

## **URBAN SPRAWL IN FLOOD-PRONE AREAS IN SKARDU DISTRICT. A GIS-BASED ASSESSMENT**

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### **ABSTRACT**

This work studies the trend of urban expansion into Skardu District's flood-prone areas from 2020 to 2025 through the integration of selected spectral indices and subsequent supervised classification in the Google Earth Engine platform. The Sentinel-2 summer composites were used for generating NDWI and NDBI, which facilitated the detection of surface water changes, moisture conditions, and built-up development. The NDWI analysis has shown prominent hydrological alterations across the district, including water body expansion on low-lying alluvial plains and the formation of moist flood-affected zones adjacent to the river channels. NDBI assessment showed a rise in built-up activity across accessible valley floors, accompanied in some locations by surface exposure consistent with erosion or sediment deposition following flood events. Supervised classification distinguished four major land-cover classes built-up, water, bare land/rock, and glacier allowing a clear comparison of land-cover distributions between the two years. Integration of index-based change detection with land-cover classification allows for a full understanding of how natural hydrological processes and human settlement growth together reshape the landscape. The results show that Skardu urban growth has continued to focus on riverbanks and alluvial fans, which are those surfaces that showed measurable hydrological change and represent a growing intersection of settlement expansion and flood-prone terrain.

**KEYWORDS:** Google Earth Engine, Flood Mapping, NDWI, NDBI, Supervised Classification, Sentinel-2

### **1. INTRODUCTION**

The movement of people from rural to urban areas in growing numbers is leading to expanding growth of urban areas (Mahtta et al., 2022; Tacoli, 2003). Urban rural migration is expected to grow rapidly, with projections that tell us that more than half of the world population will be living in cities by 2050 (Mahtta et al., 2022; Tacoli, 2003). The effect of urbanization is deep, as it impacts geographical landscapes, it changes the way the land cover and land use is done, and it contributes heavily to environmental challenges and disaster risks which affect everyone globally (Mahtta et al., 2022; Roy et al., 2022). Pakistan has the fastest urbanization rate in South Asia, as one-third of its population lives in cities currently, and it's expected to increase to 50% by 2025 (Rahman & Khan, 2025; Sathar & Arif).

Gilgit-Baltistan has been affected with climate change and rapid unplanned urban expansion that has been done without proper planning and regulation. Increasing population growth along with land use change is also a crucial reason (Shah et al., 2025). This has intensified the vulnerability of flood compared to the past flooding. Increase of urban growth along the riverbanks has exposed the population to flood hazards (Ahmad et al., 2023; Shah et al., 2025). System of urbanization has led to increased pollution and deforestation; poor waste management also has a bad impact. These processes acts as a catalysts which leads to degradation of ecosystem (Ali & Rahman, 2024).

Skardu is surrounded by huge glaciers and mountains; it is in upper Indus basin where the Indus and Shigar rivers meet. Water and river sediments after heavy rainfall move quickly through the plain terrain, as it is very close to river channels, making Skardu naturally prone to floods (Qureshi et al., 2023). Around 260,000 people reside in Skardu according to 2017 Pakistan Census and the city is still in the process of expanding as more people migrate there from the nearby areas in search of better lifestyle including healthcare, jobs, education and more facilities . Moreover, Skardu is a tourist spot and is highly visited throughout the year for different seasons. Over the last two decades rapid urbanization has been observed without proper land use planning. The people are building houses, markets and hotels for tourists on the riverbanks and low-lying areas. This enhances the potential for flooding and destruction by it (Qureshi et al., 2023).

Skardu experienced major floods in the year 2010, where houses, roads, bridges were taken down by the massive floods (Shahid, 2024). In recent years like 2022, 2023 and 2025 flash floods and glacial outburst due to the increased levels of temperatures and patterns of irregular monsoon destroyed multiple valleys (Qureshi et al., 2023; Shahid, 2024). In such a flood prone area unplanned urban expansion in river terraces and Informal housing and roads without a proper drainage system, lack of flood zoning and early warning systems make Skardu even more vulnerable. Even though it is among the fastest-growing towns in Gilgit-Baltistan, very little research has used remote sensing or GIS to investigate growth of modern urbanization the areas of Skardu (Shahid, 2024). As a result, we do not know much about how Skardu's urban landscape is changing over time or how this growth might connect to areas along the Indus River and its tributaries that are at risk of to flooding. Although several researches have already discussed Skardu's exposure to floods, they mostly describe events of the flood and damages without examining and understanding how and where the city has expanded over time (Qureshi et al., 2023; Shahid, 2024).

