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# QUANTIFYING THE 2022 FLOOD EXTENT AND LAND USE CHANGE IN SOHBATPUR DISTRICT, PAKISTAN USING SENTINEL-1 SAR AND MODIS

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**ABSTRACT**
*This study quantifies the 2022 flood extent and associated land-use changes in Sohbatpur District, Pakistan, by integrating Sentinel-1 SAR data, MODIS-based land-use/land-cover (LULC) classifications, and Global Flood Awareness System (GloFAS) hydrological data. The work addresses the problem of monitoring floods in monsoon-dominated, cloud-prone regions where optical imagery is limited, and it assesses how flood exposure interacts with agricultural land and rural populations. Sentinel-1 SAR's cloud-penetrating capabilities are leveraged to map flood extent and severity, while MODIS-derived LULC provides a contemporaneous view of agricultural and other land-use classes. Results indicate substantial flood-affected agricultural areas and a clear spatiotemporal pattern of flood severity aligned with low-lying, near-channel zones. A 100-year flood hazard map from GloFAS supports hazard–exposure analysis and highlights persistent high-risk pockets corresponding to historic flood events. The study offers data-driven insights for disaster risk reduction, agricultural planning, and flood resilience in one of Balochistan's most flood-vulnerable areas.*
***Key words:*** *2022 flood, flood extent, land use and land cover, Sentinel-1, Sohbatpur, Pakistan*

## 1. INTRODUCTION

Floods are among the most frequent natural disasters, and they have one of the biggest effects worldwide (Islam et al., 2016). In both rural and urban areas, floods are the most common natural disasters that can threaten lives, destroy property, disrupt social and economic activities, and harm the environment and ecology (Slung & Romali, 2022). South Asia is one of the most flood vulnerable regions in the world. Floods occur often in the region triggered by heavy monsoon precipitation and can cause enormous damages to lives, property, crops and infrastructure. The frequency of extreme floods is on the rise in Bangladesh, India and Pakistan (Mirza, 2011). Due to high exposure and vulnerability, the risk of floods has increased in South Asia (Nanditha et al., 2023) and it is anticipated that they will occur more often in the upcoming years due to the climate change (Alfieri et al., 2017).

Flooding is common in Pakistan (Sayed & Gonzalez, 2014) and have affected Pakistan on multiple occasions in the past (Akhtar, 2013). It is mostly caused by intense precipitation during the summer monsoon season (Nanditha et al., 2023). Pakistan's southern provinces of Sindh and Balochistan have been disproportionately affected by the devastating summer monsoon 2022 flood (NDMA, 2022; Ullah et al., 2026). Unusual torrential rains during the 2022 monsoon season triggered severe flooding in various areas of Balochistan causing severe damage to the province (Mengal et al., 2026) with Sohbatpur being one of the badly hit districts, where prolonged inundation disrupted agricultural systems and rural livelihoods.

Remote sensing offers a powerful means to assess flood impacts (Schumann & Moller, 2015). Flood extent mapping with Sentinel-1 SAR takes advantage of SAR's all-weather, day-and-night imaging capability, which is especially critical during monsoon-driven floods when cloud cover often hampers optical sensors. Several recent works demonstrate the utility of Sentinel-1 for flood delineation using SAR backscatter and change-detection approaches, offering robust inundation estimates in flood-affected areas (Akram et al., 2024; Ghouri et al., 2023). The present study extends this approach to Sohbatpur, situating district-scale flood extent estimates within a land-use framework.

Land-use and land-cover (LULC) change accompanying floods require multi-temporal perspectives. MODIS provides consistent, coarse-resolution but temporally dense information that is well-suited for monitoring large-area LULC dynamics and phenology over the flood season and recovery period, complementing higher-resolution SAR and optical data. Prior work highlights the complementary strengths of SAR (water/coherence signals) and MODIS (temporal regime) for flood and land-cover assessments in Pakistan and comparable settings (Ghouri et al., 2023; Liu et al., 2023; Talha et al., 2024).

