Flood Vulnerability in Punjab, Pakistan
A Geospatial Analysis and Cartographic Approach
Diploma Thesis

Motivation & Objectives

Flooding is one of the most severe global hazards, destroying infrastructure, impacting economies, and costing lives. In Pakistan's Punjab region, high population density, agriculture, and major rivers make it especially vulnerable, with flood risks increasing due to climate change. Punjab, Pakistan, is the country's most populous province, with nearly 130 million people (PBS, 2023). The region is an agricultural hub, thanks to the five major rivers – Indus, Jhelum, Chenab, Ravi, and Sutlej – but also faces significant flood risks (Rahman et al., 2017).

Pakistan ranks among the top ten countries exposed to high flood risk, with 38% living in flood-prone areas (Rentschler et al., 2022). Floods, particularly during the monsoon season are a recurring issue, with extreme events occurring approximately every three years. The 2022 floods were the worst since 2010, affecting 33 million people (WFP, 2024), and the 2024 floods caused 94 deaths and 238 injuries in Punjab, underscoring the urgent need for flood risk management (Islamic Relief, 2024).

While remote sensing and GIS have advanced flood assessments worldwide, studies in Punjab often focus only on flood-prone areas, overlooking the vulnerability of affected populations. This study develops a multi-dimensional flood vulnerability model, integrating physical, environmental, and population factors, to better identify the most at-risk areas. A major emphasis is also placed on visualizing results effectively through innovative mapping techniques, evaluated via user testing.

The objectives of the thesis are as follows:
I. Geospatial Analysis and Mapping of Flood Vulnerability
II. Cartographic Design and User Testing
III. Cartographic Project of the Atlas

Workflow

The processing of this study followed a structured and multi-software approach (Figure 1). Based on literature review and expert consultations, 13 vulnerability parameters were selected, processed, and classified using ArcGIS Pro. Larger datasets, such as flood extents, were derived through Google Earth Engine. For the Analytical Hierarchy Process (AHP), Excel was used to calculate parameter weights and consistency ratios. While QuestionPro was employed to collect expert opinion for the AHP weighting. Post-processing of maps, creation of figures, and the compilation of the atlas were conducted using Affinity Designer and Affinity Publisher. An interactive dashboard was developed using Leaflet and hosted on GitHub.

