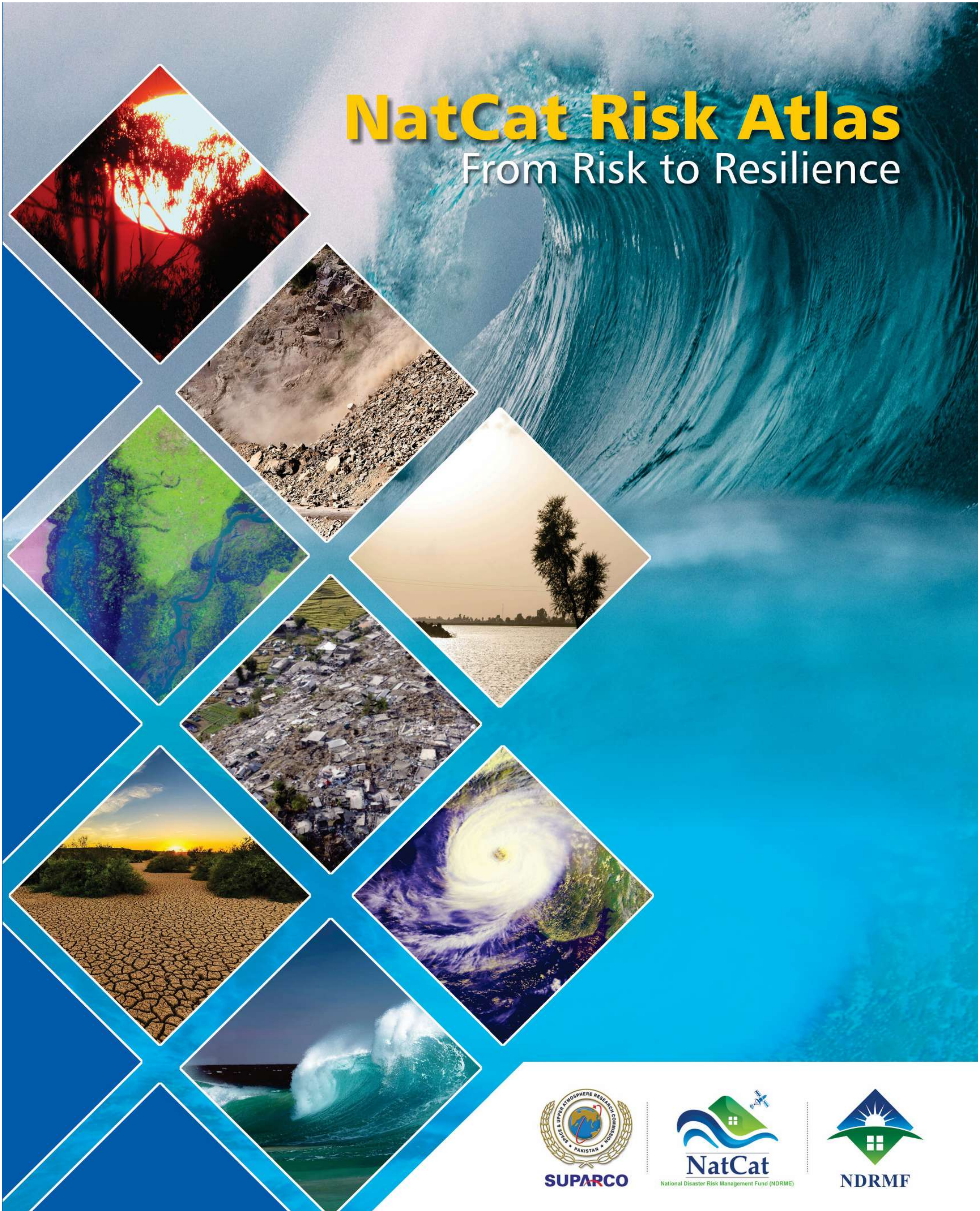
NatCat Risk Atlas
From Risk to Resilience



SUPARCO

NatCat
National Disaster Risk Management Fund (NDRMF)

NDRMF

NDRMF is a not for profit state owned organization, registered as public limited company set up under section 42 of the Companies Act 2017, which aims to reduce socio-economic and fiscal vulnerability of the country by providing grants for subprojects prioritizing and financing investments in Disaster Risk Reduction (DRR), preparedness (early warning, contingency planning) and Disaster Risk Financing (DRF). That will strengthen technical & financial capacity of the Government of Pakistan, to climatic and other natural hazards & disasters enhancing resilience.

The NatCat Risk Atlas is a flagship knowledge product of NDRMF, developed in collaboration with Pakistan Space and Upper Atmosphere Research Commission (SUPARCO) to provide spatially referenced multi-hazard risk information across Pakistan.

Aligned with NDRMF's 4th strategic pillar, *"knowledge Sharing and Risk Informed Decision Making"*, it serves as a powerful communication tool to visualize hazard risks and support inclusive Disaster Risk Reduction (DRR) and evidence based planning at national and local levels.

Conceptualized and Developed by:

- Dr Muhammad Farooq, Director SACRED, SUPARCO
- Dr Mateeul Haq, Deputy Chief Manager, SUPARCO
- Ms. Reema Zuberi, HoD, Media & Communication Department, NDRMF
- Mr. Ghulam Abbas, Manager, SUPARCO
- Mr. Rao Muhammad Saeed Ali, Manager, SUPARCO
- Ms. Sehrish Fida, Assistant Manager, SUPARCO
- Mr. Naveed Butt, Sub Engineer, SUPARCO

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We appreciate your feedback

Questions and comments concerning this publication may be address to NatCat Data Centre, NDRMF by emailing on
info-natcat@ndrmf.pk

National Disaster Risk Management Fund (NDRMF)

5th Floor, EOBI building Block 33-34, Service Road South, Mauve Area, Near NADRA Office G-10/4, Islamabad

www.ndrmf.pk

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Message from the Minister for Planning, Development & Special Initiatives

Pakistan stands at a pivotal point in its development journey. While the government continues to make concerted efforts to stabilize and revitalize the economy, our progress is increasingly threatened by the growing impacts of climate change and disaster risks. The catastrophic floods of 2022, along with recurring droughts, earthquakes, and glacial lake outburst floods, highlight our country's vulnerability to natural hazards. These events not only inflict widespread human suffering but also risk reversing decades of development gains, placing our socio economic trajectory on precarious footing.

In this context, no development strategy, investment plan, or policy vision can succeed without a sound understanding of prevailing and future disaster and climate risks.

The Disaster and Climate Risk Atlas for Pakistan is a timely and vital initiative that provides a scientific, spatial, and data driven foundation for integrating risk into the national development agenda. Developed through state of the art Natural Catastrophe (NatCat) Modelling, the Atlas presents a comprehensive multi hazard assessment based on GIS analytics, satellite Remote Sensing, and socio economic data. It maps the country's hazard exposure and vulnerabilities in a long term perspective critical for informed and resilient development planning.

This Atlas is not merely a repository of risk data; it is a decision making tool. It enables the identification of hazard specific hotspots, quantification of probabilistic risks, and prioritization of investments to support climate resilient and disaster resilient development.

The Ministry of Planning, Development & Special Initiatives fully supports this landmark effort, recognizing its strategic importance in strengthening risk governance at all levels. It complements our ongoing commitment to mainstreaming disaster risk reduction and climate adaptation within national and provincial planning frameworks, including the Public Sector Development Programme (PSDP), Vision 2035, and the URAAN Pakistan initiative.

I commend the National Disaster Risk Management Fund (NDRMF) for its leadership in developing this foundational resource and for bringing together technical institutions, disaster management authorities, and development partners. The Atlas marks a transformative shift from reactive response to proactive risk reduction and adaptation an essential step toward a safer, more resilient Pakistan.

As we move ahead, the Government remains committed to institutionalizing NatCat modelling within development planning systems and ensuring that all future investments are grounded in a clear understanding of our evolving risk landscape.

Professor Ahsan Iqbal
Minister, MoPD&SI

Message from CEO National Disaster & Risk Management Fund (NDRMF)

Pakistan is increasingly vulnerable to the intensifying impacts of climate change and natural disasters, including floods, droughts, heat waves, earthquakes, and glacial lake outburst events. These hazards continue to cause devastating consequences for communities, infrastructure, and the national economy, repeatedly disrupting lives, livelihoods, and development progress.

The National Disaster Risk Management Fund (NDRMF), as the leading disaster risk reduction financing institution, is committed to strengthening disaster risk management and climate resilience in Pakistan. It recognizes that credible risk data is critical for making informed and impactful decisions. As part of this commitment, NDRMF has initiated the Natural Catastrophe Model (NatCat) a pioneering national disaster and climate risk modelling platform. Equipped with a GIS and satellite based database, NatCat provides spatially explicit exposure and vulnerability insights. It delivers risk assessments vital for optimizing project design and guiding climate and disaster financing strategies. NatCat is now being integrated into national data systems and decision making processes, helping to foster a culture of risk informed development across the country.

This Atlas for Pakistan is a vital resource prepared jointly by NDRMF and the Pakistan Space and Upper Atmosphere Research Commission (SUPARCO). As the first of its kind in the country, it consolidates multi hazard risk assessments, combining scientific data on hazard frequency and severity with spatial information on population exposure, infrastructure, and socioeconomic vulnerability. The Atlas provides risk and exposure maps and highlights the most vulnerable areas, offering comprehensive insights to support disaster risk reduction, resilience building, and climate smart development planning.

By translating complex risk data into accessible and actionable information, the Atlas serves a wide range of stakeholders from policymakers and planners to development partners and civil society. It is designed to empower these actors to take proactive measures to reduce risk and protect lives and assets.

This Atlas represents a key step in NDRMF's ongoing efforts to enable risk informed development and support both national and sub-national stakeholders in building a safer and more resilient Pakistan. We commend the dedication of all partners and technical experts involved and are confident this will be a valuable contribution to Pakistan's disaster risk reduction and climate adaptation goals.

Bilal Anwar
CEO, NDRMF

Message from Chairman, SUPARCO

It is a moment of immense pride to witness the successful publication of the NatCat Risk Atlas, a landmark initiative that embodies our commitments to enhancing national capabilities in disaster preparedness, risk assessment and informed decision making. In an age defined by accelerating environmental challenges, the availability of accurate timely and spatially referenced data has become indispensable for mitigating the impact of natural hazards and building climate resilience.

Being the national space agency of Pakistan, SUPARCO remains committed in its mission of leveraging the power of satellite Remote Sensing and geo spatial analytics in support of sustainable development, climate actions and disaster risk reduction. The Risk Atlas represents a vital step forward in our efforts to provide scientific, data driven tools to institutions involved in emergency response, planning & development, and policy formulation.

This achievement is a testament to the dedication and technical excellence of SUPARCO's expert teams, whose tireless efforts have ensured the precision, relevance and integrity of the data. I am confident that the NatCat Risk Atlas will serve as an invaluable asset for decision makers, researchers, disaster managers, and development practitioners alike; strengthening our collective capacity to protect lives, infrastructure and ecosystems from the increasing threat of natural catastrophes.

On the behalf of SUPARCO, I extend heartfelt appreciation to all the contributing partners and stakeholders. May this milestone serve as a foundation for continued collaboration in the pursuit of a safer, more resilient Pakistan.

Mohammad Yousuf Khan
Chairman, SUPARCO

Acknowledgements

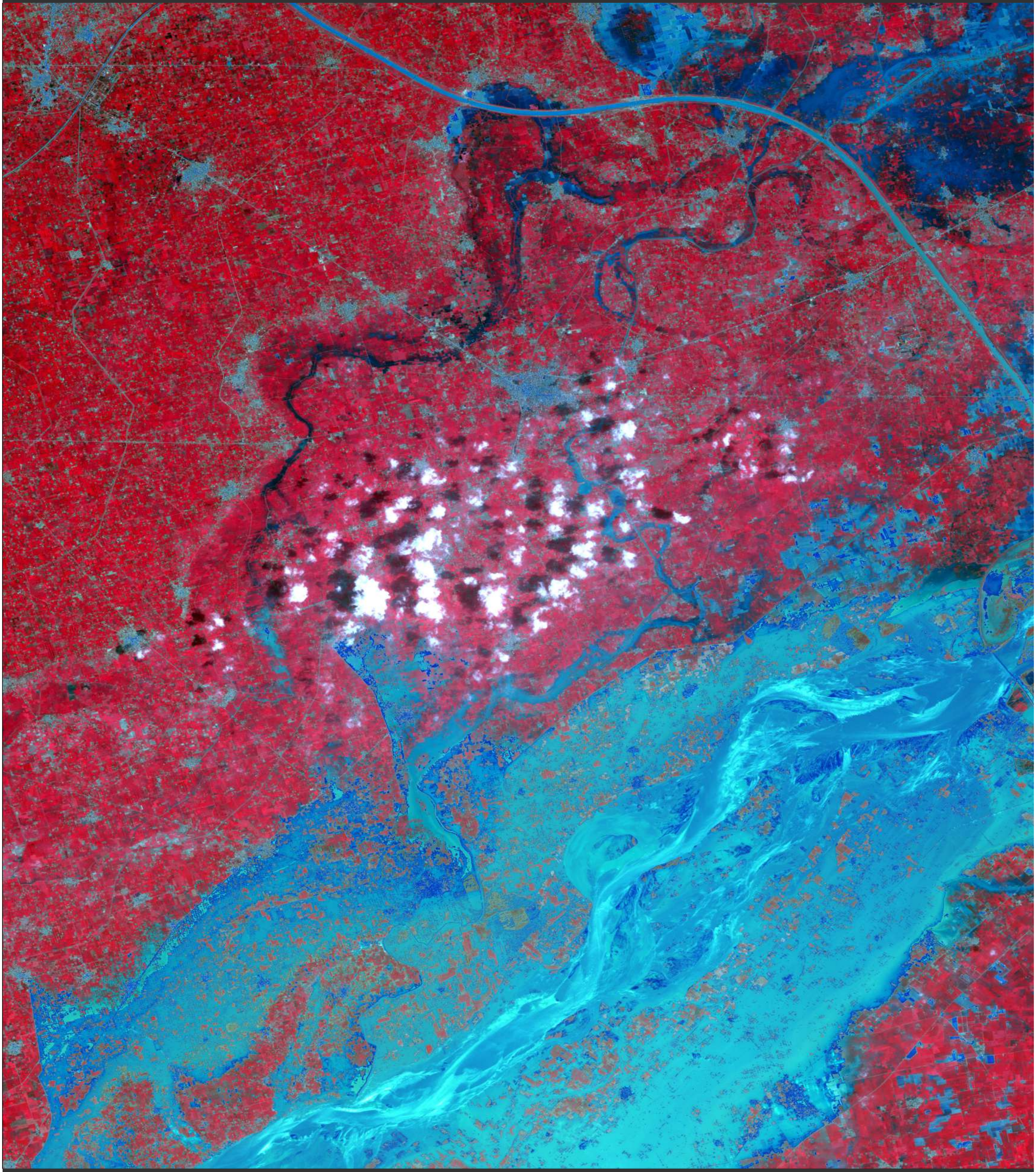
It is with great pride and satisfaction that I present the Natural Catastrophe (NatCat) Risk Atlas, a landmark initiative aimed to provide critical natural hazards risk profiles to support disaster risk reduction and informed decision making. This Atlas is the result of collaborative efforts, meticulous spatial analysis, and a shared commitment to enhancing resilience against natural hazards. As the frequency and intensity of disasters increase, a proactive and scientific approach to risk reduction and preparedness becomes essential.

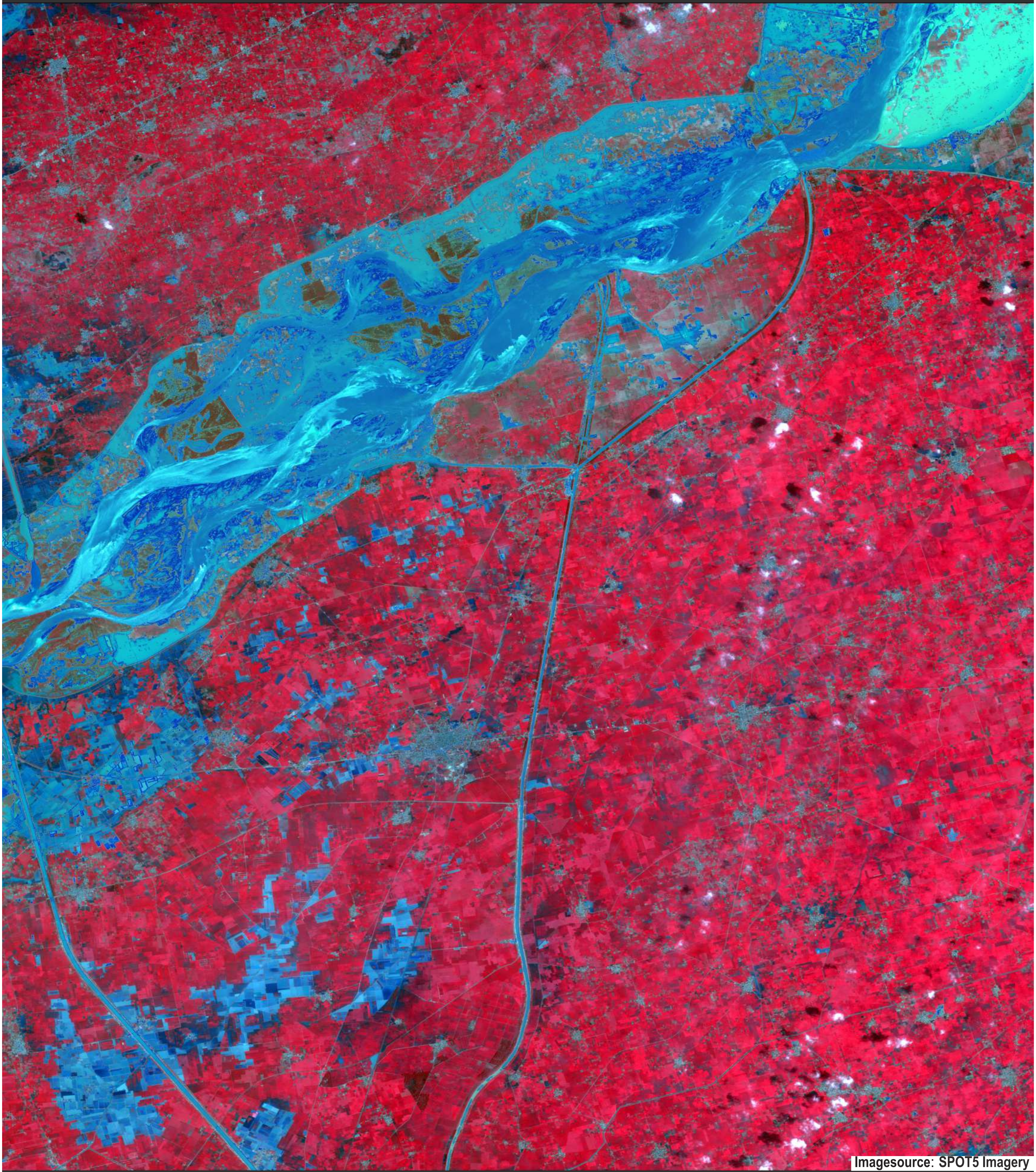
NatCat Model Project was conceived to provide harmonized database of probabilistic hazards, exposure vulnerability and risk / loss assessment at National level against 9x Perils. NatCat model project was a challenging task due to its complex scope, intensive data requirements and computationally expensive modelling. With the grace of Almighty Allah, NatCat project has been successfully completed. Outcome of the NatCat project are presented in the shape of Risk Atlas beside development of Web-based Risk Calculator. I am confident that NatCat Risk Calculator and its two special interfaces for MoPD&SI and FFC will ultimate help in disaster mitigation risk financing and spatial planning beside provision of baseline risk information for Disaster Risk Financing strategy at National Level.

The Atlas is a vital tool for policymakers, researchers, planners, and humanitarian agencies, offering region specific insights into hazard prone areas. Its development has been a collaborative journey shaped by the dedication of many individuals and organizations. I sincerely acknowledge the professionalism of SUPARCO's technical experts and the commitment of our researchers, data scientists, developers, and designers. We also acknowledge the valuable contributions of renowned international experts especially SACRED Team, Hazard Modelling Team, Landcover Team, Crop Mask Team and Software Development Team, who contributed their expertise to various aspects of natural disaster analysis, bringing global perspectives and specialized knowledge that greatly enriched the quality and depth of this work. We commend the efforts of CEO NDRMF and his team for conceiving the project and their continued dedication throughout its execution. Last not but not least, I am extremely thankful to all national and provincial level Departments / Organization for sharing secondary data for exposure assessment of key elements at risk.

Lastly, we recognize the resilience of communities living on the frontlines of natural disasters; it is for you and because of you that we strive to build better tools and deeper understanding. Thank you to everyone who contributed to NatCat Project and this Atlas.

Dr. Muhammad Farooq
Director SACRED, SUPARCO





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Pakistan Hazard Profile

Pakistan is highly vulnerable to a wide range of natural hazards due to its unique geographical location, varied topography, and climatic diversity. The country lies at the convergence of the Indian and Eurasian tectonic plates, has an extensive river system, a long coastline, arid zones, mountainous regions, and densely populated urban centers all contributing to its exposure to multiple forms of natural disasters. The most prominent hazards include earthquakes, floods, urban floods, droughts, heatwaves, and landslides. These hazards have caused significant loss of life, displacement, environmental degradation, and economic damage across the country over the decades.

Floods

Flooding is one of the most frequent and damaging hazards in Pakistan. The Indus River system, fed by snowmelt and monsoon rains, often exceeds its capacity, resulting in riverine floods that primarily affect Punjab and Sindh. The floods of 1950, 1992, and 2010 were especially destructive, displacing millions and damaging infrastructure and crops. The monsoon season (July–September), combined with upstream glacial runoff and intense storm systems from the Bay of Bengal, makes the country especially flood-prone each year.

Urban Floods

Urban areas in Pakistan are increasingly affected by urban flooding, a result of unplanned development, poor drainage, encroachment on natural waterways, and climate-induced intense rainfall. Cities such as Karachi, Lahore, Rawalpindi, and Islamabad experience regular inundation during the monsoon.These floods cause property damage, disruption of essential services, and serious public health risks particularly affecting low income urban settlements that are prone to flooding.

Heatwave

In recent decades, heatwaves have become more frequent and intense, posing serious health and survival risks. The 2015 Karachi heatwave was a tragic event that claimed more than 1,000 lives, largely due to extreme temperatures, electricity shortages, and limited public awareness. Regions most affected include Sindh, South Punjab, and parts of Balochistan, where prolonged heat exposure, especially in urban areas, is increasingly becoming a public health emergency driven by climate change.

Drought

This region has a long history of recurring droughts that have significantly impacted agriculture and water resources. The regions have been hit by the most severe droughts in Punjab in 1899, 1920, and 1935; Khyber Pakhtunkhwa (KP) in 1902 and 1951; and Sindh in 1871, 1881, 1899, 1931, 1947, and 1999. Balochistan, the largest and most drought prone province in the area. During the 1999–2002 drought, it was among the hardest hit regions, with widespread crop failure, livestock deaths, and displacement. This nationwide drought caused a nearly 10% decline in crop output and a 2.6% drop in agricultural growth in 2000–2001. Water levels fell to 51% below normal by 2001–2002. Drought continues to threaten food and water security, rural livelihoods, and ecological stability, especially in vulnerable regions.

Cyclone

Pakistan's coastal regions, especially Sindh and Balochistan, face severe wind hazards from cyclones in the Arabian Sea. Major cyclones like Cyclone 02A (1999) and Yemyin (2007) have produced winds up to 150 km/h, causing thousands of deaths and widespread damage. These storms, mostly occurring during pre-monsoon and monsoon seasons, continue to threaten coastal communities and infrastructure.

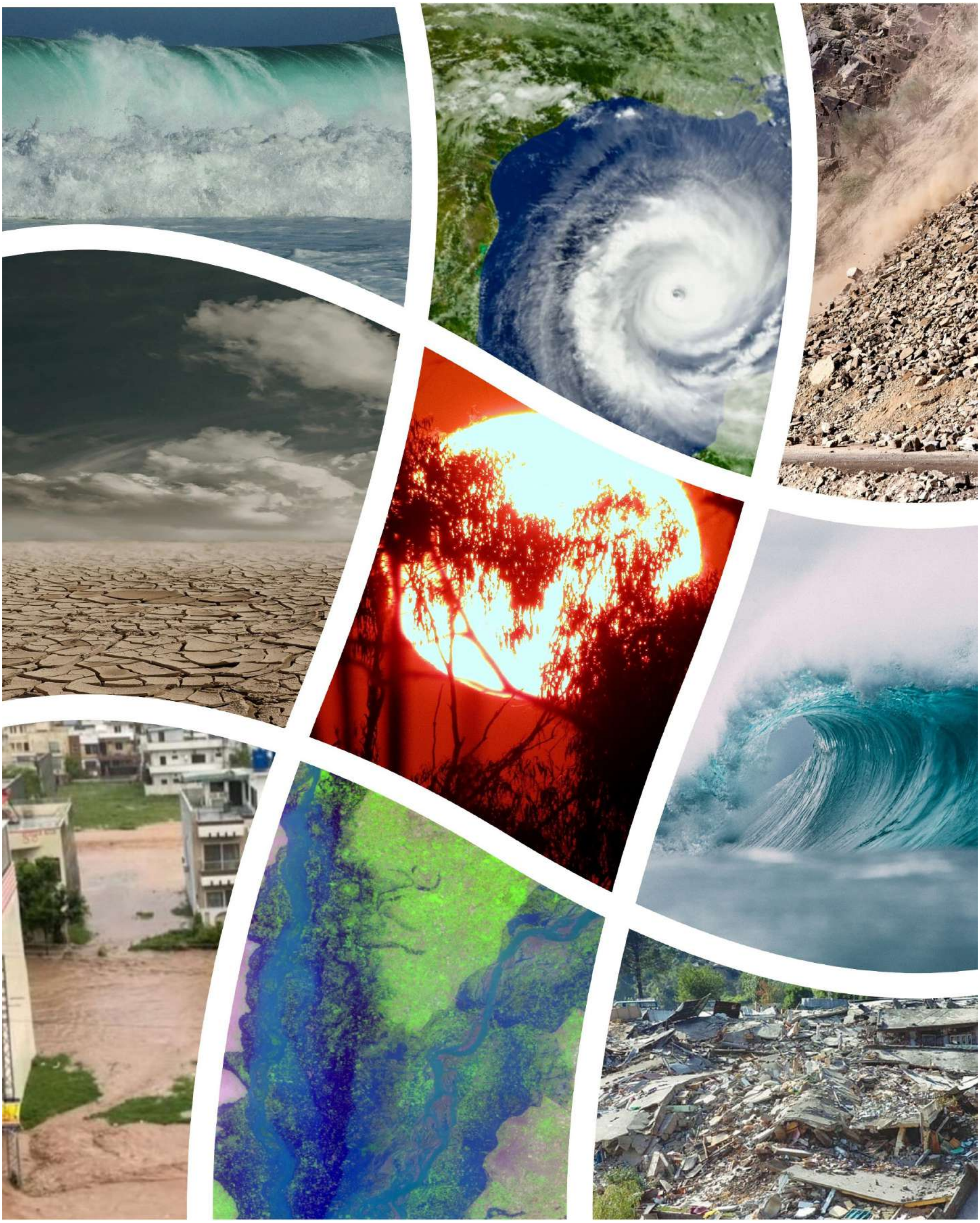
Along with strong winds, storm surges during cyclones cause significant flooding and displacement, as seen in 1993 (Keti Bandar), 2007 (Makran coast), and 2021 (Cyclone Shaheen). These hazards emphasize the need for robust coastal protection and early warning systems.

Earthquakes

This region has experienced many major earthquakes that have caused widespread destruction and long lasting impacts, particularly in the regions of Balochistan, Azad Kashmir, GB and KP. Notable seismic events include the 2005 Kashmir earthquake (magnitude 7.6), the 2013 Awaran earthquakes (magnitudes 7.4 and 6.8), the 1935 Quetta earthquake (magnitude 7.7), the 1945 Makran earthquake (magnitude 8.2), and the 1974 KP quake. These earthquakes resulted in significant damage to infrastructure, disruption of livelihoods, and displacement of communities.

Landslides

Landslides are a major hazard in Pakistan's northern mountainous regions, often triggered by heavy rainfall, earthquakes, and human activities like construction and deforestation. The Karakoram Highway (KKH), a vital trade route, is especially vulnerable to frequent landslides caused by unstable slopes and monsoon rains. The 2010 Attabad landslide in Hunza Valley, which blocked the river and submerged villages, severely disrupted the highway and displaced communities. More recently, a 2023 landslide near Torkham buried trucks and caused casualties, highlighting ongoing risks to critical infrastructure. Climate change and increasing rainfall variability are expected to further intensify the frequency and severity of landslides in these regions.



Introduction

Pakistan, with a large and growing population, is the fifth most populous country in the world and is projected to rise to the fourth position by 2030. The country's rapid population growth intensifies its exposure to natural hazards, further complicating its disaster management efforts. Pakistan is highly vulnerable to diverse natural threats such as earthquakes, floods, cyclones, droughts, landslides, and extreme heatwaves. These recurring hazards create a complex and evolving disaster risk profile, posing severe challenges to both human lives and infrastructure.

The frequency and intensity of natural disasters in Pakistan have risen sharply. In the past 70 years, Pakistan has been struck by major natural disasters, especially floods and earthquakes, and has suffered huge economic losses amounting to billions of dollars. Some of the major historical earthquakes include the Quetta Earthquake 1935, Makran Coast Earthquake 1945, Kashmir Earthquake 2005, Awaran Earthquake 2013, Pakistan-Afghanistan Earthquake 2015 and Mirpur Earthquake 2019. Likewise, major historical floods in Indus basin include those of the years: 1935, 1973, 1976, 1988, 1992, 1998, 2010, 2014, 2015, and 2022. In all of these, Kashmir Earthquake 2005, The 2010 and 2022 floods stand out as the most catastrophic events in Pakistan's history, causing extensive damage to infrastructure and displacement of millions of people.

Fluvial floods are the most prevalent type of flooding in Pakistan, occurring mainly during the summer monsoon season when heavy rainfall combines with melting snow from the northern mountains. Northern Pakistan receives the majority of its rainfall during the monsoon and winter seasons, which contribute to increased flood risks, especially in mountainous areas and downstream.

In contrast, southern Pakistan often experiences drought like conditions due to limited rainfall, leading to water shortages and challenges in agricultural production.

Water scarcity impacts crop yields and livestock, threatening food security and local economies, while prolonged dry spells deplete rivers and groundwater, further straining irrigation-dependent communities.

Pakistan's geographical location, where the Indian and Eurasian tectonic plates converge, places it in a seismically active zone, prone to powerful earthquakes. These earthquakes have caused widespread destruction, especially in densely populated areas, resulting in significant loss of life and damage to infrastructure.

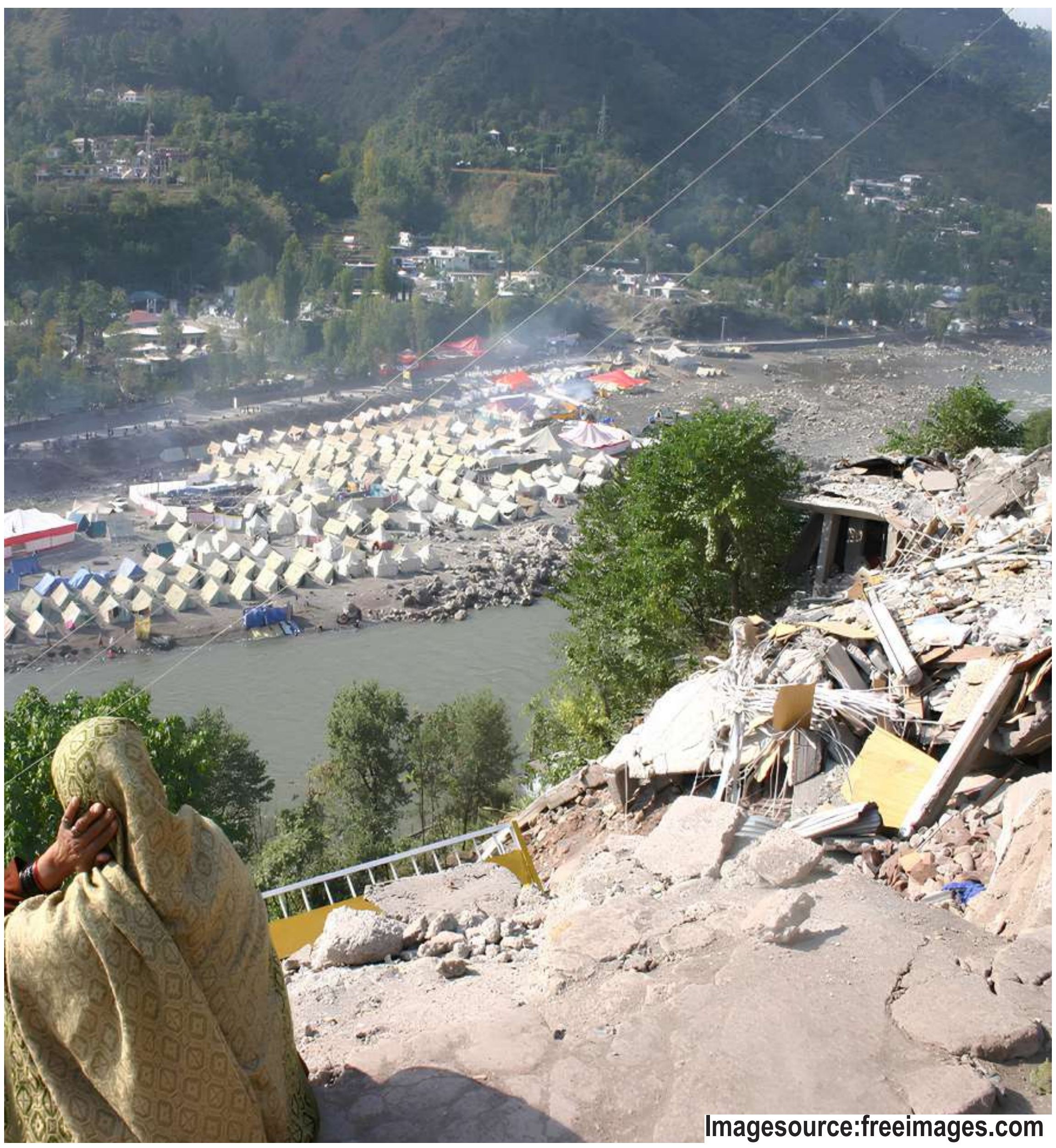
The historical frequency of such events, along with the ongoing tectonic activity, indicates that Pakistan remains at high risk for similar disasters in the future. Regions like northern Pakistan and Balochistan are particularly susceptible due to active fault lines. Past events, such as the 2005 Kashmir earthquake, highlight the severe consequences of major seismic activity. This devastating quake, which measured 7.6 on the Richter scale, caused widespread destruction of buildings and severely impacted communities across the affected region.


Imagesource:pexels.com

Introduction

Drought is a recurring hydro-meteorological hazard in southern Pakistan, typically triggered by prolonged periods of below normal rainfall. It is a slow onset disaster, intensified by factors such as low soil moisture, reduced stream flow, limited groundwater or canal water supply, and high evapotranspiration. Unlike sudden disasters, droughts develop gradually, can last from weeks to years, and impact large regions. Their effects are non structural but far-reaching, severely affecting vegetation, crops, livestock, human livelihoods. Prolonged droughts can also trigger secondary impacts like food insecurity, forced migration, and increased pressure on urban resources.

The coastal regions of Pakistan, particularly along the Arabian Sea, are vulnerable to tropical cyclones. These cyclones are most frequent during May-June and October-November, when sea surface temperatures are high and atmospheric conditions favor storm development. Climate change and warming oceans may further increase the frequency and intensity of such events in the future. The month of May has mostly experienced the highest formation of Tropical Cyclones in the Arabian Sea. Historical records show that coastal regions of Pakistan were hit by extreme Tropical Cyclone events i.e. TC 02A, TC 01A Gonu, TC Yemyin & TC Phet in 1999, 2001, 2007 and 2010 respectively.



Landslides in northern Pakistan are a major natural hazard, primarily due to the region's rugged topography, active tectonic setting, and intense monsoon rains. Mountainous areas like the Himalayas, Karakoram, and Hindu Kush are particularly prone to slope failures. The situation is worsened by human-induced factors such as deforestation, unplanned construction, and road cutting along unstable slopes. These landslides frequently result in casualties, destroy infrastructure like roads and bridges, and isolate remote communities. Their impact on livelihoods and accessibility makes them a recurring challenge for disaster management.

Heatwaves in Pakistan have become an increasingly severe climate phenomenon, especially during the summer months. Prolonged periods of extreme heat, often exceeding 40°C, affect major cities like Karachi, Lahore, and Multan, leading to health crises, water shortages, and power outages. The frequency and intensity of heatwaves are exacerbated by climate change, urbanization, and poor infrastructure. These extreme temperature events put vulnerable populations at risk and strain the country's resources.

Urban floods in Pakistan have become a growing concern, particularly in cities like Karachi, Lahore, Islamabad, Rawalpindi, Peshawar and Quetta where rapid urbanization has outpaced infrastructure development.

Poor drainage systems, encroachment on natural watercourses, and inadequate urban planning contribute to the frequent flooding, especially during heavy monsoon rains. These floods lead to property damage, loss of life, and disruption of daily activities.

Natural Catastrophe (NatCat) Model Project

SUPARCO accomplished the development of a geo-referenced database of various natural hazards, along with exposed elements, their vulnerability and quantified risks under the Natural Catastrophe (NatCat) Model project funded by NDRMF. This is among the first initiative at the National Level and ranks as the tenth of its kind, globally.

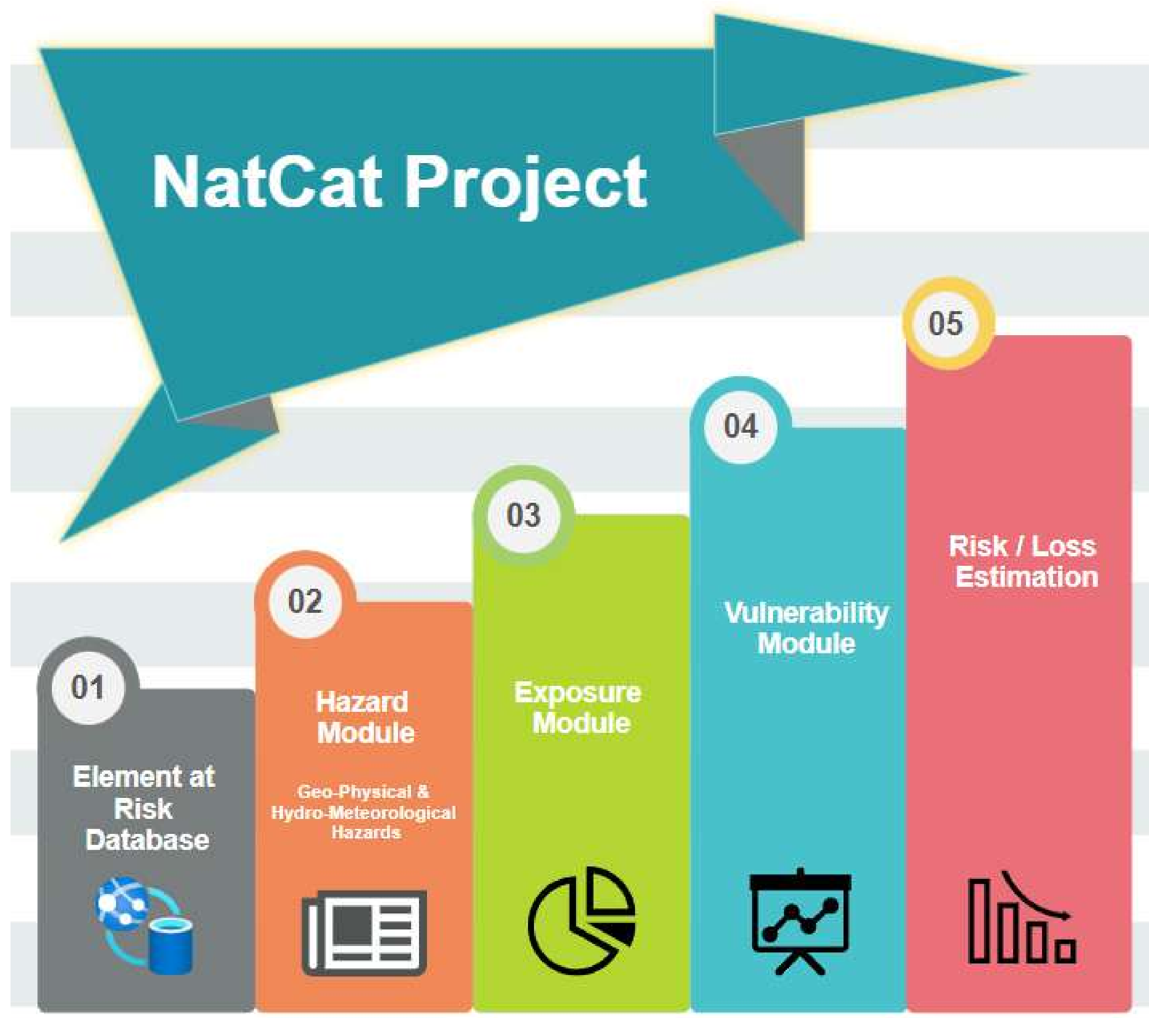
The NatCat model project quantifies the risks associated with a range of natural hazards, including hydro-meteorological events such as riverine floods, urban floods, flash floods, droughts, tropical cyclones, storm surges, and heatwaves, as well as geo-physical hazards like earthquakes, landslides, and tsunamis. The model outputs comprehensive assessments of hazard, exposure, vulnerability, and potential loss, estimating risk across different frequencies and magnitudes of natural hazards at the national scale.

Project Scope

The project encompasses the following key components:

1. **Development of a National, Spatially Geo-referenced, GIS Dynamic Database:** Creation of a centralized, geo-referenced GIS database of public and private assets and infrastructure across the country, and the associated physical vulnerability to different types and varying intensities of natural hazard along-with the reconstruction costs.
2. **Probabilistic Disaster Risk Modelling and Assessment:** Comprehensive quantification of risks posed by geophysical and hydro-meteorological hazards.
3. **Capacity Building of Government HR:** Training and capacity development of relevant government staff for the collection, generation, processing and utilization of exposure and disaster risk data along with the development of standardized protocols and operational manuals.
4. **Development of an Accessible, Sustainable Data Platform:** Establishment of a user friendly and sustainable platform to support the use of the exposure and risk data by all relevant stakeholders. Dedicated interfaces have already been developed for the Federal Flood Commission (FFC) and the Ministry of Planning Development and Special Initiatives (MoPD&SI).

Additionally, it provides a baseline for the expansion of the insurance industry in Pakistan by supporting the development of a market for disaster risk coverage.



The NatCat project outputs and interfaces support decision makers in prioritizing public investment for structural and non-structural measures to be undertaken by NDRMF and other relevant organizations. These efforts are aligned with the National Disaster management Plan (NDMP) 2012–22 and the National Flood Protection Plan (NFPP-IV), ensuring effective disaster risk reduction and optimized resource allocation across vulnerable regions.

The NatCat Model provides quantitative information on the expected levels of loss for hazard events of varying types, intensities, and return periods, including probable maximum loss curves, which are positioned on an accessible, user friendly open source platform to support disaster risk planning, decision making, and awareness among stakeholders.

NatCat Data Center

The NDRMF, in collaboration with NUST University, is embarking on a groundbreaking initiative to establish a specialized data center focused on NatCat probabilistic modeling. NDRMF has engaged SUPARCO to develop the NatCat Model: Pakistan's Geo-referenced Exposure Database for Natural Catastrophe.

It is the first initiative of its kind at the national level in the region. The NatCat model will assess risks posed by natural hazards including hydro-meteorological (flood, drought, tropical cyclone, urban flooding, hill torrents, heatwave) and Geo-physical events (earthquake, tsunami, landslide), to evaluate the exposure and vulnerability of elements at risk. It will also quantify potential risks and their financial impacts down to the Tehsil (sub district) level.

This state of the art facility aims to revolutionize NDRMF's approach to understanding, predicting, and mitigating the risks associated with natural disasters through advanced data analytics and modeling techniques.

Importance of NatCat Modeling

Enhanced Risk Assessment:
Probabilistic modeling provides a comprehensive framework for assessing the likelihood and potential impact of various natural disasters, considering multiple scenarios, variables, and uncertainties. It offers a more nuanced understanding of risk, enabling better informed decision making and resource allocation, while also supporting government staff in the collection, generation, and utilization of exposure and disaster risk data, as well as the preparation of related protocols and manuals.

Optimized Disaster Preparedness and Response:
By simulating different disaster scenarios and their probabilities, NatCat probabilistic modeling allows policymakers, emergency responders, and planners to develop and prioritize tailored preparedness and response strategies. This proactive approach minimizes vulnerabilities and enhances the effectiveness of disaster management efforts.

Risk Based Planning and Resilience Building:
Probabilistic modeling facilitates the identification of high-risk areas, infrastructure, and populations, enabling targeted investments in mitigation and resilience-building initiatives. It supports the development of adaptive and sustainable urban planning strategies that can withstand and recover from natural disasters more effectively.

Insurance and Financial Risk Management:
NatCat probabilistic modeling plays a crucial role in the insurance industry by enabling accurate risk assessment, pricing, and portfolio management. It helps insurance companies and financial institutions to develop innovative insurance products, ensure adequate coverage, and enhance financial resilience against natural catastrophes.

Installing the Data Center at NUST

Research and Innovation:
The data center will serve as a hub for multidisciplinary research on natural disasters, climate change, and resilience. It will facilitate collaborative projects, data analytics, and modeling to advance knowledge and develop innovative solutions for disaster risk reduction.

Capacity Building:
NUST University will offer specialized training programs, workshops, and courses utilizing the data center's advanced resources and infrastructure. This will significantly enhance the capacity of professionals, students, researchers, and stakeholders in NatCat modeling, risk assessment, disaster preparedness, and effective disaster management practices.

Public Awareness and Education:
The data center will support outreach programs and educational initiatives to raise public awareness about natural disasters, their impacts, and the importance of preparedness. It will foster a culture of resilience and empower communities to take proactive measures against natural hazards through public campaigns, school-based programs, stakeholder collaboration, and training activities that emphasize early warning systems, climate adaptation, and disaster risk reduction strategies.