The Sohbatpur district sits within a landscape where agriculture is a key livelihood, and the flood event likely induced land-use fluctuations with implications for food security and resilience planning. Prior studies have documented the sensitivity of paddy/rice mapping and cropland extents to multi-sensor inputs, including Sentinel-1, Sentinel-2, Landsat, and MODIS, and have underscored how sensor choice and spatial resolution influence land-cover classification outcomes in Pakistan and South Asia more generally (Aslam & Farhan, 2024; Chowdhury et al., 2023; Liu et al., 2023; Waleed et al., 2022). By quantifying flood extent and accompanying land-use transitions in Sohbatpur, this work contributes to the growing evidence base on post-flood recovery and land management in flood-prone districts.

## 2. Methodology

The present research employs a quantitative geospatial methodology that integrates multi-temporal and multi-sensor satellite cloud computing technology, remote sensing, and Geographic Information Systems (GIS) to map the extent and duration of the 2022 monsoon floods and to evaluate the corresponding changes in land use and land cover (LULC) in Sohbatpur District, Balochistan.

### 2.1 Research Design

This study uses a quantitative, multi-temporal, multi-sensor satellite approach to assess flood extent, duration, and land-use/land-cover (LULC) changes in Sohbatpur District. Sentinel-1 SAR data are used to map pre- and peak-flood areas accurately despite cloud cover through change detection and threshold-based classification, while MODIS and Landsat-8/9 imagery assess pre- and post-flood changes in settlements, agricultural land, water bodies, and vegetation. Satellite findings are validated using rainfall records, PDMA flood inventories, reference imagery, and available ground observations. The integrated approach provides evidence on flood severity, recovery patterns, and ecological and livelihood impacts to support resilience planning, disaster risk management, and policy development.

### 2.2 Study Area

Sohbatpur District lies in Balochistan between approximately 28°30′–29°10′ N and 68°30′–69°20′ E, covering an area of about 802 km². Created in 2013 after its separation from Jaffarabad District, it forms part of the lower Indus Basin. The region is characterized by a flat floodplain topography. Agriculture—mainly rice and wheat—is the primary livelihood, making the district highly vulnerable to extreme hydrological events.

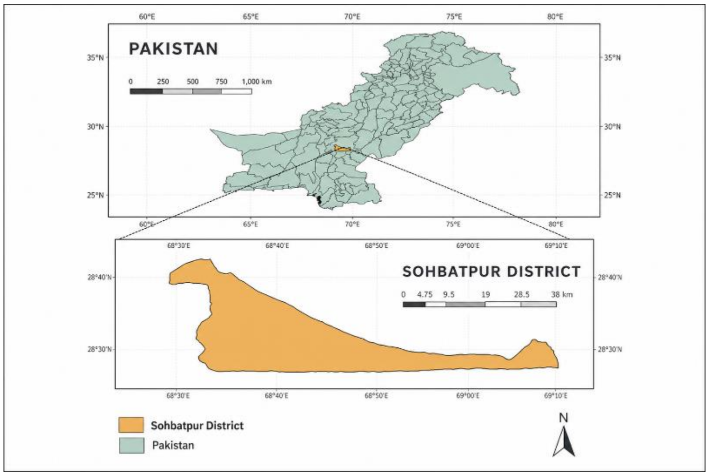


**Figure 1. Location map of Sohbatpur District, Balochistan**

### 2.3 Data Sources

This study combines remote sensing datasets with secondary data to acquire accurate flood mapping and LULC evaluation. Sentinel-1 SAR imagery gives supervision of flooded areas in different times whereas MODIS optical data provides daily information on vegetation strain and flood dimensions. Moreover, Landsat-8/9 datasets are applied for comprehensive pre- and post-flood land use/land cover assessment. All satellite-based findings are spatially assessed within the administrative boundaries of Sohbatpur district. Apart from this, another dataset named as the Global Flood Awareness System (GloFAS) 100-year flood hazard was utilized to detect continuing flood vulnerability.

Secondary data taken from the sources of the Provincial Disaster Management Authority (PDMA), the Pakistan Meteorological Department (PMD), and the International Organization for Migration (IOM), and printed works related to the study, utilized to assist in validating and interpreting the data.

