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Drought resilience and soil degradation in drought-hit Districts of Karnataka: The relevance of regenerative farming

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Abstract
Karnataka's agricultural sector is tackling significant challenges due to recurring droughts, rising temperatures, unstable rainfall, and soil degradation, particularly in drought-hit districts. These environmental challenges have caused a drop in crop production and increased risk for farmers. This article explores the interrelations between drought, temperature, rainfall, Land Surface Temperature (LST), Normalized Difference Vegetation Index (NDVI), Soil Moisture Index (SMI), and soil degradation in Karnataka, highlighting how these factors contribute to changes in agricultural output. It also discusses the role of regenerative farming as a long-term approach to mitigate these challenges. Farmers in Karnataka's drought-prone areas are increasingly adopting regenerative farming practices, including cover cropping, reduced tillage, crop rotation, and agroforestry. These practices are proven to enhance soil health, boost water retention, and strengthen resilience against climatic extremes, presenting a hopeful route for sustainable agriculture in the state.

Keywords: Drought, soil degradation, regenerative farming, drought resilience

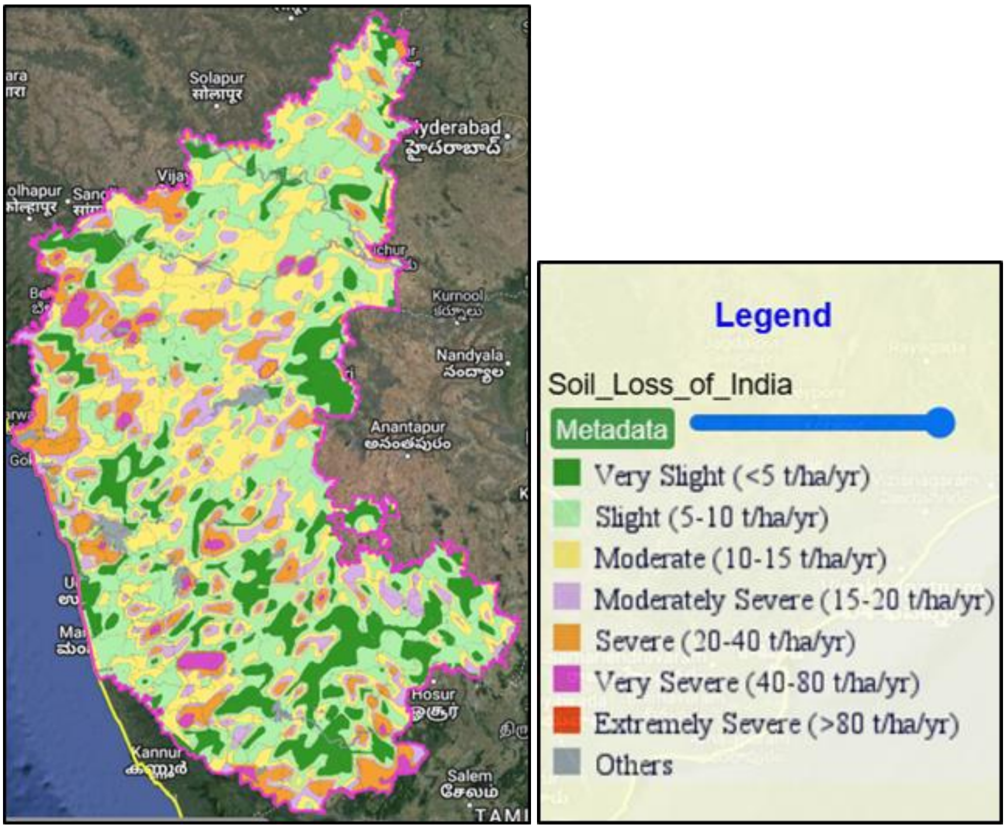
Introduction
Agriculture in India is significantly impacted by two major hydro-meteorological events: drought and flood. Given its heavy reliance on the monsoon for water, Indian agriculture remains vulnerable to these challenges. Nearly one-sixth of the country’s geographical area, accounting for 12% of the population, is prone to drought. Additionally, over 68-70% of India's cultivated land is susceptible to drought.

Drought around India
Study Area-The Drought Crisis in Karnataka
Drought has become a frequent and distressing phenomenon in Karnataka, affecting nearly 80% of the districts annually. Districts such as Bagalkote, Ballari, Bidar, Chitradurga, Kalaburagi, Koppala, Gadaga, Raichur, and Vijayapura are among the worst hit. Prolonged water scarcity periods severely impact crop yields and push farmers into liability. The lack of consistent rainfall, worsened by climate change, has led to severe water shortages, leaving irrigation systems and rain-fed agriculture vulnerable.

