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Flood Monitoring and Damage Assessment of Gwadar City Using GIS and Remote Sensing

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Abstract

Monitoring floods using Geographic Information System (GIS) and Remote Sensing (RS) is important for understanding the damages caused by flood and spatial patterns of inundation. For this study we use supervised image classification and freely available Sentinel-2 multispectral imagery and ASTER Digital Elevation Model (DEM) to map spatial extent of flood and assess damages to infrastructure caused by the February 2024 flash flood in Gwadar City. The process of Image classification was carried out using the Maximum Likelihood Supervised in ArcMap 10.8. In order to find the spatial pattern of flood we divided the land-use and land-cover (LULC) in Gwadar city into four classes. They were built-up areas, open/barren land, vegetation, and water bodies. The results of the analysis revealed extensive transformation of land-use and land-cover classed after the flood. The results showed that water bodies expanded from 0.54% to 15.26% and significant reductions in barren land (−18.35%), built-up areas (−7.89%), and vegetation (−38.26%). To assess the damages to infrastructure the whole land-use and land-cover was digitized from high-resolution mosaicked Google Earth images. Later the flood or water mask was overlaid on the land-use and land-cover layer. This approach provided us with a clear visualization of the extent of damages and inundation across different land-use and land-cover classes. The results indicated that residential areas were the most affected, with approximately 9.69% of all

households impacted, followed by commercial areas where about 3.55% of the total commercial units experienced flood damage. The classification achieved an overall accuracy of 89% and a Kappa coefficient of 0.84, confirming the reliability of the analysis. This research shows that using multispectral satellite data offers a cost-effective approach for flood mapping and damage assessment, which is particularly valuable for climate resilient urban planning in coastal Pakistan.
Keywords: Gwadar City; Flood Mapping; Remote Sensing; GIS; Sentinel-2; ASTER DEM; Land Use/Land Cover; Damage Assessment; Spatial Analysis.

1. Introduction

Flooding remains one of the most destructive natural hazards worldwide, particularly in coastal and arid regions where hydrological systems are poorly developed. In Balochistan, Pakistan's largest province by area, recurrent flash floods pose increasing risks due to erratic rainfall patterns, unplanned urbanization, and limited infrastructure (Rahman & Khan, 2019). Gwadar City, situated on the Makran coast, represents a rapidly developing urban hub facing both prolonged droughts and sudden, destructive floods.

With vast strategic & economic connotation, Gwadar has emerged as developing port city, situated on southwestern coast of Pakistan which is envisioned to become key hub for international trade & economic activities by linking Pakistan with Middle East, Africa & beyond. Swift urbanization in region vis-a-vis fascinated substantial investment has led to development of Gwadar Port & related infrastructure.

Natural disasters, primarily coastal & urban flooding makes Gwadar' geographical position vulnerable due to cyclones, storm surges & dense monsoon rains that can lead to stark flooding; quick urbanization via-a-vis natural disasters necessitates broad tactic to flood risk supervision & damage assessment.

Off late, Gwadar' vulnerability has been exposed by various major flood events underscoring need for better flood management strategies. Heavy damage to infrastructure, disruption of economic activities & displacement of communities were shaped by 207 & 2013 floods that underscored insufficiencies in current flood management strategies & significance of utilizing progressive technologies for flood assessment & its mitigation. Floods in 2024 had also validated vulnerability of Gwadar city to flooding & important need for vast damage assessment. Heavy damage to buildings, roads & utilities, caused by floods & heavy rain, underscored challenges posed by quick urbanization & scarce drainage infrastructure.

As far as academic field is concerned, methods for flood damage assessment with RS & GIS technologies used it this study makes it useful in academic field as well; by powering high resolution satellite imagery incorporated with numerous data processing methods such as NDWI, OBIA & hydrological modeling, this research enhances current body of knowledge & delivers outline that can be replicated in other urban & coastal settings by utilizing these procedures.

Incorporating multi source RS data with GIS is important for inclusive flood damage evaluation as described in this study. For reliable flood damage analysis & accurate flood mapping, integrating optical & radar satellite imagery is vital, hence proving that multi source data can be accurately utilized in disaster management research.

Modern flood assessment demands timely, spatially explicit data, which remote sensing and GIS provide with precision. The present study applies these tools to evaluate flood extent and damages in Gwadar city's following the February 2024 extreme rainfall event (ReliefWeb, 2024), using Sentinel-2 imagery. The research aims to map pre- and post-flood land-use and land cover, assess damages across major land-use and land cover types.