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There are no studies that have employed Sentinel or Landsat satellite imagery to map land use and land cover changes or combined GIS-based spatial analysis in exploring urban growth within the areas that are prone to floods. The other important and critical point is that the current evaluations of flood hazard also do not include much information on urban development, and it knows very little about the expansion of settlements could be contributing to increased local exposure. The increase in the number of settlements within Skardu district due to population, tourism, and immigration has triggered unplanned construction, especially along the river sides and low-lying floodplain (Ali, 2024). This research is significant as GIS and remote sensing methods are utilized to present and understand the temporal and spatial relationship of flood risk and urban sprawl. The maps created will show the level of urban encroachment into dangerous areas by incorporating temporal satellite images with digital elevation models (DEM). In Skardu and other similar areas with similar environmental issues the findings can be used for decision-making by the responsible authorities to promote climate resilient and planned urban development, identifying risk free zones and supporting sustainable use of land. This research work evaluates urban expansion in flood prone areas of Skardu district using GIS and remote sensing techniques. To develop GIS-based maps and propose strategies for sustainable land-use and planned construction for Skardu district.

### **1.1. Study Area**

Skardu District has been selected for the investigation of the extent of new development in flood-prone areas and recent growth of settlement. The district falls within a mountainous area with active rivers, steep slopes, and the Indus and Shigar rivers carrying a lot of glacial meltwaters. Most settlements are found along the banks of rivers, valley bottoms, and alluvial fans since there is very little flat land available. Over the last couple of years, especially since the major floods in 2022, 2023 and 2025, considerable physical changes have been seen in the landscape. Physical changes such as extensive sediment deposition, newly formed waterbodies, and shifting channels make the area ideal for a geospatial assessment of flood risk and urban sprawl (Ali, 2024).

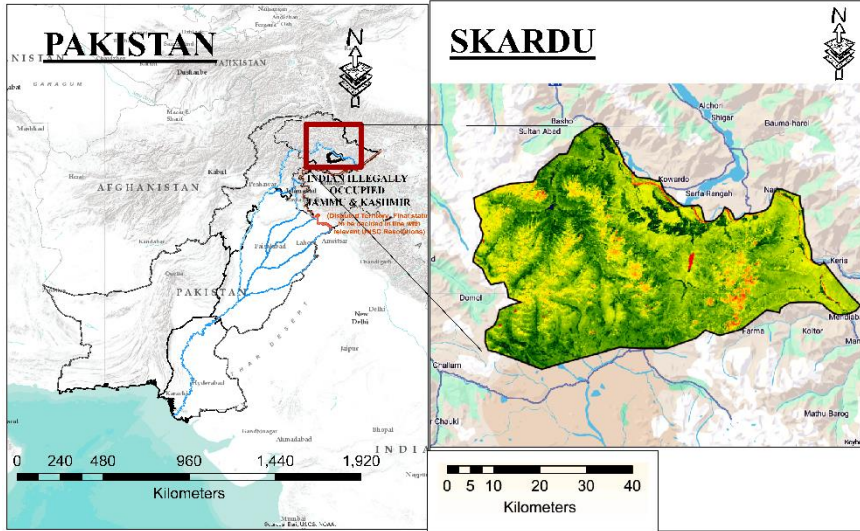


Figure 1: Study Area

## 2. MATERIALS AND METHODS

### 2.1 Methods and Data Sources

The methodological workflow consisted of data preprocessing, index computation, supervised classification, and multi-temporal change detection. Sentinel-2 Surface Reflectance (S2\_SR) imagery with 10–20 m spatial resolution was used because of its atmospheric correction to Bottom-of-Atmosphere reflectance. The CLOUDY\_PIXEL\_PERCENTAGE < 20% metadata field was applied as an image filter to retain only images with very minimal cloud cover (Roca et al., 2022). Images from June to September were selected for the two years, as summer provides distinct river channels, negligible seasonal snowfall, and clear visibility of land surfaces. All images were cropped to the Skardu District's administrative boundary to ensure consistency during analysis (Amrutha et al., 2023).

For 2020 and 2025, median composites were created to lessen noise caused by haze, cloud shadows, and abrupt variations in water levels. Median composites are chosen because it offers a consistent depiction of conditions that are seasonal and it's efficiently eliminated outliers. Digital elevation model from SRTM is used to calculate slope. Pixels with slopes greater than 35° were masked out since settlements do not take place on steep slopes, it is used to prevent mountainous terrain from being classified as barren land due to any mistake.

Since settlements do not occur on steep slopes, pixels with slopes greater than 35° were masked out to prevent mountainous terrain from being mistakenly classified as built-up or barren land.

To detect changes in water bodies, moisture levels, built-up areas, and exposed sediment, various spectral indices were created. A difference layer showing the hydrological variation between 2020 and 2025 was created, and the NDWI for both years was generated to portray soil moisture/water extent variations (Cui et al., 2023). The NDBI was developed to distinguish the built-up surface from barren surfaces. This enabled viewing of changes due to flooding, erosion-driven sediment exposure, and settlement expansion. These indices offered crucial information about surface changes over the course of the study.

