



DAMAGE ASSESSMENT OF THE 2010 INDUS RIVER FLOOD USING GIS AND REMOTE SENSING TECHNIQUES: A CASE STUDY OF RAJANPUR, MUZAFFARGARH, AND RAHIM YAR KHAN DISTRICTS, PUNJAB, PAKISTAN

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KEYWORDS	ABSTRACT
Flood Damage Assessment, GIS, Remote Sensing, Landsat Imagery, Supervised Classification, Indus River, Pakistan Flood 2010, Land Use/Land Cover, Disaster Management.	Among the most devastating natural disasters in the world, floods are one of the worst and the flood of 2010 in Indus River was one of the worst in the history of Pakistan, which also affected southern Punjab districts of Rajanpur, Muzaffargarh and Rahim Yar Khan in the State. Landsat 4-5 satellite imagery (USGS) from before the flood (11 July 2010) and after (12 August 2010) was used with supervised classification in ERDAS Imagine and spatial analysis in ArcMap to determine the spatial extent of flooding and the damage to land use, infrastructure and agriculture. About 742.13 km ² of the study area were affected and the result was shown by analysis. The largest proportion of damage was on barren land (49.62%), followed by vegetation (27.56%), settlements (17.42%) and roads (5.38%). Their impact was severe on region's agricultural output, resulting in significant losses in cotton, sugarcane and rice. The results validate the usefulness of GIS and Remote Sensing as tools for flood damage assessment and they also offer valuable geospatial data for disaster preparedness, agricultural recovery and sustainable land-use planning.
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Introduction

Flood is one of the most common and catastrophic natural hazards which cause the maximum loss of life, infrastructure, agriculture and ecology (Ahmad et al., 2020). With its extensive Indus River

system and monsoon climate, Pakistan is particularly vulnerable to floods, with the Indus and its tributaries overflowing in June to September each year, and big floods occurring in 1950, 1973, 1992, 2010 and 2022 (Sharma et al., 2022).

The Indus flood of 2010 is regarded as one of the worst floods in Pakistan's history, covering an area of about one-fifth of the country and 10 million people. Heavy rains were observed in Rajanpur, Muzaffargarh, and Rahim Yar Khan where settlements, transportation infrastructure, irrigation facilities, and standing crops were lost to the extensive floods (Singh & Kumar, 2021).

Since then, GIS and Remote Sensing have proven essential in the assessment of flood hazard, with satellite imagery providing large scale coverage of inaccessible areas at the time of the flood and GIS being used to integrate and analyse various datasets to generate the flood extent, land-use change, and flood damage (Tiwari et al., 2023).

The aims of this study are to: (1) determine the extent of the 2010 flood in the selected three districts; (2) identify land use/land cover (LULC) changes occurred before and after the 2010 flood by supervised classification of Landsat images; (3) quantify the damages to vegetation, settlements, barren land, and road; (4) evaluate the damages to major Kharif crops (cotton, sugarcane, rice) before and after the flood; and (5) assess the usefulness of GIS and Remote Sensing for flood damage assessment and future mitigation planning. The conclusions drawn are meant to help disaster management authorities, planners and policymakers at the district level by providing spatial evidence, which has been scarce in the study of the 2010 flood.

Literature Review

Generally, flood hazard assessment was done through field survey, which is time consuming and hard to carry out during or after floods, and the use of geospatial technologies has also enhanced the efficiency and precision of the large-area assessment (Uddin et al., 2020). In the field of disaster management, GIS is playing an important role by combining satellite imagery, DEMs, hydrological data, and land-use data to create flood risk maps and assist in evacuation planning and recovery operations (Wang et al. 2023). Inaccessible areas can be monitored repeatedly and quickly with remote sensing platforms like Landsat, Sentinel, MODIS, and radar satellites, to provide a flood extent, water bodies, vegetation and settlement monitoring service (Weng, 2021).

The Landsat programme (USGS/NASA) is especially well-applicable to flood studies as the 30 m multispectral image data can help with pre and post flood comparison (Hussain et al., 2020). The supervised approach has been found to achieve higher accuracy than unsupervised approaches, as representative training samples are used to establish spectral classes including water, vegetation, settlements, roads, and barren land, and is commonly adopted to identify flash flood-induced land-cover change (Kumar & Pandey, 2020).