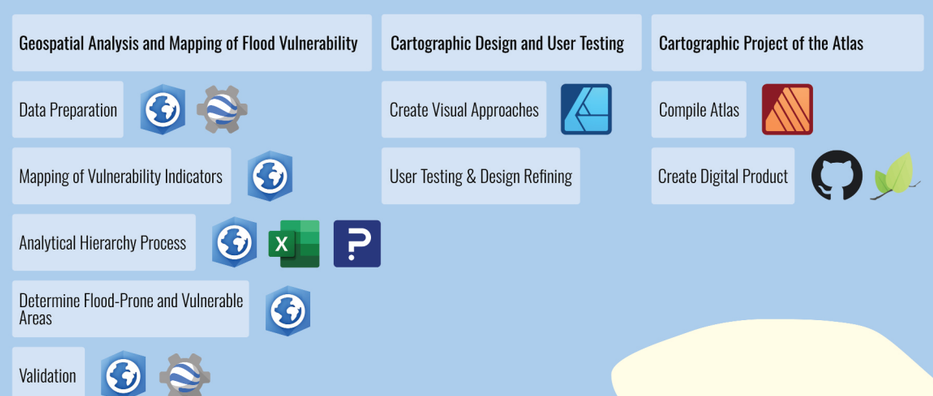
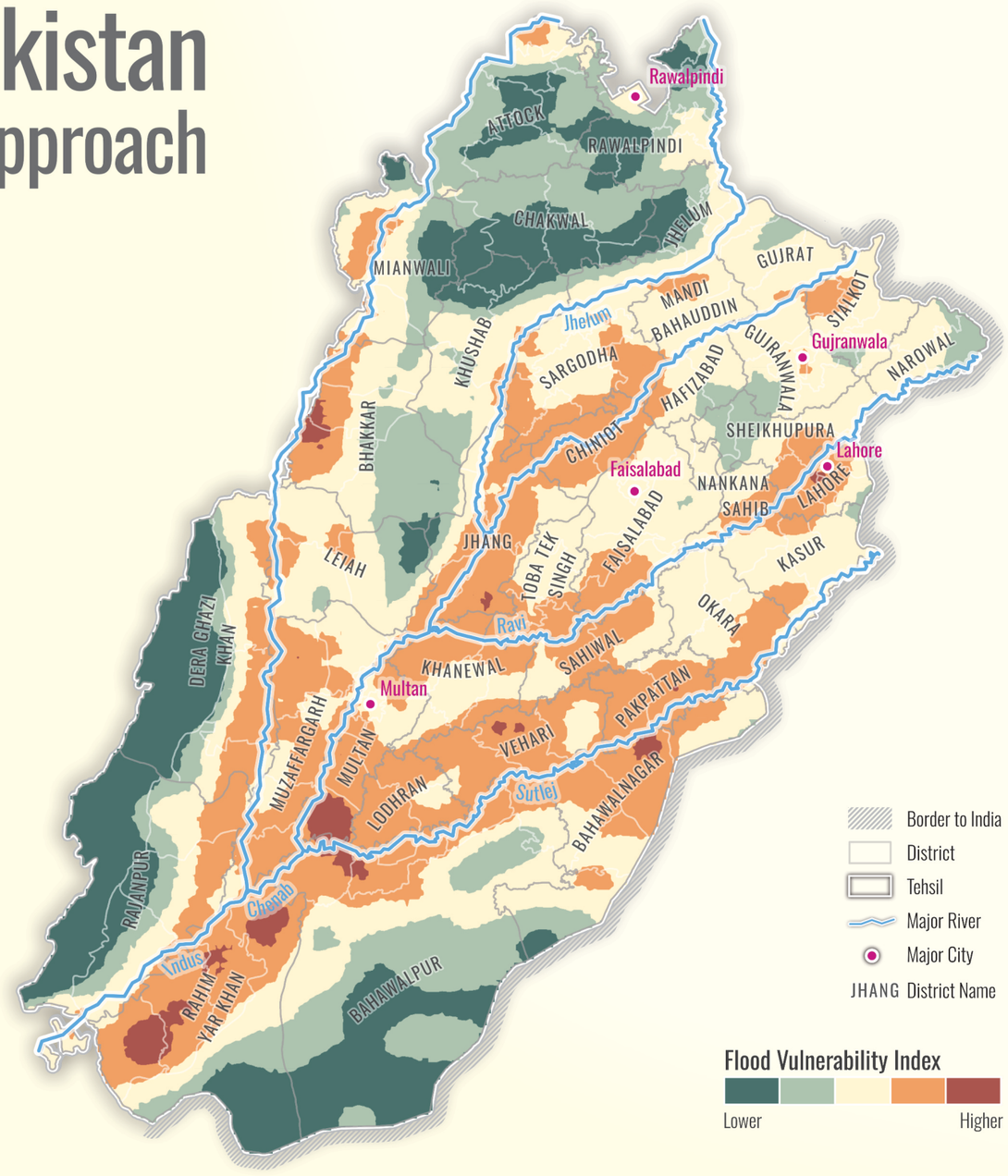


Figure 1: Study's workflow.



Map 2: FVI interpolated.

The Flood Vulnerability Index

The Flood Vulnerability Index (FVI) model consists of three components (Figure 2): Flood-Prone Component (FPC), Population Susceptibility Component (PSC), and Coping Capacity Component (CCC).

The Flood-Prone Component (FPC) includes parameters such as Annual Rainfall, Distance to River, Drainage Density, Elevation, Land Use Land Cover, Slope, and Topographic Wetness Index, which assess the physical and environmental factors influencing flood occurrence.

The Population Susceptibility Component (PSC) focuses on demographic factors and includes parameters like Dependent Population, Disabled Population, Female Population, and Population Density, which help measure a population's susceptibility to flood risks.