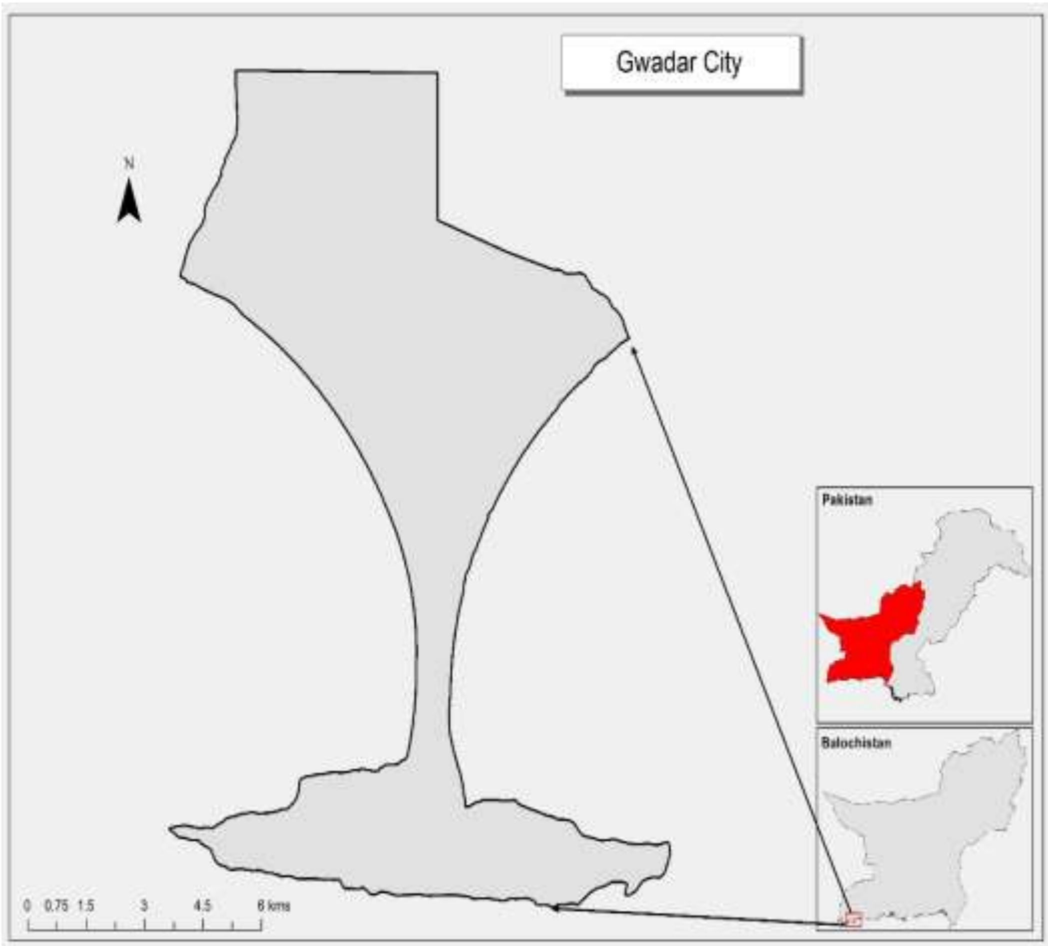
2. Methodology

2.1 Study Area

Gwadar city is situated in the southwestern Balochistan on the Arabian Sea. It is different from other parts of Balochistan which is mostly mountainous and plateaus. The city's terrain is mainly arid coastal plains, and some parts on the outskirts of the city is cultivatable land situated near the coast of the city.

Geographically Gwadar city is situated between 25°09'N latitudes to 25°24'N latitudes and 62°25'E longitudes to 62°38'E longitudes (Fig 1.0). The city has an area of 8,162 hectares. This geographical location and deep sea give it a very important place in regional and international arena. The city and the region around it experience an arid type of climate, where summers are very hot and winters and comparatively mild. The mean annual rainfall I the city is ranges from 6 to 9 inches (Pakistan Meteorological Department, 2020). Precipitation is not equally distributed throughout the year and occurs mainly in winters due to western disturbances, and some time the summer monsoon also brings some rains to this coastal city. Most of the rains recorded in January and February. Gwadar city is also prone to rare tropical systems which forms in Arabian sea and can cause devastation in coastal areas around it. (Rahman & Khan, 2019).

Fig. 1.0: Location of Gwadar City



2.2 Data Sources and Acquisition

Monitoring floods through satellite image analysis requires data from multiples sources and in various formats (Cihlar, 2000). For this study in Gwadar City freely available Sentinel-2 images and ASTER Digital Elevation Model (DEM) data were utilized. As we know that Sentinel-2 provides multispectral data with moderate spatial and high temporal resolution. This makes it suitable for detecting inundated areas, monitoring the spread of flood water , and assessing the impacts of floods (European Space Agency (ESA, 2015).

The data in form of satellites images for Sentinel-2 was acquired from the Copernicus Open Access Hub website. Fortunately, we were able to acquire the images for the dates that were required to us both for before and after the flood event of February 2024. These images due to multispectral nature offer detailed information in multiple bands, which supports the identification of water bodies, open/barren land, and other surface features that are considered relevant to flood analysis. The ASTER DEM was used to generate topographic information

such as elevation, slope, and drainage networks for the city. Both satellite images and digital elevation model can effectively be used in the analysis of floods and post floods damages assessment (NASA/METI, 2011).
All the spatial data was processed in ESRI's ArcGIS software which has great capability to handle both raster and vector data. Using satellite images and ground surveys allow us to the type of spatial analysis that is required for effective flood analysis and damages assessment.