Soil Degradation: A Growing Concern
Soil degradation is the deterioration in soil quality caused by natural processes or human activities. Soil degradation is a significant consequence of the environmental challenges faced by Karnataka. Repeated drought cycles and inadequate agricultural practices have caused a decline in soil organic matter, nutrient loss, and decreased soil fertility. In many districts of Karnataka, people are already struggling with water scarcity, and degraded soils become even less capable of retaining moisture, creating a downward spiral where the land becomes increasingly unproductive.
Soil degradation has different effects on nature as well as human well-being. Soil erosion, another significant form of degradation, is a persistent issue.

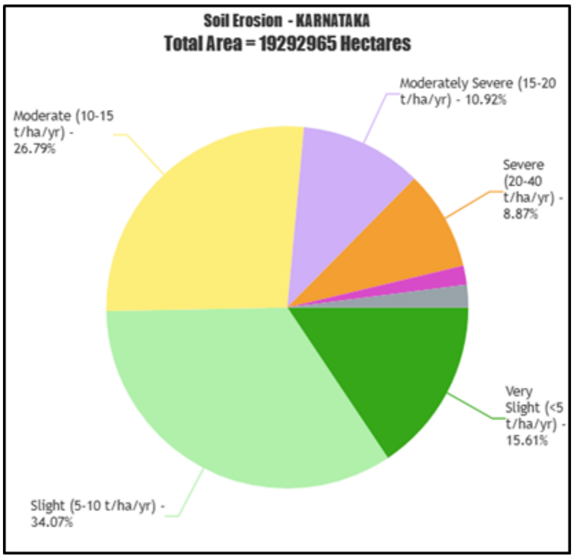
The intense and erratic rainfall that sometimes accompanies drought can easily wash away topsoil, takes away the essential nutrients required for healthy crop growth. This further lessens the land's capacity to support agriculture and worsens food insecurity in the region.

There are different kinds of soil erosions such as Physical, Chemical, and Biological. Physical soil degradation encompasses erosion by wind and water and the deterioration of soil structure. Chemical soil degradation arises from human activities and includes issues such as over-fertilization, salinization, the accumulation of microplastics, and contamination by organic chemicals. The primary Biological soil degradation includes the loss of soil organic matter and a decline in biodiversity.



Source: ICAR NBSS & LUP, Nagpur

Fig 1: Map showing soil loss in Karnataka



Source: ICAR NBSS & LUP, Nagpur

Fig 2: Severity of Soil Erosion in Karnataka (2023-2024)

Soil degradation has the main effect on agriculture. Degraded soil has lower fertility, less water-holding capacity, and reduced nutrients leading to decreased crop yields and food production. Soil degradation can diminish groundwater recharge, reduce water infiltration and storage capacity, and increase runoff, leading to water shortages for animals, plants, and human use.

The main causes of soil degradation have been sped by aggressive farming practices like intensive cultivation, deforestation, forest fires, overgrazing, climate change, and urbanization.

Methods to control and mitigate soil degradation

There are a few ways by which we can prevent soil degradation such as by cover cropping, crop rotation, contour planting, adding organic matter, controlling runoff, afforestation, etc. Regenerative farming is also an effective way of preventing soil degradation.

Regenerative Farming: A Sustainable Solution

Regenerative agriculture is a general approach aiming to support the health of soil, water, and biodiversity, intending to benefit farmer communities. Here are key practices associated with regenerative agricultural farming:

- **Soil Health:** Maintaining and building healthy, nutrient-rich soil. This can be achieved by increasing organic matter, promoting microbial activity, and improving soil structure.
- **Minimal Tillage:** Tillage refers to the method used in preparing soil for planting by mechanically disturbing or agitating it. Reduced tillage minimizes soil disturbance, helping to maintain organic matter and soil structure.
- **Cover Cropping:** Planting cover crops helps prevent soil erosion and enhances soil structure. These crops protect the soil from being washed or blown away, while also improving its physical properties by increasing organic matter and promoting better root growth, leading to healthier, more resilient soil. Biodiversity: Promoting a diversity of plant and animal species within the farming system enhances resilience, benefits pollinators, and creates a balanced ecosystem.
- **Livestock grazing:** Holistic grazing ensures livestock contribute positively to improve soil quality through natural herd movements, which helps plants grow and regenerate soil.
- **Carbon Sequestration:** This approach increases soil carbon storage, aiding in the mitigation of climate change.
- **Agroforestry:** This is the practice of incorporating trees into agricultural landscapes, offering substantial benefits in drought-prone regions by providing shade, reducing wind erosion, and enhancing water retention.

