# Drought Risk Assessment in the Yerla River Basin of India using Remote Sensing and GIS Methods

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***Abstract***
*This study provides a comprehensive evaluation of agricultural drought in the Yerla River Basin of India, leveraging satellite-based remote sensing data and advanced drought indices. Key metrics, including the Normalized Difference Vegetation Index (NDVI), Normalized Difference Water Index (NDWI), Vegetation Condition Index (VCI), Moisture Stress Index (MSI), Enhanced Vegetation Index (EVI) and Soil-Adjusted Vegetation Index (SAVI), were employed to assess drought severity over a 30-years period (1994–2023). Findings indicate that the northern and central regions of the basin are particularly vulnerable, with over 80% of the area experiencing moderate to severe drought conditions.*

*A Weighted Overlay Analysis classified the basin into five drought risk zones: normal, mild, moderate, severe and extreme. The study underscores the critical role of remote sensing in identifying drought-prone areas and supporting evidence-based water resource management. It calls for targeted mitigation measures such as improved water management practices, adoption of drought-resistant crops and sustainable agricultural strategies to enhance resilience against future droughts.*

**Keywords:** Agricultural Drought, Remote Sensing, NDVI, NDWI, Yerla River Basin.

## Introduction
Agricultural drought occurs when there is insufficient soil moisture and rainfall during critical growing periods, resulting in stress on crops, reduced productivity and significant economic losses. It is a complex phenomenon that can severely impact on food security, agricultural livelihoods and regional economies. Traditional methods of drought monitoring such as ground-based measurements, often face limitations due to their restricted spatial coverage, high costs, delays in data collection and reporting. These challenges make it harder to make quick decisions and handle droughts effectively.

In contrast, remote sensing technologies provide a powerful tool for overcoming these limitations by offering consistent, real-time data that can be used to monitor large areas over time. Remote sensing allows for continuous and spatially comprehensive assessments of various drought indicators such as vegetation health, water availability and soil moisture. By integrating spectral indices derived from satellite imagery, remote sensing provides a robust framework for assessing the severity and progression of drought conditions, offering valuable insights for early warning systems and resource management. Crespo et al[3] gave systematic reviews on satellite remote sensing tools for drought assessment. Das et al[4] used remote sensing indices for drought monitoring in the north-western Bangladesh from 1990-2020 time series Landsat data. Bashit et al[1] also used GIS and remote sensing techniques for drought assessment using remote sensing based drought indices for Klaten regency, Indonesia. Ngangom et al[13] used three sectoral indices NDVI, NDSI and NDWI for assessment of drought in the Great Rann of Kachchh and adjoining areas of Thar desert.

The Yerla river basin in Maharashtra, India, is a semi-arid region that is highly susceptible to recurring droughts, particularly during the dry seasons (Figure 1). These droughts significantly affect the agricultural productivity of the basin, as it is heavily reliant on rain-fed agriculture and limited irrigation resources. The region's vulnerability to drought is exacerbated by its geographical location in the rain-shadow zone which results in uneven rainfall distribution and frequent water shortages. Given the increasing frequency and intensity of drought events in this region, it is crucial to adopt more effective and timely methods for drought monitoring and risk assessment.

This study aims to utilize satellite-based indices such as NDVI, NDWI, EVI, MSI and SAVI, to assess the severity, spatiotemporal variability and impacts of drought in the Yerla river basin (Table 2 and graph 1). By integrating remote sensing data with geographic information system (GIS) tools, this study aims to develop a comprehensive understanding of the drought conditions in the study area. The aim is to offer practical insights to improve drought resilience and guide sustainable water management, farming practices and policies to reduce the negative impacts of drought in the region.

## Study Area
The Yerla river, a key tributary of the Krishna river, originates in the Mhaskoba Hills near Manjarewadi village in Khatav taluka (Figure 1). Spanning 142.25 km, it flows between the Vardhangad-Aundh mountains in the west and the Mahimangad mountains in the east, passing through the rain-shadowed regions of Khatav taluka in Satara district and parts of Sangli district, including Kadepur, Khanapur,

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Tasgaon, Palus and Sangli taluka. The river meets the Krishna river near Wasagade in Sangli. Covering 3035 km², the area lies between 16º 50' to 17º 50' N latitude and 74º 15' to 74º 45' E longitude, with elevations ranging from 449 to 1009 meters.