### 2.4 Data Acquisition

In order to guarantee precise mapping of the 2022 flood extent and a thorough evaluation of land use/land cover (LULC) changes in Sohbatpur District, this study mainly depends on multi-source satellite remote sensing data augmented by secondary sources. The data collection strategy was designed to achieve high spatial and temporal coverage while addressing the challenges posed by cloud cover during the monsoon season and the study area's comparatively tiny size. Secondary datasets and remote sensing were methodically attained and administered to maintain LULC categorization, validation, duration analysis, and flood delineation.

### 2.5 Data Analysis

The remote sensing analysis focused in a stepwise and systematic method to accurately outline the flood severity, flood extent, and variations in land cover/use (LULC) in Sohbatpur District. Google Earth Engine (GEE) completed all most important managing phase, assisted by mapping presentation and ultimate enhancement. Sentinel-1 SAR, Global Flood Awareness System (GloFAS), and Landsat-8/9 data were used in the analysis to overcome sensor limitations and produce reliable results.

## 3. Results and Discussion

### 3.1 Flood Extent and Severity Analysis of the 2022 Flood Event

The map discloses that flooding was extensive across the district, with the utmost severely distressed zones focused in the southern and central areas. Following areas are parallel to lowland floodplain conditions where floodwaters are inundated and persisted for prolonged periods. The spatial pattern in the figure 2 shows that flood damages vary based on topography, drainage characteristics, and closeness to water channels rather than being evenly dispersed.

A significant amount of the district was covered by areas rated as moderate to high severity, indicating widespread flooding during the 2022 event. Agricultural lands and floodplain areas were mostly linked to high-severity zones, indicating that productive land resources were significantly exposed to flooding. The extensive dissemination of inundated zones put emphasis on the extent of the catastrophe and displays the susceptibility of Sohbatpur District to risky hydrological actions.

The findings show that the 2022 flood event was categorized by widespread flooding and changing scales of the severity of flood throughout Sohbatpur District. The concentration of floods with high severity particularly in farmlands validates that agricultural practices were critically damaged. The geomorphologic topographies of district include low elevation, poor drainage, and proximity to river systems that are susceptible to inundating, are harmonious with the experimental geospatial pattern.

The observed pattern—concentration of the most severe zones in the southern and central portions of the district and proximity to low-lying floodplains—aligns with established understanding that topography, drainage architecture, and distance to watercourses govern inundation susceptibility (Nugroho et al., 2026; Radočaj et al., 2020). The spatial configuration described in figure 2 and the correspondence between high-severity zones and agricultural lands corroborate the notion that productive land resources are disproportionately exposed to hydrological hazards during major flood events (Meem et al., 2023; Radočaj et al., 2020).