The impact of regenerative farming in Karnataka

In response to these challenges, many farmers in Karnataka have adopted to regenerative agriculture practices as a means to address soil degradation and improve the flexibility of their lands to drought and climate variability. Farmers who have adopted regenerative agricultural practices in Karnataka's drought-hit districts are beginning to see the profits. Improved soil health has led to better water retention, which is critical in areas where water is limited. Healthier soils also mean more resilient crops that can withstand periods of heat and drought. Moreover, regenerative practices support carbon sequestration, which can help counteract climate change, a significant factor contributing to the increasing frequency and intensity of droughts in the region.

Regenerative farming offers a pathway to sustainable agriculture in Karnataka, one that not only addresses the immediate challenges of drought and soil degradation but also builds long-term resilience. By embracing these practices, farmers in the state's most vulnerable districts can secure their livelihoods, protect their lands, and contribute to a more sustainable future for agriculture in Karnataka.

Methodology

In Karnataka, several districts are particularly vulnerable to the interconnected challenges of drought, soil degradation, and climate variability, making regenerative agriculture practices vital. Drought, soil degradation, temperature, and rainfall are interrelated parameters that significantly impact agriculture, particularly in regions like Karnataka.

Factors that affect soil degradation

Soil degradation is caused by many factors such as natural, human-induced, Biological, etc. Natural factors include climatic conditions (temperature and rainfall), topography, soil type, and natural disasters like floods, landslides, droughts, etc. Human-induced factors include Agricultural practices, deforestation, overgrazing, urbanization, pollution, mining activities, irrigation practices, etc. Biological factor includes loss of Biodiversity. We can consider these factors as the main parameters for studying soil degradation.

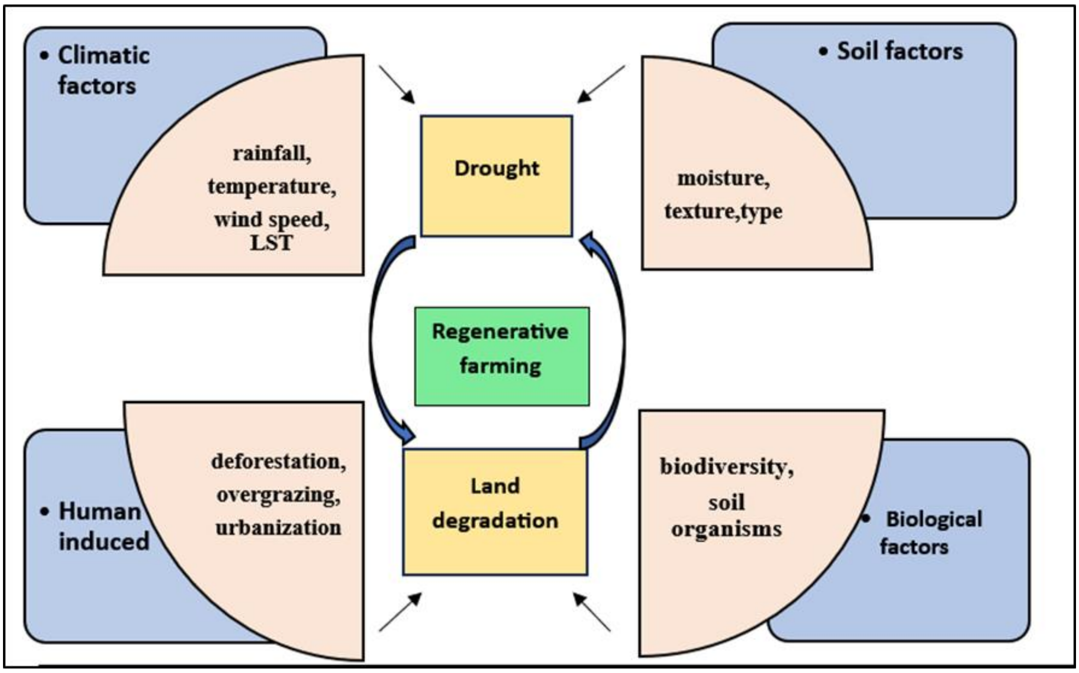


Fig 3: The causal linkage between climate change, soil, biological, human-induced factors, drought, and land degradation