For both years, land-cover maps were created using supervised classification (Roca et al., 2022). Built-up land, water, rocky or barren surfaces, and glaciers or snow were found to be the four main classes. To accurately represent each class, training points were manually digitized. To increase class segregation, the Random Forest model employed derived indices (NDVI, NDWI, and NDBI) in conjunction with Sentinel-2 bands B2, B3, B4, B8, B11, and B12. A 120-tree Random Forest classifier was trained using the dataset, which was split into 70% training and 30% testing samples. A confusion matrix was used to evaluate accuracy, and the Kappa coefficient and overall accuracy will be presented to verify classification reliability (Cui et al., 2023). The shadow areas were excluded to avoid the unrealistic classification of built-up pixels on steep terrain, and a slope mask was applied (Sathyanarayanan & Tantri, 2024). Thereafter, these resulting maps for 2020 and 2025 have been used in change analysis, focusing on those areas that have changed from built-up land into water as indicators of infrastructure loss.

## **2.2. Data analysis**

Spectral indices and land-cover maps for the two years were compared to detect changes. This process showed where river channels moved, where built-up areas grew or shrank, and where water spread into new zones. Additionally, it indicated places where fresh sediment surfaces were exposed to erosion and areas of new construction on floodplain. Built-up pixels from the 2020 classification were crossed with water pixels from 2025 to identify infrastructure loss. Pixels that changed from built-up to water were classified as flood-damaged or lost infrastructure. All datasets were processed in the WGS 84 / UTM Zone 43N projection to maintain spatial consistency. The final outputs were exported as 10-meter GeoTIFF files using Google Earth Engine (Roca et al., 2022) and were visualized and validated in ARC Map for map layout preparation. Area statistics were generated for each land-cover category to quantify the magnitude and direction of change. The overlap between newly expanded settlement areas and zones showing increased water presence was examined to

understand the extent of urban development occurring in flood-prone areas.

### **3. Results and Discussion**

Skardu is undergoing a transformation as its population grows and settlements is outgrowing from the old town, urban advancements is reshaping the landscape. More land is being converted for housing, agriculture, and infrastructure, cause pressure on natural resources. At the same time, the sensitive environment of the region already stressed by glacier melt, causing shift of river channels, and recurring floods absorbs the impact of these human activities that keep expanding (Sameer et al., 2025). Our study examines this changing landscape using supervised classification of satellite imagery.

#### **3.1. Normalised Difference Water Index**

The NDWI map for the year 2020 Figure 2 represents very limited areas with high moisture or those which are rich in water, with low NDWI values dominating most of the district. This pattern reflects normal summer conditions in Skardu, where rivers remain within their channels and moisture is limited to narrow belts scattered across agricultural fields.

By contrast, the NDWI map for 2025 Figure 3 reveals a starkly different distribution of landscape moisture. The extent of moderate to high NDWI values increased, especially along valley bottoms, river terraces, and the floodplains of both the Indus and Shigar rivers. This reflects residual hydrologic consequences of the major year of 2022 flooding event that rearranged the positions of channels of river like left in their wake large expanses of moist or recently flooded land. The surface in 2025 is far moister than the dry 2020 baseline, with much of the floodplain remaining hydrologically unstable even many years after the flood (Sameer et al., 2025).

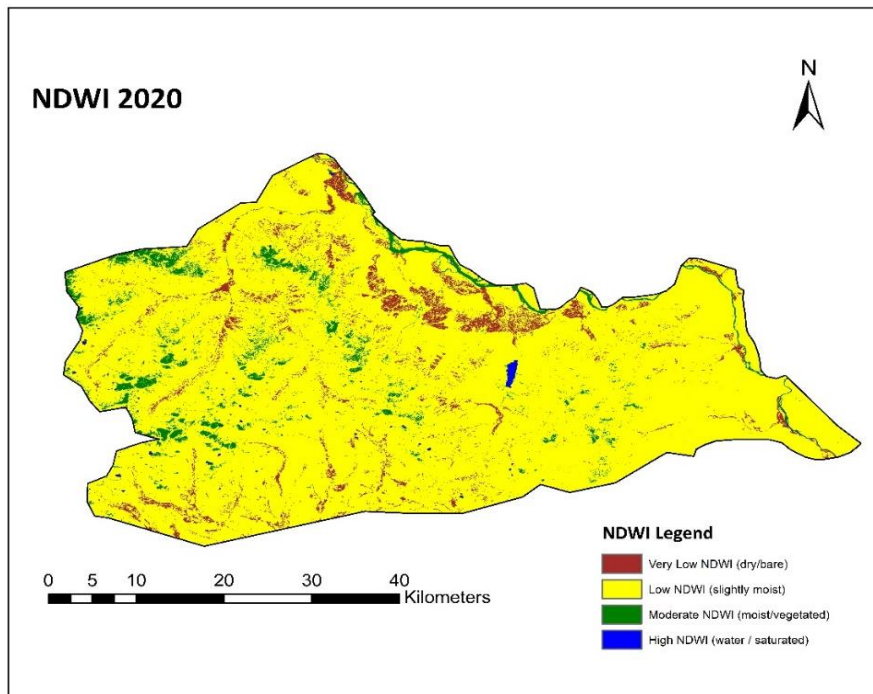
These differences are illustrated more explicitly by the NDWI change map in the years between 2025-2020 Figure 4. Large zones of continuous yellow in Figure 4 correspond with areas throughout Skardu that saw NDWI increases of +0.05 to +0.20, reflecting the wide presence of moist soil, saturated sediments, and locations that saw a temporary rise in water level. Spatially, these extensive yellow patches point out that flooding was not contained within narrow river corridors but rather extended across whole valley bottoms and alluvial fans-the exact same places where most new settlement growth is occurring. This represents a major overlap between the zones with increased flood impact and the zones with urban expansion.

