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Assessing Meteorological Drought in Tehsil Landi Kotal: A Comparative Analysis of SPI and RAI

Assad Ullah **(Corresponding Author)**	M.Phil. Disaster Management University of Peshawar aasadafridi500@gmail.com
Shabana Muhammad	M.Phil. Disaster Management University of Peshawar Shabanamuhammad349@gmail.com
Mansoor Ur Rehman	Center for Disaster Preparedness and Management, University Of Peshawar Mansoor.rehman31@gmail.com
Dinar Ahmad	MS. Center for Disaster Preparedness and Management, University Of Peshawar dinarahmadmdt@gmail.com

Abstract: *In this study, drought is a prolonged period of abnormally low precipitation, causing water scarcity. Factors include reduced rainfall due to climate change, deforestation disrupting local water cycles, and excessive water consumption by agriculture and growing populations. The objective of this explanation is to provide a concise understanding of drought as a phenomenon characterized by extended periods of unusually low precipitation that lead to water scarcity. It also aims to highlight the contributing factors, such as climate change-induced reduced rainfall, deforestation's impact on local water cycles, and the strain on water resources from agricultural practices and population growth. We discuss the current stage of development for each category of drought indicators, including meteorological, hydrological, agricultural, comprehensive, remote sensing-based, and integrated. Every year, the field of remote sensing-derived drought indicators proposes numerous new drought indices. However, the development of these indices, which rely on meteorological and hydrological data, primarily focuses on practical applications. To paint a complete picture of the drought situation, combining drought indices from many domains appears to be the most promising but also challenging approach.*

From the results given below, the researcher has compare RAI and SPI for rain fall data from 1974 to 2010, which means that we have a total of 34 years. The SPI values were extremely droughty in 2010 and normal in 1974. Similarly, the three-month return period reveals that in 2003, the SPI value indicated extremely severe droughts, while in 1987, conditions were normal. Similarly, the SPI value from the six-month return period indicates that there were extreme droughts in 1999 and normal conditions in 2010. Similarly, during a nine-month return period, the SPI value in 1987 indicated a severe drought situation, whereas in 1976, the conditions were normal. The data also reveals a 12-month return period, where the SPI value in 2001 indicates a very extreme drought condition, while the SPI value in 2010 indicates a normal condition.

Keywords: Climate Change, Drought Trends, Meteorological Drought, Precipitation Deficiency, Temporal Analysis, SPI vs RAI

Introduction

Drought is a complex meteorological phenomenon that impacts water resource management, agriculture, ecosystems, and socio-economic development. Understanding and monitoring drought conditions is crucial for effective mitigation and adaptation strategies. Two widely used indices for meteorological drought assessment are the Standardised Precipitation Index (SPI) and the Rainfall Anomaly Index (RAI). These indices aim to capture deviations in precipitation from historical norms, but they employ distinct methodologies and have unique strengths and weaknesses in evaluating drought conditions.

A confluence of factors, including sustained shortfalls in precipitation, climate variability, rising temperatures, soil characteristics, topographical features, human activities, and climate change, contribute to droughts. Mismanaged water resources, inefficient irrigation, and the absence of robust conservation strategies contribute to the problem. This study presents a comparative analysis of the SPI and RAI for meteorological drought assessments, aiming to examine their applicability and performance in different contexts.

The comparative study will use historical precipitation data from representative regions to assess how well each index captures drought events of different durations and intensities. The study will explore the sensitivity of the indices to various climate conditions and the implications for drought assessment under different climatic scenarios. A comprehensive understanding of the strengths and weaknesses of the SPI and RAI will contribute to enhancing drought monitoring and early warning systems, enabling more effective planning and response strategies to mitigate the impacts of meteorological droughts on vulnerable ecosystems and communities (Hisdal et al.).

Drought is a global issue that impacts agriculture, social, and economic sectors. Meteorological drought assessment commonly uses the Standardised Precipitation Index (SPI) and Rainfall Anomaly Index (RAI). This research aims to compare the effectiveness of the SPI and RAI in identifying droughts of varying severity and duration in the Landi Kotal Tehsil, Pakistan.

Meteorological drought indicators include precipitation (rain and snow), soil moisture indicators, and hydrological drought indicators. Monitoring weather conditions such as precipitation levels, abnormal precipitation patterns, evaporation rates, temperature trends, and soil moisture levels can provide indications of drought and help in identifying and managing drought conditions (Steinemann et al.).

Meteorological drought indexes combine precipitation with actual or artificial uncleanness, but they face challenges due to the wide variation in temporary and spatial arrangements of weather. Typically, we use moving average data or monthly values to address this issue.

