

## **A REMOTE SENSING ODYSSEY ON PERSPECTIVE OF HUMANITARIAN ENGINEERING: DROUGHT MAPPING FOR KHULNA BY TRACKING DROUGHT PARAMETERS**

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### **ABSTRACT**

One of the most serious climate-related challenges Bangladesh faces is drought. Although drought has been constant in Bangladesh, its effects have been increasingly noticeable to the residents of Khulna in recent years. In addition to unpredictable rainfall and increasing temperatures, the Khulna district in Bangladesh's southwest coastal region has to deal with saline intrusion from tidal rivers. In order to map and characterize drought behaviors in Khulna, this work offers a thorough 30-year remote sensing expedition from 1994 to 2024. It integrates many satellite-derived indices and meteorological factors. This study uses an integrated suite of drought indicators, including the Normalized Difference Vegetation Index (NDVI), Vegetation Health Index (VHI), Palmer Drought Severity Index (PDSI), and Standardized Precipitation Index (SPI), using the MODIS satellite platform, CHIRPS precipitation data, images from Landsat 8 and Landsat 5, ERA5 reanalysis, and ground-based meteorological observations. The findings show a contrary pattern: while vegetation production has somewhat increased over the past three decades (NDVI increased from 0.180 in 1994 to 0.221 in 2024), drought danger areas have become more intense and have spread geographically. A multi-temporal mapping of drought hazards from 2000 to 2024 shows that climate change, increasing temperature-induced evapotranspiration, and moisture deficit buildup are the main causes of the drought's increased severity. Except for 2003, 2013, 2019, and 2020, seasonal vegetation condition indicators show increased stress over the winter. Long-term moisture shortage conditions are indicated by soil moisture anomalies obtained from PDSI mapping, especially in areas where soil salinity affects around 37% of coastal cropland. In addition to showing the important advantages of multi-parameter satellite monitoring for locating drought areas, forecasting agricultural stress, and assisting evidence-based water resource management in circumstances with limited data, this integrated remote sensing study offers solid proof of changing drought patterns in this climate-vulnerable area. Policymakers and local organizations may use these results to prioritize water management over agriculture and assist farmers in developing agricultural strategies that are climate resilient. In the end, the drought in Khulna is a lived experience for millions of people rather than a theoretical idea found in climate data.

**Keywords:** *Drought mapping, drought parameter, remote sensing, humanitarian engineering, Khulna;*

## **1. INTRODUCTION**

Drought's effects on ecosystems and human cultures are among the most important and significant effects of global climate variability. (Sadiq et al., 2023) Urbanization, human demands, and climate change have made drought more frequent and severe in Bangladesh. (Chowdhury, 2023) Bangladesh is ranked eighth in the world for natural catastrophe susceptibility, with increasingly frequent and severe drought periods, according to the Asian Development Bank. (Chowdhury, 2023) Salinity, drought, and waterlogging severely restrict agricultural productivity in the southwestern coastal area, particularly in the Khulna District, which encompasses Khulna, Bagerhat, Satkhira, and Narail. (Hossain, 2024) Khulna is situated in a severe hydro-meteorological zone characterized by considerable intrusion of salt from tidal rivers and the Bay of Bengal, unpredictable rainfall patterns, and increasing temperatures. (ADB, 2022; Hossain, 2024) According to the Khulna Water Supply Project, the area is prone to high salinity levels, which are made worse by excessive groundwater extraction and increasing sea levels. (ADB, 2022) Rice farming has been severely damaged by historical occurrences like Cyclone Sidr in 2007 and Cyclone Aila in 2009, which have affected around 3.45 million people and contaminated the land for a long time. (Rabbani et al., 2013; Shapna et al., 2024) Currently, different levels of soil salinity have impacted around 37% of farmland along the coast. (Shapna et al., 2024)