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The analysis also identifies 82.32 km<sup>2</sup> of new water surfaces in 2025 with NDWI > 0.20. These represent areas where water either accumulated on temporary basis during the flood or where river channels expanded or shifted. Many of these new water surfaces show up along the Indus River, where the channel migrated. Smaller clusters of new water pixels also show up in agricultural depressions and areas that most likely experienced ponding during the 2022 flood.

The flood-affected moist land classification covers a much larger area of 1,057.81 km<sup>2</sup>, representing those areas where NDWI increased moderately due to sediment deposition, soil saturation, and residual surface wetness. The magnitude of this widespread increase in moisture agrees with ground observations where the 2022 floods inflicted long-lasting geometric disturbances and deposited fresh sediments which retain water more strongly than the older compacted surfaces (Sameer et al., 2025).

On the contrary, 87.57 km<sup>2</sup> exhibits a very high negative NDWI change (< - 0.05), indicating drying or receding water zones; these represent riverbank zones where channels had contracted after the flood, drained agricultural fields, and patches where temporary floodwater evaporated or infiltrated into the ground. These drying zones indicate the dynamic nature of Skardu hydrology, where water spreads during floods and then pulls back into narrower channels afterward.



**Figure 2: NDWI 2020**

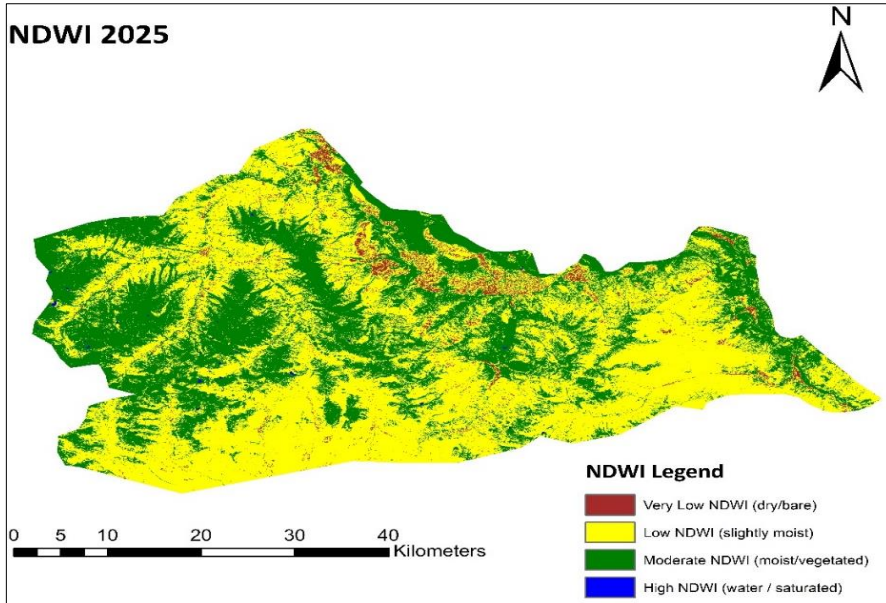


Figure 3: NDWI 2025

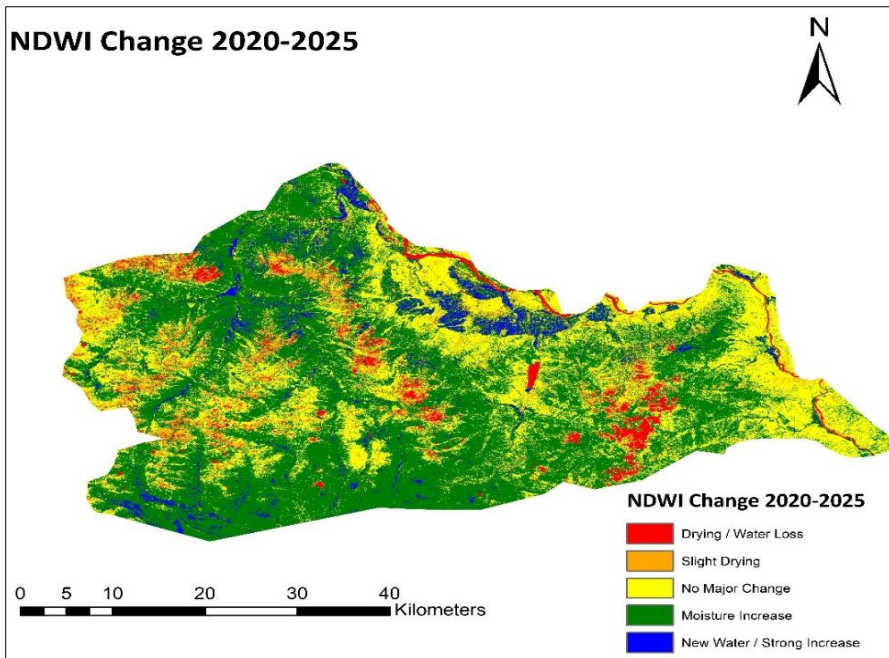


Figure 4: NDWI change

Overall, the NDWI results demonstrate that floodplain of Skardu's underwent transformation between the years 2020 and 2025, it was substantial hydrological transformation. The presence of new water bodies, large expanses of moist sediment, and shifting river margins confirm the long-term physical impact of the 2022 floods. The important

part is that many of these newly saturated or areas that got affected by flood coincide with regions of urban growth, indicating that recent settlement expansion has increasingly occurred within zones that are prone to floods. This connection establishes a strong foundation for evaluating the risks associated with continued urban development in Skardu's floodplain environment that is weak and fragile.