2.3 Data Analysis

In order to know the area covered by each land-use and land-cover class before the flood, we classified a satellite image from the Sentinel 2 before the flood even occurred. This classification gave us a clear picture of LULC in Gwadar city (Fig 3.0). After that, we classified the image (Fig 4.0) which was captured right after the flood event, and we were fortunate to have the image for that date with almost clear sky. The cloud free image allowed us to carry out a better and more reliable classification process. After the classification process, we overlaid the water mask extracted from the classified image and overlaid it on a digitized LULC layer derived from high-resolution Google Earth imagery, which were mosaicked and georeferenced with DGPS points. This helped us in assessing the damages of floodwater to infrastructure in the Gwadar city.

3. Results and Discussion

3.1 Pre-Flood Image Classification Results

In order to know the land-use and land-cover classes and the area cover by each class we download and used the sentinel 2 image collected in January 2024. The image was classified using Maximum Likelihood Supervised process and the LULC was divided into four classes, these four classes were built-up areas, open/barren land, water bodies, and vegetation. This classification (Fig 2.0) provided us with crucial data about the land-use and land-cover of the Gwadar city for analyzing the flood event that occurred in the month of February.

Built-up Areas: The results of the analysis showed that built-up areas covered around **35.53%** of the total land surface in Gwadar city (Table 1.0). This represents the urban area of Gwadar city along with some suburban and few rural settlements. Before the flooding event these areas were in a compact and stable distribution but at the same time this distribution suggested vulnerability to floods and other disasters due the its nature and arrangement of settlements.

Table 1. Area covered by each class in Gwadar before the February 2024 flood

Class	Hectares	Acres	%
Open/Barren Land	5124.00	12661.40	62.77%
Water Bodies	44.13	109.05	0.54%
Vegetation	94.55	233.64	1.16%
Built-up Area	2900.25	7166.52	35.53%
Total	8162.93	20170.60	100.00%

- **Open/Barren Land:** This class represented around 62.77% of the total area of Gwadar city and it includes rocky terrain, hills, and unused land, open patches.

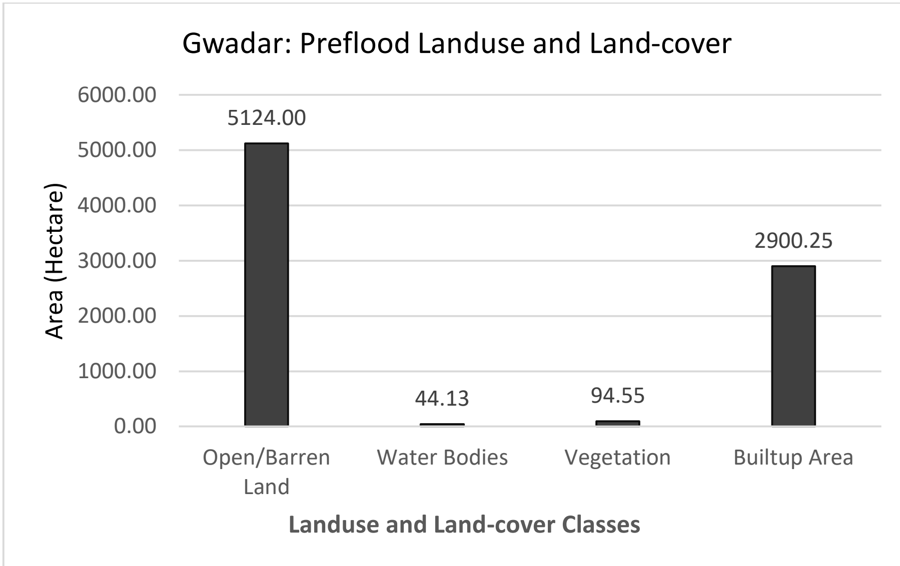


Fig 2. Graph showing LULC classification before flood

- **Water Bodies:** Water bodies covered only 0.54% of the total area of Gwadar city. It represented rivers, streams, and small lakes, ponds and stagnant water that formed the hydrological setup of the area.
- **Vegetation:** It constituted around 1.16% of the total surface area. Vegetation is concentrated mainly along cultivated spots, green belts, and natural patches. This class represented the relatively sparse vegetation cover in this costal setup.