Numerous possibilities for tracking drought conditions at various temporal and geographical scales are provided by remote sensing technologies. (Chowdhury, 2023; Sadiq et al., 2023) Satellite-derived drought indices offer reliable and impartial assessments of temperature-related stress, moisture availability, and vegetation health. (Malook, 2025; NASA, 2014; Zeng et al., 2023) A thorough evaluation of the features and effects of drought is made possible by the integration of several drought indicators, including vegetation-based indices like the Normalized Difference Vegetation Index (NDVI), meteorological indices such as the Palmer Drought Severity Index and the Rainfall Anomaly Index (RAI), as well as the Vegetation Health Index (VHI). (Munysi, 2024; PDSI) (Chowdhury, 2023; Sadiq et al., 2023) Using meteorological findings and satellite-derived data collected between 1994 and 2024, this study aims to characterize Khulna's drought patterns. The long-term study shows crop dynamics, long-term rainfall patterns, and soil moisture anomalies that impact agricultural productivity and water availability in this vulnerable coastal region.

## **2. STUDY AREA**

### **2.1 Geographic Information**

Khulna District is between latitudes 21.27°N and 23.53°N and longitudes 88.00°E and 90.20°E in Bangladesh's southwest coastal area. (Chowdhury, 2023; Tabassum, 2024) The Ganges, Brahmaputra, and Meghna river systems, along with significant tidal impacts from the Bay of Bengal, compose that area's complex hydrological matrix. (Hossain, 2024) Although it is increasingly threatened by saline intrusion and rising mean sea levels, the Sundarbans, the biggest mangrove forest in the world, borders the area and plays vital roles in biodiversity conservation, coastal protection, and the storage of carbon. (Rahman, 2025). Khulna has a tropical monsoon climate with variations in temperature and precipitation. (Hossain, 2024; tasnim et al., 2024) Flash droughts frequently occur during the growth season, while significant rainfall events can occasionally cause problems like waterlogging, according to historical patterns. (Hossain, 2024; Mamun et al., 2024) Due to its reliance on vegetables, aquaculture, and rice production (Aman, Boro, and Aus varieties), the area's agricultural industry is especially vulnerable to climatic fluctuations. (Hossain, 2024; Mamun et al., 2024). In Figure 1, the map of Khulna has been illustrated using ArcGIS Pro.

### **2.2 Data Sources**

The Bangladesh Meteorological Department provided the monthly rainfall, temperature, and relative humidity statistics. The Moderate Resolution Imaging Spectroradiometer (MODIS) satellite platform, which offers reliable, long-term observations of vegetation and land surface features at high temporal resolution, was the source of the remote sensing data. (Didan, 2021; NASA, 2014). Also, CHRIPS data has been used in Google Earth Engine to evaluate SPI, VHI, VCI, NDVI, Drought Hazard mapping,

and soil mapping. The SPI 20-year trend map has been created using the ERA5 data set, which is available for 1-month daily resolution.

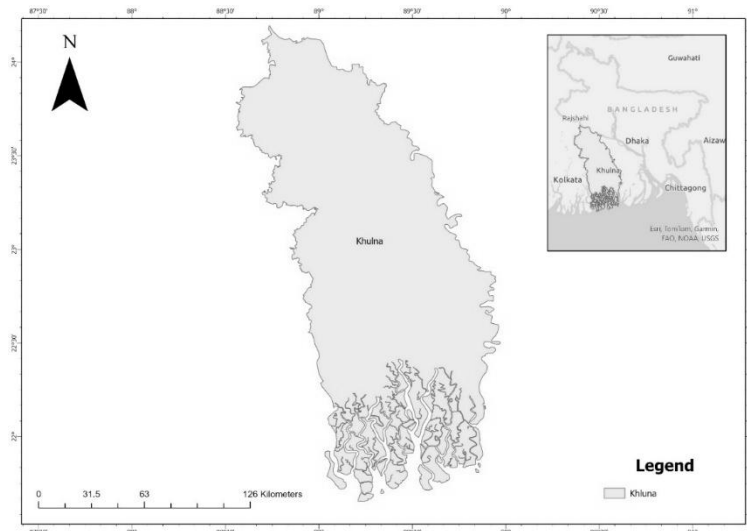


Figure 1: Study Area

### 3. METHODOLOGY

#### 3.1 Normalized Difference Vegetation Index (NDVI)

One of the most used vegetation monitoring indices in drought assessment studies is the Normalized Difference Vegetation Index (NDVI). (Didan, 2021; NASA, 2014; Wiki, 2020) NDVI can be computed from satellite reflectance data using the following formula:

