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Flood-Resilient Infrastructure Design Using GIS and Remote Sensing in Pakistan

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ABSTRACT:

Pakistan is very susceptible to floods due to its geographical position, the monsoon variability and the poor planning of urban development. Flood events not only result in huge losses to people and their economy, but also destruction of critical infrastructures. Design of flood-resistant infrastructure is critical in order to reduce these impacts. Geographic Information System (GIS) and Remote Sensing (RS) can be used to give an edge-to-edge tool for mapping flood risk, hazard risk analysis, and resilient infrastructure planning. This study discusses the use of GIS and RS in the design of flood-resilient infrastructure in Pakistan as it includes the methodologies, challenges, and benefits of the methodologies. The studies highlighted the importance of spatial analysis, hydrological modelling, and satellite images to aid infrastructure plans in order to mitigate flood risks, improve disaster planning and adaptive resilience to such issues and sustainable urban development. Findings fall that combining GIS and RS as part of the national and local planning frameworks can facilitate better decision-making while also minimizing the adverse impacts of floods on infrastructure and communities.

Keywords: Flood resilience, Geographic Information System (GIS), Remote Sensing, flood risk map, disaster management, infrastructure planning, Hydrological modeling, spatial analysis, Climate adaptation, Pakistan

INTRODUCTION:

Floods are one of the most devastating natural calamities in Pakistan that bring a huge loss of life, economic damage, and disruption of the important infrastructure of Pakistan. The vulnerability of the country is brought on by its various topographical features like the mountainous area at the northern side, river plains in Punjab and Sindh, and wide areas on coastal side in the south (Ahmed and Khan, 2021). Climate change combined with erratic monsoon rains has compounded the frequency and intensity of floods, putting millions of people's lives at risk every year (Raza et al., 2020). Historical incidents, for example, floods in 2010 and 2022, have brought home the necessity of having infrastructure that is able to cope with extreme hydrological events and ensures people's safety and continuity of essential services (Ali et al., 2022).

Urbanization and population growth also serves to further increase the vulnerability to flood. Rapid urbanization of cities like Karachi, Lahore and Islamabad has led to the increase in impervious surfaces, loss of natural drainage ecosystems and encroachment on the floodplains, causing flooding problems in the cities on a regular basis (Hussain & Shah, 2021). Traditional infrastructure planning in Pakistan often has not considered the risks posed by floods, and as a result the damage to roads, bridges, dams, drainage system and residential areas becomes a repetitive phenomenon (Shah et al., 2020). Therefore, the level of disaster risk assessment in the infrastructure design process is imperative for sustainable development.

Geographic Information Systems (GIS) and Remote Sensing (RS) have come into picture as one of the key tools for flood vulnerability issues. GIS offers a stage for incorporating area map information so that planners can identify flood explicitly areas, and look at exposure, and simulate hydrological situations (Khan & Rehman, 2021). RS, using satellite imagery and aerial data, enables one to track precipitation patterns, river discharge, changes in land use and flood extent in near real-time (Zaman et al., 2022). Combining the two technologies, GIS and RS make it possible to completely map flood risks, as well as identifying critical infrastructures at risk and creating mitigation strategies. These types of technologies enable evidence based decision making which is particularly useful in a resource constrained environment where traditional survey methods might be long or lacking.

Flood Resilient Infrastructure design comprises structural measures and also non-structural measures. Structural measures include elevated road design, flood walls, embankments and resilient bridge designs to withstand high velocity of flows (Rahman & Ali, 2020). Non-structural measures include land use planning, zoning rules, early warning systems and community preparedness (Ahmed et al., 2021). GIS and RS can support either these approaches, by helping to identify high-risk areas, by simulating the spatial information for flood cases and their return periods, and by ordering areas for intervention, and. For example, spatial models can be used to estimate the water depth and flow velocity during periods of higher rainfall to help engineers provide design information for bridges and culverts that let the extreme flows through.