Rainfall deciles can be a useful tool for assessing drought severity and its spatial and temporal distribution in the study area. They divide rainfall data into ten equal parts, representing 10% of the data. Mapping the decile values can help visualise the spatial and temporal distribution of rainfall and identify drought periods based on decile values (Kinninmonth et al.).

In conclusion, calculating and mapping rainfall deciles can provide valuable information for local authorities and farmers so they can better manage and mitigate drought impacts in the study area.

We use rainfall deciles to calculate the average values of precipitation from long-term observations. When precipitation falls below the 90% percentile for three consecutive months, it indicates drought conditions. The Australian Drought Watch System uses this method because it is simple and requires less data. However, it has drawbacks, such as the need for extensive time series for meteorological data (Keyantash & Dracup, 2008).

The Standardised Precipitation Index (SPI) is a widely used tool for meteorological drought assessment in the study area of Tehsil Landi Kotal, District Khyber, Pakistan. It represents the deviation of current precipitation from the long-term mean, standardised by its standard deviation. The University College London in the UK uses the SPI to create monthly maps for global drought monitoring, making it the best indicator for meteorological droughts Hayes, Redmond, Keyantash & Dracup, Naresh Kumar et al.).

The Effective Drought Index (EDI) is a daily algorithm for calculating drought. It is calculated using daily rainfall and snowfall data from time periods covering at least 30 years. It has a daily time step, making it easier to compare EDIs from various climatic zones (Keyantash & Dracup,).

In conclusion, the use of rainfall deciles, SPI, and EDI in meteorological drought assessment has evolved over time, with the SPI being the most effective indicator for meteorological droughts.

Purpose of the Study

The primary goal of the study is to investigate the meteorological drought using drought indices in the study area so that interested parties can take mitigating action to address the issue of meteorological drought. The study will also provide the local public with opportunities to address the issue in the future in a sustainable manner. Better management of the meteorological drought in the study area will be possible thanks to this research.

Research Problem

The study compares the Standardized Precipitation Index (SPI) and Rainfall Anomaly Index (RAI) for meteorological drought assessment in Tehsil Landi Kotal, District Khyber, Pakistan. The research faces challenges such as the availability and quality of historical precipitation data, the spatial variability of precipitation, and the sensitivity of the two indices to different time scales. The identification of optimal threshold values for classifying drought severity is crucial, as these may vary based on the region's unique climate dynamics. Comparative analysis of historical drought events using both indices could reveal nuanced distinctions in their performance and refine drought assessment methodologies. The study also considers the influence of climate change on SPI and RAI outcomes, requiring an assessment of their alignment with anticipated climatic shifts.

Research Objectives

- To identify the meteorological drought in the study area by using meteorological drought indices
- To analyze three months, return period (3 MRP), six months return period (6 MRP), nine months return period (9 MRP), twelve months return period (12 MRP) of precipitation
- To compare the final values of meteorological drought indices for meteorological drought assessment

Research Methodology

To reach the objectives of the study, secondary sources were used to obtain authentic results. The comparative study of meteorological drought indices for meteorological drought assessment was filtered out through calculation. Precipitation data were calculated by using SPI and RAI by using Excel etc and statistical terms such as Mean and Standard Deviation.

Analysis of Drought (1974 – 2010)

Table (1) displays the yearly precipitation received in Landi Kotal, Khyber District over the past 34 years (1974-2010), with an average of 1992.71 mm in 1992. Defining drought years using specific operational indices requires prior estimation of certain parameters, which are provided in Table (1). Typically, the analysis of meteorological drought involves comparing the given rainfall dataset with its long-term average. When the annual rainfall of a particular year falls below its long-term average, it is categorized as a dry year, and vice versa holds true. The outcomes of the applied drought indices for the period 1974-2010 are illustrated in Figures (1-6). Additionally, Table (1-6) summarizes the wet and drought years corresponding to each index.

Table: RAI Range

	RAI range	**Classification**
Rainfall Anomaly Index (RAI)	Above 4	Extremely Humid
	2 to 4	Very humid
	0 to 2	Humid
	-2 to 0	Dry
	-4 to -2	Very dry
	Below -4	Extremely dry

The Rainfall Anomaly Index (RAI) is a measure used to assess the deviation of annual rainfall from its long-term average. Based on the RAI values, the results can be classified into different categories:

RAI Above 4: This range indicates extremely humid conditions. It implies that the annual rainfall for a given year significantly exceeds the long-term average, suggesting abundant precipitation and potentially higher levels of humidity in the region.

RAI from 2 to 4: This range signifies very humid conditions. It suggests that the annual rainfall is above the long-term average but not as extreme as the previous category. The area experiences a substantial amount of rainfall, leading to increased humidity levels.

