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Mitigating flood risks through regenerative farming: Addressing soil degradation and enhancing resilience in flood-prone regions of Karnataka

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Abstract
India faces a significant challenge with 30% of its land affected by soil degradation, which has reduced water retention capacity by 60%, increasing flood risks. India is the second most flood-affected country, trailing behind Bangladesh. Over the past two decades, Karnataka has been subjected to severe flooding. Keeping the above in view, the districts of Bagalkot, Uttara Kannada, Kodagu, Dakshina Kannada, and Belagavi, in Karnataka were chosen for this study due to their frequent flooding and varied landscapes, from coastal plains to hilly regions, making them vulnerable to both soil degradation and floods. Kodagu, for instance experienced eight major flood events between 2015 and 2023 (KSNDMC, 2023). This study investigates the relationship between soil health (nitrogen, phosphorus, potassium, pH, and texture) and flood severity, along with NDVI and proximity to rivers. Statistical analysis, including correlation analysis and multiple linear regression, reveals that proximity to rivers and NDVI are significant predictors of flood frequency. The findings underscore the potential of regenerative farming to improve soil health and reduce flood risks enhancing water retention by up to 40%. These insights provide a framework for sustainable land management in Karnataka's flood-prone regions.

Keywords: Soil degradation, regenerative farming, flood risks, NDVI, Karnataka, India

Introduction

Flooding and Soil degradation are two of the most significant environmental challenges, especially in regions prone to heavy rainfall and recurrent floods. Degraded soils, often a result of unsustainable land use practices, lose their capacity to absorb and retain water, leading to increased surface runoff and elevated flood risks. At the same time floods make soil degradation worse by washing away the top layer of soil, causing water to build up, and adding harmful sediments and pollutants to the soil. This ongoing cycle of soil damage and flooding creates serious problems for farming and the environment.

Flooding is a big problem in India, affecting millions of people and causing significant damage every year. Karnataka, a state in southern India, is especially prone to flooding due to its varied landscape and climate. The type of soil in an area plays a crucial role in determining how flood happens. Soil characteristics like nutrient levels, texture, and depth affect how quickly water is absorbed, while forests and land use patterns impact how much water runs off. Therefore, understanding the detailed relationships between soil properties and flood dynamics is vital for developing effective flood management and land use strategies that mitigate the risks associated with flooding in Karnataka.

Earlier studies looked at how soil properties affect flood risks in different areas. For example, research in the US found that soil texture and organic matter content can increase flood risk (Wang *et al.*, 2012) [1]. In Australia, studies found connections between soil pH, nutrient levels, and how often floods happen. In the Ganges River basin, soil texture and land use patterns were key to managing flood risk. However, more research is needed to understand how soil degradation affects flooding in specific regions like Karnataka, where the local environment may require special solutions.

Regenerative farming tackles soil degradation and flooding by restoring soil health and resilience. Practices like composting, crop rotation and agroforestry enhance soil structure, reduce erosion and boost water retention. This improves agricultural productivity and mitigates flood risks by reducing runoff and increasing infiltration. Regenerating farming offers a comprehensive solution to these interconnected issues, promoting long-term environmental sustainability.
Research has extensively explored the soil health-flood risk connection, yet the interactions between specific soil properties and flood dynamics in Karnataka's diverse agroclimatic regions remain poorly understood. This study bridges this knowledge gap by investigating how nitrogen, phosphorus, potassium, pH, vegetation cover (NDVI), and proximity to rivers influence flood frequency and severity across five flood-prone districts in Karnataka. The findings will inform sustainable land management strategies and support policymakers and land managers in mitigating flood risks.

Objectives

The primary objectives of this study are:

- To analyse the relationship between soil properties (nitrogen, phosphorus, potassium, pH, and texture) and flood frequency and severity.
- To investigate the role of NDVI and proximity to rivers in influencing flood risks.
- To evaluate the potential of regenerating farming practices to mitigate flood risks by improving soil health.

This study is important because it helps us understand how soil health affects flood risks in areas prone to flooding. The findings can guide policymakers and stakeholders in adopting regenerative farming practices that:

- Improve soil health
- Reduce runoff and erosion
- Decrease flood frequency and severity

This research contributes to the growing understanding of sustainable agriculture and flood management in India's flood-prone regions, informing better decision-making and policy development.

