 doi:10.20944/preprints202110.0393.v1

Appraisal of Drought Indices based on Climatic Variability using DrinC Software for Potwar Region in Punjab Pakistan during 1981–2019

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Abstract: Drought is treated as a key natural disaster that affects numerous segments of the natural environment and economy throughout the world. Drought indices (DIs) were computed for Potwar region (PR) in Punjab-Pakistan, using DrinC software which are deciles, Standard Precipitation Index (SPI) and Reconnaissance Drought Index (RDI). Drought situation of 12, 9, 6 and 3 months was estimated on temporal basis. DIs obtained by deciles technique showed that for the last 39 years, 8-years are with drought severity in a cycle and are occurring every 2 to 7-years just the once repetitively. The RDI and SPI index showed the analogous trends as of deciles. Though, for RDI and SPI, the extremely dry and severely dry class was merely two years and rest of the drought affected years with respect to deciles were normally and intermediately dry. SPI is better as compared to deciles as the severity is better understood in the context of SPI. Regression analysis revealed that the RDI and SPI indices are mutually interrelated and if first 3 month precipitation is obtainable one can forecast yearly RDI. This investigation is valuable to devise future development plans to contest vulnerable drought incidents, its mitigation and impacts on socio-economic sectors.

Keywords: Drought indices, Climate variables, DrinC, Potwar, Pakistan

1. Introduction

Drought is a worldwide incident which is observed in various climatic regions of the globe. This condition is caused by the shortage of water supply to crops, plants and livestock which are directly or indirectly related to the humans. The initial condition of drought is described as stress on water resources by inadequate water supply due to insufficient rainfall in the region [29, 37, 35, 47, 36, 41, 40]. The natural deficiency of precipitations is termed as meteorological drought. The Potwar region is located in the northern Punjab-Pakistan. This area is hilly and includes a lot of highland ranges including the Salt Range and the altitude of these highland ranges between 300-600 m. The topographic slopes of the Potwar do not permit any canal networks to be implemented by utilizing the nearby River Indus in the west and River Jhelum in the East. Agriculture is mainly dependent on the rainfall. Water retention capability is also very limited due to irregular drainage network. These days, drought is commonly treated an environmental disaster and has got tremendous attention from scientific researchers of numerous disciplines viz., agriculture, geology, meteorology, hydrology ecology and environmental science due to their immense effects on agriculture, ecology, hydrology and environment [36,33,39,49,44,45,48]. It is termed as water security availability that extremely influences the prospective crop productions, causes water scarcity for livestock/human utilization and affects the economic sectors. In the last century, a significant variation throughout the global setting and climate has been witnessed [28,30,38,43,42,11,18]. This has resulted into intensification of water cycle and recurrent extreme and severe open incidents like floods and droughts at large scales [3,2].

The frequency of drought incidents is predicted to rise due to increased greenhouse gases causing earth warming [3]. Collectively, water scarcity due to spatiotemporal variation between water demand and supply is anticipated to befall intensified due to increased global warming. Drought is robustly affecting the livings of deprived masses in several manners by varying numerous economic segments worldwide and is treated as a significant natural disaster. Majority of researchers explains drought in many ways, for example, agriculture experts describe drought with shortage of moisture known as effective precipitation that affects the crop productions, Meteorologists attribute drought as a prolonged rainfall scarcity, and hydrologists correlates drought to lower water run-off. Such variations underline the comparative roles of evapotranspiration (ET), precipitation and water run-off in drought due to climatic variability factors. Drought is a repeated, multi-dimensional, and regional incidence influencing huge areas and a large number of people. For the past few decades, droughts are significantly increasing in intensity and frequency and large number of people is influenced as compared to other natural hazards. Drought is a composite event that may be categorized by its duration, areal extent and severity. Amongst these three scopes, for drought investigation, the severity of drought can be utilized. Consequently, it is crucial to look into evolution characteristics of the drought, and particularly the mechanism of its propagation and formation in a variable environment and climatics. Generally, in a major context, DIs determines the drought severity. DIs will describe and analyze the food security, by abridging the composite climate factors that measure climate variability in the background of their duration, severity and occurrence. Moreover, DIs is extremely valuable, as they correspond to the relavent stake-holders in the background of drought severity [24,15].

The results obtained from theses DIs show and aid numerous potential users from researchers, academics and bankers to make decisions and preparedness (drought monitoring, proactive management mitigation etc.,). For the drought investigation, literature review indicates that no particular and suitable index is adequate, but more than one index. SPI has been broadly used by drought investigators [6, 4, 1, 9,14,7,24,13,27,8,55, 28,30,38,43,42,11,18,]. There are techniques and equations for computing the DIs by through different models/tools or manually. This investigation utilized DrinC (Drought index calculator) to compute the DIs. Particulars about the computations and sequence of instructions are according to [21]. DrinC computes DIs via an easy platform that gives a plain and clear result. On the other hand, for excellent outputs, meteorological dataset may be for longer durations (minimum of 35 years. DrinC computes the DIs as outputs of deciles, RDI, and SPI, that facilitates the investigation of drought severity and can predict the drought occurrence trend in future. DrinC is appropriate to monitor drought, its assessment, spatial distribution, drought scenarios, climatic investigations and drought declaration for the purpose of subsidy associated concerns. Now, it is a recognized fact that Pakistan is experiencing drought on repeated intervals, for example once in 5-6 years. For this reason, it is difficult for the decision making institutions to deal with the concerns of all the stakeholders, industry persons and farmers [5,36,33, 39,28,30,38,43,42,11,18]. Lot of procedures pursued by the governments to declare, and therefore some consistent techniques are needed to be rationalized in Pakistan which may envelop different agroecological zones. In Pakistan, if a farmer intends to claim the crop insurance in case of harvest collapse due to water scarcity/drought, then whole district is confirmed as drought striken. For these reasons, the DIs will assist the state administrators and to evaluate the drought impact. Consequently, DIs computed through DrinC has been analyzed for semi-arid-to-arid Potwar region of Punjab-Pakistan and

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may be utilized in a different place with the comparable environment and climatic conditions.