In the past, the 2010 Pakistan flood was estimated to have impacted around 20 million people and claimed millions of hectares of agricultural land on the basis of satellite data analysis of Landsat,

MODIS, SAR and GIS-based flood modelling (Khan et al., 2021). Most of the above work was done at the provincial or national level, while very little work was done at the district level and even fewer were conducted that integrated flood-extent mapping with assessment of the damage to the vegetation, settlement, road, and crop in the case of Rajanpur, Muzaffargarh and Rahim Yar Khan in particular (Pandey & Kumar, 2022). The purpose of this study is to fill this void by conducting a GIS and remote-sensing-based assessment of the 2010 flood in an integrated fashion at the district level.

Materials and Methods

Study Area and Data

It addresses the flood plain of Indus river in southern Punjab districts of Rajanpur, Muzaffargarh and Rahim Yar Khan, where 95% of the population is engaged in agriculture (mostly cotton, sugarcane, rice and wheat) and topography of the region is low, making it one of the hottest and most flood-prone areas of Pakistan. Pre-flood (11 July 2010) and post-flood (12 August 2010) Landsat 4-5 Thematic Mapper (TM) (30 m resolution) scenes were downloaded from the USGS Earth Explorer archive, alongside administrative maps which were used to delineate the study area; agricultural-damage statistics were provided from published government reports.

Processing and Classification

The geospatial analysis was performed in ERDAS Imagine (supervised classification and spectral analysis) and ArcMap (spatial data management, extract by mask, and extract by attribute), where the study area and individual land cover classes were isolated using Extract by Mask and Extract by Attribute tools, respectively (Nazir et al., 2024). Geometrically corrected all images to common reference system and minimised inconsistencies caused by atmosphere /radioactive decay prior to classification. For both dates, supervised classification using representative training samples was performed in order to classify vegetation, water, settlements, barren land and roads (Rahman et al., 2023).

Damage Assessment and Accuracy

Damage was estimated by comparing the land-cover classes from the pre- and post-flood images, both of which were classified in GIS, and overlaying the images to determine the areas of damage, using the pixel size of the Landsat images (30 × 30 m) to convert the affected pixels to area (Roy et al., 2022). For the purpose of classification reliability, a confusion matrix (overall accuracy, producer's accuracy, user's accuracy and Kappa coefficient) was used to compare the classification result with reference data and existing land-use maps and published reports, which showed satisfactory performance for the flood-affected classes (Shah et al., 2020). Yousaf et al. (2024) summarised the results as area statistics, percentage change, thematic maps, and graphical summaries.

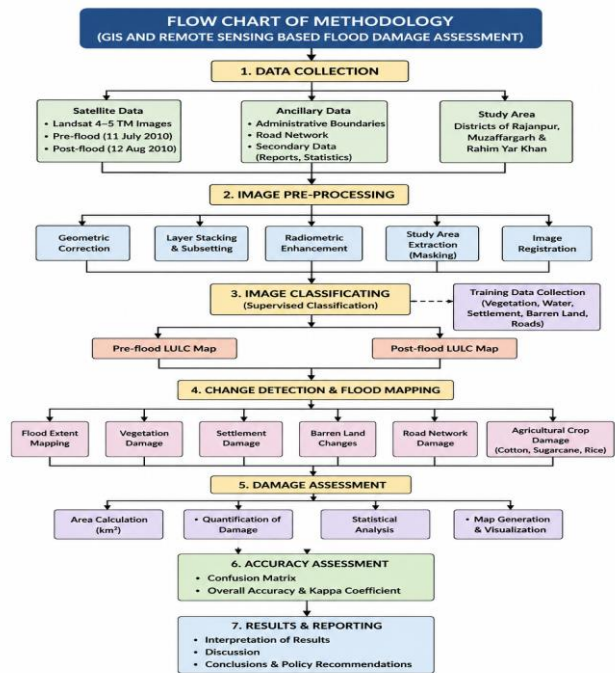


Figure 1. Flowchart of the GIS and remote sensing-based methodology used in the study