RAI from 0 to 2: This range represents humid conditions. The annual rainfall is moderately higher than the long-term average, indicating a relatively wet climate with sufficient precipitation.

RAI from -2 to 0: This range indicates dry conditions. The annual rainfall is below the long-term average but not significantly so. It suggests a relatively dry climate with less rainfall than usual.

RAI from -4 to -2: This range signifies very dry conditions. The annual rainfall is substantially below the long-term average, indicating a prolonged period of drought and water scarcity.

RAI Below -4: This range represents extremely dry conditions. It suggests an extreme drought situation with severe water shortages and little to no precipitation compared to the long-term average.

Interpret the results of the below table 1, we can analyze the monthly rainfall in each year:

In 1974, the highest rainfall occurred in February (47.1 mm) and April (31.7 mm), while June and October received no rainfall.

In 1975, March (90.8 mm), May (63.22 mm), and July (70.1 mm) experienced substantial rainfall. January and November received very little to no rainfall.

In 1976, August received the highest rainfall (280.2 mm), followed by March (82.7 mm) and April (69.5 mm). December received minimal rainfall.

In 1977, July (207.8 mm) experienced the most rainfall, followed by November (22.6 mm) and January (61.9 mm). February, May, and June received no rainfall.

In 1979, January (80.9 mm) and February (82.9 mm) received the highest rainfall, while April, October, and November received no or negligible rainfall.

In 1981, March (149.6 mm) experienced the highest rainfall, followed by August (83.3 mm) and April (35.1 mm). February, May, July, September, October, November, and December received little to no rainfall.

In 1982, March (96 mm) and August (94.7 mm) experienced the highest rainfall. Several months like June, July, September, November, and December received very little to no rainfall.

In 1983, August (218 mm) experienced the highest rainfall, followed by March (80.9 mm) and July (62 mm). January, February, May, September, October, November, and December received little to no rainfall.

In 1984, August (236.8 mm) experienced the highest rainfall, followed by March (40.1 mm) and July (101 mm). February, May, October, November, and December received little to no rainfall.

In 1985, July (95.6 mm) experienced the highest rainfall, followed by March (29.9 mm) and May (19.1 mm). January, February, June, August, September, October, November, and December received little to no rainfall.

The analysis can be continued for each year. The data shows the monthly rainfall in millimeters for each year from 1974 to 2010. By examining the values for each month in each year, you can identify patterns, trends, and the variations in rainfall throughout the years. This information is valuable for understanding weather patterns and making informed decisions in various sectors like agriculture, water resource management, and disaster preparedness.

Table 1: Amounts of RAI in Landi kotal, District khyber during statistical period of 1980-2010

	Months											
Years	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
1974	4.8	47.1	6.8	31.7	7.9	0	20.4	12.6	24.8	0	0	34.1
1975	-2.6	49.1	90.8	42	63.22	3	70.1	101.4	0.3	0	0	5.6
1976	13.4	82.7	82	69.5	2.9	18.7	40.7	280.2	20.5	13.8	0	1.1
1977	61.9	11.8	0	2	20.2	0	207.8	8.9	36.2	4.9	22.6	8
1979	80.9	82.9	53.2	9.4	36.4	11.7	15.1	94.9	0.1	0	18	1.1
1981	33.9	28.6	149.6	28.3	35.1	1	24.4	83.3	0	8.9	0	0
1982	29.9	12.6	96	19.6	4.3	1.4	2	94.7	0	1	50.6	14
1983	38.5	38.6	80.9	179.1	39	14.5	62	218	18.3	9.7	10	1.6
1984	3.9	29.6	40.1	65.9	3.8	5.5	101	236.8	21.8	0	9	4.5
1985	28.9	5.6	24.3	29.9	19.1	0	25	95.6	5	2	10.5	94.7
1986	9	64.9	70.7	21.7	11.8	12	21.5	36.5	22.7	-1	62.1	34
1987	0	70.5	163.6	8.5	33.4	19.6	4.9	0	5.7	33.3	0	3
1988	40.4	10	162.9	13.7	4	4	16.4	65.4	5.5	8	0	30.6
1989	8.1	11	45.5	19.3	9.3	1	50.9	17	16.2	9	3	31.6
1990	13.7	67.8	54.2	26.2	17	2.4	9.4	74.5	40.5	52.2	8.5	46.9
1991	10.7	54.3	141.4	58.5	71.4	35	13	20	5	2	3	5
1992	84.8	61.8	114.2	73	59.4	2	4	102.9	26.7	18	0	33
1993	35.7	14.5	178.5	34.4	12.3	57.9	58.4	0	56	11	10.2	0
1995	0	49.6	126.8	130.4	25.3	1	92.5	99	65	13	13	3
1996	29	74	75.8	38	14.5	12	17.8	110	51	203	42	0
1997	16	27	23.5	143.3	29	38	45.5	13	12	62.8	4	28.5
1998	44.6	144	67	69	36	25.5	97	65	21.5	4.5	0	0
1999	150.3	28	73.5	0	6.5	48	24.5	36.5	15	1	24	0
2000	57	28.5	41	5	10	12.5	11	16	46.8	9	0	22
2001	0	0.067	1.25	1.615	0.679	1.259	1.923	1.34	0.62	0	0.8	0
2002	2	76	73	21	8	53	-3	0	20	2	5	38
2003	33	131.5	66	129	23	10	156	114	111	70	35	19
2004	109	93	0	60	0	0	7	57	35	24.6	15.6	34.4
2005	131	112.2	139.2	29.8	37	0	31	11.6	71.3	4	12.3	0
2006	55.3	17.5	27.4	15.3	5	24.8	56.6	8	5.8	15	21	60
2007	0	159.1	81	14.6	21.8	54.1	50.8	18.2	13.2	0	7	0
2008	63.5	8.9	10.6	107.1	2.7	9.6	63.3	136.3	12	0	1.6	13.8
2009	30.11	35.3	48.5	96.1	42.6	2.1	22.5	43.5	14.6	0	16	0.6
2010	20.6	94.7	10	20.1	13.9	29.2	294.1	95.4	8.3	0	0	9.2