2. Materials and Methods

2.1. Study Area

Potwar Plateau is situated at latitude 32º 10 to 35º 9 N and longitude 71º 11 to 73º 56 E and covers a significant part as arid agricultural region of Pakistan (Figure 1). It comprises four districts (Attock Chakwal, Jhelum and Rawalpindi) of Punjab-Pakistan. The region adds considerably, to livestock and agricultural production of Pakistan. The regional farmers apply low inputs in agriculture because of high costs of production, improbability of precipitation and lack of knowledge of state of the art modern machinery and techniques. The climate of the Potwar region is semi-arid-to-arid with yearly precipitation that ranges 950-1950 mm [53]. Usually, two key weather schemes, i.e., south-western monsoon [52] and westerlies [34,51], cause precipitation during winter (December– March) season and summer season (July–September) respectively. Temperature varies with respect to change in elevations. The maximum elevation in the Potwar region is at the Southern edge of Hazara Range adjacent to Muree formation, where these extreme elevations usually surpass more than 1,200 m ASL. The minimum elevations are connected with Plains of the Jhelum and Indus River, where the river bed falls as lower as 300 m. The mean elevations over the Potwar region are generally between 300-600 m. The mean annual minimum and maximum temperature varies from 26.5°C and 14°C, respectively [54]. Rabi (October–April) and Kharif (May–September) are the two main crop cultivation durations in the Potwar region. For, Kharif crops (ground nut, rice, cotton, maize, moong, soybean, jowar etc.), the planting time is May–June and harvest duration is October–November, while for Rabi crops (onion, tomato, wheat, barley, mustard, carrot, potato, isabgol, oat, etc.) are planted during (November–December) and their harvesting time is in (March–April). The Potwar region contributes a crop yield of roughly 10% of the entire agricultural yield [50]. The easterly monsoon precipitation reduces moisture pressure environment throughout the Kharif times and meets the necessary water supplies for Rabi crops (Adnan et al. 2018). The variations of rainfall in a spatio-temporal context during both the Rabi and Kharif seasons can influence GDP of a country negatively, as agricultural segment is responsible for approximately 23% of GDP [52].

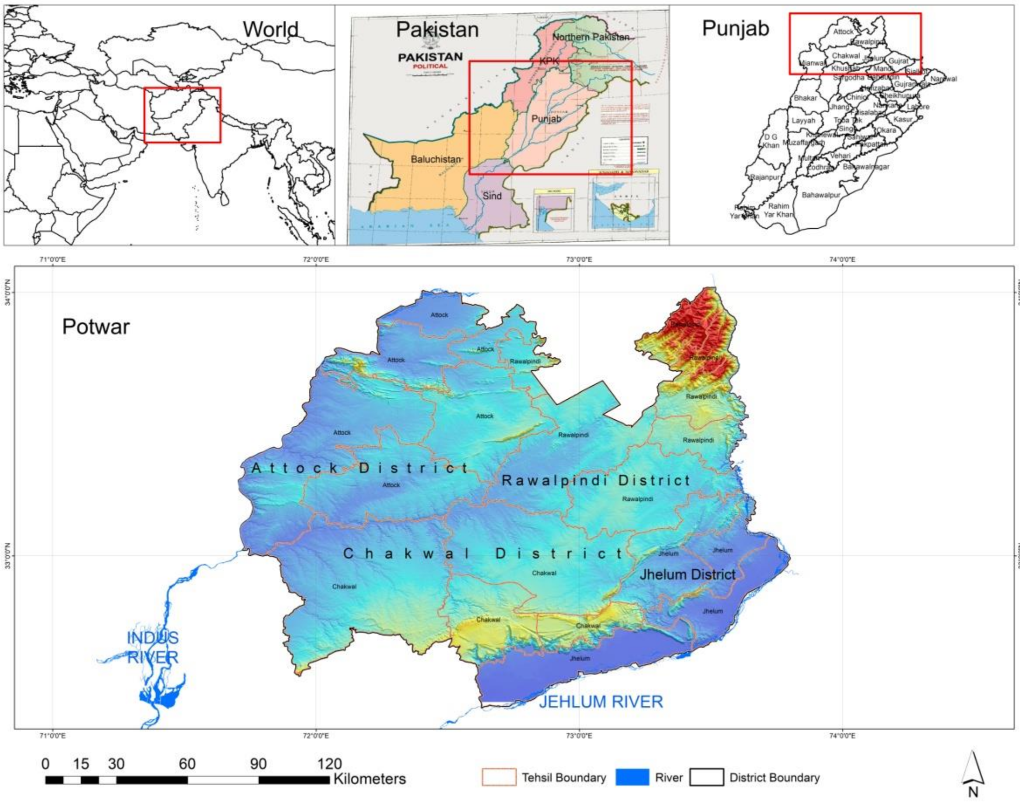

Figure 1. Location of the Potwar Region.

The main input dataset utilized for this investigation are minimum and maximum temperature, every day precipitation from TERRACLIMATE (high resolution gidded temperature and precipitation data) and meteorological ground stations Potwar region. Computations of DIs such as deciles, RDI and SPI were carried out on the basis of Terra-climate data along with the verifications from the ground dataset wherever possible. DrinC assist the calculation of above DIs on the basis of the log-normal technique on the basis of 12, 9, 6 and 3 month duration. DIs with their short description based on their severity are described as follow.

2.2. Standardized Precipitation Index (SPI)

SPI is computed on the basis of longer term precipitation datasets which is fitted to a probability distribution and lastly convert into a normal distribution so as the mean SPI value for desired period and location is null [4,8]. This conversion is worked out on the basis of monthly precipitation and is usually not distributed normally so that the resultant SPI observes a normal distribution. SPI index corresponds to the numerous standard deviations which means an experimental value that may depart from the long-term mean values, for a random variable distribution normally. [21] explained the complete step by step technique. When the SPI index is smaller than mean rainfall, it is negative and vice versa. Higher SPI minus values represent the severe dry situation. With respect to SPI, the categorization of DIs is given below in Table 2.