### **3.2. Normalized Difference Built-up Index**

The Normalized Difference Built-up Index (NDBI) was used in the years between 2020 and 2025 for accessing changes in the exposed surfaces across the whole Skardu. Because NDBI is highly responsive to impervious surfaces, rock exposure, sediment deposits, and barren land, it provides an important indication of where settlement expansion occurred and where surfaces were stripped or altered by flood processes. The NDBI maps for both years show a similar overall spatial pattern, with higher values (yellow to red tones) concentrated in valley floors, alluvial fans, and settlement clusters, while lower values (blue to green tones) appear in densely vegetated or moist zones.

In the 2020 NDBI map Figure 5, large portions of Skardu's valley bottoms have high values of NDBI, indicating the presence of built-up areas and either rocky or barren surfaces. In contrast, many upland areas have low values, consistent with vegetation, moist surfaces, and glacial influence. The 2025 NDBI map Figure 6 shows distinct changes across several of the flood-impacted plains. Notably, the eastern and southern valley bottoms display enlarged areas of yellow-orange pixels. These reflect increased surface exposure with the expansion of built-up or barren patches, consistent with visible sediment deposition and consequent land striping resulting from the 2022 floods.

These surface changes are more apparent in the NDBI change map 2025–2020 Figure 7. Positive NDBI values (orange to red colors) indicate where the intensity of built-up areas increased, or flooding removed vegetation or compacted surfaces. Negative values (ranging from blue to cyan hues) show where moisture or vegetation increased, probably owing to prolonged saturation, regrowth on sediments that are affected by the flood, or wetness that is caused by flood in abandoned channels.

Using a change threshold of +0.10 for significant increases in exposed surfaces, the analysis indicates that about 193.31 km<sup>2</sup> of land exhibited strong positive change. This large value may indicate not only the expansion of urban areas but also the broad geomorphological modification resulting from flooding in 2022. Much of the increase comes from extensive scouring and exposed sediment boosting NDBI even

without infrastructure. The outcomes consequently point out how strongly flood processes shape the valley floor surface reflectance in Skardu.

On the other hand, areas with NDBI decline greater than  $-0.10$  represent possible built-up loss or increased vegetation/wetness. This change class covers approximately  $95.45 \text{ km}^2$ , and many of these patches coincide with zones where NDWI showed water expansion or prolonged moisture. This overlap indicates that several previously exposed surfaces were submerged, eroded, or replaced by moist sediment after the floods.