Extent and Results

Flood Extent and Land Cover Change

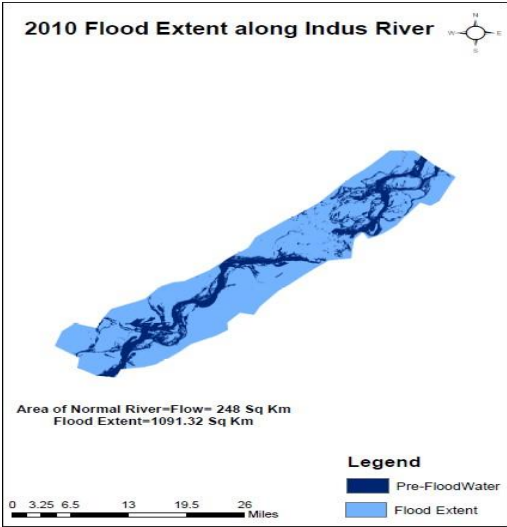


Figure 2. Flood extent map along the Indus River, 2010

The post-flood Landsat images revealed a wide extent of inundation in all three districts along the Indus River, with the river's discharge reaching a very high level during the 2010 monsoon season, resulting in significant flooding and inundation of agricultural land, settlements, and transport corridors (Li et al., 2021). Substantial land-cover conversion was confirmed through supervised classification: plenty of areas under vegetation and settlement were converted to water and barren land post flood, which was an effective classification-based change detection for flood speed monitoring (Xu et al., 2024; Zhang & Chen, 2022).

Vegetation, Settlement, and Barren Land Damage

The losses of vegetation amounted to about 204.55 km², which were due to the prolonged inundation and deposition of sediments on agricultural lands, orchards, and natural vegetation along the river (Zhou et al., 2024). Loss of life and property in the settlements were estimated to cover about 129.32 km², many villages were inundated, homes, schools, health facilities were either destroyed or surrounded by flood water (Jain et al., 2022). The maximum change was among barren land, which rose by around 368.26 km², due to erosion and deposition in fertile fields (Islam et al., 2021) — the largest one-size-fits-all damage category in the study.

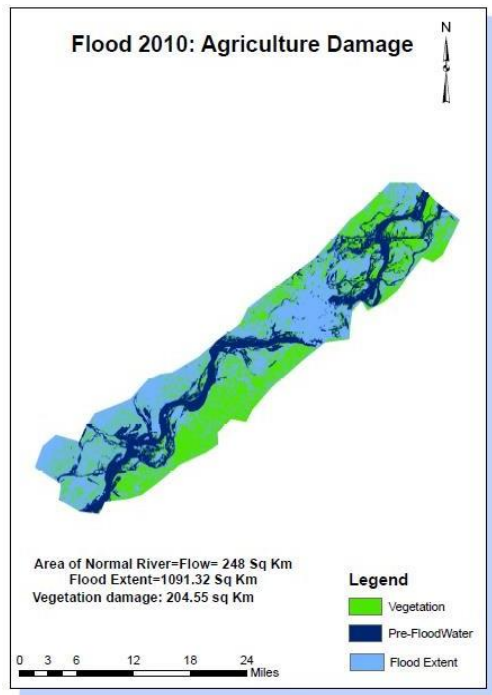


Figure 3 (left). Vegetation/agricultural damage

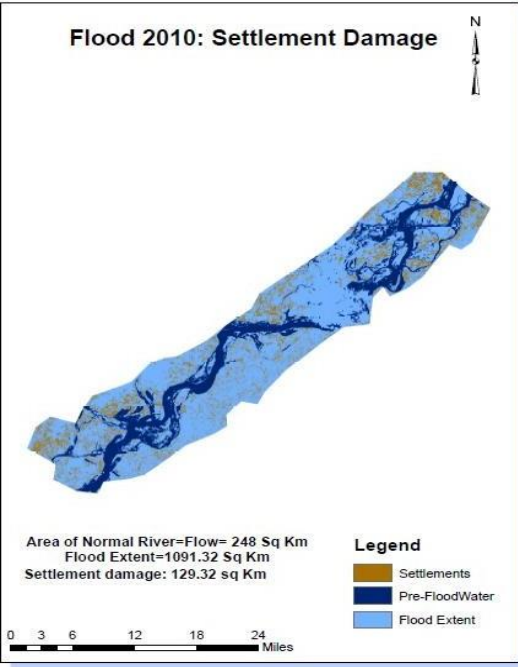


Figure 4 (right). Settlement damage.

