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Designing Flood Risk Reduction Plan for Kalat Division, Balochistan

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Flood risk mitigation is crucial in the Kalat Division of Balochistan Province due to frequent flooding events that endanger lives and infrastructure. This study introduces a novel approach by integrating Landsat 8-9 OLI data with advanced remote sensing techniques to address flood risks in the region, an approach not previously utilized. Covering the period from 2015 to 2022, the research employs satellite imagery and indices such as NDWI, MNDWI, NDVI, LULC, and Watershed Analysis, with thorough pre-processing to ensure data accuracy. NDWI and MNDWI analyses effectively mapped and monitored water bodies, pinpointing vulnerable areas essential for flood risk assessment. NDVI analysis revealed significant correlations between vegetation dynamics and flooding, highlighting ecological impacts. LULC analysis identified substantial changes in land use patterns, emphasizing the role of human activities in flood vulnerability. Watershed Analysis offered valuable insights into hydrological dynamics and precipitation patterns, supporting flood prediction and mitigation efforts. This integrated approach provided a comprehensive understanding of climatic, hydrological, and land cover factors contributing to flood vulnerability, enabling the development of evidence-based flood risk management strategies. The findings enhance the Kalat Division's resilience against future floods through informed, evidence-based mitigation strategies.

Keywords: Kalat Division, Satellite Imagery, Remote Sensing Techniques, Watershed Analysis.

Introduction:

Globally, flood disasters are increasingly risky due to heightened vulnerability and exposure [1][2]. Changing climatic conditions, including severe alterations in precipitation patterns and rising temperatures, are key factors contributing to flood disasters [3]. Developing countries face significant economic losses from direct damage to agriculture and infrastructure, with millions affected by flooding worldwide over recent decades [4]. Geographic factors make many countries, especially low-lying areas near rivers or coastlines, particularly susceptible to floods. Rising sea levels from rapid snow and ice melt exacerbate flooding risks, further intensified by inadequate infrastructure such as dams, levees, and drainage systems [5].

Effective flood risk mitigation requires a comprehensive assessment of flood hazards, analyzing topography, climate, hydrology, and associated metadata to identify flood-prone areas. This assessment is crucial for community safety, infrastructure resilience, disaster preparedness, environmental protection, and sustainable development [6]. Accurate risk identification enables proactive measures, including early warning systems, evacuation plans, and resilient infrastructure design. Without a thorough understanding of flooding, prioritizing resources and development remains challenging [7][8]. Flood risk mitigation involves both structural and non-structural approaches, including physical modifications to manage floodwaters, as well as planning, policy development, and community education [9][10]. Continuous monitoring of flood-prone areas using satellite data and field surveys is essential for assessing flood hazards. Incorporating changing climatic projections into assessments can help anticipate future flooding risks. Flood hazard mapping can visualize impacts, prioritize mitigation efforts, and communicate risks to stakeholders [3][11].

The southern regions of Balochistan province are particularly vulnerable to flash flooding during the monsoon season, causing extensive damage to communities, agriculture, infrastructure, and road networks [12]. The catastrophic flooding in 2022 underscored the urgent need for robust flood risk management, as the province faced severe economic losses and widespread infrastructural damage. Addressing flood risk in Balochistan necessitates improved urban planning, disaster management strategies, and resilient infrastructure [13][14]. This paper serves as a foundational resource for developing effective flood mitigation strategies, offering valuable insights for disaster planners and guiding future studies to identify and protect vulnerable areas [15][8].

Novelty Statement:

This research introduces a novel flood risk reduction plan for the Kalat Division in Balochistan, combining advanced GIS and remote sensing techniques with local hydrological data. This comprehensive approach has not been previously implemented in the region.

Research Objectives:

The following objectives are set to achieve the purpose of this research:

- Evaluate the effectiveness of various flood risk mitigation measures, including both structural and non-structural approaches, to reduce flood-related damages and enhance community resilience.
- Optimize the integration of flood risk mitigation strategies in the Kalat Division.
- Quantify the socio-economic and environmental impacts of flooding in the Kalat Division.
- Improve early warning systems in the Kalat Division.

Study Area:

The Kalat Division includes the districts of Mastung, Surab, Khuzdar, Kalat, Awaran, Hub, and Lasbela, with Khuzdar serving as its capital. Covering approximately 140,612 km², the division features predominantly mountainous terrain interspersed with valleys, with elevations ranging from 1,525 to 1,928 meters above sea level. Key physical features include the Sheerinab River, dry temperate scrub forests, and fertile soils conducive to agriculture. Mastung, Surab, Kalat, and Awaran districts exhibit significant agricultural potential and diverse topographies, from valleys to rugged mountains [16][15]. Lasbela, with its extensive forest cover and coastal plain, supports diverse economic activities such as agriculture, forestry, and fisheries. The division faces environmental and infrastructural challenges, notably highlighted by the severe flooding in 2022, underscoring the need for detailed geographic and topographic assessments for effective flood risk management and sustainable development [17][18].

Kalat Division has an average annual temperature of about 25.29°C, slightly above the national average. Annual precipitation is minimal at 12.93 mm, with the highest rainfall occurring in February [19]. Summers are hot, with average July temperatures around 40.64°C, while winters are cold, especially in high-altitude areas like Kalat, which experiences heavy snowfall. Mastung and Surab districts endure extreme temperatures, with Mastung reaching lows of -3°C in winter (Climate.org). Awaran district is prone to frequent and severe dust storms from June to September, while Lasbela, influenced by its coastal proximity, enjoys milder winters and moderate temperatures due to continuous winds [15][20].