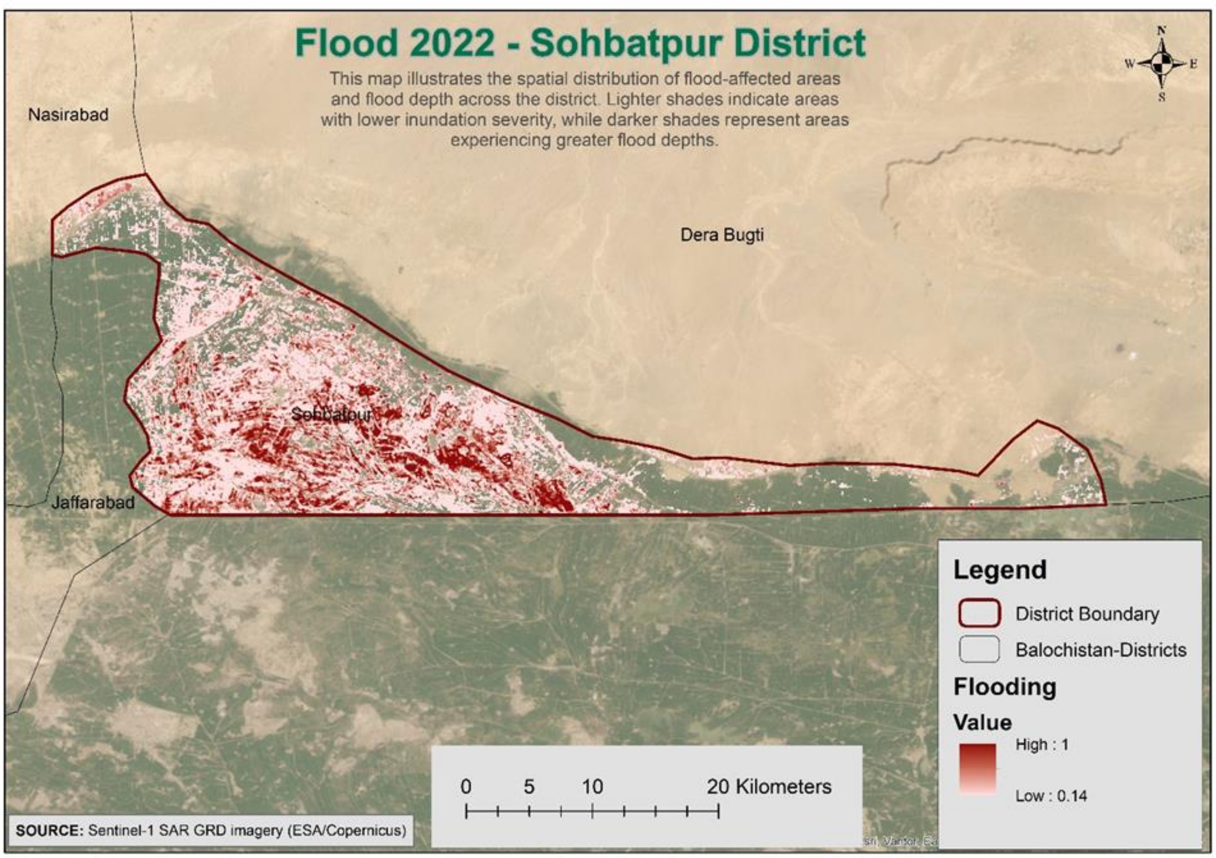


**Figure 2. Flood Extent and Severity in Sohbatpur District (2022)**

### 3.2 Spatial Pattern of Flood Hazard

Figure 3 illustrates the 100-year flood hazard map taken from GloFAS data recognizes areas vulnerable to inundation under a severe flood occurrence. This displays that a considerable part of Sohbatpur District falls in areas that are prone to flooding. The southern part of the district and the main drainage corridors are the main locations of high-hazard areas.

The spatial association between the flood map of 2022 and the map of 100-year hazard validates that current inundating mainly happened within parts already categorized by long-standing flood vulnerability. The concordance between the predicted flood hazard zones and historical flood occurrence indicates that the hydrological processes governing flooding in Sohbatpur have stayed mostly stable throughout time.

Across multiple sources, a consistent theme emerges: areas that are low-lying, poorly drained, and situated along major river corridors are essentially more vulnerable to inundation, and these same zones frequently coincide with regions of historical flood activity (Ekeu-wei & Blackburn, 2018; Psomiadis et al., 2020; Radočaj et al., 2020). The observed concentration of high-hazard areas in the southern portion of the district and along principal drainage channels aligns with this broader understanding of hydrogeomorphic susceptibility, suggesting that contemporary flood exposure is governed by enduring physiographic and hydrological controls rather than ephemeral factors alone (Cotugno et al., 2021; Hou et al., 2026; Theilen-Willige & Wenzel, 2019). Therefore, when it comes to planning for disaster preparedness, flood control, and infrastructure protection, high-risk locations should be prioritized.