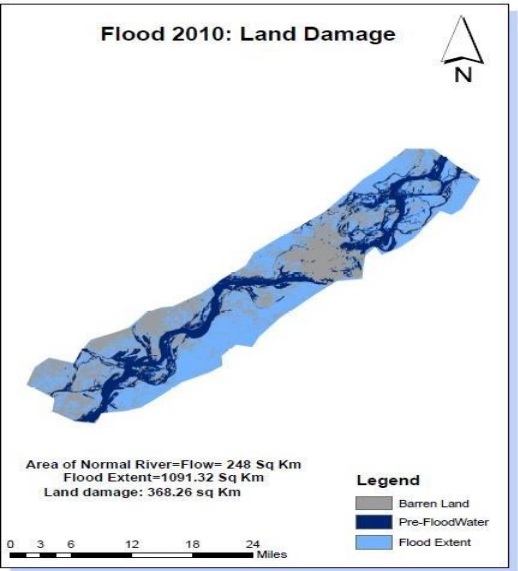


Figure 5. Barren land change map

Road Network Damage

Around 40km of roads were impacted, several rural roads were cut off by the flood water and washed away, slowing down the evacuation and the delivery of food, medical and humanitarian aid (Hassan & Rahman, 2021).

Agricultural Crop Damage

Agriculture was the worst hit sector. The prolonged waterlogging and sediment deposition had severe impacts on all the kharif crops of southern Punjab, namely cotton, sugarcane and rice crops, showing varying degree of damage by district (Gaur & Singh, 2023).

Cotton

Cotton suffered the most with maximum damage in Muzaffargarh and Rajanpur. An estimated loss of 0.87 million bales, involving approximately 254,000 hectares, and likely having a knock-on effect on Pakistan's textile exports.

Districts	Area Damaged (ha, '000)	Yield Loss / ha	Projected Loss (million)
Muzaffargarh	124	2.8 bales	0.35 bales
Rahim Yar Khan	22.9	4.4 bales	0.10 bales
Rajanpur	107.1	3.9 bales	0.42 bales
Total	254	—	0.87 bales

Sugarcane

There was an estimated loss of 39,800 hectares of sugarcane, particularly in Muzaffargarh, which caused a delay in the harvesting and also affected sugar recovery. Note: the source data labels sugarcane yield/loss in "bales" (which is the same unit as cotton – most likely a units error in the original data as sugarcane is normally measured in tonnes).

Districts	Area Damaged (ha, '000)	Yield Loss / ha	Projected Loss (million)
Muzaffargarh	22.5	50.9	0.9
Rahim Yar Khan	7.5	30	0.2
Rajanpur	9.8	63.1	0.5
Total	39.8	144.0	1.6

Rice

The damage to the rice crop was district-wise depending upon the duration and height of the flood with complete crop loss in many low lying paddy fields. Same units as above; the original source

table also includes the term "bales", which is not a standard rice unit.) The Area and Projected Loss totals below have been totaled using district figures, as the Total row was blank in the source document.