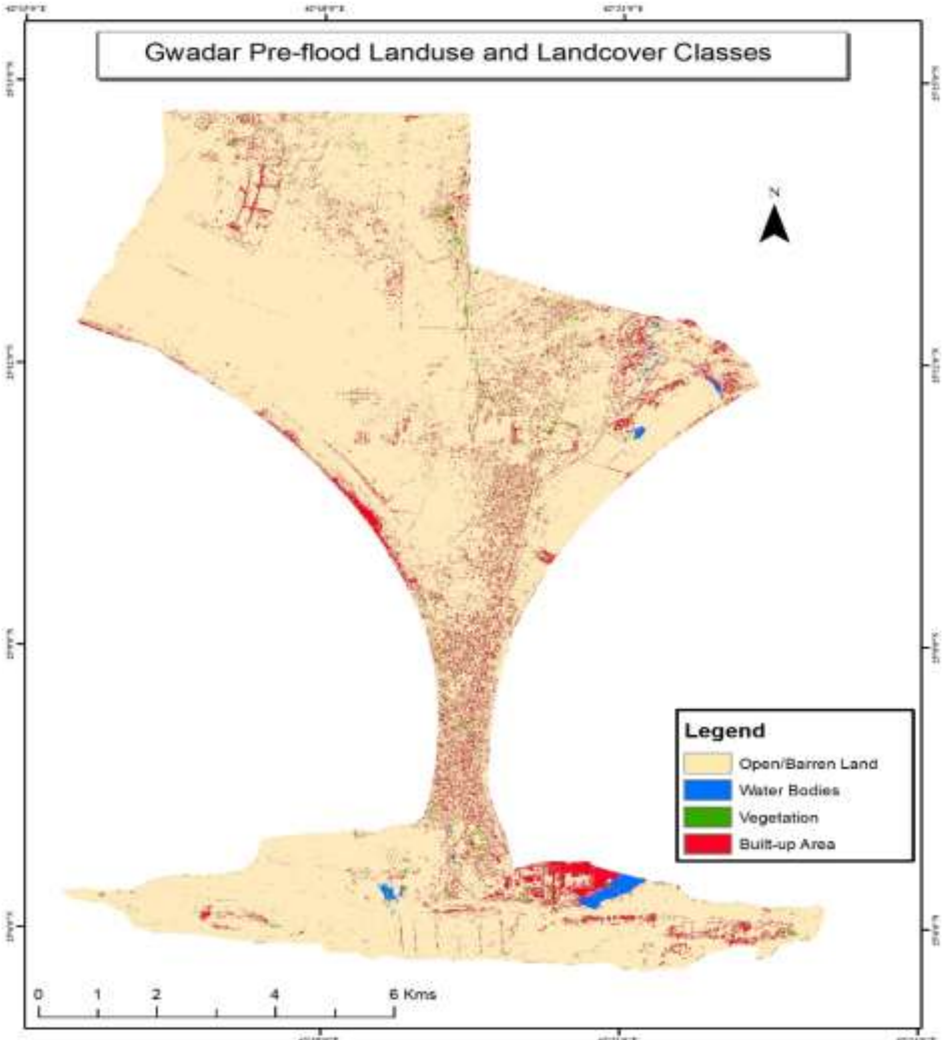


Fig 3. Pre-flood LULC Classification

3.2 Post-Flood Image Classification Results

In order to know the spread of flood water in Gwadar city the post flood satellite image of Sentinel 2 was classified in ArcMap. All the four classes such as built-up areas, Open/Barren Land, water bodies, and vegetation were extracted digitally with area of each class. The results of the analyzed imaged showed that flooding has significantly changed the surface cover within the study area.

- **Built-up areas:** This class accounted for 32.73% of the city's area. This includes urban area of Gwadar city along with some suburban and few rural settlements. Many urban areas experienced inundation, which reflects city's vulnerability flood water accumulation and inundation.
- **Open/Barren Land**: Open/barren land includes rocky terrain, mountains, uncultivated land and open patches etc. this is the dominated the landscape with 51.26% of the area covered by it.
- **Water bodies:** This class represented rivers, streams, small lakes, ponds and stagnant water and after the classification of the image it occupied 15.30% which reflects significant increase in its area coverage.
- **Vegetation:** Vegetation covered around 0.72% of the total area in Gwadar city. Vegetation was around 1.16% before the flooding event. The decrease shows the inundation of vegetation's to a significant level following the record breaking rainfall of 183 mm in 24 hours (ReliefWeb, 2024; The Nation, 2024).

The detailed area covered by each class is presented in Table 2.0.

Table 2. Area covered by each class in Gwadar after the February 2024 flood

Class	Hectares	Acres	%
Open/Barren Land	4184.00	10338.66	51.26%
Water Bodies	1249.21	3086.80	15.30%
Vegetation	58.37	144.24	0.72%
Built-up Area	2671.35	6600.91	32.73%
Total	8162.93	20170.60	100.00%

3.3 Change Detection

The results that were generated after classifying and analyzing the pre and post flood images of Gwadar city shows a significant impact of urban flash floods caused by heavy rains on land cover and land use patterns. In urban areas flash floods are generally caused by heavy and rapid rains which overwhelms the drainage system causing the overflow of water which in turn cause flood. The impact of floods on each landuse and landcover class is discussed below.

Open/Barren Land

The particular class of open/barren land experienced a decrease of 940 hectares (Table 3.0), which is around 18.35% reduction in land area. This drop in open land can be attributed to the flooding, which may have either submerged or transformed these areas that were once open/barren land. We know that in those cities where there is poor drainage and low elevation, the flood water often spread over wide areas which leads to the inundation of previously dry or open land. This reduction in open/barren land suggests that the flood has significantly impacted the open land in Gwadar city.