Despite of the potential there are challenges in adoption of GIS and RS in making use of ICT for Development (ICT4D) in Pakistan. Data scarcity, old topographic maps, technical capacity and poor institutional coordination limit effective use (Raza et al., 2020). Besides, the process of integrating spatial technology into infrastructure planning at the national level requires policy support, investment in training, and cooperation among government bodies, research institutions and local communities (Hussain and Shah, 2021). Lessons from international experiences show that flood resilient design is not solely based on technology and that durable flood resilient design is based on proper governance and stakeholder participation - as well as long term maintenance.

Recent researches in Pakistan show high prospects for GIS and RS in Flood Risk Management. For example, flood mapping based on satellite imagery has been adopted to detect damage following the 2022 floods, and a combination of hydrological modeling and GIS has helped to prioritize construction of embankments along the Indus River (Khan & Rehman, 2021). Moreover, integration with early warning systems has since improved on disaster response times in some districts, which get the mere idea of the practicality of spatial technologies for saving lives and reducing infrastructure losses.
In conclusion, due to the increased vulnerability of Pakistan to floods, it has become the need of the hour for infrastructure to be flood-friendly. GIS and Remote Sensing offer vital tools to help in risk assessment, planning resilient design and disaster preparedness. While there are challenges such as data gaps, technical limitations and integrating with policy, making use of these technologies has the potential to greatly diminish the impacts of floods to infrastructure and communities. The integration of the use of GIS and RS in infrastructure planning is not only a technological solution but also a step towards sustainable and climate adaptive developmental of Pakistan.

LITERATURE REVIEW:

Vulnerability to Floods in Pakistan:

Pakistan is one of the flooding-prone countries of South Asia, as a result of its geographical and river system as well as the monsoon prevailing climate (Ahmed & Khan, 2021). The Indus River Basin which offers shelter to the major part of the population and cultivated responsibilities is especially sensitive to the high lividity rain and the melting of glaciers (Raza et. al., 2020). Historical records reveal that floods in 2010 impacted more than 20 million people and destroyed infrastructures and economic losses well over USD10 billion (Ali et al., 2022). Urban areas are subject to further risks because of unplanned urbanization, encroaching of floodplain and inefficient drainage system (Hussain & Shah, 2021). These conditions have highlighted the need for flood resilient infrastructure that will be able to withstand recurring hydrological extremes.

Concept of Flood Resilient Infrastructure:

Flood-resilient infrastructure can be considered as those structures and systems that predict, tolerate, and rebound from the flood events. It encompasses both structural measures, such as elevated roads, embankments, bridges and levees and non-structural measures, such as zoning and flood mapping, early warning systems, (Rahman, Ali., 2020, Ahmed, et al., 2021). Structural resilience is focused on design to ensure the survival of physical assets to flood events without loss of major function. Non-structural resilience focuses on planning, governance and preparedness to make people, individuals, assets and communities less exposed and vulnerable. Studies reveal the need for bringing together spatial information, hydrological modelling and community involvement in good resilience planning (UNDRR, 2021).

Role of Geographical Information System in Flood Management:

Geographic Information Systems (GIS) makes it possible to have a platform to collect, store, analyze and visualize spatial data related to the floods. The wide range of applications of GIS in last flood risk mapping, infrastructure vulnerability assessment and hazard zoning, Khan & Rehman, 2021 For example, with the help of GIS, planners can overlay flood prone areas with critical infrastructure, population centre and land use patterns to identify areas which are at high risk. GIS-based multi-criteria decision analysis (MCDA) is helpful in ranking locations for resilient infrastructure such as levees or higher bridges by characteristics such as exposure to risk, economic value and number of individuals living in the community (Zaman et al., 2022). Additionally, GIS can be used to combine historical flood data with hydrological models in order to simulate future flood scenarios in the context of climate change.

There are a number of research works that demonstrate the effectiveness of GIS in Pakistan. For example, the spatial modelling of Indus River Basin with the help of GIS helped the researchers of the study to assess inundation areas and plan the roads and bridges in the inundated districts (Khan and Rehman, 2021). GIS has also been applied for monitoring urban flooding in the Karachi and Lahore cities and identification of affected areas and bottlenecks in the drainage infrastructure (Hussain & Shah, 2021).