$$NDVI = \frac{(NIR-Red)}{(NIR+Red)} \quad (1)$$

where Red stands for visible red reflectance and NIR for near-infrared reflectance. (NASA, 2014; Wiki, 2020) Water bodies are represented by negative NDVI values, barren regions of rock, sand, or snow by values close to zero, and vegetation cover by positive NDVI values, which vary from -1 to +1. (NASA, 2014; Wiki, 2020) Low positive values show sparse or stressed vegetation, and high positive values (around 1) show thick, healthy vegetation. (NASA, 2014; Wiki, 2020)

#### 3.2 Evaporative Stress Index (ESI)

Temporal changes in consumption of water over the land surface are described by the Evaporative Stress Index, a thermal indication of anomalous evapotranspiration conditions. (NOAA, 2022; USDA, 2025) ESI's primary benefit is its capacity to identify early indicators of "flash drought," which is caused by extended hot, dry, windy weather that quickly depletes soil moisture. (USDA, 2025) (Li, 2024; NOAA, 2022) The NOAA Centre for Satellite Applications and Research (STAR) and USDA-ARS Hydrology and Remote Sensing Laboratory develop ESI, which has data accessible from 2001 to the present and has a 4-kilometer geographical resolution and weekly temporal resolution. (NOAA, 2022) For drought monitoring applications, the index is offered in both 4-week and 12-week ESI packages. (NOAA, 2022)

#### 3.3 Palmer Drought Severity Index (PDSI)

One of the most advanced drought indicators for long-term drought evaluation is the Palmer Drought Severity Index. (Dai, 2025; PDSI, 2023; Rhee & Carbone, 2007) Palmer created PDSI in 1965 to measure cumulative deviation in surface water balance. It combines potential evapotranspiration and prior and present moisture supply (precipitation) into a hydrological accounting system. (Dai, 2025;

Rhee & Carbone, 2007) A standardized metric, the PDSI ranges from -10 (extreme drought) to +10 (very wet), with values below -3 indicating severe to extreme drought. (Dai, 2025; Rhee & Carbone, 2007) PDSI is useful in predicting long-term drought, particularly across low and medium latitudes, since it takes into account both moisture received (precipitation) and moisture remaining in the soil, allowing for possible moisture loss due to temperature impacts. (Dai, 2025; PDSI, 2023)

### 3.4 Vegetation Health Index (VHI)

One of the first and most used techniques for monitoring and recognizing drought-related effects on agriculture using remote sensing data is the vegetation health index (VHI). (IDMP, 2023b; Malook, 2025; Zeng et al., 2023) Compared to vegetation indices alone, VHI provides a more accurate estimate of vegetation stress by combining temperature conditions and vegetation appearance. (Malook, 2025; Zeng et al., 2023)

$$VCI = 100 * \frac{NDVI - NDVI_{min}}{NDVI_{max} - NDVI_{min}} \quad (2)$$

$$TCI = 100 * \frac{BT_{max} - BT}{BT_{max} - BT_{min}} \quad (3)$$

$$VHI = \alpha * VCI + (1 - \alpha) * TCI \quad (4)$$

This formula demonstrates how VHI combines many indicators to offer a thorough evaluation of drought. where VHI values range from 0 to 100, with higher values denoting healthy circumstances and lower values denoting severe drought or vegetation stress. (Kogan, 1990; Kogan, 1997) VCI is the Vegetation Condition Index. (Malook, 2025) VCI is a percentage that shows the range of the observed NDVI value between the climatological record's extreme minimum and maximum values. For very bad vegetation conditions, VCI is 0; for ideal situations, it is 100. (INRDMS, 2025) Also, BT from equation 3 represents the brightness temperature. (INRDMS, 2025)