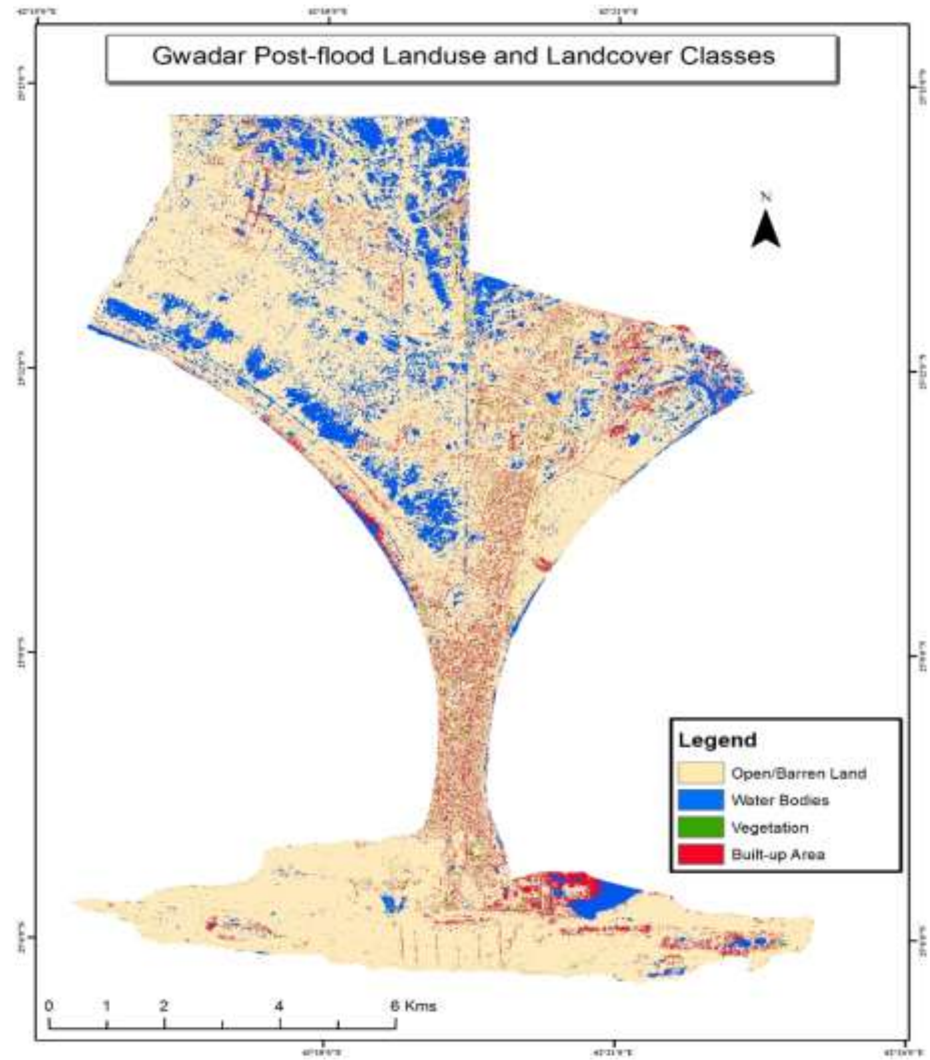


Fig 4. Post-flood LULC Classification

Water Bodies

The most noticeable change occurred in the water bodies class with an increase of 1205.08 hectares which reflects a remarkable 2730.75% increase (Fig 5.0). Heavy and rapid rains in urban areas often lead to the overflow of rivers, streams, and drainage channels, creating new water body that overflow and causes flood like situation. In this case of Gwadar city floodwaters overwhelmed the urban drainage systems causing flooded streets and roads etc. Such sudden and often lead to the inundation of once dry areas into flooded sections.

Vegetation

Due to the flooding event and increase in the flooded areas in and around Gwadar city vegetation experienced a reduction of 36.18 hectares or a 38.26% in area. This decrease in vegetated area can be attributed to the fast flowing water which may have uprooted the vegetation or may have inundated the area covered by vegetation once the water becomes stagnant.