Districts	Area '000)	Damaged (ha,	Yield Loss / ha	Projected (million)	Loss
Muzaffargarh	19		1902	36.1	
Rahim Yar Khan	2.1		1807	3.9	
Rajanpur	9.8		2031	20	
Total	30.9		5740	60.0	

Overall Damage Summary

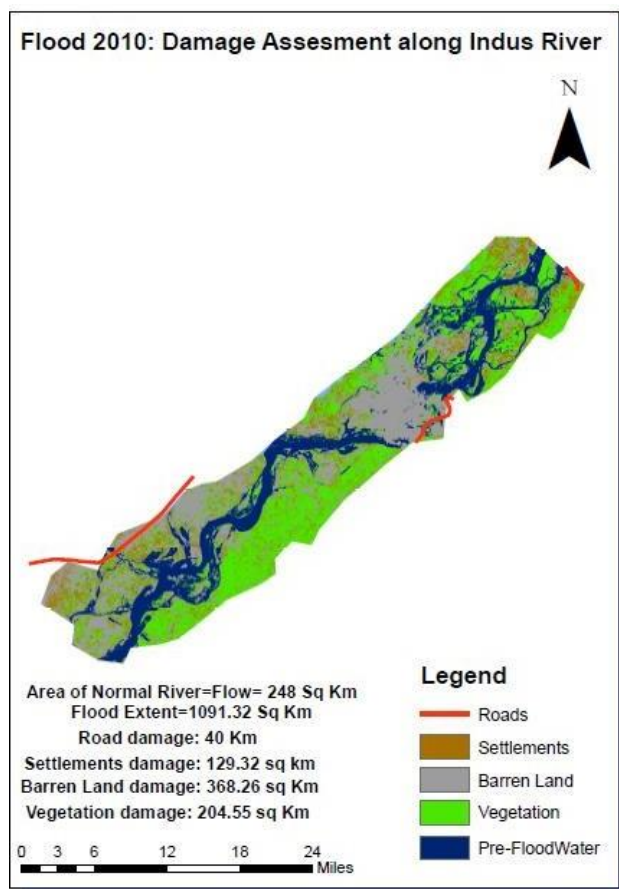


Figure 6. Overall flood damage assessment map

Sr.No.	Land Cover / Feature Affected	Area (km ²) / Length (km)	% of Total Damage
1	Barren Land	368.26	49.62%
2	Vegetation	204.55	27.56%
3	Settlement	129.32	17.42%
4	Roads	40	5.38%
	Total	742.13	100%

The overall flood inundated area was around 742.13 km² in the study area. Barren land was the largest damage category (49.62%), followed by vegetation (27.56%), settlements (17.42%), and roads (5.38%). Overall economic losses were highest in agriculture. The thematic maps were able to successfully identify the spatial distribution of impact and districts that are most susceptible to future flood events, making GIS and remote sensing a very accurate and efficient tool for flood damage assessment.

Discussion

The findings reveal that the environmental, agricultural and infrastructural damage was widespread in 2010 Indus flood in the areas of Rajanpur, Muzaffargarh and Rahim Yar Khan. The impacts on vegetation cover, sediment deposition turning productive lands into barren surfaces and the disruption of settlements and transport networks were recorded in the immediate and long-term socio-economic impacts in previous national and provincial studies (Bountos et al., 2023).

This study's spatial analysis of the land-cover and crop damage, conducted at the district level, provides more detailed spatial data for local disaster planning and resource allocation than previous research on the 2010 flood, which was mostly carried out at the provincial or national level (Chen et al., 2021). GIS overlay analysis was helpful in mapping flood extent and quantifying damage based on land cover categories compared to conventional field surveys (Ghaffarian et al., 2020; Das et al., 2020) and multispectral, multi-temporal Landsat data was found effective for separating vegetation, settlements, water, barren land, and infrastructure in the large study area (Hasan et al., 2022; Chander et al., 2020).

Agriculture was the most affected sector with most losses including cotton, a major local export crop, sugarcane and rice, and it is expected that yields will continue to be low for the next couple of growing seasons due to sediment deposition (Ali et al., 2022). The results indicate the urgent need for strategies to modify farming practices to become climate-smart, the development of flood-tolerant crop varieties, and strengthening of irrigation and insurance mechanisms at both federal and provincial/local levels, as well as strengthening early warnings systems and monitoring of the river, and coordinated institutional response (Arshad et al., 2024; Akbar et al., 2021).

Conclusion

Through this study, it is proved that GIS and Remote Sensing make a reliable, accurate and cost-effective method to assess the flood damages on a large geographical area. The extent of the 2010 Indus flood was quantified using pre- and post-flood Landsat images and supervised classification, which revealed that 742.13 km² was flooded, with barren land, vegetation, settlements, and roads being heavily impacted, and agriculture being the most impacted sector, especially cotton, sugarcane, and rice.

