.2. Discussion. The data of precipitation is used for the classification of drought occurrences. These drought occurrences are used to classify the drought categories in the selected region. The classified values of the drought are calculated using SPI-3. The SPI provides the standardized values for the given precipitation in the selected station for monthly data. The varying probability distributions were used for the standardization of the precipitation values for SPI. The selection of the distributions is based on BIC values. Information related to seasonal drought frequency and drought persistence play a vital role in water resource management, agricultural development, energy consumption, and crop yields. Despite their importance to the water resource management and agriculture sectors, there are very few studies available in the literature that focus on seasonal drought frequency and drought persistence [45]. Therefore, dynamic procedures are required in drought monitoring for providing relief to affected areas. Suitable drought monitoring is a key factor in preparation for water resources and disaster mitigation and making a climate-resilient society
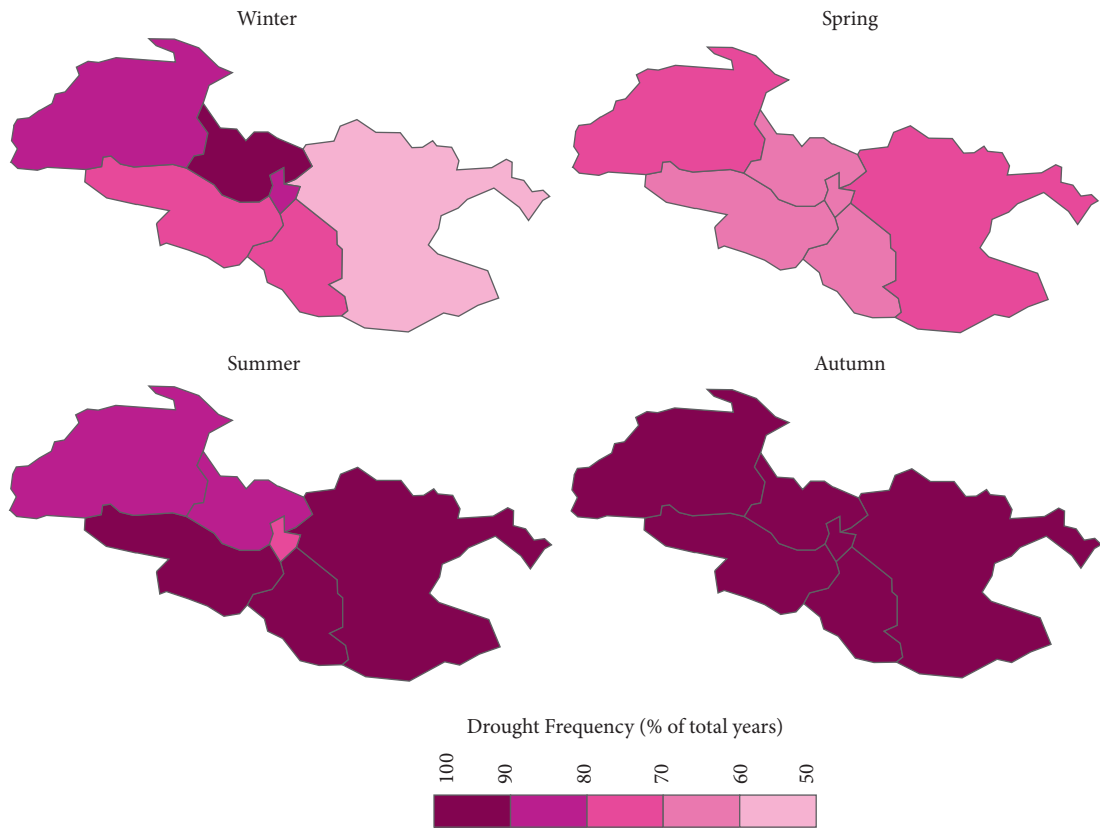
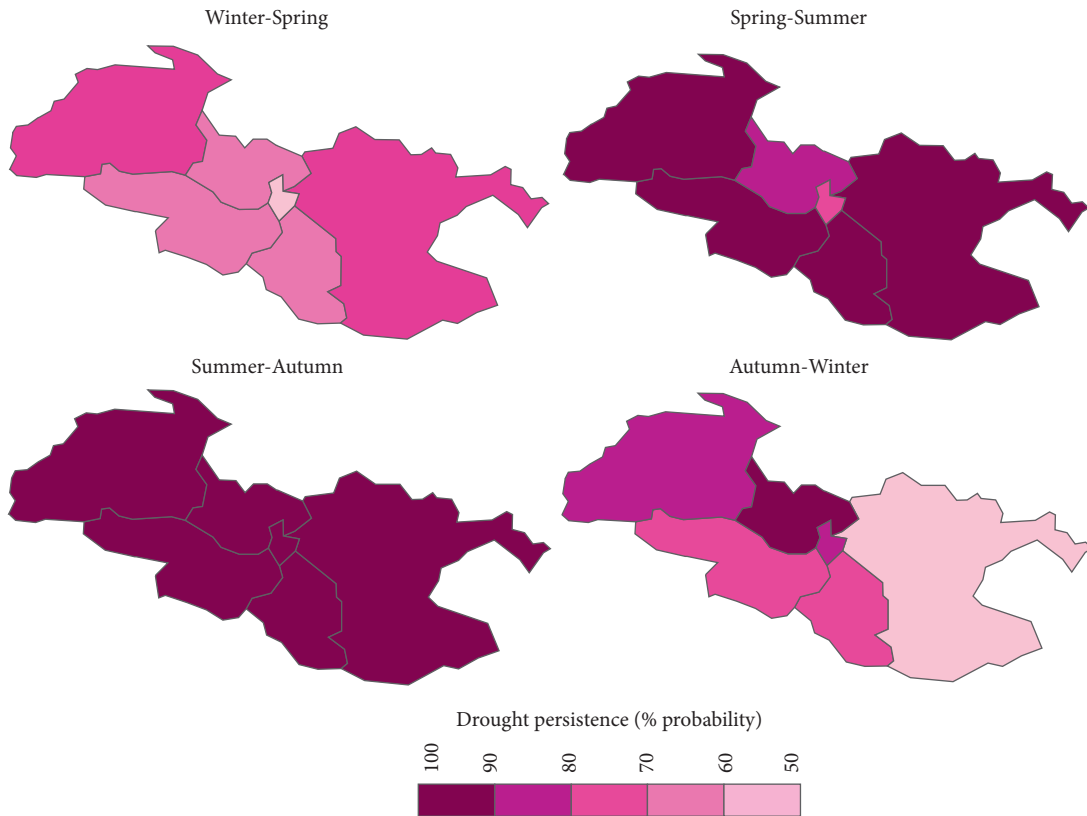FIGURE 7: Seasonal drought frequency for each selected station as a percent of total (1971–2017) years.