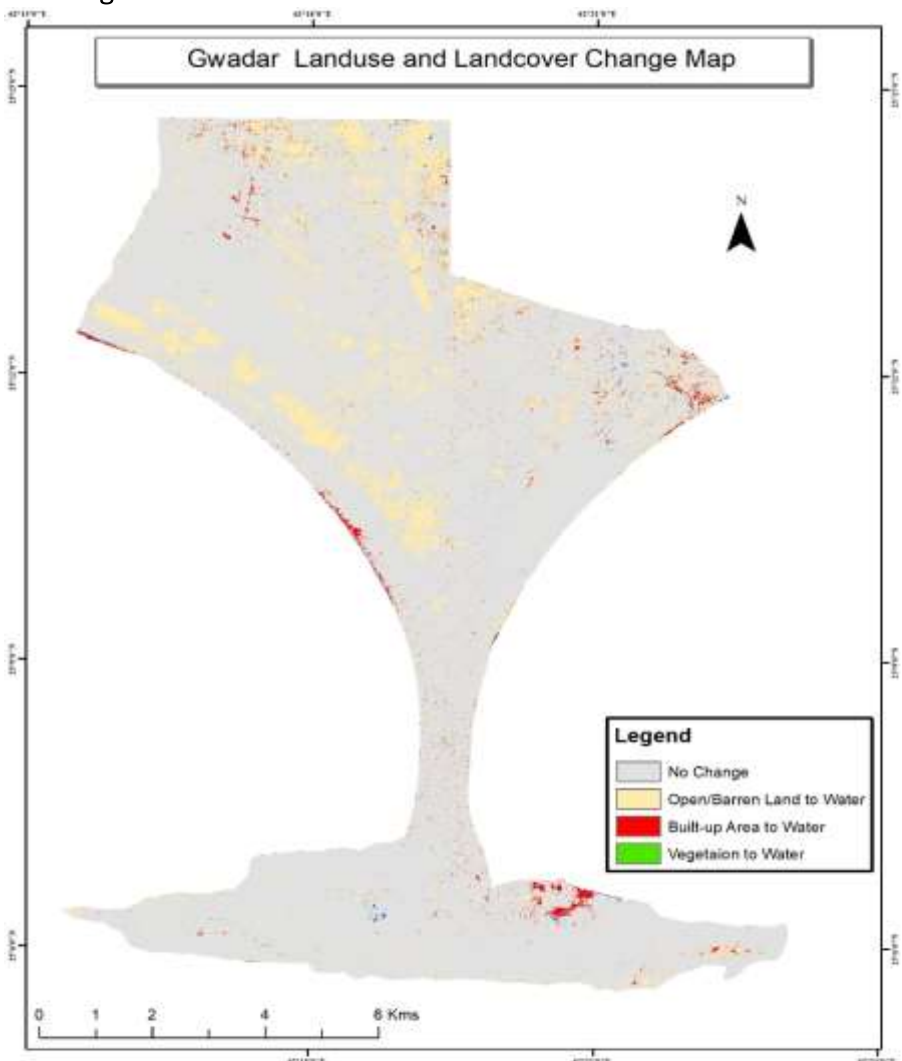


Fig 5 LULC Change Map

Flash floods and stagnant waters from flooding event often causes waterlogging which in turn cause to suffocate the plants and reduce the growth which often lead to death of the plants. This reduction in vegetation clearly highlights the negative impact of flash floods on urban ecosystems. This leads to immediate damages and also long term ecological problems.

Table 3.0: Land Cover Changes Before and After Floods.

Class	Before Flood (Hectare)	After Flood (Hectare)	Change (Hectare)	%
Open/Barren Land	5124.00	4184.00	-940.00	-18.35%
Water Bodies	44.13	1249.21	1205.08	2730.75%
Vegetation	94.55	58.37	-36.18	-38.26%
Built-up Area	2900.25	2671.35	-228.90	-7.89%
Total	**8162.93**	**8162.93**		

Built-up Area

This particular category of built-up area category decreases by 228.90 hectares, or a 7.89% (Fig 6.0). This decrease can be attributed to the direct damage caused to urban infrastructure by the floodwaters and its destructive force. Urban areas such as Gwadar city with limited and poor drainage capacity often suffer significant damage during flash floods, as roads, buildings, and other structures are inundated. The decrease in this particular class that how much an urban is when it comes to extreme natural events such as floods.

Total Area

Despite these significant changes in almost all the classes, the total area of Gwadar city stays constant at 8162.93 hectares. This number strongly suggest that the floods only redistributed land classes rather than permanently destroying land. These changes certainly shows that urban floods can have great impact on the infrastructure of a city prone to flood events. The effects of floods on the urban infra structure.

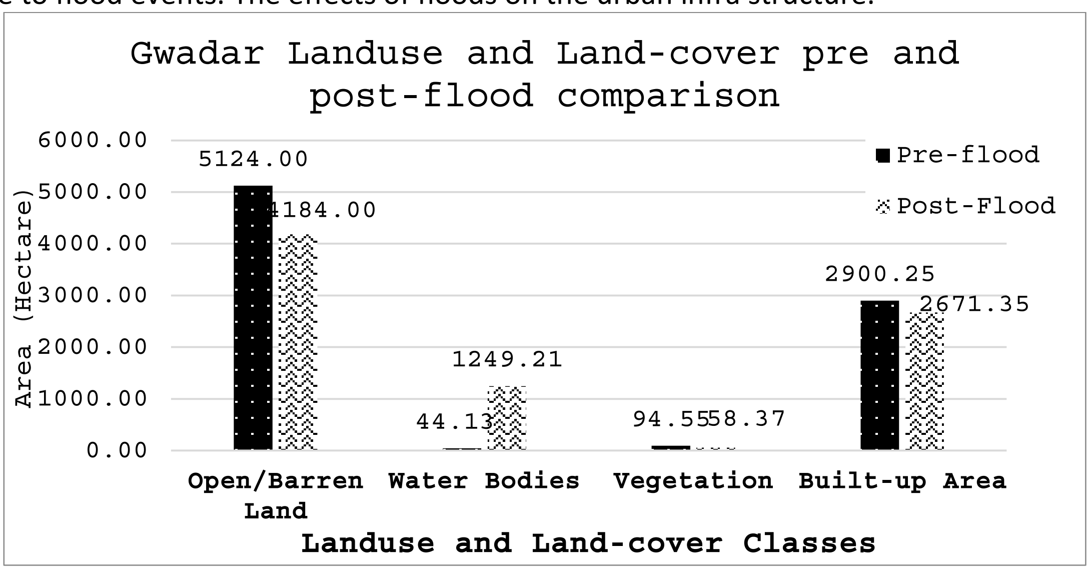


Fig 6. Graph showing pre- and post-flood LULC classes comparison

3.4 Damage Assessment Results

To evaluate the spatial extent of flood damage, the flood-water mask was extracted and later overlaid on a detailed LULC vector data digitized from high resolution Google Earth mosaics. The LULC was divided into nine categories which were digitized after extensive ground surveys conducted for each household and settlement in the city these categories were: commercial, educational, government, residential, religious, recreational, open/barren, vegetated, and water bodies (Table 1.3).