Table 1. Categorization of drought situations as per SPI

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SPI or RDI value	Drought Category
2.0 or more	Extremely Wet
1.5 to 1.99	Severely Wet
1.0 to 1.49	Moderately Wet
-0.99 to 0.99	Near Normal
-1.0 to -1.49	Moderately Dry
-1.5 to -1.99	Severely Dry
-2 or less	Extremely Dry

2.3. Reconnaissance Drought Index (RDI)

For the expression of the water scarcity, in a precise way, [24] and [21] devised the (RDI) and worked it to monitor and characterize the drought. RDI corresponds to both growing potential evapotranspiration (PET) and precipitation (P), where PET is computed and P is measured. The primary condition value (αk) for RDI is computed in terms of ith year versus time based k-months) and arithmetically is written as,

$$\mathbf{a_k^i} = \frac{\sum_{j=1}^{k} \mathbf{P_{ij}}}{\sum_{j=1}^{k} \mathbf{PET_{ij}}} \text{ , i=1 (1) N and j = 1 (1) k} \quad (1)$$

Where, PETij and Pij are the potential evapotranspiration and precipitation of the jth month of the ith year, N correspond the complete duration of years for the existing dataset. Where, αk-values trail the log normal at different time scales within a broad range of spatial locations [24] suitably. With the assumption and application of log-normal distribution, RDI 1st computed with the following eq. (2).

$$\mathbf{RDI_{st}^{(i)}} = \frac{\mathbf{y^{(i)}-y}}{\mathbf{\sigma\hat{}y}} \quad (2)$$

where, y(i) is the ln of (ak (i)), y is the arithmetic mean, and σ̂y corresponds to standard deviation. Positive RDI correspond to wet seasons as compared to negative RDI indicating dry episodes in comparison with the normal situation of the investigation region. Drought severity (DS) may be classified as extreme, severe, intermediate and mild classes, with consequent border line RDI (< -2.0), (-1.5 to -2.0), (-1.0 to -1.5) and (-0.5 to -1.0).

3. Results and Discussion

The climatic situation of Potwar region is semi-arid-arid to-humid, cold winter and dry hot summers. The average yearly observed rainfall over the periods (1981 to 2019) is 1145 mm, and almost 75% of the precipitation is received in monsoon during July-September. Average maximum and minimum temperatures were observed as 32°C and 15.5 °C for the Potwar region. The DIs of Attock, Chakwal, Jhelum and Rawalpindi districts in Potwar Region by deciles technique demonstrated that for the 39 years, 8 years were severely drought striken in a cycle and nature occurring approximately every 2 to 7 years just the once repetitively, apart from a little constant years, i.e., 1985-1986 and 1988-1992, 1998-2003, 2005, 2018-19 etc. (Figure 2). These dataset demonstrated cyclic nature of the drought which occurs approximately every 2 to 7- years one time repetitively, apart from for a few periods where it did occur successively, i.e.1985-1986,

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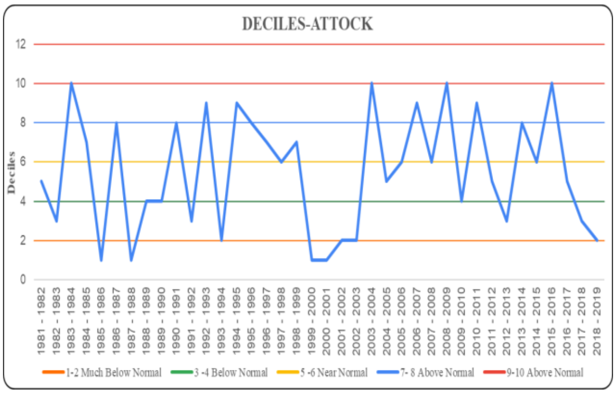
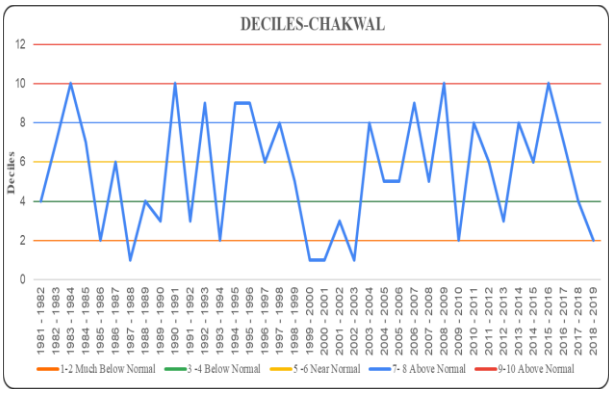


(a)



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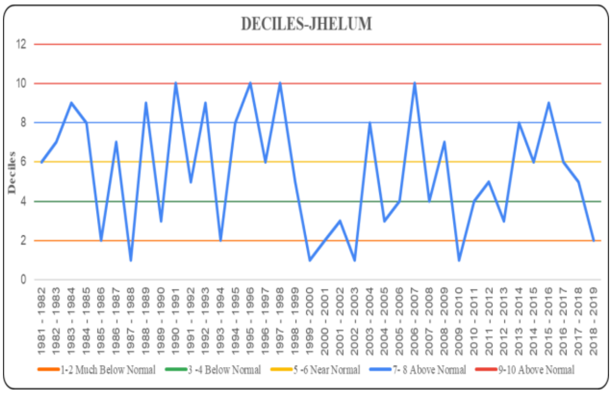

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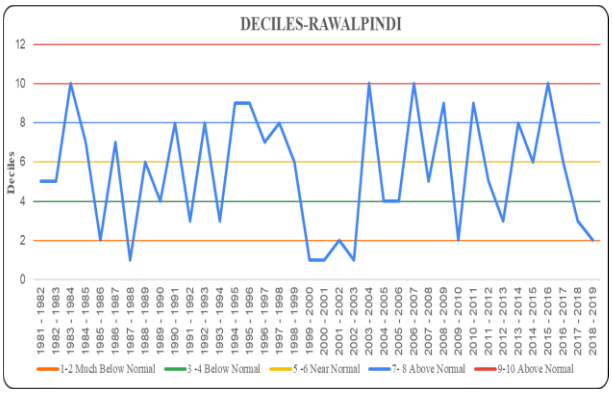

(d)

Figure 2. Deciles for four districts of Potwar region.