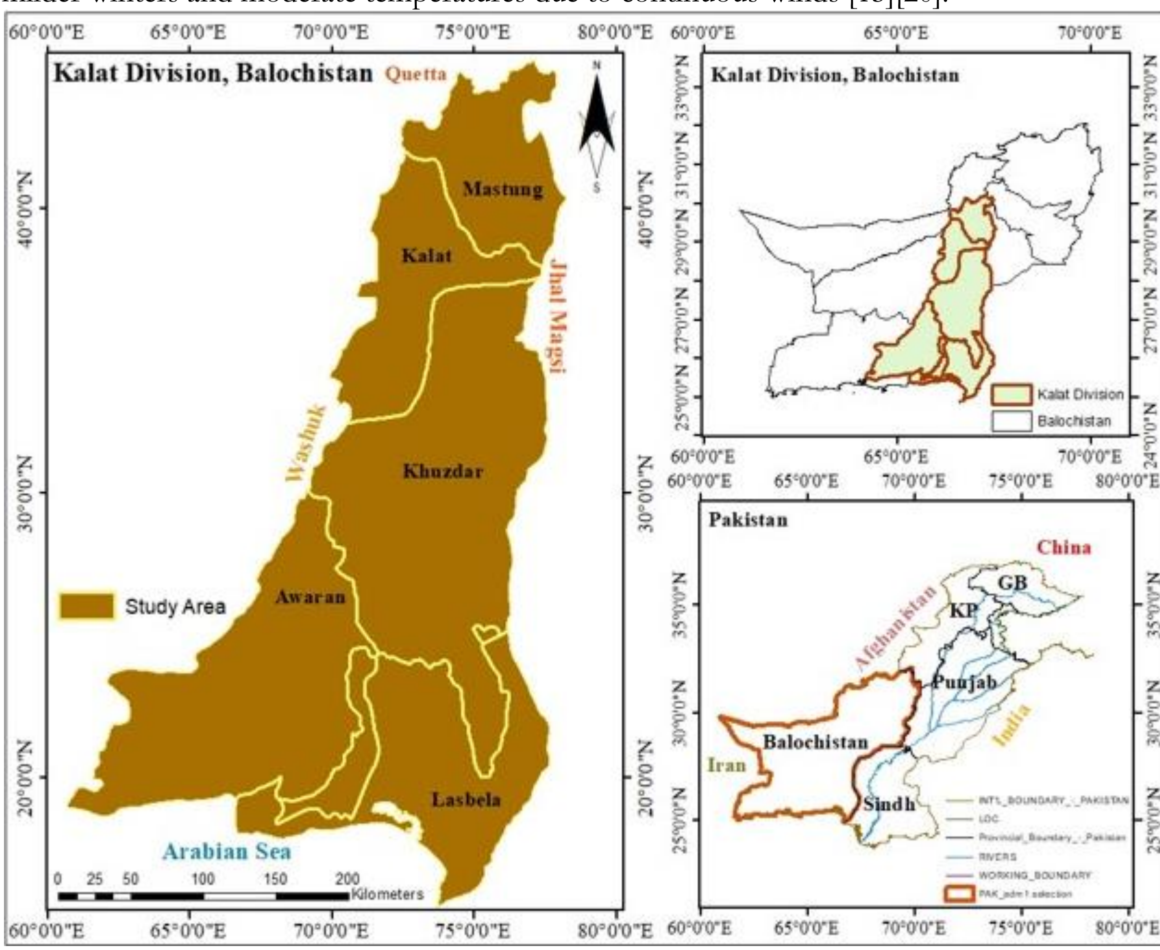


Figure 1: Study Area Map Kalat Division, Balochistan

Research Methodology:

The research aims to develop a flood risk mitigation strategy for the Kalat Division by leveraging satellite data and high-resolution Digital Elevation Models (DEMs). Watershed analysis is conducted using DEM data, while temperature and precipitation metrics are obtained from the MERRA Satellite with a 50m x 50m resolution. Landsat 8-9 OLI images are used to calculate NDVI, NDWI, and MNDWI, as well as to perform land use/land cover (LULC) analysis. Buffer Analysis is employed to delineate flood-prone areas. Landsat 8-9 OLI images with minimal cloud cover (0-5%) from the USGS Earth Explorer, covering the period from 2015 to 2022, are utilized. Image processing is performed using ArcGIS 10.5, and supplementary graphs are created using data from the Meteoblue website.

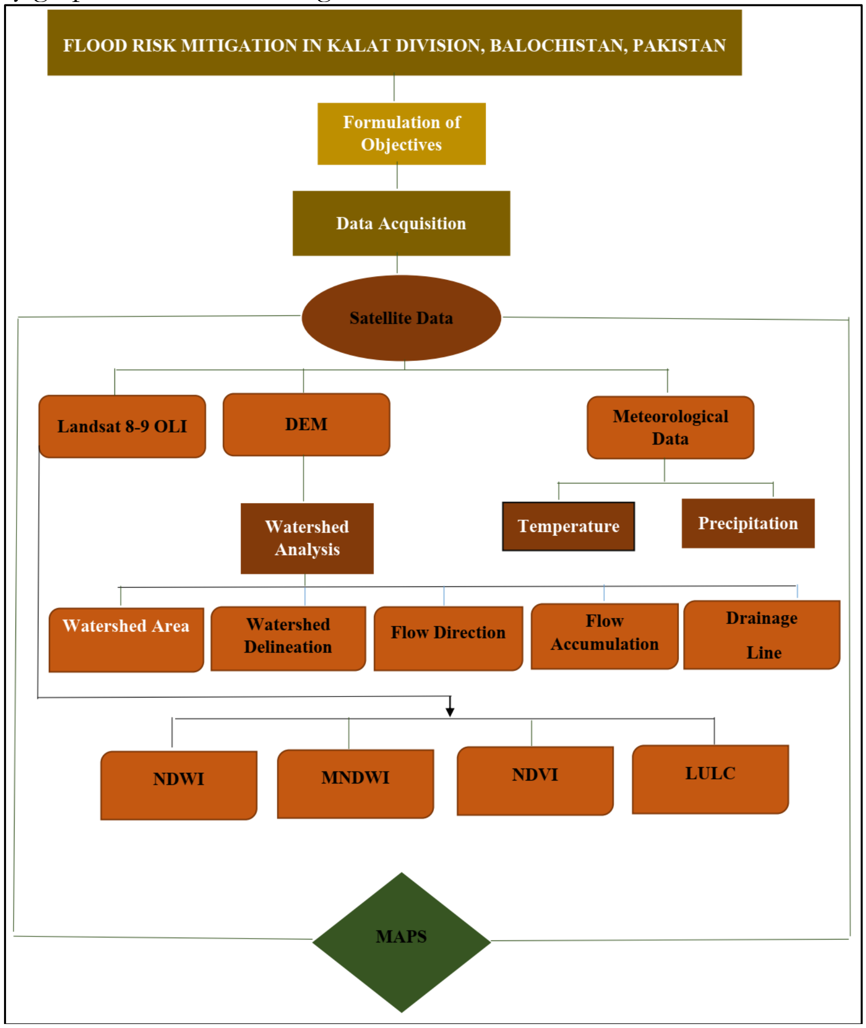


Figure 2: Flow of Methodology

Results:

This research conducts a comprehensive analysis of climatic factors and hydrological parameters to explore flood risk mitigation strategies in the Kalat Division. The primary objectives are to identify potential flood risks, assess their implications, and evaluate vulnerable areas within the division. Using satellite imagery, remote sensing, and GIS techniques, we have accurately pinpointed areas at risk of flooding. The analysis includes detecting changes in land use, identifying factors contributing to recurrent flooding, and precisely mapping water bodies and their volumes in the region.