The flood damage assessment demonstrated a varied degree of damage across different land use and land cover (LULC) categories. The Built-up Area experienced notable inundation, accounting for a total of 229 hectares. Within this class, households were the most severely affected, with 116.8 hectares (9.69%) submerged, followed by commercial areas (Table 4.0) such as shops, shopping malls, and warehouses (42.8 ha; 3.55%). Educational institutions including schools and training centers covered 25.1 hectares (2.08%), while recreational places such as parks and playgrounds experienced flooding over 19 hectares (1.58%). Similarly, government services including administrative offices and health centers were inundated across 16.3 hectares (1.35%), and religious places, primarily mosques, occupied 9.1 hectares (0.76%) of the affected land.

Outside the built-up zones, Open/Barren Land represented the largest flood-impacted category, with 940 hectares (78.01%) submerged, indicating that undeveloped or vacant areas absorbed a significant portion of floodwaters. The Vegetation class, comprising agricultural fields, orchards, and scattered urban greenery, was also moderately affected, with 36.2 hectares (3.00%) inundated. Collectively, these results highlight that both densely inhabited and undeveloped landscapes were exposed to considerable flood risks within the study area. The results of the damage assessment were validated through field visits for each class separately.

Major Flood-Induced inundations:

- Households experienced the highest level of inundation, with 116.8 hectares (9.69%) affected.
- Commercial areas suffered significant damage across 42.8 hectares (3.55%).
- Educational institutions faced flooding over 25.1 hectares (2.08%).
- Open/Barren Land was extensively inundated, covering 940 hectares (78.01%) of the total affected area.
- Vegetation, including croplands and orchards, was impacted over 36.2 hectares (3.00%).
- **3.5 Accuracy Assessment of the Classified Image**
- The Sentinel-2 imagery covering the flash flood event of February 2024 in Gwadar city was classified using the maximum likelihood supervised classification approach. To evaluate the reliability of the classification, 50 random validation points were generated according to the recommended rule of thumb for accuracy assessment (Congalton, 1991). These points were compared against field observations and reference data, and an error matrix was prepared (Table 5).
- The results showed that the user's accuracy for flooded areas was slightly lower than for other classes, at 84%. This discrepancy can be explained by the fact that some rocky surfaces and shadowed regions exhibited spectral responses similar to floodwater, leading to occasional misclassification. Despite this limitation, the classification still achieved an overall accuracy of 89%, indicating that the majority of pixels were correctly identified across all classes.

Table 4. Flood-affected area by land use/land cover class in Gwadar city (February 2024)

LULC Class	Sub-categories (examples)	Flood-Affected Area (ha)	% of Class Flooded
Built-up Area (229 ha flooded)			
Commercial	Shops, shopping malls, wholesale markets, warehouses etc.	42.8	3.55%
Educational Institutes	Schools, colleges, universities, training centres etc.	25.1	2.08%
Government Services	Administrative offices, health centers, police stations, post offices etc.	16.3	1.35%
Households	Houses, apartments, informal settlements, housing colonies, residential plaza etc.	116.8	9.69%
Religious Places	Local and central mosques etc.	9.1	0.76%
Recreational Places	Parks, playgrounds, sports areas etc.	19	1.58%
Open/Barren Land	Vacant urban plots, barren rocky terrain, desert patches, unused construction sites etc.	940	78.01%
Vegetation	Agricultural fields, orchards, scattered greenery and tress in urban areas etc.	36.2	3.00%

The confusion matrix highlights that while most classes achieved above 86% producer's and user's accuracy, flooded areas had a slightly lower accuracy due to spectral confusion with non-flood dark surfaces. Nevertheless, the overall classification accuracy of 89% confirms that the methodology produced reliable results for flood mapping in Gwadar city.

Table 5. Error matrix for the classified Sentinel-2 image of Gwadar city (February 2024)

Classified Data	Open/Barren Land	Built-up Areas	Vegetation	Water Bodies	Total Classified	Producer's Accuracy
Open/Barren Land	**44**	4	3	3	54	84.61%
Built-up Areas	3	**45**	2	0	50	90.00%
Vegetation	2	3	**44**	2	51	86.27%

Water Bodies	1	0	2	**43**	46	91.49%
Total Samples	50	50	51	49	**200**	
User's Accuracy	**88%**	**90%**	**86%**	**93%**		**Overall = 88.6%**

Kappa Coefficient (κ)

The Kappa coefficient (κ) is a widely used statistical measure that evaluates the degree of agreement between a classified image and reference data, while considering the agreement that might occur by random chance. Unlike overall accuracy, which only quantifies the proportion of correctly classified samples, the Kappa coefficient provides a more rigorous assessment by adjusting for chance agreement. Its values typically range from −1 to 1, where $\kappa = 1$represents perfect agreement, $\kappa = 0$indicates random agreement, and negative values denote disagreement worse than random classification. According to Landis and Koch (2008), values between 0.81–1.00 reflect "almost perfect" agreement, demonstrating high reliability of the classification results.