Data Collection

To assess the parameters, we initially collected climatic data, including rainfall and temperature, from the national weather department, India Meteorological Department (IMD), the state disaster monitoring agency Karnataka State Natural Disaster Monitoring Centre (KSNDMC), and other official sources for the years 2013 to 2023. Additionally, spatial data on land degradation was obtained from ICAR-NBSS&LUP, Bangalore. The second step in the methodology is to draft a drought database. The next step involved creating a drought database. This database categorizes data by district, agricultural season, and soil degradation levels. It includes detailed, district-wise information on climatic conditions, Standardized Precipitation Index (SPI), and Soil Moisture Index (SMI) for each year.

Statistical Analysis

A review of literature on land degradation and drought severity reveals that factors such as temperature, rainfall, vegetation, soil type, soil texture, soil moisture, and water resources are crucial in influencing these conditions. To further understand their impact, the study incorporated remote sensing variables including the Standardized Precipitation Index (SPI), Land Surface Temperature (LST), Soil Moisture Index (SMI), and Normalized Difference Vegetation Index (NDVI). A correlation analysis was then conducted to examine the relationships among these risk factors.

SPI, LST, NDVI and SMI

The Standardized Precipitation Index (SPI) is a key indicator for tracking and quantifying drought severity. It measures deviations from normal precipitation over a specific period, ranging from -2 to +2. SPI values closer to -2 signals extreme drought, with -1 indicating moderate drought conditions. Conversely, values above +1 represent wetter-than-normal conditions, with +2 indicating unusually high precipitation. This index helps to identify the intensity and duration of droughts, as lower values directly correlate with increasingly severe water scarcity.

Land Surface Temperature (LST) measures the temperature at the Earth's surface and is valuable for detecting soil heat and dryness. It helps assess thermal patterns and moisture conditions in the land. This tool helps understand heat-related land degradation and drought, and it can complement soil moisture studies.

The Normalized Difference Vegetation Index (NDVI) measures vegetation moisture content and typically ranges from -1 to +1. Negative NDVI values (approaching -1) indicate deep water, while values near zero (-0.1 to 0.1) represent barren areas such as rock, sand, or snow. Values between 0.1 and 0.2 are generally associated with sandy terrain. Low positive values (0.2 to 0.4) indicate shrub lands and grasslands, while higher values signify dense vegetation, such as temperate and tropical rainforests (values closer to 1). In most cases, NDVI ranges from about -0.1 for sparsely vegetated areas to 0.6 for areas with lush vegetation. NDVI is useful for monitoring vegetation health and identifying regions experiencing moisture stress or drought. The combination of LST and NDVI would provide a comprehensive study of both temperature effects and vegetation conditions, offering an important understanding of land degradation and soil moisture dynamics.

Soil Moisture Index (SMI) indicates wetness or dryness of soil. SMI helps in assessing drought conditions by measuring soil moisture compared to normal levels. It typically ranges from -4.0 to +4.0.

- **SMI values between -2.0 and -4.0:** These values indicate low soil moisture. As the index approaches -4.0, the soil becomes increasingly dry, leading to arid conditions and intensifying water shortages. This range is typically associated with moderate to severe drought conditions.
- **SMI values between 0.0 and -2.0:** This range signifies mild dryness. Soil moisture is below average, but not critically low. These conditions may lead to early signs of crop stress or the need for water management interventions, though the situation is not yet severe.
- **SMI values between 0.0 and +2.0:** These values reflect optimal soil moisture conditions. The soil contains sufficient moisture to support healthy plant growth and agricultural activities, providing favorable conditions for crop productivity.
- **SMI values between +2.0 and +4.0:** As the index approaches +4.0, it indicates that the soil is saturated. This suggests the presence of excessive moisture, which can lead to waterlogging or flooding, potentially harming crops and causing soil degradation.

Results and Findings

Year-wise drought occurrence

From 2013 to 2023, the number of drought occurrences shows an increasing trend. The data highlights fluctuations in drought frequency, with the highest occurrences recorded in 2023 (21). Notable peaks occurred in 2016 and 2018, while 2021 saw the lowest number (4). Overall, the data indicates a general rise in drought events over the decade, suggesting intensifying drought conditions and the need for enhanced management strategies. Table 1 and Figure 4 show Year-wise drought occurrence.