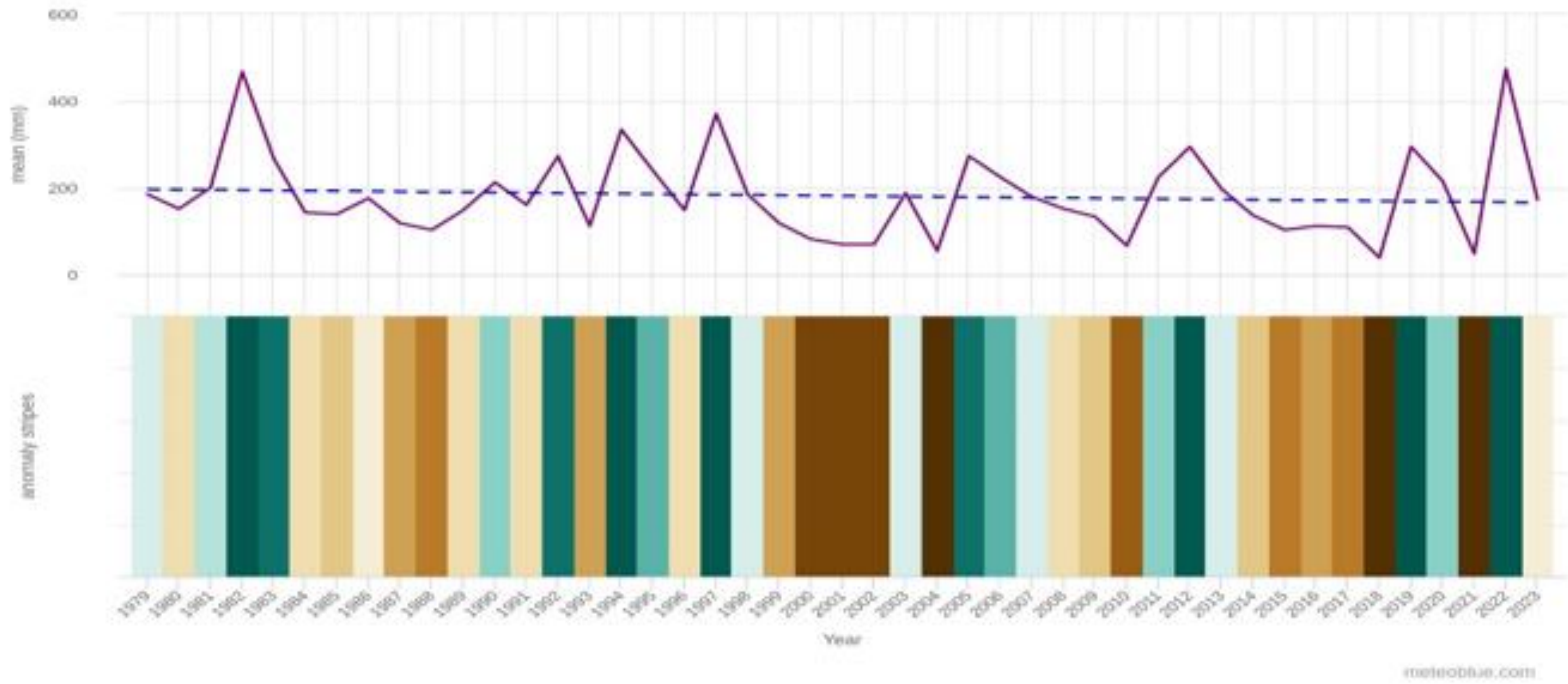


Figure 3: Mean Yearly Precipitation, Trend and Anomaly, 1979-23

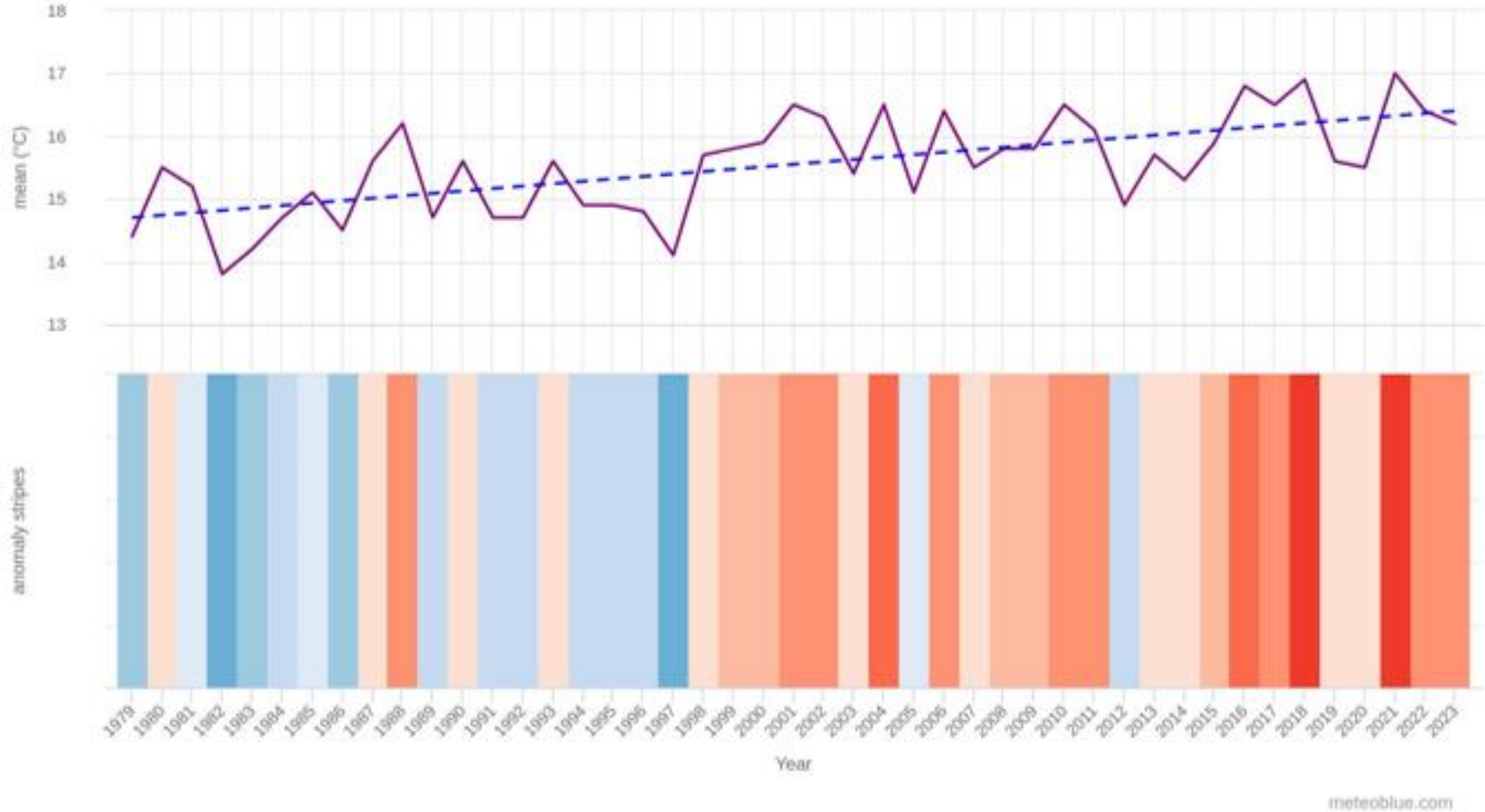


Figure 4: Mean Yearly Temperature, Trend, and Anomaly 1979-23

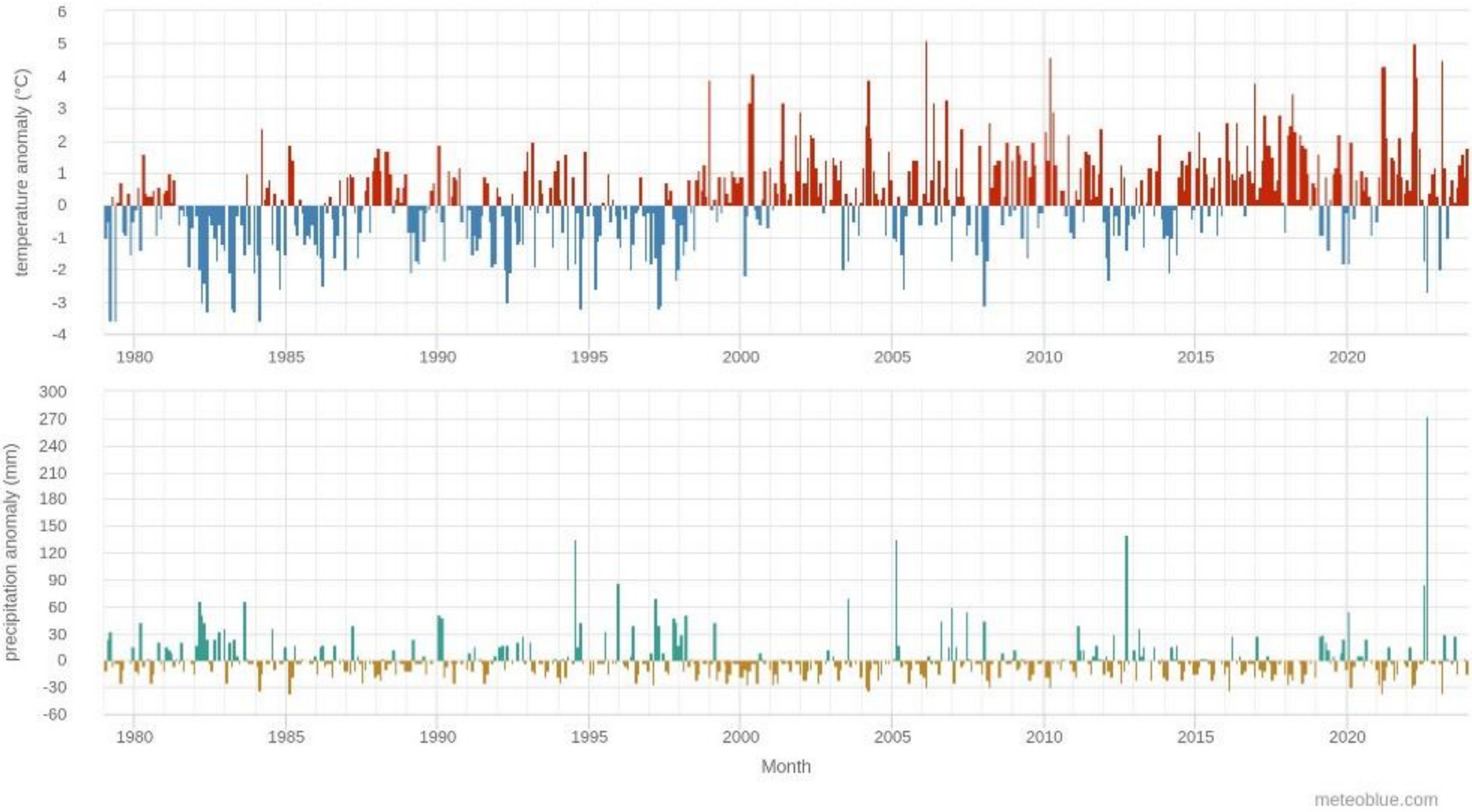


Figure 5: Monthly Anomalies for Temperature and Precipitation, 1979-23

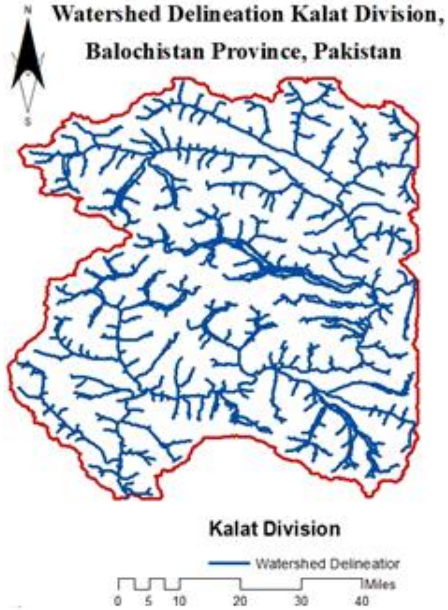


Figure 6: Watershed Analysis

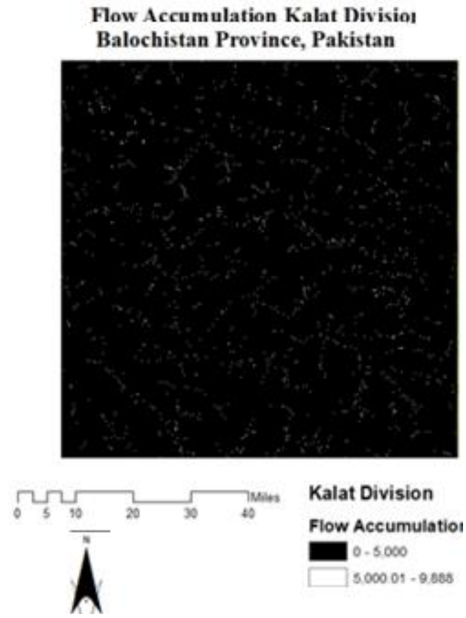


Figure 7: Watershed Analysis

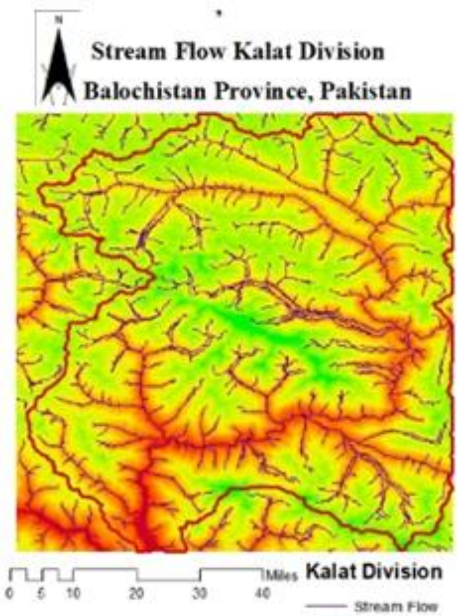


Figure 8: Watershed Analysis