In this study, the Kappa coefficient was computed from the error matrix using 200 validation samples, according to the following expression:

$$\kappa = \frac{P_o - P_e}{1 - P_e}$$

where $P_o$is the observed agreement (overall accuracy), and $P_e$is the expected agreement calculated from the marginal totals of the confusion matrix. The observed agreement was $P_o = \frac{176}{200} = 0.88$, while the expected agreement was derived as:

$$P_e = \frac{\sum(r_i \times c_i)}{N^2} = \frac{10055}{40000} = 0.2514$$

where $r_i$and $c_i$are the row and column totals, respectively, and $N$is the total number of samples. Substituting these values into the main equation yields:

$$\kappa = \frac{0.88 - 0.2514}{1 - 0.2514} = 0.84$$

The resulting κvalue of 0.84 indicates a strong level of agreement between the classified and reference datasets, confirming the reliability and accuracy of the classification results beyond random chance.

3.6 Findings and Recommendations

3.6.1 Key Findings

1. The open or barren land category decreased by approximately **18.35%**, reflecting that a large portion of previously exposed terrain was temporarily converted into other cover types following the flood.
2. Water bodies showed the most prominent change, increasing by about **2730.75%**, which indicates extensive inundation across the study area and highlights the magnitude of the flood event.
3. Vegetation cover declined by nearly **38.26%**, consistent with the widespread loss of crops, trees, and green patches observed in the post-flood landscape.

4. Built-up areas experienced a decline of around **7.89%**, suggesting that portions of the urban fabric were submerged or damaged due to floodwater encroachment.
5. The analysis revealed a dominant land cover transition from barren and vegetated surfaces to water bodies, signifying the large-scale hydrological alteration brought about by the flood.
6. The post-event landscape suggests that these changes were predominantly short-term, with vegetation and certain built-up areas expected to recover through natural regeneration and reconstruction activities in the following months.

3.6.3 Recommendations

This study provides an early assessment of flood-induced land use and land cover changes in Gwadar through Geographic Information Systems (GIS) and Remote Sensing (RS) techniques. The findings highlight significant spatial alterations resulting from flooding and underline the need for integrated data-driven planning and management approaches. Based on the outcomes, the following recommendations are proposed:

1. The study employed medium-resolution imagery, which effectively captured overall spatial variation but limited the detection of finer details. Future research should incorporate high-resolution or commercial datasets for more accurate mapping and improved classification precision.
2. Updated topographic maps and UAV-based aerial imagery are recommended to enhance the accuracy of flood delineation and to support terrain-based interpretation for future assessments.
3. Advanced classification algorithms such as object-based image analysis, random forest, or decision tree models can be tested to minimize misclassification and improve the reliability of land cover mapping.
4. A comprehensive storm water drainage system should be developed across Gwadar city to ensure efficient runoff management and reduce the frequency of urban flooding.
5. Topography-based zoning regulations must be enforced to prevent construction in flood-prone and low-lying areas, promoting safer land use practices.
6. The establishment of real-time early warning systems that integrate rainfall forecasts and hydrological data can significantly improve preparedness and emergency response.
7. Local government bodies should institutionalize GIS- and RS-based flood monitoring mechanisms within municipal planning authorities to support informed and timely decision-making.
8. Public awareness and community preparedness programs should be implemented to enhance resilience and promote proactive disaster response at the community level.
9. Strengthening inter-departmental coordination among meteorological, spatial, and disaster management institutions is essential for effective data sharing and unified response mechanisms.
10. Adoption of green infrastructure and nature-based flood buffers, including vegetated swales, retention ponds, and mangrove restoration, can mitigate flood intensity and support ecological stability.
11. Critical infrastructure such as transport networks, healthcare facilities, and administrative buildings should be retrofitted to enhance resilience against future flood events.
12. Sustained investment in long-term hydrological and climate modeling research in coastal Balochistan is necessary to understand changing flood patterns and guide adaptive urban development strategies.

4. Conclusion

Land use and land cover assessment using satellite imagery and GIS techniques has proven essential for evaluating flood-induced transformations in urban environments. This study, carried out for Gwadar city, analysed pre- and post-flood Sentinel-1 data to quantify spatial changes across major land use categories. The results indicated a substantial increase in water bodies by 2730.75%, signifying large-scale inundation across the city. Conversely, open and barren land decreased by 18.35%, vegetation cover declined by 38.26%, and built-up areas were reduced by 7.89%, reflecting the extent of flood impact on both natural and developed surfaces. Damage assessment within the built-up category revealed that residential areas were the most affected (9.69% of total), followed by commercial zones (3.55%), recreational places (1.58%), educational institutions (2.08%), government services (1.35%), and religious places (0.76%). These losses collectively demonstrate that the flood primarily disrupted areas of dense human settlement and socio-economic activity. Overall, the study underscores that integrating remote sensing with GIS provides a reliable and efficient means for assessing and quantifying disaster-induced land cover changes. The outcomes not only enhance understanding of Gwadar's flood vulnerability but also serve as a critical reference for sustainable land management, urban zoning, and flood risk mitigation in similar coastal settings.

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