The area has a tropical monsoon climate, with peak rainfall occurring in July and August. Rainy season lasts from June to September. The average annual precipitation is 597.73 mm (IMD). The area's geology shows that this area is predominantly covered by basaltic rock and the landscape features distinct wet (July-October) and dry (January-May) seasons. The river Krishna drainage system supports local irrigation system, which significantly influences the socio-economic conditions of the region, particularly in contrast to the economically drier rain-shadow zones.

## Material and Methods

**Data:** Landsat series data were obtained from the USGS Earth Data Portal.

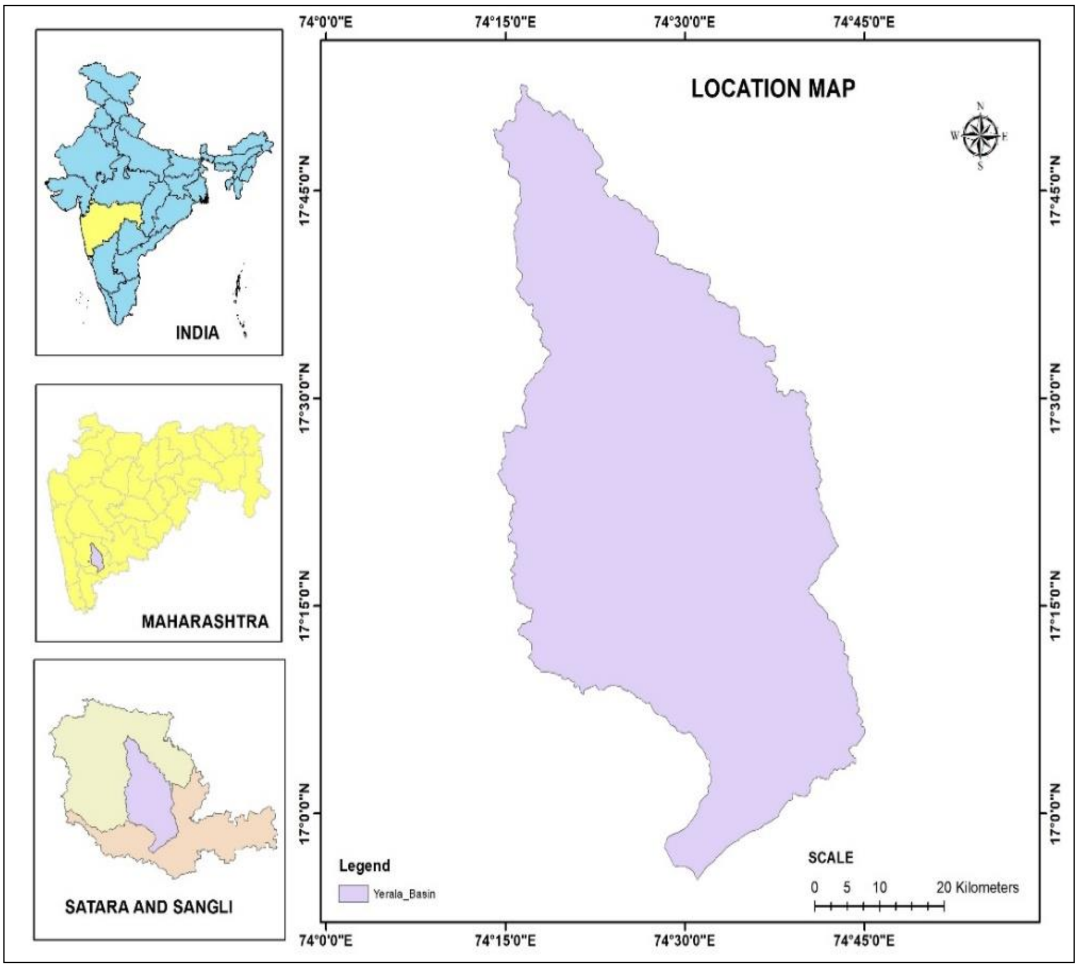



**Figure 1: Location Map**

**Table 1**
**Secondary Data Sources**

| S.N. | Parameter | Details |
|---|---|---|
| 1 | Satellite & Sensors | Landsat 7 (ETM), Landsat 8 & 9 (OLI) |
| 2 | Spatial Resolution | 30 meters |
| 3 | Temporal Range | 1994–2023 (30 Years) |
| 4 | Season | Summer months (April and May) |
| 5 | Revisit Interval | 16 days |
| 6 | Swath Width | 185 kilometres |
| 7 | Path & Row | Path 146 and 147, Row 048 |
| 8 | Bands Used | Landsat 7: Bands 1–7; Landsat 8/9: Bands 1–11 |
| 9 | Purpose | Analysis of remote sensing-based drought indices |
| 10 | Dataset Characteristics | Consistent spatial-temporal data for drought analysis across the study period |

**Table 2**
**Remote Sensing Based Drought Indices**

| Index | Formula | Purpose | Range/Key Insights |
|---|---|---|---|
| NDVI[15] | (NIR−R) / (NIR+R) | Measures vegetation health. | -1 to +1; higher values = healthy vegetation. |
| NDWI[6] | (NIR−SWIR) / (NIR+SWIR) | Assesses vegetation water content. | Higher values = better water availability. |