Role of Remote Sensing (RS) in Monitoring Floods:

Remote Sensing (RS): It is the method by which the remote sensing data is collected using the assistance of satellite, aerial photo and drone-based data. RS is very useful for real-time flood detection, mapping, and assessing the damage occurring post-disaster (Raza et al., 2020). Techniques such as Synthetic Aperture Radar (SAR), Landsat and Sentinel become useful for monitoring the situation even under cloud cover which is important during monsoon floods.

RS can provide maps of flood extent, estimation of water depth and detection of land cover change which are very important for the infrastructure planning. Studies done in Pakistan have shown that post-flood satellite images can be used much better to assess the extent of damage to roads, bridges and embankments, and can thus foster quicker recovery planning (Ali et al., 2022). RS data can also be combined with GIS to perform dynamic flood risk modelling for planners allowing them to gain understanding of flood resiliency design actionable insights.

Incorporation of GIS and RS in Infrastructure design:
The combination of GIS and RS contributes to the improvement of planning flood resilient infrastructure. While RS ensures an accurate provision of spatial information about water levels and flood extent as well as land use, the analysis, visualization, and the making of decisions is supported by the use of GIS. Integration supports:

1. **Flood Risk Assessment:** Infrastructure and High-Risk Zones.
2. **Infrastructure Prioritization:** Informing the decision on where to invest in the things like bridges, roads, embankments and drainage improvements
3. **Scenario Modeling:** Modeling various flood intensities to build structures that can withstand flooding.
4. **Early Warning Systems:** Killing the communities and authorities about imminent flood risks (Rahman & Ali, 2020; Zaman et al., 2022).

International studies show that such integration will reduce damage to infrastructure, economic loss and human casualties. For example, in Indonesia and Bangladesh, GIS-RS based flood models have helped to guide floodANK elevated road approaches and drainage upgrades and have allowed a 30% reduction in reconstruction costs following a flood (UNDRR, 2021).

Challenges in Pakistan:
Despite the potential of technologies, adoption of GIS and RS in Pakistan is confronted with a number of challenges:

- **Data Scarcity:** Limited high-resolution topographic and hydrological data (Raza et al., 2020).
- **Technical Capacity:** Shortage of skilled personnel to operate GIS-RS tools (Hussain & Shah, 2021).
- **Institutional Coordination:** Poor integration among federal, provincial, and local agencies (Ahmed & Khan, 2021).
- **Policy Gaps:** Lack of formal guidelines for incorporating GIS-RS in infrastructure planning (Ali et al., 2022).

These hurdles attempt to limit successful implementation of GIS-RS for flood withstanding infrastructures in Pakistan.

Emerging Trends and Opportunities:
A number of ways for enhancing flood resilience is suggested by the latest research:

1. **High-Resolution** Satellite Data-Ability to use the free data sets from the sentinel & Landsat Satellite to monitor the data in real-time.
2. **Hydrological Modeling:** Integration with GIS - RS Flood Modeling.
3. **Drone Technology:** Determining places for damages after being flooded
4. **Community Based** Mapping Getting local people engaged in the data gathering and risk evaluation
5. **Policy Integration:** Application of GIS-RS tools in entry into National planning strategy on flood management or urban planning (UNDRR, 2021; Zaman et al, 2022)

These innovations can be useful in terms of accuracy, efficiency, and sustainability when it comes to flood-resilient infrastructure design.
From the literature, the importance of usage of GIS and Remote Sensing for flood resilient infrastructure planning is shown. While structural and non-structural measures are required, technological measures provide the ability to evidence-based decision making. Despite the hurdles including data availability and insufficiency of technical capacity, use of GIS and RS together with hydrological modeling, spatial analysis and policy frameworks can counter flood impacts to infrastructure, as well as assist in the process of climate adaptive development in Pakistan.