### 3.5 Standardized Precipitation Index (SPI)

The World Meteorological Organization's suggested standard for tracking meteorological drought is the Standardized Precipitation Index (SPI), which was developed in 1992 at Colorado State University by McKee et al. ((Eds), 2025; IDMP, 2023a) SPI creates a probability of precipitation that may be calculated at any number of timeframes, from one month to 48 months or more, using historical precipitation statistics for any place. (IDMP, 2023a) A dimensionless formula that analyses observed precipitation with historical distributions is used to compute SPI:

$$SPI = \frac{P - P^*}{\sigma_P} \quad (5)$$

where P stands for precipitation, P\* for mean precipitation, and  $\sigma_P$  for precipitation standard deviation. ((Eds), 2025)

The following are the main benefits of SPI for monitoring drought in Bangladesh: (Dev & Snahomoni, 2025; IDMP, 2023a)

1. It is simple to compute using current meteorological station networks since it simply requires precipitation data as input.
2. Suitable for various climate regimes, enabling the comparison of drought indicators between climatically diverse locations
3. Beneficial for data-poor areas like Bangladesh, it may be calculated for brief periods of record with incomplete data.
4. Applications outside station-based networks are possible since they may be computed on gridded precipitation datasets.

Wet and dry incidents are directly correlated with both positive and negative numbers on SPI's intensity scale. (IDMP, 2023a) When SPI consistently drops and hits a value of -1, a drought event is detected; it is deemed to be ongoing until SPI hits 0. (IDMP, 2023a) Drought beginning is indicated by an SPI of -1 or below; however, some studies employ thresholds that are slightly beyond 0. (IDMP, 2023a)

## 4. RESULTS AND DISCUSSION

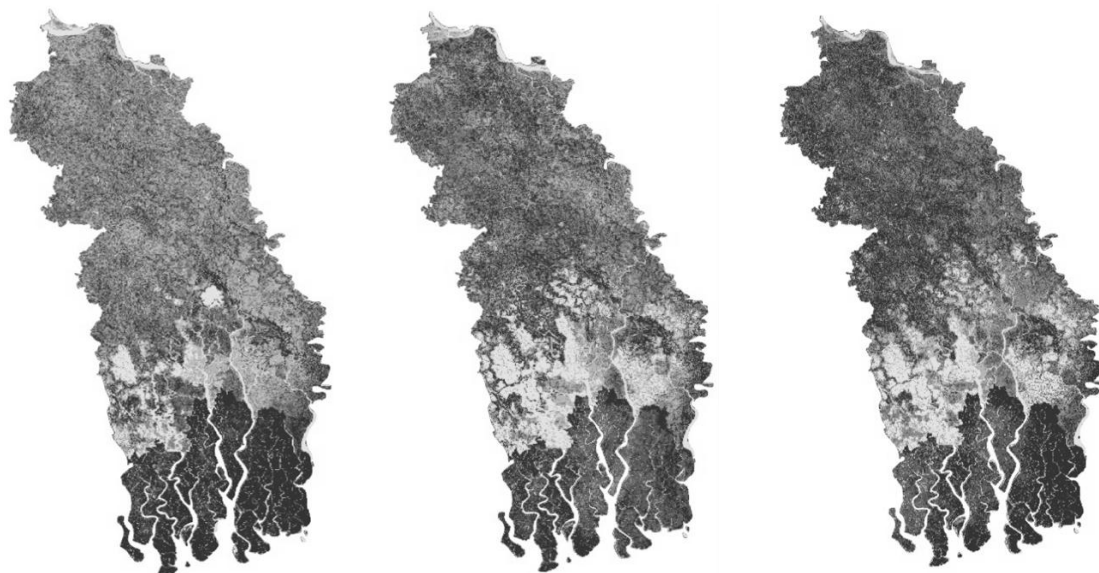
### 4.1 Multi-Decadal NDVI Analysis

Although geographical differences within Khulna may reflect regional changes in land use, soil salinity, and water availability, the steady rise in mean NDVI from 1994 to 2024 indicates some improvement in plant conditions during these 30 years. A large portion of Khulna's land is made up of cultivated agricultural fields and places with scant vegetation or moisture stress. This is compatible with the region's agricultural character and climate, according to the comparatively low absolute NDVI values (below 0.25). (Rahman et al., 2022) From Table 1, it has been seen from the year 1994 for that its Mean NDVI is 0.180, which reflects low vegetation productivity, sparse vegetation, and early-stage land use conversion. (Rahman et al., 2022) But in 2013, the modest increase (+1.5% over 1994) indicates slight vegetation recovery or agricultural intensification. This mean value further increases (+0.6% from 2013), suggesting continued vegetation improvements or changes in agricultural practices 30-year NDVI time series record shows modest but notable shifts in vegetation productivity:

Table 1: Mean NDVI values

Year	Means NDVI
1994	0.180
2013	0.208
2024	0.221

In contrast to alarming patterns seen in other regions of Bangladesh and the Sundarbans, the mean NDVI has steadily increased over the past 30 years. (Rahman et al., 2022) Research on Sundarbans vegetation degradation has shown dramatic drops in NDVI from 0.88 in 1997 to 0.53 in 2019, indicating a 34% loss of dense vegetation. (Rahman et al., 2022; Rahman, 2025) This discrepancy implies that Khulna's agricultural regions may have responded to management interventions or changes in cropping patterns, whereas the Sundarbans face significant vegetative stress due to saline intrusion and climate change. Khulna's actual NDVI values, however, are still low when compared to healthy natural vegetation, suggesting that the region's environment is characterized by moisture-stressed areas, cultivated agricultural fields, and places with little plant cover. (Rahman et al., 2022) Because salty soils have a lower ability to store water, which results in stunted growth and less vegetative growth, the low NDVI values are in keeping with predicted trends for areas under salinity stress. (Shapna et al., 2024) In Figure 2, NDVI mapping for Khulna has been done on Google Earth Engine, and the value of NDVI changes has been seen as noticeable in the coastal part of Khulna.





Year 2000

Year 2024

Figure 4: Drought Hazard Map of 2000 and 2024

A comparison of drought danger maps from 2000 and 2024 reveals some significant trends:

- 2000 Evaluation: Following the El Niño phenomenon of 1997-1998, 2000 was a year of global drought concern. (Khalid, 2024) This time period's mapping of drought hazards probably shows how pervasive moisture stress affects precipitation and soil moisture throughout Bangladesh. (Kamruzzaman & Cho, 2025)
- 2024 Evaluation: Drought conditions under current climate change and land use dynamics are captured in the most recent evaluation. One of the biggest risks to Khulna's agricultural production is the increased frequency and severity of droughts brought on by climate change. (Donald Wilhite, 2017; Hossain, 2024; Mamun et al., 2024)

#### 4.4 PDSI and Soil Moisture Anomalies

Khulna's cumulative drought severity and soil moisture conditions are estimated from Palmer Drought Severity Index maps from 2000 to 2024. (Figure 5) PDSI is especially suitable for evaluating agricultural drought scenarios when soil moisture availability directly limits crop productivity, since it incorporates soil water balance mechanics. (Figure 4)(Dai, 2025; PDSI, 2023)

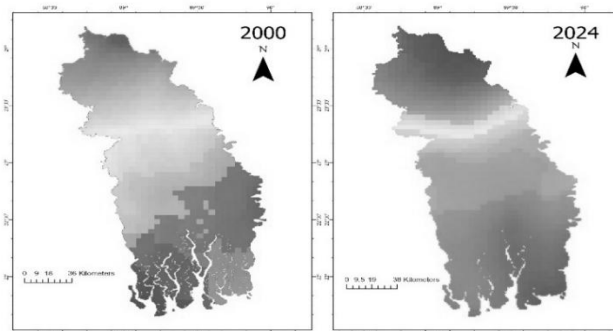


Figure 5: PDSI map of the years 2000 and 2024

Particularly across low and medium latitudes where temperature-driven processes dominated in moisture availability, the PDSI is useful in identifying long-term drought. Even when precipitation is close to average, Khulna's potential evapotranspiration rises with temperature increase, which exacerbates the moisture deficit that causes agricultural dryness. (Dai, 2025; PDSI, 2023) Maps of soil conditions from 2000 and 2024 reveal that soil properties have changed, affecting water availability and retention. Increases in soil salinity lower the soil's ability to store water and raise the osmotic barrier that plants must overcome to draw moisture from the soil. (Md. Mizanur Rahman, 2024) (Shapna et al., 2024) Therefore, compared to non-salty soils, a given amount of soil moisture in saline soils means less available water to plants, thereby amplifying drought stress. (Shapna et al., 2024).