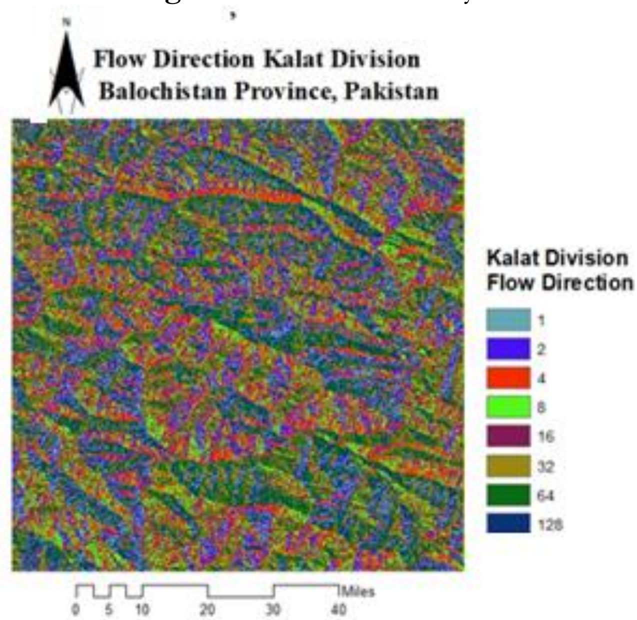


Figure 9: Watershed Analysis

To understand the hydrology of the Kalat Division, we performed a watershed analysis that includes stream flow analysis, watershed delineation, flow accumulation assessment, and flow direction analysis to clarify precipitation patterns. Using a high-resolution 2023 Digital Elevation Model from the USGS Earth Explorer, we found that intense monsoon rains, such as the 2022 event with rainfall 5.1 times the 30-year average, significantly impacted flooding dynamics in the division.