METHODOLOGY:

Flood Resilient Infrastructure Design using GIS and remote Sensing in Pakistan:

This study uses a combination of quantitative spatial data analysis and qualitative expert insights using a mixed methods research design. The methodology emphasizes on the assessment of flood vulnerability and identifying vital infrastructure at risk and the design of resilient infrastructure solutions based on GIS and Remote sensing 3D (RS).

Research Design:

A mixed ecosystems approach was taken in order to develop the knowledge towards a comprehensive understanding of the flood risk and the resilience of infrastructure:

- **Quantitative Component:** Uses spatial analysis and mapping of flood hazard and vulnerability of infrastructures using the tools of GIS and RS.
- **Qualitative Component:** Semi structured interviews with the experts (engineers, urban planners, disaster management officials), in understanding design challenges and institutional barriers and policy recommendations.

This approach will ensure both data-driven insights as well as context information for decision-making.

Study Area

The study area is in the Multan District, Punjab as well as its surroundings in the Indus River Basin, which has been chosen on account of:

- High flood prone nature due to monsoon rainfall and river overflowing.
- Presence of the critical infrastructure (roads, bridges, urban settlements) at risk.
- Presence of flood data over time and satellite imagery.

Population and Sampling:

Target Population:

1. **Spatial Data:** Satellite imagery, historical flood data, land use maps, and topographic maps of the study area.
2. **Key Informants:** Experts from relevant organizations, including:
3. Pakistan Meteorological Department
4. Irrigation and Flood Management Authorities
5. Urban Planning Departments

Sampling Technique:

- **Spatial Data Selection:** Satellite images from **Landsat 8**, **Sentinel-2**, and **RADARSAT/SAR** were selected based on pre- and post-flood periods.
- **Key Informants: 12 experts** were purposively selected based on their experience with flood management and infrastructure planning.

DATA COLLECTION METHODS:

Remote Sensing Data Acquisition:

- Multi-temporal satellite images were acquired from which flood extension and surface changes in our study area could be monitored together with land cover change.
- RS data were pre-processed by georeferencing data, atmosphrically normalization data, and removing cloud data.

GIS Spatial Analysis:

GIS software (ArcGIS/QGIS) was used for:

- Flood hazard mapping using **Digital Elevation Models (DEM)** and historical flood data.

SCHOLAR CLUB
GLOBAL RESEARCH COMMUNITY

- Identifying **critical infrastructure at risk**.
- Conducting **suitability analysis** for flood-resilient infrastructure placement.

Expert Interviews:
Semi-structured interviews explored:

- Challenges in flood-resilient design.
- Institutional and policy barriers.
- Recommendations for integrating GIS and RS in planning.

Interviews were audiotaped with the consent of the participant and were transcribed for analysis.

Document Review:

- The secondary sources were government reports, disaster management plans, research articles, flood risk assessments, etc.
- Documents were used to supplement spatial analysis and to provide context for the recommendations of experts.

Data Analysis Techniques:

Quantitative Analysis:

- **Flood Extent Mapping:** Based on classification of pre and post flood imagery, the inundated areas were detected.
- **Hydrological Modeling:** DEMs were used to simulate water flow, identify flood-prone zones, and estimate flood depths.
- **Vulnerability Assessment:** GIS layers of infrastructure, population, and elevation were overlaid to identify high-risk zones.
- **Suitability Analysis:** Weighted overlay analysis determined optimal locations for resilient infrastructure.

Qualitative Analysis:
Thematic analysis of expert interviews identified recurring issues:

- Financial and technical constraints
- Coordination gaps among government agencies
- Prioritization of infrastructure in flood-prone zones

Themes were integrated with GIS-RS results to inform **design recommendations**.

Validity and Reliability:

- **Spatial Accuracy:** Proven to be accurate by ground truth data and historical records of floods.
- **Reliability of Expert Insights:** Ensured through **triangulation** of interview responses and document review.
- **Software Verification:** GIS and RS outputs cross-checked with multiple tools (ArcGIS and QGIS) to ensure consistency.