Collaboration and Partnership:
By hosting the data center at NUST University, NDRMF will strengthen collaboration with academic institutions, research organizations, government agencies, and international partners. This collaborative ecosystem will foster knowledge exchange, innovation, and collective action to address the complex challenges posed by natural catastrophes, support evidence-based policymaking, encourage interdisciplinary research, and enhance technical capabilities for effective disaster risk management, climate resilience, and sustainable development across vulnerable regions in Pakistan.


NDRMF
NatCat
NATCAT DATA CENTER

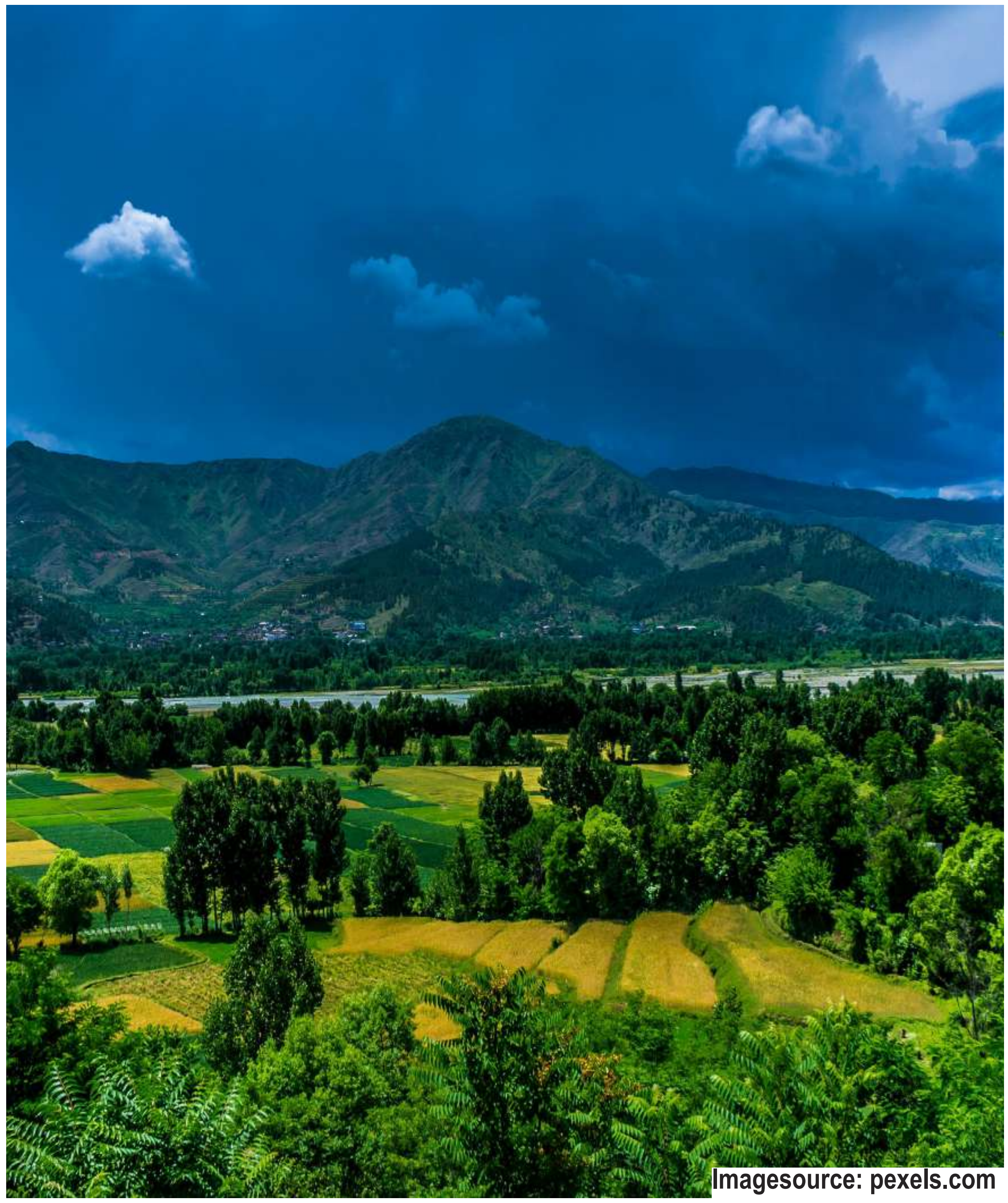

From Risk To Resilience

Elements at Risk


Imagesource: SUPARCO EO-1 Imagery

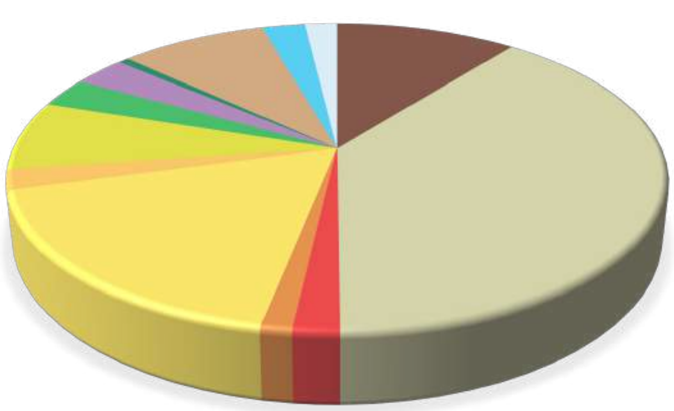
Landcover

Pakistan's diverse landcover is at risk to various natural hazards. Agricultural lands in the Indus plains are at risk from floods, droughts, and soil erosion, impacting food security. Deforestation in the northern forests increases the likelihood of landslides and reduces flood protection. Desert areas face extreme heatwaves and drought, while the mountain regions are prone to landslides and glaciated regions to glacial lake outburst floods. Coastal areas are threatened by tsunami, storm surges, erosion, cyclones, and rising sea levels. Additionally, rapid urbanization and poor infrastructure exacerbate the effects of climate change, increasing the frequency and severity of these disasters.



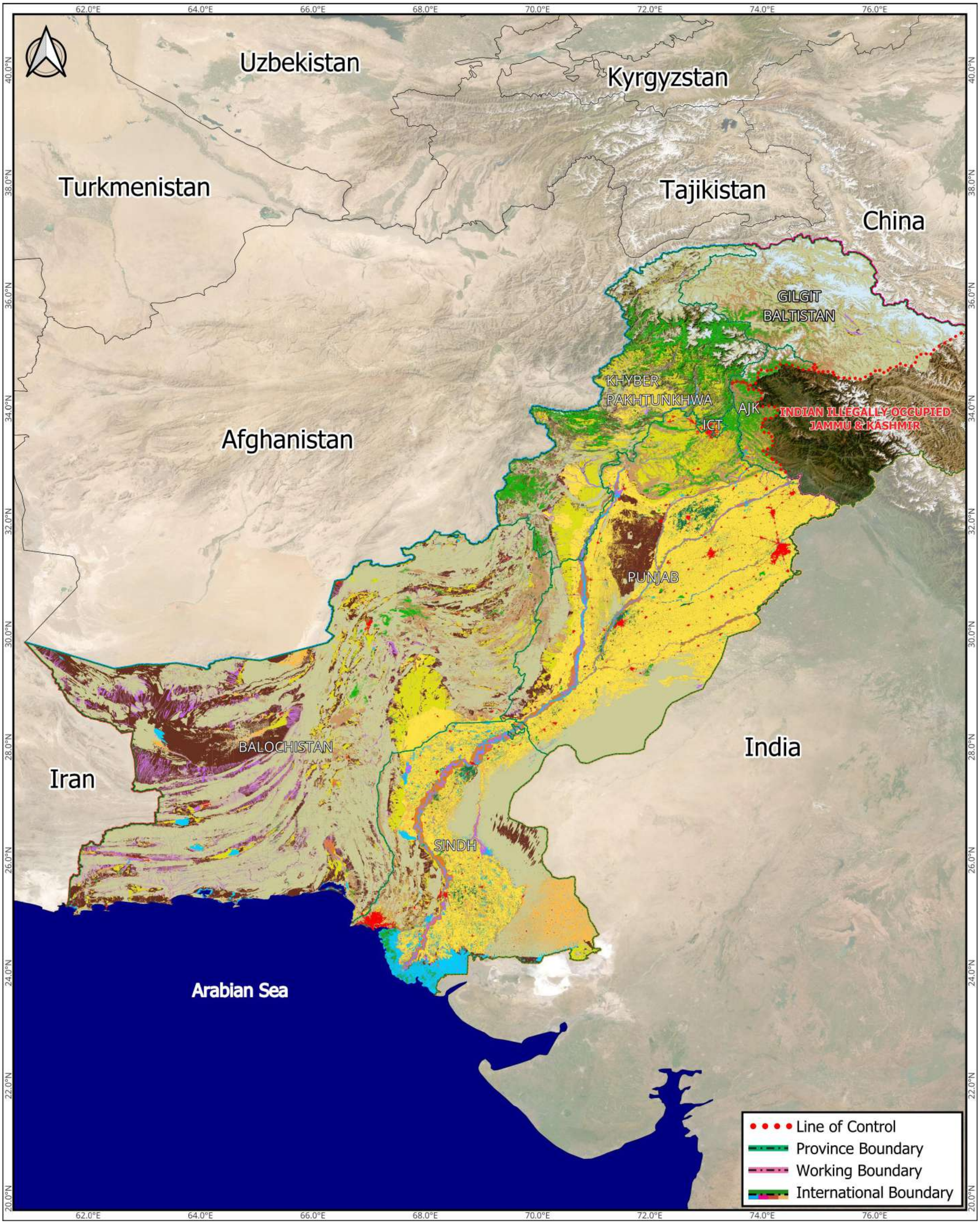
Imagesource: pexels.com

Landcover Classes (%)



Landcover Classes

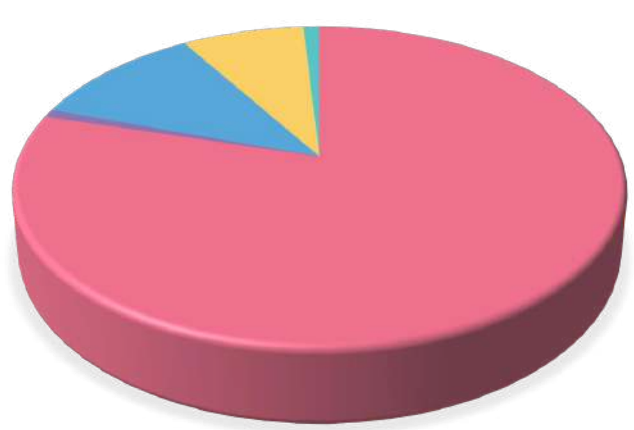
Class Name	Area (sq. km)	Percentage
Bare Areas	122,794.81	10.61
Bare Areas with Sparse Natural Vegetation	453,823.21	39.21
Built-up	22,196.73	1.92
Crop in Flood Plain	15,017.51	1.30
Crop Irrigated	203,425.06	17.57
Crop Marginal and Irrigated Saline	24,768.81	2.14
Crop Rainfed	83,700.07	7.23
Forest - Natural Trees and Mangroves	35,684.26	3.08
Natural Vegetation in Wet Areas	36,394.19	3.14
Orchards	7,126.06	0.62
Range Lands - Natural Shrubs and Herbs	99,624.88	8.61
Snow and Glaciers	29,459.77	2.55
Wet Areas	21,707.33	1.88


Uzbekistan
Kyrgyzstan
Turkmenistan
Tajikistan
China
GILGIT
BALTISTAN
KHYBER
PAKHTUNKHWA
ICT
AJK
INDIAN ILLEGALLY OCCUPIED
JAMMU & KASHMIR
Afghanistan
PUNJAB
BALOCHISTAN
Iran
India
SINDH
Arabian Sea
Line of Control
Province Boundary
Working Boundary
International Boundary

Educational Institutes

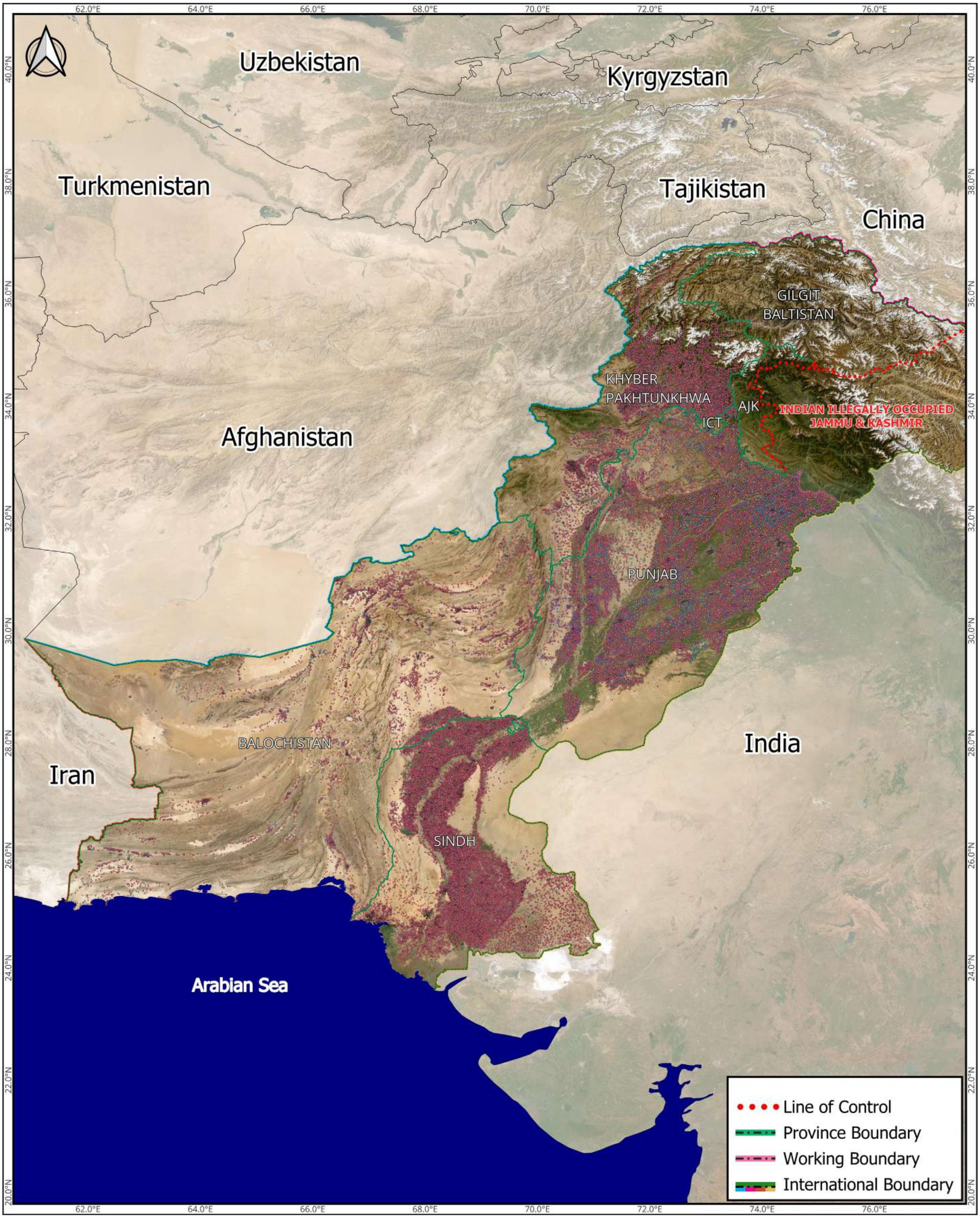
Educational institutions in Pakistan including primary schools, middle schools, secondary schools, higher secondary schools, and madrasas, are at risk due to various natural hazards. These hazards can disrupt educational activities, damage infrastructure, and disturb communities, leading to prolonged school closures and limited access to education. Floods, earthquakes, and extreme weather events can make school buildings unsafe for students and teachers. Without proper disaster preparedness and recovery plans, these disruptions can have lasting effects on learning outcomes and literacy rates.

Educational Institutes (%)



Educational Institutes

Level	Number of Schools	Percentage
Primary	106615	79.4
Madrisa	1089	0.81
Middle	14821	11.04
Secondary	10387	7.74
Higher Secondary	1369	1.02



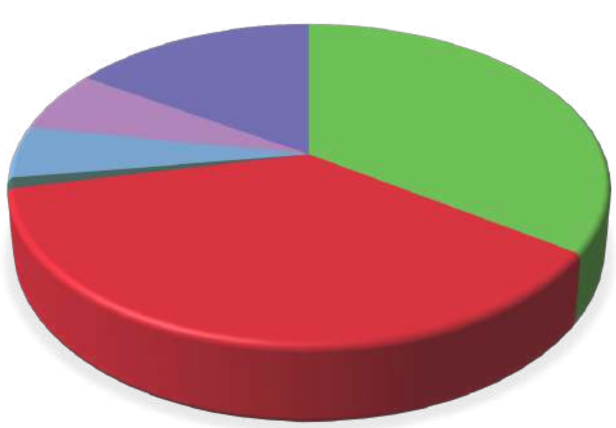
Uzbekistan
Kyrgyzstan
Turkmenistan
Tajikistan
China
GILGIT BALTISTAN
KHYBER PAKHTUNKHWA
AJK
ICT
INDIAN ILLEGALLY OCCUPIED JAMMU & KASHMIR
Afghanistan
PUNJAB
BALOCHISTAN
India
Iran
SINDH
Arabian Sea
Line of Control
Province Boundary
Working Boundary
International Boundary

Health Facilities

Health facilities in Pakistan, including hospitals, clinics, and dispensaries, are at risk due to various natural hazards. These hazards can disrupt healthcare services, damage infrastructure, and affect patients, doctors, and staff, leading to limited access to medical care and prolonged service interruptions. Floods and earthquakes can render medical equipment inoperable, straining emergency response. Without adequate disaster preparedness, healthcare systems struggle to provide essential services during crises, worsening health risks for affected populations.

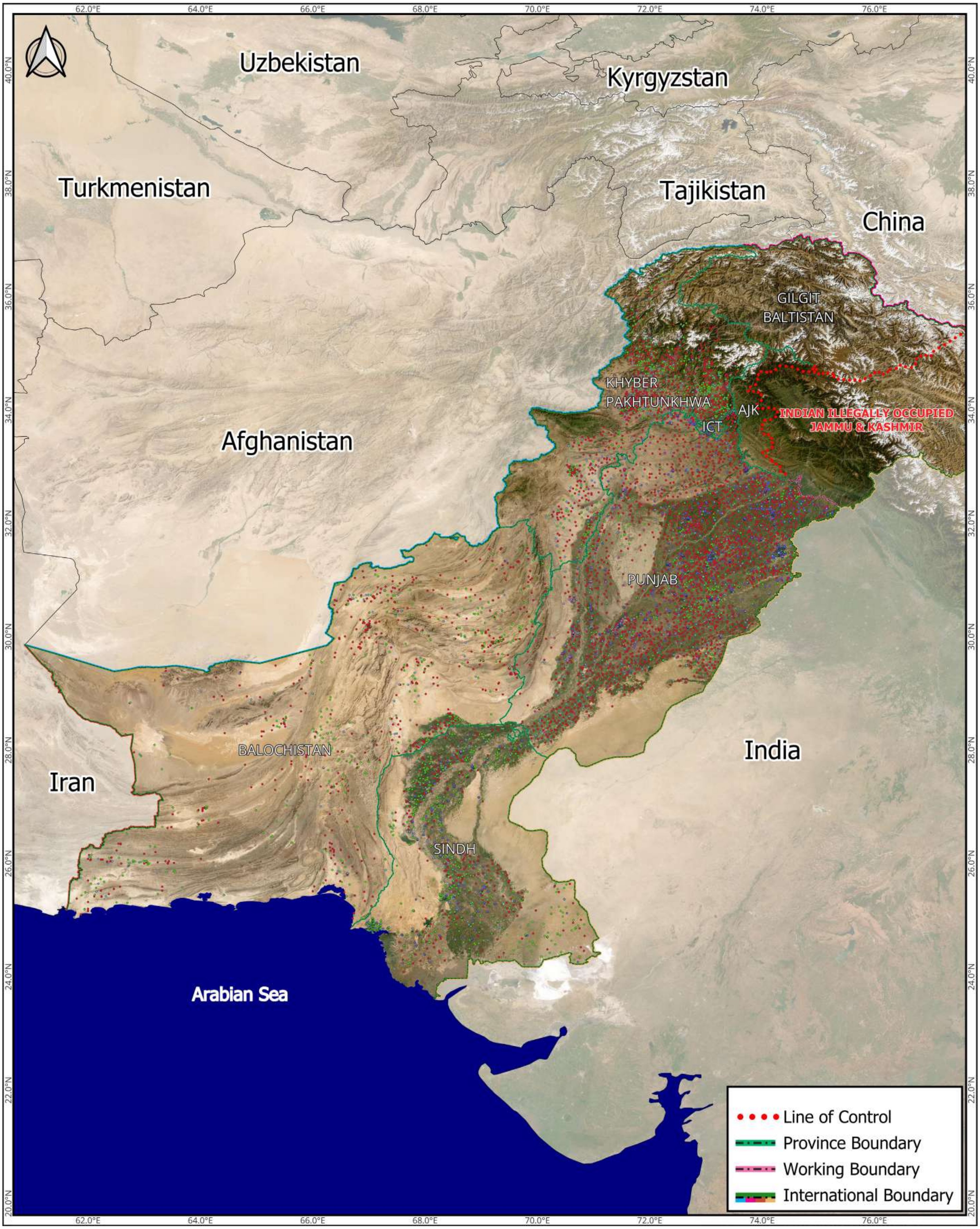
Imagesource:cpmc.edu.pk

Health Facilities (%)



Health Facilities

Health Facility	Number of Facilities	Percentage
BHU	3665	37.85
RHC	583	6.02
THQ	106	1.09
DHQ	75	0.77
Clinic	2071	21.39
Lab	48	0.50
Zacha Bacha Center	435	4.49
Other	2700	27.88

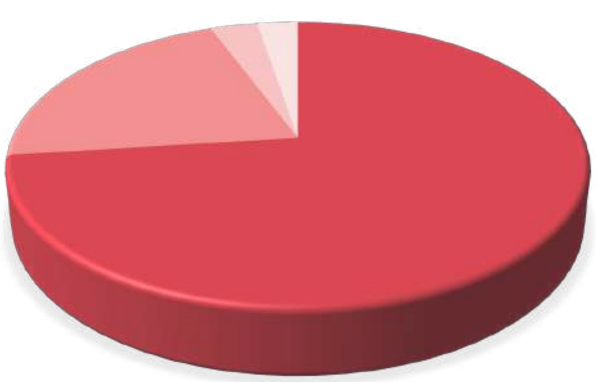

Uzbekistan
Kyrgyzstan
Turkmenistan
Tajikistan
China
GILGIT BALTISTAN
KHYBER PAKHTUNKHWA
AJK
ICT
INDIAN ILLEGALLY OCCUPIED JAMMU & KASHMIR
Afghanistan
PUNJAB
BALOCHISTAN
Iran
India
SINDH
Arabian Sea
Line of Control
Province Boundary
Working Boundary
International Boundary

Rabi Crop

Wheat, the primary Rabi crop in Pakistan, faces significant risks from natural hazards such as floods, droughts, and untimely rainfall. These events can damage crops, disrupt harvests, and lead to reduced yields, ultimately affecting national food security and the livelihoods of rural farming communities. Adopting modern farming practices, efficient irrigation systems, and disaster preparedness measures are crucial for ensuring stable crop yields and protecting the farmers and the economy.

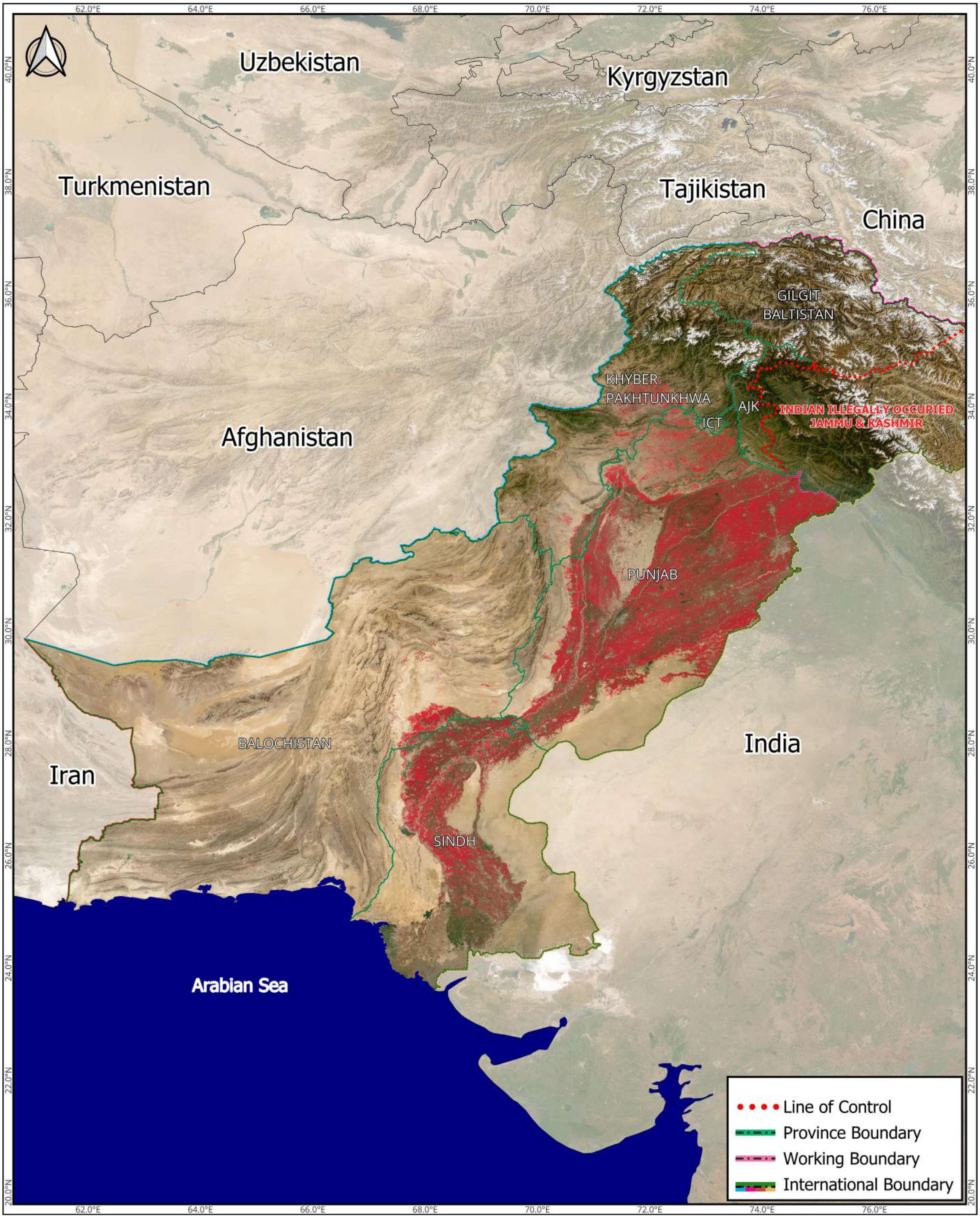
Imagesource:unsplash.com

Rabi Crop (%)



Rabi Crop

Crop	Province	Area (sq. km)	Percentage
Wheat	Punjab	62581.77	73.04
Wheat	Sindh	18085.99	21.10
Wheat	Balochistan	2696.73	3.14
Wheat	Khyber Pakhtunkhwa	2316.01	2.70


Uzbekistan
Kyrgyzstan
Turkmenistan
Tajikistan
China
GILGIT
BALTISTAN
KHYBER
PAKHTUNKHWA
AJK
ICT
INDIAN ILLEGALLY OCCUPIED
JAMMU & KASHMIR
Afghanistan
PUNJAB
BALOCHISTAN
India
Iran
SINDH
Arabian Sea
Line of Control
Province Boundary
Working Boundary
International Boundary

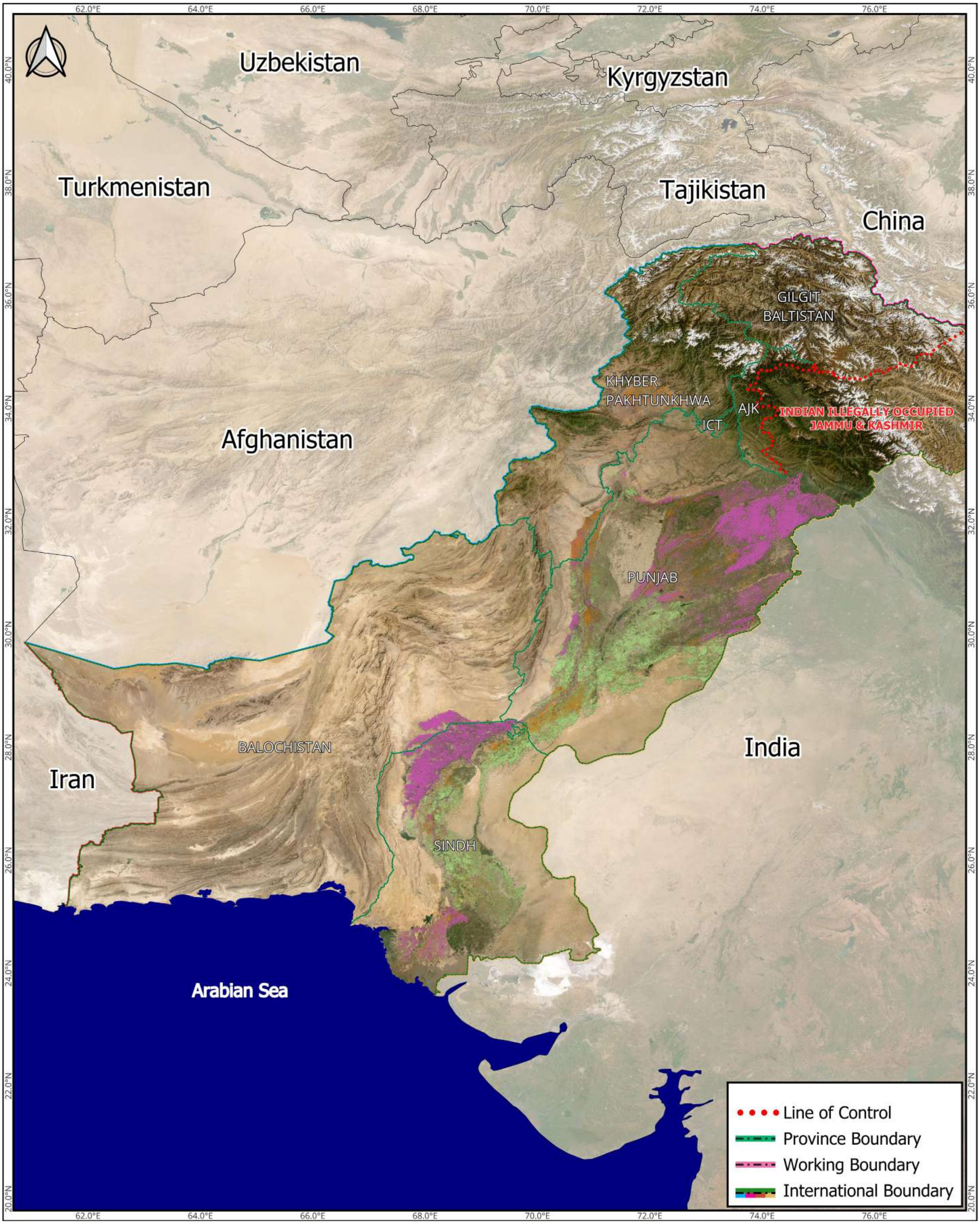
Kharif Crops

Kharif crops in Pakistan, such as rice, cotton, maize, and sugarcane, are at risk due to natural hazards like floods, droughts, and heavy monsoon rains, which can damage crops and disrupt harvests. These hazards often lead to significant losses in agricultural productivity, affecting food security and rural livelihoods. Enhancing climate resilience through advanced irrigation systems, sustainable farming techniques, soil conservation, and proactive disaster preparedness are crucial to maintaining stable Kharif crop production and mitigating potential losses.

Kharif Crops (%)

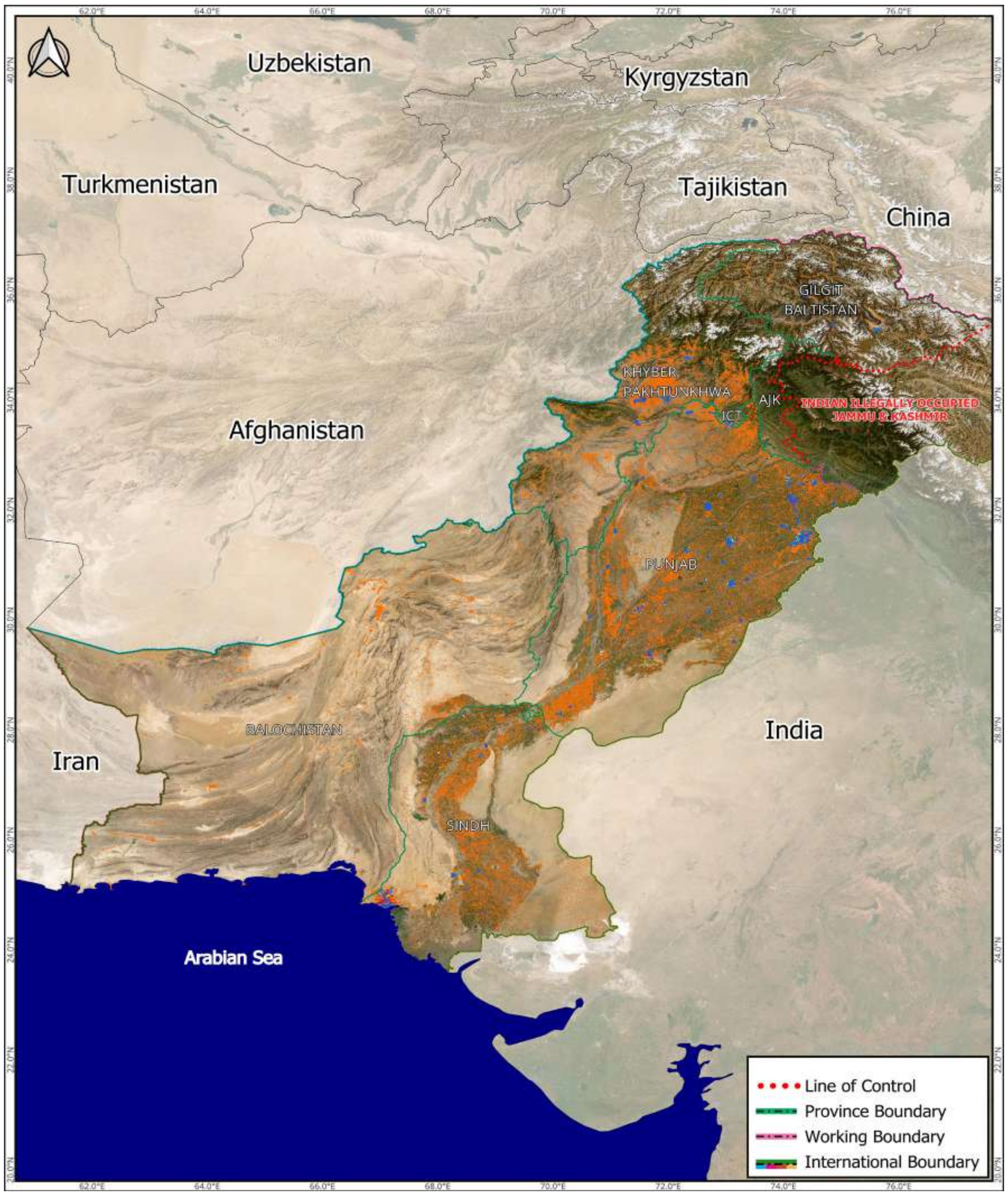
Kharif Crops

Province	Crop	Area (sq. km)	Percentage
Punjab	Rice	20498.35	30.61
	Cotton	16718.76	24.97
	Sugarcane	4388.55	6.55
Sindh	Rice	9967.58	14.88
	Cotton	9658.53	14.42
	Sugarcane	2199.97	3.28
Khyber Pakhtunkhwa	Rice	302.26	0.45
	Sugarcane	1361.92	2.03
Balochistan	Rice	1850.89	2.76

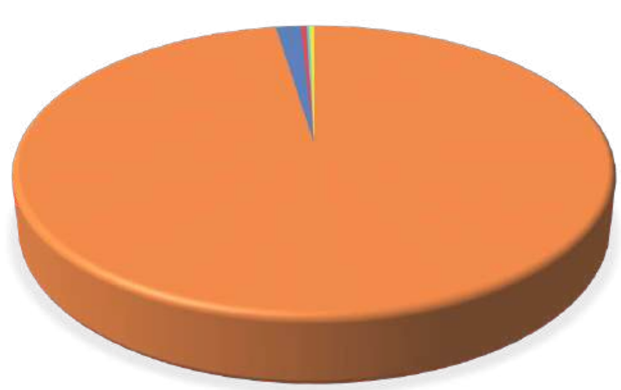

Uzbekistan
Kyrgyzstan
Turkmenistan
Tajikistan
China
GILGIT BALTISTAN
KHYBER PAKHTUNKHWA
AJK
ICT
INDIAN ILLEGALLY OCCUPIED JAMMU & KASHMIR
Afghanistan
PUNJAB
BALOCHISTAN
India
Iran
SINDH
Arabian Sea
Line of Control
Province Boundary
Working Boundary
International Boundary

Builtup

Builtup areas in Pakistan are at risk due to various natural hazards, including floods, earthquakes, landslides. These hazards can cause structural damage, disrupt infrastructure, and lead to significant losses in property and livelihoods. Poor urban planning and inadequate drainage systems further exacerbate disaster risks, particularly in rapidly expanding cities. Investing in resilient construction, effective landuse planning, and disaster response strategies is essential for minimizing damage and ensuring long term sustainability.

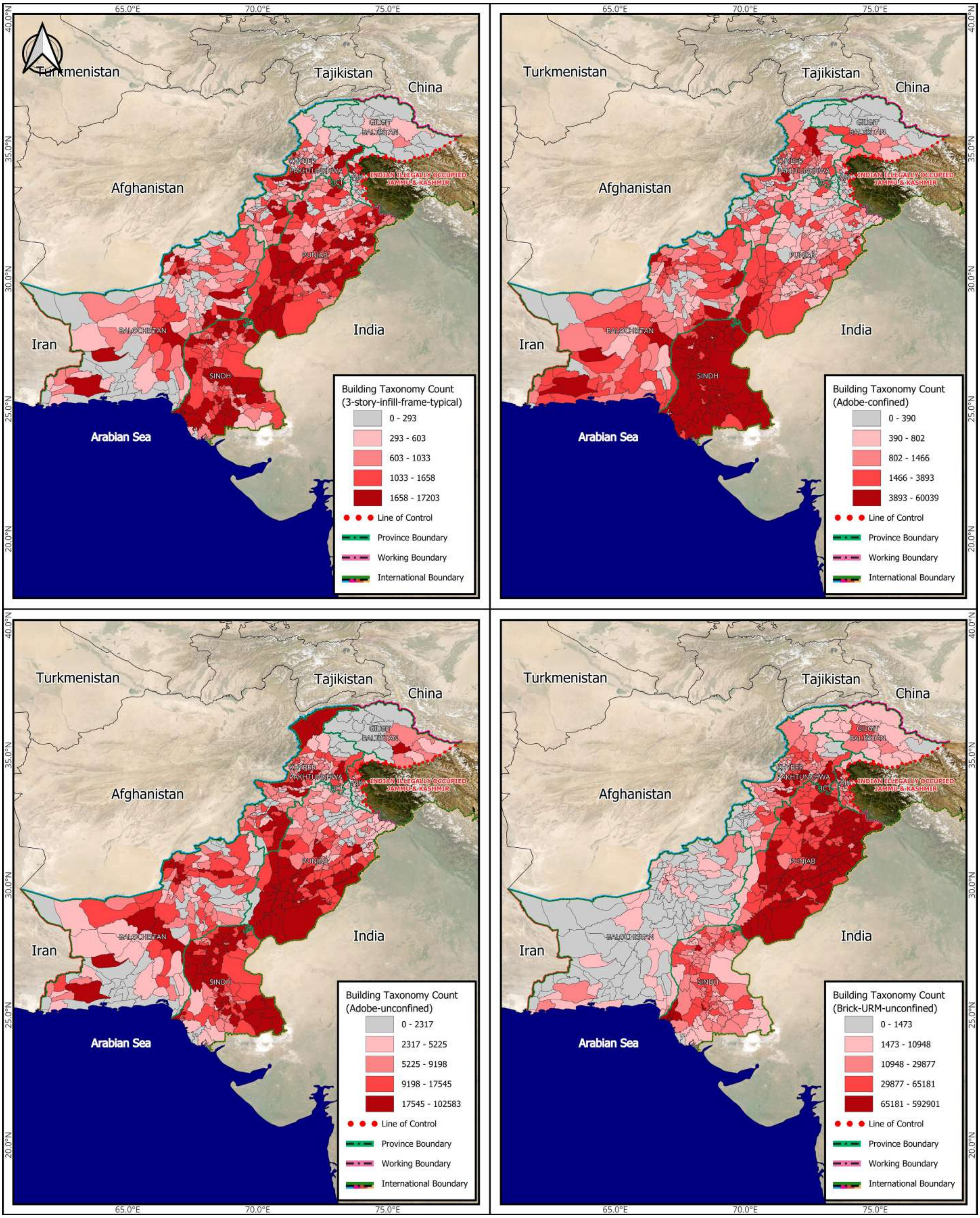


Builtup Classes (%)



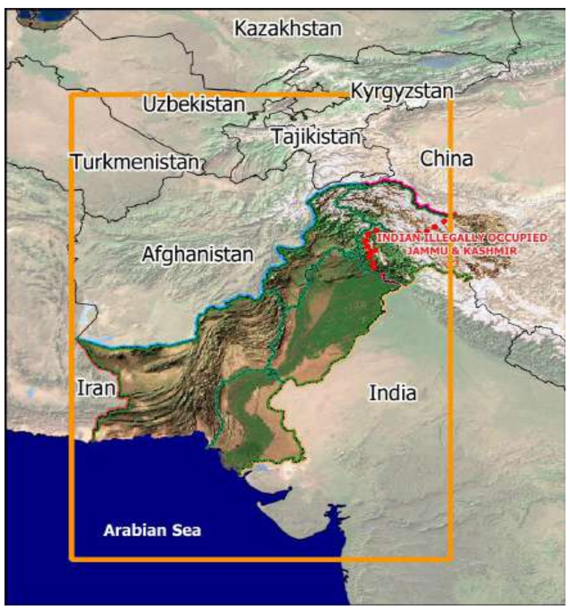
Builtup Classes

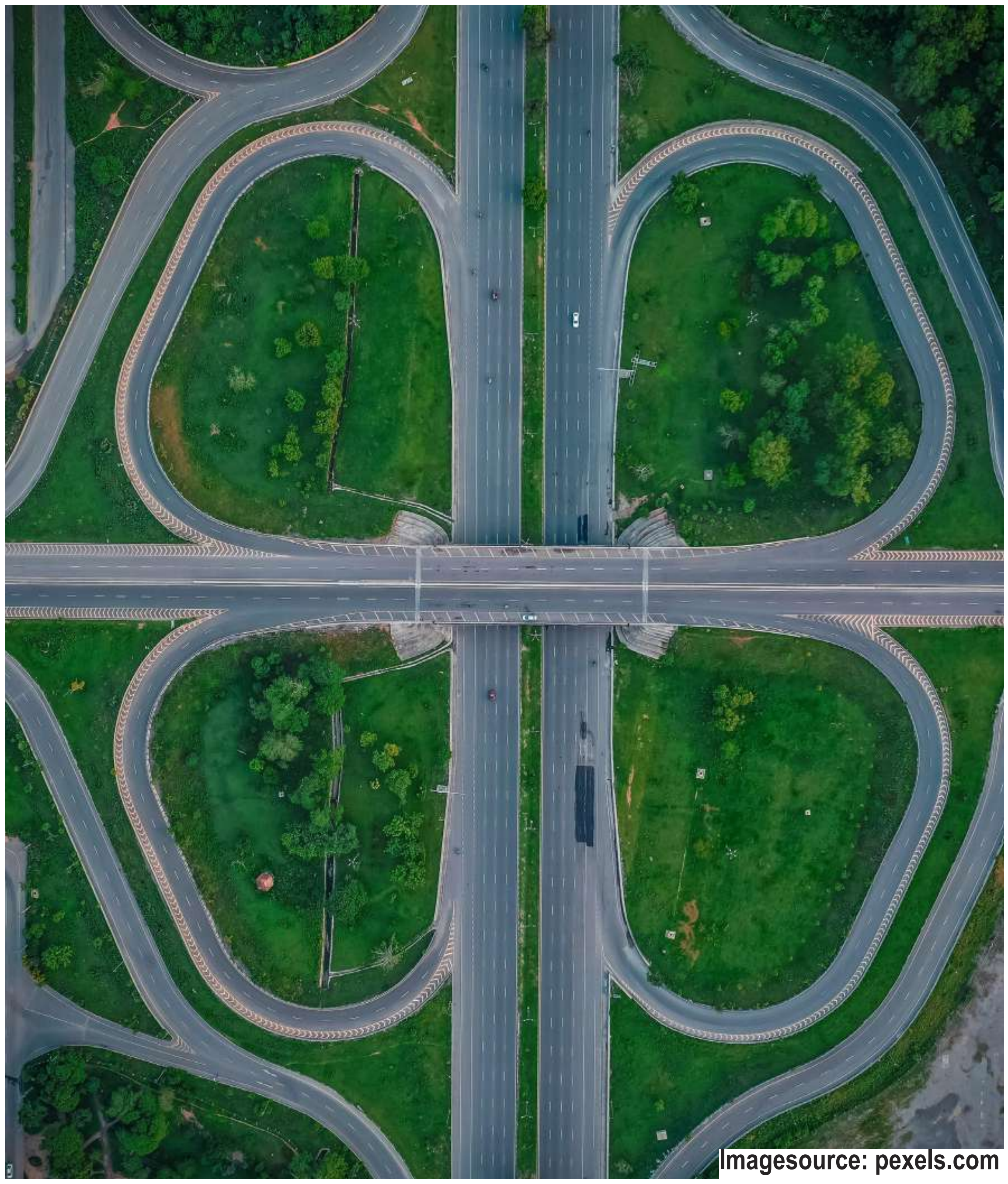
Class of Builtup	Area (sq. km)	Percentage
Low Rise Residential	12605.16	94.54
Low Rise Commercial	210.97	1.58
High Rise Residential	43.96	0.33
High Rise Commercial	25.98	0.19
Slums	3.37	0.03


Turkmenistan
Tajikistan
China
Afghanistan
Iran
India
Arabian Sea
GILGIT BALTISTAN
KHYBER PAKHTUNKHWA
ICT
INDIAN ILLEGALLY OCCUPIED JAMMU & KASHMIR
PUNJAB
BALOCHISTAN
SINDH
65.0°E
70.0°E
75.0°E
40.0°N
35.0°N
30.0°N
25.0°N
20.0°N
Building Taxonomy Count (3-story-infill-frame-typical)
0 - 293
293 - 603
603 - 1033
1033 - 1658
1658 - 17203
Building Taxonomy Count (Adobe-confined)
0 - 390
390 - 802
802 - 1466
1466 - 3893
3893 - 60039
Building Taxonomy Count (Adobe-unconfined)
0 - 2317
2317 - 5225
5225 - 9198
9198 - 17545
17545 - 102583
Building Taxonomy Count (Brick-URM-unconfined)
0 - 1473
1473 - 10948
10948 - 29877
29877 - 65181
65181 - 592901
Line of Control
Province Boundary
Working Boundary
International Boundary

Roads Infrastructure

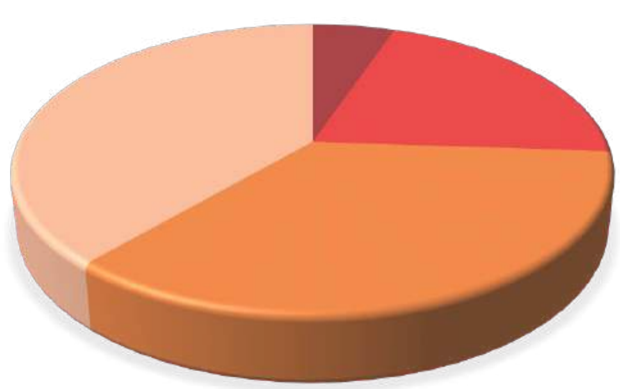
Roads in Pakistan are at risk due to various natural hazards, including floods, landslides, and earthquakes. These hazards can damage road infrastructure, disrupt transportation, and lead to significant economic losses. Enhancing transportation resilience through sustainable road design, durable construction materials, and advanced drainage solutions is essential to maintaining functionality and safety during disasters. Additionally, early warning systems, rapid response mechanisms, and sustainable land management play a crucial role in minimizing disruptions and preserving vital transportation networks.