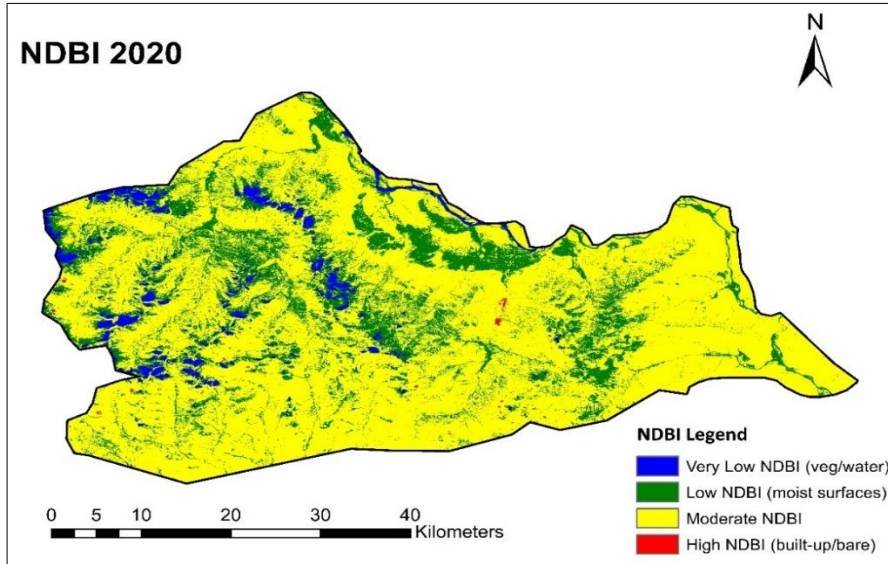


Figure 5: NDBI 2020

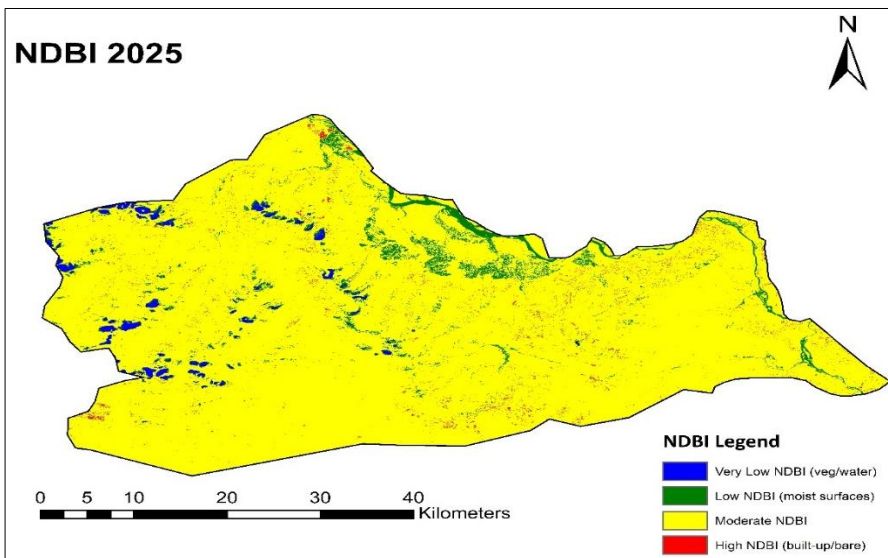
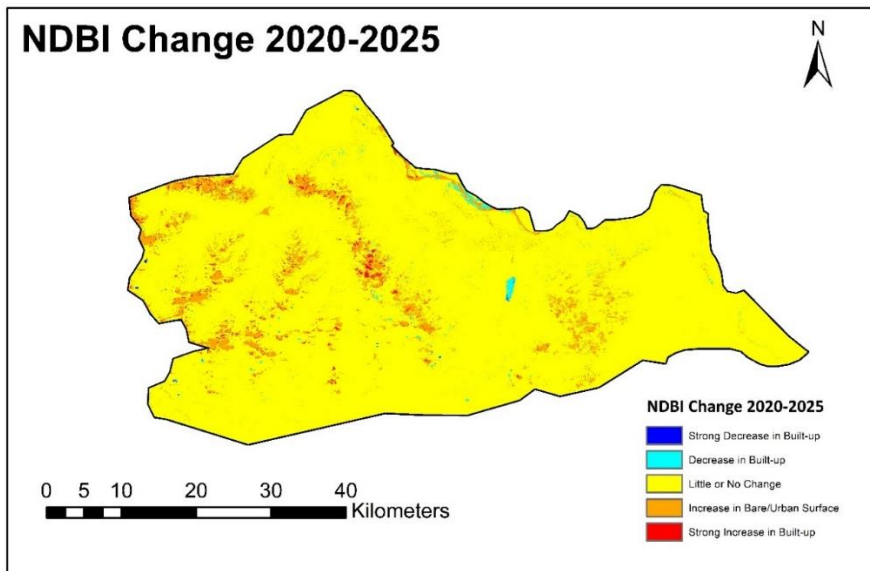