FIGURE 8: Drought persistence percent probability for all seasons in the selected stations.
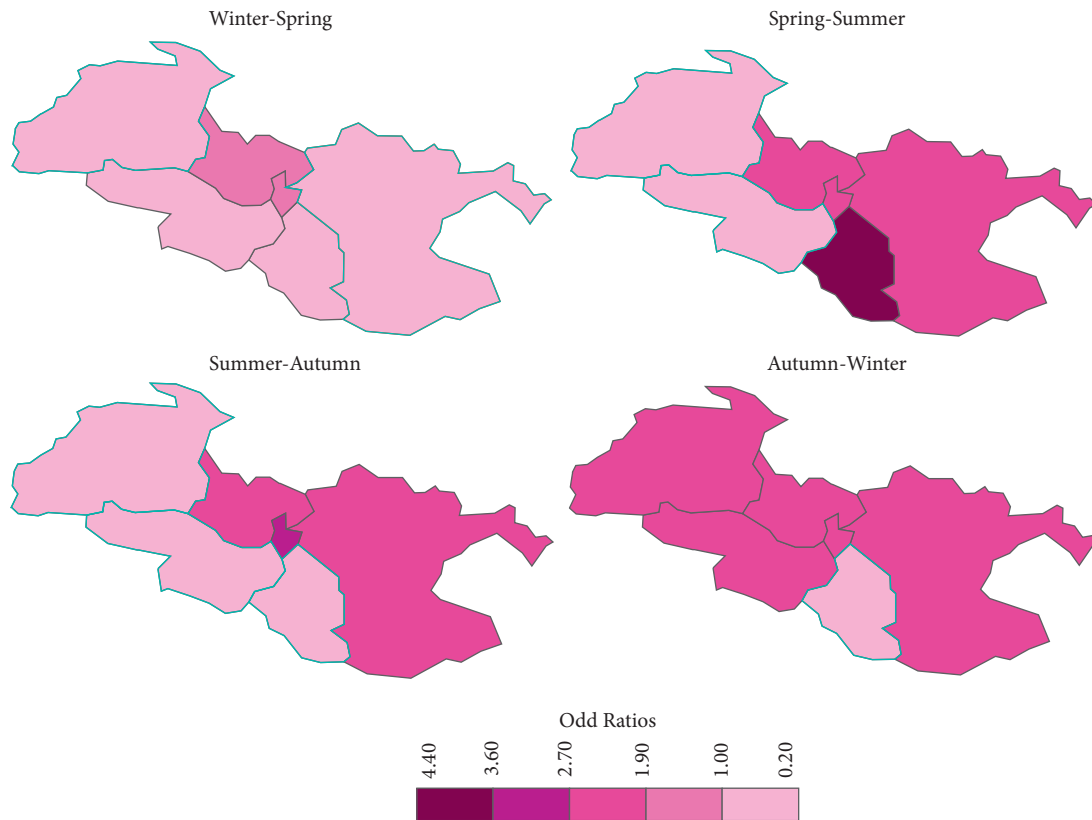
FIGURE 9: Odds ratio for various seasons in the selected stations. The relationship in the bolded stations is significant at $\alpha < 0.05$.