Methodology

Study Area

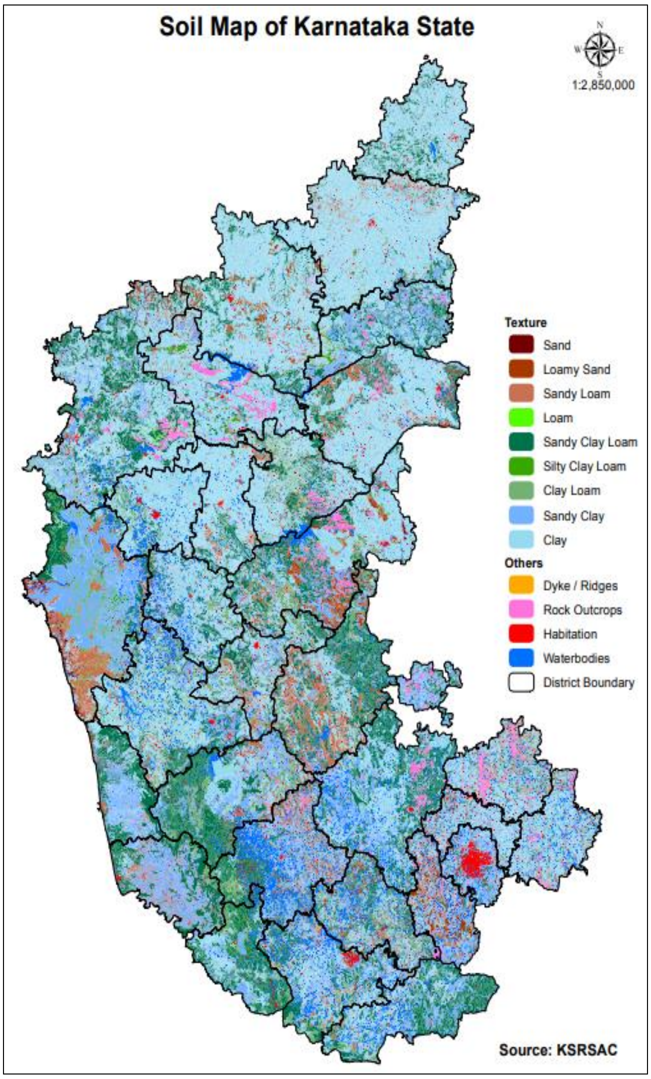
This study focuses on five districts in Karnataka- Bagalkot, Dakshin Kannada, Uttara Kannada, Kodagu, and Belagavi- which has been identified as highly susceptible to both soil degradation and recurrent flooding. The districts are geographically diverse, encompassing coastal regions, hill terrains, and plains, providing a robust dataset for analysing the interactions between soil properties and flood risks.

Data collection

The data for this study were gathered from various reliable sources between 2015 and 2023, covering the following parameters:

Soil Properties

Nitrogen (N), Phosphorus (P), Potassium (K), Soil pH, Soil Texture, and Soil Depth (cm) were collected from soil health cards and survey reports provided by the Karnataka State Department of Agriculture. These reports document annual soil testing and nutrient analysis carried out across different districts of Karnataka. Figure1 below shows the soil map of Karnataka state, Karnataka state remote sensing applications centre.



Source: KSRSAC) which shows soil texture for different districts of Karnataka.

Fig 1: Soil map of Karnataka (source-KSRSAC)

Land Use and Land Cover

The Normalized Difference Vegetation Index (NDVI) was derived from satellite imagery provided by the National Remote Sensing Centre (NRSC), Hyderabad, using data from Landsat and sentinel satellites. Land use data, classified into agricultural, forested, and built-up areas, were sourced from the Bhuvan Geoportal maintained by ISRO Indian Space Research Organisation, which provides geospatial data and mapping services for India.

Flood Data

Information on the frequency and severity of floods was obtained from the Karnataka State Natural Disaster Monitoring Centre (KSNDMC). Flood severity was recorded on a scale of 1 (low severity) to 5 (high severity), based on damage assessments reported in annual disaster managements reports.