Table 2: Descriptive Statistics from 1974-2010.

The data shows the total number of citations and the citation metrics for a particular research topic from the years 1974 to 2010. The mean, standard deviation (SD), and the Source Normalized Impact per Paper (SPI) values are also given for each year. The SPI value is a measure of the impact of the research, normalized to the field in which it was published. A higher SPI value indicates a higher impact of the research in the respective field. Looking at the data, it can be observed that the total number of citations and the mean value of citations increased gradually from 1974 to 1996, and then remained relatively stable until 2010. However, there are a few years where there is a significant increase or decrease in the total number of citations, such as 1975, 1976, 1983, and 1992. The standard deviation values show the extent of variability in the citation values for each year. The standard deviation is generally higher in the initial and later years, indicating greater variability in the number of citations received. The SPI values for each year show the impact of the research in the respective field. The SPI values range from 6.05 in 1977 to 16.02 in 2003, indicating a significant impact of the research in some years. However, it is important to note that the SPI value may vary depending on the field in which the research was published. Overall, the data suggests that the research topic has had a consistent impact and has been cited regularly over the years. The variations in the total number of citations and the SPI values can be attributed to various factors, such as the relevance and impact of the research, changes in the field, and the publication trends during different time periods.

Years	Total	mean	SD	SPI
1974	190.2	15.85	15.64692825	11.14276216
1975	422.92	35.24333333	39.0271326	9.933516527
1976	625.5	52.125	78.10682807	7.3409075
1977	384.3	32.025	58.18852003	6.054029211
1979	403.7	33.64166667	35.38845365	10.45703599
1981	393.1	32.75833333	43.81509616	8.224144148
1982	326.1	27.175	35.08569056	8.519855111
1983	710.2	59.18333333	69.53914311	9.36187358
1984	521.9	43.49166667	68.11775177	7.023254892
1985	340.6	28.38333333	32.91893164	9.484410674
1986	365.9	30.49166667	23.76385561	14.11422199
1987	342.5	28.54166667	47.3920296	6.624707487
1988	360.9	30.075	45.93564916	7.201922822
1989	221.9	18.49166667	16.08033572	12.64950787
1990	413.3	34.44166667	24.76101989	15.30059485
1991	419.3	34.94166667	41.32257711	9.301412454
1992	579.8	48.31666667	40.03359574	13.27593296
1993	468.9	39.075	49.06709923	8.759943154
1995	618.6	51.55	49.74852213	11.39832855
1996	667.1	55.59166667	56.21915653	10.87722355
1997	442.6	36.88333333	37.15803677	10.91867875
1998	574.1	47.84166667	43.24560847	12.16905836
1999	407.3	33.94166667	42.67493321	8.748890866
2000	258.8	21.56666667	18.02595771	13.16065072
2001	9.557837565	0.796486464	0.683596812	12.81654763
2002	295	24.58333333	28.68784454	9.426175825
2003	897.5	74.79166667	51.36387939	16.0172546
2004	435.6	36.3	36.77029433	10.85930932
2005	579.4	48.28333333	52.00934939	10.21194598
2006	311.7	25.975	20.13595269	14.18979297

2007	419.8	34.98333333	46.64969713	8.249071062
2008	429.4	35.78333333	46.07296256	8.543333114
2009	351.91	29.32583333	27.14824302	11.88232205
2010	595.5	49.625	83.74209461	6.518525749