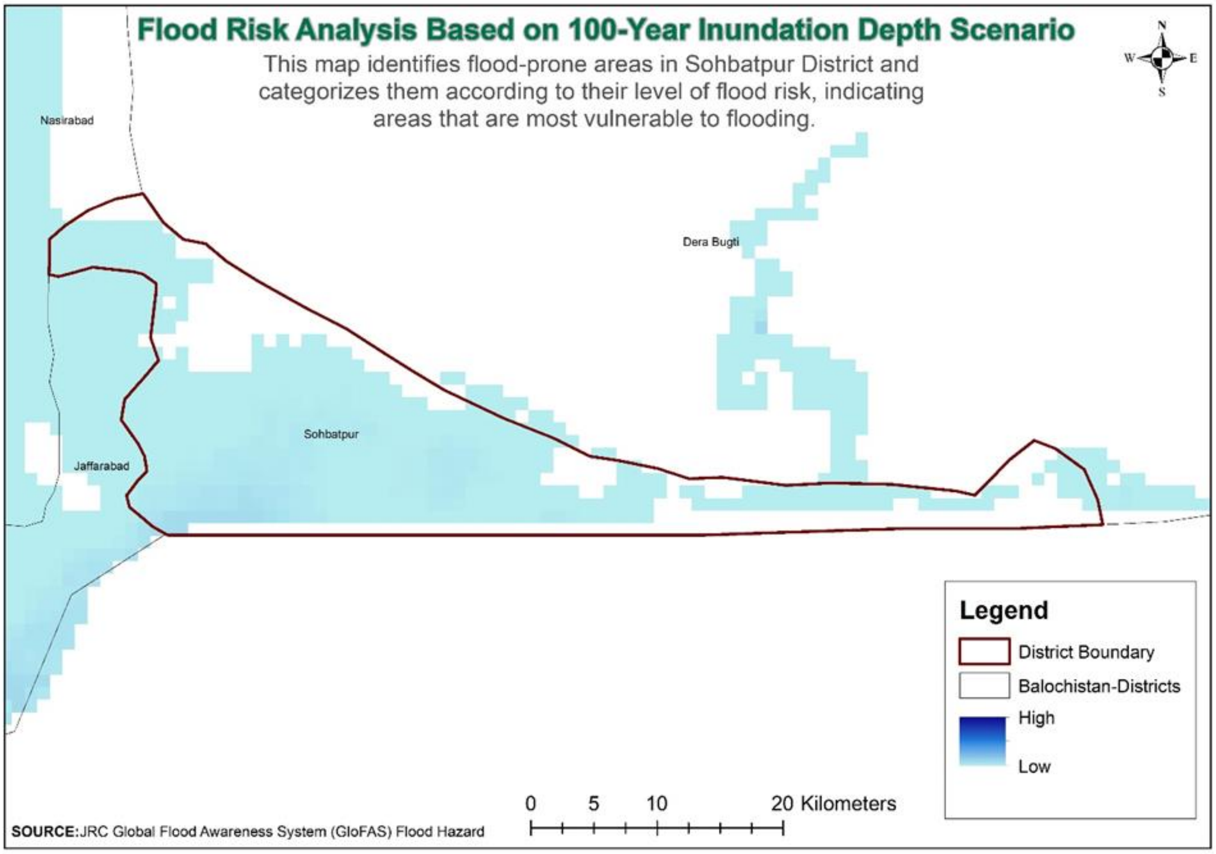


**Figure 3. 100-Year Flood Hazard Map of Sohbatpur District**

### 3.3 Land Use and Land Cover (LULC) Characteristics

Because many agricultural areas are located in flood-prone locations, the wide spread of irrigated agriculture is especially noteworthy. This spatial overlap suggests that fertile farmland is highly vulnerable to flood risks. The findings of the LULC determine that farming formulates the basis of the district's economy. Accordingly, food security, household income, and rural development are all directly impacted by floods on agricultural land.

Land-use exposure analysis reveals a pronounced overlap between irrigated agriculture and flood-prone zones, underscoring agriculture as both a critical economic sector and a primary exposure pathway for flood impacts. This finding corroborates the notion that agricultural lands situated in floodplains experience elevated risk, with direct implications for crop loss and rural livelihoods in Sohbatpur (Akram et al., 2024; Alahacoon et al., 2018; Dinh et al., 2021).