The LULC analysis offers crucial insights into the spatial distribution and characteristics of the Kalat Division. It reveals that 60.9% to 67.6% of the land is vegetated, 43.9% to 53.2% is barren, and 53.3% to 56.3% is underutilized, presenting opportunities for agricultural and economic development. By categorizing different land types and evaluating their contributions to flood dynamics—such as increased surface runoff from urban areas and altered water retention due to vegetation changes—we used Landsat 8-9 OLI images from 2019-2022 to formulate targeted flood mitigation measures, which were processed using ArcGIS 10.5 software.

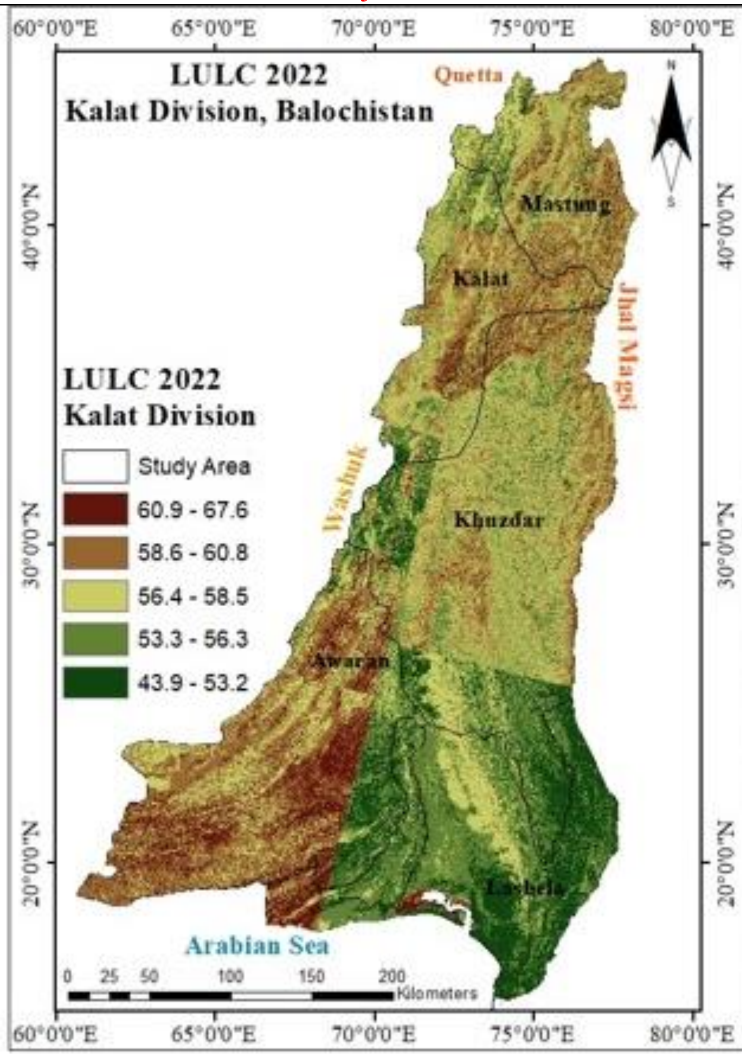


Figure 10. Land Use Land Cover Map

NDWI Analysis:

Satellite images from 2015-2022, acquired via Landsat 8-9 OLI, were processed using ArcGIS 10.5 for NDWI analysis to evaluate water content in the Kalat Division. Applying the formula NDWI = (NIR – SWIR) / (NIR + SWIR) improved water feature accuracy by minimizing atmospheric effects. This analysis successfully delineated water bodies in the Kalat Division, aiding in flood risk mitigation and providing precise assessments of flood extent during the 2022 floods.

MNDWI Analysis:

Satellite imagery from 2015-2022, acquired from Landsat 8-9 OLI, was processed using ArcGIS 10.5 for MNDWI analysis to assess water content in the Kalat Division. Applying the formula MNDWI = (Band 3 – Band 6) / (Band 3 + Band 6) effectively delineated water bodies while minimizing interference from built-up areas and vegetation. This analysis accurately identified open water surfaces and provided precise mapping for flood risk management in the region.

NDVI Analysis:

Satellite imagery from 2015-2022, acquired from Landsat 8-9 OLI, was processed using ArcGIS 10.5 to conduct NDVI analysis, assessing vegetation health and land cover changes. Applying the formula NDVI = (Band 5 – Band 4) / (Band 5 + Band 4), the analysis quantified vegetation density and vigor, while also highlighting flood-affected areas. The NDVI time-series analysis provided insights into vegetation recovery post-flooding, offering valuable information on the spatial and temporal dynamics of vegetation to enhance flood risk management in the Division.