| MSI[8] | SWIR / NIR | Indicates vegetation water stress. | Higher values = increased moisture stress. |
| EVI[8] | G × [ (NIR−R) / (NIR+C1×R−C2×B+L) | Enhances vegetation sensitivity in dense areas. | Effective in areas with high biomass. |
| SAVI[7] | [(NIR−R)×(1+L)] / (NIR+R+L) | Adjusts for soil brightness in sparse vegetation. | Useful in regions with low vegetation cover. |

Drought risk zones were identified by integrating remote sensing-derived indices with GIS tools. Key indices including NDVI, NDWI, VCI, MSI, EVI and SAVI were analyzed to classify the study area into drought severity levels i.e. extreme, severe, moderate, mild and normal risk (Table 2).

Spatiotemporal data from the Landsat series, obtained via the USGS Earth Data Portal, was processed in ArcGIS 10.4 to evaluate vegetation health, water availability and soil conditions. Risk zones were then delineated using weighted overlay analysis combined with the Inverse Distance Weighting (IDW) interpolation method.

## Results and Discussion

**(A) Assessment of Remote Sensing based Drought Indices:** The temporal variation of remote sensing indices (NDVI, NDWI, EVI, MSI and SAVI) reveals important trends related to vegetation health, water availability and drought stress in the study area (Figure 1 and table 1). NDVI max values display a relatively stable and slightly increasing trend which indicate consistent vegetation health under favorable conditions. while the fluctuating NDVI min values reflect periodic stress in vulnerable areas. Notably, stress years such as 1994, 2002, 2003, 2011, 2012, 2016, 2018 and 2023 show pronounced dips in NDVI, highlighting significant vegetation stress during these periods (Table 2).