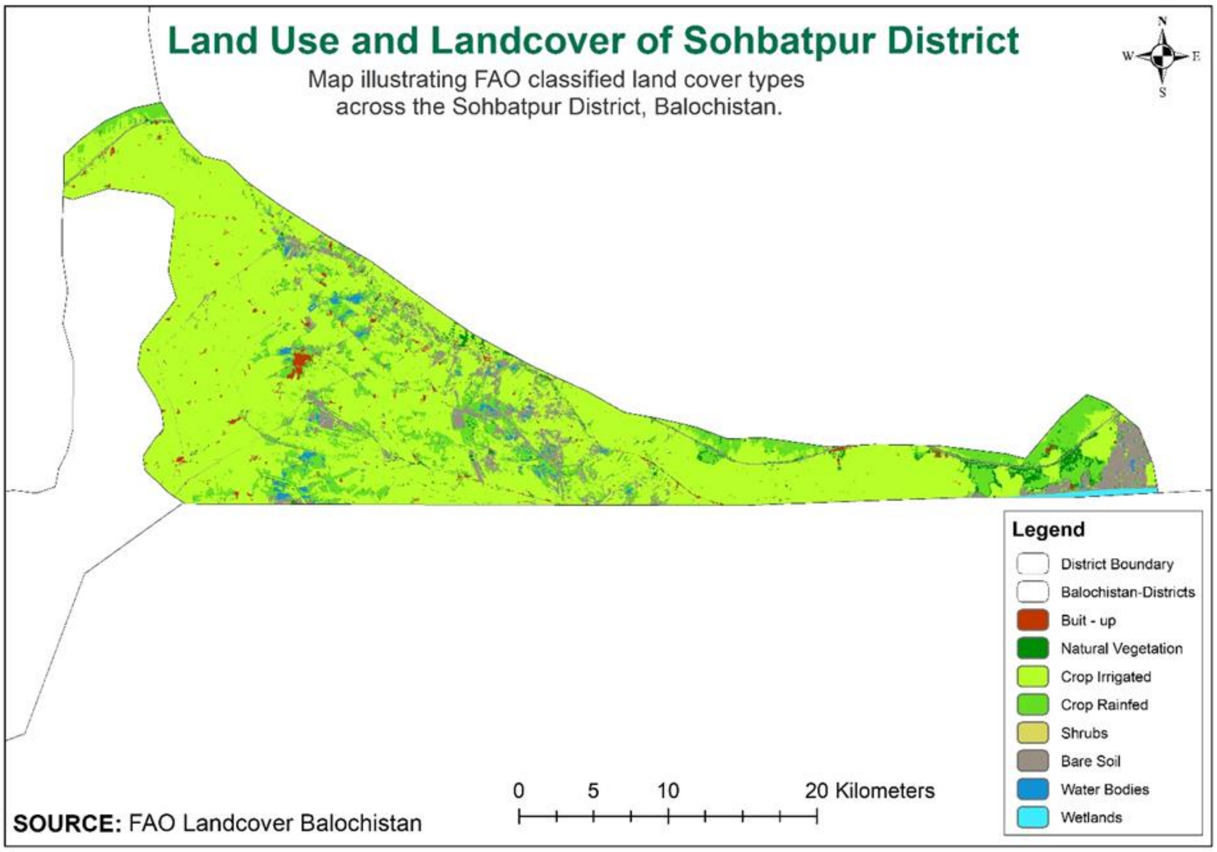


**Figure 4. Sohbatpur District Land Use and Land Cover (LULC) Map**

### 3.4 Flood Trends Based on Sentinel-1 Observations (2018–2024)

Annual flood area graph, which was created using Sentinel-1 imagery, depicts variations in flood extent from 2018 to 2024. Significant inter-annual fluctuation in flood occurrence was indicated by the considerable variation in flooded area between years. The largest flooded area was noted in 2022, indicating that the effects of the disastrous 2022 event are still being felt. Increased hydrological instability in the district is suggested by elevated flood extent in 2022, 2023, and 2024.

These results show that the risk of flooding in Sohbatpur is growing and could be impacted by extreme precipitation events and shifting climate conditions. This pattern aligns with a growing literature emphasis on using SAR observations for near-real-time monitoring of flood dynamics in data-sparse regions, where cloud cover persisting during the monsoon season often hampers optical approaches (Ekeu-wei & Blackburn, 2018; Hirpa et al., 2015; Uddin et al., 2019). The pronounced year-to-year fluctuations documented here are consistent with the understanding that flood exposure in this district is highly sensitive to antecedent hydrologic conditions, precipitation extremes, and catchment-scale runoff processes that govern antecedent moisture and peak discharge timing (Kar & Schumann, 2022; Wu et al., 2016).