Proximity to Rivers

Proximity to major rivers in each district was measured using Geographic Information System (GIS) tools, with spatial data sourced from the Survey of India (SoI) topographic maps and Karnataka Water Resources Department. GIS mapping was used to calculate the distance (in kilometers) from the major rivers to flood-prone areas in each district.

This comprehensive data set provides a strong foundation for analysing the relationship between soil properties, land use, and flood dynamics across Karnataka's diverse agroclimatic zones.

Statistical Analysis

The soil characteristics along with flood frequency has been classified and has been tabulated. Table 1 provides a detailed overview of soil health across different districts from 2015 to 2023, focusing on the availability of three key nutrients Nitrogen, Phosphorus, and Potassium along with soil pH status and soil types. It highlights the availability of three essential nutrients Nitrogen, Phosphorus, and Potassium categorizing them as either "Sufficient" or "Deficient" in each district. Additionally, it indicates whether the soil is acidic or alkaline and specifies the soil type, such as sandy, loamy, or clay. This information is essential for understanding the agricultural potential and needs of each district. Soil nutrient levels and pH status significantly affect crop growth and health, influencing decisions on fertilizer application, crop selection, and soil management practices. For instance, knowing that a district has acidic soil with deficient potassium can guide farmers to apply appropriate lime and potassium fertilizers to enhance soil fertility. The data presented in the table has been sourced from soil analysis reports and agricultural surveys conducted in the respective districts between 2015 and 2023.

Table 1: District showing soil nutrients, soil type and soil pH level for different district (2015-2023)

Districts	Nitrogen	Phosphorus	Potassium	Soil pH status	Soil type
Bagalkot	Deficient	Deficient	Sufficient	Alkaline	Sandy
Dakshina Kannada	Sufficient	Sufficient	Deficient	Acidic	Loamy
Uttara Kannada	Deficient	Deficient	Sufficient	Acidic	Clay
Kodagu	Sufficient	Sufficient	Deficient	Acidic	Loamy
Belagavi	Sufficient	Sufficient	Sufficient	Alkaline	sandy

Result and discussion

The soil data across five districts shows varying levels of Nitrogen (N), Phosphorus (P), and Potassium (K), alongside differences in soil pH and types, all of which have implications for soil degradation and flood severity. Nitrogen is deficient in Bagalkot and Uttara Kannada, falling below the sufficient threshold of 40 kg/ha, indicating degraded soil health that may contribute to increased flood risk due to poor plant cover and weak soil structure. In contrast, Dakshina Kannada, Kodagu, and Belagavi have sufficient nitrogen levels, promoting healthier soil. Phosphorus is deficient in Bagalkot and Uttara Kannada, where it falls below 22 kg/ha, further contributing to soil degradation and making these areas more prone to erosion and flooding. Potassium is sufficient in Bagalkot, Uttara Kannada, and Belagavi (above 110 kg/ha) but deficient in Dakshina Kannada and Kodagu, where soil fertility is compromised.

The soil pH ranges from acidic in Dakshina Kannada (pH 5.5), Uttara Kannada (pH 6.0), and Kodagu (pH 5.8) to alkaline in Bagalkot (pH 8.0) and Belagavi (pH 8.1). Acidic soils can reduce nutrient availability, further accelerating soil degradation. The soil types, with sandy soils in Bagalkot and Belagavi, loamy soils in Dakshina Kannada and Kodagu, and clay soils in Uttara Kannada, influence water retention and soil stability. Sandy soils, which are more prone to erosion and poor water retention, increase flood severity. Flood severity is likely higher in districts with nutrient-deficient, sandy soils and degraded vegetation. Regenerative farming practices, such as crop rotation, cover cropping, and no-till farming, can help restore soil health, improve nutrient content, and enhance water retention. By promoting healthy soil structure and improving nutrient cycles, regenerative farming can mitigate the impacts of floods and reduce soil degradation, creating more resilient ecosystems in flood-prone areas like Bagalkot and Uttara Kannada.

By integrating regenerative farming practices, these regions can address both soil degradation and flood severity, improving long-term agricultural productivity and environmental sustainability.