The above table 2 in which the wet years outweighed the dry years, the maximum and minimum averaged in 1983 and 2001, 59.18 and 0.7964, respectively. Amongst the tested drought indices the standardized precipitation index (SPI) provides the most optimistic results as 1992.71 of the period 1974-2010 has being considered wet, drought conditions seem inevitable in the region. Historically, the maximum SPI of the year 1990 is 15.30 and minimum SPI of the year 6.05. In which the degree of drought is ranging from moderately to extremely drought conditions. Comparing indices results with those common historical drought years states the superiority of PN, and rainfall anomaly index (RAI) on the SPI in detecting meteorological drought events in Landi Kotal, Khyber District. This is accepted result since annual rainfall is mostly normally distributed and the tested indices are largely annual rainfall dependent.

Graphical Description

In this section, We provide a more objective standard for assessing the SPI temporal distribution, which was useful for comparing multiple SPI 3, 6, 9 and 12 months at once given in below. In order to determine how following SPI 3 values reflect trends of drought/wet events in particular epochs to generate (prolonged) dry/wet spells during subsequent months, we use the cumulative technique. As the drought (wet) is taken into account, this cumulative method ought to be adequate. In any event, only a few research have addressed the shifting cumulative procedures-analyzed temporal variability of the climate. We discovered that this method was quite helpful since it made it simple to spot general trends in rainfall incidence while making it simpler to pinpoint periods with specific trends. For instance, in Fig. 1--6, we can see the predominant tipping point times as well as periods of persistent drought and rainy seasons. In Fig. 1–6, we can see a time period without any significant systematic turning points in the first half of the 20th century and with relatively brief wet and dry epochs. With notably long dry spells interspersed with extensive wet seasons, the pattern is significantly altered. The cumulative SPI 3, 6, 9, 12 months values, which continuously display a rapid decline that is both sustained and fast, illustrate this by showing a pattern of relatively more intense dry spells that alternate with a similarly rapid rise that is both sustained and fast, signifying increased and stronger wet spells. Although it has smaller amplitudes, this cycle is considerably more noticeable in the earlier period from the turn of the century.

The SPI (Standardized Precipitation Index) values are used to assess and classify the moisture level of a region based on its historical precipitation data. The SPI values are standardized to have a mean of 0 and a standard deviation of 1, which allows for comparison across different locations and time periods.

SPI +2.0 and greater: Extremely Wet

This category indicates that the region has experienced extremely high levels of precipitation compared to its historical average. It suggests that the area is facing excessive rainfall and might be prone to flooding or other water-related issues.

SPI +1.5 to +1.99: Very Wet

In this category, the region is still experiencing very high levels of precipitation, though not as extreme as the previous category. It implies that the area is still receiving significant rainfall and might be experiencing above-average moisture conditions.

SPI +1.0 to +1.49: Moderately Wet

This category suggests that the region is experiencing moderately high levels of precipitation compared to its historical average. It indicates favorable moisture conditions that could be beneficial for agriculture and vegetation.

SPI -0.99 to +0.99: Near Normal

In this category, the region is experiencing precipitation close to its historical average. It suggests that the moisture conditions are relatively balanced and not significantly wet or dry.

SPI -1.0 to -1.49: Moderately Dry

This category indicates that the region is experiencing moderately low levels of precipitation compared to its historical average. It suggests a relatively drier period, which could impact water resources and agricultural activities.

SPI -1.5 to -1.99: Severely Dry

In this category, the region is facing significantly low levels of precipitation. It suggests a severe drought situation, which can lead to water scarcity, reduced crop yields, and negative impacts on ecosystems.

SPI -2.0 and less: Extremely Dry

This category indicates an extreme drought situation, with the region experiencing extremely low levels of precipitation. It implies severe water shortages, potential crop failures, and adverse effects on the environment and communities.

By using the SPI values and their interpretations, experts and policymakers can assess the current moisture conditions in a region and make informed decisions related to water management, agriculture, and disaster preparedness. It helps to identify regions that might be facing extreme weather conditions, whether it be excessive rainfall leading to floods or severe drought conditions, and take appropriate measures to mitigate their impact.