Table 1: Year-wise drought occurrence (2013-2023)

Year	Drought Occurrence
2013	5
2014	6
2015	11
2016	17
2017	9
2018	20
2019	12
2020	7
2021	4
2022	8
2023	21
Total	120

District-wise drought occurrence

The data on drought occurrences across various districts reveals that Yadgir experienced the highest number of droughts, with 16 occurrences. Bidar, Chitradurga, and Vijayapura each reported 15 droughts. Other districts with significant drought occurrences include Koppala (13), Ballari and Raichur (12 each), and Bagalkote and Kalaburagi (11 each). In total, there were 120 reported drought occurrences across these districts. Table 2 and Figure 5 show District-wise drought occurrence.

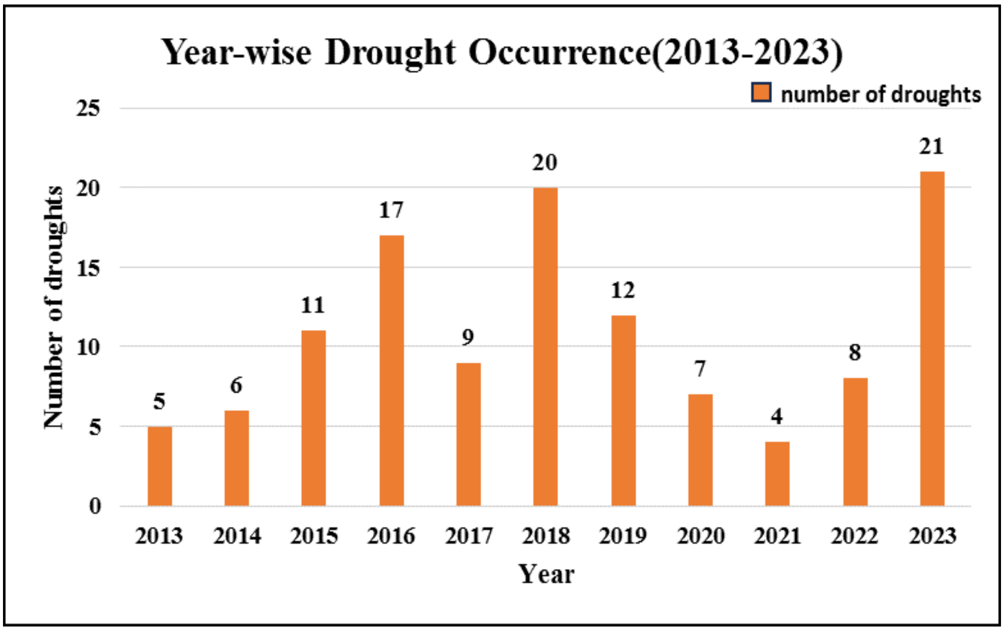


Fig 4: Year-wise drought occurrence

Table 2: District-wise drought occurrence (2013-2023)

District	Drought Occurrence
Bagalkote	11
Ballari	12
Bidar	15
Chitradurga	15
Kalaburagi	11
Koppala	13
Raichur	12
Vijayapura	15
Yadgir	16
Total	120