The implications of these findings are clear: Government governments need to increase the coverage of satellite-based flood monitoring, incorporate GIS in early-warning and land-use planning systems and safeguard exposed agricultural areas by strengthening flood protection and building community preparedness. With the growing impact of extreme weather events due to climate change, the use of geospatial technologies in national disaster management is increasingly vital to save lives, livelihoods and protect the economic stability in flood prone areas of Pakistan.

Policy Recommendations

- Improve GIS-based flood monitoring: increase frequency of real-time satellite monitoring, nationalize disaster management system to incorporate GIS-based flood monitoring, and keep flood hazard maps up to date.
- Supporting farmers' adaptation to climate change through promoting and supporting: floods-tolerant crop varieties, improved irrigation, post-flood soil rehabilitation training, crop insurance and timely compensation.
- Enhance infrastructure and land-use planning: mandate flood hazard assessment for development; develop roads and embankments that will withstand flooding; limit development in high-risk floodplains identified through GIS hazard mapping.
- Enhance institutional coordination: enhance federal-provincial-local coordination, hold community disaster-awareness programs, and invest in the monitoring and warning of hydrological conditions by communication.

Limitations and Future Research

The study has used only two temporal snapshots (before and after flooding) of Landsat 4-5 imagery (30 m resolution) which reduced the ability to achieve the small-scale detection and flood progression over time and findings from the three southern Punjab districts cannot be extrapolated to all flood-affected regions of Pakistan, and damage estimates have been undertaken primarily through geospatial analysis and secondary data sources and with limited field verification. Researchers should also consider using more detailed imagery (such as Sentinel-2 or PlanetScope),

integrating SAR capability with optical data to track flood events in the cloudy region, expanding ground validation and studies of the longer-term socio-economic and ecological consequences, and using machine learning to automatically detect floods and predict damages across the broader Indus River basin.

References

- Ahmad, S., Ali, M., & Hussain, A. (2020). Flood hazard assessment using GIS and remote sensing techniques in Pakistan. *Arabian Journal of Geosciences*, 13(18), 1–16.
- Akbar, M., Hassan, Q. K., & Ishaq, S. (2021). Monitoring flood inundation using Sentinel-1 SAR and GIS techniques. *Remote Sensing Applications: Society and Environment*, 22, 100487.
- Ali, A., Khan, F., & Ahmed, N. (2022). Spatial assessment of flood vulnerability using geospatial technologies. *Natural Hazards*, 112(2), 1453–1474.
- Arshad, A., Nazir, U., & Khan, A. (2024). 2022 flood impact in Pakistan: Remote sensing assessment of agricultural and urban damage. *Remote Sensing*.
- Bountos, N. I., Sdraka, M., Zavras, A., et al. (2023). Kuro Siwo: A global multi-temporal satellite dataset for rapid flood mapping. *Scientific Data*, 10, 1–18.
- Chander, G., Markham, B., & Helder, D. (2020). Landsat satellite calibration and applications in environmental monitoring. *Remote Sensing*, 12(4), 653.
- Chen, Y., Wang, J., & Li, Z. (2021). Flood mapping using machine learning and satellite imagery. *ISPRS International Journal of Geo-Information*, 10(9), 620.
- Das, S., Patel, P. P., & Sengupta, S. (2020). Evaluation of flood hazards using geospatial techniques. *Environmental Monitoring and Assessment*, 192(5), 320.
- Gaur, S., & Singh, R. (2023). A comprehensive review on land use/land cover change modeling. *Sustainability*, 15(1), 164.
- Ghaffarian, S., Kerle, N., & Farhadabad, A. R. (2020). Post-disaster recovery monitoring with Google Earth Engine. *Applied Sciences*, 10(13), 4574.
- Hasan, M., Islam, M., & Rahman, M. (2022). GIS-based flood risk mapping for sustainable disaster management. *Sustainability*, 14(11), 6710.
- Hassan, Q. K., & Rahman, K. (2021). Remote sensing applications in flood monitoring: A review. *Geocarto International*, 36(15), 1673–1692.
- Hussain, E., Mahmud, I., & Ahmed, S. (2020). Climate change and flood disasters in South Asia. *Environmental Challenges*, 1, 100005.
- Islam, A. S., Bala, S. K., & Haque, M. A. (2021). Flood inundation mapping using Landsat imagery and GIS. *Journal of Hydrology*, 603, 127115.
- Jain, S., Sinha, R., & Babu, K. (2022). Satellite-based flood mapping and damage estimation in river basins. *Hydrological Sciences Journal*, 67(5), 712–727.
- Khan, M. A., Ali, Z., & Rehman, H. (2021). Geospatial analysis of flood-affected regions in Pakistan. *Natural Hazards Review*, 22(3), 04021014.
- Kumar, P., & Pandey, A. (2020). GIS-based flood hazard zonation using remote sensing data. *Journal of Earth System Science*, 129(1), 180.