Table 2 provides a statistical analysis of the relationship between various environmental variables and two flood-related factors: Flood Frequency and Flood Severity. The table reports the Pearson's correlation coefficient (r), which measures the strength and direction of the linear relationship between the variables, and the p-value, which indicates the statistical significance of these relationships.

The variables analysed encompass nutrient levels (Nitrogen, Phosphorus, Potassium), soil properties types of soil, soil pH, soil texture, soil depth, land characteristics, presence of forest, land use, land cover, proximity to rivers, and NDVI (Normalized Difference Vegetation Index).

Table 2: Correlation and Significance of Environmental Variables with Flood Frequency and Severity

Variables	Pearson's r with flood frequency	P-value with flood frequency	Pearson's r with flood severity	P-value with flood severity
Nitrogen	0.162	0.287	0.201	0.184
Phosphorus	0.003	0.987	-0.004	0.981
Potassium	-0.065	0.673	0.002**	0.99
Types of Soil	0.312	0.037*	0.43	0.003**
Soil pH Level	-0.219	0.148	-0.375	0.011*
Soil Texture	-0.081	0.597	-0.097	0.528
Soil Depth (cm)	0.02	0.895	0.029*	0.848
Presence of Forest	0.397	0.007**	0.541	0.001**
Land Use	0.268	0.075	0.266	0.078
Land Cover	0.289	0.054	0.402	0.006**
Distance from River	-0.482	0.001**	-0.553	0.001**
NDVI	0.383	0.009**	0.551	0.001**
Frequency of Floods	-	-	0.915	0.001**

**significant at 1%, *significant at 5%

Results and Discussion

The analysis reveals key factors influencing both flood frequency and severity. Positive correlations with flood frequency include soil type (r = 0.312, P=0.037) and the presence of forests (r = 0.397, P=0.007), indicating that certain soil types and forested areas are more prone to frequent floods. Distance from rivers shows a strong negative correlation (r = -0.482, P=0.001), suggesting that areas closer to rivers experience more frequent floods.

For flood severity, positive correlations are found with soil type (r = 0.430, P=0.003), presence of forests (r = 0.541, p<0.001), and NDVI (vegetation cover) (r = 0.551, p<0.001), indicating that these factors contribute to more intense floods. On the other hand, soil pH shows a negative correlation (r = -0.375, P=0.011), meaning that more acidic soils are linked to less severe flooding.

The data reveals that forested areas and regions close to rivers are more susceptible to both frequent and severe flooding. Additionally, soil type and higher vegetation cover play a significant role in flood dynamics. A strong positive correlation (r = 0.915, p<0.001) between flood frequency and severity highlights that regions with frequent floods are also at risk for more severe flooding.

These findings suggest that flood management strategies should focus on tailored land-use planning, forest management, and soil conservation efforts in flood-prone areas.

The analysis was initiated using data obtained from the Karnataka State Natural Disaster Monitoring Centre (KSNDMC), Bangalore. The flood frequency for each year was determined with the help of daily recorded rainfall data for all districts over the years. The recorded rainfall patterns were analysed to assess the number of floods occurring annually, leading to the formation of this table. To convert daily recorded rainfall data into a flood frequency table, the process involves several key steps. First, daily rainfall data for each year is collected from sources like KSNDMC. Then, a rainfall threshold is established, which defines a flood event-typically based on historical patterns or meteorological guidelines (e.g., when rainfall exceeds a specific amount that causes flooding).

Next, the daily data is analysed to identify days where rainfall surpasses this threshold, marking potential flood days. These days are then grouped into distinct flood events, as continuous days of heavy rainfall may be considered a single flood, while separate events are determined by breaks in rainfall. The number of distinct flood events in each year is counted to provide the flood frequency.

Finally, these counts are summarized into a table showing the total number of floods that occurred in each year, compressing the detailed daily data into a clear annual flood frequency summary.

Table 3 provides an overview of the flood frequency in the Bagalkot district from the year 2015 to 2023. It lists the number of floods that occurred each year during this period. To further illustrate this data, a pie chart is used to show the proportion of floods for each year in relation to the total number of floods over the 9-year period. Each slice of the pie chart represents the percentage of total flood events that occurred in a specific year. For example, 2019, having the highest number of floods, takes up the largest portion of the chart, accounting for approximately 21% of the total floods. In contrast, 2016 and 2021, with only 1 flood each, take up the smallest slices, representing about 4% each of the total. This pie chart provides a visual representation of flood frequency distribution, across different years.