Imagesource: pexels.com

Road Classes (%)



Road Classes

Road Type	Length (km)	Percentage
Motorway	3456.20	5.33
Highway	13458.08	20.75
Primary	22977.11	35.42
Secondary	24981.19	38.51

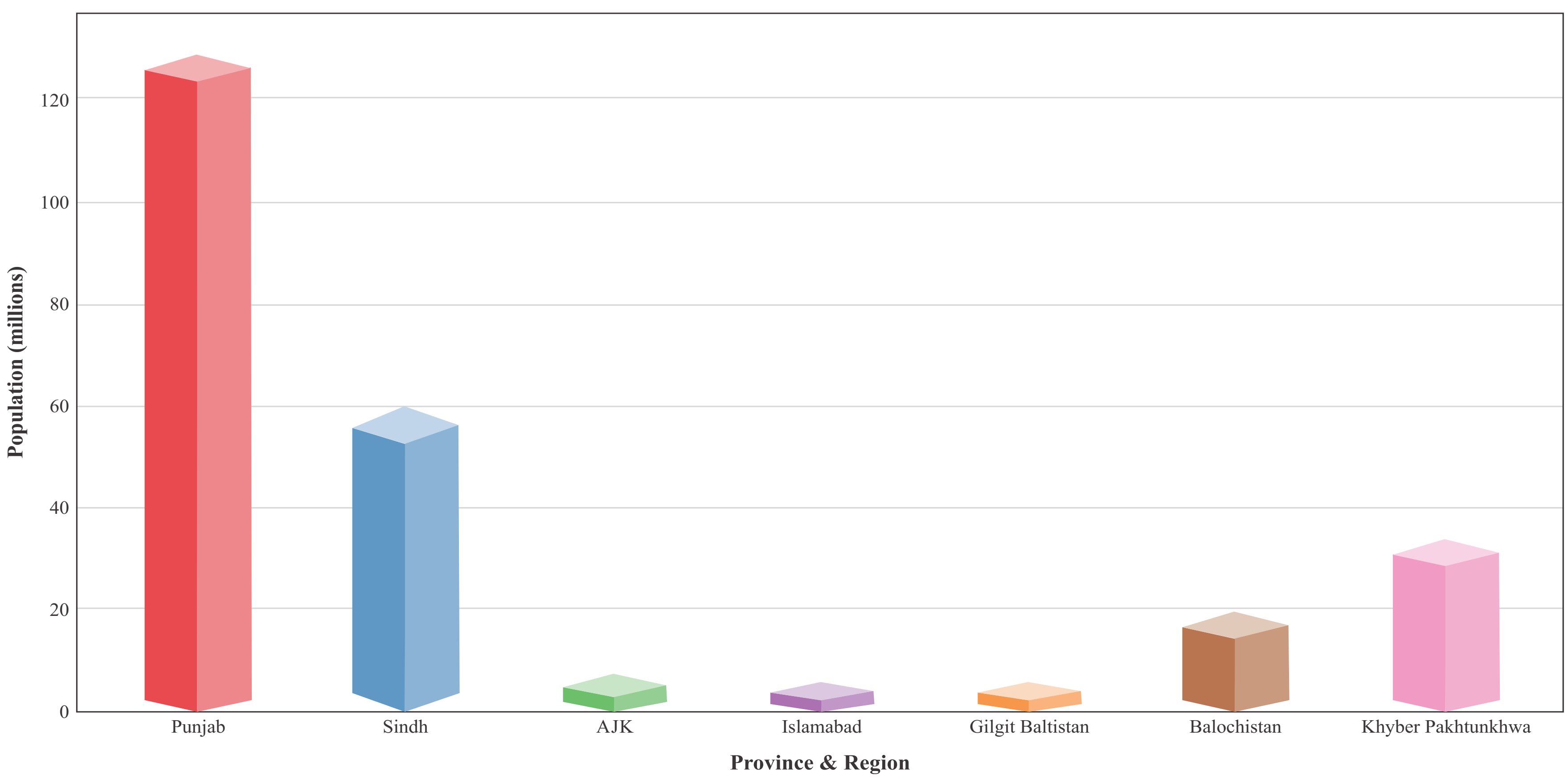

Uzbekistan
Kyrgyzstan
Turkmenistan
Tajikistan
China
GILGIT
BALTISTAN
KHYBER
PAKHTUNKHWA
AJK
ICT
INDIAN ILLEGALLY OCCUPIED
JAMMU & KASHMIR
Afghanistan
PUNJAB
BALOCHISTAN
India
Iran
SINDH
Arabian Sea
Line of Control
Province Boundary
Working Boundary
International Boundary

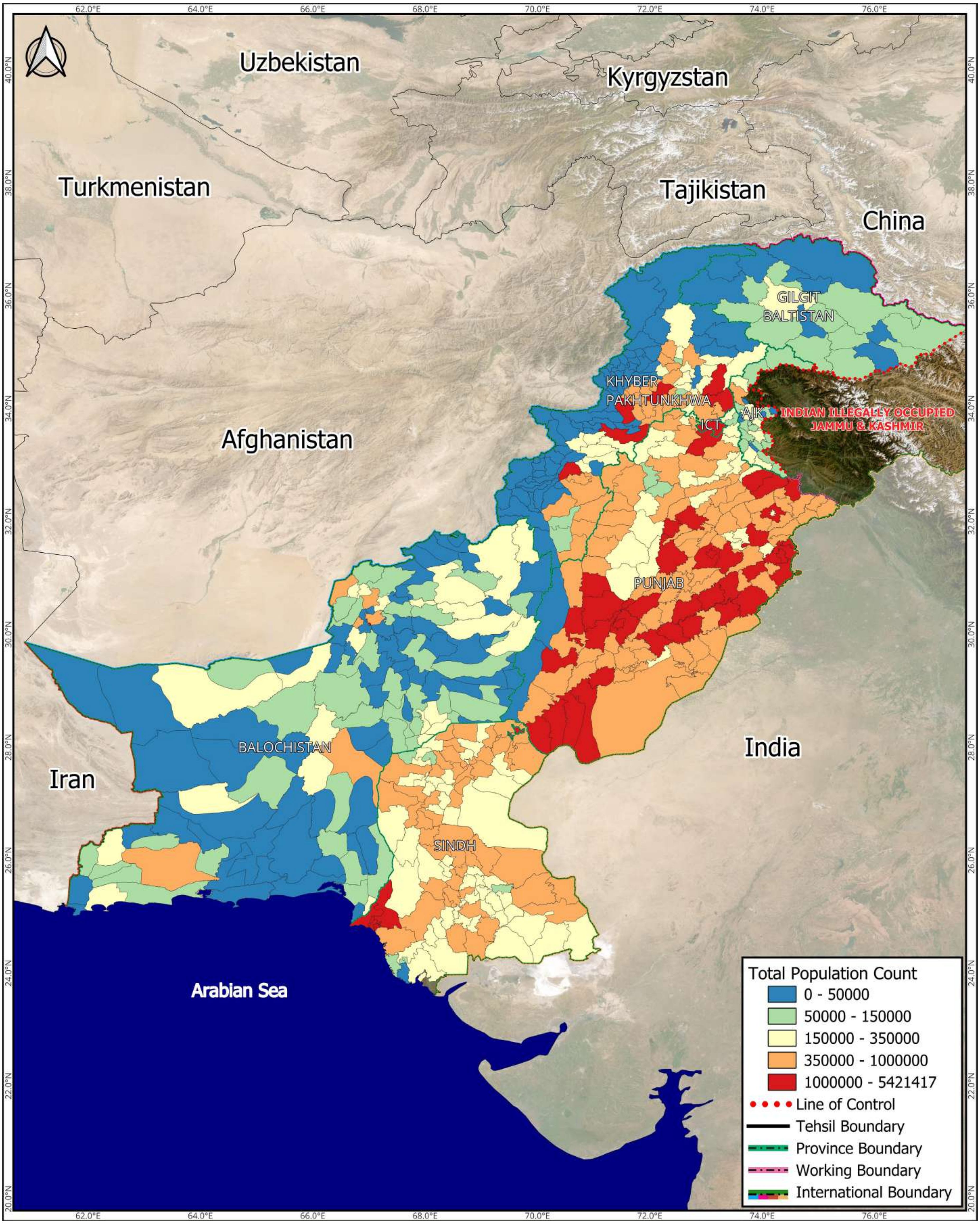
Population

Pakistan's population faces significant risk from natural disasters such as floods, heatwaves, landslides, and earthquakes. Dense populations in Punjab and Sindh increase vulnerability to these hazards. Although Khyber Pakhtunkhwa and Balochistan have lower population densities, they are still exposed to disaster risks. Marginalized communities in GB are at high risk from multiple hazards and the increasing impacts of climate change. Rapid urbanization across the country strains resources and infrastructure, further amplifying risk of population due to these natural disasters.

Imagesource:pexels.com

Population Distribution

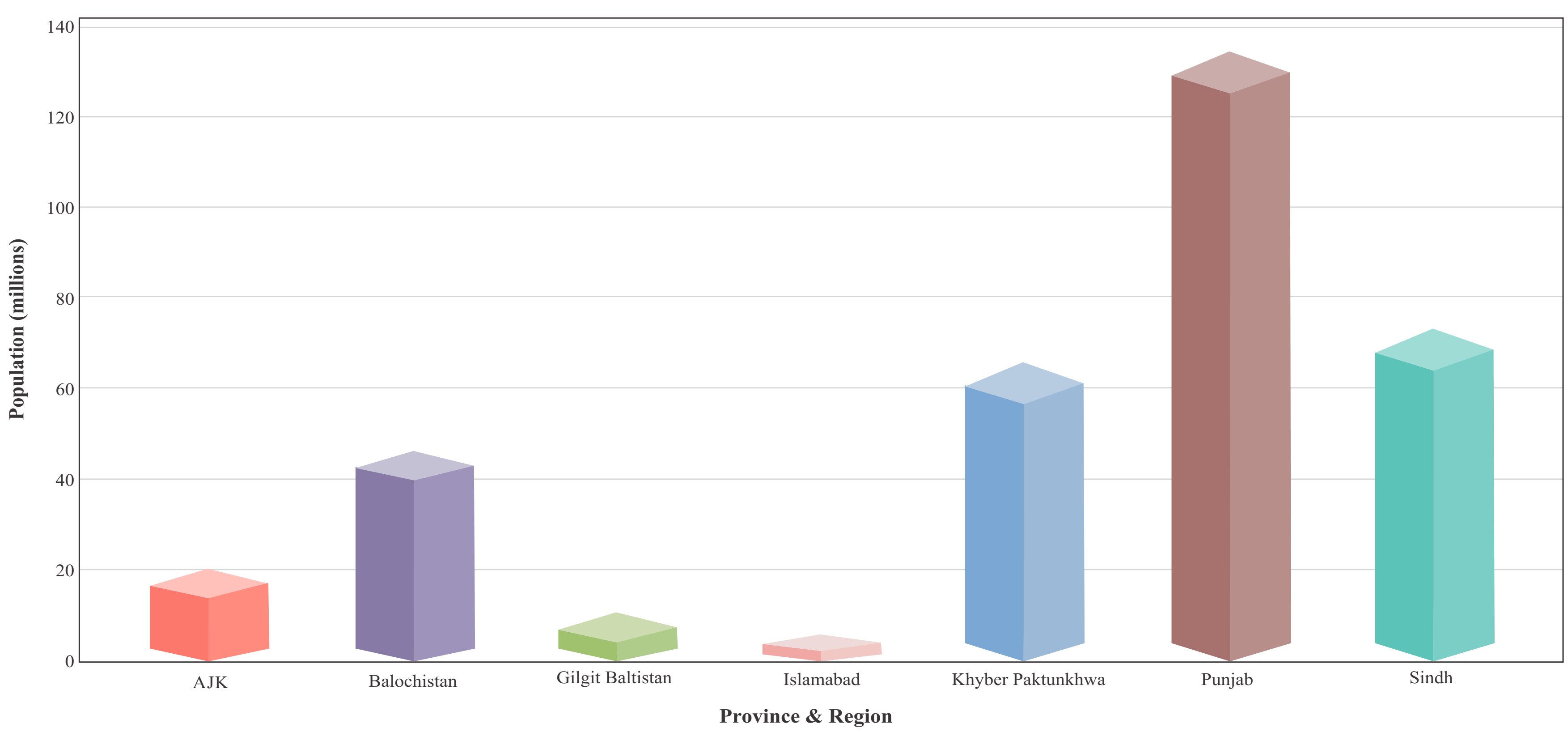


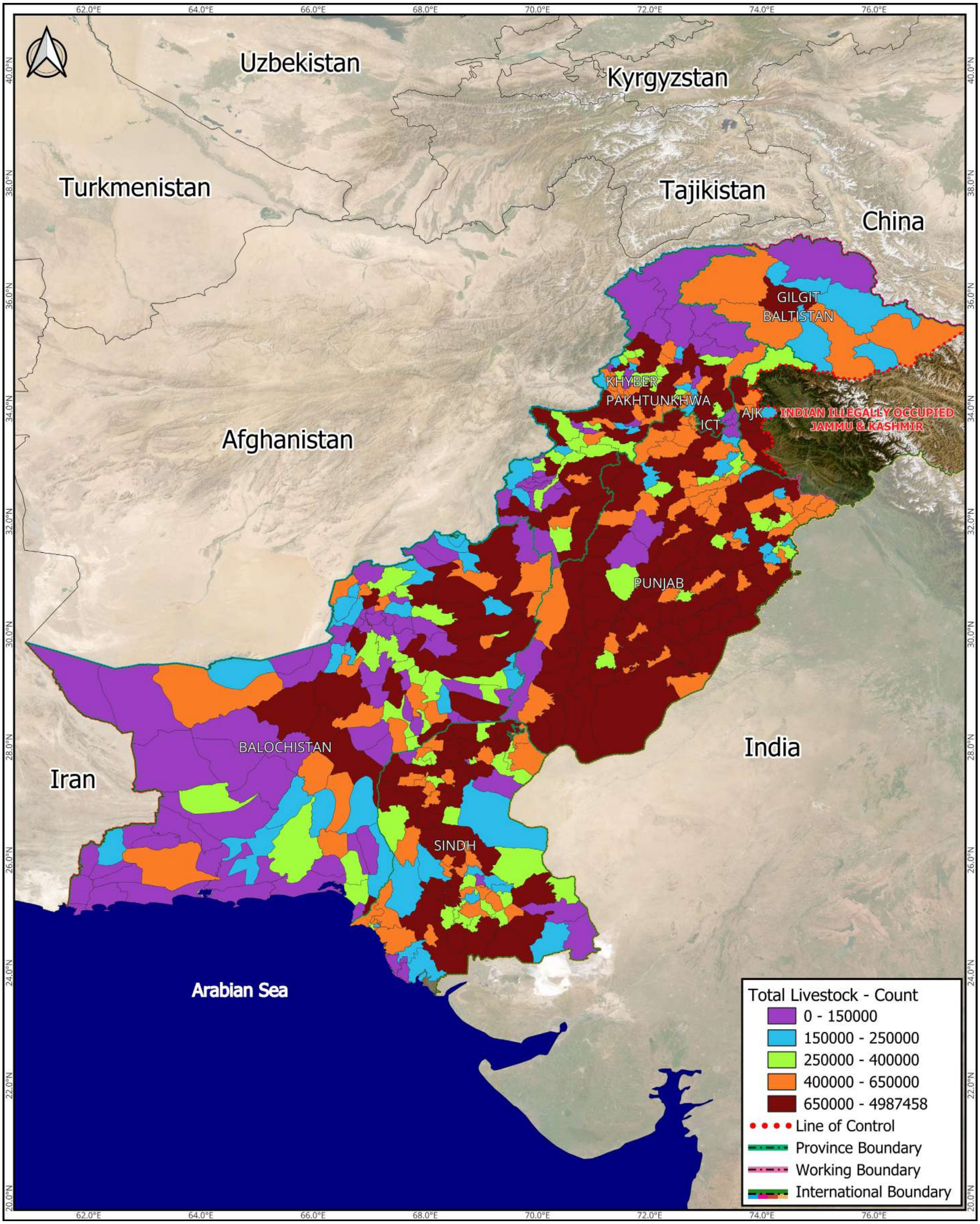

Uzbekistan
Kyrgyzstan
Turkmenistan
Tajikistan
China
GILGIT BALTISTAN
KHYBER PAKHTUNKHWA
AJK
ICT
INDIAN ILLEGALLY OCCUPIED JAMMU & KASHMIR
Afghanistan
PUNJAB
BALOCHISTAN
Iran
India
SINDH
Arabian Sea
Total Population Count
0 - 50000
50000 - 150000
150000 - 350000
350000 - 1000000
1000000 - 5421417
Line of Control
Tehsil Boundary
Province Boundary
Working Boundary
International Boundary

Livestock

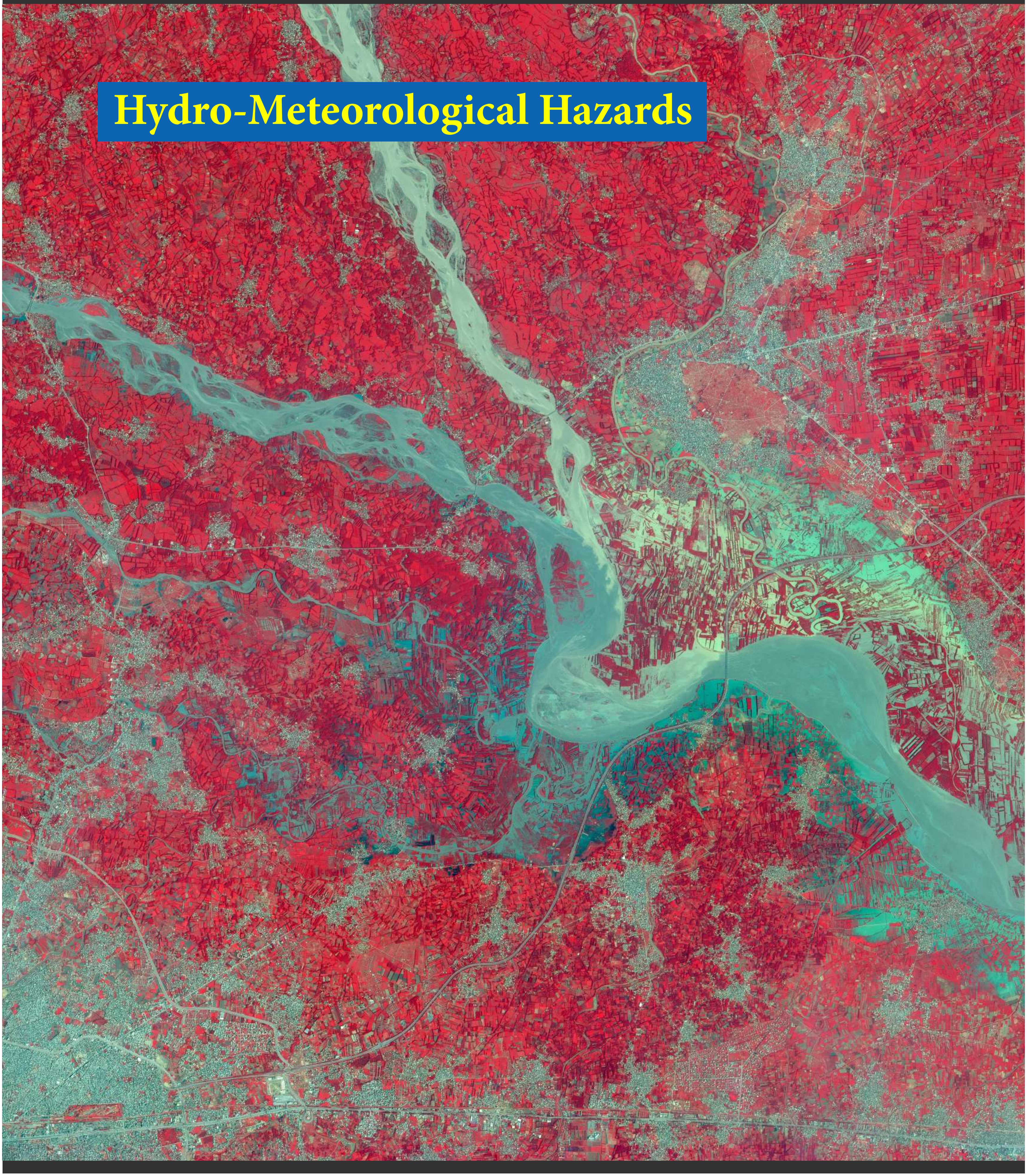
The livestock sector in Pakistan faces significant risks from natural hazards, including floods, droughts, and extreme weather events. These threats can cause injuries, spread diseases, and disrupt farming, leading to major losses in animal health and livelihoods. Harsh climatic conditions, inadequate veterinary care, and limited access to emergency support further worsen the impact on livestock.

Livestock Distribution




Uzbekistan
Kyrgyzstan
Turkmenistan
Tajikistan
China
GILGIT BALTISTAN
KHYBER PAKHTUNKHWA
ICT
AJK
INDIAN ILLEGALLY OCCUPIED JAMMU & KASHMIR
Afghanistan
PUNJAB
BALOCHISTAN
India
Iran
SINDH
Arabian Sea
Total Livestock - Count
0 - 150000
150000 - 250000
250000 - 400000
400000 - 650000
650000 - 4987458
Line of Control
Province Boundary
Working Boundary
International Boundary

Hydro-Meteorological Hazards




Imagesource: SPOT 6/7 Imagery

Hydro-Meteorological Hazards - Floods

Floods in Pakistan are a recurring and devastating natural hazard, primarily driven by intense monsoon rains, snow and glacial melt, and poor drainage systems. The Indus River and its vast network of tributaries often overflow, inundating large swathes of land across Punjab, Sindh, and Khyber Pakhtunkhwa. These floods result in widespread displacement, damage to infrastructure, loss of livestock, destruction of crops, and significant economic setbacks.

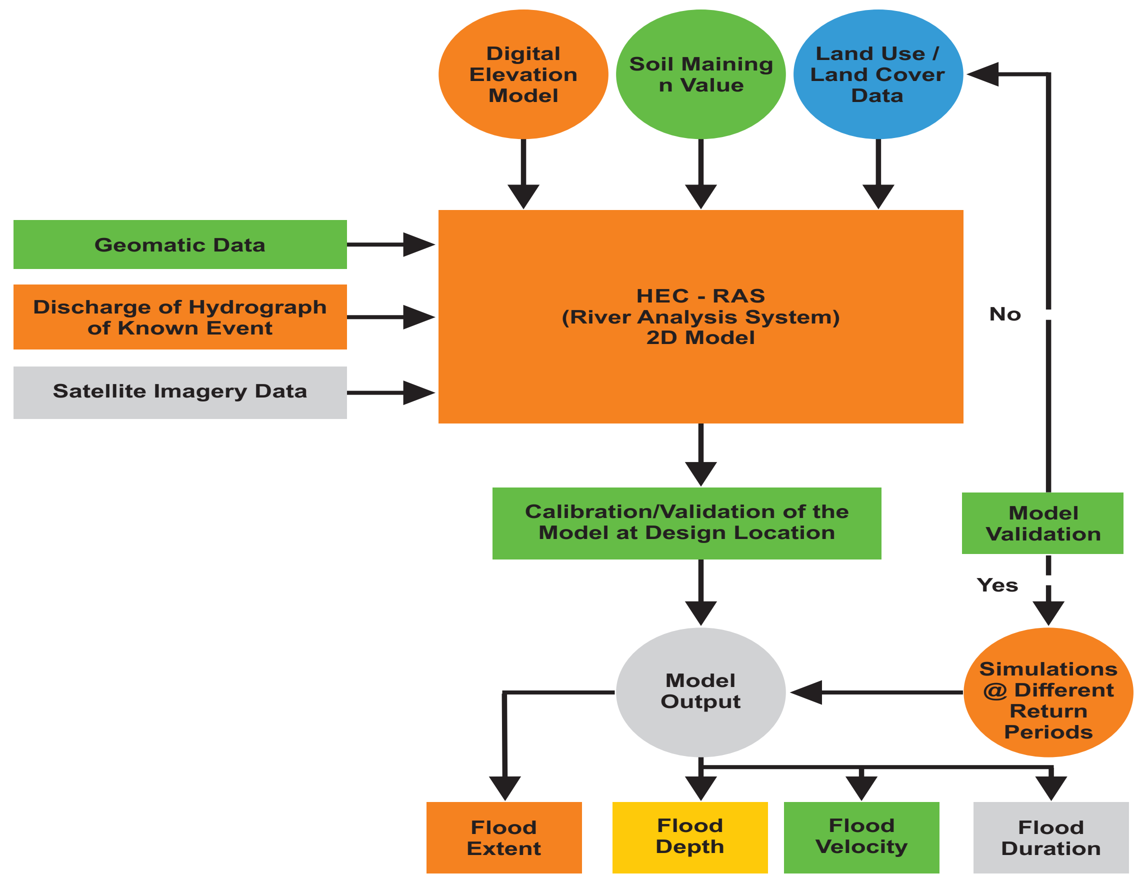
The flood hazard assessment was performed across major rivers of Pakistan. Flood hazard maps were prepared for various return periods, i.e., 5, 10, 25, 50, 100, and 200 years. The outputs generated include flood depth, velocity, and duration maps for different return periods, helping decision-makers in risk assessment.

HEC-RAS 2D Model

HEC-RAS model can perform ID, 2D, and combined 1D/2D unsteady flow routing. 2D flow modeling is achieved by including a 2D flow area component into the flood model. HEC-RAS flood model uses the 2D Saint-Venant equations and the 2D Diffusive Wave equations for flood simulation.

A detailed flood frequency analysis and hazard modeling of Pakistan's major rivers were conducted at key discharge stations, such as dams and headworks. Discharge hydrographs from historical flood events were utilized to calibrate the model accurately.

Annual peak discharges recorded at each station were analyzed to estimate flood return periods, helping predict the likelihood of future events. The HEC-RAS 2D model was then employed to simulate designed hydrographs for different return periods, providing critical insights into flood behavior and potential risk areas.



Data Inputs

The input data layers for the HEC-RAS model include:

- Long-term (30-40 years) annual peak flows of the major rivers at discharge stations
- Observed flow and stage hydrographs of historical extreme floods
- Designed hydrographs were prepared based on the flood frequency analysis for various return periods
- Return periods and known flood event hydrographs were used to prepare designed hydrographs
- 12 meter WorldDEM Digital Surface Model (DSM)
- River geometry (centerline and bank line)
- Historical flood satellite imagery & cumulative flood extent

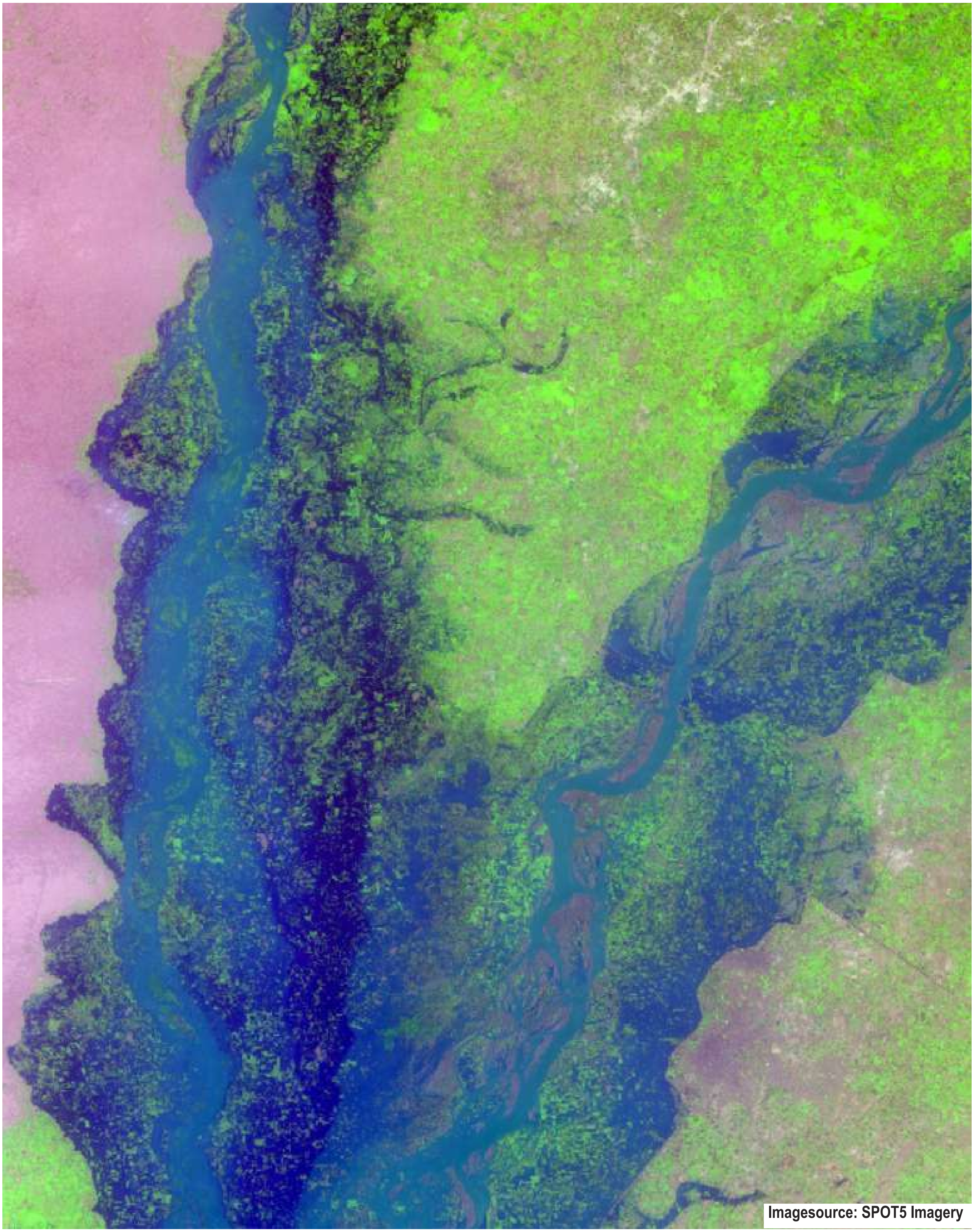
Model Calibration and Validation

Model calibration and validation were carried out against historical maximum flood events, including significant floods that occurred in 1988, 1992, 2010, 2014 and 2015. Observed hydrographs, infiltration components, and satellite imagery based flood extents were used to improve the model's accuracy and performance. These datasets helped in better understanding the hydrological response of the catchment during extreme events. Subsequently, the calibrated and validated model was simulated for various return periods to analyze the potential extent, depth, and impact of future flood scenarios under different hydrological conditions.

Model Output

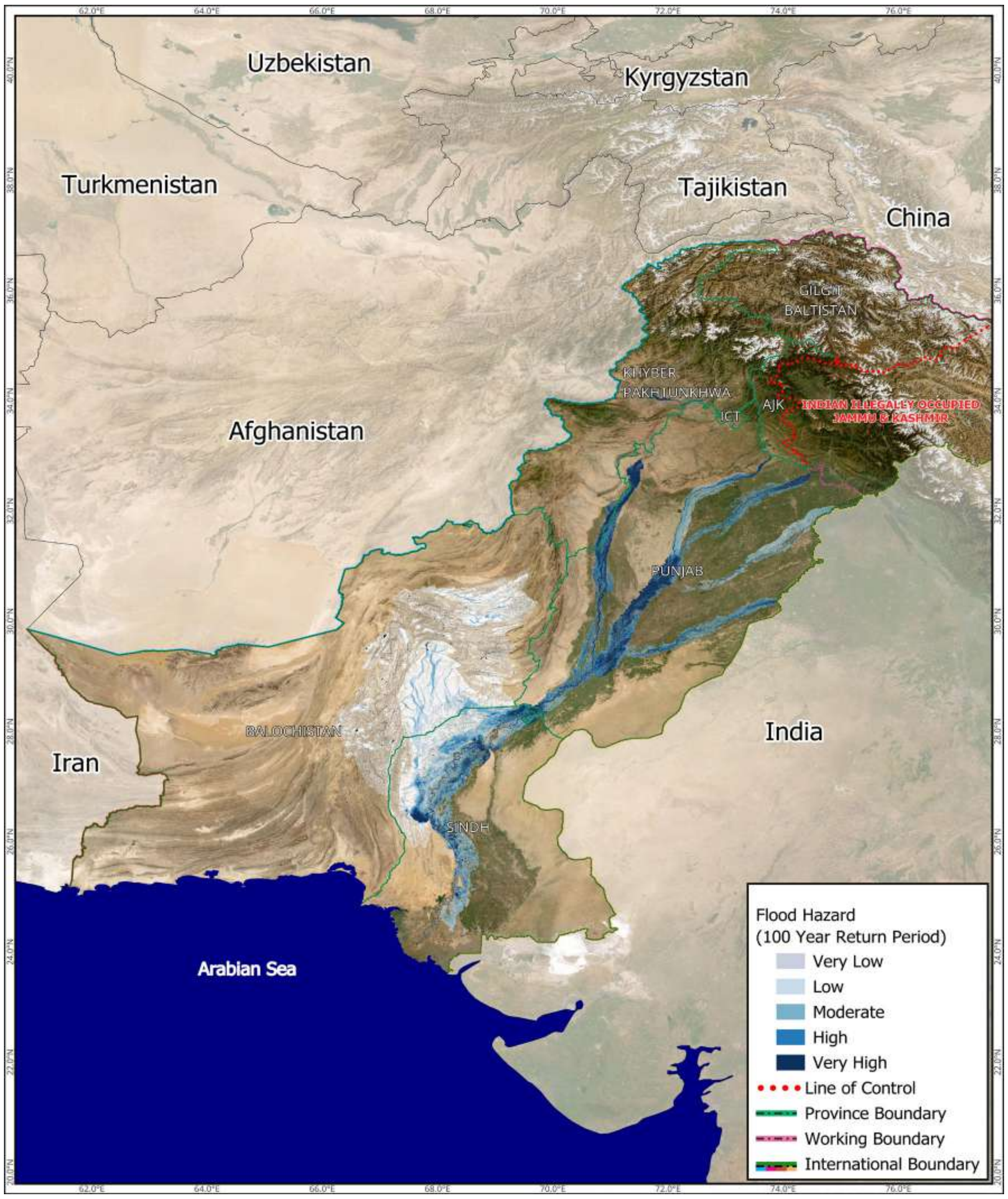
HEC-RAS provides outputs in raster grid format, including flood extent, flood depth, flood velocity, and flood duration for detailed flood analysis.

These outputs are crucial for flood hazard mapping and mitigation planning.

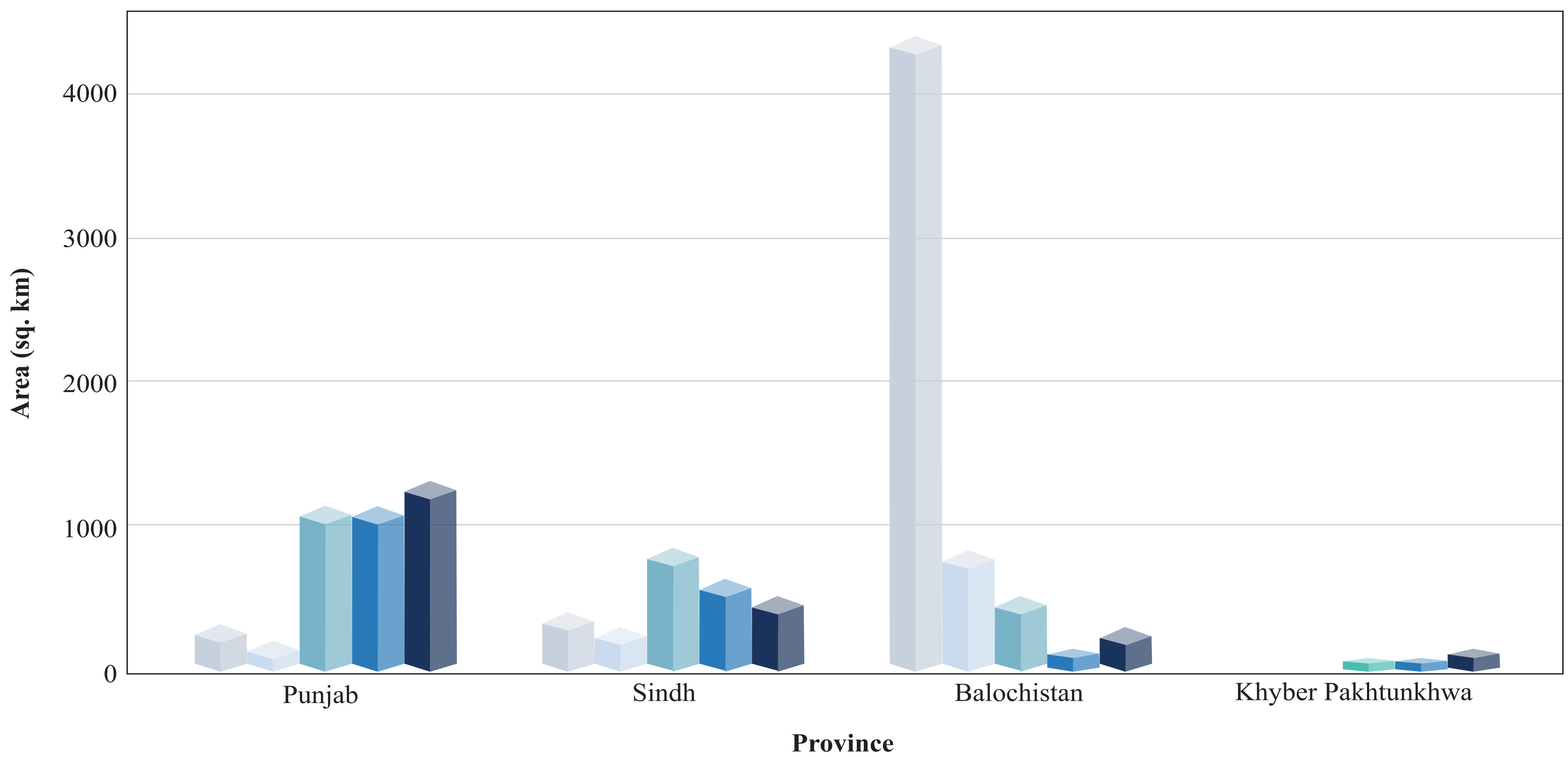

Imagesource: SPOT5 Imagery

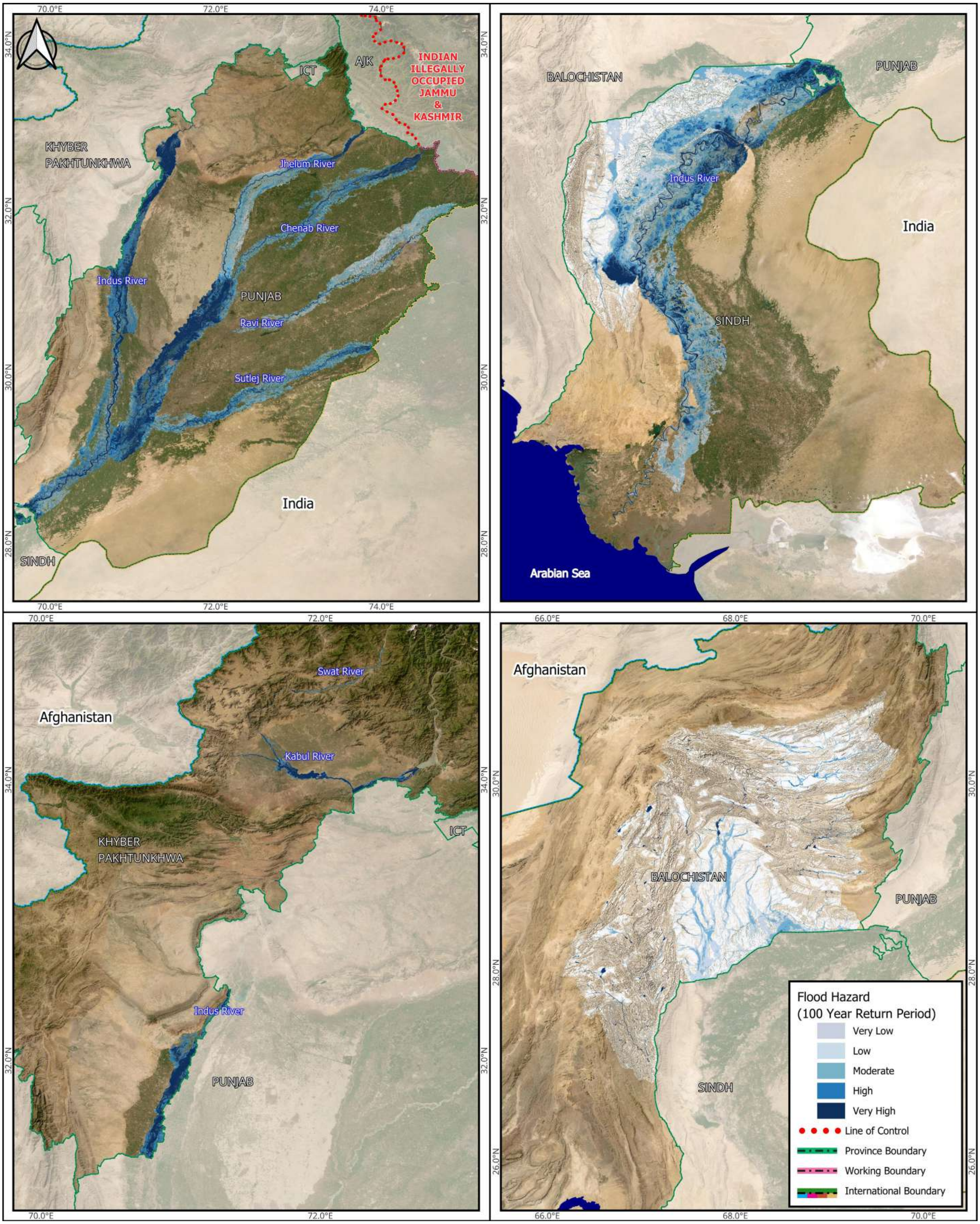
Floods

Floods in Pakistan, driven by heavy rainfall or snow/glacier melt, cause widespread destruction to infrastructure, agriculture, and communities, resulting in displacement, economic losses, and fatalities. To mitigate these impacts, a comprehensive flood hazard assessment was conducted along major river systems. This assessment produced detailed flood hazard maps for known return periods of 5, 10, 25, 50, 100, and 200 years. The flood hazard maps highlighted critical flood metrics, including depth, velocity, and duration, offering insights into potential flood behavior and affected regions.