- Li, X., Zhang, H., & Wang, L. (2021). Advances in supervised image classification for land cover mapping. *Remote Sensing*, 13(6), 1135.
- Nazir, U., Gomathinayagam, D., Kamran, M., & Khalid, S. (2024). Multi-sensor remote sensing framework for flood monitoring in South Asia. *Remote Sensing*.
- Pandey, B., & Kumar, R. (2022). Flood risk assessment using GIS and multi-temporal satellite data. *Environmental Earth Sciences*, 81(5), 129.
- Rahman, M. M., Islam, M. T., & Hasan, M. (2023). Remote sensing applications in flood disaster management: A systematic review. *Remote Sensing Applications: Society and Environment*, 29, 100901.
- Roy, P. S., Ramachandran, R. M., Paul, O., Thakur, P. K., & Ravan, S. (2022). Anthropogenic land use and land cover changes: Environmental consequences and climate change. *Journal of the Indian Society of Remote Sensing*, 50(8), 1475–1492.
- Shah, S. A., Hussain, T., & Iqbal, M. (2020). Spatial modeling of flood susceptibility using GIS techniques. *Environmental Monitoring and Assessment*, 192(9), 596.
- Sharma, V., Gupta, A., & Singh, P. (2022). Change detection analysis using Landsat imagery for flood assessment. *Geocarto International*, 37(14), 4213–4231.
- Singh, A., & Kumar, S. (2021). Remote sensing and GIS for agricultural damage assessment after floods. *Journal of Applied Remote Sensing*, 15(3), 036512.
- Tiwari, V., Mishra, S., & Kumar, D. (2023). Multi-temporal satellite image analysis for flood impact assessment. *Environmental Monitoring and Assessment*, 195(4), 463.
- Uddin, K., Shrestha, B., & Gurung, D. (2020). Remote sensing applications for flood hazard assessment in South Asia. *Geography Journal*, 2020, 1–14.
- Wang, C., Liu, Y., Zhang, X., et al. (2023). Rapid post-disaster building damage detection using InSAR imagery. *IEEE Transactions on Geoscience and Remote Sensing*.
- Weng, Q. (2021). Remote sensing and GIS integration for environmental monitoring and disaster management. *ISPRS Journal of Photogrammetry and Remote Sensing*, 173, 10–23.
- Xu, P., Tsendbazar, N., Herold, M., et al. (2024). Comparative validation of recent 10 m-resolution global land cover maps. *Remote Sensing of Environment*, 315, 114345.
- Yousaf, A., Khan, A., Tahseen, Z., & Taj, M. (2024). Satellite-based assessment of agricultural damage following the Pakistan floods. *Remote Sensing Applications: Society and Environment*, 35, 101320.
- Zhang, C., & Chen, X. (2022). Flood mapping using optical and SAR remote sensing data: Recent advances. *International Journal of Applied Earth Observation and Geoinformation*, 108, 102741.
- Zhou, Y., Li, J., & Wang, S. (2024). Artificial intelligence and remote sensing for flood monitoring and disaster management: A review. *Remote Sensing*, 16(3), 512.