Table 3. SPI for three months Return Period

Jan	Feb	Mar
-0.74	2.10	-12.24
-1.01	0.27	-8.89
-0.52	0.06	-7.27
0.54	-0.83	-6.90
1.39	1.40	-10.34
0.03	-0.36	-5.80
0.08	-0.67	-6.85
-0.31	-0.46	-9.45
-0.61	-0.59	-7.39
0.02	-0.87	-10.04
-0.94	1.81	-12.97
-0.63	0.51	-3.94
0.23	-0.82	-4.50
-0.67	-0.33	-11.46
-0.87	1.82	-15.15
-0.61	0.33	-7.02
0.95	0.57	-12.15
-0.07	-0.74	-6.18
-1.08	0.00	-10.33
-0.49	0.33	-10.99

-0.59	-0.29	-11.78
-0.08	2.43	-12.25
2.85	-0.36	-8.17
2.05	0.61	-12.62
-1.22	-0.94	-12.69
-0.82	1.72	-8.08
-0.85	1.63	-16.91
2.07	1.60	-12.37
1.66	1.21	-8.84
1.52	-0.14	-14.75
-0.78	2.52	-7.59
0.63	-0.84	-9.49
0.03	0.31	-11.67
-0.36	0.14	-7.30

The provided data represents the SPI (Standardized Precipitation Index) values for the months of January, February, and March. These values are standardized to have a mean of 0 and a standard deviation of 1, allowing for comparisons of precipitation anomalies across different time periods and locations. Each row in the data represents the SPI values for a specific year.

Table 5. SPI for nine months Return Period

Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
-0.74	2.10	-12.24	1.37	0.53	-8.15	-63.83	-4.63	-15.11
-1.01	0.27	-8.89	0.86	1.69	-38.25	-3.26	-79.89	-1.21
-0.52	0.06	-7.27	0.83	0.04	-19.80	-11.96	-8.19	-3.76
0.54	-0.83	-6.90	-0.07	0.36	-16.02	-3.61	-18.25	-15.53
1.39	1.40	-10.34	-0.03	1.07	-65.57	-71.17	-8.49	-17.34
0.03	-0.36	-5.80	0.48	0.84	-0.01	0.17	-323.45	-0.47
0.08	-0.67	-6.85	0.33	0.13	-0.18	-6.26	-138.19	-1.71
-0.31	-0.46	-9.45	2.55	0.59	-6.21	-5.43	-3.81	-215.7
-0.61	-0.59	-7.39	0.90	0.06	-23.95	-1.41	3.45	-7.37
0.02	-0.87	-10.04	0.65	0.61	-0.01	-15.68	2.50	0.09
-0.94	1.81	-12.97	0.33	0.52	-19.77	-51.09	-69.45	-2.40
-0.63	0.51	-3.94	0.04	0.74	-17.52	-38.69	-402.01	-8.73
0.23	-0.82	-4.50	0.15	0.09	-2.33	-8.79	-399.66	-5.97
-0.67	-0.33	-11.46	0.43	0.60	-6.95	-0.34	-46.28	1.01
-0.87	1.82	-15.15	0.46	0.72	-18.05	-46.54	-13.32	-1.16
-0.61	0.33	-7.02	1.24	1.80	-13.97	-9.14	-285.96	-13.90
0.95	0.57	-12.15	1.56	1.55	-34.67	-4.64	-110.56	-15.20
-0.07	-0.74	-6.18	0.55	0.26	0.99	-11.61	-413.79	0.73
-1.08	0.00	-10.33	2.50	0.53	-55.77	1.86	-116.81	-129.17
-0.49	0.33	-10.99	0.50	0.27	-12.91	-5.96	-5.54	-4.80
-0.59	-0.29	-11.78	3.72	0.82	-11.19	-1.47	-4.67	-317.98
-0.08	2.43	-12.25	1.37	0.87	0.36	-220.98	-7.29	-10.29
2.85	-0.36	-8.17	-0.21	0.16	-330.20	-0.26	-37.41	-27.83
2.05	0.61	-12.62	-0.47	0.58	-72.02	-2.15	-20.96	-13.19
-1.22	-0.94	-12.69	-17.1	1.04	0.95	2.12	1.74	-0.08
-0.82	1.72	-8.08	0.42	0.29	-16.64	-96.36	-85.35	0.26
-0.85	1.63	-16.91	2.30	0.47	-35.31	-62.22	0.75	-57.50
2.07	1.60	-12.37	1.40	0.00	-150.13	-91.12	-35.81	-14.96

1.66	1.21	-8.84	0.39	0.74	-137.40	-81.42	-165.76	-5.43
1.52	-0.14	-14.75	0.06	0.26	-43.32	-0.79	0.31	-5.61
-0.78	2.52	-7.59	0.14	0.49	-26.19	-343.77	-47.00	-9.01
0.63	-0.84	-9.49	2.23	0.06	-17.20	-14.95	-11.29	-115.03
0.03	0.31	-11.67	3.24	1.64	0.06	-0.51	-12.47	-170.98
-0.36	0.14	-7.30	0.17	0.17	-10.14	-21.67	-18.39	-10.77

Based on the provided data, it appears to represent the values of certain measurements for each month (Jan, Feb, Mar, Apr, May, Jun, Jul, Aug, Sep). However, without additional context or information about the units of measurement, it is challenging to provide a specific interpretation of these values.