[59–61]. The present study is employed to identify the seasonal drought frequency and drought persistence in the region. However, none of the authors have worked to identify the seasonal drought frequency and drought persistence for Pakistan in previous research. Therefore, it is a new approach in terms of spatial patterns of drought persistence in northern areas, Pakistan. The outcome of the current analysis effectively works for early warning and mitigation policies and enhances the competencies in forecasting procedures, making better management, and planning to decrease the vulnerability of society to drought and its forgoing impacts.

4. Conclusion

Drought is a kind of complex recurrent climatic phenomenon, least understood to monitor and challenging for the past several decades. Because of the significant influences, various techniques have been developed to overcome its impacts. Due to the development of new methodologies, the drought characteristics have been monitored more accurately. Information about the drought characteristics and its persistence provides the direction to the water resource management and agriculture sectors to minimize the negative impacts of drought. Therefore, the current study used logistic regression to analyze the odds and probability of drought persistence from one season to the next in the selected stations by identifying the spatial pattern of seasonal drought frequency and persistence. From the results, we

observed that the ND category is prevailing among other categories in various seasons of the selected stations. Furthermore, the seasonal drought frequency is found significantly high in summer and autumn. The spring meteorological drought in selected stations of the northern areas of Pakistan can persist to the summer with the probability of 90 to 100%. The drought persistence percent probability for summer to autumn is highest among other climate divisions. Furthermore, it was observed that there are large spatial variations in seasonal drought persistence in various seasons and stations. However, the probabilities of drought persistence in spring-summer and summer-autumn show a more similar pattern among the selected stations. However, the Skardu station has a lower probability of autumn-winter drought persistence. Moreover, the odds ratios from the logistic regression model for the seasonal drought persistence showed that the significant relationship between various seasons and SPI is negative in selected stations. This means increases 1 unit in the SPI the odds of drought occurrence are negatively influenced. The Astore, Gupis, Chilas, and Gilgit found significant at $\alpha < 0.05$ in various seasons. Moreover, the current analysis is applied for the present situation and application site; however, for other climatic conditions results cannot be generalized. As climatology conditions of the regions vary, the results can be affected for the assessment of drought occurrence. Furthermore, the use of other indices can significantly increase the capabilities for drought monitoring and its persistence in the selected region. The outcomes associated with the

present assessment provide the basis for getting more considerations on early warning systems and can be used for decision-making.

Data Availability

The data used for the preparation of the manuscript are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

Acknowledgments

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