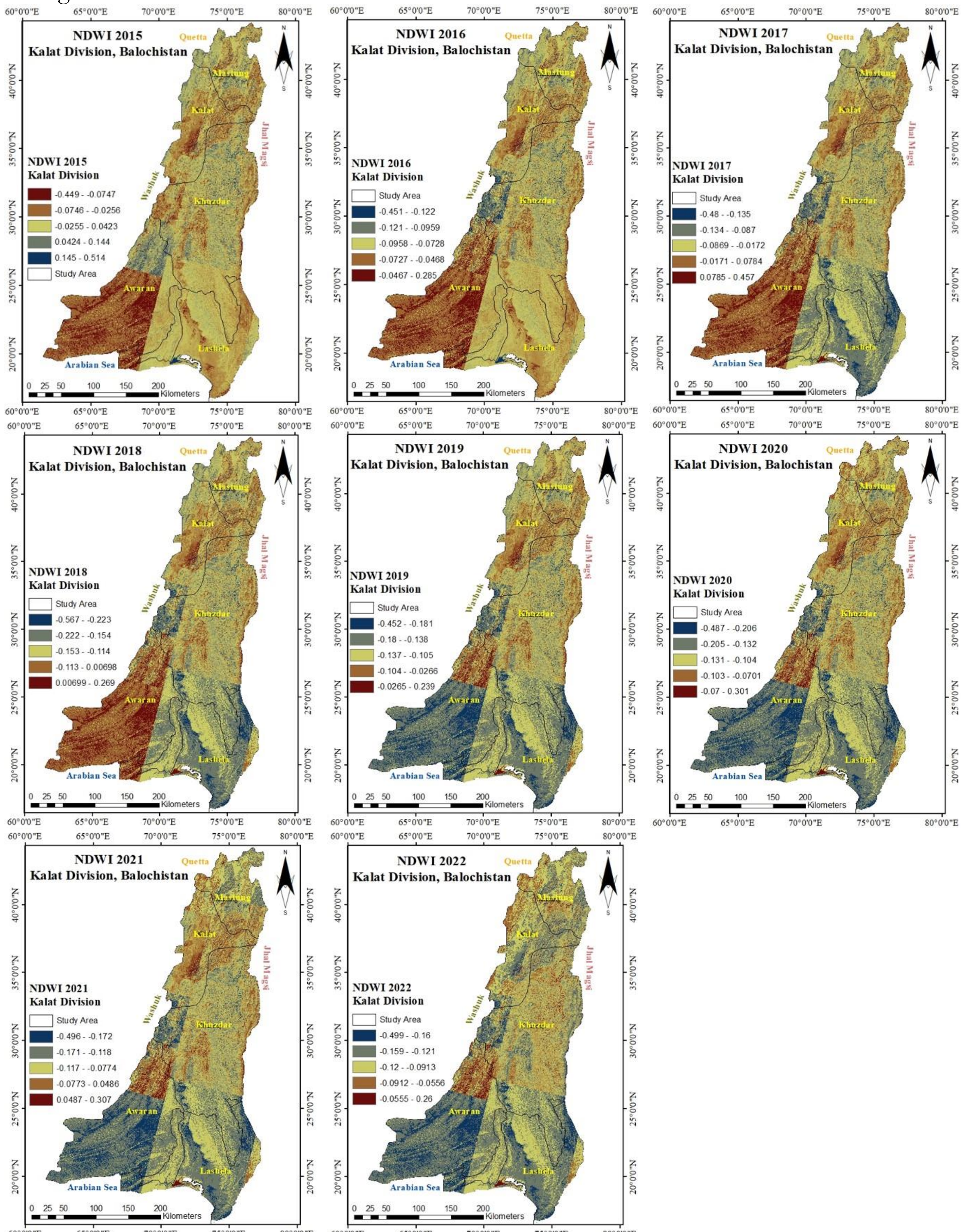


Figure 11. NDWI Analysis 2015-22

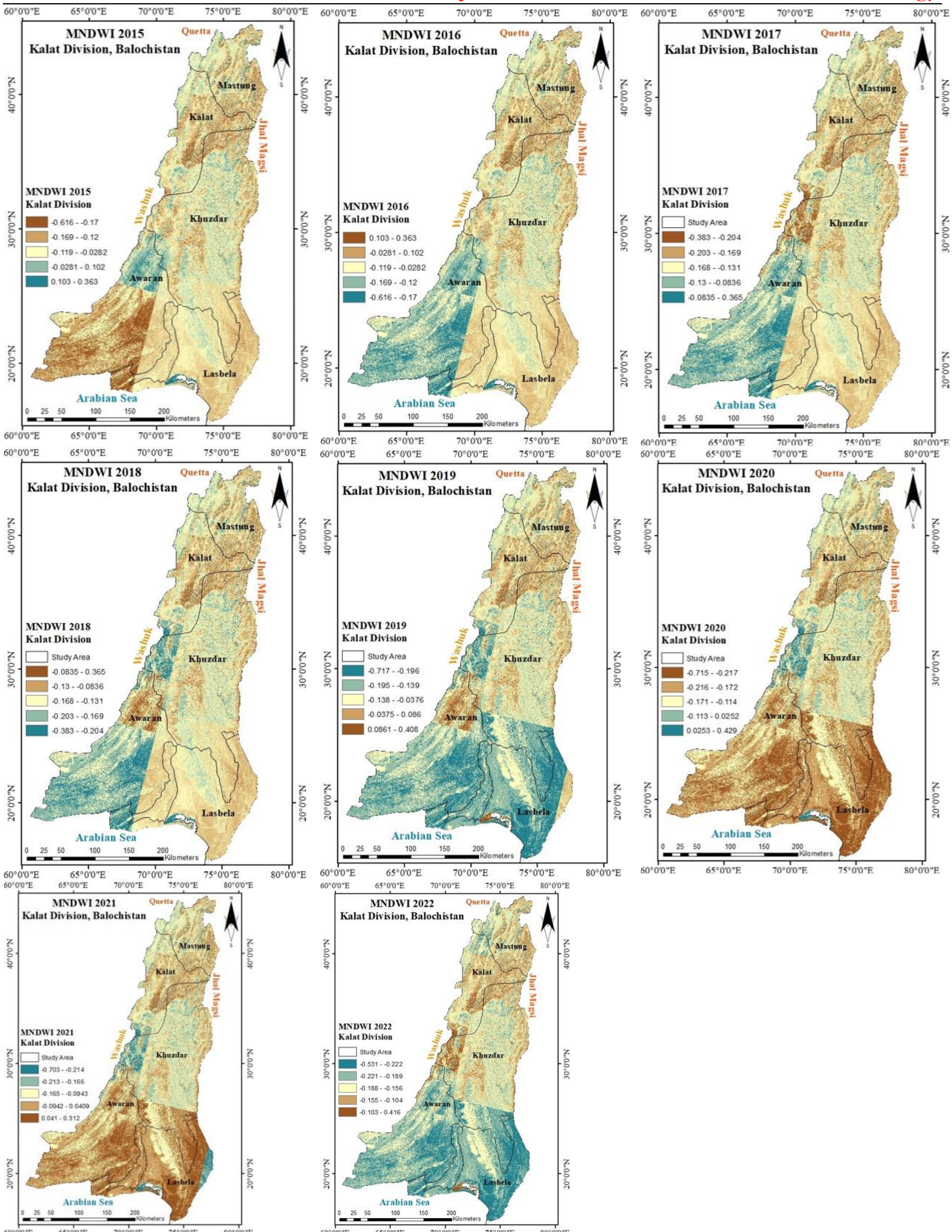


Figure 12: MNDWI Analysis

Flood Risk Reduction Plan:

As we confront the critical issue of flood risk reduction in Kalat Division, Balochistan Province, it is crucial to recognize both the urgency and complexity of the challenge. This region's vulnerability to flooding presents a serious threat to human lives and the socioeconomic stability of its communities. Therefore, we must undertake a thorough land use planning process that identifies and implements effective flood mitigation strategies. Our goal is to safeguard lives and livelihoods, ensuring resilience for future generations within a 3 to 5-year timeframe.