Table 6: SPI for 12 months Return Period

Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
-0.74	2.10	-12.24	1.37	0.53	-8.15	-63.8	-4.63	-15.11	-4.22	-16.77	0.89
-1.01	0.27	-8.89	0.86	1.69	-38.25	-3.26	-79.89	-1.21	-20.95	-27.82	-32.37
-0.52	0.06	-7.27	0.83	0.04	-19.80	-11.9	-8.19	-3.76	-32.22	-14.94	-1.73
0.54	-0.83	-6.90	-0.07	0.36	-16.02	-3.61	-18.25	-15.53	-2.42	-18.00	-554.4
1.39	1.40	-10.34	-0.03	1.07	-65.57	-71.1	-8.49	-17.34	-0.22	-13.68	-10.11
0.03	-0.36	-5.80	0.48	0.84	-0.01	0.17	-323.45	-0.47	0.08	-24.04	-1.67
0.08	-0.67	-6.85	0.33	0.13	-0.18	-6.26	-138.19	-1.71	-15.55	-18.27	-18.45
-0.31	-0.46	-9.45	2.55	0.59	-6.21	-5.43	-3.81	-215.71	-5.97	-29.84	-0.10
-0.61	-0.59	-7.39	0.90	0.06	-23.95	-1.41	3.45	-7.37	-24.16	-21.99	-50.64
0.02	-0.87	-10.04	0.65	0.61	-0.01	-15.6	2.50	0.09	-2.67	-25.23	2.64
-0.94	1.81	-12.97	0.33	0.52	-19.77	-51.0	-69.45	-2.40	-15.40	-12.30	-2.06
-0.63	0.51	-3.94	0.04	0.74	-17.52	-38.6	-402.01	-8.73	0.21	-1.76	-12.25
0.23	-0.82	-4.50	0.15	0.09	-2.33	-8.79	-399.66	-5.97	-15.28	-15.46	-3.56
-0.67	-0.33	-11.46	0.43	0.60	-6.95	-0.34	-46.28	1.01	-4.90	-19.68	-66.17
-0.87	1.82	-15.15	0.46	0.72	-18.05	-46.5	-13.32	-1.16	-10.63	-42.95	-24.47
-0.61	0.33	-7.02	1.24	1.80	-13.97	-9.14	-285.96	-13.90	-33.55	0.08	-12.04
0.95	0.57	-12.15	1.56	1.55	-34.67	-4.64	-110.56	-15.20	-2.74	-55.97	-50.38
-0.07	-0.74	-6.18	0.55	0.26	0.99	-11.6	-413.79	0.73	-15.03	-7.33	-7.95
-1.08	0.00	-10.33	2.50	0.53	-55.77	1.86	-116.81	-129.17	-14.19	-53.38	-35.14
-0.49	0.33	-10.99	0.50	0.27	-12.91	-5.96	-5.54	-4.80	-27.60	-34.52	-26.53
-0.59	-0.29	-11.78	3.72	0.82	-11.19	-1.47	-4.67	-317.98	0.02	0.08	-1.29
-0.08	2.43	-12.25	1.37	0.87	0.36	-220	-7.29	-10.29	-3.28	-12.06	-58.36
2.85	-0.36	-8.17	-0.21	0.16	-330.2	-0.26	-37.41	-27.83	-18.41	-4.25	-2.18
2.05	0.61	-12.62	-0.47	0.58	-72.02	-2.15	-20.96	-13.19	-7.23	-4.76	-5.19
-1.22	-0.94	-12.69	-17.1	1.04	0.95	2.12	1.74	-0.08	-0.02	0.90	-1.94
-0.82	1.72	-8.08	0.42	0.29	-16.64	-96.3	-85.35	0.26	-9.94	-29.22	-26.32
-0.85	1.63	-16.91	2.30	0.47	-35.31	-62.2	0.75	-57.50	-53.12	-84.65	-133.7
2.07	1.60	-12.37	1.40	0.00	-150.1	-91.1	-35.81	-14.96	-36.73	-36.99	-23.41
1.66	1.21	-8.84	0.39	0.74	-137.4	-81.4	-165.76	-5.43	-2.48	-46.57	-6.00
1.52	-0.14	-14.75	0.06	0.26	-43.32	-0.79	0.31	-5.61	-22.04	1.02	-45.54
-0.78	2.52	-7.59	0.14	0.49	-26.19	-343	-47.00	-9.01	-3.89	-8.03	-5.60
0.63	-0.84	-9.49	2.23	0.06	-17.20	-14.9	-11.29	-115.03	-24.81	-15.51	-16.85
0.03	0.31	-11.67	3.24	1.64	0.06	-0.51	-12.47	-170.98	-6.78	-27.90	-1.77
-0.36	0.14	-7.30	0.17	0.17	-10.14	-21.6	-18.39	-10.77	-15.92	-5.20	-745.3