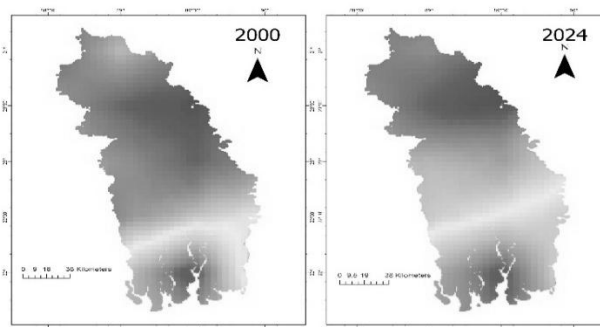


Figure 6: Soil Map of Khulna for the years 2000 and 2024

#### 4.5 Temporal Variability in Seasonal VCI and VHI

The temporal patterns of vegetative stress are revealed by the 24-year seasonal vegetative Condition Index time series from MODIS data in Bangladesh. In Figure 7, it has been seen that in the monsoon season, very healthy vegetation is seen. In case of winter, mild to moderate drought has been seen from the year 2000 to 2023, except in 2003, 2013, 2019, and 2020. Noticeably, 2019-2020 shows good vegetation throughout the year in terms of VCI.

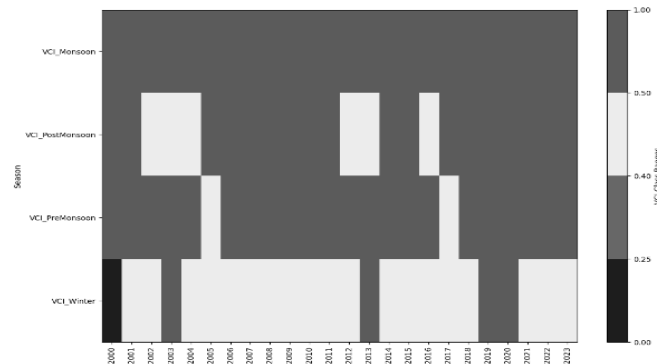


Figure 7: VCI Classified Heatmap (Severe → Normal)

The seasonal VCI map of 1994 has been created using the AVHRR NDVI dataset, which is available from the year 1981, and the MODIS dataset is used for the map of year 2024 seasonal VCI mapping. The difference between the two data sets is clearly visible in Figure 8. From this, it can be said that a good dataset can be used for clear and visible mapping. In Figure 8, the effect of winter is clearly visible in the coastal area of Khulna for the year 2024. But for 1994, it is hard to find the seasonal effects.

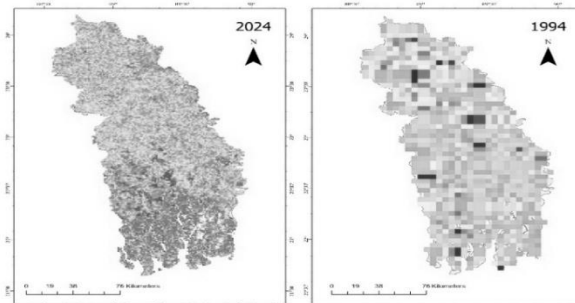


Figure 8: Seasonal VCI of the years 1994 and 2024

The agricultural drought situation in Khulna has now broken out for the four major seasons of 2024. The VCI maps of Figure 9 illustrate the areas where vegetation is most stressed during the various agricultural seasons. Depending on the figure 8 observations, Table 2 has been prepared to indicate the dominant condition due to drought and the location of maximum stress.