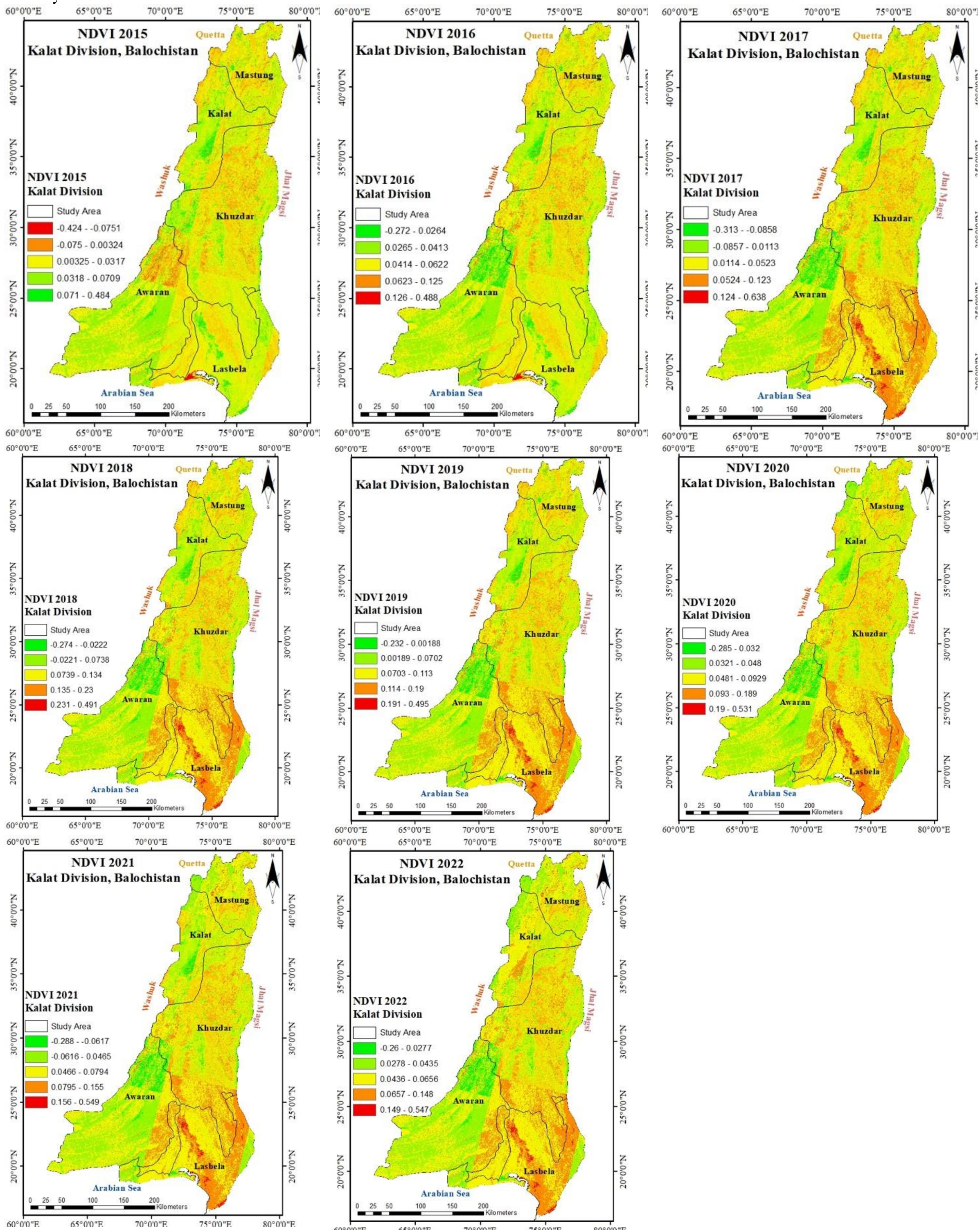
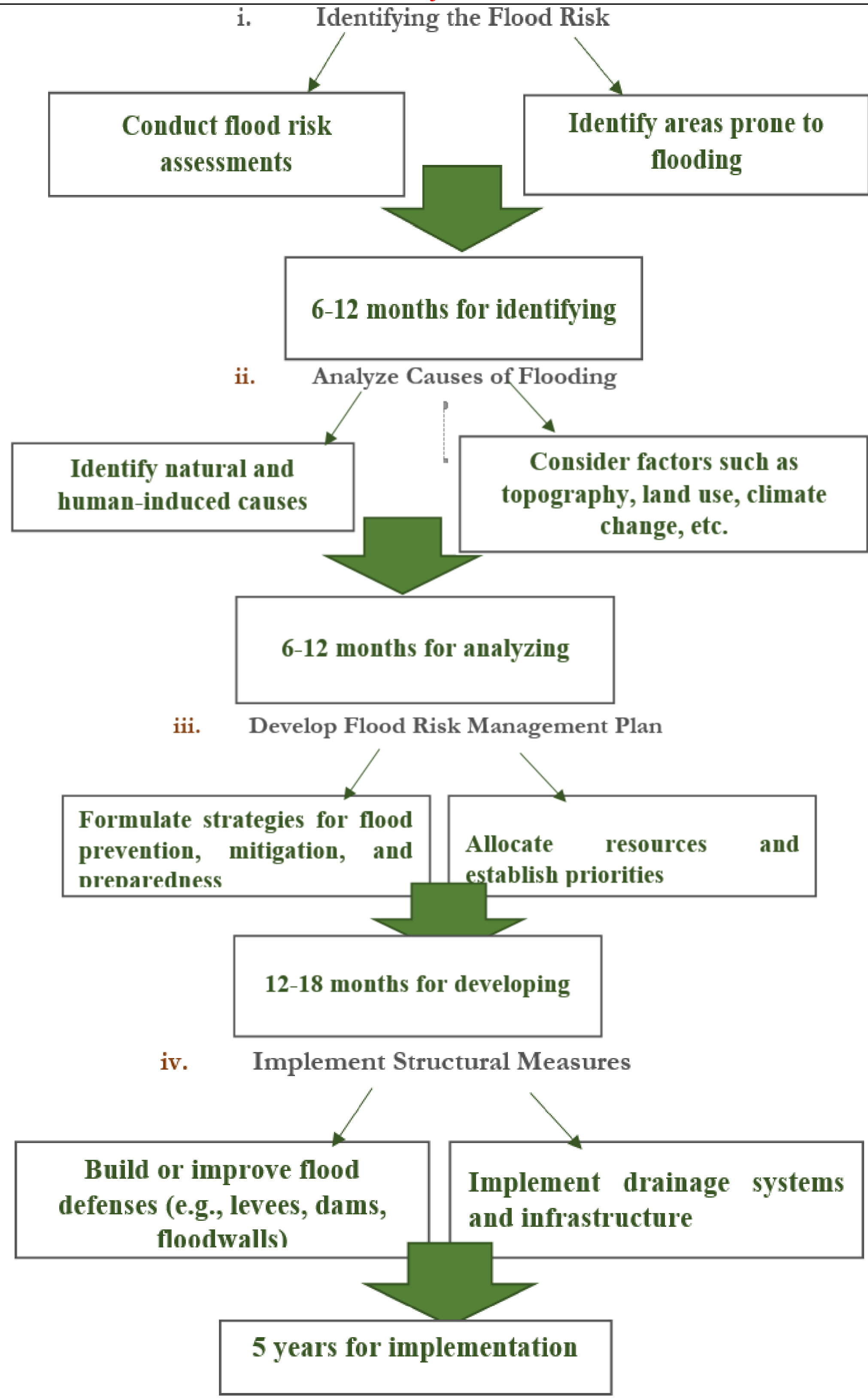
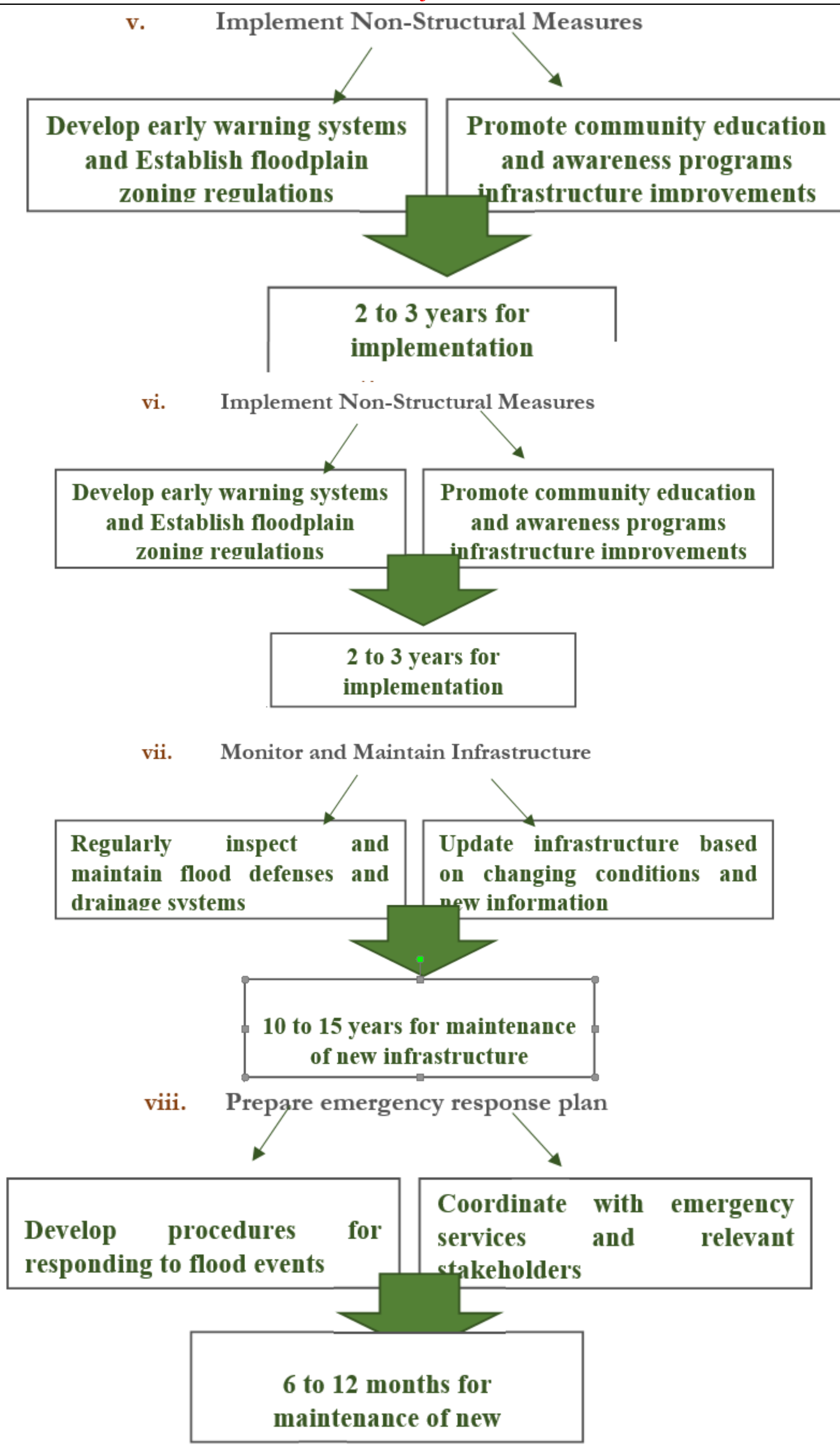