Potential Flood Prone Areas (100 Year Return Period)





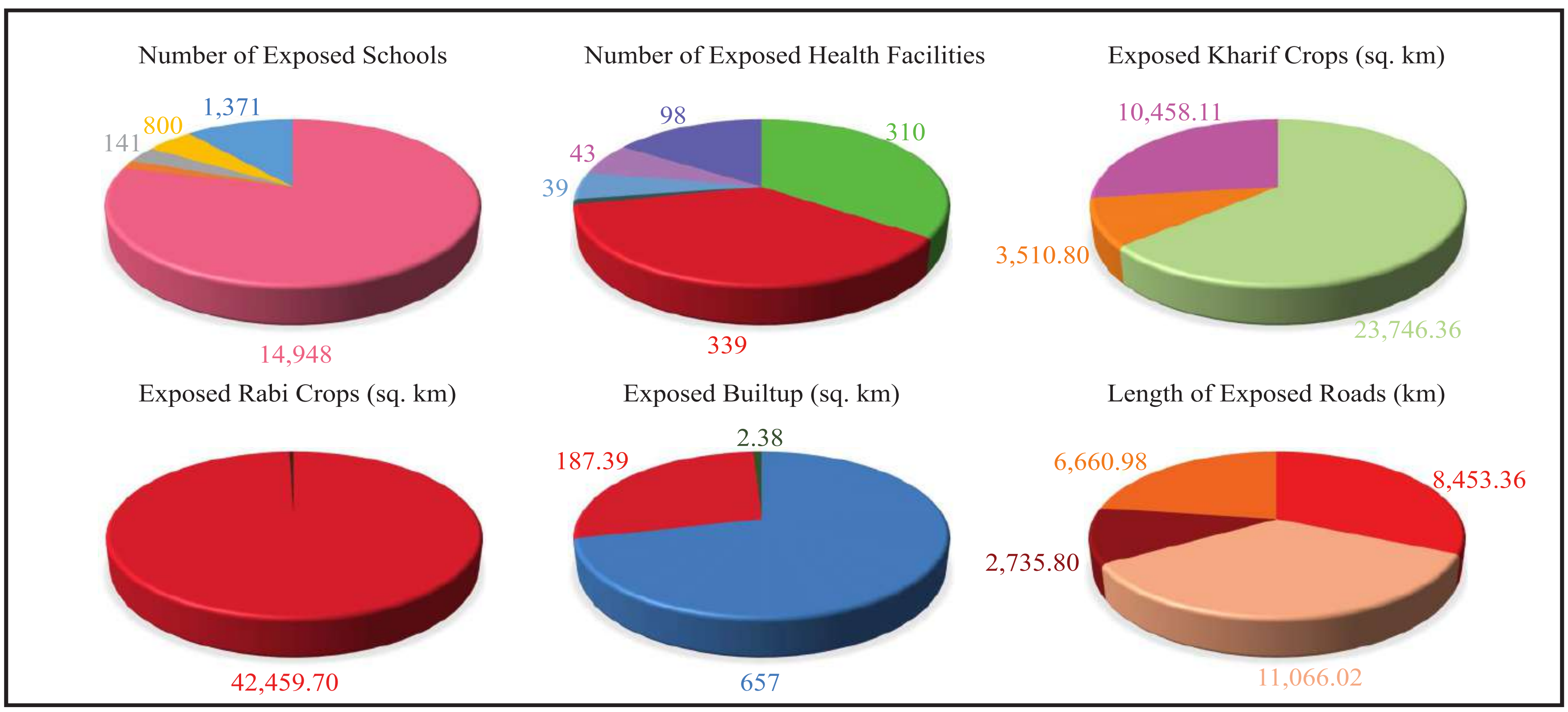
INDIAN ILLEGALLY OCCUPIED JAMMU & KASHMIR
AJK
ICT
KHYBER PAKHTUNKHWA
Jhelum River
Chenab River
Indus River
PUNJAB
Ravi River
Sutlej River
India
SINDH
BALOCHISTAN
SINDH
Arabian Sea
Afghanistan
Swat River
Kabul River
Flood Hazard (100 Year Return Period)
Very Low
Low
Moderate
High
Very High
Line of Control
Province Boundary
Working Boundary
International Boundary

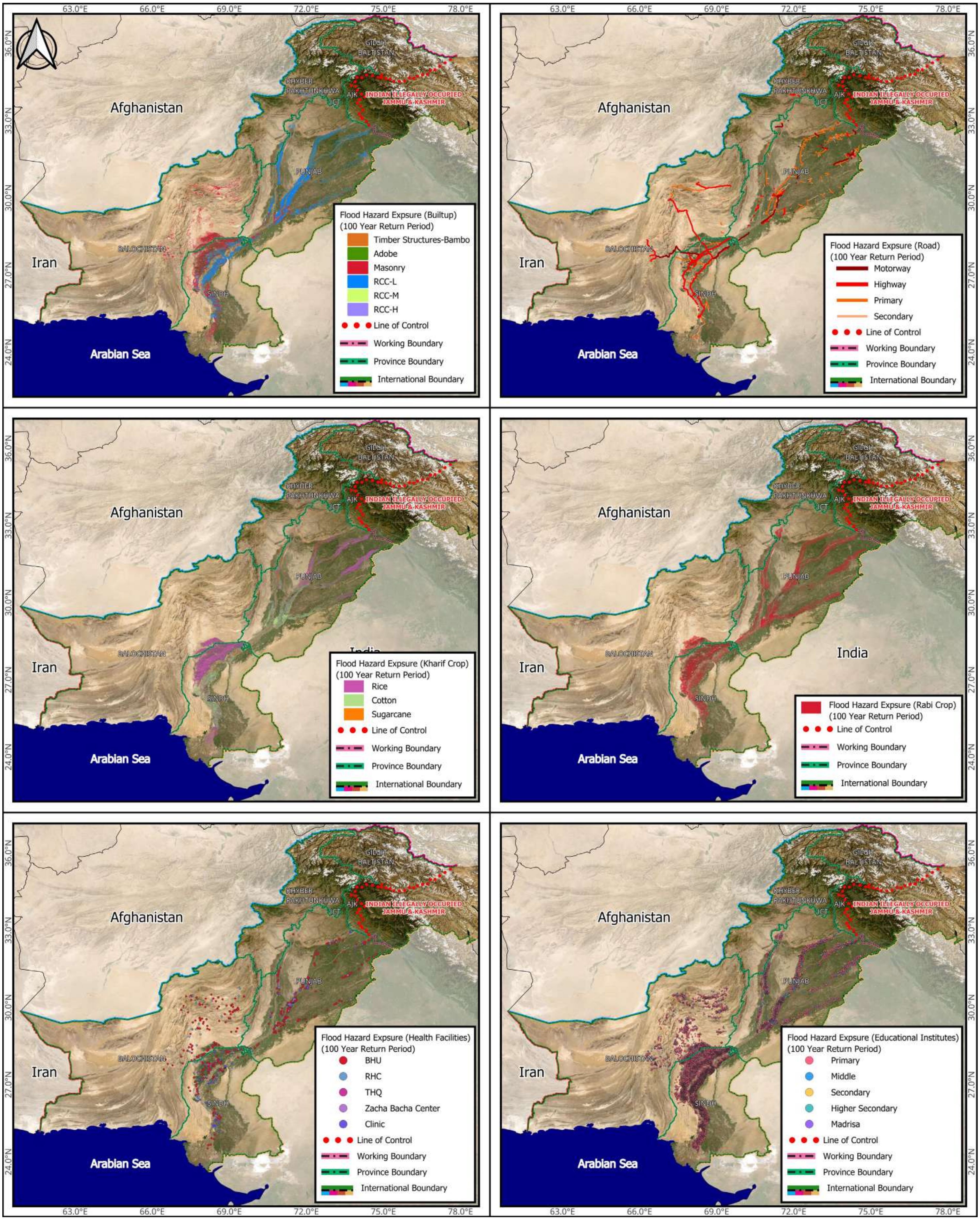
Floods - Pakistan

Pakistan faces significant flood exposure due to rainfall, flash floods, and contributions from major rivers like the Indus. The country's diverse topography from mountainous regions to arid plains makes many areas highly exposed to sudden water flows. Key sectors such as education, healthcare, agriculture, infrastructure, and transportation networks often suffer extensive damage and disruptions. Wheat, cotton, rice, and sugarcane are major agricultural crops exposed to flood events of varying magnitudes.

Imagesource:pexels.com

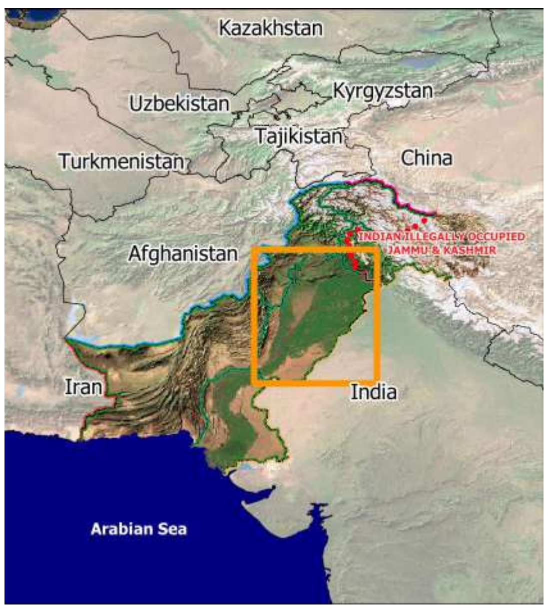
Potential Flood Exposure of Key Sectors (100 Year Return Period)

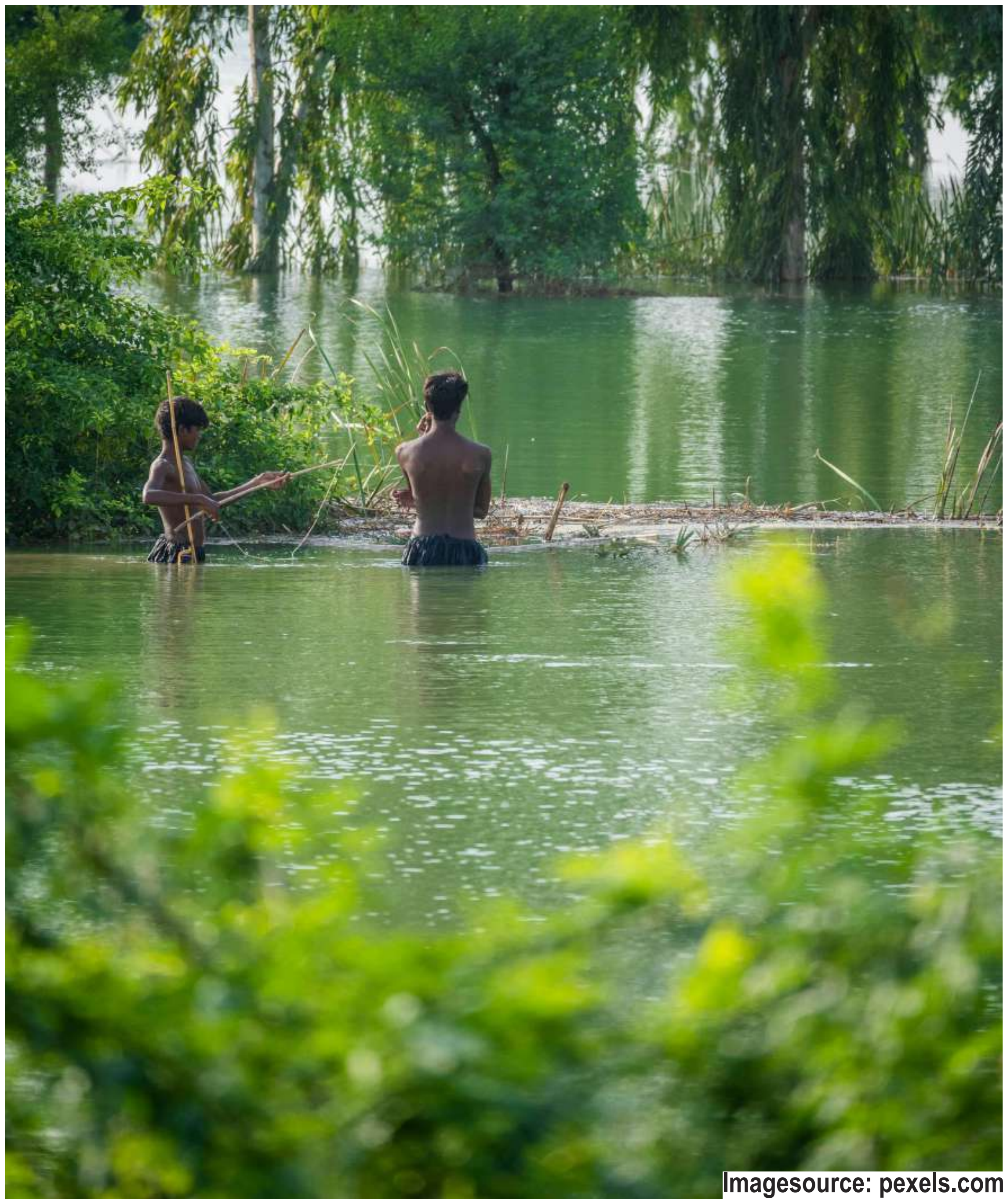



Flood Hazard Expsure (Builtup)
(100 Year Return Period)
Timber Structures-Bambo
Adobe
Masonry
RCC-L
RCC-M
RCC-H
Line of Control
Working Boundary
Province Boundary
International Boundary
Flood Hazard Expsure (Road)
(100 Year Return Period)
Motorway
Highway
Primary
Secondary
Flood Hazard Expsure (Kharif Crop)
(100 Year Return Period)
Rice
Cotton
Sugarcane
Flood Hazard Expsure (Rabi Crop)
(100 Year Return Period)
Flood Hazard Expsure (Health Facilities)
(100 Year Return Period)
BHU
RHC
THQ
Zacha Bacha Center
Clinic
Flood Hazard Expsure (Educational Institutes)
(100 Year Return Period)
Primary
Middle
Secondary
Higher Secondary
Madrisa
Afghanistan
Iran
India
Arabian Sea
BALOCHISTAN
PUNJAB
SINDH
KHYBER PAKHTUNKHWA
GILGIT BALTISTAN
AJK
ICT
INDIAN ILLEGALLY OCCUPIED JAMMU & KASHMIR
63.0°E
66.0°E
69.0°E
72.0°E
75.0°E
78.0°E
24.0°N
27.0°N
30.0°N
33.0°N
36.0°N

Floods - Punjab

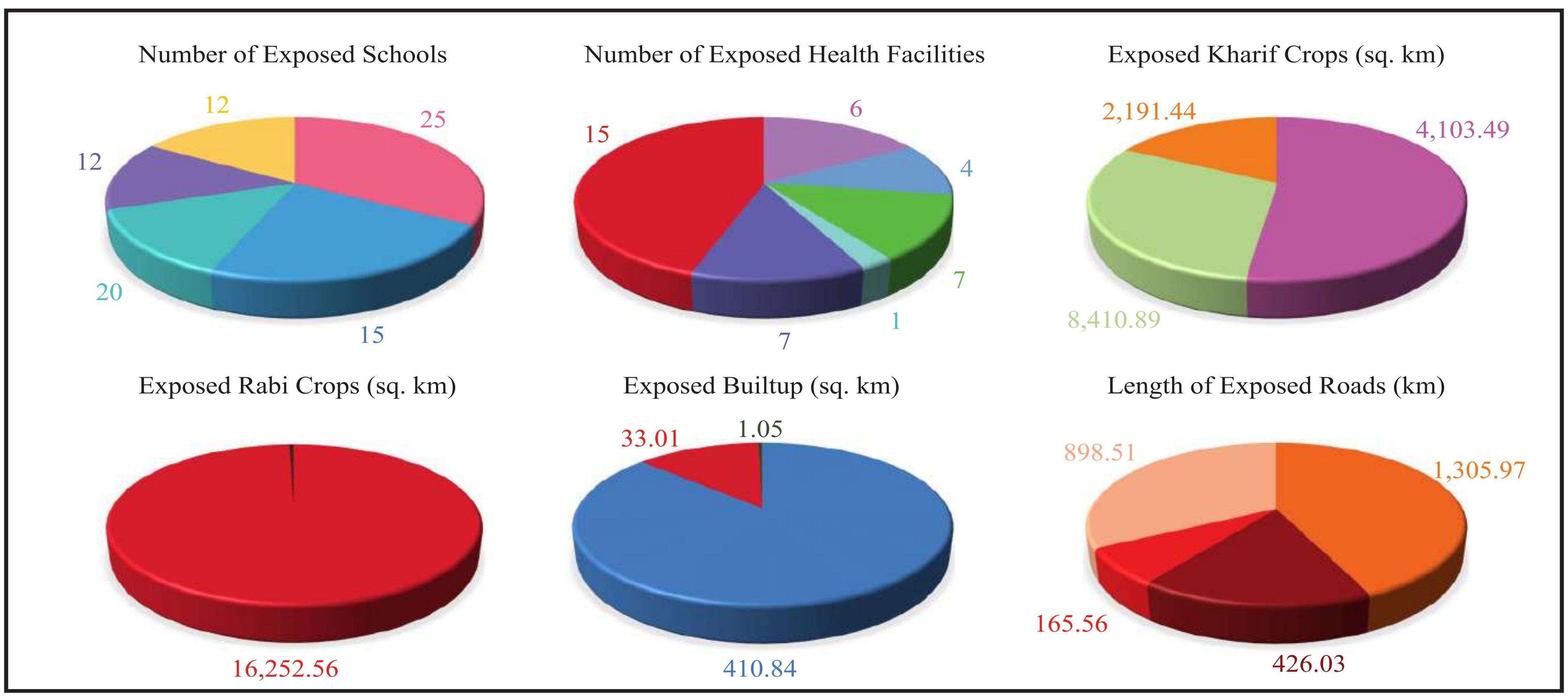
Punjab faces considerable flood exposure, especially in regions along major rivers like the Indus, Chenab, Ravi, and Sutlej. Critical sectors such as education, healthcare, agriculture, infrastructure, and transportation networks are particularly vulnerable. Schools, hospitals, Rabi and Kharif crops, urban areas, and roads often endure significant damage and disruptions during flood events, highlighting the urgent need for improved flood protection, early warning systems, and long term resilience measures.

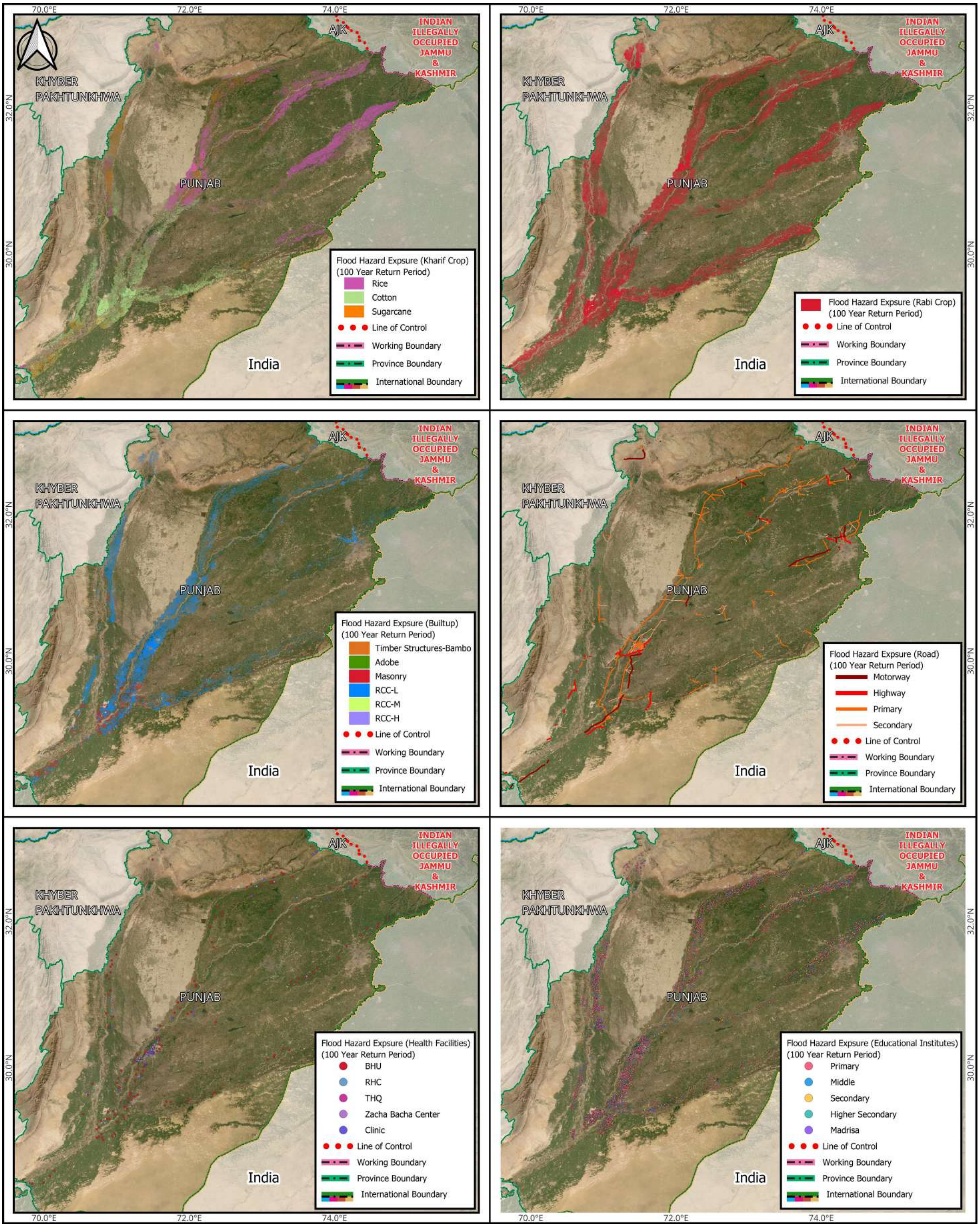




Imagesource: pexels.com

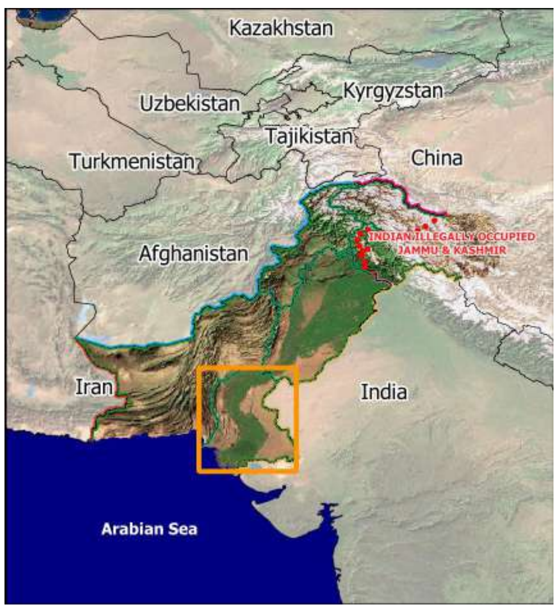
Potential Flood Exposure of Key Sectors (100 Year Return Period)




70.0°E
72.0°E
74.0°E
32.0°N
30.0°N
AJK
INDIAN ILLEGALLY OCCUPIED JAMMU & KASHMIR
KHYBER PAKHTUNKHWA
PUNJAB
India
Flood Hazard Exposure (Kharif Crop) (100 Year Return Period)
Rice
Cotton
Sugarcane
Line of Control
Working Boundary
Province Boundary
International Boundary
Flood Hazard Exposure (Rabi Crop) (100 Year Return Period)
Line of Control
Working Boundary
Province Boundary
International Boundary
Flood Hazard Exposure (Builtup) (100 Year Return Period)
Timber Structures-Bambo
Adobe
Masonry
RCC-L
RCC-M
RCC-H
Line of Control
Working Boundary
Province Boundary
International Boundary
Flood Hazard Exposure (Road) (100 Year Return Period)
Motorway
Highway
Primary
Secondary
Line of Control
Working Boundary
Province Boundary
International Boundary
Flood Hazard Exposure (Health Facilities) (100 Year Return Period)
BHU
RHC
THQ
Zacha Bacha Center
Clinic
Line of Control
Working Boundary
Province Boundary
International Boundary
Flood Hazard Exposure (Educational Institutes) (100 Year Return Period)
Primary
Middle
Secondary
Higher Secondary
Madrisa
Line of Control
Working Boundary
Province Boundary
International Boundary

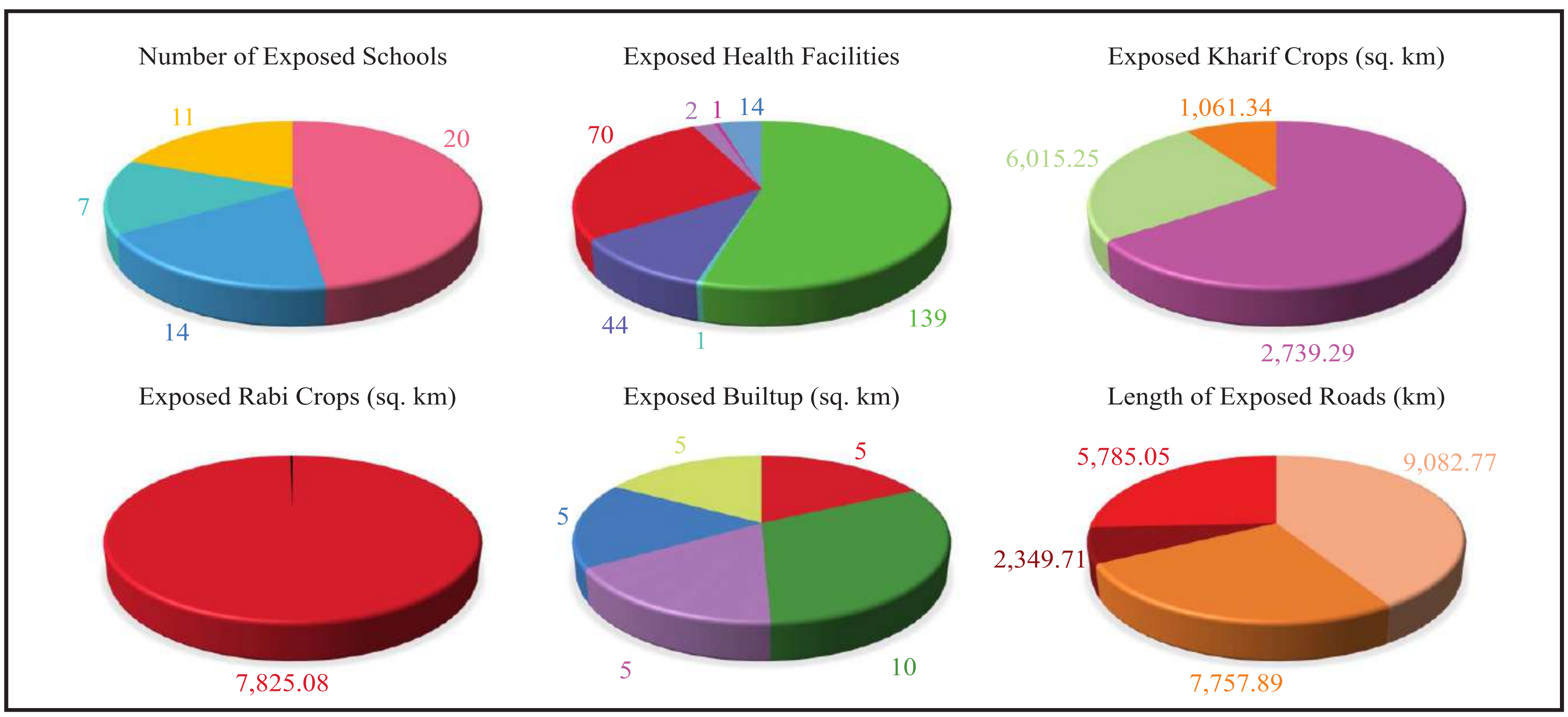
Floods - Sindh

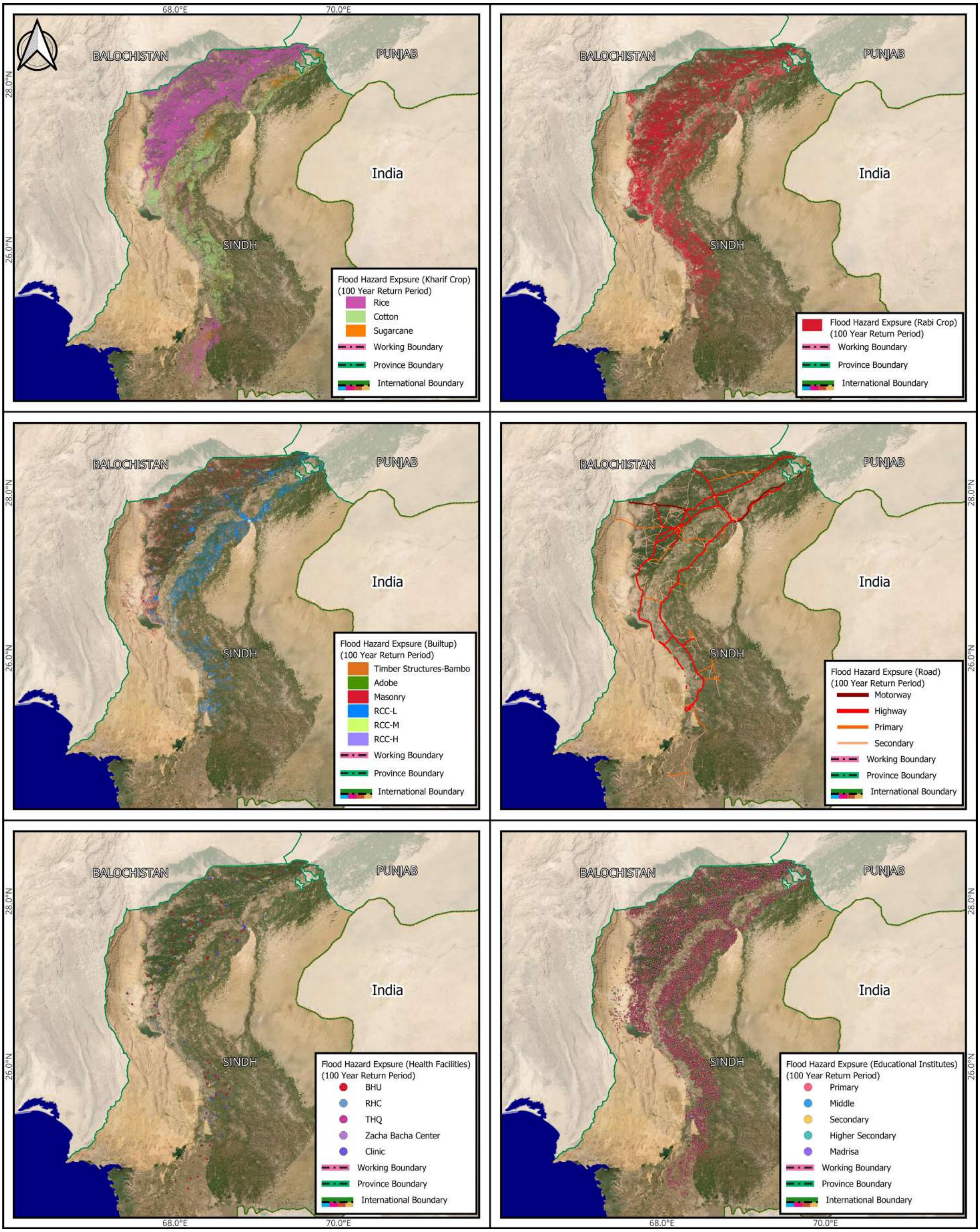
Sindh grapples with significant flooding challenges, particularly in areas surrounding the Indus River and its delta. Key sectors such as education, healthcare, agriculture, infrastructure, and transportation networks face considerable risks. Floods often result in extensive damage to schools, hospitals, Rabi and Kharif crops, urban settlements, and roads, creating disruptions and highlighting the need for enhanced flood protection measures.




Imagesource: pexels.com

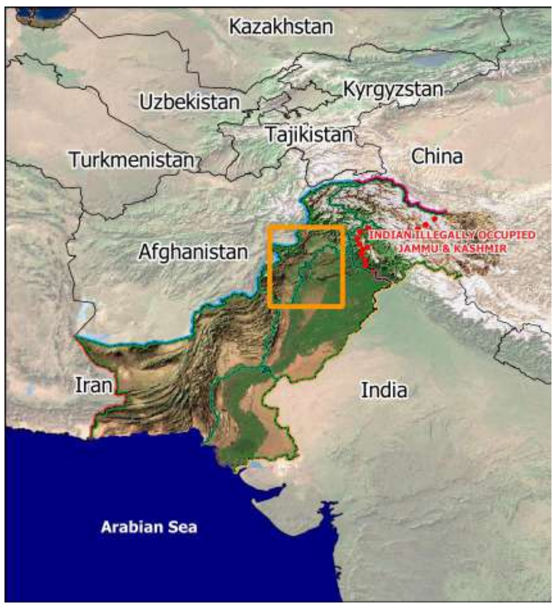
Potential Flood Exposure of Key Sectors (100 Year Return Period)

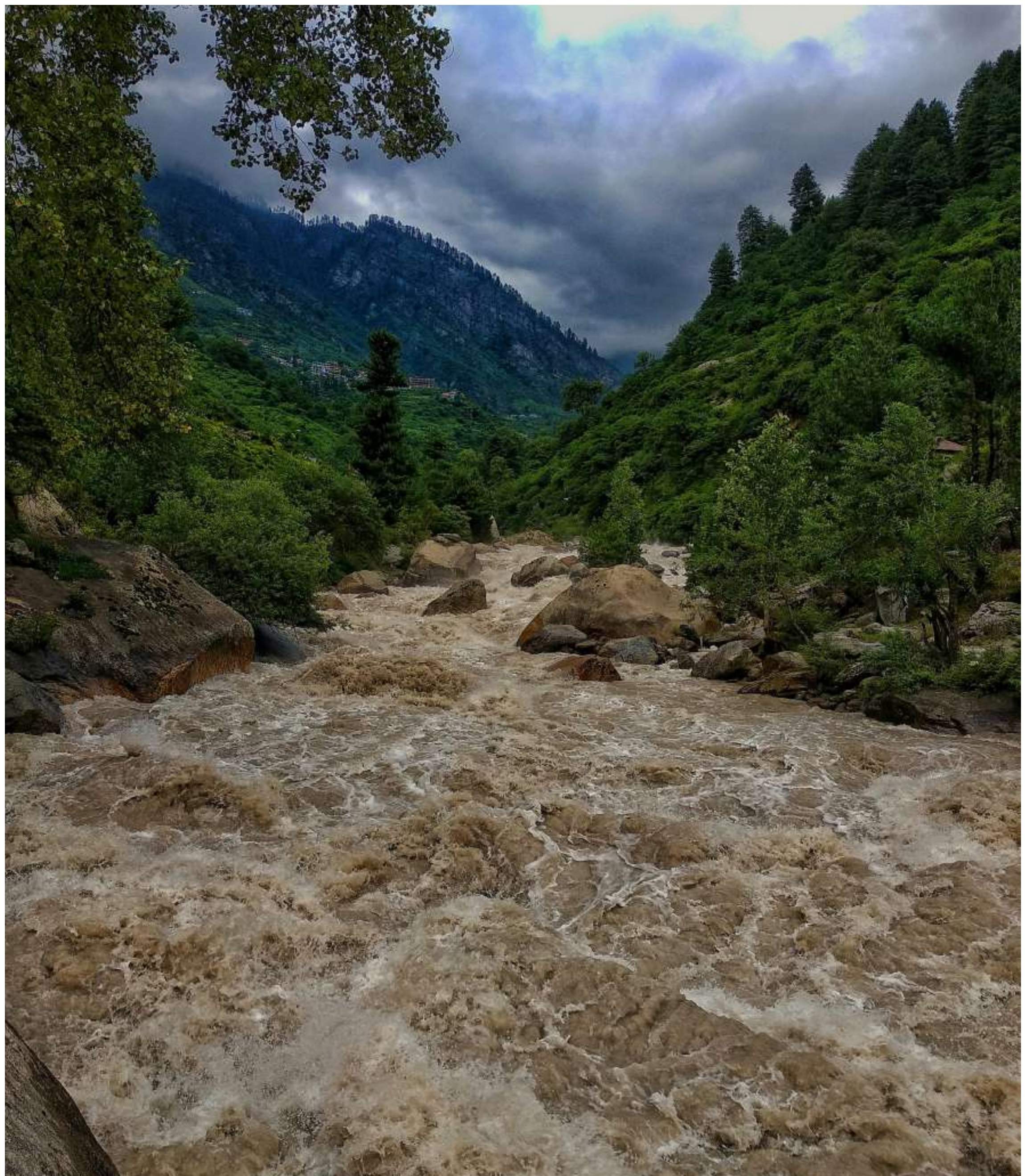



68.0°E
70.0°E
28.0°N
26.0°N
BALOCHISTAN
PUNJAB
India
SINDH
Flood Hazard Expsure (Kharif Crop)
(100 Year Return Period)
Rice
Cotton
Sugarcane
Working Boundary
Province Boundary
International Boundary
Flood Hazard Expsure (Rabi Crop)
(100 Year Return Period)
Flood Hazard Expsure (Builtup)
(100 Year Return Period)
Timber Structures-Bambo
Adobe
Masonry
RCC-L
RCC-M
RCC-H
Flood Hazard Expsure (Road)
(100 Year Return Period)
Motorway
Highway
Primary
Secondary
Flood Hazard Expsure (Health Facilities)
(100 Year Return Period)
BHU
RHC
THQ
Zacha Bacha Center
Clinic
Flood Hazard Expsure (Educational Institutes)
(100 Year Return Period)
Primary
Middle
Secondary
Higher Secondary
Madrisa

Floods - Khyber Pakhtunkhwa

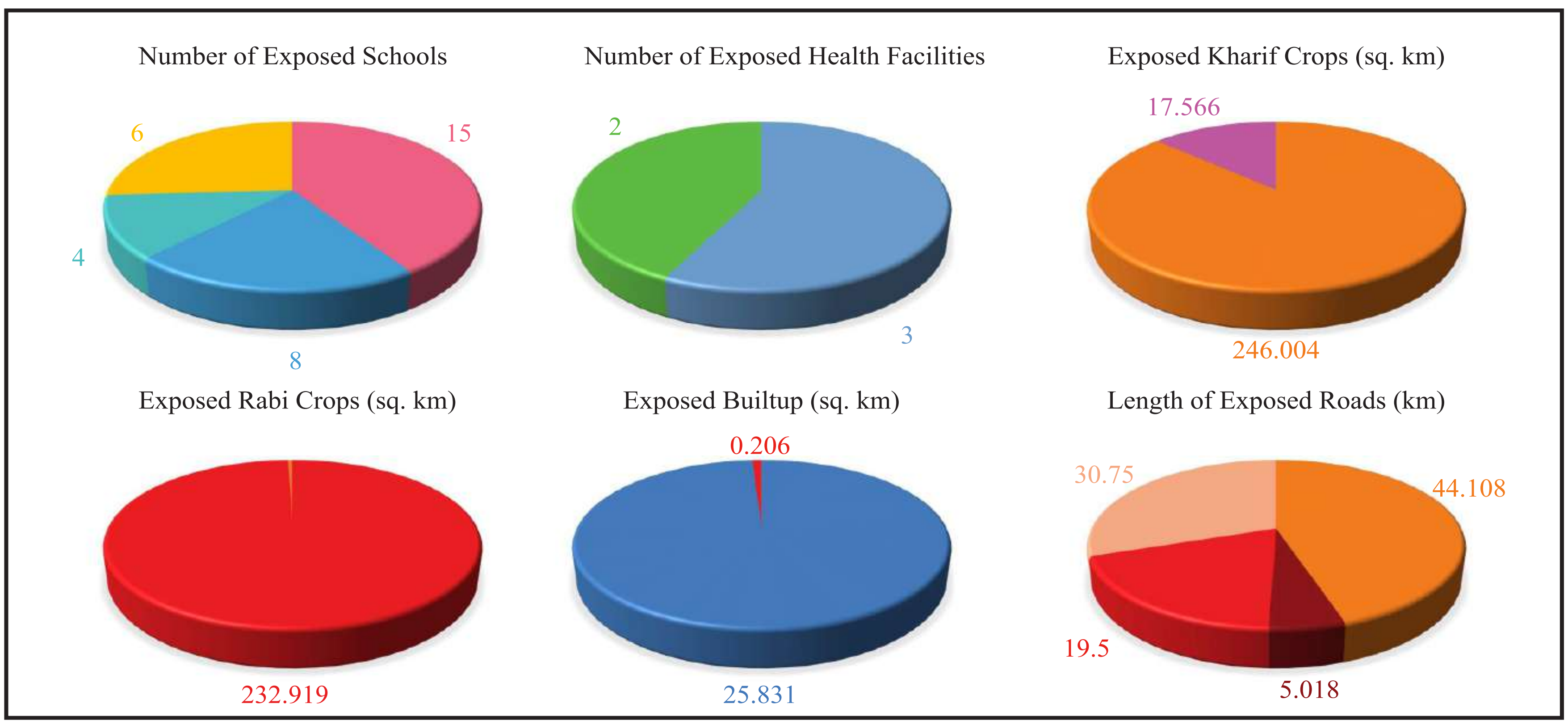
Khyber Pakhtunkhwa faces significant flooding challenges, with both rainfall and snowmelt contributing to the risks. These factors particularly affect areas along major rivers and mountainous regions prone to flash floods. Floods often result in extensive damage to schools, hospitals, Rabi and Kharif crops, urban settlements, and roads, causing widespread disruptions. The loss of infrastructure and agricultural productivity due to recurring floods places immense pressure on local economies and disaster recovery efforts.