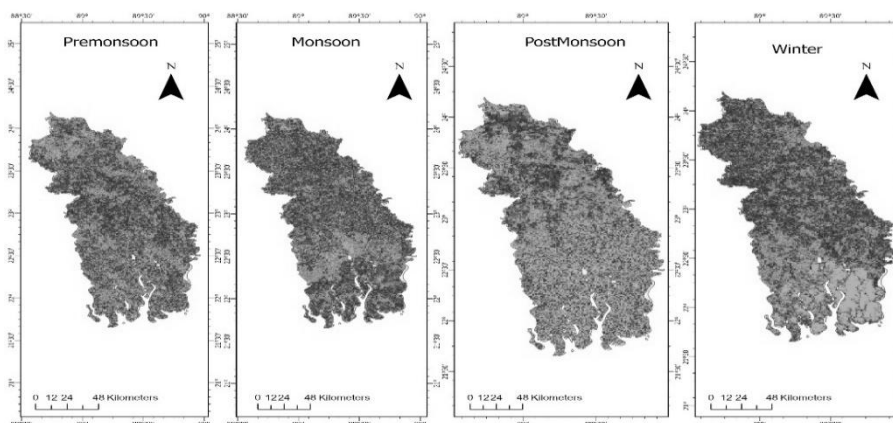


Figure 9: Seasonal VCI observation of 2024

Table 2: Season-wise VCI observations of 2024

Map (Season)	Primary Dates	Dominant Condition	Location of Maximum Stress
Pre-Monsoon	March - May	Severe Drought	Northern and Northwestern regions.
Monsoon	June - September	Favourable/Wet	Widespread Green across the country.
Post-Monsoon	October - November	Emerging Dryness	Dry conditions begin to appear, especially in the Southern/Coastal belt.
Winter	December - February	Moderate Drought	Southern, Coastal, and Deltaic areas show the most persistent stress.

Now, in terms of VHI, low VHI values (Red/Orange) are clearly concentrated in the North-western and perhaps Central-Eastern portions of the 2000 map. (Figure 10) Because of MODIS data availability from the year 2000, the VHI has been calculated from 2000. Due to a combination of high temperatures and little rainfall, the vegetation in the historically drought-prone areas was most stressed in 2000. The region of greatest tension has clearly changed on the 2024 map. The Southern, Coastal, and Deltaic districts currently have the lowest VHI values, whereas the Northern/North-western regions seem to have improved. The coastal area will have the worst vegetation health crisis in 2024 due to a combination of temperature stress and rainfall. The conclusion of a drought change is supported by this. This change implies that while the North may have benefited from better irrigation or changed weather patterns, the South is becoming more vulnerable to heat stress and saline intrusion, which drastically reduces agricultural yields.

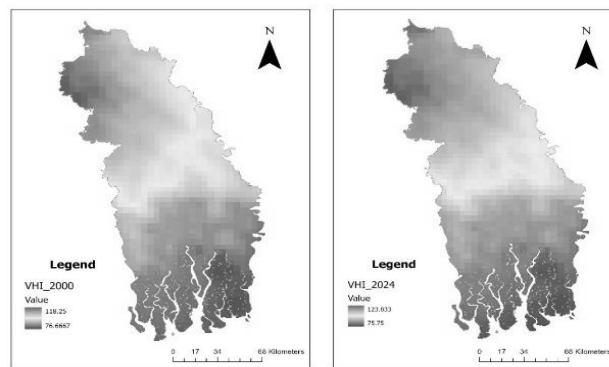


Figure 10: VHI map of 2000 and 2024.

## 5. HUMANITARIAN ENGINEERING ASPECTS

Millions of people in the Khulna District who depend on agriculture, fishing, and freshwater resources are affected by the drought, which is more than just an environmental issue. In order to improve community resilience and dignity for humans in the face of climate hazards, humanitarian engineering must close the knowledge gap between science and practical solutions.

### 5.1 Water Security and Resilience Infrastructure

Humanitarian engineers may create targeted water infrastructure, i.e., rainwater harvesting type infrastructure, which is climate-resistant and location-specific, by using remote sensing to identify substantially changing drought hazards. In areas identified as high-risk drought zones, engineers can give priority to building resilient water storage systems, and effective irrigation networks with controlled aquifer recharge facilities are preferable to standardized strategies. This spatial precision ensures equitable distribution of limited water supplies and reduces the likelihood of maladaptation.