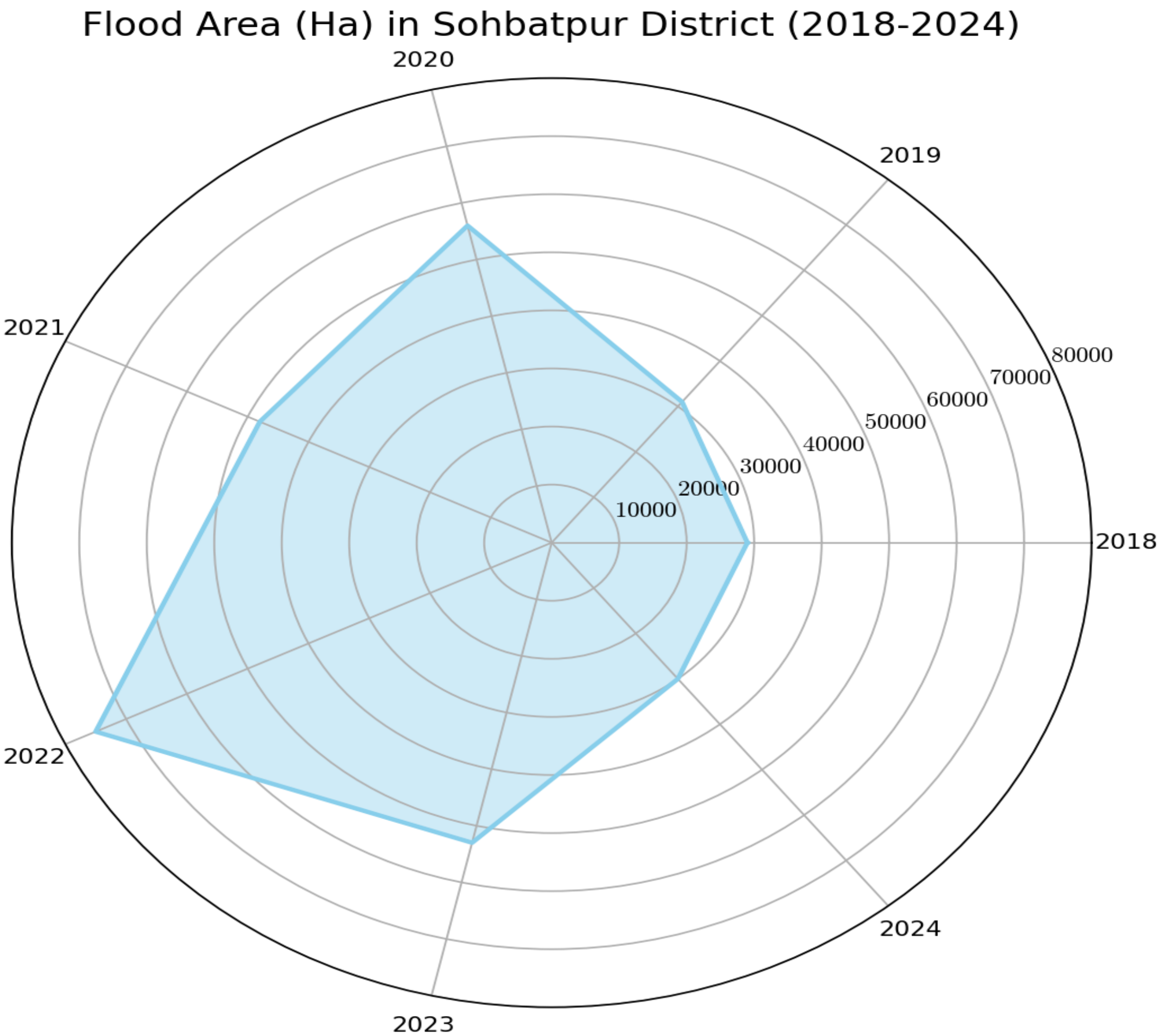


**Figure 5. Annual Flooded Area in Sohbatpur District (2018–2024)**

### 3.5 Flood-Induced Damages and Losses in Sohbatpur District

Sohbatpur District's infrastructure, livelihoods, and human settlements were severely damaged by the 2022 monsoon floods. The PDMA (2022) evaluation documented significant flood-related damages in Sohbatpur District, including 2,839 fully damaged homes, 10,980 partially damaged homes, 226.75 km of damaged roads, and 7,515 animal losses (Table 1).