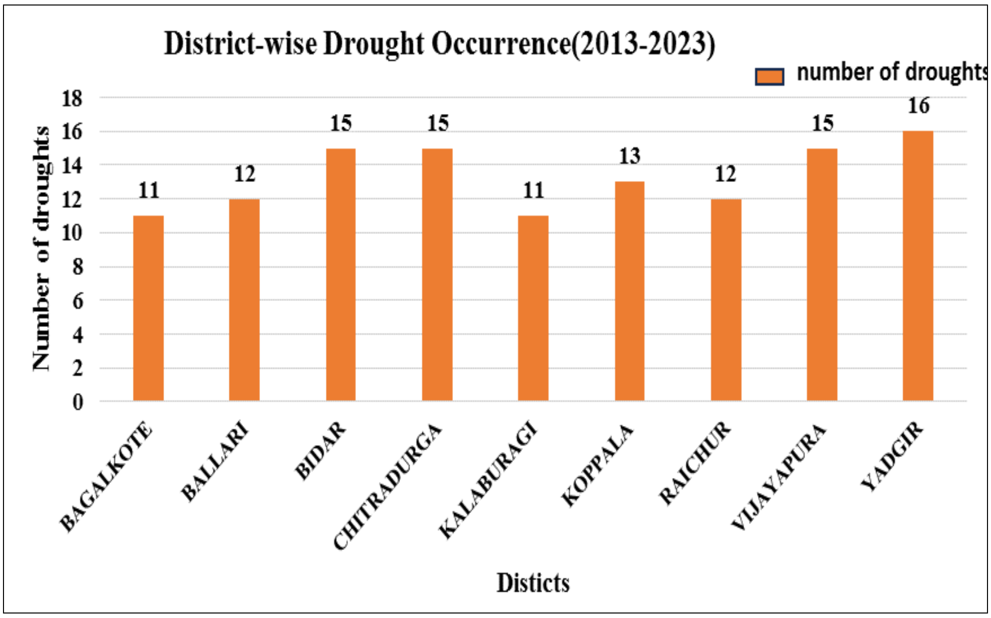


Fig 5: District-wise drought occurrence

Season-wise drought occurrence

In Karnataka district, season-wise drought occurrence varies based on climatic patterns. Among the three agricultural seasons Kharif (June to September), Rabi (October to February), and Zaid (March to May), drought conditions were less frequently observed during the Kharif season. In Bagalkote, Ballari, and Yadgir districts there is a severe drought in the Rabi season, followed by the Ballari district. Also, it may be noted that Chitradurga, Koppala, Raichur, Vijayapur, and Yadgir reported consistent drought occurrence in the Rabi and Zaid seasons. In Ballari, drought occurrences were the same in all three seasons. Table 3 and Figure 6 show Season-wise drought occurrence.

Table 3: Season-wise drought occurrence

District	Kharif	Rabi	Zaid	Total
Bagalkote	3	6	2	11
Ballari	3	6	3	12
Bidar	5	5	5	15
Chitradurga	5	4	6	15
Kalaburagi	3	4	4	11
Koppala	4	4	5	13
Raichur	3	4	5	12
Vijayapura	4	5	6	15
Yadgir	4	6	6	16
Total	34	44	42	120

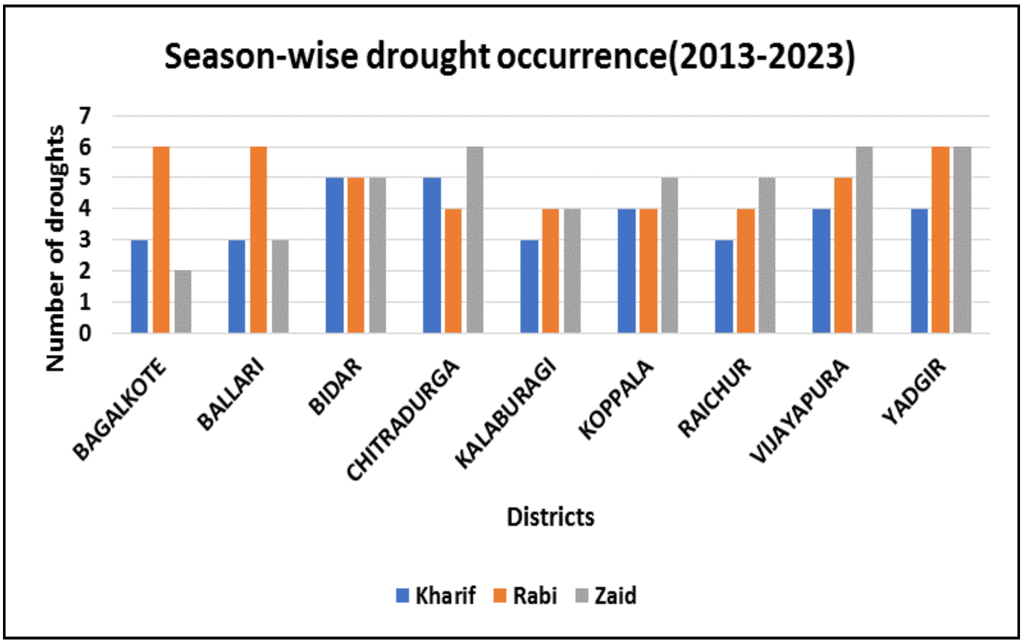


Fig 6: Season-wise drought occurrence

Year-wise Seasonal drought occurrence

In Karnataka district, the highest number of droughts occurred in the year 2018 and 2023, in Karif and Rabi seasons. In 2017, 2020, 2021, and 2022 there is a significant decrease in drought occurrence in Karif and Rabi seasons. Also, there were no drought occurrences in the Karif season during the year 2013, 2020, and 2022. Table 4 and Figure 7 show Season-wise drought occurrence.