1988-1992, 1998-2003 and 2018-2019 etc. Though, for 2006-2017 (for 12 years) no drought incidence occurred, that is associated with the some shifts in the precipitations and climatic variables mainly. The significant observation is during the recent four decades, During the last 4 decades, the drought incidents are high with 7 events, while for the last twenty years the number of incidents is 2. The SPI shows the similar trends and followed the deciles pattern (Figure 3).

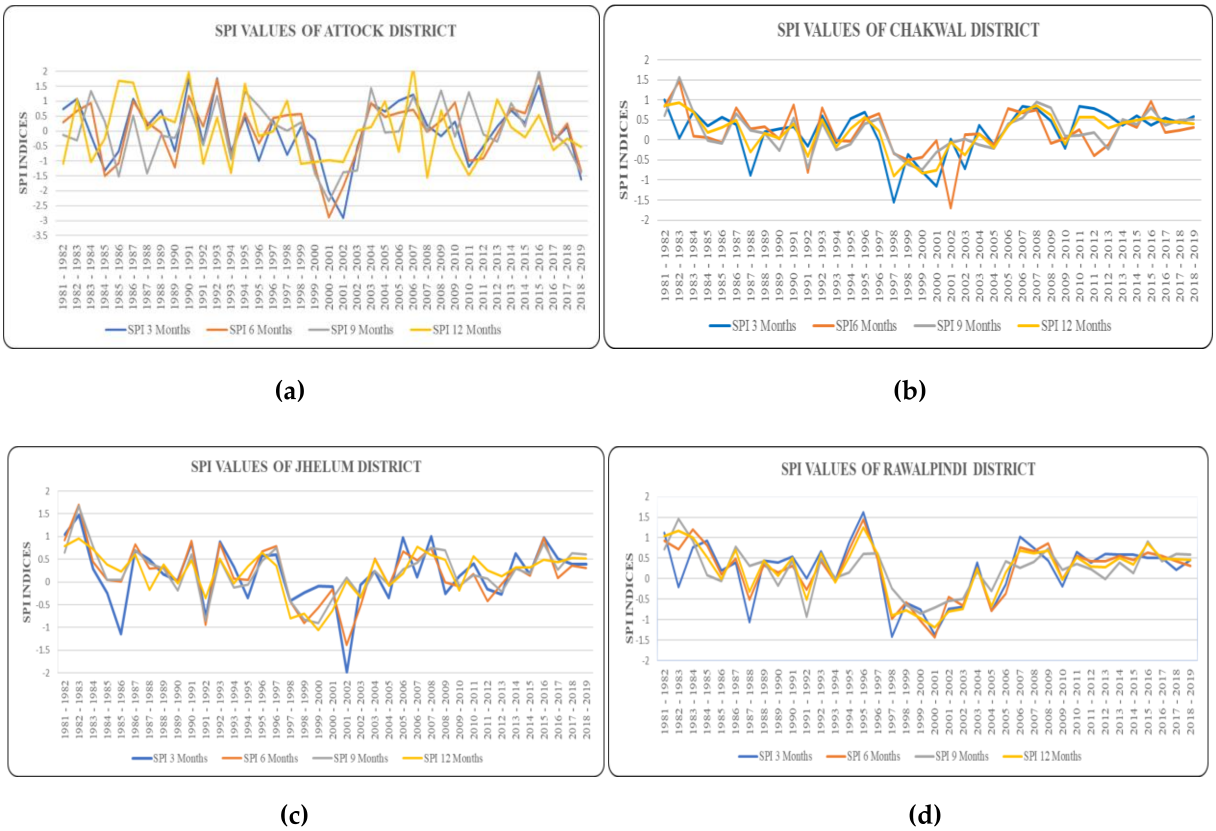

Figure 3. SPI for four districts of Potwar region.

Conversely, in the context of SPI Index, the severely dry years (1984, 1985, 1986, 1987, 1988, 1989, 1993 and 1994, 2009, 2010) and extremely dry category (1999, 2001, 2002, 2003, 2018, 2019) was just six years and rest of the drought years in the context of deciles fall under the category of near normal to a moderately dry. The SPI highlighted the dryness severity in comparison to deciles which assists to evaluate the drought impact in the context of drinking water and crop yield productions, etc., [21]. Therefore, SPI is good index and pointer as compared to deciles, because it assists us to recognize severity of dryness in a better way. Out of 39 years, only 3 years correspond to enormously dry situation due to low incidents of precipitations during this time in comparison to the rest of the drought episodes. The RDI follows the same pattern (Figure 4) as shown by SPI. Though, for SPI, the years 1999, 2000-2001 that corresponds to extremely dry class and fall below severe conditions of drought.

DIs for Semi-Arid to humid Region class in RDI and rest of the drought classes were comparable to SPI. SPI and RDI indicate the severe of dry condition with respect to deciles. Therefore, SPI is a strong index that predicts the impact of drought by studying the crop yield, drinking water, crop failure and irrigation network availability [26,21]. The farmers in Pakistani may obtain financial advantages from the insurance of crops by the state government, when the whole district is declared as drought striken. Hence, DIs will assist the stakeholders, decision and policy makers for efficient agricultural landuse developments to control the extended bad impacts of drought. In a nutshell, DIs computed by DrinC do not miss severely dry/extremely dry conditions of drought and is a good tool for the semi arid to humid areas of Pakistan, provided that the climatic conditions are similar. Drought is a significant aspect which is responsible for the socioeconomic inequality in numerous areas of the Pakistan on a recurring basis (after 3 or 7 years). Drought severe affects on the economy of Pakistan. For instance, crop loss during the above mentioned drought years had caused GDP declined by 3.7 %. Hence, the DIs will assist to develop strategic and planning integrated information for drought disaster