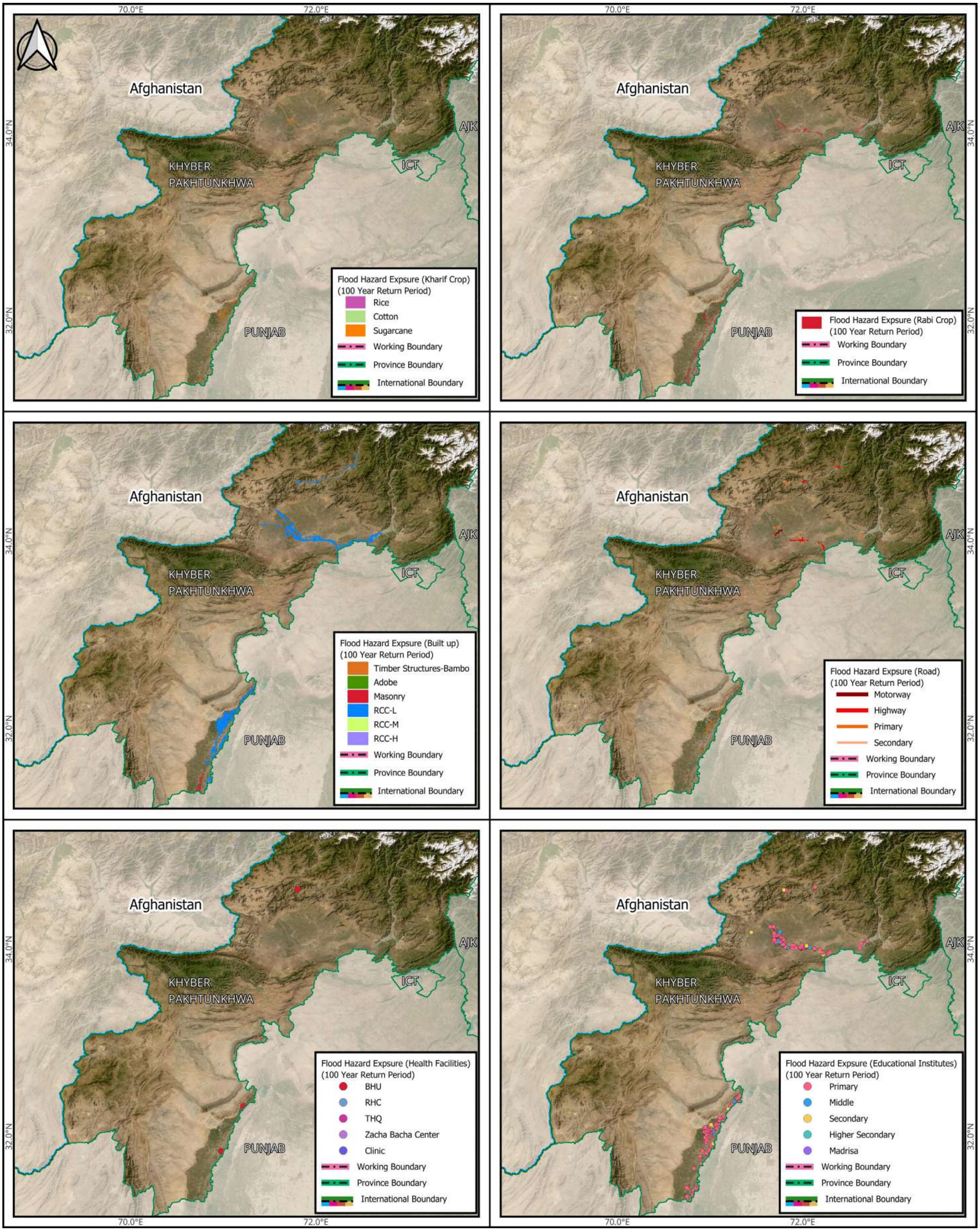




Imagesource: archdaily.com

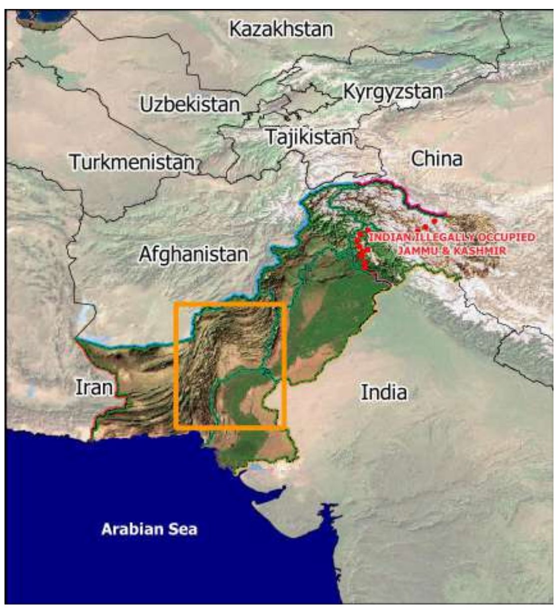
Potential Flood Exposure of Key Sectors (100 Year Return Period)




70.0°E
72.0°E
34.0°N
32.0°N
Afghanistan
KHYBER
PAKHTUNKHWA
PUNJAB
AJK
ICT
Flood Hazard Expsure (Kharif Crop)
(100 Year Return Period)
Rice
Cotton
Sugarcane
Working Boundary
Province Boundary
International Boundary
Flood Hazard Expsure (Rabi Crop)
(100 Year Return Period)
Working Boundary
Province Boundary
International Boundary
Flood Hazard Expsure (Built up)
(100 Year Return Period)
Timber Structures-Bambo
Adobe
Masonry
RCC-L
RCC-M
RCC-H
Working Boundary
Province Boundary
International Boundary
Flood Hazard Expsure (Road)
(100 Year Return Period)
Motorway
Highway
Primary
Secondary
Working Boundary
Province Boundary
International Boundary
Flood Hazard Expsure (Health Facilities)
(100 Year Return Period)
BHU
RHC
THQ
Zacha Bacha Center
Clinic
Working Boundary
Province Boundary
International Boundary
Flood Hazard Expsure (Educational Institutes)
(100 Year Return Period)
Primary
Middle
Secondary
Higher Secondary
Madrisa
Working Boundary
Province Boundary
International Boundary

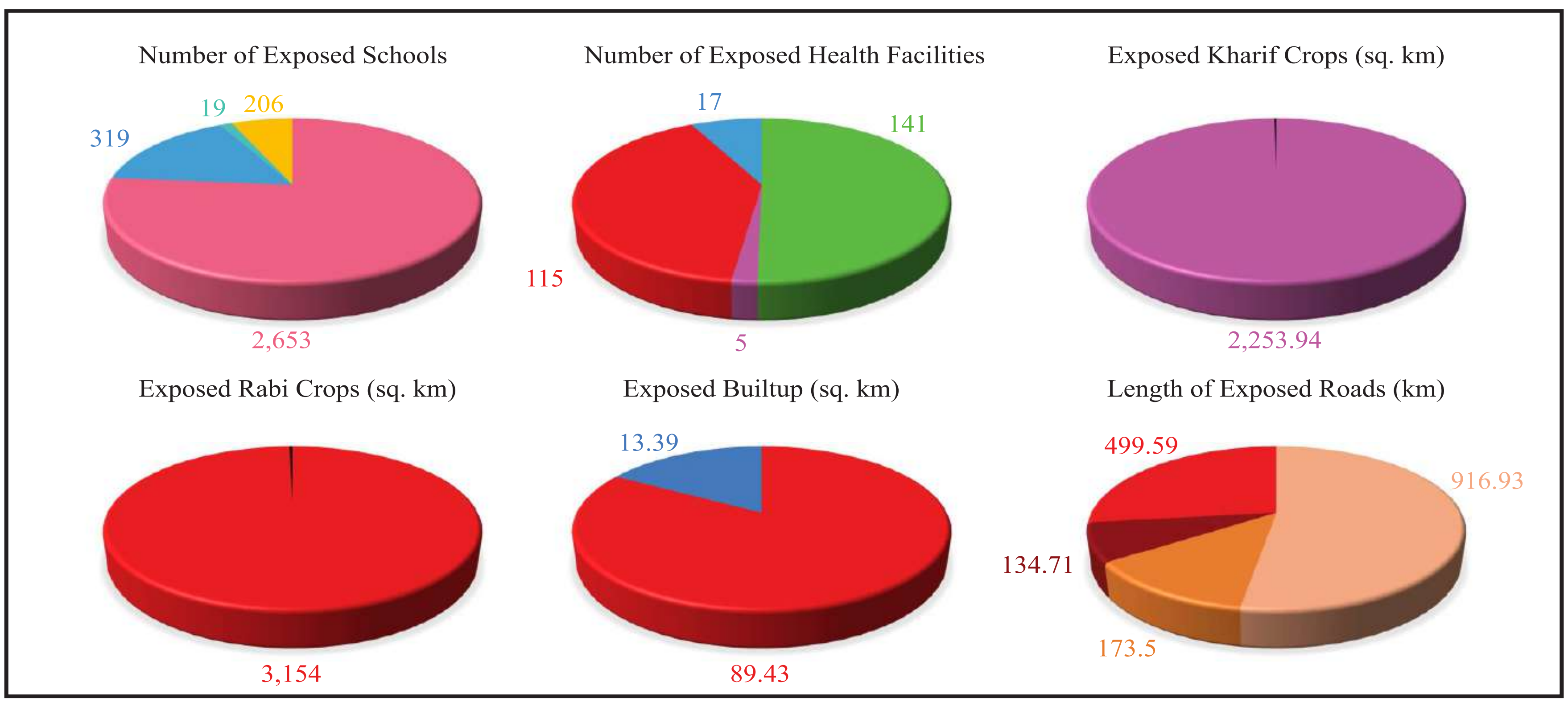
Floods - Balochistan

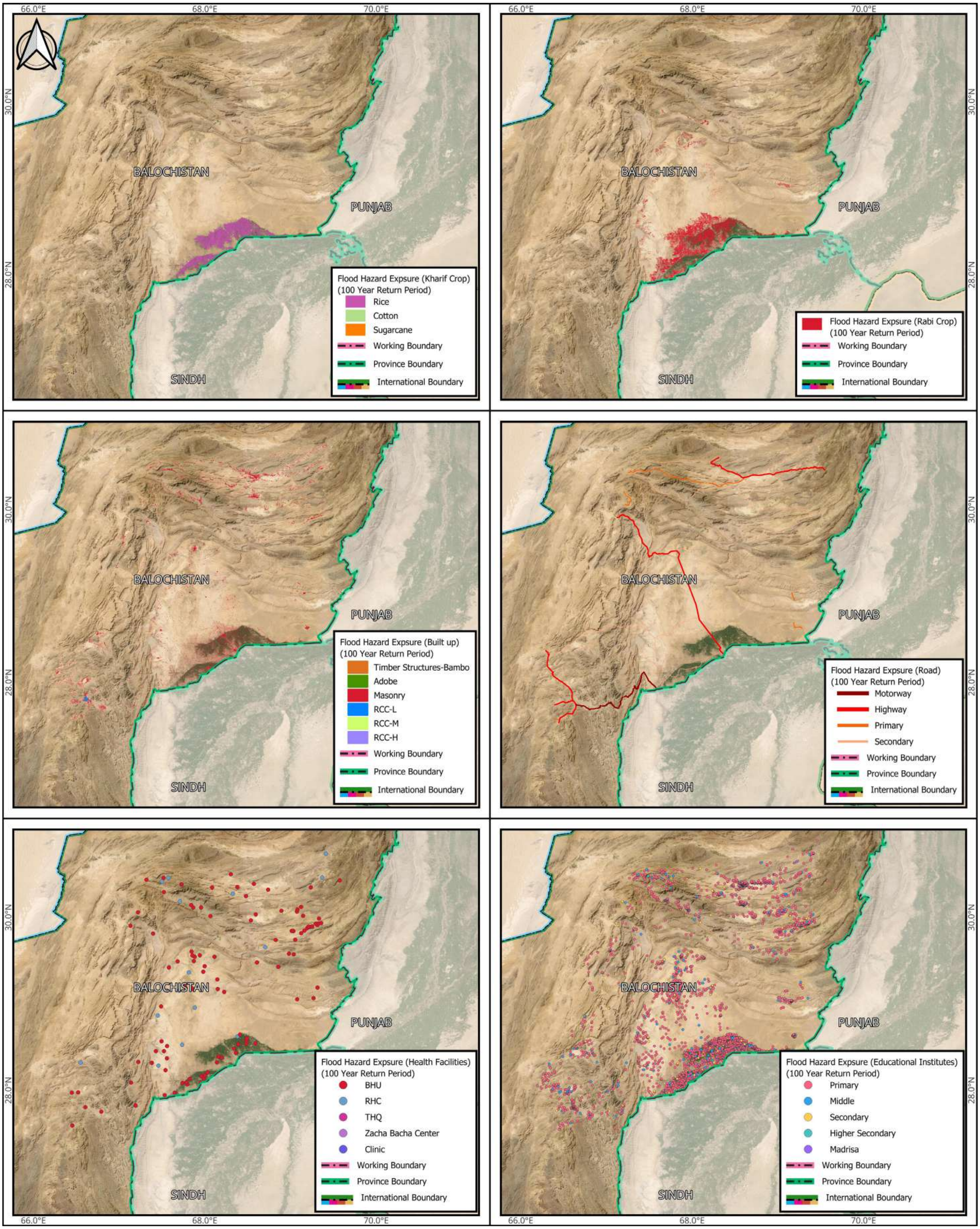
Balochistan faces significant flooding challenges, driven by rainfall, flash floods, and contributions from rivers like the Nari. The province's dry valleys and arid topography make it especially vulnerable to sudden water flows. Key sectors, including education, healthcare, agriculture, infrastructure, and roads, often suffer extensive damage and disruptions. The economic toll of floods highlights the need for comprehensive flood management, strengthened resilience measures, and advanced early warning systems to protect services, lives, and stability across the province.




Imagesource: pexels.com

Potential Flood Exposure of Key Sectors (100 Year Return Period)





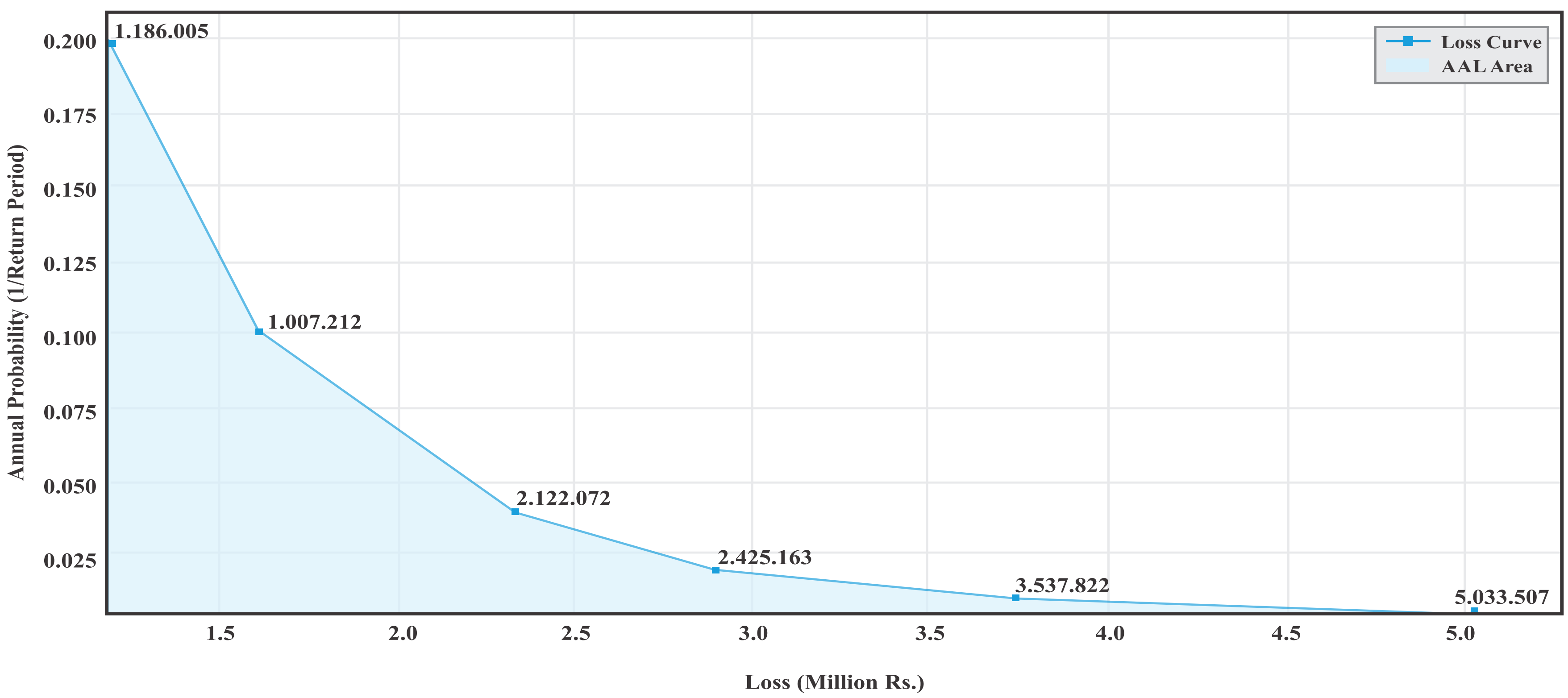
66.0°E
68.0°E
70.0°E
30.0°N
28.0°N
BALOCHISTAN
PUNJAB
SINDH
Flood Hazard Expsure (Kharif Crop)
(100 Year Return Period)
Rice
Cotton
Sugarcane
Working Boundary
Province Boundary
International Boundary
Flood Hazard Expsure (Rabi Crop)
(100 Year Return Period)
Flood Hazard Expsure (Built up)
(100 Year Return Period)
Timber Structures-Bambo
Adobe
Masonry
RCC-L
RCC-M
RCC-H
Flood Hazard Expsure (Road)
(100 Year Return Period)
Motorway
Highway
Primary
Secondary
Flood Hazard Expsure (Health Facilities)
(100 Year Return Period)
BHU
RHC
THQ
Zacha Bacha Center
Clinic
Flood Hazard Expsure (Educational Institutes)
(100 Year Return Period)
Primary
Middle
Secondary
Higher Secondary
Madrisa

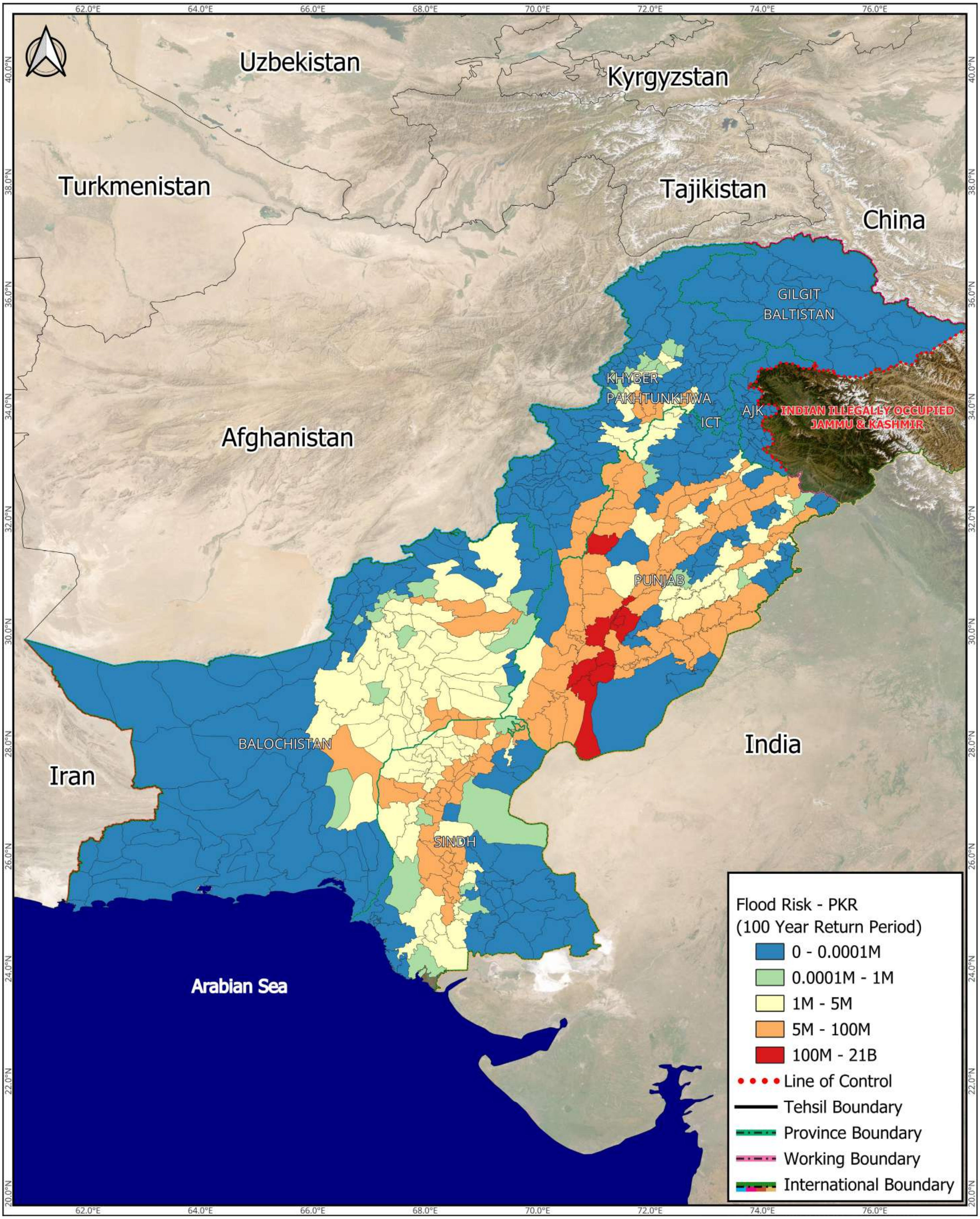
Floods

Flood risk in Pakistan, estimated to range from 0 to 21 billion PKR, is driven by frequent flooding, particularly along major rivers. Vulnerable populations, critical infrastructure, and agriculture are often severely affected, leading to displacement and economic losses. Inadequate drainage systems, encroachments, and limited early warning mechanisms exacerbate the risk. The recurring impact of floods also places a strain on government resources, making long term recovery and adaptation efforts increasingly challenging.

Imagesource: estonianworld.com

Average Annual Loss (AAL) - Floods




Uzbekistan
Kyrgyzstan
Turkmenistan
Tajikistan
China
GILGIT
BALTISTAN
KHYBER
PAKHTUNKHWA
ICT
AJK
INDIAN ILLEGALLY OCCUPIED
JAMMU & KASHMIR
Afghanistan
PUNJAB
BALOCHISTAN
India
Iran
SINDH
Arabian Sea
Flood Risk - PKR
(100 Year Return Period)
0 - 0.0001M
0.0001M - 1M
1M - 5M
5M - 100M
100M - 21B
Line of Control
Tehsil Boundary
Province Boundary
Working Boundary
International Boundary
62.0°E
64.0°E
66.0°E
68.0°E
70.0°E
72.0°E
74.0°E
76.0°E
40.0°N
38.0°N
36.0°N
34.0°N
32.0°N
30.0°N
28.0°N
26.0°N
24.0°N
22.0°N
20.0°N

Hydro-Meteorological Hazards - Urban Floods

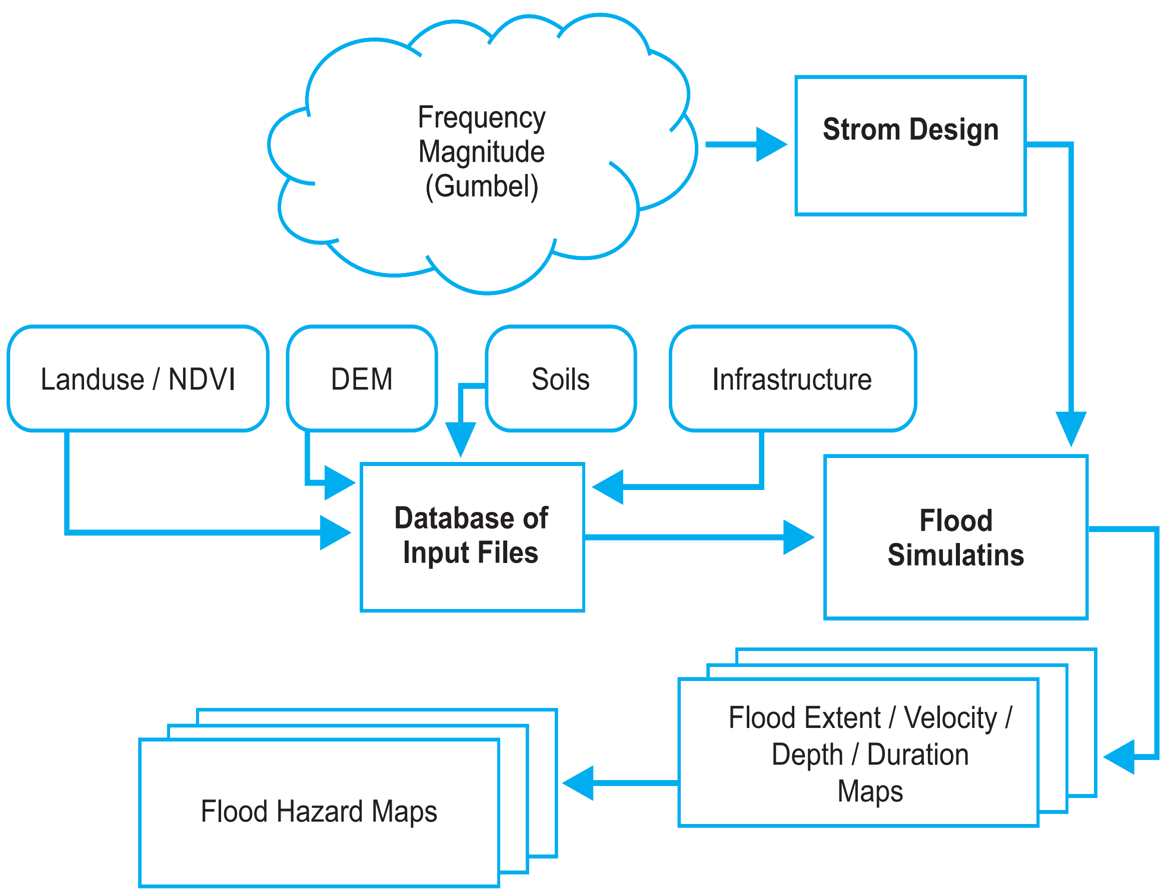
Urban floods are severe flooding events in cities caused by poor drainage, heavy rainfall, and blocked infrastructure. They are intensified by urbanization, which limits natural water infiltration and lead to rapid surface runoff, resulting in property damage, traffic disruptions, public health risks, and increased pressure on emergency response and urban planning systems. Urban flood modelling in conjunction with exposure evaluations of the affected buildings and population is a vital non-structural technique to effectively manage urban flood occurrences and their detrimental effects. It is also an essential step in mitigating and preventing disasters. The urban flood modeling is conducted for five major cities in Pakistan, i.e., Lahore, Peshawar, Karachi, and Quetta, as well as the federal capital Islamabad with its twin city Rawalpindi. Additionally, the Nari River basin was investigated for flash floods using the same modeling methodologies. Flood hazard maps were generated for different return periods, i.e., 5, 10, 25, 50, and 100 years.

OpenLISEM (Open-Source LImburg Soil Erosion Model)

OpenLISEM is a physically based spatially distributed, open source model originally developed to simulate soil erosion and surface runoff in rural areas. It has since been adapted for urban environments to simulate urban flooding, incorporating detailed terrain, rainfall, land use, soil data and infrastructure data for accurate, high-resolution hydrological and erosion modeling. OpenLISEM uses physical laws to simulate the movement of water, rather than relying solely on empirical data. This means it can simulate the hydrological processes at a detailed level, including rainfall, runoff, infiltration, and overland flow, allowing for more accurate predictions under varying environmental conditions and land surface characteristics.

Data Inputs

- Very High Resolution Digital Elevation/Surface Model data. The DSM is generated from very high resolution (0.3 meter) satellite based stereo imagery. The model is run using 5 meter DSM of Islamabad, Lahore, Peshawar, Karachi, and Quetta cities of Pakistan
- Sentinel-2 satellite data for Landuse/Landcover data extraction
- Recorded Rainfall Data for extracting maximum 24 hours rainfall probability
- Soil information is downloaded from https://Soilgrids.org (ISRIC Wageningen). The LISEMDBase generator automatically downloads the data, often derived from field measurements or satellite imagery.



- Buidings, roads, rivers and drainage channels

Model Calibration and Validation

Calibrating an urban flood model involves adjusting parameters to align simulation results with observed data, For this study, satellite data from an equivalent flood event is used to extract the flood extent for comparison with the model results and calibration/ validation process. Infiltration and interception maps, influenced by hydraulic conductivity and soil water content, are tuned to impact simulated surface runoff. OpenLISEM's calibration tab adjusts map values: those above 1 increase the parameter, while those below 1 decrease it

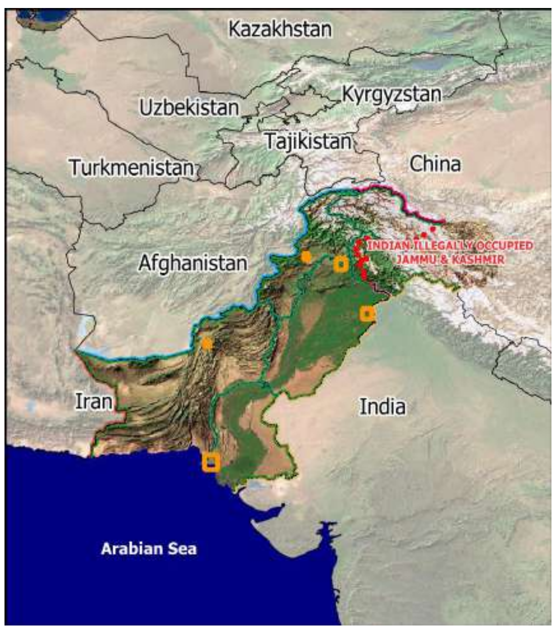
Model Output

The model output consists of the maximum flood depths during the respective rainfall events, the maximum water flow velocity, and duration of the flood in minutes (the time since the start of the rainfall when a pixel is first inundated).

Imagesource:unsplash.com

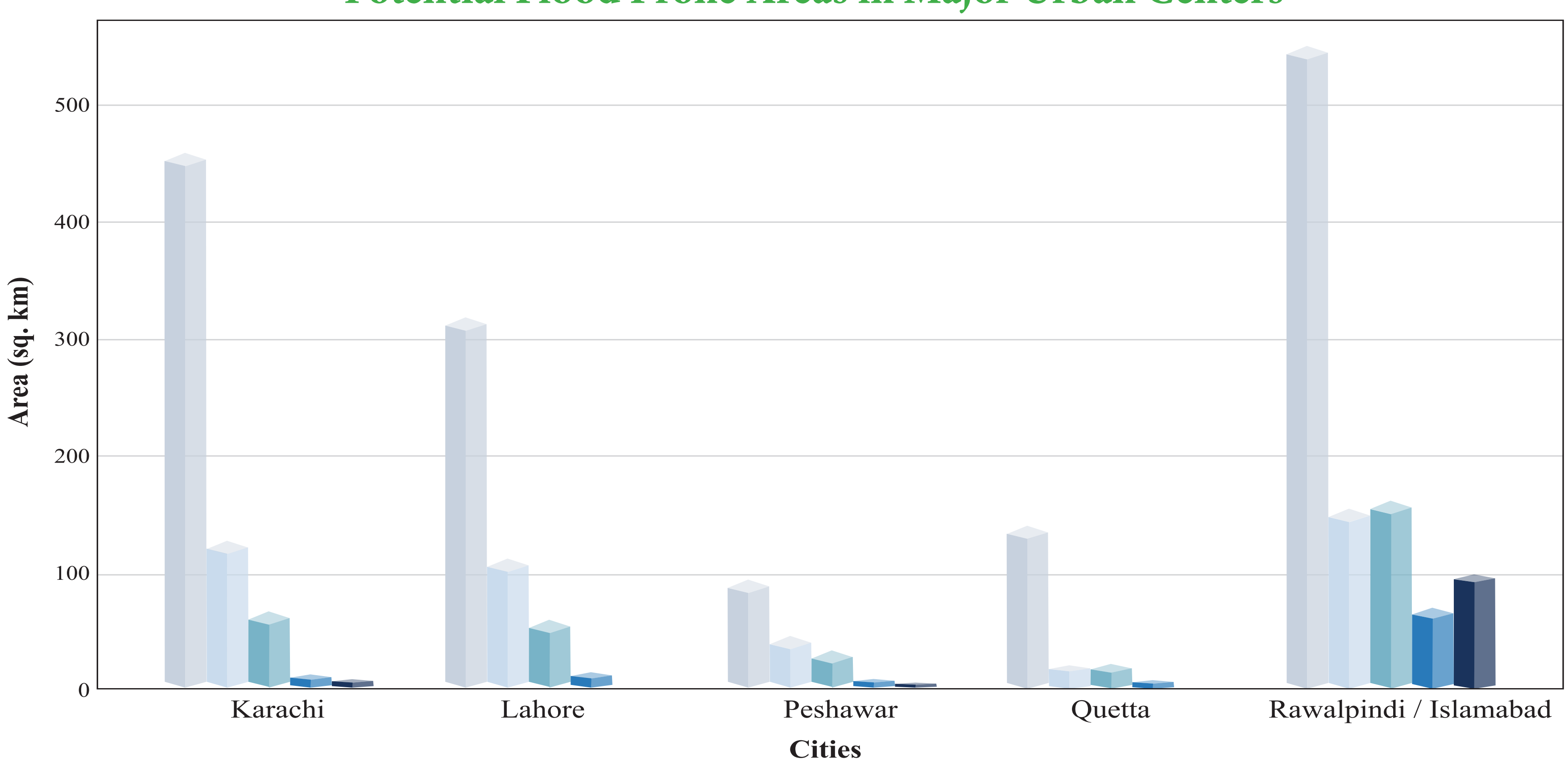
Urban Floods

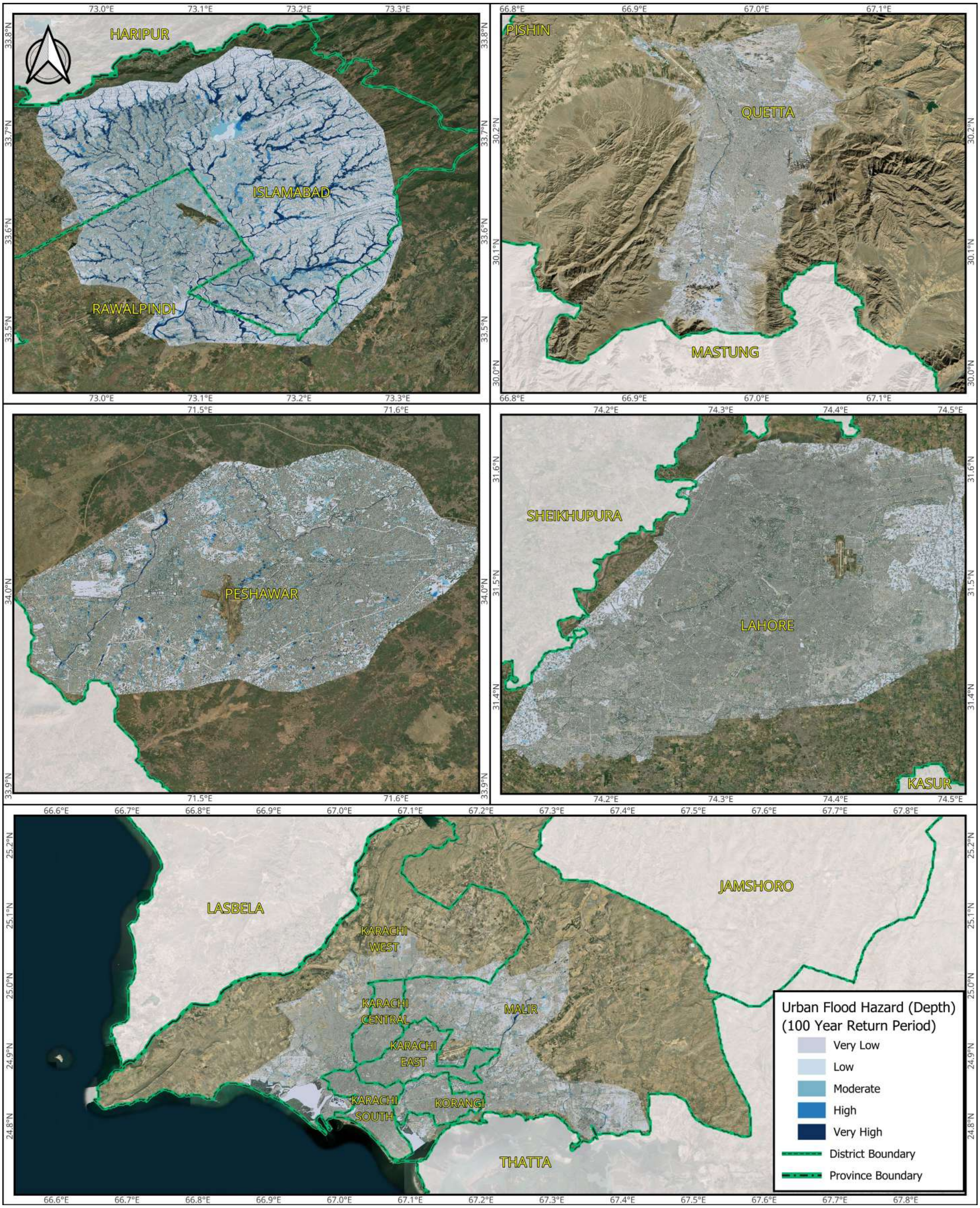
Urban flooding in Islamabad, Lahore, Karachi, Quetta, Rawalpindi, and Peshawar is driven by rapid urbanization, inadequate drainage systems, and frequent heavy rainfall. Flood modeling has been carried out for these cities, with hazard maps created for return periods of 5, 10, 25, 50, and 100 years, detailing flood depth, velocity, and duration. These models help pinpoint flood prone areas, water flow paths, and vulnerabilities, offering essential data for improving flood risk management, urban planning, and infrastructure development.



Imagesource: Pak River Updates

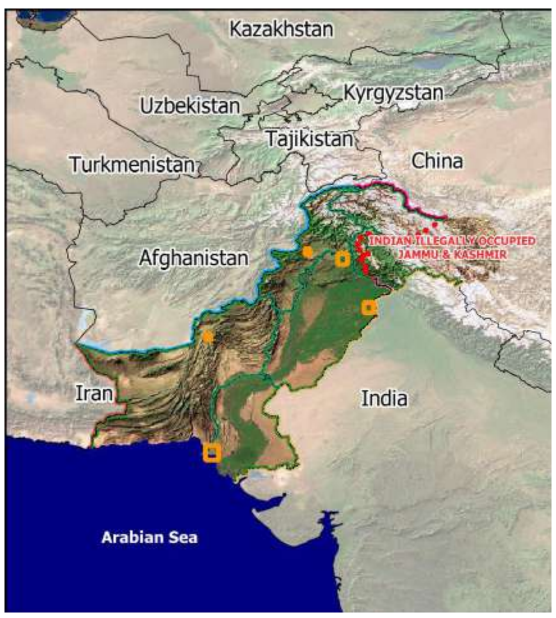
Potential Flood Prone Areas in Major Urban Centers




HARIPUR
ISLAMABAD
RAWALPINDI
PISHIN
QUETTA
MASTUNG
PESHAWAR
SHEIKHUPURA
LAHORE
KASUR
LASBELA
JAMSHORO
KARACHI WEST
KARACHI CENTRAL
MALIR
KARACHI EAST
KARACHI SOUTH
KORANGI
THATTA
Urban Flood Hazard (Depth)
(100 Year Return Period)
Very Low
Low
Moderate
High
Very High
District Boundary
Province Boundary

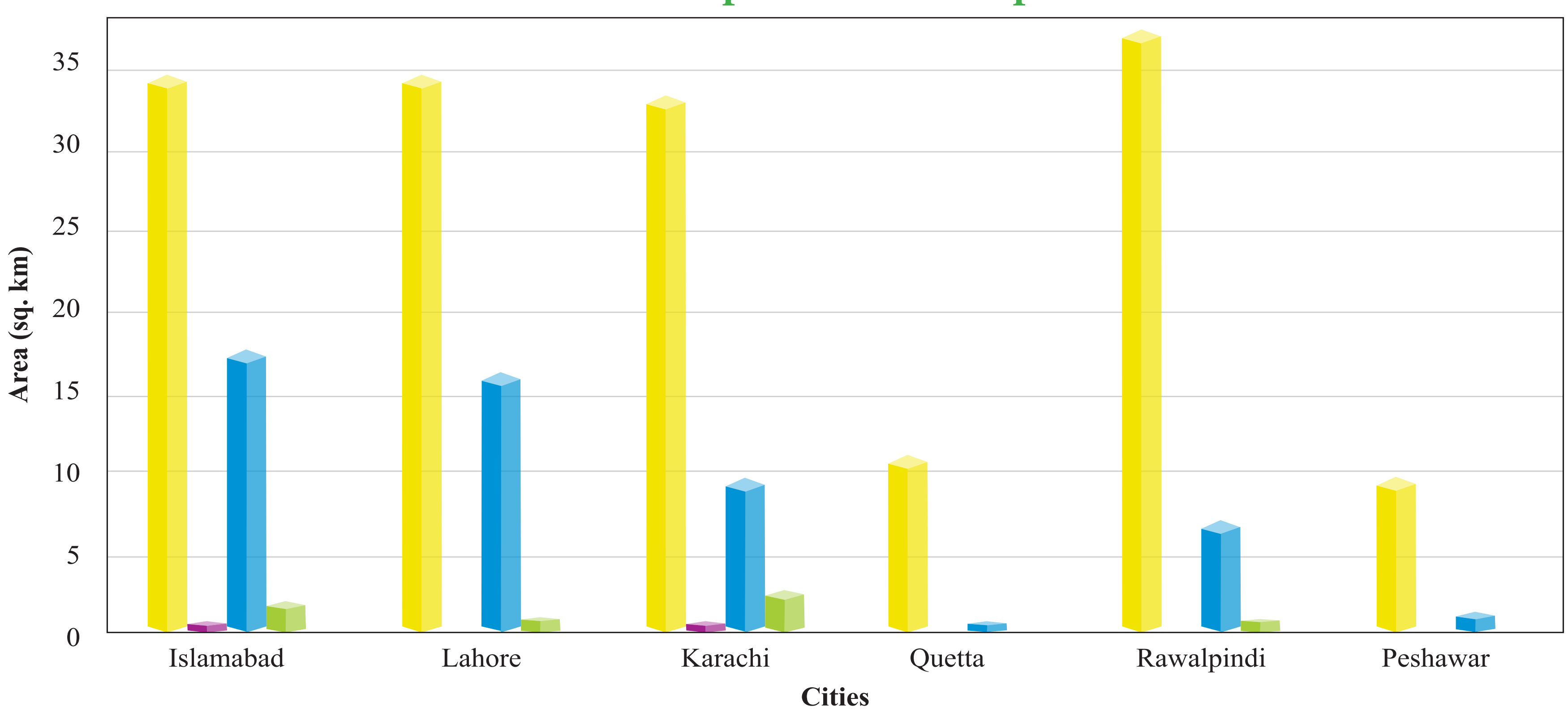
Urban Floods - Builtup

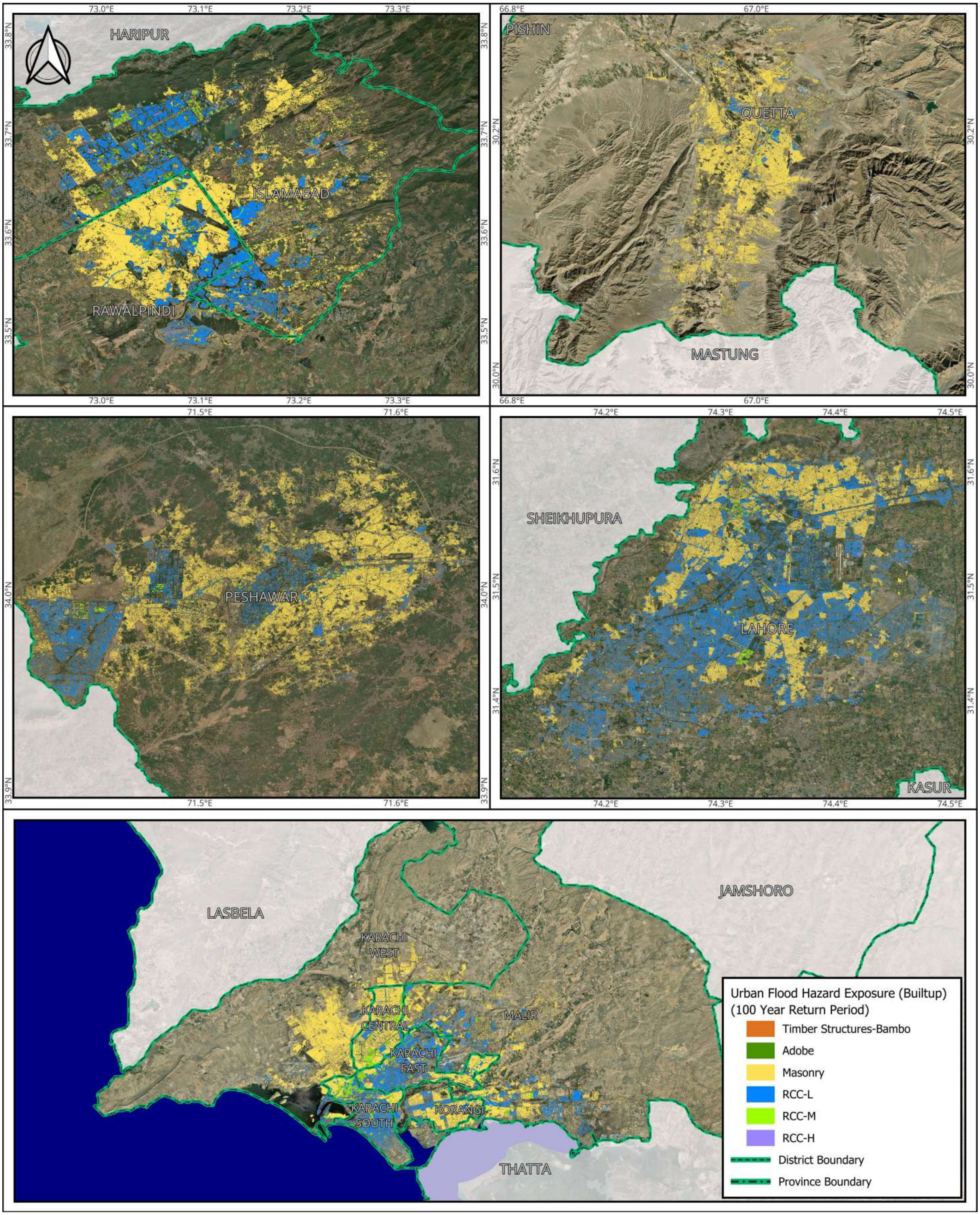
Urban flood exposure in Pakistan, particularly in cities like Lahore, Peshawar, Karachi, Quetta, Islamabad, and Rawalpindi, is assessed using hazard maps for return periods of 5, 10, 25, 50, and 100 years. Rapid urban development, poor urban planning, and inadequate drainage systems have significantly increased the exposure of builtup areas to flooding. Through detailed flood modeling, critical builtup zones prone to high flood risk are identified. This data guides proactive flood risk management, infrastructure upgrades, and resilient urban planning strategies to minimize the impacts of future flooding events.




Imagesource:aljazeera.com

Potential Exposure of Builtup

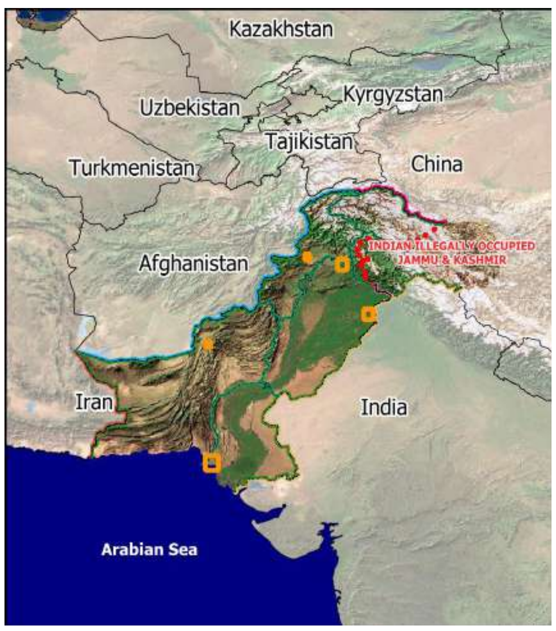



HARIPUR
ISLAMABAD
RAWALPINDI
73.0°E
73.1°E
73.2°E
73.3°E
33.8°N
33.7°N
33.6°N
33.5°N
PISHIN
QUETTA
MASTUNG
66.8°E
67.0°E
30.2°N
30.0°N
PESHAWAR
71.5°E
71.6°E
34.0°N
33.9°N
SHEIKHUPURA
LAHORE
KASUR
74.2°E
74.3°E
74.4°E
74.5°E
31.6°N
31.5°N
31.4°N
LASBELA
JAMSHORO
KARACHI WEST
KARACHI CENTRAL
MALIR
KARACHI EAST
KARACHI SOUTH
KORANGI
THATTA
Urban Flood Hazard Exposure (Builtup)
(100 Year Return Period)
Timber Structures-Bambo
Adobe
Masonry
RCC-L
RCC-M
RCC-H
District Boundary
Province Boundary

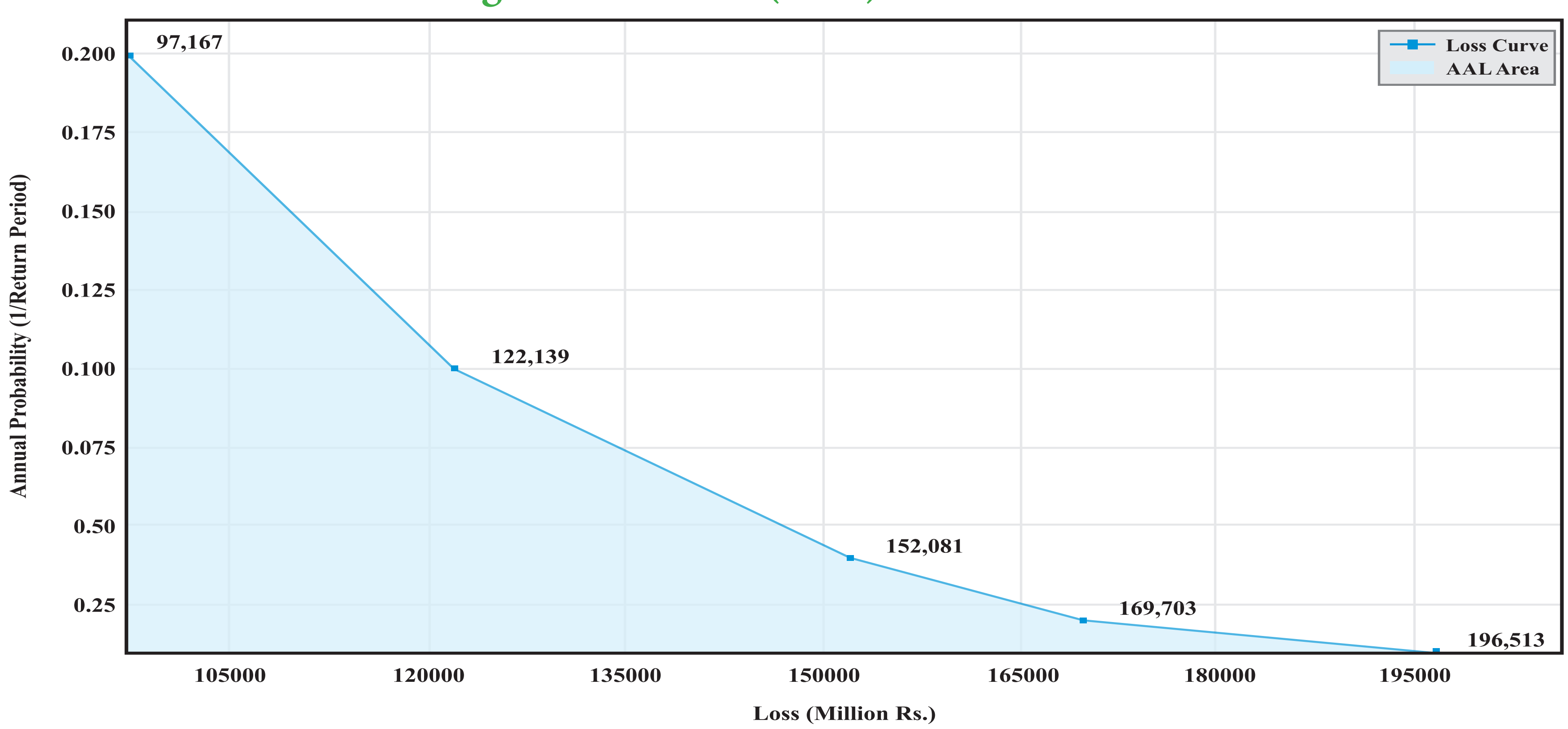
Urban Floods

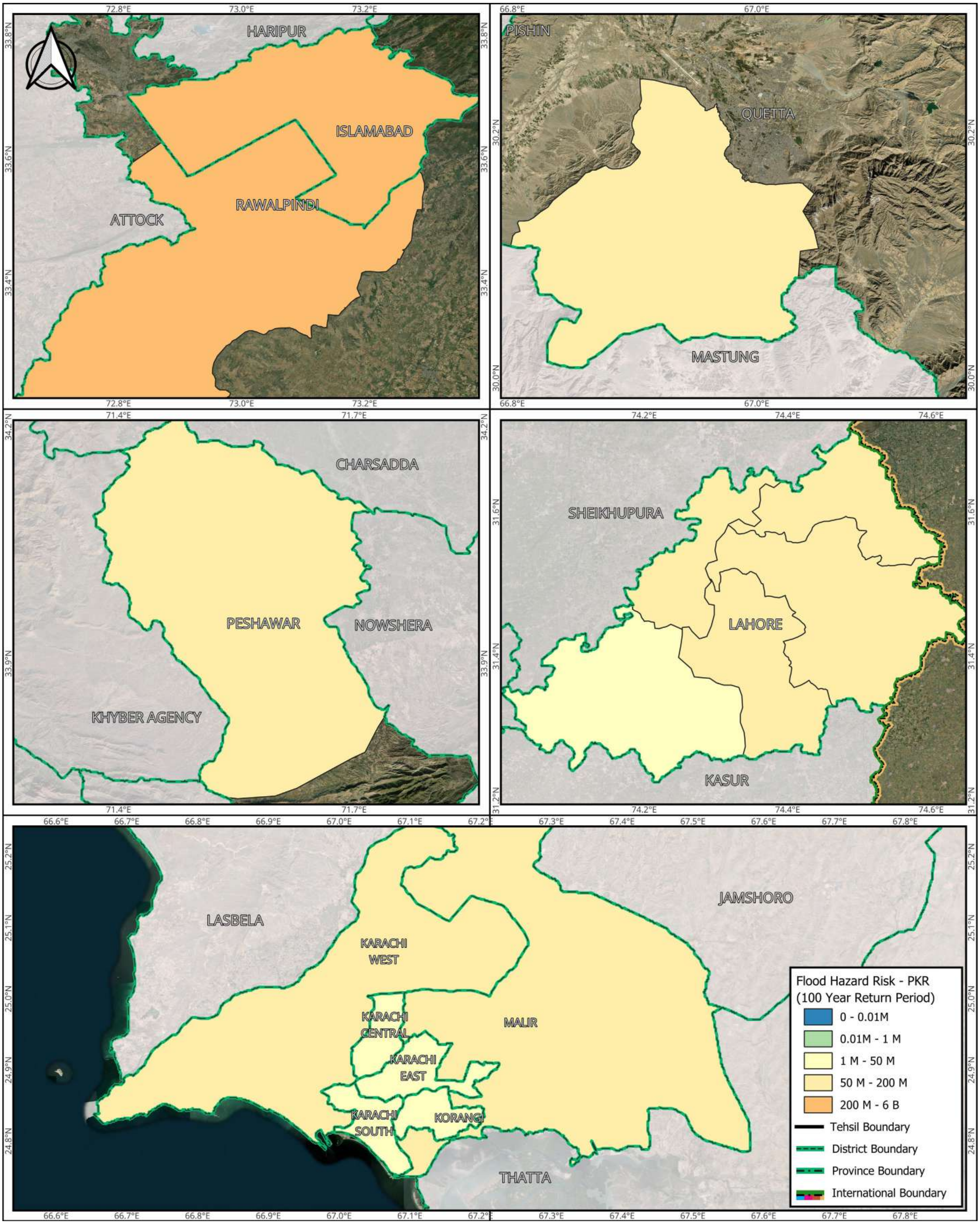
Urban flood risk maps, created using hazard, exposure, and vulnerability maps, identify high risk hotspots and guide flood management. Risks range from low (0 - 0.01 Million) to extreme (300 Millions - 6 Billions), especially in areas with poor planning and encroachment on natural drainage. These maps highlight the need for community awareness, collaborative efforts, and effective policy enforcement to reduce flood risks and protect vulnerable populations, helping prioritize flood resilience in urban policies.