Table 3: Flood frequency distribution in Bagalkot (2015-2023)

Year	Flood frequency
2015	2
2016	1
2017	3
2018	4
2019	5
2020	3
2021	1
2022	2
2023	3

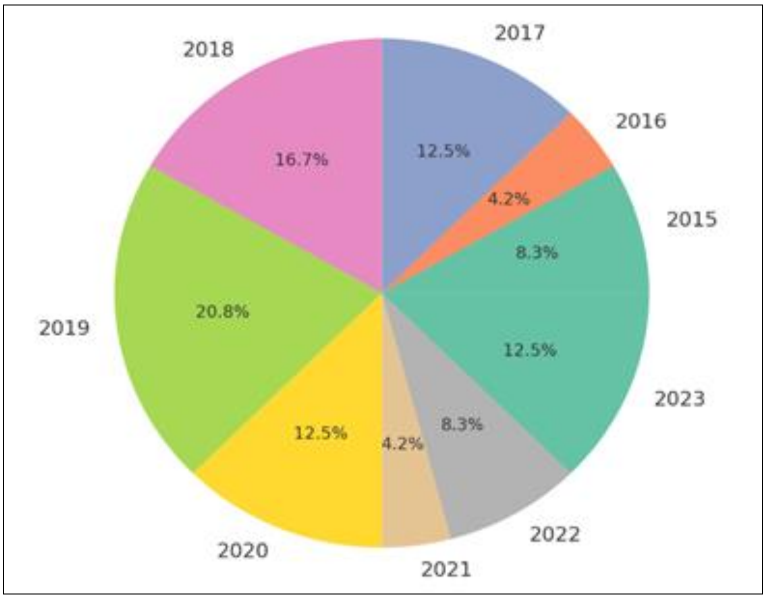


Fig 2: Flood frequency distribution in Bagalkot (2015-2023)

Table 4 presents the flood frequency for the Dakshina Kannada district over a period of nine years, from 2015 to 2023. During this period, the district experienced a range of 3 to 5 floods per year. The data indicates that the highest number of floods (5) occurred in 2017, 2018, and 2022, while the lowest number of floods (3) were recorded in 2015, 2019, and 2021. The flood frequency in other years, such as 2016, 2020, and 2023, was moderate, with 4 flood events each.

Table 4: Flood frequency distribution in Dakshin Kannada (2015-2023)

Year	Frequency of Floods
2015	3
2016	4
2017	5
2018	5
2019	3
2020	4
2021	3
2022	5
2023	4

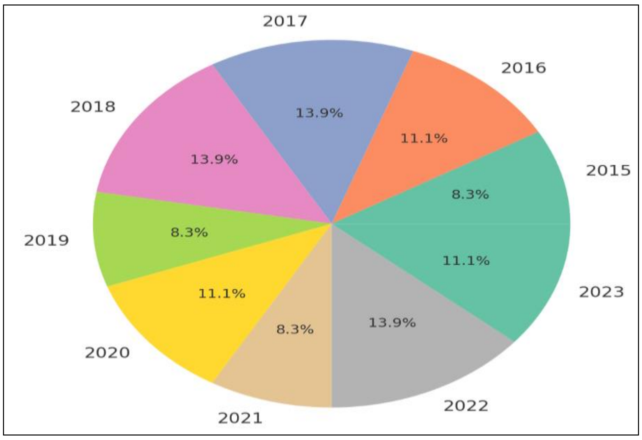


Fig 3: Flood frequency distribution in Dakshina Kannada (2015-2023)

Table 5 presents the flood frequency in Kodagu district from 2015 to 2023, showing the number of flood events each year. Kodagu experienced a fluctuating number of floods over this period, with the highest flood occurrences (5 floods) in 2018, 2019, and 2023. The district had a moderate number of 4 floods in 2020 and 2022, and 3 floods in 2015, 2017, and 2021. The lowest flood frequency was 2 floods in 2016. This data highlights a consistent occurrence of floods in Kodagu, with some years experiencing higher flood activity than others.