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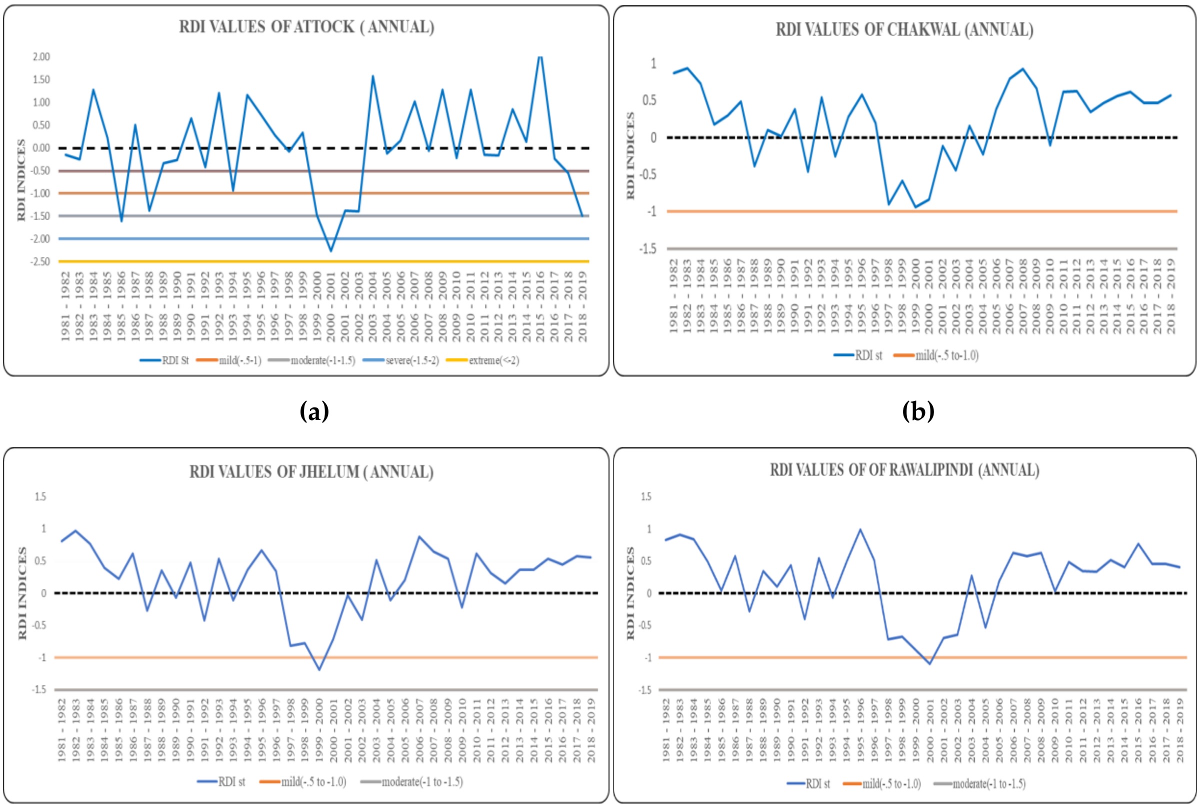
management but also to make responsive to take a proactive approach to cope with drought.



(a) (b)

(c) (d)

Figure 4. RDI for four districts of Potwar region. (a, b, c, d)

3.1. Regression Analysis

The Meteorological Drought of 12, 9, 6 and 03 months was computed with the SPI and RDI. The RDI shows correlation with the SPI for the study area and the best-fit regression line was generated among various drought classes and is shown in Figure 5. The obtained results demonstrated that SPI and RDI are notably correlated to each other. Drought years may be forecasted with the following formula described in SPI-RDI-plots by computing RDI-values yet by rain-fall dataset only. The value of R2 is 0.990 for (Attock), 0.993 for (Chakwal), 0.996 for (Jhelum) and 0.991 for (Rawalpindi), and illustrates that annual RDI and SPI was in correlation with best-fit regression-line (Figures 5-8).

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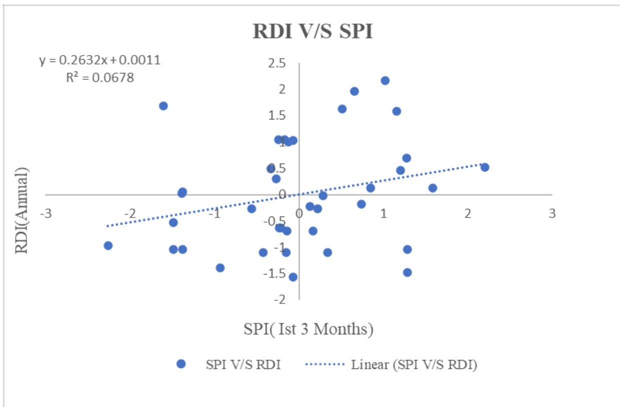
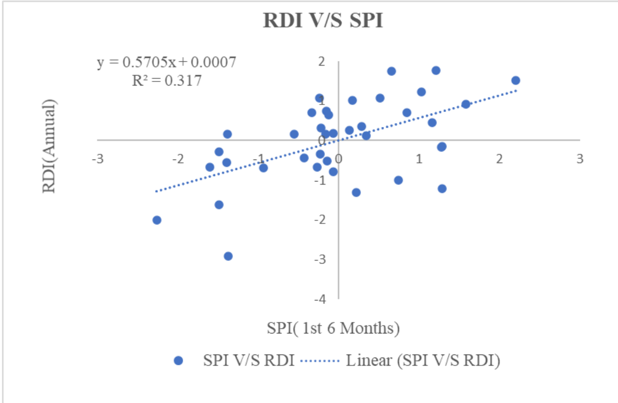
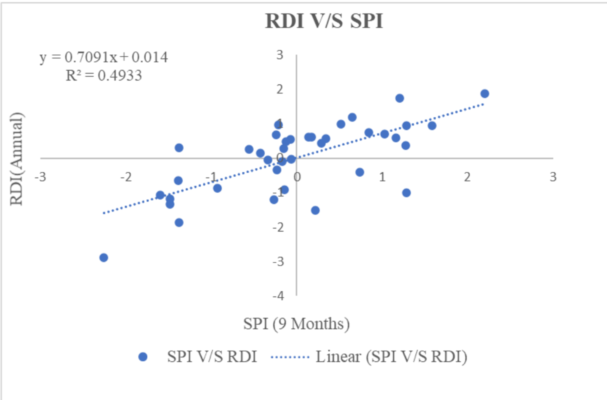
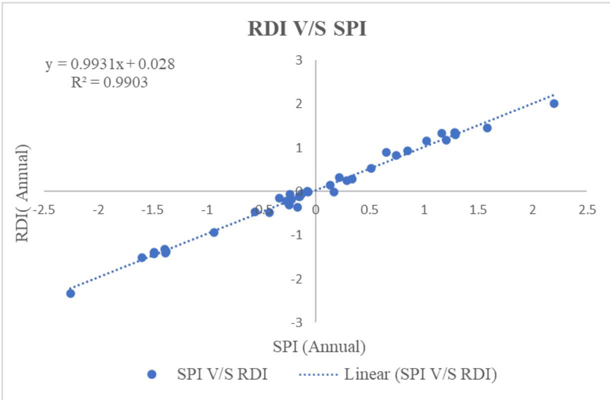