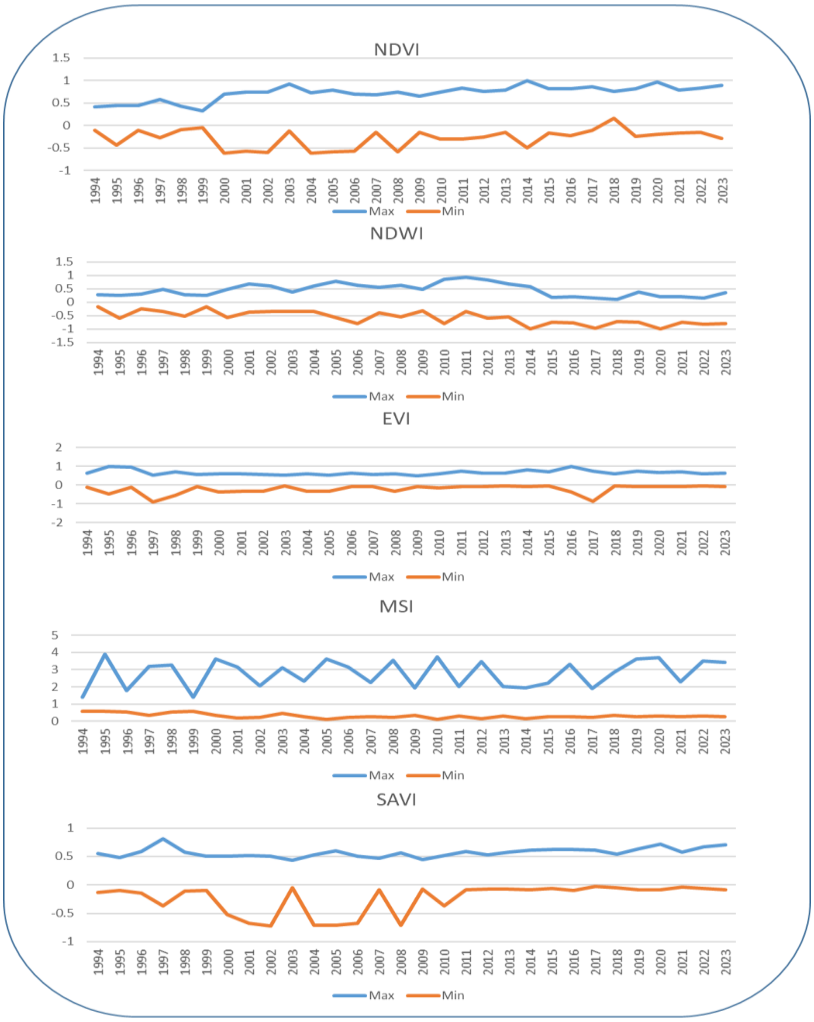
Similarly, the NDWI maximum values reached their highest levels around 2006–2007, with slight variations in subsequent years, while the minimum values consistently decreased after 2010, indicating a decline in water availability in drought-affected regions. These stress years also coincide with reduced NDWI values, further affirming periods of water scarcity. EVI values remain stable throughout the analyzed period, highlighting trends in vegetation density, while MSI exhibits significant fluctuations in max values during the stress years, indicating heightened water stress. SAVI exhibits initial fluctuations in minimum values due to sparse vegetation cover but stabilizes after 2010, with significant declines during stress periods, indicating reduced vegetation activity during those years (Graph 1).

Overall, the steady stability of maximum values across indices indicates that favorable conditions continue in certain parts of the basin. In contrast, the pronounced fluctuations in minimum values during stress years highlight the vulnerability of specific areas to drought and water scarcity. These findings underscore the importance of spatio-temporal analysis using remote sensing data to support effective drought risk assessment and mitigation efforts.

**(B) Drought Risk Zones using Weightage overlay:** Using a Weighted Overlay Analysis of the NDVI, NDWI, EVI, MSI and SAVI indicators, drought risk zone mapping was conducted to evaluate the spatial distribution of drought risk in the study area (Figure 1, table 3 and table 4). Each indicator was assigned a specific weight based on its significance in reflecting different drought aspects. NDVI, which assesses vegetation health and serves as an indicator of agricultural drought, was assigned the highest weight of 30%. NDWI, representing water availability and signaling hydrological drought, received a weight of 25%. EVI, reflecting vegetation density and productivity under drought conditions, was given a weight of 20%. MSI, which highlights moisture stress and soil dryness, was assigned 15% while SAVI, used to evaluate vegetation health in sparsely vegetated areas, was weighted at 10%.

These weighted layers were integrated using the Weighted Overlay tool in ArcGIS 10.4 to create a composite drought risk map. The map classified the study area into five distinct drought risk zones: normal, mild, moderate, severe and extreme, with ranks ranging from 1 to 5. This comprehensive analysis offers valuable insights into drought risk across various dimensions, aiding informed decision-making for water resource management and targeted drought mitigation efforts. The combination of these indicators through the weighted overlay process provided a holistic view of the drought risk across the study region. The outcome helps in understanding the spatial variation in drought severity and prioritizing areas for intervention.

The analysis of the drought risk zone classification in the study area reveals that the majority of the area is experiencing moderate to severe drought conditions. A significant 51.61% of the area falls under the severe risk category, indicating that more than half of the region is highly affected by drought, with substantial impacts on agriculture, water availability and ecosystems (Figure 2 and figure 3, table 5).