### 5.2 Agricultural Resilience and Food Security

The high level of salt-affected soils and the observed impact on plants over the winter provide some significant hurdles to food production. Humanitarian engineers must collaborate with agricultural experts to develop and implement climate-resilient farming methods, such as salt-tolerant crop varieties, water-efficient drip irrigation systems, and improved soil management practices. Remote sensing-based early warning systems can alert farmers to impending drought conditions weeks in advance, enabling them to make preventive adjustments to crop selection, planting schedules, and water distribution.

### **5.3 Community-Centered Adaptation Planning**

Implementing standard adaptation measures is challenging due to the unpredictable nature of drought cycles. This is supported by 30 years of remote sensing data. Involving vulnerable populations in the design process is something that humanitarian engineers should do. They can also combine local knowledge equally with scientific data. (Akter & Dev, 2025) Establishing climate-resilient housing and infrastructure that can withstand humidity stress, developing multipurpose water facilities that simultaneously supply drinking water, irrigation, and aquaculture, and establishing decentralized water management systems that let communities respond to droughts on their own terms are all part of this process.

### **5.4 Gender and Equity**

The southwestern coastal area is also feeling the brunt. This means that the water sources and adaptation tools are supposed to protect the environment. This will be shared among smallholder farmers, landless laborers, and disadvantaged communities. Also, this will promote environmental justice through humanitarian engineering. It requires the growth of personnel and resources in the institutions, participation in policy-making, and transparent management systems. This will give priority to the most marginalized and vulnerable groups. Additionally, because men are involved with their professions, women are responsible for fetching drinkable water from a far location. They do not consume enough water owing to water scarcity. In order to prevent illnesses like dehydration, the health of the female family members should be regularly monitored. Besides this, supplying bottled water as an anticipatory action should be taken to ensure that they consume enough water if there is a drought.

### **5.5 Data-Based Decision Making for Limited-Resource Settings**

Developing countries with inadequate resources for real-time monitoring may now get high-quality environmental data. This is possible due to the development of remote sensing technology. This technology works by integrating satellite-derived drought indicators into the decision-support systems. The decision support system is also available to farmers, water managers, and policymakers. Humanitarian engineers might enable the international distribution of planning and resource allocation based on evidence. This will help the communities move from reactive to preventative actions. Also, it will reduce the humanitarian cost of drought-related incidents.

## **6. CONCLUSIONS**

A detailed analysis of the drought in Khulna district reveals a complex environmental issue, intensified by human activity, coastal hydrodynamics, and climate change. The region is becoming increasingly vulnerable, as indicated by rising humidity stress and climate extremes. On the other hand, the slight increase in the vegetation index may suggest localized recovery or adaptive farming practices. Using various remote sensing indices (NDVI, VHI, PDSI, and SPI), a comprehensive view of drought dynamics is created, also exposing limitations of relying on a single index. The 24-year analysis of drought hazard maps (2000–2024) and soil moisture anomalies shows that evapotranspiration and precipitation variability are key factors driving agricultural drought. Seasonal trends from VCI analysis suggest higher drought likelihood in winter, with notable outliers needing further investigation. These findings provide a scientific foundation for developing evidence-based adaptation and mitigation strategies. Priorities for future action include sustainable groundwater management, climate-smart farming techniques that boost water efficiency, ecosystem restoration—especially in the nearby Sundarbans—and adaptive water collection infrastructure. Continuous remote sensing monitoring is

vital for the success of these efforts, as it offers high-frequency, cost-effective assessments over large areas, which is particularly important for regions like Bangladesh with limited ground data. This study relies entirely on satellite data processed through the Google Earth Engine platform. No ground validation was performed due to data limitations and scale mismatches. Therefore, the results depict relative drought patterns and trends rather than exact ground conditions. Future research should include in-situ observations and stakeholder validation to improve drought hazard assessments. Long-term satellite-based drought monitoring remains essential in Khulna and other vulnerable coastal areas for early warning, agricultural planning, and water security management.

## **DECLARATION OF USE OF AI**

Artificial intelligence-assisted tools are used solely for language editing and improving clarity. All research content, data analysis, and conclusions were developed by the authors, who take full responsibility for the work.

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