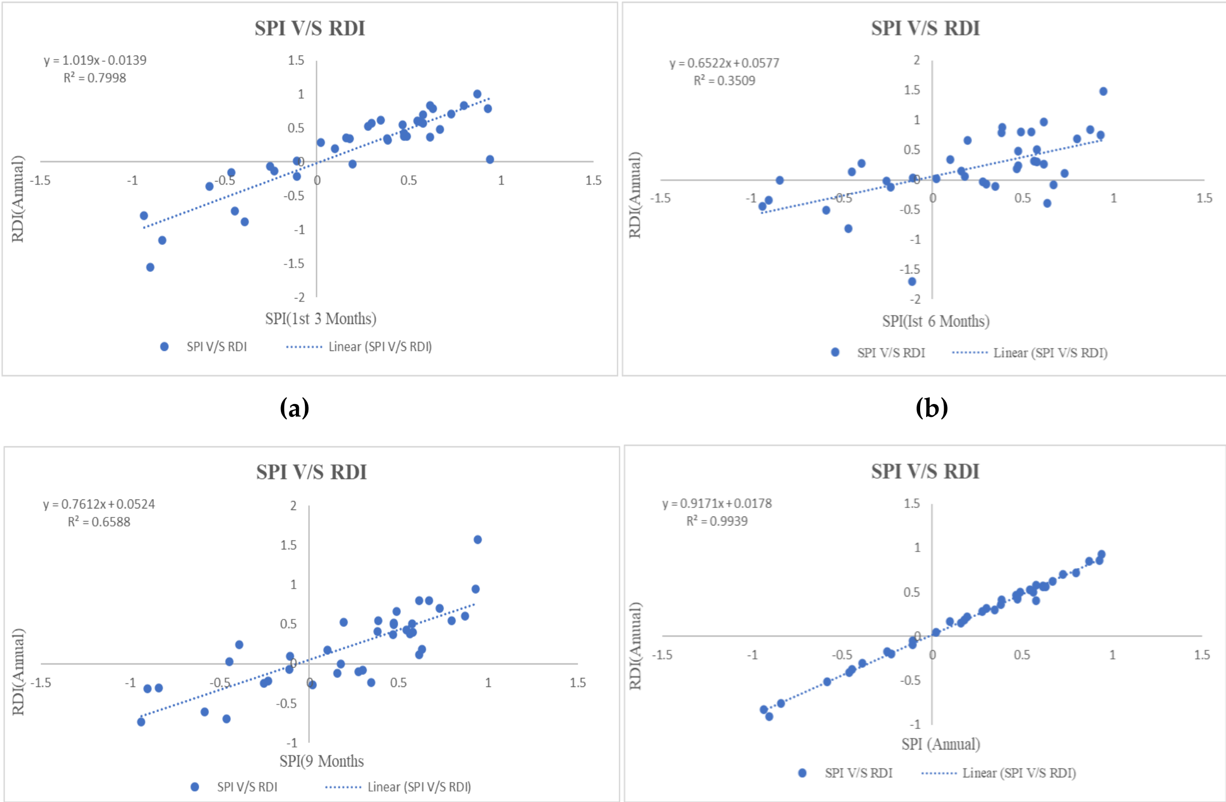
(a) **(b)**





(c) **(d)**

Figure 5. (a) 3 months SPI Vs Annual RDI, (b) 6 months SPI Vs annual RDI, (c) 9 months SPI Vs annual RDI and (d) 12 months SPI Vs Annual RDI for Attock district Potwar region.



(c) (d)

Figure 6. (a) Regression analysis for 3 months SPI Vs Annual RDI, (b) 6 months SPI Vs annual RDI, (c) 9 months SPI Vs annual RDI and (d) 12 months SPI Vs Annual RDI for Chakwal district Potwar region.