**Graph 1: Temporal Variation of drought indices.**

**Table 3**
**Weightage Table for Drought Risk Zone Mapping**

| S.N. | Indicator | Weight (%) | Description |
|---|---|---|---|
| 1 | NDVI | 30 | Assesses vegetation health, indicating agricultural drought conditions. |
| 2 | NDWI | 25 | Measures water availability, reflecting hydrological drought. |
| 3 | EVI | 20 | Highlights vegetation density and productivity under drought stress. |
| 4 | MSI | 15 | Indicates moisture stress and soil dryness. |
| 5 | SAVI | 10 | Evaluates vegetation health, particularly in areas with sparse vegetation cover. |
| **Total** | | **100** | |

**Table 4**
**Classes for Hydrological Drought Risk Assessment**

| Drought Category | NDVI | NDWI | EVI | MSI | SAVI | Assigned Risk Value |
|---|---|---|---|---|---|---|
| Extreme Drought | < 0.2 | < -0.1 | < 0.1 | > 2.0 | < -0.1 | 5 |
| Severe Drought | 0.2 - 0.3 | -0.1 - 0.0 | 0.1 - 0.15 | 1.5 - 2.0 | -0.1 - 0.1 | 4 |
| Moderate Drought | 0.3 - 0.4 | 0.0 - 0.1 | 0.15 - 0.2 | 1.0 - 1.5 | 0.1 - 0.2 | 3 |
| Mild Drought | 0.4 - 0.5 | 0.1 - 0.2 | 0.2 - 0.25 | 0.5 - 1.0 | 0.2 - 0.3 | 2 |
| Normal Condition | > 0.5 | > 0.2 | > 0.25 | < 0.5 | > 0.3 | 1 |