Ethical Considerations:

- Informed consent was obtained from all interviewees.
- Personal data were kept confidential.
- Spatial data used adhered to **publicly available satellite datasets**, with no private or sensitive information included.
- The findings are reported for purposes of academics and policies only.

DATA ANALYSIS AND FINDINGS:

Designing of Flood-Resilient Infrastructure by employing GIS and Remote Sensing in Pakistan:

This section discusses the spatial, quantitative and qualitative analyses conducted to identify flood vulnerability, list out critical infrastructure in need of protection and discuss strategies for resilient design through the use of GIS and Remote Sensing (RS).

Flood Extent mapping based on Remote Sensing:
Pre- and post-flood satellite imagery (Landsat 8 satellite and Sentinel-2 satellite) have been analyzed to identify flooded areas in Multan and adjacent districts that are located at the Indus River Basin.

Table 1: Flood Extent in Selected Districts (2022 Monsoon Floods)

District	Total Area (km²)	Flooded Area (km²)	Percentage Flooded (%)
Multan	3,721	562	15.1
Muzaffargarh	8,249	1,340	16.2
Dera Ghazi Khan	11,294	1,585	14.0

Analysis:

- The areas affected by flood inundation ranged between 12-16% on average of the district.
- RS-based flood mapping identified **previously unrecorded flood-prone zones**, including low-lying urban settlements and critical road networks.
- Spatial patterns show that **river-adjacent areas and poorly drained urban zones** were most affected.

Critical Infrastructure Vulnerability Analysis:
GIS overlays were used to identify infrastructure that was at risk encompassing roads, bridges, hospitals, schools and embankments.

Table 2: Infrastructure Exposure to Floods

Infrastructure Type	Total Units	Units in Flood-Prone Zones	Percentage at Risk (%)
Roads	1,250 km	280 km	22.4
Bridges	112	28	25.0
Hospitals	45	9	20.0
Schools	215	41	19.1
Embankments	65	15	23.1

Analysis:

- Bridges and roads are especially susceptible, and there is a need for high designs and strengthened construction.
- Hospitals and schools located in flood-prone areas need to be adapted to this reality with, for example, higher platforms and better drainage.

Hydrological Modelling and Analysis of Flood Depth:
Modeling based on Digital Elevation Models (DEM) of the floods was used to simulate depth and flow velocity of waters of flood accounting for different precipitation periods (rainfall return period of 10-, 50- and 100-year events).

Table 3: Simulated Flood Depth in Multan District (m)

Zone Type	Mean Flood Depth (m)	Max Flood Depth (m)	Notes
Low-Lying Urban	1.2	2.8	Critical roads submerged
Agricultural Plains	0.8	2.0	Crop damage risk high
Riverbanks	1.5	3.5	Embankment failure risk

Analysis:

- Low-lying urban zones experience higher flood impact due to **drainage inefficiency**.
- Flood depth modeling informs **bridge height, culvert design, and road elevation** requirements.

Flood Hazard and Risk Mapping:

Using GIS based Weighted Overlay Analysis, flood hazard maps were generated taking in account:

- Elevation (from DEM)
- Distance from river channels
- Land use/land cover
- Historical flood frequency

Analysis:

- Approximately **28% of the district area falls under high-risk zones**.
- Urban clusters near riverbanks are the **highest priority for resilient infrastructure interventions**.
- The hazard map serves as a **decision-support tool** for planners and engineers.

Expert Insights from Interviews:

A total of 12 experts underwent interview sessions such as engineers, urban planners, and disaster management officials. There were five major themes identified in Thematic analysis:

Theme 1: Structural Design Challenges

- Explanation: - Excessive designing of bridges and roads in flood prone areas.
- Poor consideration of extreme events in history construction.

Theme 2: Data and Technical Limitations

- Limited access to high-resolution DEMs and real-time satellite data.
- Lack of GIS-RS trained personnel in provincial planning departments.

Theme 3: Institutional Gaps

- Weak coordination between the Irrigation Departments, Municipal Authorities and the Disaster Management.
- Lack of standardized policies for flood-resilient infrastructure design.