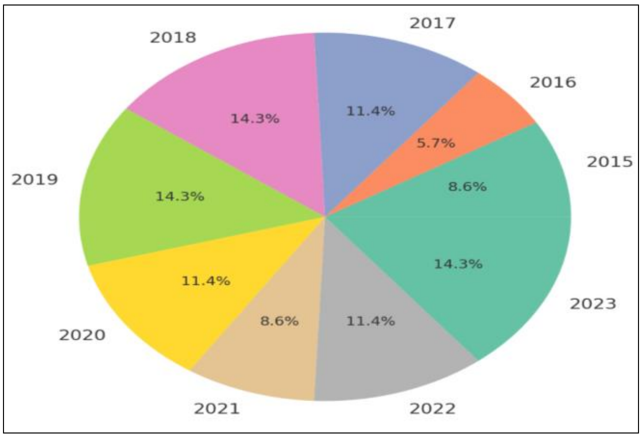


Fig 4: Flood frequency distribution in Kondaku (2015-2023)

Table 5: Flood frequency distribution in Kodagu (2015-2023)

Year	Flood frequency
2015	3
2016	2
2017	3
2018	5
2019	5
2020	4
2021	3
2022	4
2023	5

The flood frequency data for Uttara Kannada district given in Table 6 reveals a varying trend over the years, with some years experiencing more frequent floods than others. The years 2015, 2016, 2019, 2021, and 2023 recorded a higher number of floods, with 4-5 instances each, indicating a potential increase in rainfall intensity, storm surges, or other factors contributing to flooding. In contrast, the years 2017 and 2020 experienced a relatively calm period with only 2 floods each. The years 2018 and 2022 fell in the moderate category with 3 floods each.

Table 6: Flood frequency distribution in Uttara Kannada (2015-2023)

Year	Flood frequency
2015	4
2016	4
2017	2
2018	3
2019	5
2020	2
2021	4
2022	3
2023	4

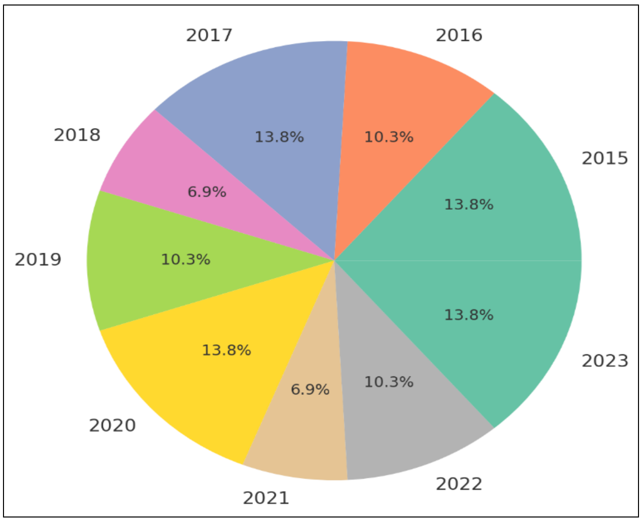


Fig 5: Flood frequency distribution in Uttara Kannada (2015-2023)

The flood frequency data for Belagavi district in Table 6 shows a fluctuating trend over the years. In 2015, the district experienced a relatively calm year with only 1 flood, followed by a slight increase to 2 floods in 2016. However, the flood frequency spiked to 4 instances in 2017, indicating a significant increase in rainfall intensity or other contributing factors. The years 2018 and 2020 experienced a relatively moderate flood frequency with 2 instances each. In contrast, the years 2019 and 2022 recorded a higher number of floods, with 4 instances each, suggesting a potential increase in flood risk. The years 2021 and 2023 fell in the moderate category with 3 floods each.