Figure 6: NDBI 2025



**Figure 7: NDBI change**

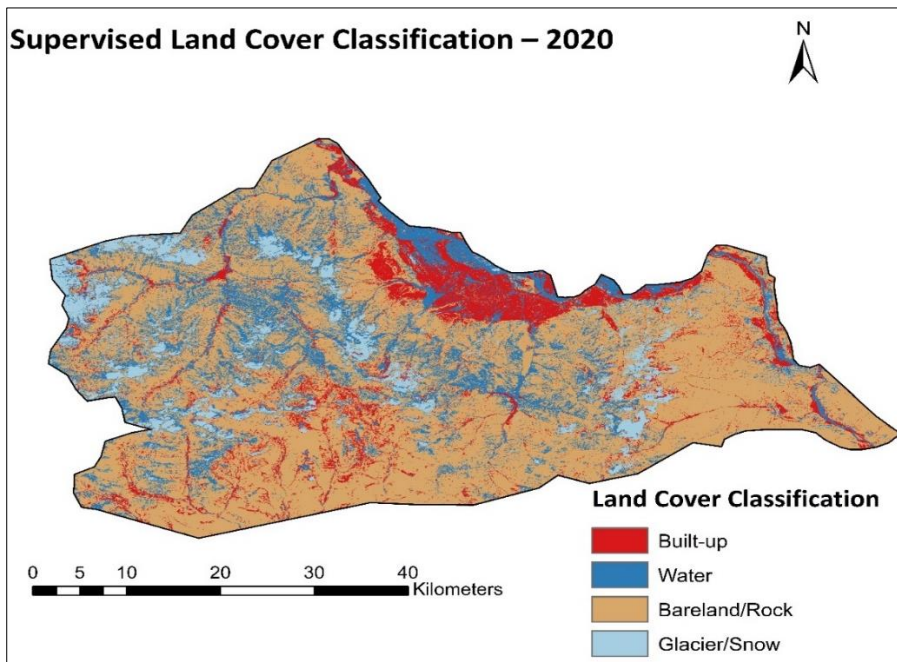
Overall, the results that are NDBI-based shows that Skardu’s built environment and surrounding land surfaces underwent considerable transformation between the year of 2020 and 2025. While part of the positive NDBI change reflects settlement growth in some locations, the majority corresponds to sediment exposure and land stripping caused by the 2022 flood events. The combination of positive and negative NDBI patterns indicates that urban development is occurring in highly unstable, prone to flood and that major geomorphic disturbances can erase or drastically modify surfaces that are built-up within a short period of time.

### **3.3. Supervised Classification**

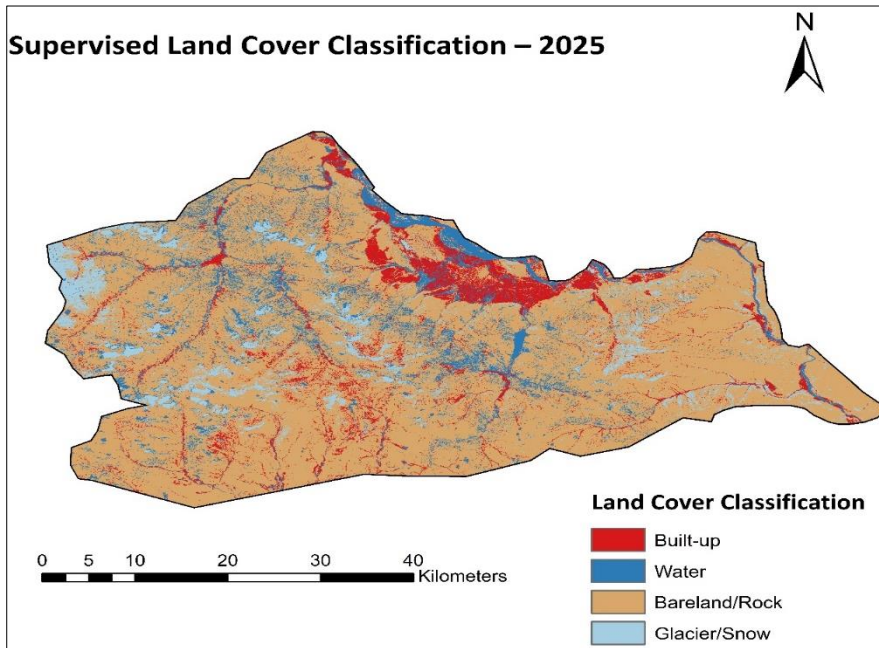
The result of the supervised land cover classification for the years 2020 and 2025 depicted clear spatial patterns of land that is built-up, water bodies, rocky surfaces, and glacial areas throughout Skardu District. The Random Forest classifier performed reliably in both years. It achieved an overall accuracy of 82.28% for the year 2020 and 78.78% for the year 2025, hence confirming consistent model performance despite surface changes caused by the 2022 floods. The confusion matrix for 2020 showed strong variation between the four classes, with especially high accuracy for distinguishing rock surfaces and glacial areas. The matrix for 2025 had a little decreased accuracy, as one might have expected due to the spectrally similar nature of many surfaces resulting from sediment deposition and moisture. Still, the classification was robust enough to support comparative change analysis between the two years.

Spatially, the Figure 8 classification for 2020 yielded a result of 215.53 km<sup>2</sup> for built-up land, essentially to be found along the corridor of Skardu Shigar, Satpara valley, and along the Indus River floodplain. Water bodies including rivers, lakes, and perennial channels covered an area of 369.93 km<sup>2</sup>, while barren and rocky land was the dominant feature of the landscape with 1214.22 km<sup>2</sup>. Glacier-covered surfaces covered 133.95 km<sup>2</sup>, essentially concentrated in the northern and north-eastern high-altitude zones. This baseline shows pre-flood surface conditions where the settlement distribution and land cover can be considered quite stable.