The Coping Capacity Component (CCC) consists of two parameters: Distance to Health Facilities and Literacy Rate, which reflect the capacity of the population to respond to and recover from flood events.

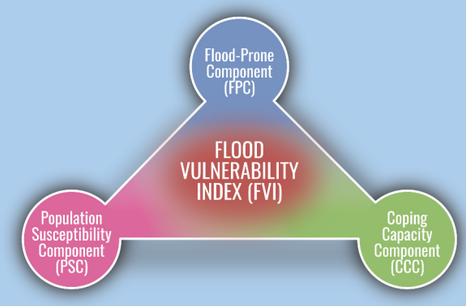


Figure 2: Flood Vulnerability Index and its components.

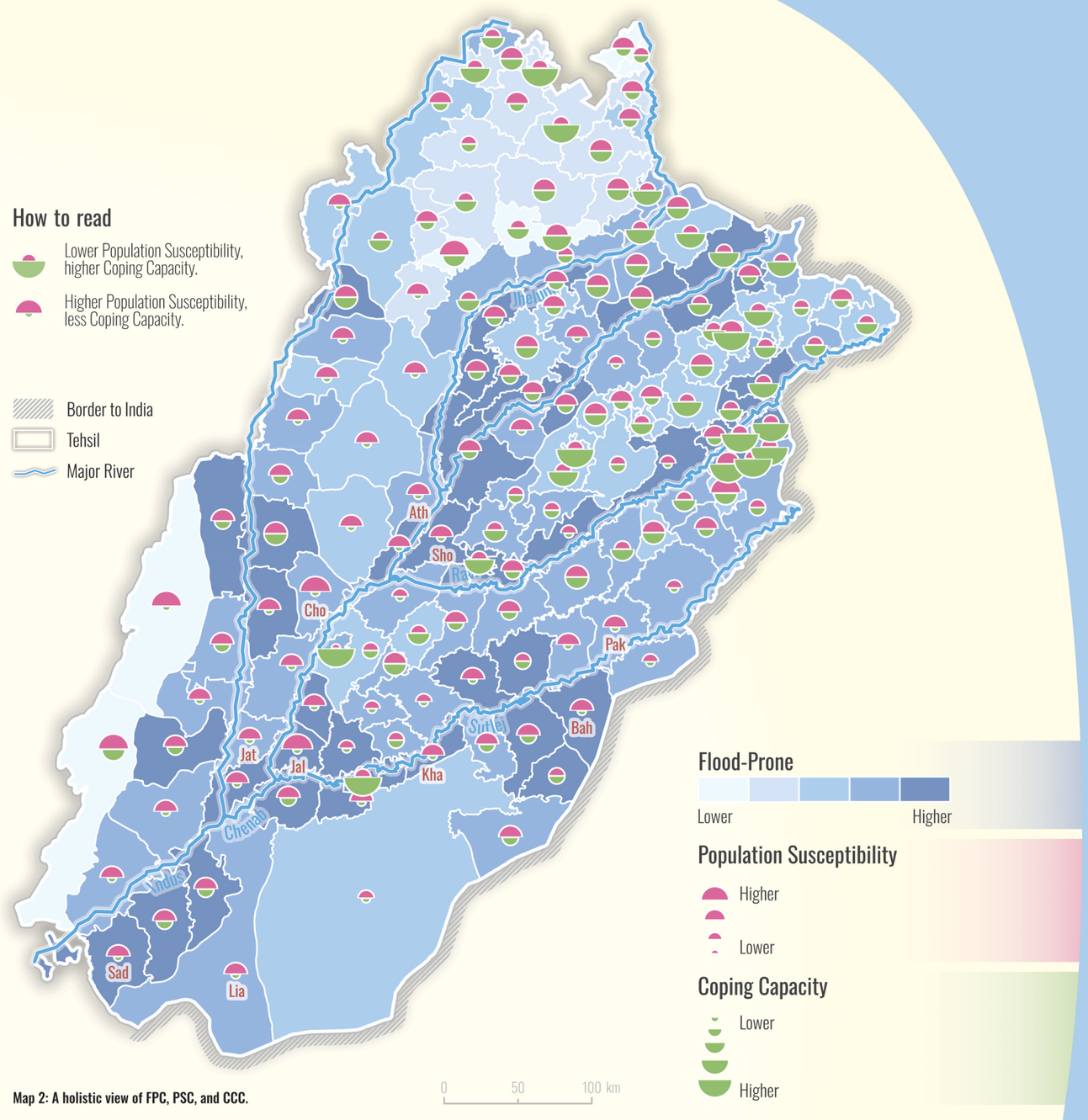
Results & Outcomes

The results of the flood vulnerability assessment are presented through several visualizations, showcasing the aggregated FVI and its individual components across the study area. These maps were refined in user testing. Two maps are shown on the poster.

Map 1: FVI interpolated.
The FVI - calculated by multiplying FPC by PSC, and divding by CCC - has been interpolated, providing a view of the flood vulnerability across Punjab. This map identifies the areas with the highest flood vulnerability, taking into account both environmental and human factors, while avoiding artificial boundaries.

Map 2: A holistic view of FPC, PSC, and CCC.
While the FPC illustrates the physical and environmental factors contributing to flood risk in the background aggregated to the Tehsils, the PSC and CCC are represented within half-circles indicating their average values in the Tehsil.

Find more information, the atlas, and an interactive dashboard via the QR code or at https://gernotnikolaus.github.io/MasterThesis_FloodVulnerabilityPunjab.



Map 2: A holistic view of FPC, PSC, and CCC.

Conclusion

This study provides a comprehensive flood vulnerability assessment for Punjab, Pakistan, integrating environmental, demographic, and coping capacity factors. The developed Flood Vulnerability Index and its components - Flood-Prone Component, Population Susceptibility Component , and Coping Capacity Component - offer a detailed and multidimensional understanding of flood vulnerability. The results, visualized through maps and component-specific overlays, serve as a valuable tool for stakeholders in flood risk management and mitigation. By combining geospatial analysis with user-centered visualizations, the study contributes to more effective flood preparedness and decision-making strategies.