Figure 13. NDVI Analysis


i. Identifying the Flood Risk
Conduct flood risk assessments
Identify areas prone to flooding
6-12 months for identifying
ii. Analyze Causes of Flooding
Identify natural and human-induced causes
Consider factors such as topography, land use, climate change, etc.
6-12 months for analyzing
iii. Develop Flood Risk Management Plan
Formulate strategies for flood prevention, mitigation, and preparedness
Allocate resources and establish priorities
12-18 months for developing
iv. Implement Structural Measures
Build or improve flood defenses (e.g., levees, dams, floodwalls)
Implement drainage systems and infrastructure
5 years for implementation


v. Implement Non-Structural Measures
Develop early warning systems and Establish floodplain zoning regulations
Promote community education and awareness programs infrastructure improvements
2 to 3 years for implementation
vi. Implement Non-Structural Measures
Develop early warning systems and Establish floodplain zoning regulations
Promote community education and awareness programs infrastructure improvements
2 to 3 years for implementation
vii. Monitor and Maintain Infrastructure
Regularly inspect and maintain flood defenses and drainage systems
Update infrastructure based on changing conditions and new information
10 to 15 years for maintenance of new infrastructure
viii. Prepare emergency response plan
Develop procedures for responding to flood events
Coordinate with emergency services and relevant stakeholders
6 to 12 months for maintenance of new

ix. Early Warning and Monitoring

- Utilize flood monitoring systems
- Issue warnings and alerts as necessary

1 to 2 years for implementation

x. Respond to Flood Event

- Activate emergency response plans and Evacuate affected areas if necessary
- Provide emergency relief and support

28 to 48 hours for implementation

xi. Evaluate Response and Recovery Efforts

- Assess effectiveness of response actions
- Identify areas for improvement

6 to 12 months for implementation

xii. Learn and Adapt

- Incorporate lessons learned into future planning and response efforts
- Continuously update flood risk management strategies based on new information and changing conditions

2 to 3 years for implementation

Discussion:

The findings of this study closely align with existing research, affirming the effectiveness of Landsat 8-9 OLI imagery and remote sensing techniques for flood risk mitigation. The use of NDWI, MNDWI, and NDVI indices was effective in mapping water bodies and assessing vegetation health, consistent with similar studies that emphasize their role in flood monitoring. Incorporating LST data enhanced precision by including thermal dynamics, reflecting research that highlights the importance of surface temperature in flood assessments. The comprehensive watershed analysis supports existing methodologies that stress the importance of hydrological factors in identifying flood-prone areas. These results contribute to the advancement of flood risk management strategies in the Kalat Division. Mahmood (2019) recommended developing a flood risk reduction plan for each watershed, and Ali and Mahmood (2024) emphasized the need for a flood preparedness plan for flood-prone areas.

Conclusion:

The exploration of flood risk mitigation in the Kalat Division from 2015-22 utilized advanced remote sensing techniques and Landsat 8-9 OLI satellite imagery. This study employed various methodologies, including NDWI, MNDWI, NDVI, LULC analysis, and Watershed Analysis, to comprehensively assess factors contributing to flood vulnerability. Rigorous pre-processing of the imagery eliminated atmospheric and sensor-related anomalies, enhancing data accuracy. NDWI and MNDWI analyses effectively mapped and monitored water bodies, revealing inundation dynamics and identifying vulnerable regions. NDVI analysis provided insights into vegetation dynamics, highlighting ecological impacts and changes in land cover due to flooding. LULC analysis detected land use changes, illustrating the impact of human activities on flood risk, while Watershed Analysis offered a deeper understanding of hydrological complexities, including stream flow and precipitation patterns. Developing a flood risk plan will aid scientific communities in studying future flood risks and implementing strategies to mitigate devastation in the division. These findings are essential for creating evidence-based flood risk management strategies, thereby strengthening the Kalat Division's resilience against future flooding events.

Recommendations:

- Implement real-time monitoring systems
- Enhance spatial resolution
- Integrate machine learning algorithms
- Conduct detailed land-use planning
- Establish an early warning system
- Collaborate with hydrologists and climatologists
- Evaluate the feasibility of green infrastructure
- Conduct community awareness campaigns
- Explore the potential of unmanned aerial vehicles (UAVs)
- Establish a data-sharing platform

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