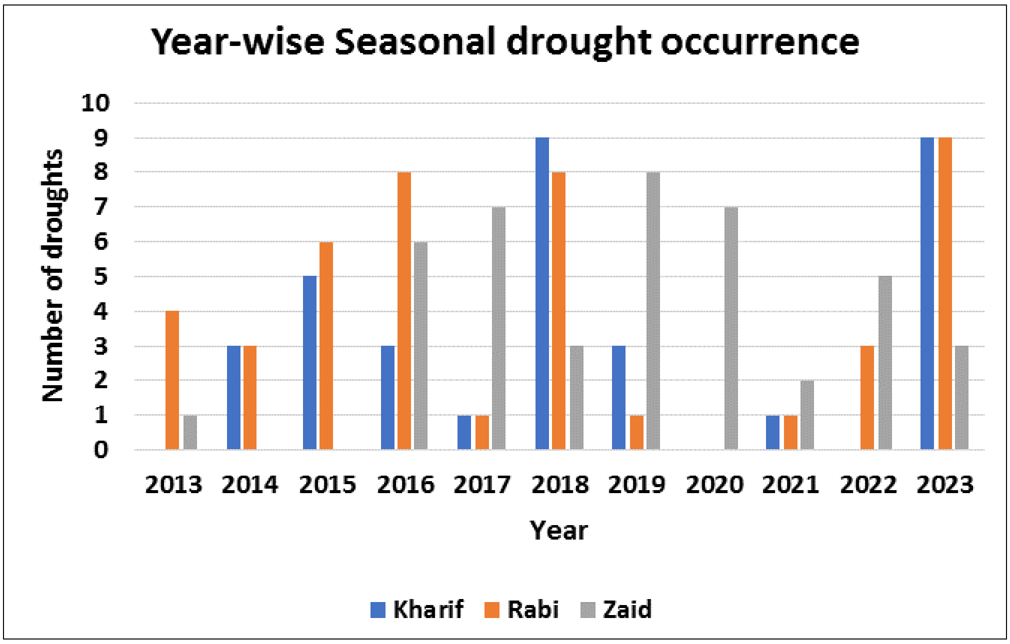


Fig 7: Year-wise Seasonal drought occurrence

Table 4: Year-wise Seasonal drought occurrence (2013-2023)

Year	Kharif	Rabi	Zaid	Total
2013	0	4	1	5
2014	3	3	0	3
2015	5	6	0	11
2016	3	8	6	17
2017	1	1	7	9
2018	9	8	3	20
2019	3	1	8	12
2020	0	0	7	7
2021	1	1	2	4
2022	0	3	5	8
2023	9	9	3	21
Total	34	44	42	120

Soil Moisture Index and Drought

The Soil Moisture Index (SMI) and drought occurrences across districts show varying moisture conditions and their impact. Districts with higher SMI values, such as Bagalkote, Bidar, Chitradurga, and Koppala (ranging from 0.47 to 0.48), experienced 11 to 15 drought occurrences. In contrast, districts with lower SMI values, including Ballari and Vijayapura (0.25) and Yadgir and Kalaburagi (0.26), had 12 to 16 drought occurrences. This indicates that lower soil moisture levels are associated with more frequent drought events. Overall, the data, totalling 120 drought occurrences, highlights the relationship between soil moisture and drought frequency. Table 5 and Figure 8 shows Season-wise drought occurrence

Table 5: District-wise SMI and drought occurrence

District	Smi	Droughts
Bagalkote	0.48	11
Ballari	0.25	12
Bidar	0.47	15
Chitradurga	0.48	15
Kalaburagi	0.26	11
Koppala	0.47	13
Raichur	0.27	12
Vijayapura	0.25	15
Yadgir	0.26	16
Total		120