Theme 4: Community Vulnerability

- Low-income settlements in flood-prone areas have limited capacity for self-adaptation.
- Infrastructure design often ignores informal settlements.

Theme 5: Recommendations for GIS-RS Integration

- Use of multi-temporal satellite data to monitor flood progression.
- GIS-based prioritization for elevated roads, bridges, and drainage improvements.
- Integration of flood risk maps into urban planning frameworks.

Integration of Quantitative and Qualitative Findings

- **Flood extent mapping** confirms that **critical infrastructure** is at high risk, corroborated by expert insights.
- **Hydrological modeling** informs technical design specifications such as road elevation, bridge height, and embankment reinforcement.
- GIS hazard maps provide a way to make sure that policymakers are thinking about the 'what where?' of intervention in high-risk areas.
- Experts underpin need being able to build capacities, integration of policies in the countries and continuous monitoring to improve resilience.

Key Findings

- **Flood Extent and Infrastructure** Risk 12-16% of District Areas are Farms Flood The Risk to city and critical infrastructure such roads and bridges are highly exposed to hazards (Roads, Bridges, Hospital etc).
- **Flood Depth** and Hazard Zones Low lying areas of cities and river banks have maximum water depth and velocity that have to have given priority for intervention.
- **Technology Potential:** Precision information, in real time and actionable is available from the GIS and RS throughout the flood-resilient infrastructural planning.
- **Barriers - Both technical capacity** and institutional coordination as well as financial limitation are inhibiting widespread adoption.
- **Policy Implications:** According to the context involves policy decision making, hence using GIS-RS to integrate infrastructural planning helps to mitigate the impact of future floods and secure safety of the community.

Conclusion from Data

The study illustrates the effectiveness using Geographic Information System (GIS) and Remote Sensing tools for site identification about the areas being prone to flooding and the area of infrastructure and providing for resilient design. Structural improvements coupled with policy and planning intervention can go a long way to reduce flood-related losses as much as enhancing sustainability of infrastructure in Pakistan.

CONCLUSION:

Floods faced in Pakistan due to the twin aspects of monsoon vagaries, rivers overflow and climate change are a serious threat for infrastructure and community. The results from this study illustrate the remarkable nature of usefulness of GIS and Remote Sensing (RS) in flood hazard mapping, infrastructure vulnerability mapping and planning for resilient design solutions.

The spatial analysis indicates that a good part of the urban, agriculture, and riverbank areas of Multan and the surrounding districts are under high risk of flooding with critical infrastructure (including roads, bridges, hospitals, and schools) being the most vulnerable. Hydrological modeling shows the depth and velocity of floodwaters, which will help to develop engineering requirements for elevated and reinforced structures.

Expert interviews demonstrate that despite the enormous potential in GIS-RS integration, constraints such as a lack of technical capacity, lack of data, institutional coordination, and lack of policy frameworks make it difficult to integrate GIS with RS at full capacity. However, mixing spatial data analysis with knowledge of experts enables planners to set priorities for interventions, plan for resilient infrastructure and minimise losses associated with floods.

Overall, the study confirms the need for flood resilient design of infrastructure with the help of GIS and RS for sustainable development and disaster preparedness and climate adaptation in Pakistan.

RECOMMENDATIONS:

1. **Policy Integration**
   - Incorporate GIS-RS-based flood hazard assessments into **national and provincial infrastructure planning** frameworks.

2. **Capacity Building**
   - Train engineers, urban planners, and disaster management officials in **GIS, RS, and hydrological modeling techniques**.

3. **Infrastructure Design Improvements**
    - Elevate roads, bridges, and drainage systems in **high-risk flood zones**.
    - Reinforce embankments and implement **flood-adaptive structural designs**.

4. **Data Management and Accessibility**
    - Develop **high-resolution DEMs, historical flood databases, and multi-temporal satellite archives**.
    - Ensure interoperability of datasets between federal and provincial agencies.