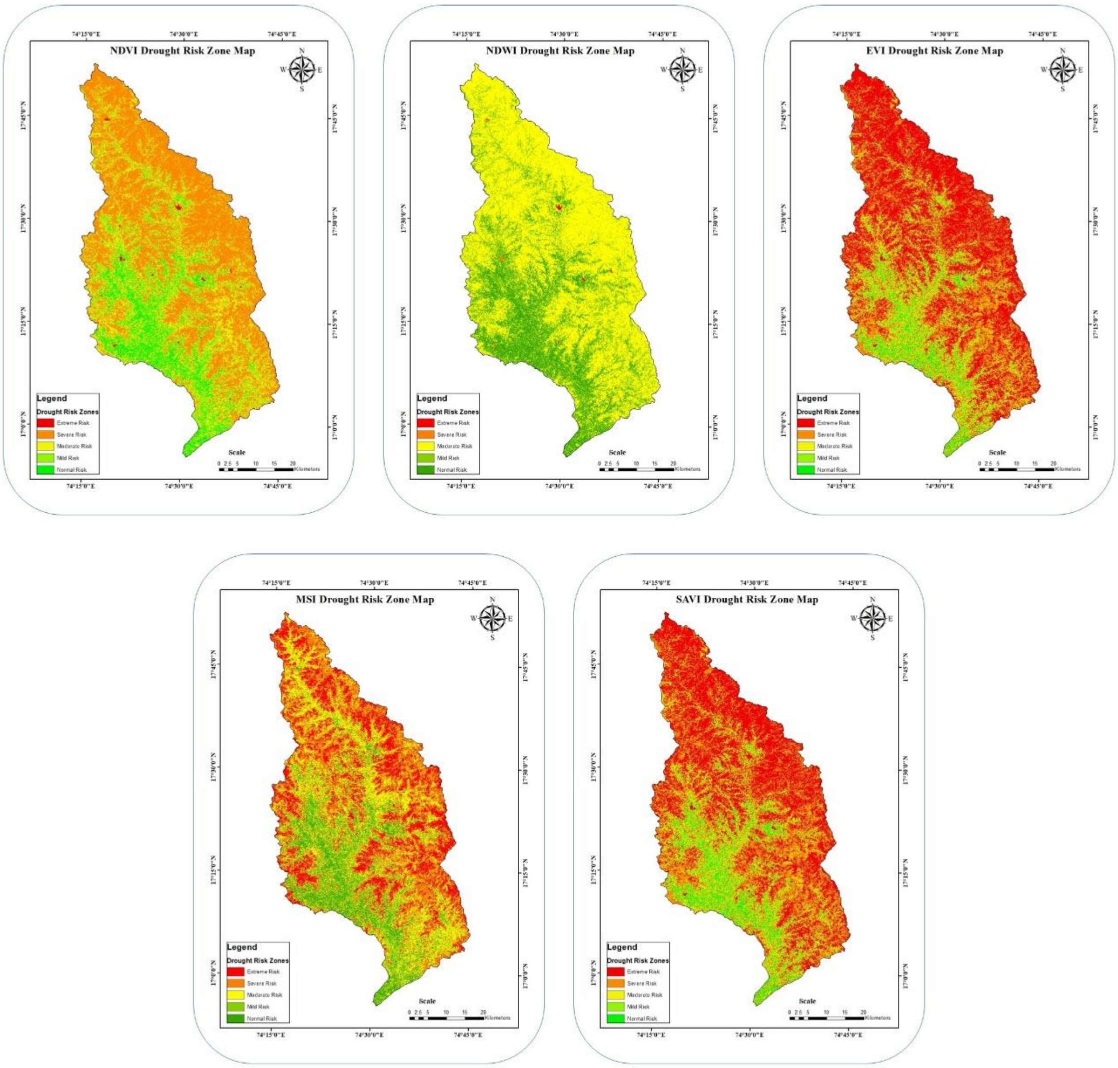



**Figure 2: Remote Sensing Indices Based Drought Risk Zone Maps**

**Table 5**
**Drought Risk Zone area coverage in percentage**

| Risk Zone Class | Rank | RS based Drought Risk Zone Area % |
|---|---|---|
| Normal | 1 | 4.11 |
| Mild | 2 | 16.38 |
| Moderate | 3 | 27.81 |
| Severe | 4 | 51.61 |
| Extreme | 5 | 00.09 |

Additionally, 27.81% of the area is classified under moderate drought, highlighting a notable portion of the region facing moderate drought stress.

On the other hand, the mild risk zone constitutes 16.38%, suggesting that a considerable portion of the basin is experiencing milder drought conditions. The normal risk zone accounts for only 4.11% of the area, indicating that only a small fraction of the basin remains unaffected by drought. Fortunately, the extreme drought category impacts a minimal 0.09% of the area. Overall, the analysis underscores the widespread and significant drought impacts across the region, with over 80% of the area falling under severe to moderate drought, necessitating urgent drought management and mitigation strategies (Table 5).

## Conclusion

This study highlights the critical vulnerability of the Yerla River Basin, Maharashtra to agricultural drought with over 80% of the area experiencing moderate to severe drought conditions between 1994 and 2023. The findings reveal that 51.61% of the basin is severely drought-affected, 27.81%

faces moderate drought stress and only 4.11% remains unaffected, while 0.09% endures extreme drought conditions. These patterns reflect significant challenges for agriculture, water availability and ecosystem stability in the region.