Imagesource: unsplash.com



Average Annual Loss (AAL) - Urban Floods




HARIPUR
ISLAMABAD
RAWALPINDI
ATTOCK
PISHIN
QUETTA
MASTUNG
CHARSADDA
PESHAWAR
NOWSHERA
KHYBER AGENCY
SHEIKHUPURA
LAHORE
KASUR
LASBELA
JAMSHORO
KARACHI WEST
KARACHI CENTRAL
KARACHI EAST
MALIR
KARACHI SOUTH
KORANGI
THATTA
Flood Hazard Risk - PKR
(100 Year Return Period)
0 - 0.01M
0.01M - 1 M
1 M - 50 M
50 M - 200 M
200 M - 6 B
Tehsil Boundary
District Boundary
Province Boundary
International Boundary

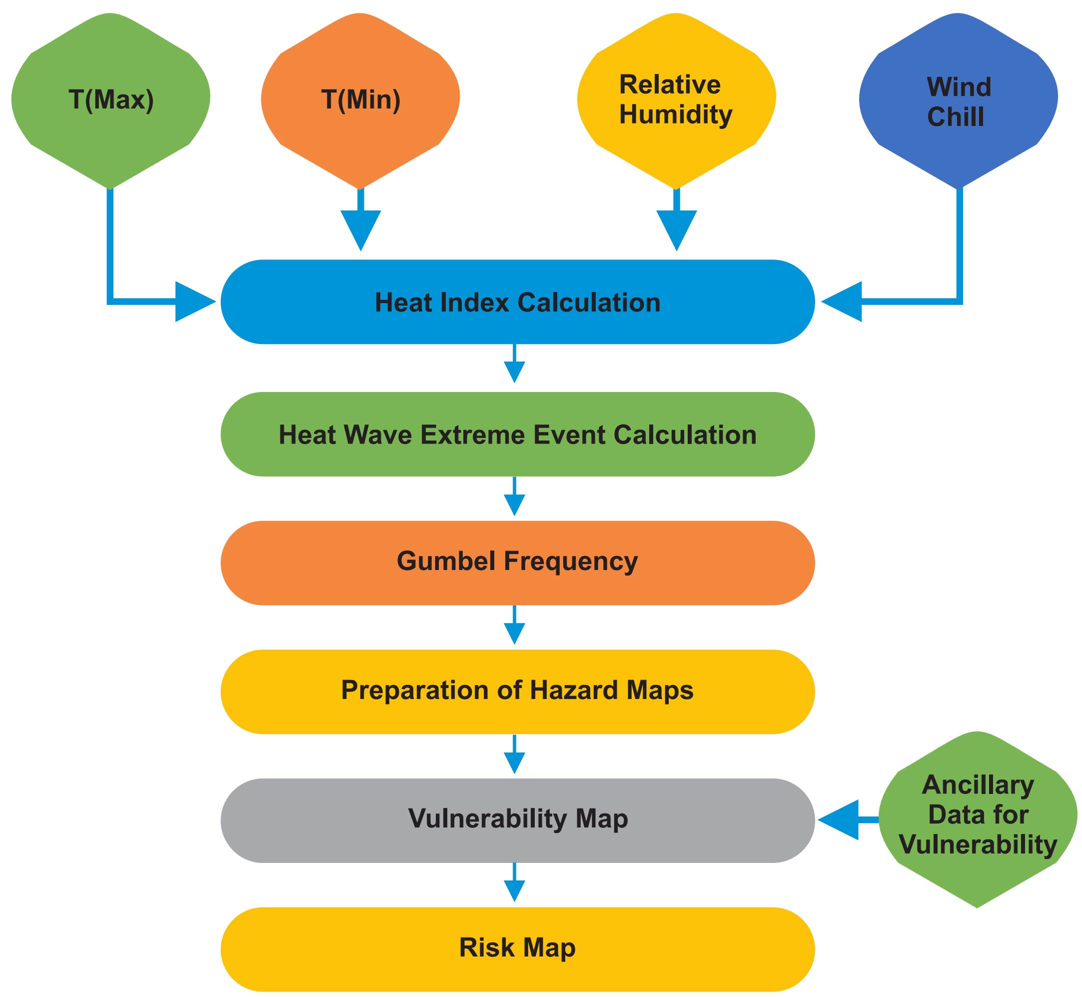
Hydro-Meteorological Hazards - Heatwave

Heatwaves have become a growing environmental concern, and at the time when the study was conducted there was a lack of specific guidelines for developing heatwave return period models in Pakistan, as highlighted by the National Disaster Management Authority (NDMA). To address this gap, the World Health Organization's (WHO) guidelines were utilized to assess heatwave risks. These guidelines provided global parameters for risk assessment, facilitating the creation of heatwave hazard maps. The maps were generated by using a global heatwave index model, which allows for the estimation of heatwave return periods. These return periods were analyzed for multiple timeframes: 5, 10, 25, 50, 100, 250, and 500 years. This approach helps in understanding the long-term frequency and intensity of heatwaves in different regions.

EClimMOD Model

The World Health Organization (WHO) study was applied to three continents, including Asia, and was published as a package for WHO EClimMOD V1.0. The WHO EClimMOD V1.0 is a valuable tool for conducting comprehensive heatwave studies, enabling researchers and policymakers to estimate the health impacts of future heatwaves and evaluate the effectiveness of adaptation strategies. The Heat Index Method (adopted in this study) for heatwave studies provides a more comprehensive understanding of heatwaves by combining temperature and humidity. By calculating the Heat Index, identifying heatwave events based on thresholds, and assessing impacts, this method allows for a better evaluation of heat stress on human health and other sectors.

This approach is particularly valuable in regions with high humidity, as it takes into account the heat index, which combines air temperature and humidity to provide a more accurate representation of perceived temperature. In such areas, the actual discomfort and health risks can be much greater than what air temperatures alone indicate. By incorporating this factor, the heatwave hazard maps offer a more comprehensive risk assessment for these regions. This is vital to help communities and infrastructure withstand extreme heat, including heat stress and related illnesses, especially dangerous in humid climates.



By improving the model's ability to predict heatwave impacts on vulnerable populations, it provides critical insights to support more effective adaptation and resilience strategies.

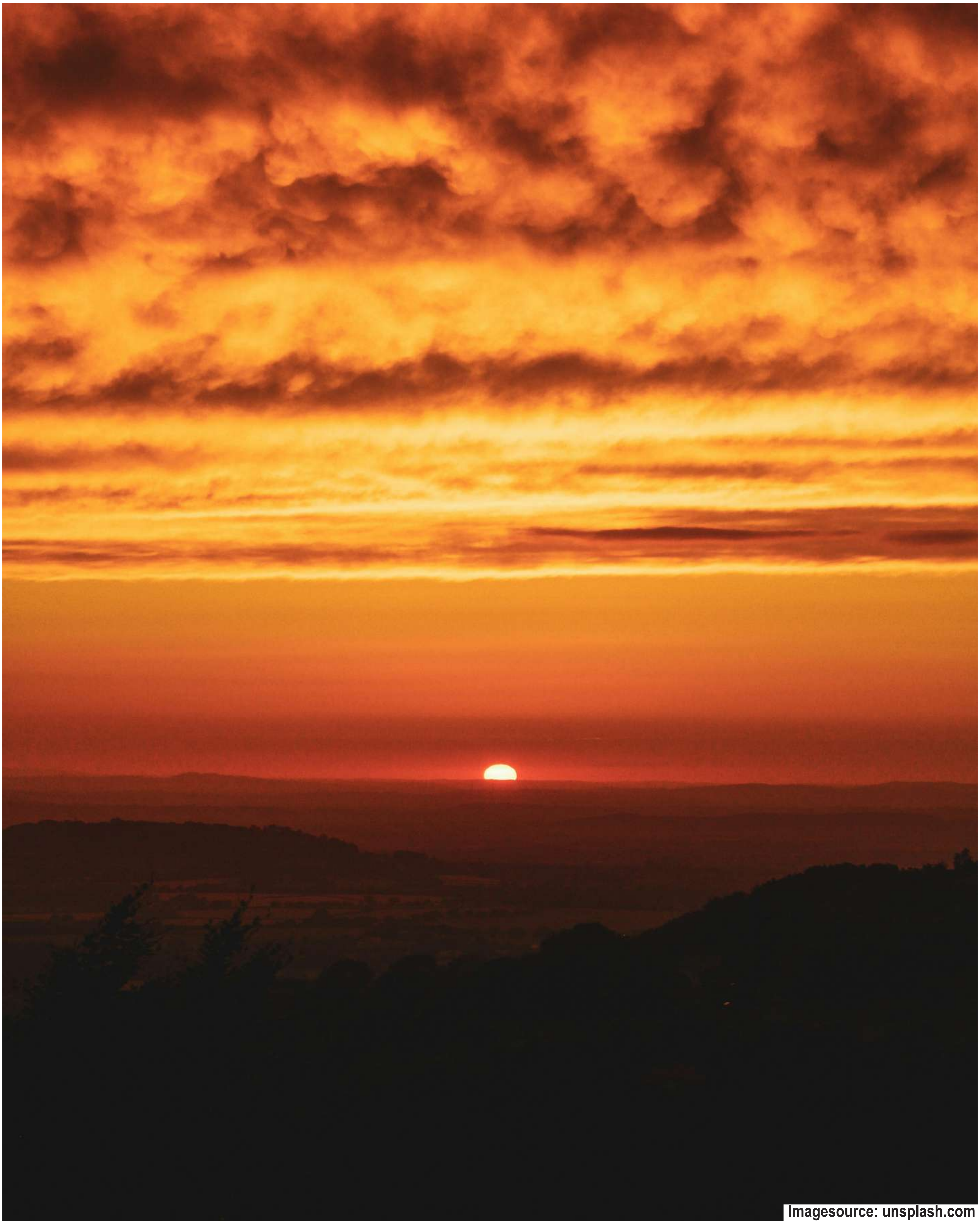
Data Inputs

The analysis used the following data layers as input:

- Maximum and minimum temperature: Monitoring these helps identify heatwave intensity and duration especially when high night temperatures offer no relief
- Humidity data: High humidity worsens heat stress, making heatwaves more dangerous by hindering the body's cooling mechanism
- Satellite imagery and modelled data: Provides land surface temperature and urban heat island data crucial for heatwave mapping and analysis

Model Output

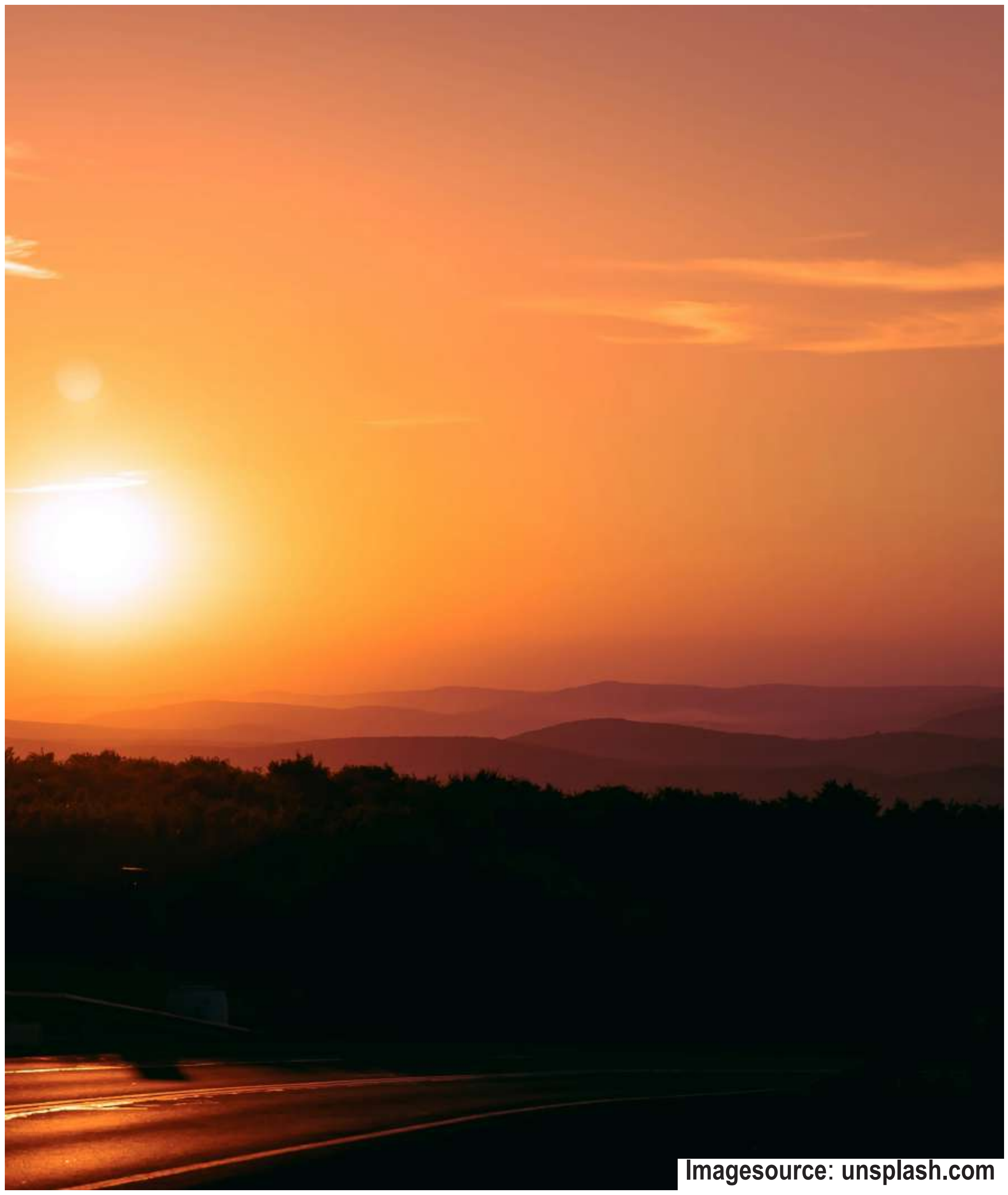
The model outputs include heatwave hazard maps and return period estimations (5 to 500 years), highlighting the frequency and intensity of heatwaves across regions. These outputs support risk assessment and adaptation planning.



Imagesource: unsplash.com

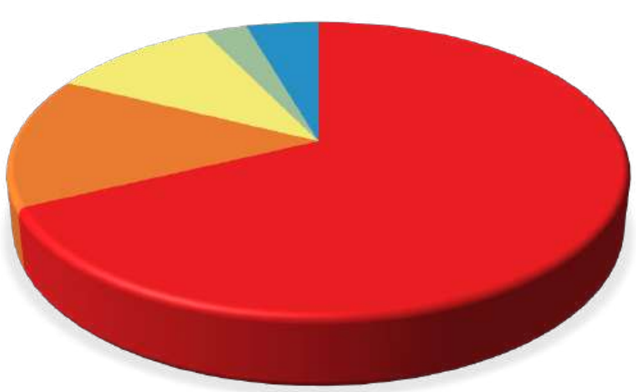
Heatwave

Heatwaves are an intensifying hazard in Pakistan, posing risks to public health, agriculture, and infrastructure. Following WHO guidelines, heatwave hazard maps were developed to estimate return periods of 5, 10, 25, 50, 100, 250, and 500 years. The maps were developed using a global heatwave index model, these maps offer critical insights into the severity and frequency of heatwaves, empowering authorities to enhance preparedness and implement targeted mitigation strategies. By incorporating detailed meteorological data, the model ensures higher accuracy.



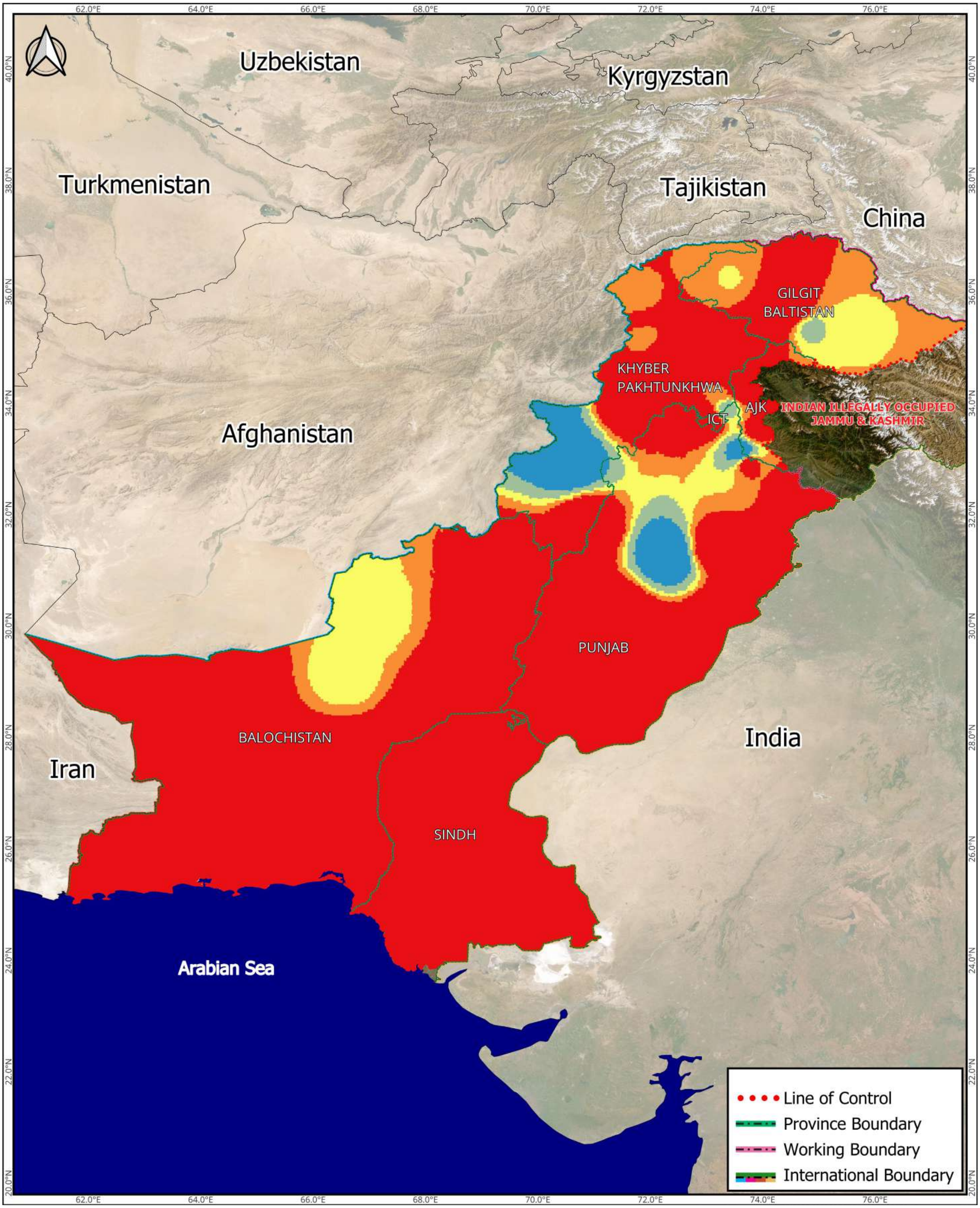
Imagesource: unsplash.com

Heat Intensity (%)



Heat Intensity Classes

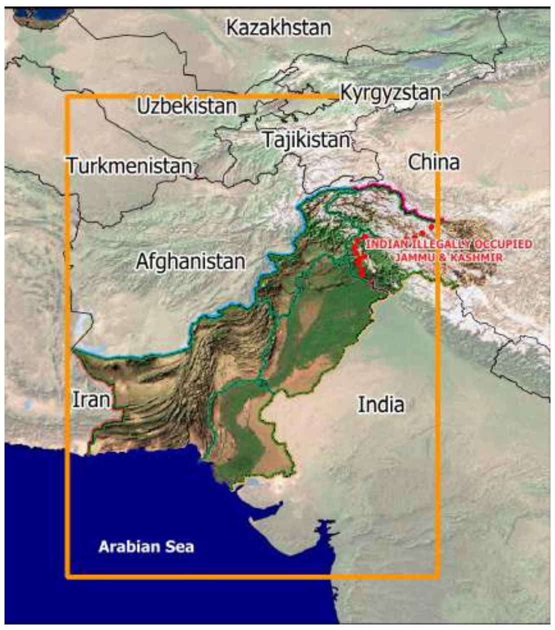
Severity Class	Area (sq. km)	Percentage
Low	41,369	3.59
Medium	24,608	2.14
High	103,426	8.98
Severe	117,253	10.23
Extreme	889,461	74.06

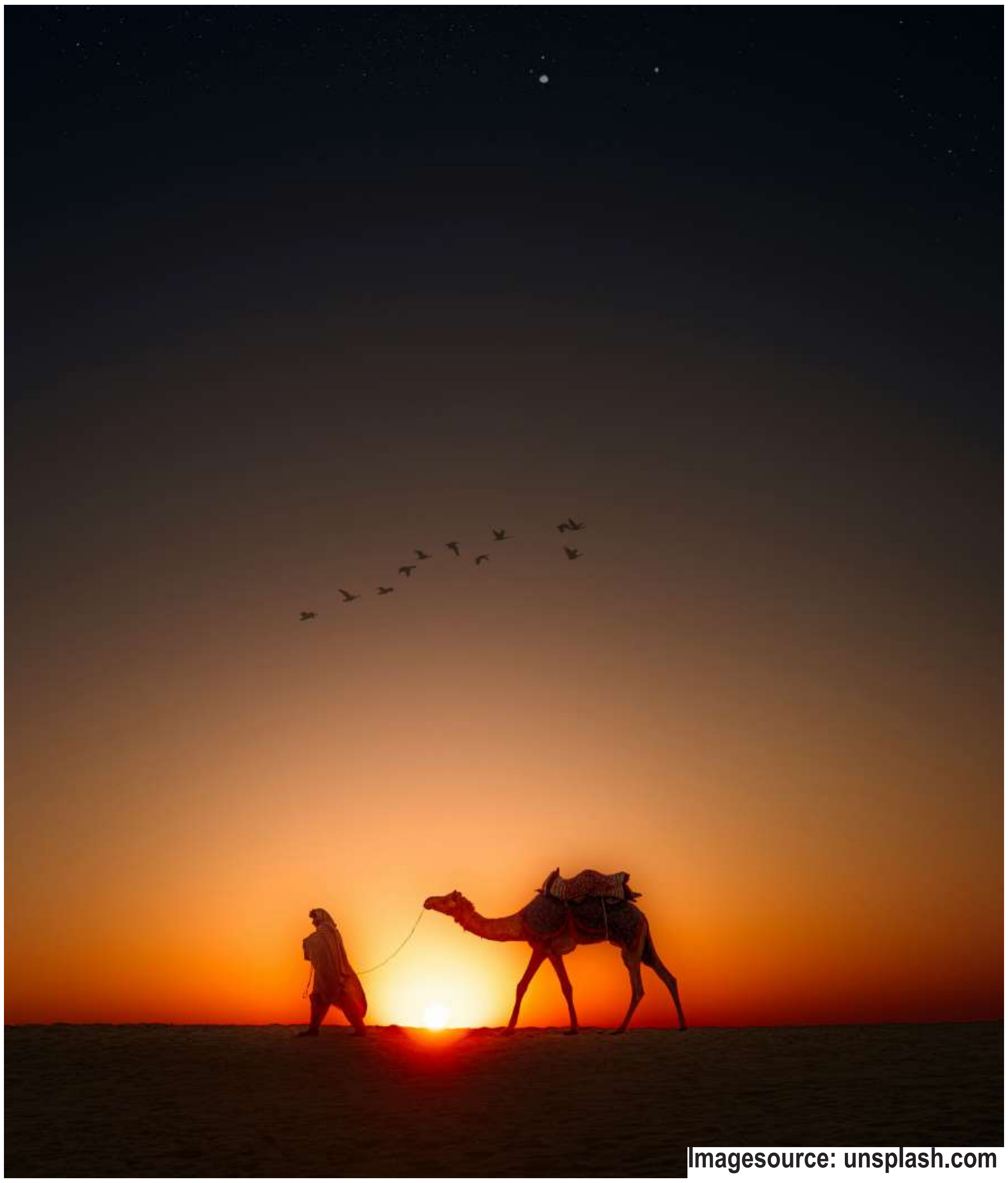


Uzbekistan
Kyrgyzstan
Turkmenistan
Tajikistan
China
Afghanistan
GILGIT BALTISTAN
KHYBER PAKHTUNKHWA
ICT
AJK
INDIAN ILLEGALLY OCCUPIED JAMMU & KASHMIR
PUNJAB
BALOCHISTAN
India
Iran
SINDH
Arabian Sea
Line of Control
Province Boundary
Working Boundary
International Boundary

Heatwave

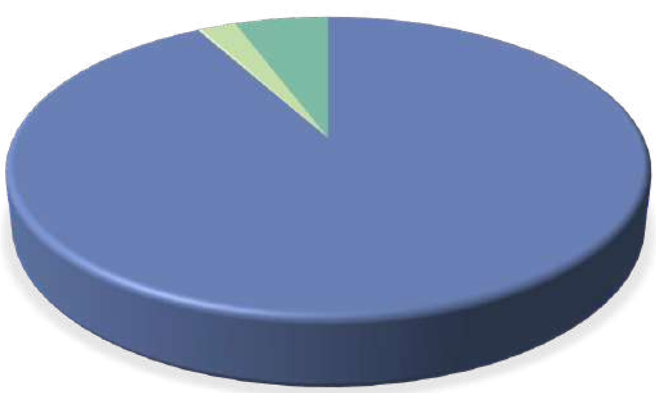
Heatwaves have emerged as a significant hazard in Pakistan, with risk maps developed in accordance with WHO guidelines for return periods of 5, 10, 25, 50, 100, 250, and 500 years. These maps, based on a global heatwave index model, analyze both the frequency and severity of heatwave occurrences. The risk levels are categorized into four classes, ranging from low to severe risk, with low risk (0 fatality) and severe risk (4-8 fatalities) being the extremes. These categories help authorities in heatwave preparedness, mitigation, and public health planning.





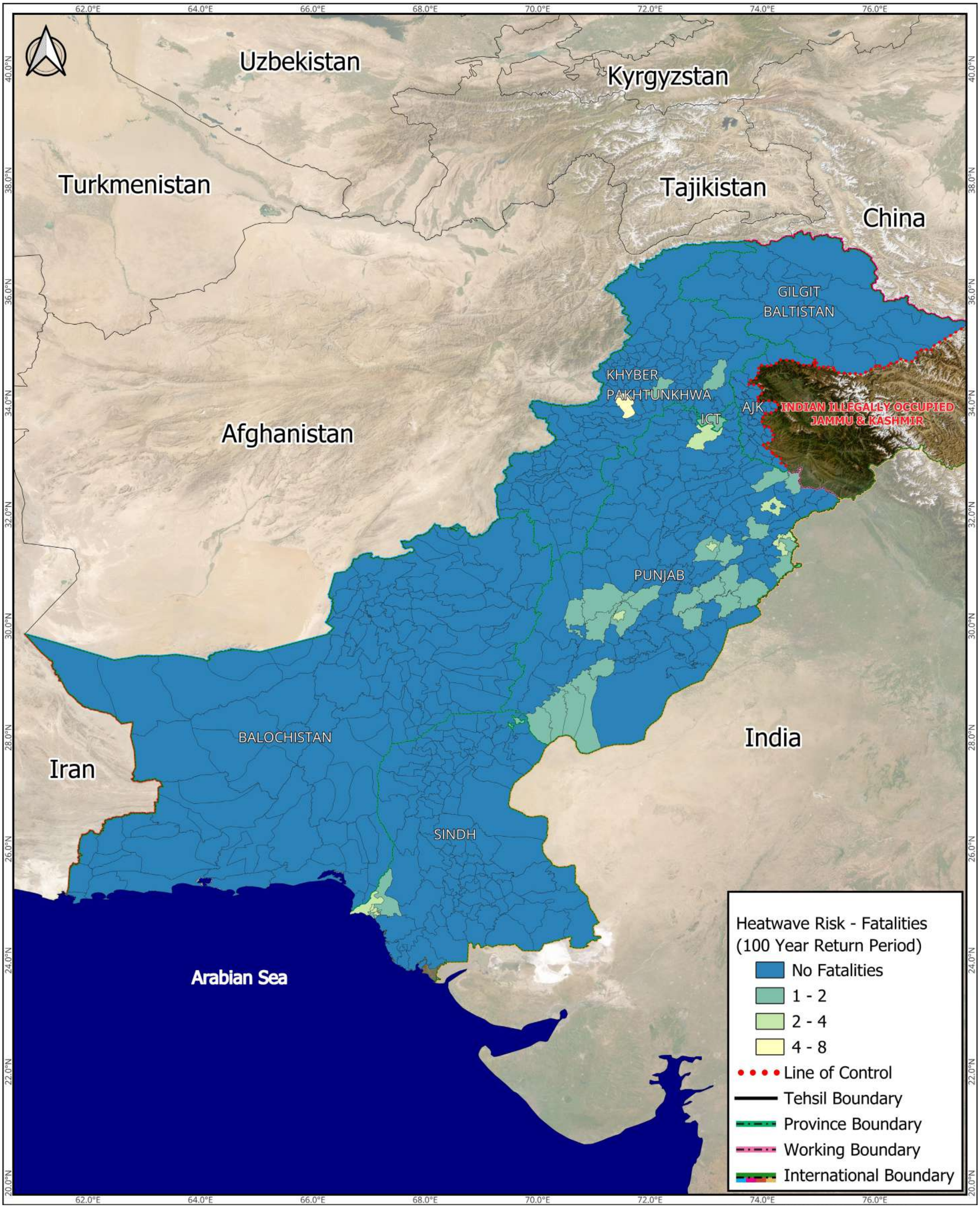
Imagesource: unsplash.com

Heatwave Risk (%)



Heatwave Risk Classes

Severity Class	Tehsil Count	Percentage
No Loss	470	91.97
1 - 2	29	5.67
2 - 4	11	2.15
4 - 8	1	0.20



Uzbekistan
Kyrgyzstan
Turkmenistan
Tajikistan
China
GILGIT BALTISTAN
KHYBER PAKHTUNKHWA
ICT
AJK
INDIAN ILLEGALLY OCCUPIED JAMMU & KASHMIR
Afghanistan
PUNJAB
BALOCHISTAN
India
Iran
SINDH
Arabian Sea
Heatwave Risk - Fatalities (100 Year Return Period)
No Fatalities
1 - 2
2 - 4
4 - 8
Line of Control
Tehsil Boundary
Province Boundary
Working Boundary
International Boundary

Hydro-Meteorological Hazards - Cyclonic Winds

Tropical cyclones create significant wind damage, often causing destruction to buildings, crops, and infrastructure. The strong winds during cyclones pose a threat to life and property, especially in coastal regions. The impacts of cyclones extend far beyond immediate damage, affecting recovery times for affected areas.

The current study assessed Tropical Cyclone (TC) wind hazard frequency and associated storm surge using Tropical Cyclone Risk Model (TCRM) for return periods of 25, 50, 100, 500, and 1,000 years. Wind hazard maps were generated with wind speeds in meters per second on the Saffir-Simpson Wind Scale for the coastal areas of Pakistan. Outputs include wind speed maps across different return periods, indicating the severity of wind damage.

Tropical Cyclone Risk Model (TCRM)

The Tropical Cyclone Risk Model (TCRM) is a valuable tool for assessing and managing the risks associated with tropical cyclones. This model produced wind hazard maps representing the scale of the hazard at the district level. Synthetic cyclone tracks up to 10,000 years of return periods were generated using the this model. The wind fields of the probabilistic cyclones were mapped for specific return periods.

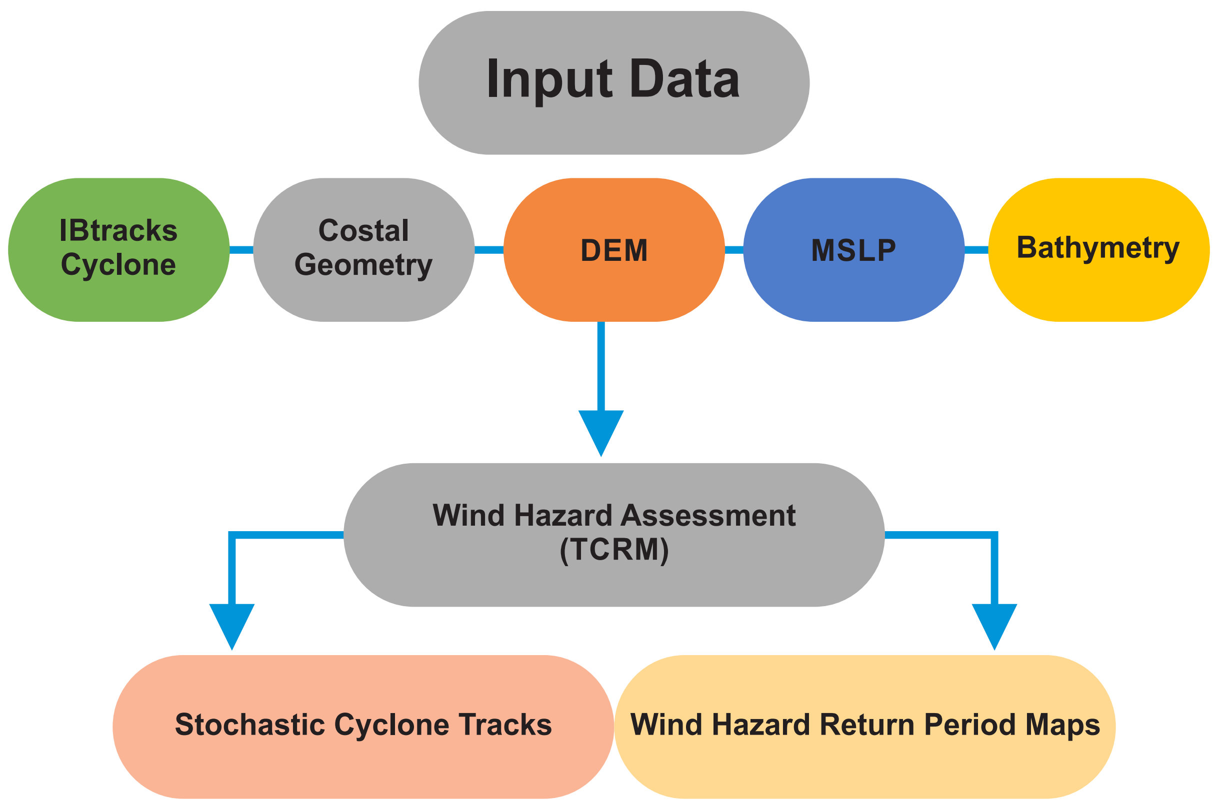
In the TCRM model, DEM, bathymetry, coastal geometry, and land use data were integrated to develop the land mask, with daily mean sea level pressure from NCEP/NCAR reanalysis and stochastic cyclone tracks for the ERN Hurricane Model.

The model estimated storm surge along Pakistan's coast, generating surge maps for up to 1,000-year return periods and estimating overland flow using the bathtub method.

Data Inputs

The input data includes:

• International Best Track Archive for Climate Stewardship (IBTrACS) track data
• Maximum Sustained wind speed
• Digital Elevation Model: Copernicus hydro-enforced digital elevation model with 1 arc-second spatial resolution.
• Daily mean sea level pressure from NCEP/NCAR
• Bathymetry: GEBCO data with a spatial resolution of 500 meters, interpolated from sonar surveys.
• Landuse/Landcover Data: Developed by SUPARCO



Model Calibration and Validation

The TCRM model generated synthetic tracks for 10,000 years of return peri ods based on IBTrACS data. The model was calibrated using recent records from 1980 to 2022, sourced from the International Best Track Archive for Climate Stewardship (IBTrACS) database. The IBTrACS dataset indicated a mean annual cyclone frequency of 8.8, with a standard deviation of 3.24. In contrast, the Tropical Cyclone Risk Model (TCRM) produced a higher mean annual frequency of 19.7, with a larger standard deviation of 22.6, reflecting greater variability in cyclone generation. Calibration statistics were rigorously evaluated to ensure the model's accuracy, focusing on key performance metrics.

IBTrACS data and TCRM-simulated cyclone tracks were compared to assess model accuracy, focusing on return periods up to 1,000 years., ensuring the simulation could capture both frequent and rare cyclonic events.

This long-term analysis strengthened the model's ability to predict rare extreme events, enhancing its overall predictive robustness.

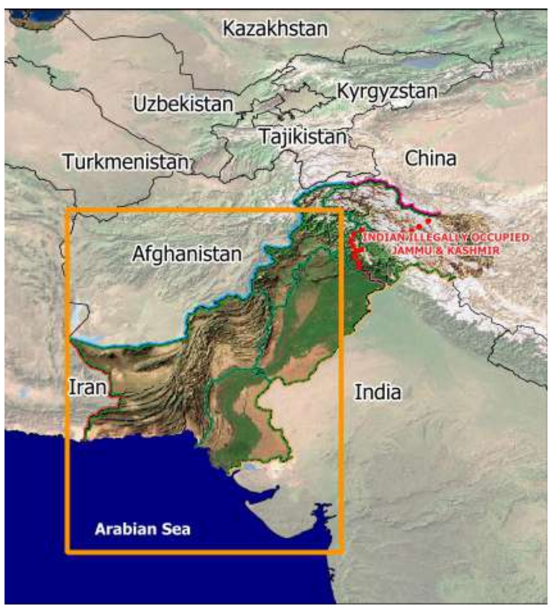
Model Output

The model outputs include wind hazard and storm surge maps for return periods up to 1,000 years, showing spatial variation in cyclone wind speeds and surge levels.


Imagesource: pixabay.com

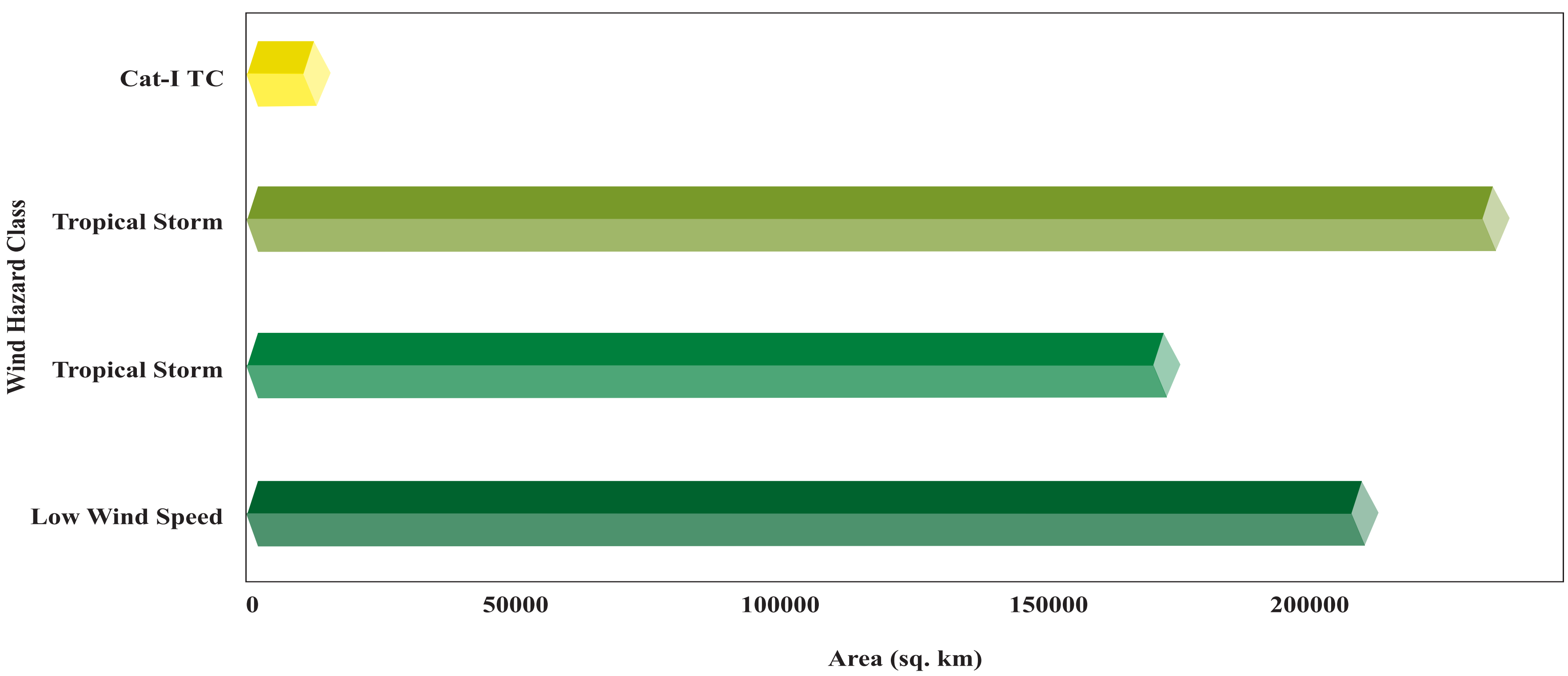
Cyclone (Wind Hazard)

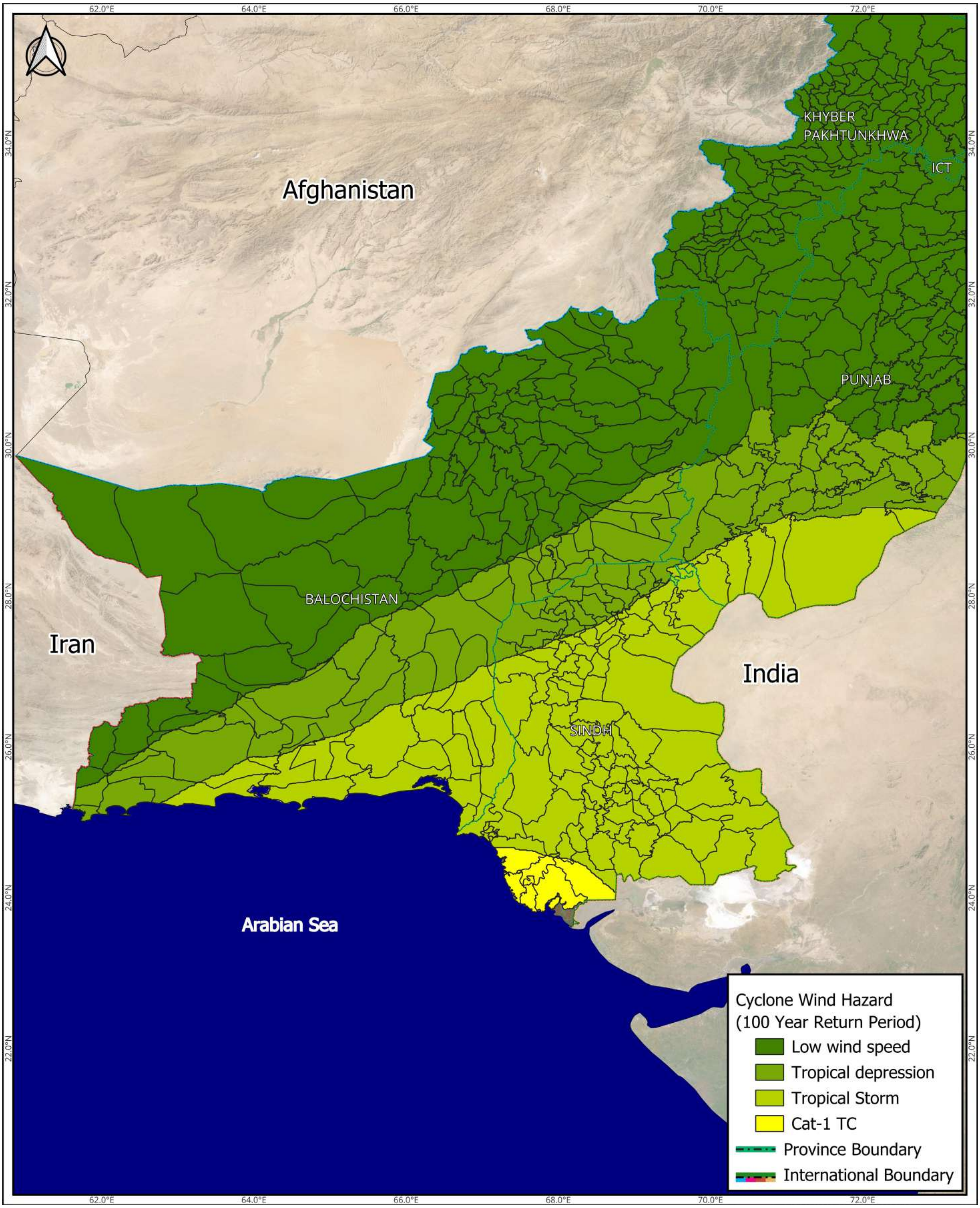
Tropical cyclones in coastal Pakistan pose a significant threat to life, property, and infrastructure due to intense winds and storm surges. This study evaluated the frequency of tropical cyclone wind hazards and storm surges, utilizing advanced modeling techniques to estimate return periods of 25, 50, 100, 500, and 1,000 years. Wind hazard maps were developed, depicting wind speeds according to the Saffir-Simpson scale and highlighting vulnerable areas. These maps offer critical insights for disaster preparedness, risk management, and strategic planning to mitigate potential cyclone impacts.