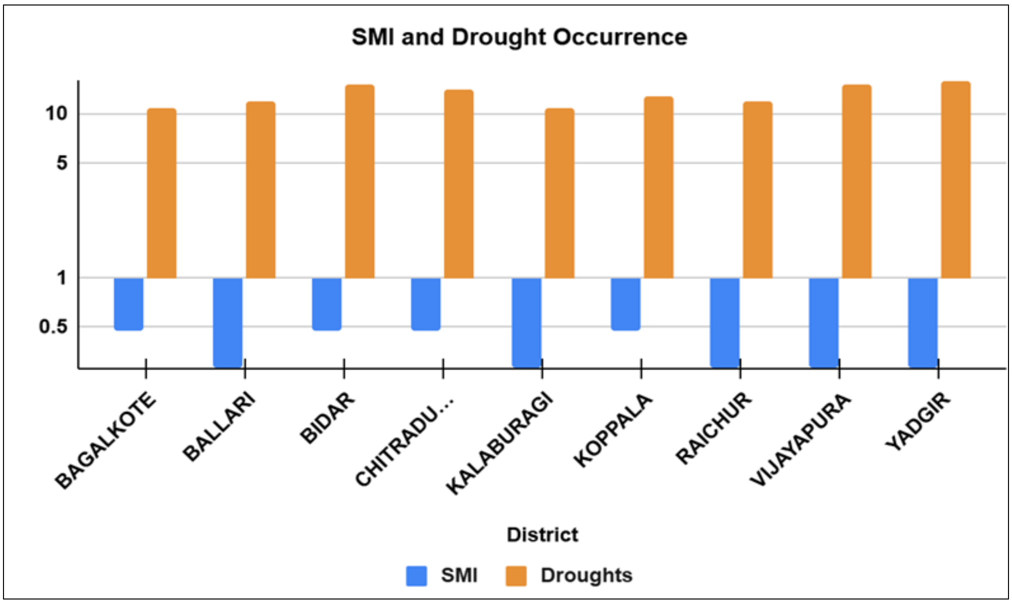


Fig 8: District-wise SMI and drought occurrence

The Correlation analysis

The variables amount of rainfall, temperature, NDVI, LST, and SPI were assessed for their contribution to the occurrence of drought. The correlation study was based on the district-wise average values of the variables. The results are shown in the correlation matrix below. Refer to Table 6 for detailed numerical values.

Table 6: Correlation matrix showing the relationship between Rainfall, Temperature, NDVI, SPI, LST, and Drought occurrence

Variable	Correlation Coefficient	P-Value
Rainfall	-0.8295	0.002*
Temperature	0.5778	0.070+
NDVI	-0.3812	0.252
SPI	-0.9101	<0.001**
LST	0.440	0.041*

**significant at 1%, *significant at 5% and +significant at 10%

Results

- **Rainfall**: Strong negative correlation with drought (r = -0.8295, P=0.002), meaning less rainfall is associated with more severe drought.
- **Temperature**: Moderate positive correlation (r = 0.5778, P=0.070), indicating higher temperatures might contribute to drought conditions.
- **SPI**: Strong negative correlation (r = -0.9101, $p<0.001$), meaning lower SPI values (indicating drier conditions) are strongly linked to drought.
- **LST**: Slightly positive correlation (r = 0.440, P=0.041), indicating higher temperatures might contribute to drought conditions.
- **NDVI**: Moderate negative correlation (r = -0.3812, P=0.252), meaning reduced vegetation (lower NDVI) tends to occur during drought, but this is not statistically significant.

In summary, Rainfall and SPI have the strongest negative correlations with drought, indicating that lower rainfall and more negative SPI values are strongly associated with drought. Temperature shows a moderate positive correlation with drought, suggesting that higher temperatures may exacerbate drought conditions. NDVI shows weaker relationships with drought, with NDVI displaying a moderate but non-significant negative correlation.

Conclusion

The drought-hit districts of Karnataka face a multifaceted web of challenges, including rising temperatures and erratic rainfall patterns to severe soil degradation. Analyzing the interrelationships among rainfall, temperature, land surface temperature (LST), normalized difference vegetation index (NDVI), soil moisture index (SMI), standardized precipitation index (SPI), and drought occurrences offers valuable insights into agricultural productivity. Variations in temperature and rainfall patterns significantly influence LST, which in turn affects soil moisture levels and vegetation health, as reflected by the SMI and NDVI, respectively. By studying the SMI, NDVI, SPI, and the frequency of droughts across selected districts of Karnataka, one can effectively assess trends in land degradation and their potential impact on agriculture. Accurate monitoring of these parameters is crucial for understanding and addressing land degradation. However, adopting regenerative farming practices can effectively address these challenges. Regenerative farming not only revitalizes the health of the soil but also strengthens the resilience of the agricultural system, providing a sustainable answer to the environmental challenges facing Karnataka's farming community. As more farmers adopt this approach, the future of agriculture in Karnataka's drought-prone regions looks more promising and sustainable.

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