The year 2025 classification Figure 9 showed spatial changes, representing floods' geomorphic effects of the 2022. The built-up area was reduced to 169.09 km<sup>2</sup>, representing the loss of more than 46 km<sup>2</sup> of built structures. The losses are consistent with the field reports of housing cluster damages situated exactly on floodplains and alluvial fans. Water bodies reduced to 201.80 km<sup>2</sup> in 2025, and this decrease does not suggest lower flood activity; it indicates the disappearance of short-term floodwater developed during 2022 and contraction of channels following deposition of sediments. Correspondingly, rock and barren land increased significantly to 1409.13 km<sup>2</sup>, indicating the frontal exposure of fresh sediment, scoured soil, and eroded land surfaces. Glacier area increased marginally to 153.61 km<sup>2</sup>, although this change probably represents variability in classification rather than any real glacial advance.



**Figure 8:** Supervised Classification 2020



**Figure 9:** Supervised Classification 2025

A pixel-level comparison between the 2020 and 2025 classified maps was done to specifically identify destruction induced by the flood. Regions that were built-up in 2020 but turned into water in 2025 were extracted as damaged infrastructure. This intersection revealed 13.08 km<sup>2</sup> of area that is built-up that was completely lost to water by year 2025. These zones form a continuous pattern along the Indus River floodplain and the Shigar valley which coincides with the major flood routes reported during the flood event in the year 2022.

In summary, the land-cover transitions in the supervised classification results are distinct and quantifiable for both urban expansion and flood hazards. The loss of built-up area, the significant gain in rocky and barren surfaces, and the documented 13 km<sup>2</sup> of lost infrastructure together stress how devastating floods are to settled areas. At the same time, the maps indicate that substantial areas of new and existing settlements are still being placed on highly unstable alluvial plains. When combined with NDWI and NDBI analyses, classification results strongly reinforce the conclusion that urban sprawl in Skardu takes place directly within dynamic flood-prone landscapes and is thus increasingly vulnerable to future hazard events.

#### **4. CONCLUSION**

This study investigated the Skardu District's pattern of urban expansion and flood exposure by integrating satellite-derived spectral indices with a

supervised land-cover classification for the years 2020 and 2025. Combining NDWI, NDBI, and classification analyses offers a multilayered insight into how hydrological changes and changing surface conditions affect the settlement pattern within this very dynamic mountainous environment.

Clear changes in the distribution of water and moisture were evident in the valley floor based on NDWI results. The river corridor indicated channel migration and temporary flooding, while local increases in flooded and glacier-fed hydrology were observed. On the other hand, the NDBI indicated a gain in the built-up or exposed surfaces only in some locations, reflecting recent development being fostered on the alluvial plains and deposits created by past floods. Together, both hydrologic processes and human activities are reconfiguring the district, as revealed by these two indices.

The spatial distribution was further detailed for the categories of built-up areas, water bodies, rocky terrain, and glacial surfaces by the use of supervised classification. When the two maps classified were compared against each other, some key land-cover changes became apparent, especially the expansion of built-up areas along riverbanks and flat terraces, which are naturally flood-prone. A small fraction of built areas in 2020 seemingly transformed into water-covered surfaces by 2025, indicating that this infrastructure has probably been affected by flooding or erosion directly.

## **5. RECOMMENDATIONS**

- Limit future development in areas that are flood-prone specifically those areas that, according to the NDWI change maps, show a persistent moisture increase or a recurrent water expansion, must be declared no-construction zones. The expansion of settlements in these areas increases long-term vulnerability.
- Implement controlled urban expansion on stable alluvial fans as results of NDBI indicate that most new development is occurring on accessible, flat ground near rivers. These locations require strict planning standards for the land use, constructions that are resistant to flood, guidelines, and drainage planning.
- Introduce an early warning and monitoring system using data from the satellite and to do so NDWI and NDBI must be recalculated annually to track changes in hydrological shifts, glacier melt impacts, and unregulated construction. GEE provides a low-cost and repeatable technique for real-time risk monitoring.

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- Prioritize restoration of flood-damaged zones as the areas labelled “built-up in 2020 and water in 2025” are those zones which have likely lost physical infrastructure. They should be surveyed and stabilized by embankments, vegetation buffers, and engineered barriers.
- Develop a district-level urban growth model because Skardu needs a long-term spatial growth plan considering rapid settlement development seen between 2020 and 2025, based on terrain, slope, and hydrological hazards to guide further sustainable expansion.
- Strengthening local governance and building regulations by zoning, incentives to relocate, and flood-resistant infrastructure codes are some measures necessary for informal construction near the riverbanks to reduce losses experienced lately due to floods.
- Encourage community-based awareness programs and those living within the vicinity of high-risk areas should be educated on migration of rivers, recurrence of floods, and hazards of occupation of alluvial plains and riverbanks without protection.

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