Imagesource: thestatesman.com

Potential Cyclonic Wind Prone Areas

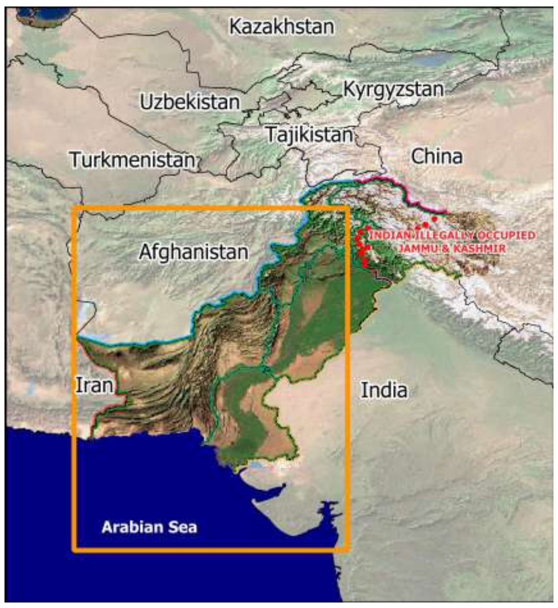




62.0°E
64.0°E
66.0°E
68.0°E
70.0°E
72.0°E
34.0°N
32.0°N
30.0°N
28.0°N
26.0°N
24.0°N
22.0°N
Afghanistan
KHYBER PAKHTUNKHWA
ICT
PUNJAB
BALOCHISTAN
Iran
India
SINDH
Arabian Sea
Cyclone Wind Hazard (100 Year Return Period)
Low wind speed
Tropical depression
Tropical Storm
Cat-1 TC
Province Boundary
International Boundary

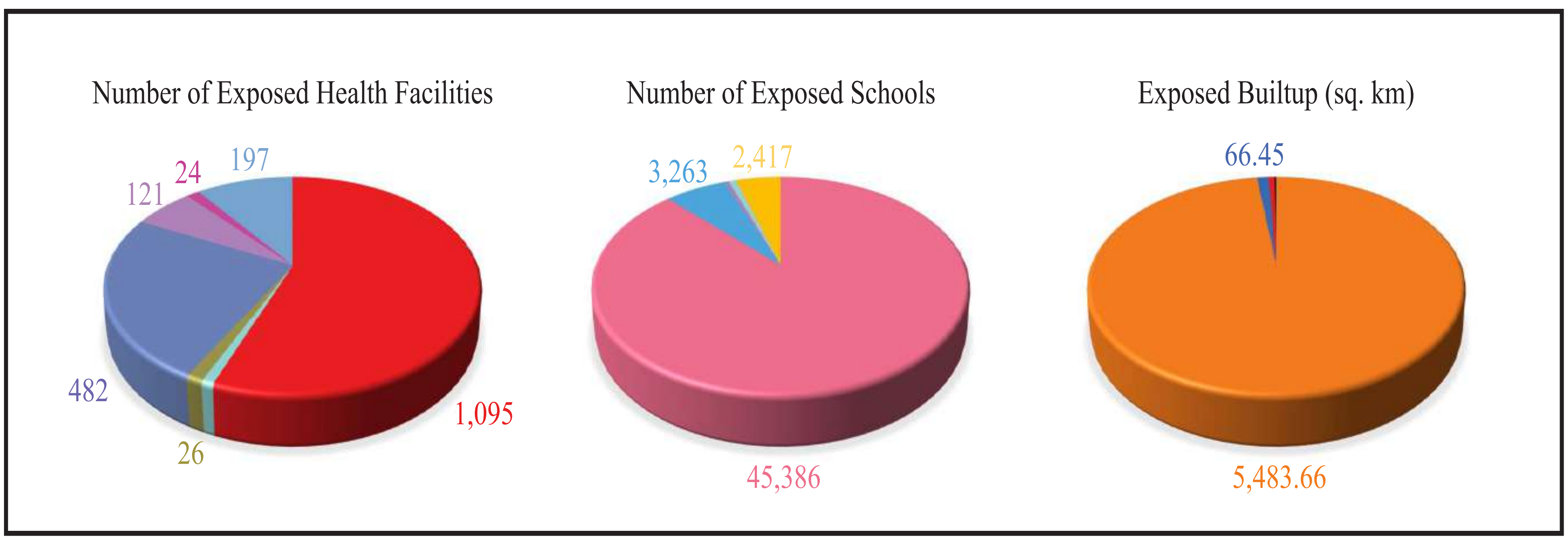
Cyclone (Wind Hazard)

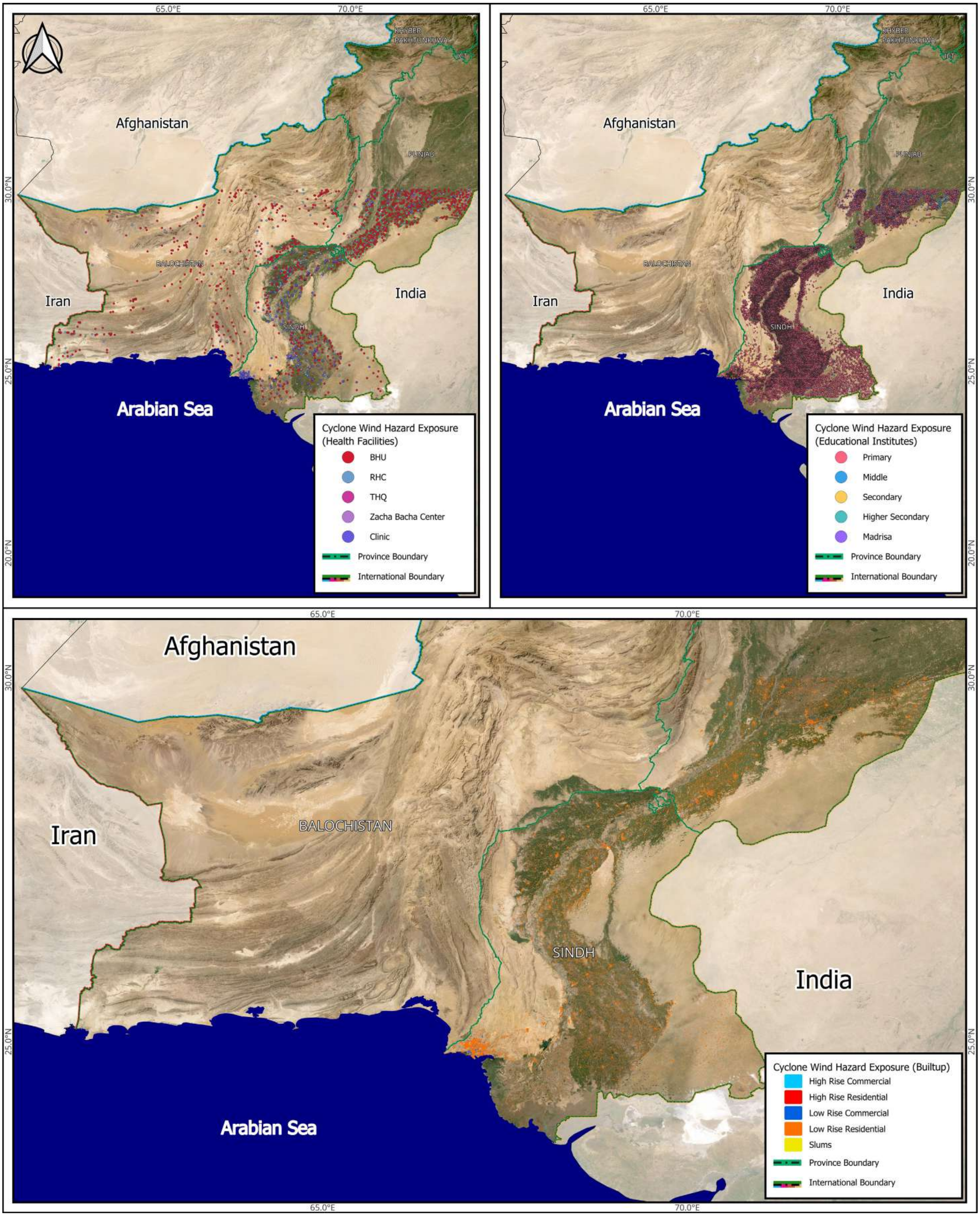
In coastal Pakistan, educational facilities, healthcare infrastructure, and the surrounding builtup environment are increasingly at risk from the impacts of tropical cyclones. The intense winds associated with these cyclones can cause severe damage to vital infrastructure, disrupt essential services, and threaten community well being. Understanding the exposure of these key sectors education, healthcare, and urban development to wind hazards is critical for implementing effective disaster preparedness strategies, improving resilience, and reducing risks in cyclone prone areas.



Imagesource: unsplash.com

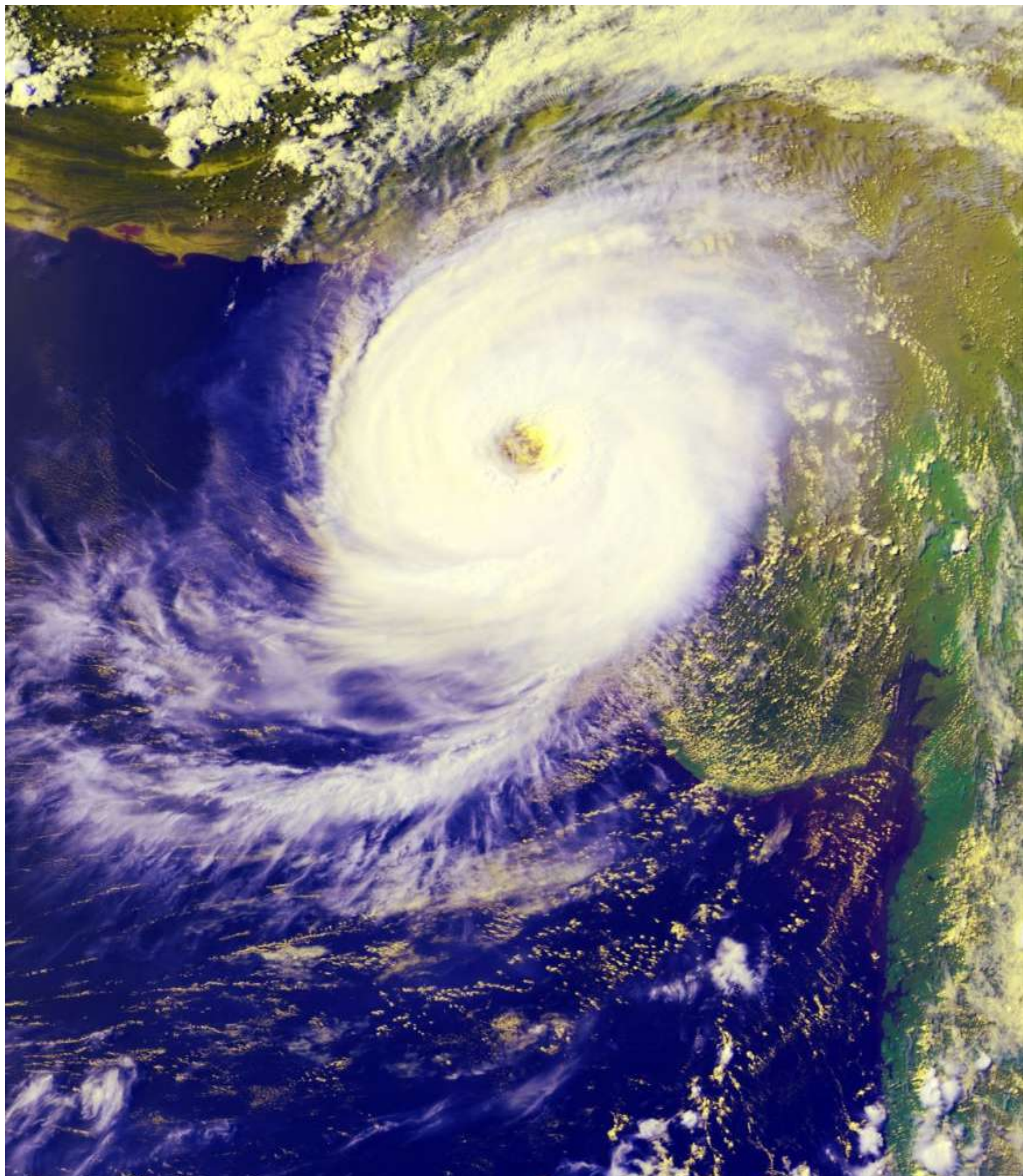
Potential Key Sector Exposure




65.0°E
70.0°E
30.0°N
25.0°N
20.0°N
KHYBER PAKHTUNKHWA
ICT
PUNJAB
Afghanistan
BALOCHISTAN
Iran
India
SINDH
Arabian Sea
Cyclone Wind Hazard Exposure (Health Facilities)
BHU
RHC
THQ
Zacha Bacha Center
Clinic
Province Boundary
International Boundary
Cyclone Wind Hazard Exposure (Educational Institutes)
Primary
Middle
Secondary
Higher Secondary
Madrisa
Province Boundary
International Boundary
Cyclone Wind Hazard Exposure (Builtup)
High Rise Commercial
High Rise Residential
Low Rise Commercial
Low Rise Residential
Slums
Province Boundary
International Boundary

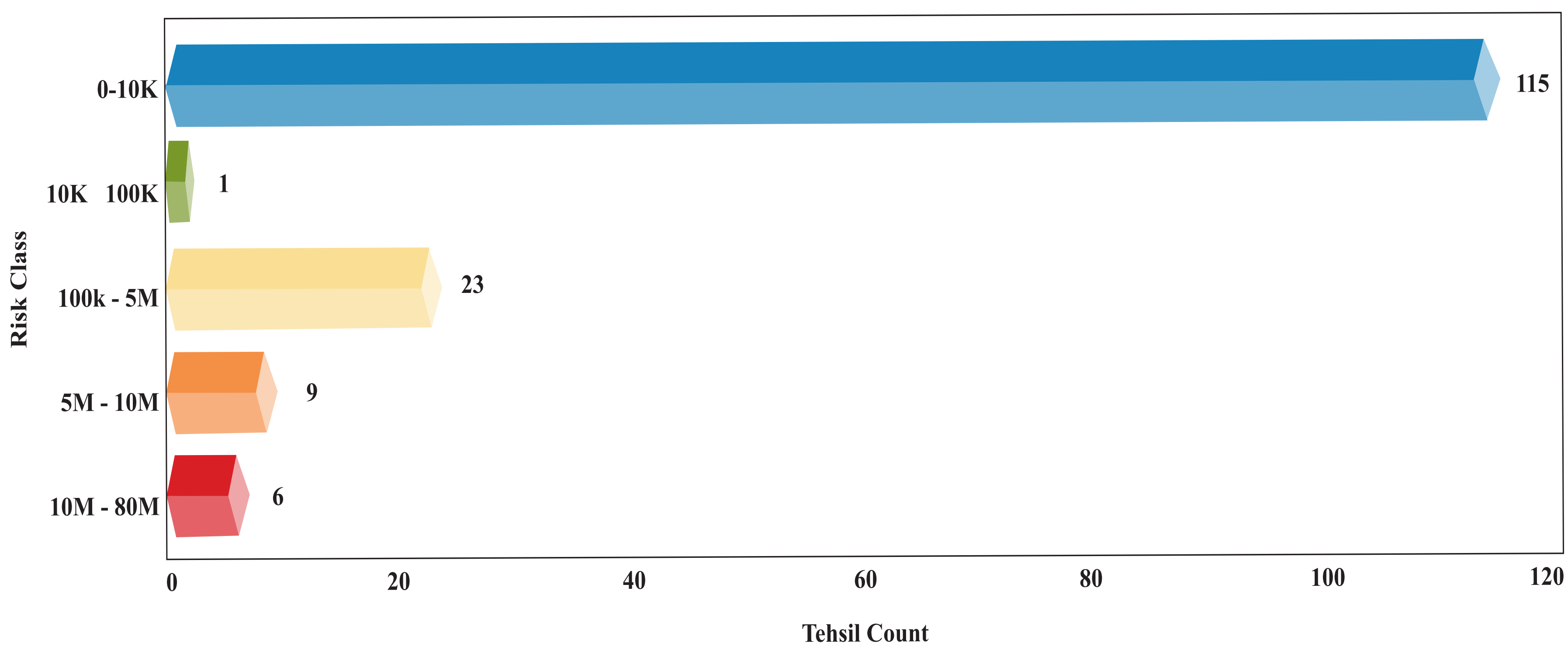
Cyclone (Wind Hazard)

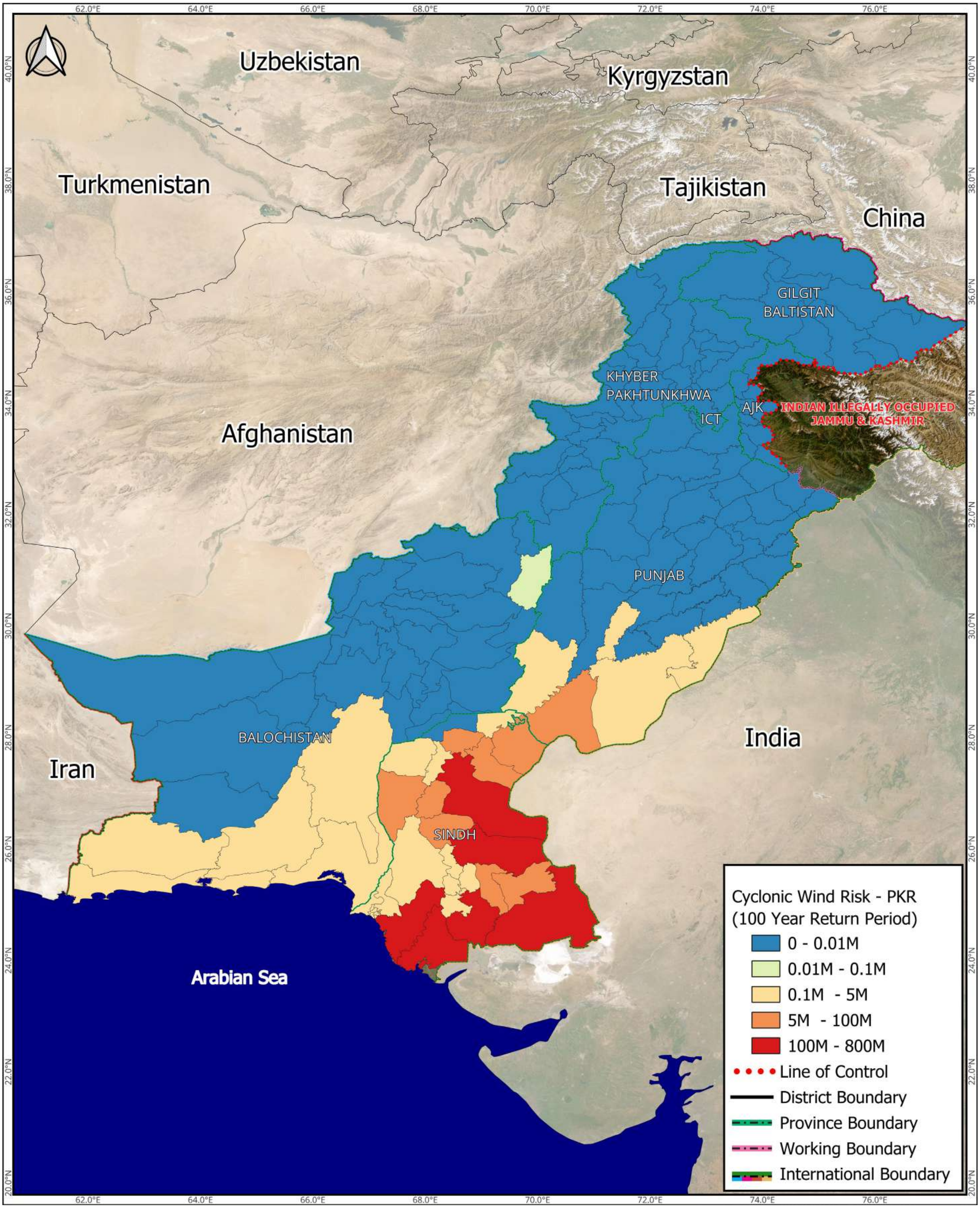
Tropical cyclones in coastal Pakistan pose significant wind hazards, and this study assessed these risks using advanced modeling for return periods of 25, 50, 100, 500, and 1,000 years. Wind hazard maps, based on the Saffir-Simpson scale, were created to evaluate the potential impact. The risk levels identified include low risk, with estimated damage ranging from 0.00001 to 0.01 Million PKR, and extreme risk, with damage ranging from 100 to 800 Million PKR. These risk categories are essential for guiding disaster planning and prioritizing areas for mitigation efforts.



Imagesource: wikimedia.org

Wind Hazard Risk Classes





Uzbekistan
Kyrgyzstan
Turkmenistan
Tajikistan
China
GILGIT
BALTISTAN
KHYBER
PAKHTUNKHWA
ICT
AJK
INDIAN ILLEGALLY OCCUPIED
JAMMU & KASHMIR
Afghanistan
PUNJAB
BALOCHISTAN
India
Iran
SINDH
Arabian Sea
Cyclonic Wind Risk - PKR
(100 Year Return Period)
0 - 0.01M
0.01M - 0.1M
0.1M - 5M
5M - 100M
100M - 800M
Line of Control
District Boundary
Province Boundary
Working Boundary
International Boundary

Hydro-Meteorological Hazards - Cyclone (Storm Surge)

Storm surges, primarily driven by intense cyclonic winds, have the potential to inundate coastal regions and cause widespread destruction. These surges occur due to the combined effect of strong winds and elevated tidal forces, pushing seawater inland. As a result, large stretches of coastal zones can be submerged, leading to both immediate and long-term impacts. Coastal communities are especially at risk, facing severe threats to human life, infrastructure, and property. To support disaster preparedness and mitigation efforts, storm surge hazard maps were generated for 25, 50, 100, 500, and 1000-year return periods. These maps are essential tools for planning evacuation routes, designing resilient infrastructure, and guiding emergency response strategies.

ERN Hurricane Model

Storm surge modeling was conducted using the ERN Hurricane Model, a specialized tool designed for comprehensive cyclone hazard assessment.

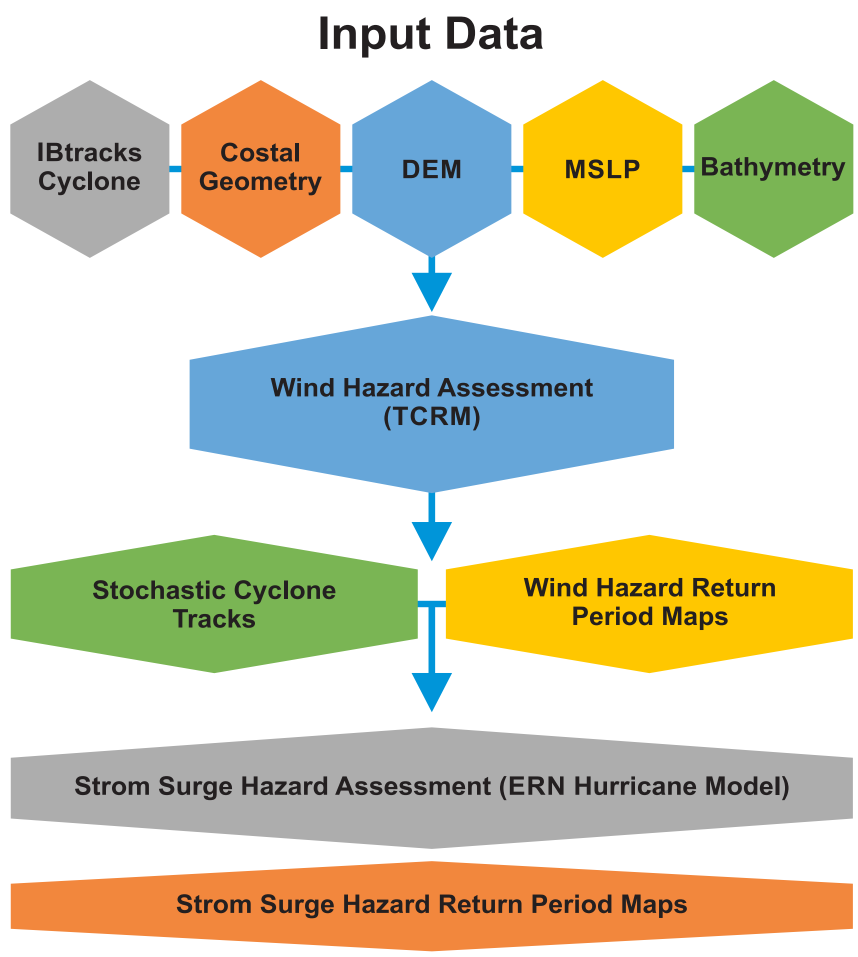
Developed by ERN Ingenieros Consultores S.C., the model estimates tropical cyclone hazards by analyzing three key intensity measures: wind, storm surge, and rainfall. It is an integral component of the CAPRA 2.0 platform, which supports risk analysis for natural hazards through advanced computational techniques.

The model relies on multiple input datasets, including Digital Elevation Models (DEM), bathymetry, coastline geometry, wind speed reduction factors, and land cover characteristics. Additionally, it incorporates detailed cyclone track data to simulate the spatial and temporal evolution of storm systems for accurate hazard estimation.

Data Inputs

The input data layes include:

• TCRM Cyclone Tracks
• Landuse / Landcover Data: Developed by SUPARCO
• Digital Elevation Model: Copernicus hydro-enforced digital elevation model with 1 arc-second spatial resolution
• Bathymetry: GEBCO data with a spatial resolution of 500 meters, interpolated from sonar surveys
• Topographic wind speed-up factor



• The coastline extracted from digital elevation model on the basis of zero elevation points closer to elevation of 1 meter
• The wind speedup factor was developed from digital elevation model

Model Calibration and Validation

For calibration and validation, wind speed and mean sea level pressure data were considered.

However, the absence of buoy data in deep sea areas near the coast of Pakistan posed a challenge. Only Gwadar and Karachi had sea level measurement stations. Validation would require actual data on wind speed, mean sea level central pressure, and cyclone coordinates, along with precipitation data. Meteorological stations in the Arabian Sea, essential for observations, are not available in Pakistan.

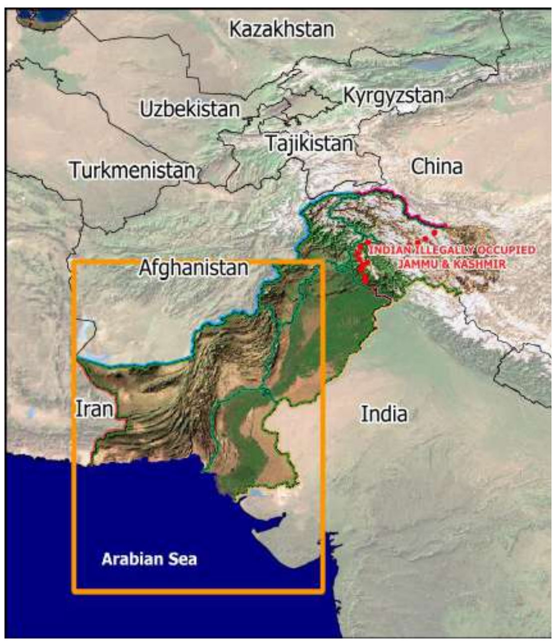
Model Output

The Tropical Cyclone Hazard analysis was conducted with the help of TCRM output results, which produced a wind hazard map representing the scale of Hazard at the Districts level. Through the TCRM simulations, a 2-dimensional wind field at 0.02° horizontal resolution, covering the entire track of a TCs in the Arabian Sea, is calculated. The model was also used to evaluate the impact of individual TCs on Pakistan's coast.

Imagesource: pixabay.com

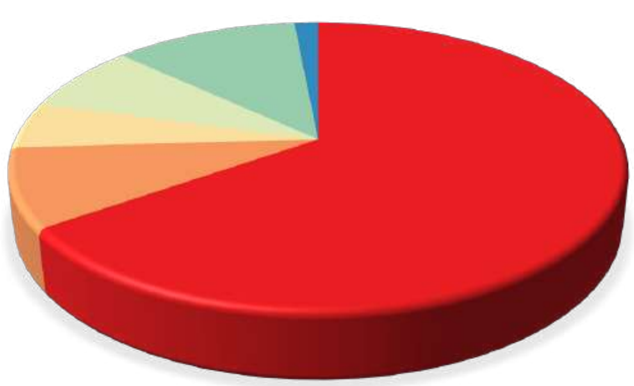
Cyclone (Storm Surge)

Storm surges, driven by cyclonic winds, flood coastal areas, causing significant damage and loss of life. Hazard maps for storm surges were created for return periods of 25, 50, 100, 500, and 1000 years. The ERN Hurricane Model was used for storm surge modeling, assessing tropical cyclone hazards based on wind, storm surge, and rain intensity. This model incorporates data such as DEM, bathymetry, coastline, wind speed reduction, land cover, and cyclone tracks. These hazard maps are essential tools for identifying vulnerable areas, informing coastal planning, and enhancing early warning systems to minimize the impacts of future storm surges.



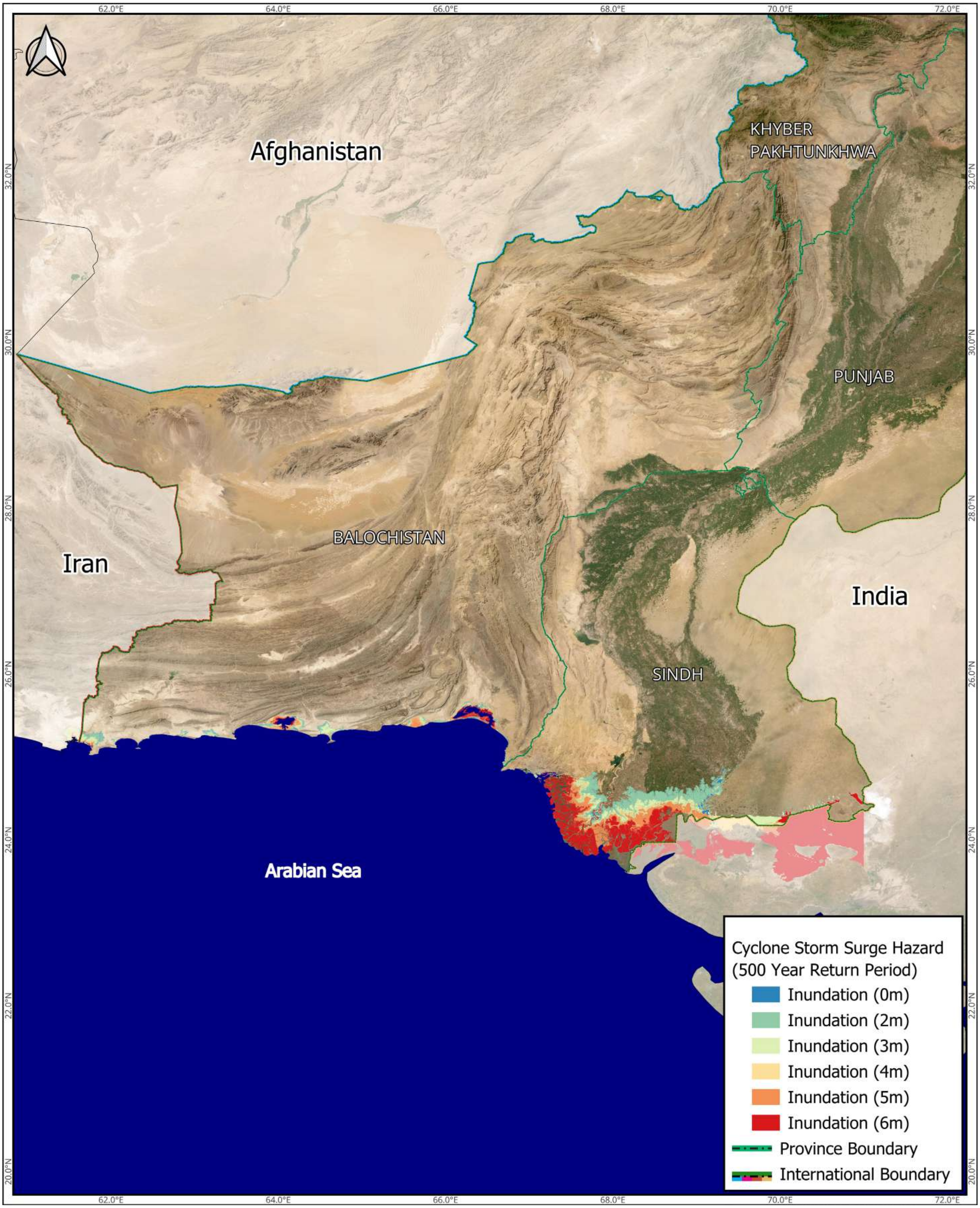

Imagesource: elevation.maplogs.com

Potential Storm Surge Prone Areas



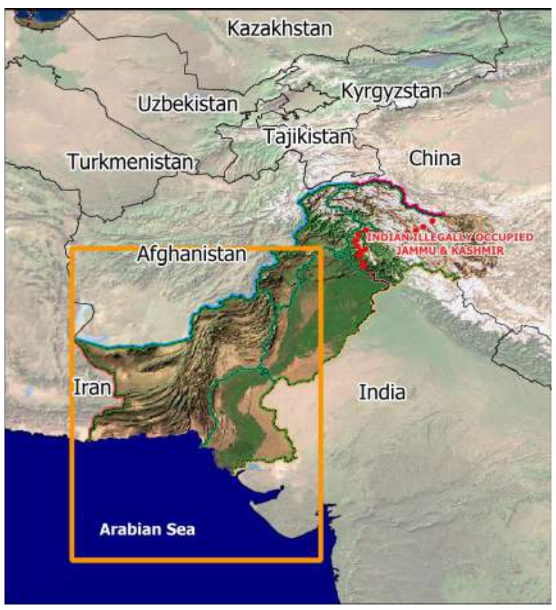
Potential Storm Surge Hazard Classes

Inundation Level	Area (sq. km)	Percentage
0	616.63	1.50
2	4,794.51	11.67
3	3,140.28	7.66
4	2,166.23	5.27
5	3,645.42	8.88
6	17,165.44	65.72

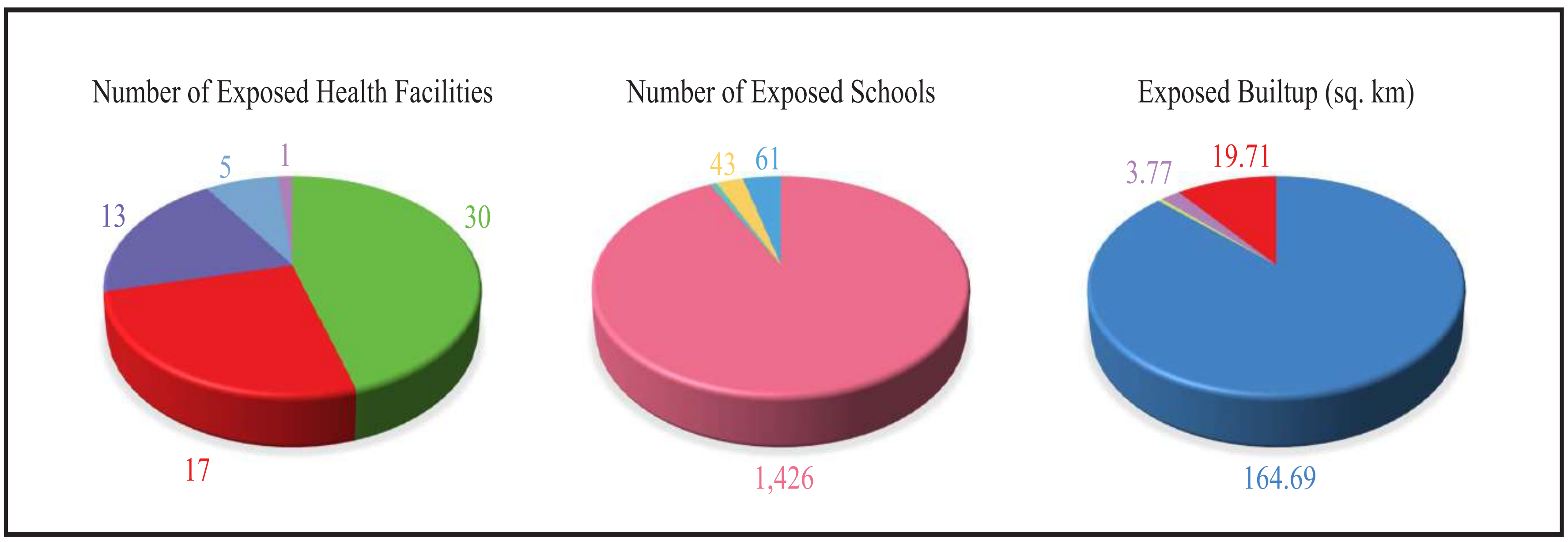

Afghanistan
KHYBER PAKHTUNKHWA
PUNJAB
BALOCHISTAN
Iran
India
SINDH
Arabian Sea
Cyclone Storm Surge Hazard (500 Year Return Period)
Inundation (0m)
Inundation (2m)
Inundation (3m)
Inundation (4m)
Inundation (5m)
Inundation (6m)
Province Boundary
International Boundary
62.0°E
64.0°E
66.0°E
68.0°E
70.0°E
72.0°E
32.0°N
30.0°N
28.0°N
26.0°N
24.0°N
22.0°N
20.0°N

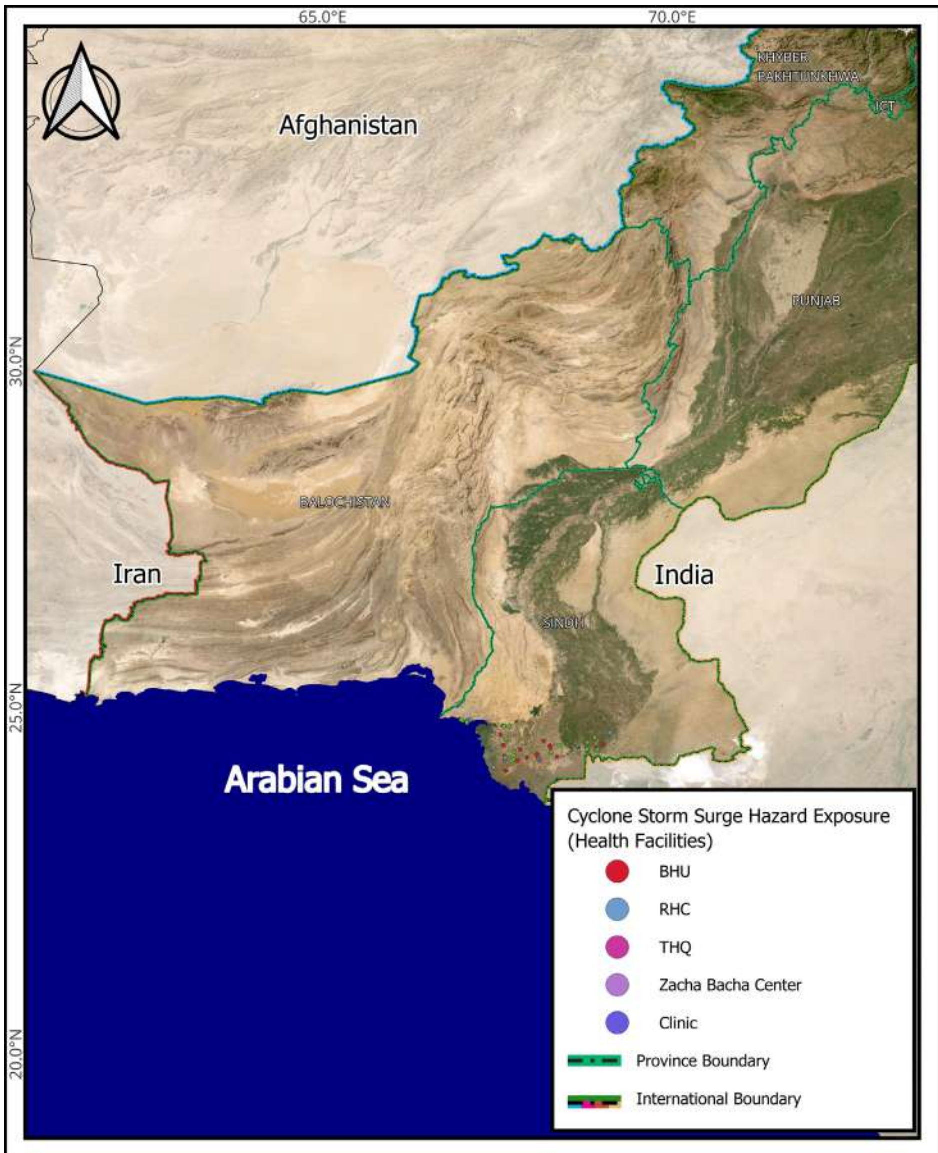
Cyclone (Storm Surge)

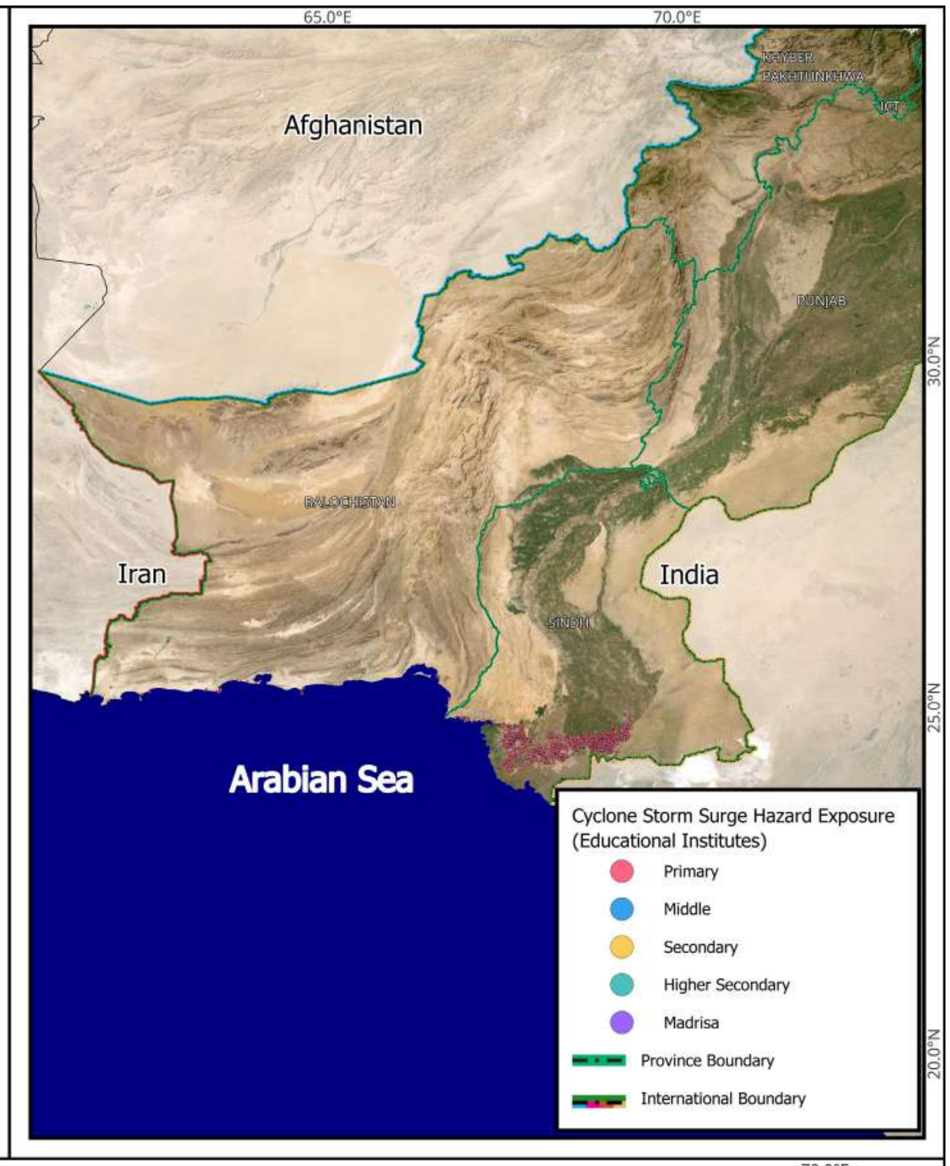
Coastal Pakistan's educational institutions, health facilities, and builtup infrastructure are exposed to significant storm surge hazards. Advanced modeling techniques estimate that areas in high risk zones could experience flooding, structural damage, and severe disruption of services. This could lead to prolonged outages in education and healthcare, as well as the loss of vital resources, underscoring the urgent need for targeted risk reduction and disaster preparedness. Effective mitigation strategies, such as resilient infrastructure and early warning systems, are essential to protect these critical facilities and reduce the impact of storm surges.