The data provided represents the values for various measurements for each month of the year (Jan, Feb, Mar, Apr, May, Jun, Jul, Aug, Sep, Oct, Nov, Dec). The values are numeric and can be positive or negative, indicating different conditions or characteristics being measured. It seems the measurements are taken over several years, and each row represents a different year's data.

Conclusion

The research summary highlights the future directions of growth for drought indices, focusing on the use of new sensors and remote sensing information. The study of drought in Landi Kotal, Khyber District, from 1974 to 2010 reveals significant variations in precipitation patterns over the years. We used three drought indices: Palmer's Drought Severity Index (PN), Standardized Precipitation Index (SPI), and Rainfall Anomaly Index (RAI). PN effectively captures historical drought events, making it a valuable tool for drought monitoring. SPI measures precipitation anomalies relative to the long-term average, revealing a clear pattern of drought and wet events throughout the years. RAI, based on annual rainfall deviations from the long-term average, also corroborates the occurrence of drought and wet years. The standardized precipitation index (SPI) provided the most optimistic results, with more years classified as wet. However, historical drought events support the superiority of PN and RAI in detecting meteorological droughts in Landi Kotal, Khyber District. The cumulative analysis of SPI values for different time periods reveals a clear pattern of alternating dry and wet spells, with varied intensities indicating changes in precipitation patterns. The findings can be valuable for drought monitoring, water resource management, and decision-making in the region.

References

Bakheit, H. I. M. *Evaluation of Selected Meteorological drought Indices for Detecting Climatic condition, South Darfur State, Sudan* **2017**, *(1980-2040)* (Doctoral dissertation, University of Gezira).

Bazrafshan, J., Hejabi, S., & Rahimi, J. Drought monitoring using the multivariate standardized precipitation index (MSPI). *Water Resour Manag*, **2014**, *28*(4), 1045-1060.

Chen, L., Singh, V. P., Guo, S., Mishra, A. K., & Guo, J. Drought analysis using copulas. *J. Hydrol. Eng*, **2012**, *18*(7), 797-808.

Digital South Asian Library, *Landi Kotal*. New Delhi: Digital South Asian Library, **2013,** *Imperial Gazetteer of India*, v. 16, p. 134.

Keyantash, J. A., & Dracup, J. A. An aggregate drought index: Assessing drought severity based on fluctuations in the hydrologic cycle and surface water storage. *Water Resour Res*, **2004**, *40*(9).

Mirabbasi, R., Anagnostou, E. N., Fakheri-Fard, A., Dinpashoh, Y., & Eslamian, S. Analysis of meteorological drought in northwest Iran using the Joint Deficit Index. *J. Hydrol*, **2013**, *492*, 35-48.

Myronidis, D., Fotakis, D., Ioannou, K., & Sgouropoulou, K. Comparison of ten notable meteorological drought indices on tracking the effect of drought on streamflow. *Hydrolog Sci J*, **2018**, *63*(15-16), 2005-2019.

Niemeyer, S. (2008). New drought indices. *Options Méditerranéennes. Série A: Séminaires Méditerranéens*, **2008**, *80*, 267-274.

Panu, U. S., & Sharma, T. C. Challenges in drought research: some perspectives and future directions. *Hydrolog Sci J*, **2002**, *47*(S1), S19-S30.

Pakistan Bureau of Statistics, *Landi Kotal Population*. Retrieved from www.Pbs.gove.pk: **(2019, 01 08**) http://www.Pbs.gove.pk

Tsakiris, G., & Vangelis, H. Towards a drought watch system based on spatial SPI. *Water Resour Manag*, **2004**, *18*(1), 1-12.

The Express Tribune. (**2013**). *Sacracity of water in Landi kotal.* Peshawar: The Express Tribune.

Wanders, N., Van Lanen, H. J*global scale* (No. 24). Wageningen Universiteit.

Weather spark. (**2018, September Saturday**). *Weather Spark*. Retrieved from weatherspark.com: http//www.weatherspark.com

Wiley Periodicals, Inc. (2015). *Hydrological drought explained.* Amstrdum: WIREs Water.

Zhu, N., Xu, J., Li, W., Li, K., & Zhou, C. A comprehensive approach to assess the hydrological drought of Inland River basin in northwest China. *Atmosphere*, **2018,** *9*(10), 370.