Furthermore, as per the findings it is estimated that approximately 226.75 km of road infrastructure were reported to be damaged, validating that at what extent transportation sector was affected. In different localities of the district, the loss of road infrastructure intervened with access to markets, mobility, and emergency assistance and rehabilitation services. Livestock losses were another substantial impact of the flood, 7,515 animals have been reported missing.

As we know that rural communities depend on cattle for both income and food security, these damages intensified the impact in such rural areas which were economically susceptible. Similar findings were reported in other areas of Balochistan during 2022 floods which affected the province badly (Ambreen et al., 2026; Mengal et al., 2026; Rehman & Mengal, 2025; Ullah et al., 2026).

As per the PDMA assessment report, Sohbatpur district was severely affected by a substantial flood disaster. The severity of the damages presents Sohbatpur district vulnerable to severe flood occurrences and accentuates to make planning for disaster management which include before and after the disaster preparations as will, to improve infrastructure, and to adapt efficient flood risk management plans to minimize future flood impacts.

**Table 1: Flood Damages in Sohbatpur District (PDMA, 2022)**

| District Name | Causalities due to flood | Injuries | Houses Damaged Completely | Houses Damaged Partially | Road Damages in (km) | Livestock Losses | Bridge Damages |
|---|---|---|---|---|---|---|---|
| Sohbatpur | 1 | 4 | 2839 | 10980 | 226.75 | 7515 | None |

### 3.6 Human Habitation Expulsion in Sohbatpur District due to the 2022 Floods

The impacts of 2022 monsoon floods in Sohbatpur district were so severe that the expulsion of population from the district occurred in a large scale. As per the Flood Response Baseline Assessment carried out in October 2022 conducted by the International Organization for Migration (IOM), about 6,183 households, or roughly 40,376 people, were momentarily displaced from their homes due to flood inundation all over the district. It is estimated that approximately 223 villages were displaced, validating the fact at what extent disaster produced humanitarian effects extensively. This aligns with research that disasters trigger migration (Rehman et al., 2019).

The catastrophe severely changed settlement patterns throughout the district and impacted many settlements, as Table 2 illustrates.

**Table 2: Sohbatpur District's Displaced and Returning Population (IOM, 2022)**

| District Name | Temporarily Displaced Households (TDPs) | Temporarily Displaced Persons (Individuals) | Returning Households | Returning Persons | Villages with displaced populations |
|---|---|---|---|---|---|
| Sohbatpur | 6,183 households | 40,376 persons | 9,365 households | 60,065 persons | 223 villages |

### 4. Policy and Practical Implications

The results offer concrete inputs for disaster risk reduction in Sohbatpur: identify high-priority agricultural zones for flood-proofing, prioritize drainage improvements in southern-central lowlands, and design climate-resilient agricultural practices to mitigate crop losses in flood-prone districts.

### 5. Conclusion

The analyzed study provides a data-driven assessment of how the 2022 monsoon flood affected Sohbatpur District, Pakistan, by integrating Sentinel-1 SAR, MODIS-based LULC, Landsat-8/9, and GloFAS 100-year flood hazard information. The LULC analysis establishes irrigation agriculture as the dominant land-use category and highlights a persistent overlap between irrigated cropland and flood-prone areas, implying substantial exposure of productive lands to inundation and consequent implications for food security and rural livelihoods. This study provides a robust, data-driven basis for disaster preparedness, agricultural planning, and flood-risk management in Sohbatpur, and offers a scalable methodological template for similar districts facing cloud-prone, flood-prone environments where SAR data can complement optical LULC products and hazard models.

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