Table 7: Flood frequency distribution in Belagavi (2015-2023

Year	Flood frequency
2015	1
2016	2
2017	4
2018	2
2019	4
2020	2
2021	3
2022	4
2023	3

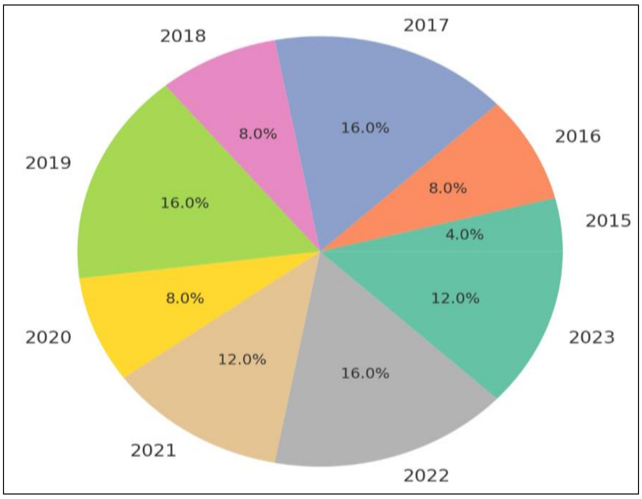


Fig 6: Flood frequency distribution in Belagavi (2015-2023

Results and Discussion

The observed flood patterns across the districts of Karnataka can be closely linked with soil degradation, which further exacerbates flood risks. In districts like Bagalkot and Belagavi, where urbanization and changes in land use are prevalent, increased flooding in recent years could be associated with the degradation of soil quality. Urban expansion, deforestation, and intensive agricultural practices contribute to soil compaction, reduced infiltration, and loss of organic matter, making the soil less capable of absorbing excess water. This leads to more surface runoff, thereby increasing the likelihood of floods.

In Kodagu and Uttara Kannada, which are known for their hilly terrain and dense forests, the relationship between soil degradation and flood frequency becomes more evident. Deforestation and the removal of vegetation for agricultural or commercial purposes lead to soil erosion, landslides, and loss of fertile topsoil. The degraded soil, with its reduced water-holding capacity, exacerbates flood intensity and frequency, as observed in these districts during the monsoon seasons. The steep slopes and fragile soil structure in these regions, combined with heavy rainfall, contribute to rapid runoff, further eroding the soil and increasing the severity of floods.

Dakshina Kannada, with its coastal location, also exhibits a link between soil degradation and flood occurrences. Over-extraction of groundwater, coastal erosion, and changes in land cover degrade the soil's structure and fertility, reducing its ability to manage floodwaters. The decline in vegetation cover (NDVI), which is seen in some years, corresponds with an increase in flood severity, highlighting the critical role that vegetation plays in maintaining soil health and mitigating floods.

In conclusion, the increasing flood frequency and severity across these districts can be strongly linked to ongoing soil degradation, driven by deforestation, unsustainable agricultural practices, and urbanization. Degraded soils lose their ability to absorb and retain water, resulting in higher surface runoff and more severe floods. Addressing soil degradation through regenerative farming practices, reforestation, and sustainable land management will be key to mitigating flood risks and restoring soil health in these regions. By improving soil structure and organic matter content, these regions can enhance water infiltration and retention, reducing the impact of future floods.

Conclusion

In conclusion, this analysis reveals that districts like Dakshina Kannada, Kodagu, and Uttara Kannada are more prone to frequent and severe floods due to factors like denser vegetation, proximity to rivers, and specific soil properties. The positive correlation between NDVI and flood frequency/severity highlights the importance of considering vegetation cover in flood risk assessments. To mitigate the effects of soil degradation caused by frequent flooding, regenerative farming practices such as agroforestry and conservation tillage are essential. By adopting localized flood management strategies and promoting regenerative farming, vulnerable districts can enhance resilience, promote sustainable land use, and protect agricultural productivity. Ultimately, this integrated approach will help build a more sustainable and flood-resilient future for these regions.

Future research directions

Future research directions should focus on understanding the long-term effects of regenerative farming on reducing flood risks and improving soil health, particularly in the context of climate change and its impact on flood patterns. Developing advanced hydrological models that incorporate variables like topography, vegetation, and soil properties will help simulate future flood scenarios.

Further studies should also explore soil erosion, nutrient loss, and the use of remote sensing and GIS for real-time monitoring of flood risks. Research into urbanization, land use changes, and the socioeconomic impacts of soil degradation and flooding will provide valuable insights for policy-making. Finally, the development of adaptive land management strategies and linking biodiversity with flood resilience will enhance sustainable agricultural practices and flood risk mitigation.

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