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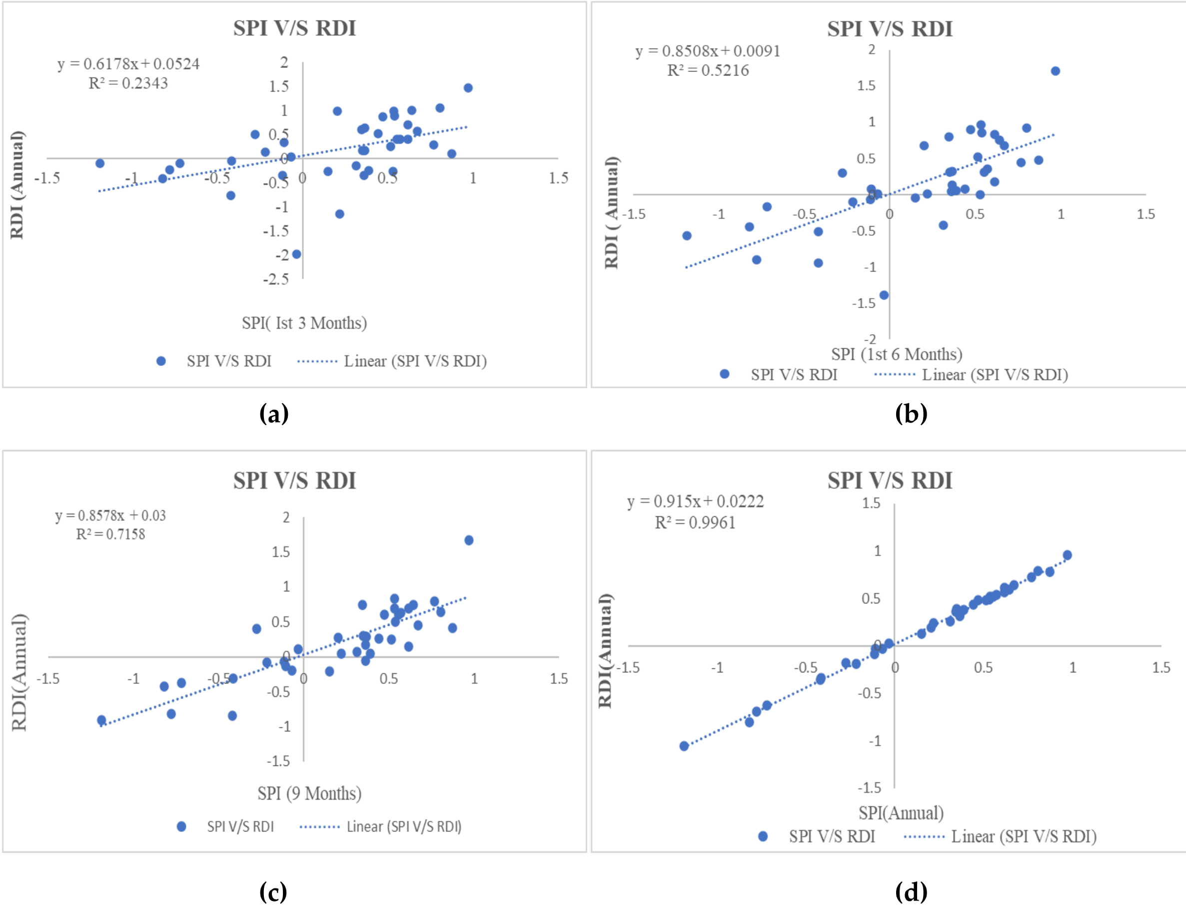

Figure 7. (a) Regression analysis for 3 months SPI Vs Annual RDI, (b) 6 months SPI Vs annual RDI, (c) 9 months SPI Vs annual RDI and (d) 12 months SPI Vs Annual RDI for Jhelum district Potwar region.

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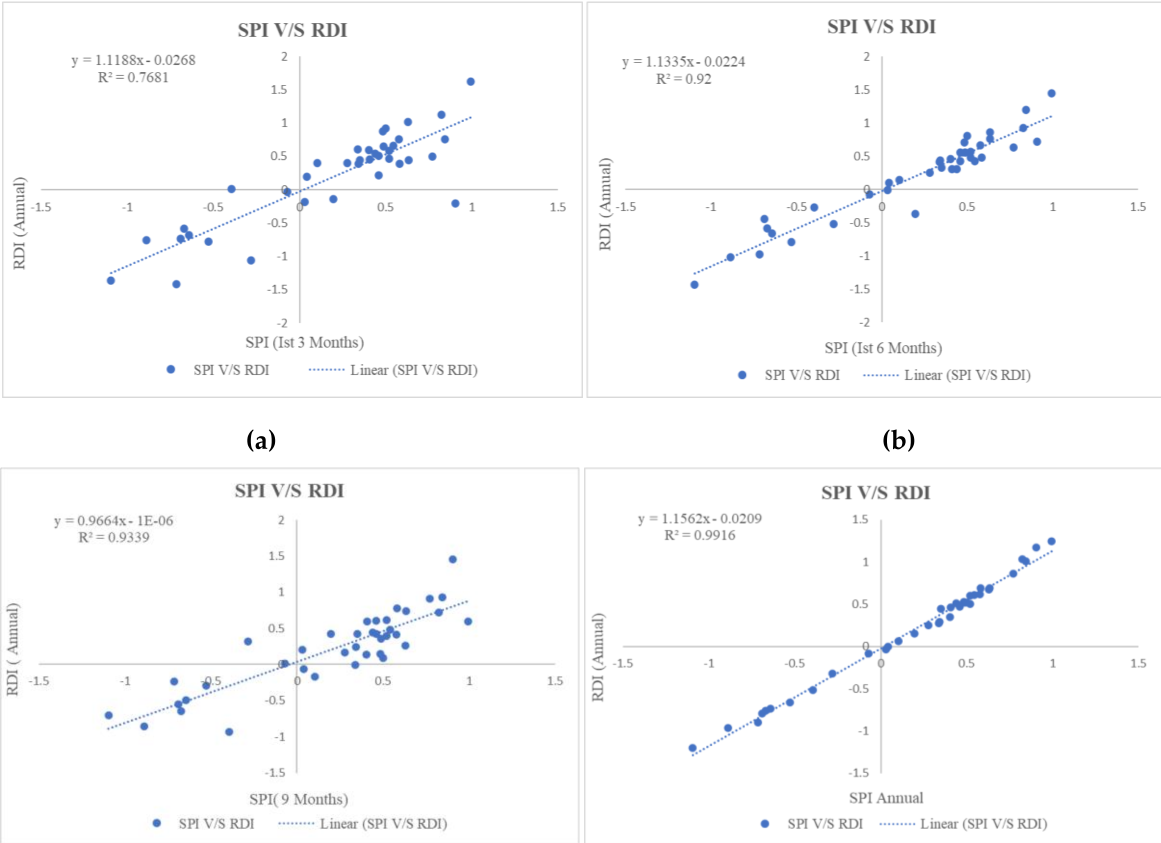

(a) (b)

(c) (d)

Figure 8. (a) Regression analysis for 3 months SPI Vs Annual RDI, (b) 6 months SPI Vs annual RDI, (c) 9 months SPI Vs annual RDI and (d) 12 months SPI Vs Annual RDI for Jhelum district Potwar region.