5. **Community-Based Risk Reduction**
    - Prioritize flood protection measures in **informal settlements and vulnerable communities**.
    - Develop **early warning systems** integrated with spatial flood modeling.

6. **Monitoring and Evaluation**
    - Establish **continuous flood monitoring programs** using RS and GIS.
    - Regularly update hazard maps and vulnerability assessments for decision-making.

7. **Financial and Technical Support**
    - Provide incentives for adoption of **flood-resilient design technologies**.
    - Invest in research and pilot projects demonstrating GIS-RS integration benefits.

REFERENCES:

1. Ahmed, S., & Khan, F. (2021). Flood risk assessment in Pakistan using geospatial techniques. *Journal of Flood Risk Management, 14*(3), e12734.
2. Ali, R., Rehman, S., & Zaman, H. (2022). GIS-based flood hazard mapping in Pakistan. *Natural Hazards, 111*, 2001–2019.
3. Hussain, A., & Shah, N. (2021). Urban flooding and drainage issues in Pakistan: A GIS perspective. *Urban Water Journal, 18*(5), 413–426.
4. Khan, M., & Rehman, A. (2021). Application of GIS and RS for flood-prone infrastructure planning. *International Journal of Disaster Risk Reduction, 57*, 102163.
5. Rahman, M., & Ali, S. (2020). Flood-resilient infrastructure design using spatial technologies. *Sustainable Cities and Society, 60*, 102244.
6. Raza, H., Ahmed, M., & Khalid, F. (2020). Remote sensing-based flood monitoring in Pakistan. *Journal of Hydrology, 590*, 125392.
7. Shah, H., Rehman, S., & Malik, A. (2020). Infrastructure vulnerability and flood risk in Pakistan. *Water, 12*(9), 2578.
8. UNDRR. (2021). *Global assessment report on disaster risk reduction 2021*. United Nations Office for Disaster Risk Reduction.
9. Zaman, K., Baig, M., & Tariq, S. (2022). Integrating GIS and remote sensing for flood hazard assessment in developing countries. *Natural Hazards, 110*, 1203–1220.
10. Ahmed, M., & Rehman, S. (2021). Hydrological modeling for flood management in Pakistan. *Journal of Water and Climate Change, 12*(6), 1650–1665.
11. Ali, F., & Hussain, T. (2020). Spatial vulnerability assessment of urban infrastructure during floods. *International Journal of Disaster Risk Science, 11*(4), 512–526.
12. Baig, M. A., & Tariq, S. (2021). Satellite-based monitoring of flood extent in Pakistan. *Remote Sensing Applications: Society and Environment, 21*, 100470.
13. GoP. (2022). *National flood management program report*. Government of Pakistan, Ministry of Water Resources.
14. Iqbal, R., & Shah, A. (2020). GIS for disaster risk reduction in Pakistan: Opportunities and challenges. *Disaster Prevention and Management, 29*(5), 667–683.

15. Khan, S., & Zaman, K. (2021). Flood hazard mapping using multi-source satellite data. *Environmental Monitoring and Assessment, 193*(4), 201.
16. Malik, H., Rehman, A., & Ali, S. (2022). Critical infrastructure vulnerability assessment using GIS. *Journal of Infrastructure Systems, 28*(3), 04022023.
17. Qureshi, A. S., & Ahmed, F. (2021). Flood resilience planning for urban areas in Pakistan. *Sustainable Cities and Society, 65*, 102600.
18. Rahman, S., & Khalid, F. (2020). Remote sensing applications in flood disaster management. *Natural Hazards, 102*, 1245–1263.
19. UNDP. (2020). *Disaster risk management framework for Pakistan*. United Nations Development Programme.
20. Zafar, M., & Rehman, T. (2021). Assessment of flood risk using GIS and remote sensing in Punjab. *Environmental Earth Sciences, 80*(12), 456.
21. Ahmed, R., & Tariq, M. (2022). Flood-resilient urban infrastructure: Lessons from South Asia. *International Journal of Disaster Risk Reduction, 66*, 102667.