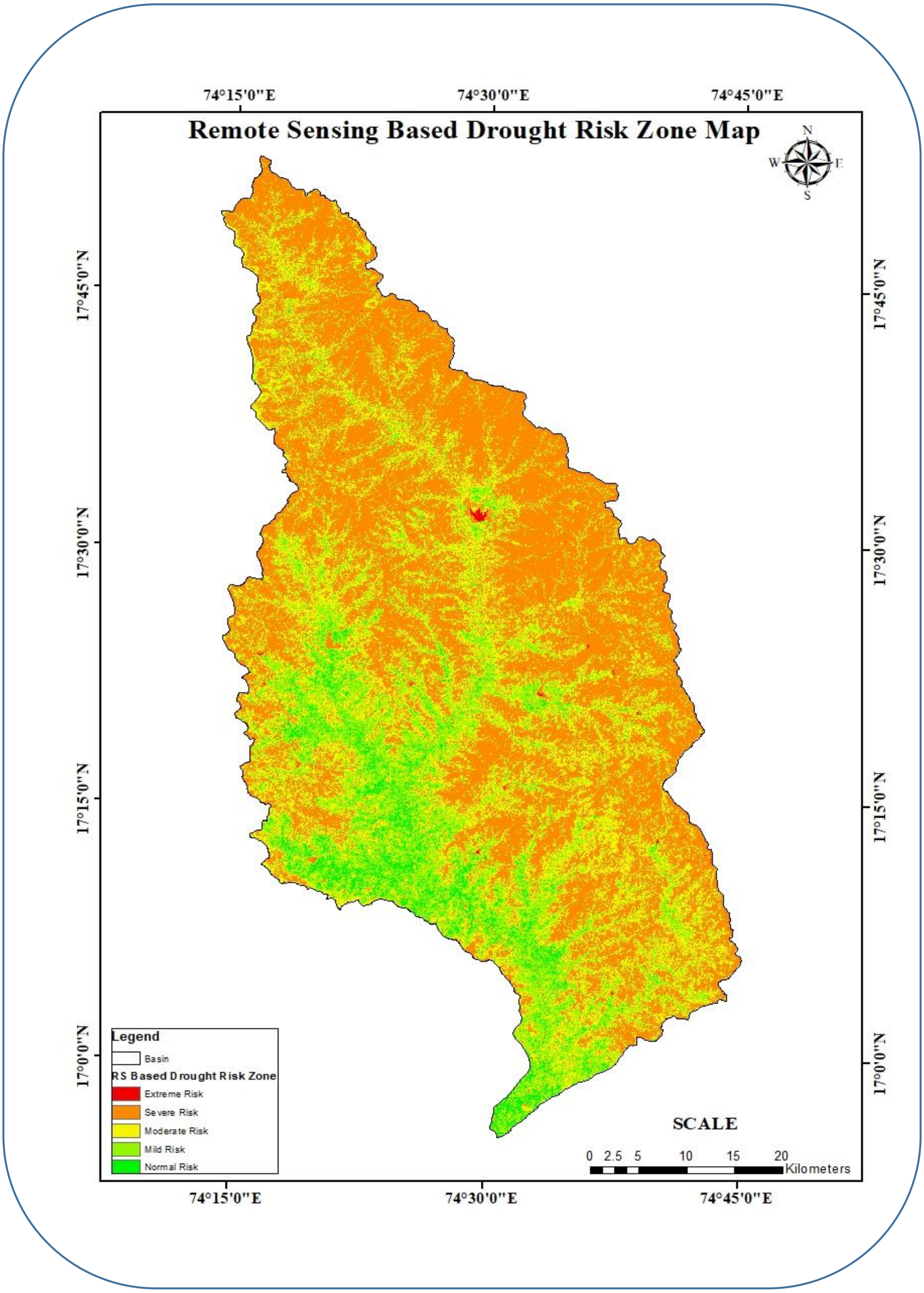



**Figure 3: Remote Sensing Indices based Drought Risk Zone Maps**

The integration of remote sensing and GIS technologies proved invaluable in accurately assessing drought risks and identifying vulnerable zones. This study highlights the urgent need for targeted mitigation measures, such as enhanced water resource management, adoption of drought-resistant crops and promotion of sustainable agricultural practices, especially in severely affected areas. Implementing these strategies can strengthen the basin's resilience to future droughts, safeguarding both environmental sustainability and community livelihoods.

## Recommendation

To mitigate the impacts of drought in the study area, a comprehensive approach is essential. Efficient water management strategies such as drip, sprinkler irrigation and rainwater harvesting, should be prioritized in severely affected areas. Encouraging the cultivation of drought-resistant crops and diversifying cropping patterns can help to reduce agricultural vulnerability. Additionally, strengthening early warning systems through remote sensing and GIS technologies will enhance timely drought monitoring and forecasting. Adopting sustainable land and water management practices such as soil conservation and watershed management, are essential for enhancing ecological resilience.

Additionally, active community participation through awareness programs and capacity building plays a vital role in ensuring effective resource management. Furthermore, supportive government policies including incentives for water-efficient technologies, financial aid for farmers and subsidies for sustainable agricultural practices, are crucial for strengthening long-term resilience, ensuring water security and fostering agricultural sustainability in the region.

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