Author: Gernot Nikolaus
Supervisor: prof. RNDr. Vít Voženílek, CSc., Department of Geoinformatics, Faculty of Sicence, Palacký University Olomouc
Co-Supervisor: Zahra Dabiri, Ph.D., Department of Geoinformatics, Paris Lodron University Salzburg
Olomouc, 2025
Attachment to diploma thesis no. 1

Palacký University Olomouc
PARIS LODRON UNIVERSITÄT SALZBURG
COPERNICUS MASTER IN DIGITAL EARTH
With the support of the Erasmus+ Programme of the European Union

Islamic Relief (2024) Pakistan Monsoon Floods 2024 Situation Report - August 29, 2024 - Pakistan. Available at: https://reliefweb.int/report/pakistan/pakistan-monsoon-floods-2024-situation-report-august-29-2024 (Accessed: 14 February 2025). PBS (2023) Pakistan Bureau of Statistics, 7th Population and Housing Census - Detailed Results. Available at: https://www.pbs.gov.pk/digital-census/detailed-results (Accessed: 20 January 2025). Rahman, M. et al. (2019) 'Flood Susceptibility Assessment in Bangladesh Using Machine Learning and Multi-criteria Decision Analysis', Earth Systems and Environment, 3(3), pp. 585–601. Available at: https://doi.org/10.1007/s41748-019-00123-y. Rentschler, J., Salhab, M. and Jafino, B.A. (2022) 'Flood exposure and poverty in 188 countries', Nature Communications, 13(1), p. 3527. Available at: https://doi.org/10.1038/s41467-022-30727-4. WFP (2024) WFP Pakistan Floods Situation Report (August 2022 - December 2023) - Final report (January 2024) - Pakistan. Available at: https://reliefweb.int/report/pakistan/wfp-pakistan-floods-situation-report-august-2022-december-2023-final-report-january-2024 (Accessed: 14 February 2025).