For regression investigation, all the various combinations, for example, SPI 12, 9, 6 and 3 months with yearly RDI were performed. Figure 6 give details about the results obtained demonstrated that SPI-index with 9, 6 and 3 months dataset showed that annual RDI duration forecast is satisfactory with higher value of R^2. Rest of the combination of SPI does not fit well. Such results revealed that RDI can be forecasted even with the availability of 1st 3-month precipitation data and SPI can be computed for the future years. In the entire world in drought investigation, the SPI is frequently used. This investigation also demonstrated that, SPI can examine the impacts for short and long term duration of drought and is comparable for four districts of Potwar region because of its probabilistic behaviour. Significantly, the essential benefit of SPI-index is its computation itself over a wide range of time scales. [10]. Additionally, the correct instant rank of SPI index reflects the delay time of hydrologic reaction to meteorological changes. SPI Varies at various scales of time that may be associated to water scarcity in diverse hydrological factors (e.g., stream flows and soil wetness content) [25]. Moreover, in the context of different scenarios corresponding to various probable climate variations and incidents of drought of variable nomographs, severity of drought can be formulated through regression equation and these models t which demonstrated better-fit as clear from their higher R2-value. Results obtained from these investigations are practical tools to design premeditated and well-planned preparedness to fight with droughts and to alleviate their impacts on the different sectors of the socio-economic uplifts of the country. Apart from being treated as a drought index, RDI is also utilized in the context of climatic index which can be appropriate to recognize likely climatic variations and trends on seasonal basis or annually. To notice the trends based on temporal annual RDI-values, we can exercise all suitable techniques for the pattern recognition (e.g. Mann-Kendall, Runs and

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Spearman etc.). Statistically, if the line trend is important, then it represents robust clues of climatic variation based on yearly duration [12, 21].

On the basis of synthetic and real data, DrinC can assess the upcoming and likely drought climatic scenarios to evaluate impacts of drought on the national economic condition, the environment and the society (e.g. stream flow variations, potable water, crop production,). Generally, preparedness for drought in any country is based on following two processes, 1) Adoption of preventive actions; 2) Drought preparedness planning and development. In Pakistan, the drought prediction function is the responsibility of National Drought Monitoring Center (NDMC) at Pakistan Meteorological Department (PMD) constituted by Ministery of Defence, and National Disaster Management Authority (NDMA) which cautiously keeps a watch on the easterlies monsoon (July-September) and suggests remedial steps to alleviate drought impacts on all socio-economic sectors with appropriate emergency plan. This forecasts a plan of actions for drought administration and management, with appropriate organizational framework and aims to execute the long, short and medium term policies to alleviate the hardships of the relavent people. This ensures the availability and provision of food grains and fodder to the masses and livestock, surface water, ground water, adoption of appropriate methods in agricultural practices such as changes in the plantation periods, choice of early / short-term growing varieties, agronomic practices in the context of conservation and soil and water, preventing the migration of livestock and humans, organizing the resultant income for the affectees through local and rural government employment system [16,19,17]. For the earlier drought years, even NDMC-PMD and NDMA recommended the researchers to make appropriate models to forecast drought and expected environmental impact assessment (EIA), since climatic variability and change is a broad day reality, and consequently the drought mitigation planning may be devised accordingly [5]. In the existing conditions, our investigation established that based on 3 month precipitation, the possibility of drought incidence may be forecasted on the basis of DrinC and best fitting regression technique and the state policy makers can ensure green signal for the anticipated preparedness plans in all the relavent sectors directly affected from drought conditions.

4. Conclusions

DrinC computes the DIs by giving an easy user-interface that considers the whole parameters. The DIs computed from DrinC are deciles, SPI and RDI. The DIs of Potwar region through decile technique showed that for the period of 39 years, 8 years are severely drought striken in a cycle and naturally occurring approximately once every 2 or 7 years repetitively, apart from the years of 1985-1986 and 1988-1992, 1998-2003, 2005, 2018-19 etc. DIs of Potwar region by deciles technique discovered that between the 39 years, 8 years were severely drought striken in a cycle and naturally occurring approximately every 2 to 7 years once repetitively, with the exception for little constant years, i.e., 1985-1986 and 1988-1992, 1998-2003, 2005, 2018-19 etc. The RDI and SPI indices also showed the similar developments as of deciles. Though, under RDI and SPI, the extremely and severely dry classes were only for two years and rest of drought years for deciles technique were intermediately and normally dry. Our investigation indicates that SPI is a superior DI as compared to deciles as the severity is better understood in the context of SPI. Regression analysis revealed that the RDI and SPI indices are considerably and mutually interrelated and if there is an availability of 3 month precipitation dataset only, one can forecast annual RDI. The obtained results revealed that DIs are very significant and useful to develop a contingent future plan to contest the drought consequences. The findings of these investigation are valuable tools to devise future development plans to contest vulnerable drought events, its mitigation and possible effects on the socioeconomic sectors in Pakistan. This investigation also concludes that the satellite based meteorological parameters can be used to identify spatial variations of drought. The output may be used for the prediction of agricultural drought and its mitigation.

This methodology may be extended towards other regions of Pakistan as well, as tool for the drought management.

Author Contributions: All authors have read and agree to the published version of the manuscript. Conceptualization, all authors. Methodology S.B. and S. A. M Writing, Software and Visualization, S.B. Writing—original draft, S.B.Writing—review and editing, all authors.

Funding: Please add: "This research received no external funding". The University of Punjab, Lahore-Pakistan is financing this research project and is responsible for future publishing cost of this article.

Data Availability Statement: In this section, please provide details regarding where data supporting reported results can be found, including links to publicly archived datasets analyzed or generated during the study. Please refer to suggested Data Availability Statements in section "MDPI Research Data Policies" at https://www.mdpi.com/ethics. You might choose to exclude this statement if the study did not report any data.

Acknowledgments: The authors acknowledge the department of Geography and department of Space Science for provision of all research and technical facilities.

Conflicts of Interest: The authors declare no conflict of interest.

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