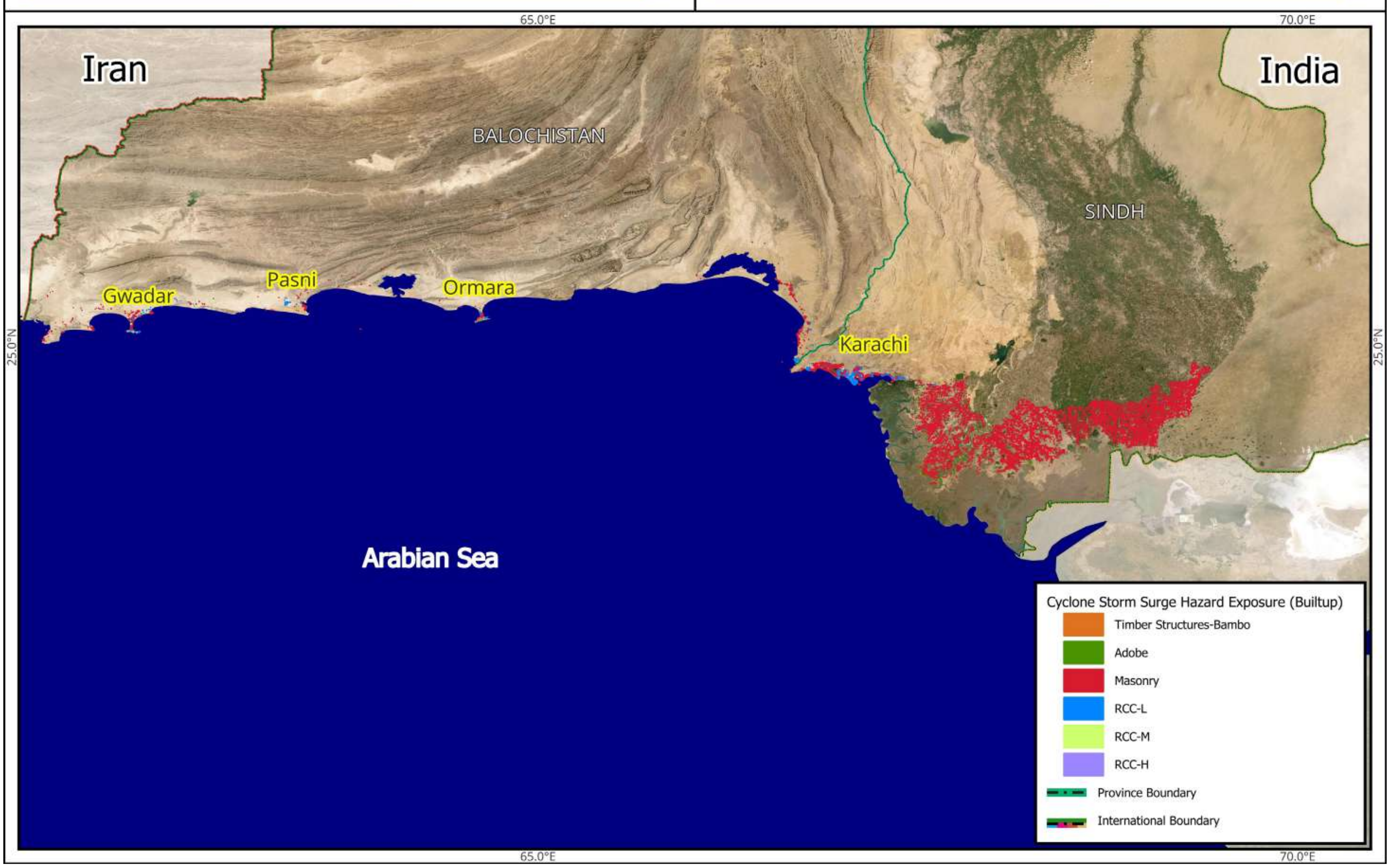


Potential Exposure of Key Sectors




65.0°E
70.0°E
30.0°N
25.0°N
20.0°N
Afghanistan
KHYBER PAKHTUNKHWA
ICT
PUNJAB
BALOCHISTAN
Iran
India
SINDH
Arabian Sea
Cyclone Storm Surge Hazard Exposure (Health Facilities)
BHU
RHC
THQ
Zacha Bacha Center
Clinic
Province Boundary
International Boundary


65.0°E
70.0°E
30.0°N
25.0°N
20.0°N
Afghanistan
KHYBER PAKHTUNKHWA
ICT
PUNJAB
BALOCHISTAN
Iran
India
SINDH
Arabian Sea
Cyclone Storm Surge Hazard Exposure (Educational Institutes)
Primary
Middle
Secondary
Higher Secondary
Madrisa
Province Boundary
International Boundary

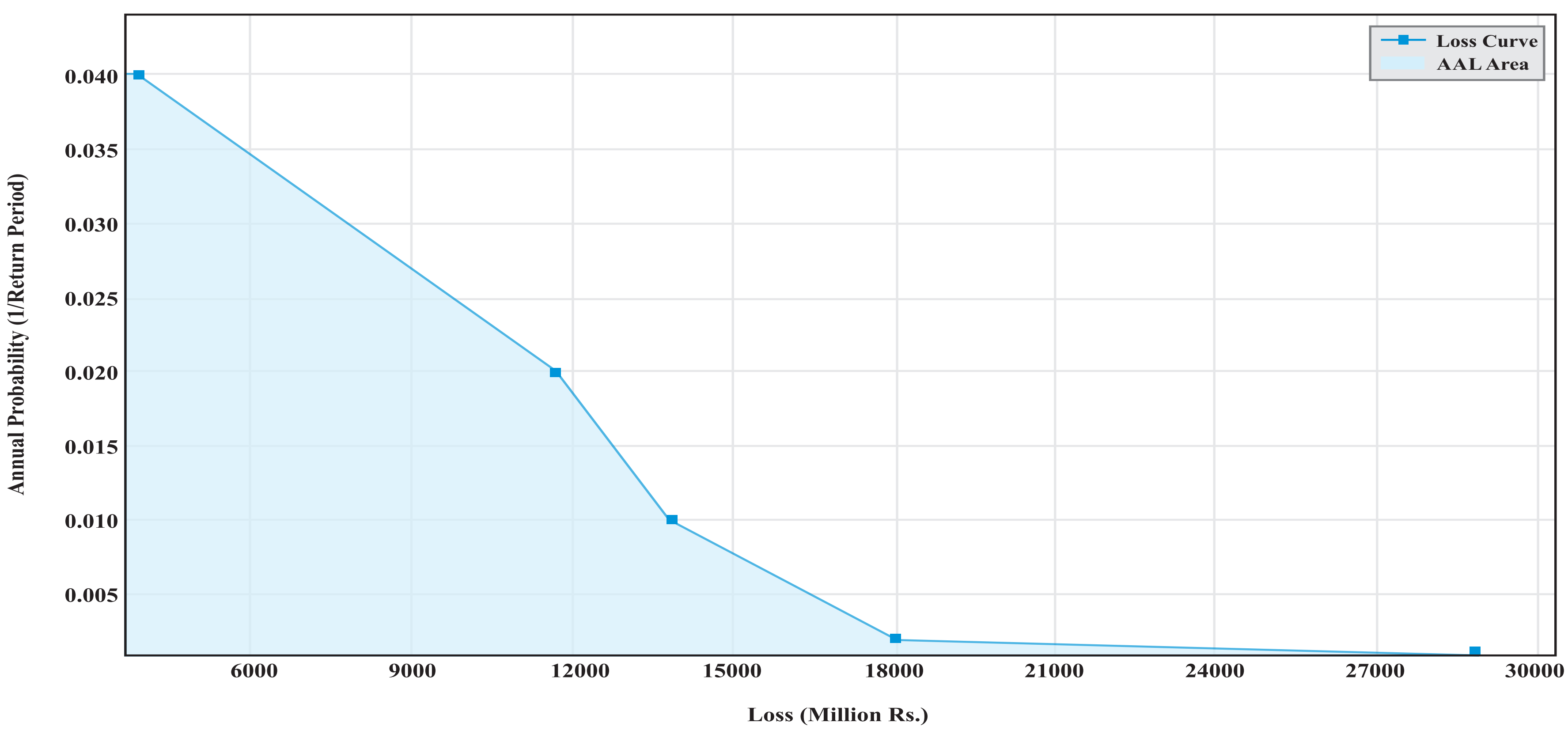

65.0°E
70.0°E
25.0°N
Iran
India
BALOCHISTAN
SINDH
Gwadar
Pasni
Ormara
Karachi
Arabian Sea
Cyclone Storm Surge Hazard Exposure (Builtup)
Timber Structures-Bambo
Adobe
Masonry
RCC-L
RCC-M
RCC-H
Province Boundary
International Boundary

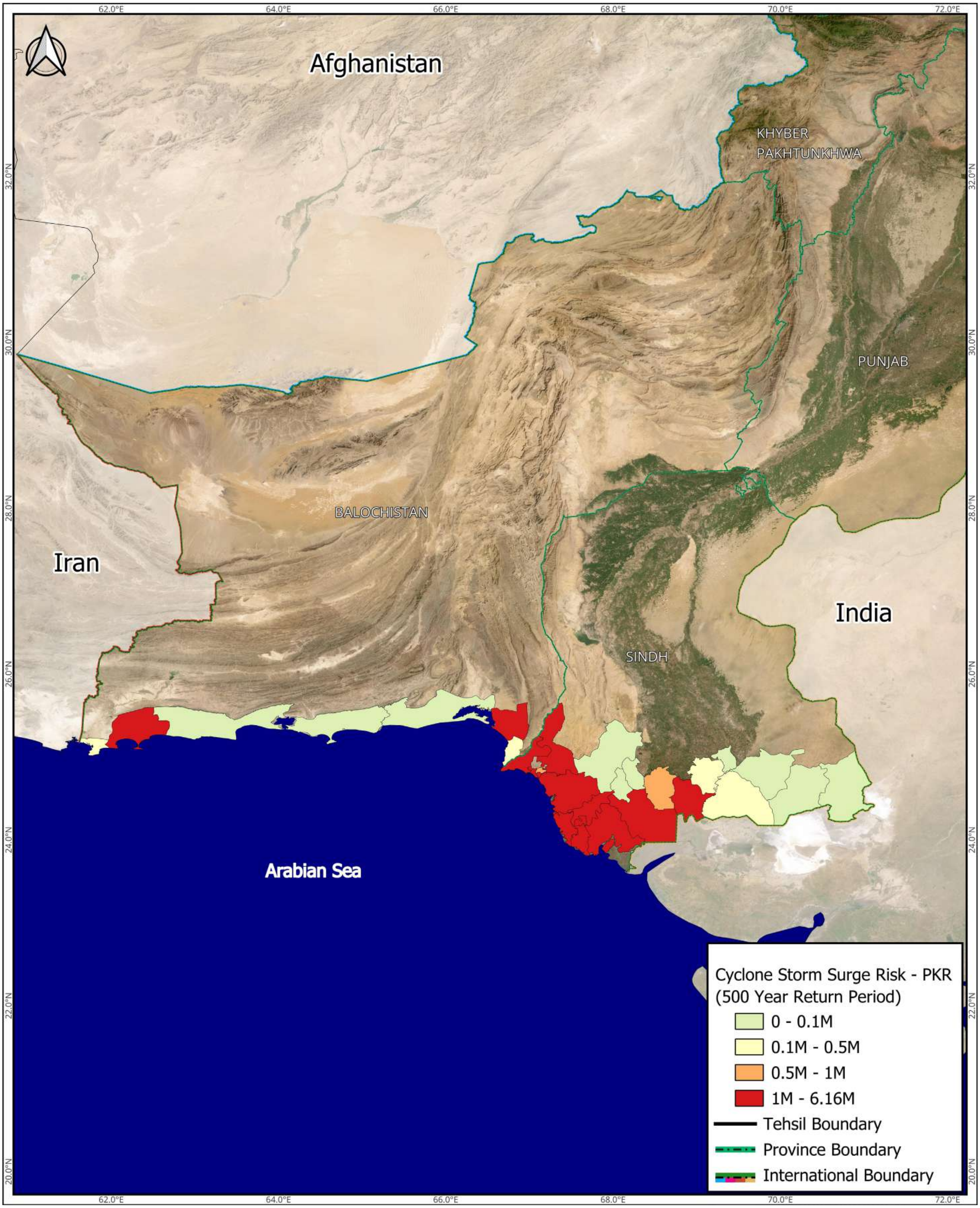
Cyclone (Storm Surge)

Storm surges, driven by cyclonic winds, flood coastal areas, causing extensive damage and loss of life. Hazard maps for storm surges were developed using the ERN Hurricane Model, incorporating data such as DEM, bathymetry, coastline features, and cyclone tracks. The risk levels for storm surge hazards are categorized from negligibly low to extremely high i.e. 1 - 6.16 Million PKR, enabling the identification of high risk areas for focused disaster preparedness and mitigation efforts.


Imagesource: unsplashcom

Average Annual Loss (AAL) - Storm Surge





Afghanistan
KHYBER PAKHTUNKHWA
PUNJAB
BALOCHISTAN
Iran
India
SINDH
Arabian Sea
Cyclone Storm Surge Risk - PKR
(500 Year Return Period)
0 - 0.1M
0.1M - 0.5M
0.5M - 1M
1M - 6.16M
Tehsil Boundary
Province Boundary
International Boundary
62.0°E
64.0°E
66.0°E
68.0°E
70.0°E
72.0°E
32.0°N
30.0°N
28.0°N
26.0°N
24.0°N
22.0°N
20.0°N

Hydro-Meteorological Hazards - Drought

Droughts cause long-term damage to agriculture and water resources, leading to food shortages and economic losses. They often go unnoticed initially but can have severe cumulative effects. Droughts in Pakistan result in water scarcity, affecting both rural and urban areas, leading to agricultural failures.
Drought hazard assessments were based on meteorological, hydrological, and agricultural indices, including SPI and NDVI. These assessments focused on the impact of drought under climate scenarios SSP245 and SSP585 for period near (2011-2040), mid (2041-2070) and far (2071-2100).

Meteorological Drought

Meteorological drought hazard assessment was conducted using the Standardized Precipitation Index (SPI), recommended by the WMO as the primary drought index. The DrinC model was used to calculate SPI from long-term monthly rainfall records obtained from PMD. Seasonal (3-month) and crop-season (6-month) SPIs were computed for Kharif and Rabi periods to capture short- and medium-term drought patterns. Additionally, SPI-12 was used to estimate drought return periods at the tehsil level. Drought severity was classified based on SPI values, considering rainfall deficits below 75% of long-term seasonal averages.

Hydrological Drought

Hydrological drought hazard assessment was conducted using the Streamflow Drought Index (SDI), developed by Nalbantis and Tsakiris. SDI, calculated using the DrinC model, analyzed both wet and dry periods based on monthly streamflow data. The assessment required long term climatic data including rainfall, temperature, and soil moisture. SPI was also computed using the same model for comparative drought analysis.

Agricultural Drought

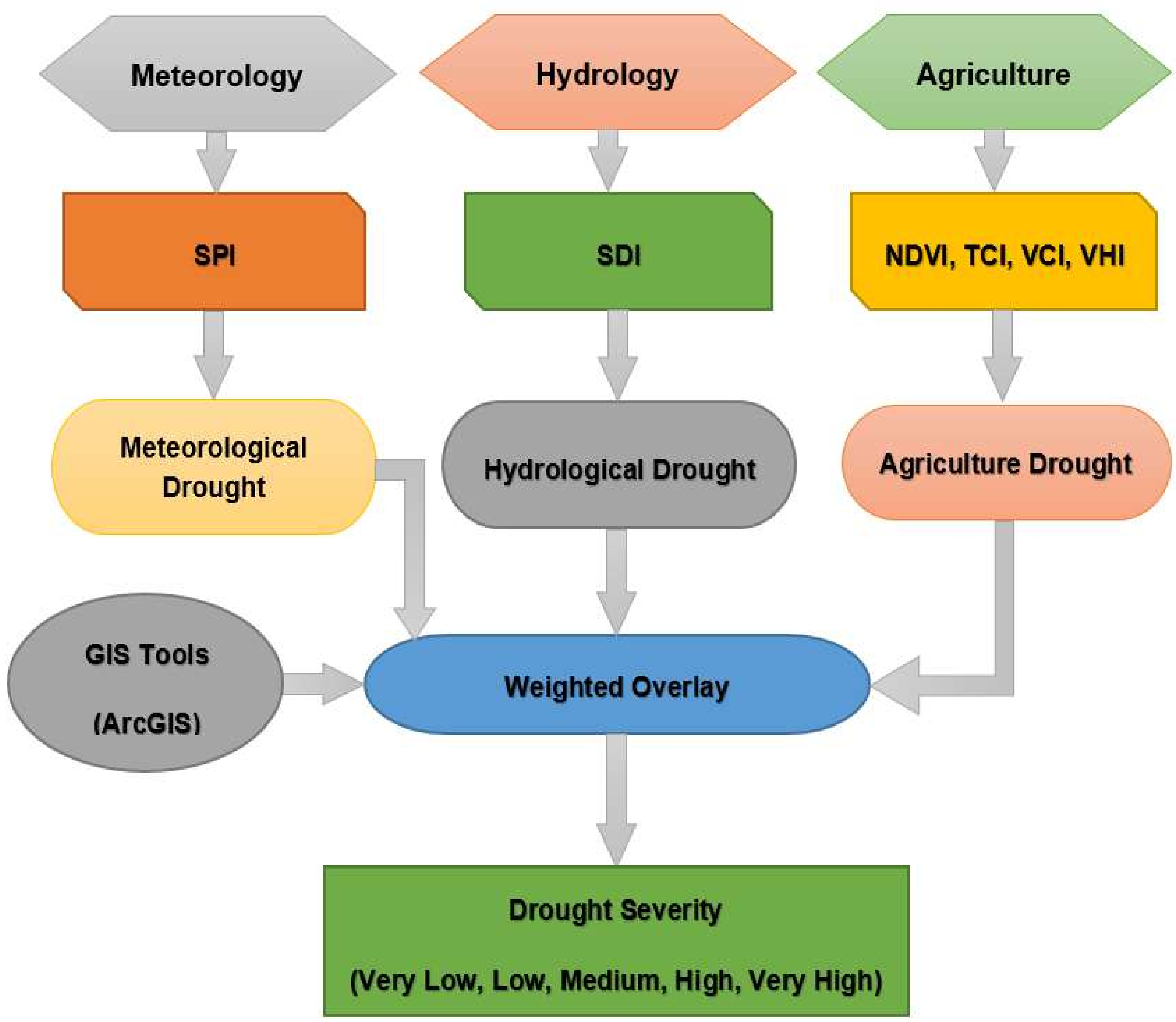
Agricultural drought hazard assessment was conducted using long-term satellite-derived indices. NDVI was calculated from the normalized difference between NIR and Red bands to assess vegetation health. TCI, based on land surface temperature, was used to detect water stress, while VCI measured vegetation condition relative to historical NDVI extremes. VHI, a combined index of VCI and TCI, was used for comprehensive drought monitoring with a weighting factor of 0.5. These indices were derived from MODIS, Landsat, and AVHRR satellite data using Google Earth Engine.

Data Inputs

The input data layers include:
• Normalized Difference Vegetation Index (NDVI)
• Vegetation Condition Index (VCI)
• Vegetation Health Index (VHI)
• Temperature Condition Index (TCI)
• Standardized Precipitation Index (SPI)
• Streamflow Drought Index (SDI)
• River discharge & rainfall data

Model Output

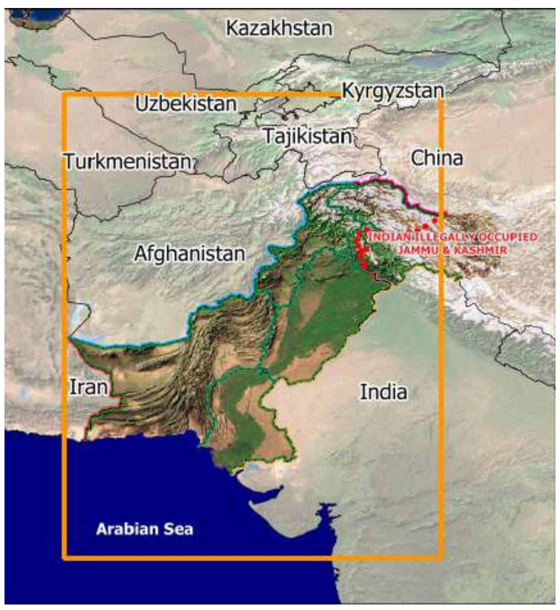
The outcomes derived from the drought hazard mapping consist of:
• Drought spatial extent
• Drought severity maps
• Drought hazard maps
• Drought indicators / indices data



Imagesource: unsplash.com

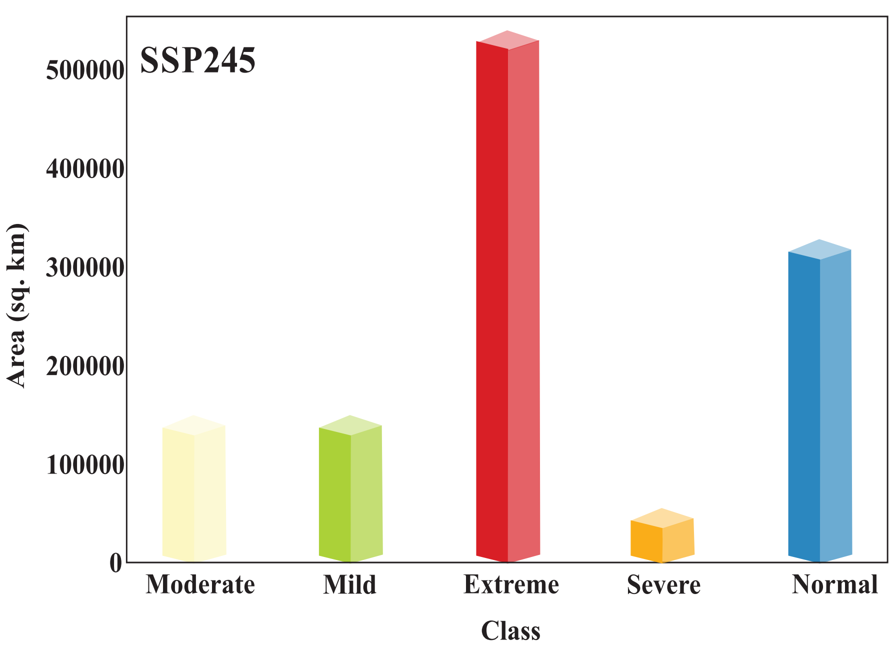
Drought - Rabi Crops

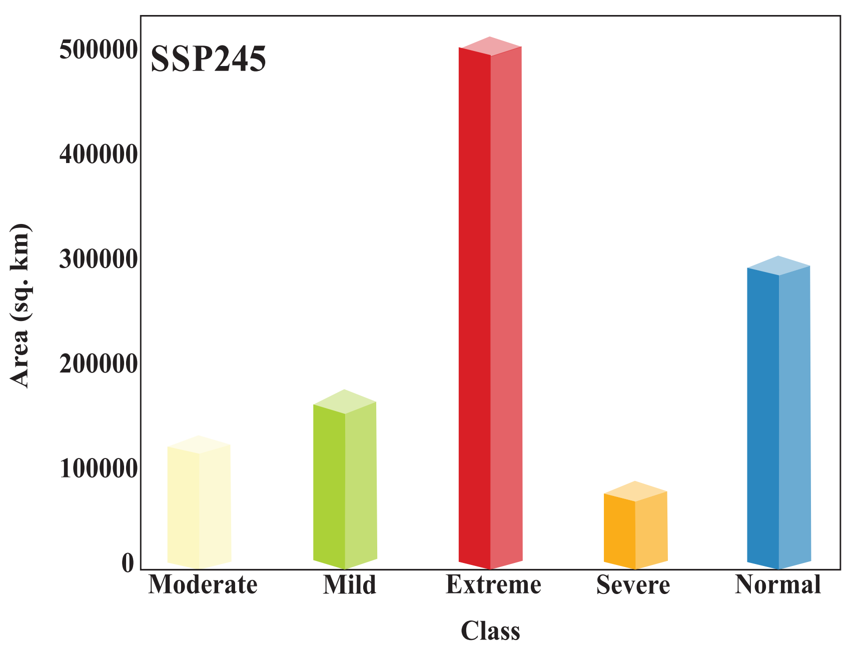
Droughts during the Rabi season in Pakistan significantly impact winter crops and water availability, resulting in reduced agricultural productivity and economic stress. Drought hazard assessments based on the Standardized Precipitation Index (SPI) and Normalized Difference Vegetation Index (NDVI) were carried out for the Rabi season under climate scenarios SSP245 and SSP585, spanning the near term (2011–2040), mid term (2041–2070), and long term (2071–2100) periods. These assessments support decision makers in developing targeted drought mitigation and adaptation strategies to enhance water and agricultural resource management.

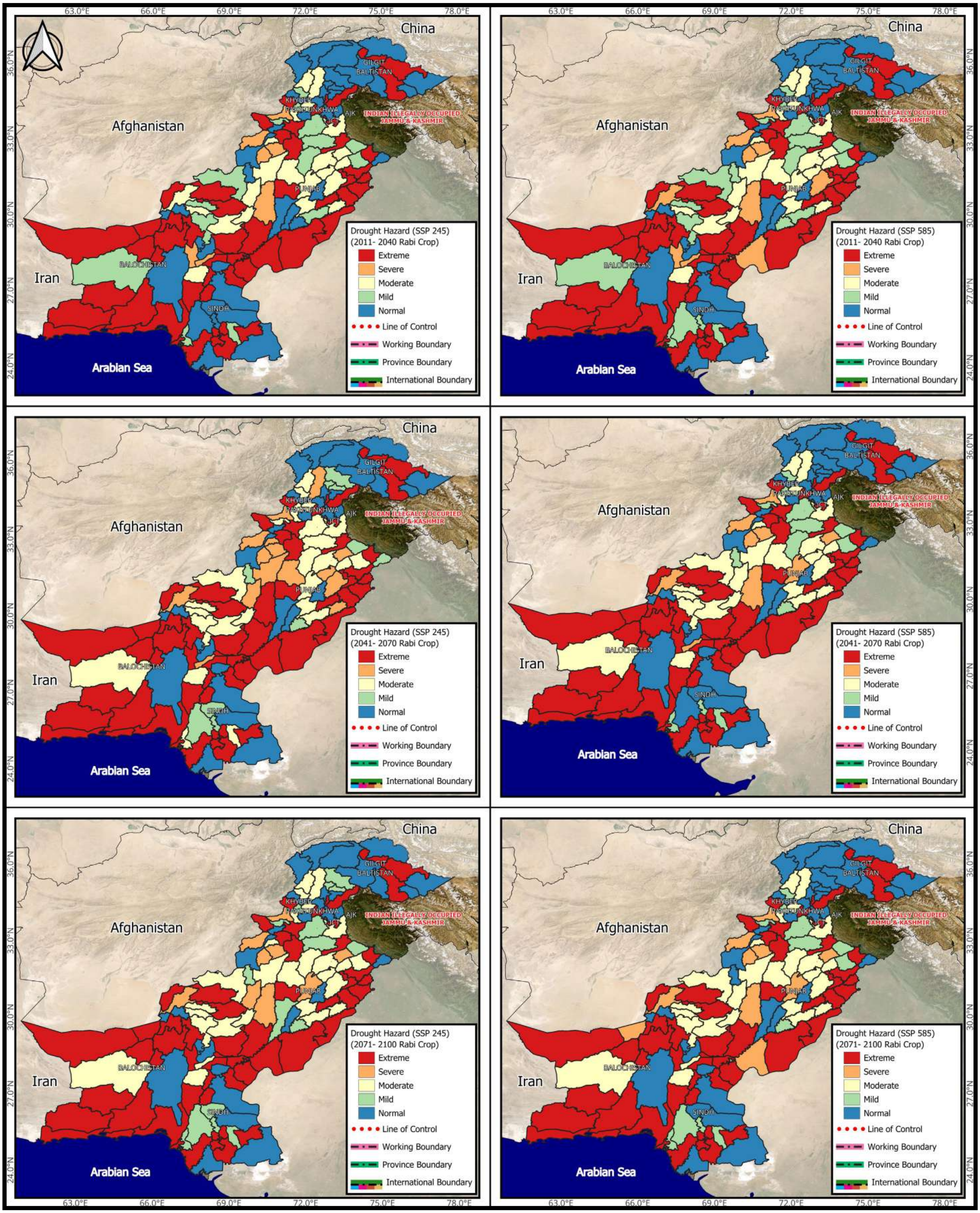


Imagesource: pngtree.com

Drought Severity for Rabi Crop (2011-2040) Under SSP245 & SSP585

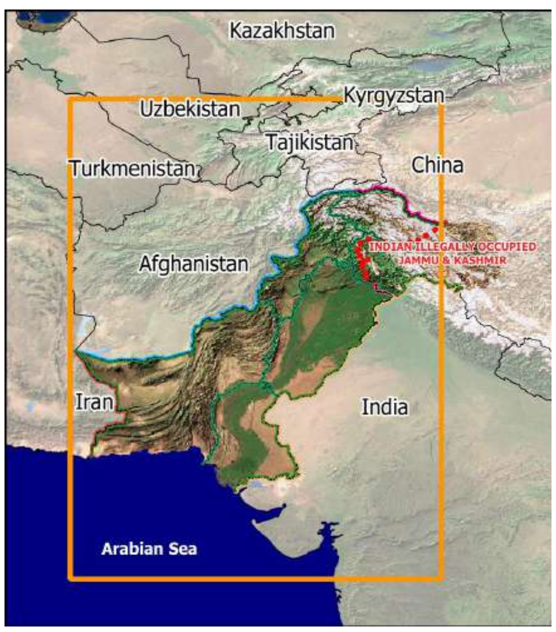





63.0°E
66.0°E
69.0°E
72.0°E
75.0°E
78.0°E
36.0°N
33.0°N
30.0°N
27.0°N
24.0°N
China
Afghanistan
Iran
Arabian Sea
GILGIT BALTISTAN
KHYBER PAKHTUNKHWA
AJK
ICT
INDIAN ILLEGALLY OCCUPIED JAMMU & KASHMIR
PUNJAB
BALOCHISTAN
SINDH
Drought Hazard (SSP 245) (2011- 2040 Rabi Crop)
Drought Hazard (SSP 585) (2011- 2040 Rabi Crop)
Drought Hazard (SSP 245) (2041- 2070 Rabi Crop)
Drought Hazard (SSP 585) (2041- 2070 Rabi Crop)
Drought Hazard (SSP 245) (2071- 2100 Rabi Crop)
Drought Hazard (SSP 585) (2071- 2100 Rabi Crop)
Extreme
Severe
Moderate
Mild
Normal
Line of Control
Working Boundary
Province Boundary
International Boundary

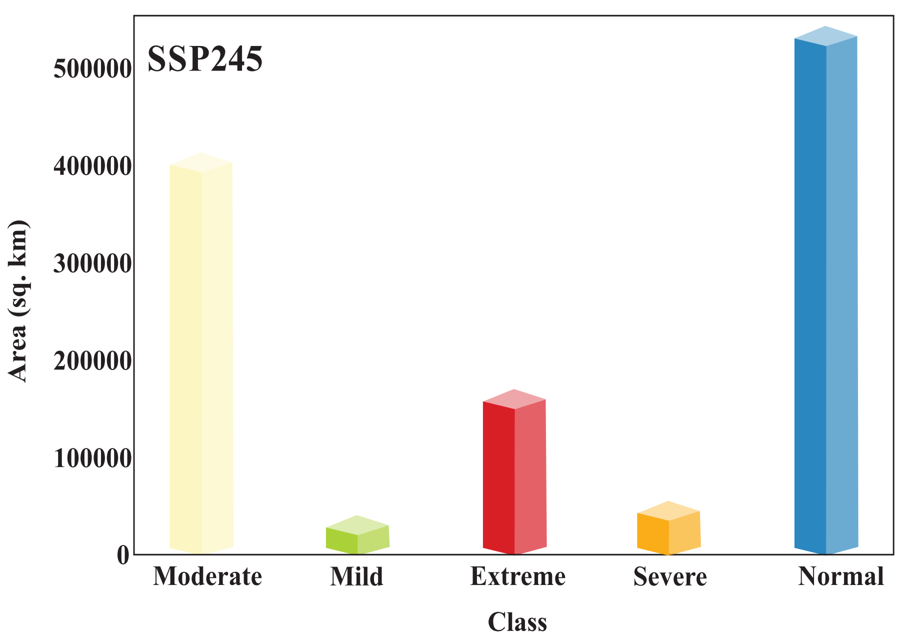
Drought - Kharif Crops

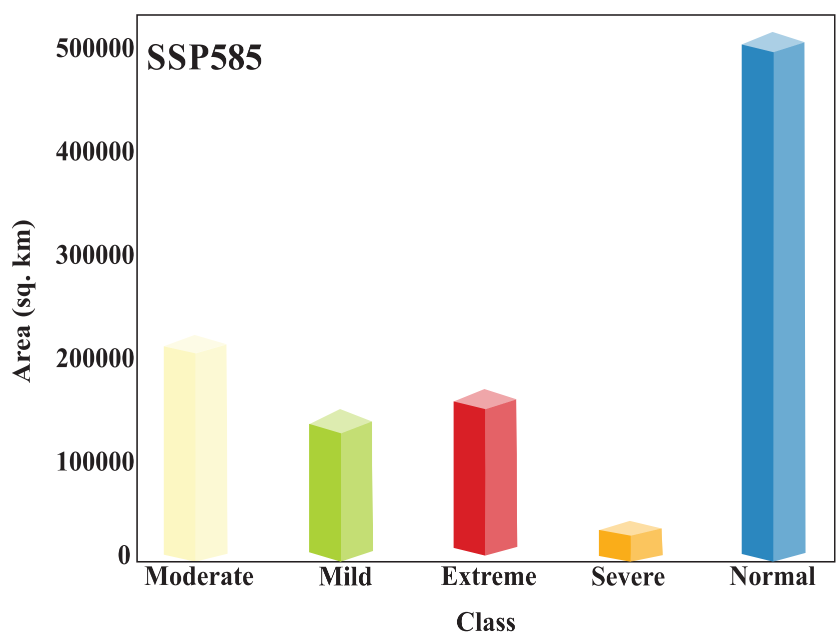
Droughts during the Kharif season in Pakistan severely affect summer crops and water availability, leading to substantial agricultural losses and economic disruptions. Drought hazard assessments using the Standardized Precipitation Index (SPI) and Normalized Difference Vegetation Index (NDVI) were conducted for the Kharif season under climate scenarios SSP245 and SSP585, across the near term (2011–2040), mid term (2041–2070), and long term (2071–2100) periods. These insights aid policymakers in formulating effective drought mitigation and adaptation strategies to ensure sustainable water and crop management.

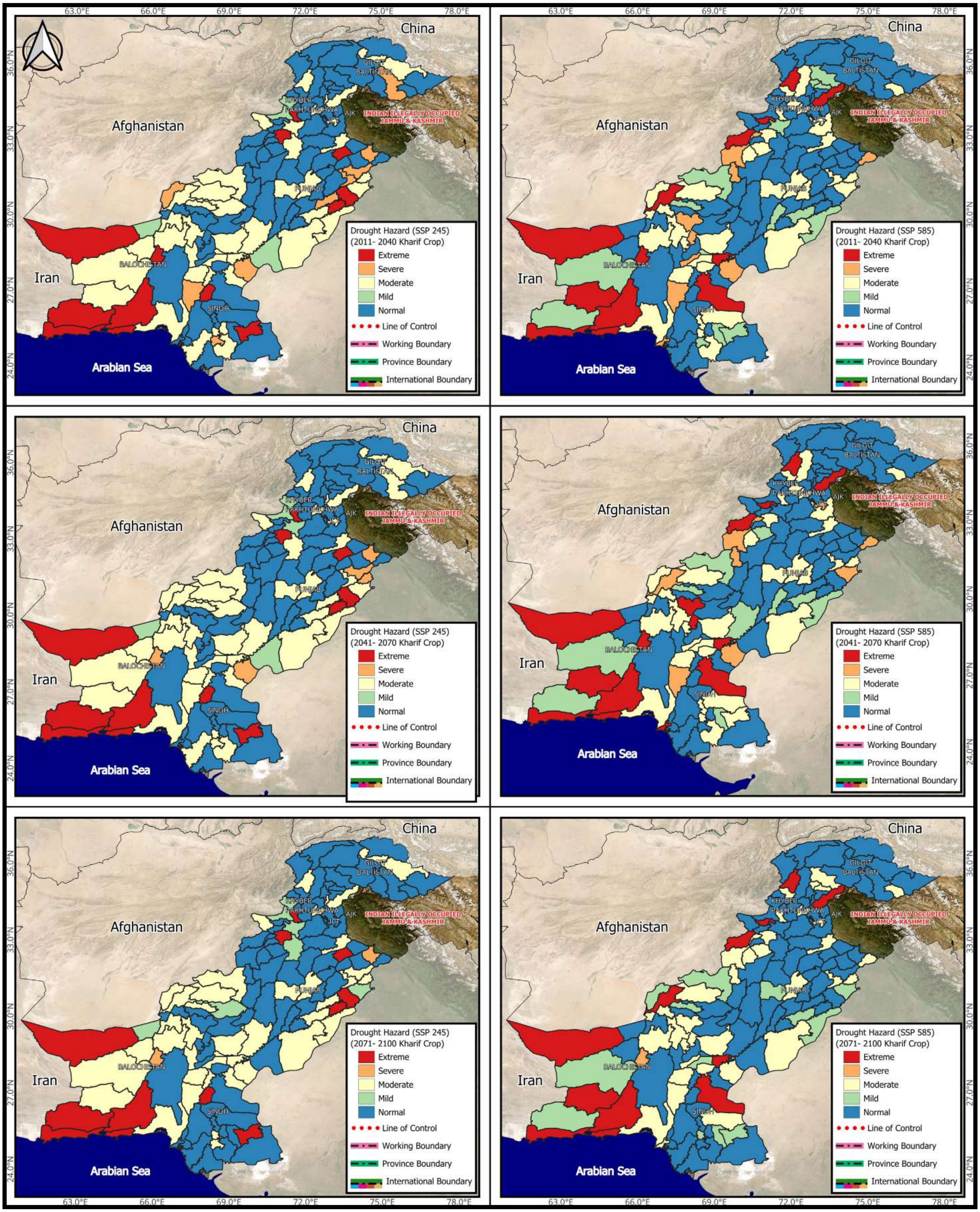


Imagesource: unsplash.com

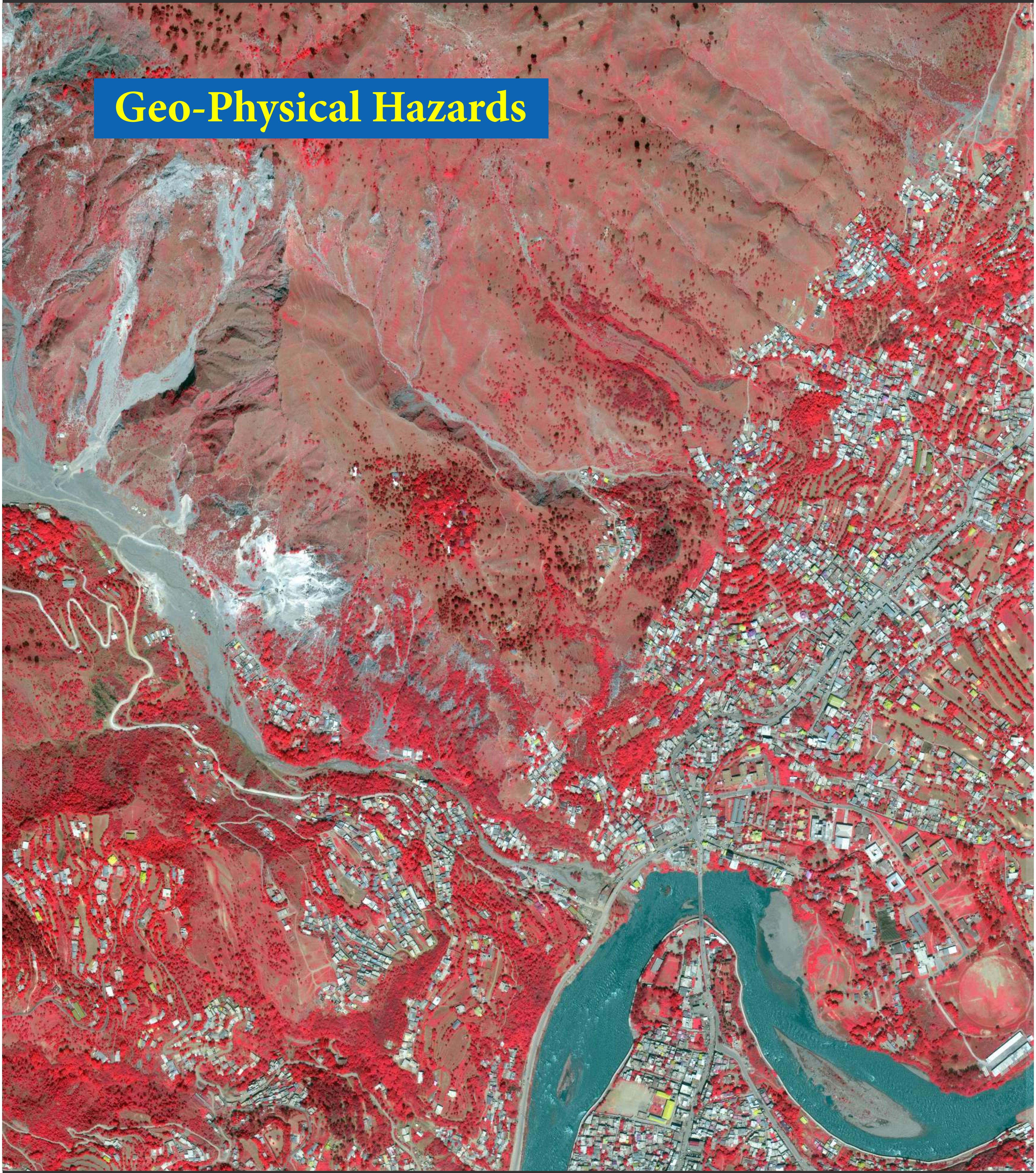
Drought Severity for Kharif Crop (2011-2040) Under SSP245 & SSP585






China
Afghanistan
Iran
Arabian Sea
GILGIT BALTISTAN
KHYBER PAKHTUNKHWA
AJK
ICT
INDIAN ILLEGALLY OCCUPIED JAMMU & KASHMIR
PUNJAB
BALOCHISTAN
SINDH
63.0°E
66.0°E
69.0°E
72.0°E
75.0°E
78.0°E
36.0°N
33.0°N
30.0°N
27.0°N
24.0°N
Drought Hazard (SSP 245) (2011- 2040 Kharif Crop)
Drought Hazard (SSP 585) (2011- 2040 Kharif Crop)
Drought Hazard (SSP 245) (2041- 2070 Kharif Crop)
Drought Hazard (SSP 585) (2041- 2070 Kharif Crop)
Drought Hazard (SSP 245) (2071- 2100 Kharif Crop)
Drought Hazard (SSP 585) (2071- 2100 Kharif Crop)
Extreme
Severe
Moderate
Mild
Normal
Line of Control
Working Boundary
Province Boundary
International Boundary

Geo-Physical Hazards




Imagesource: SUPARCO EO-1 Imagery

Geo-Physical Hazards - Earthquake

Earthquakes in Pakistan result from the complex tectonic interactions among the Indian, Eurasian, and Arabian plates, making the region highly seismically active. These events can cause significant destruction, particularly in mountainous and densely populated areas. To better understand and mitigate this risk, a Probabilistic Seismic Hazard Assessment (PSHA) was conducted. The PSHA analyzed ground motion hazards over return periods of 95, 475, 975, and 2475 years. Corresponding Peak Ground Acceleration (PGA) maps were developed for various spectral periods, aiding in earthquake-resistant infrastructure planning and disaster risk reduction.

OpenQuake Model

Probabilistic Seismic Hazard Assessment was carried out using the Cornell-McGuire (1968–1976) classical approach in OpenQuake. The Cornell (1968) approach was considered the most appropriate for computing hazards in this study due to its suitability for the available data. In the Cornell (1968) approach, the source model is the most critical input, defined by combining the seismicity and local geological information in the study area. OpenQuake engine (Pagani et al., 2014), an open-source application for seismic hazard and risk assessment, was used for numerical computations, keeping in view the quantity of data and NatCat Model Project ToRs. Seismic hazard computation was carried out at a grid size of 5 km x 5 km and ground motion values were obtained as peak ground acceleration and spectral acceleration values at 0.075, 0.1, 0.2, 0.3, 0.5, 1.0, 1.5, and 2.0s periods.
The study incorporated faults earthquake catalogs, and ground motion prediction equations (GMPEs) appropriate for the tectonic settings.

Site conditions were considered using Vs30 values to reflect local soil and rock properties. Results were expressed as hazard curves, uniform hazard spectra, and hazard maps for various return periods. These outputs are intended to support earthquake-resilient infrastructure planning and policy development in seismically vulnerable regions.

Data Inputs

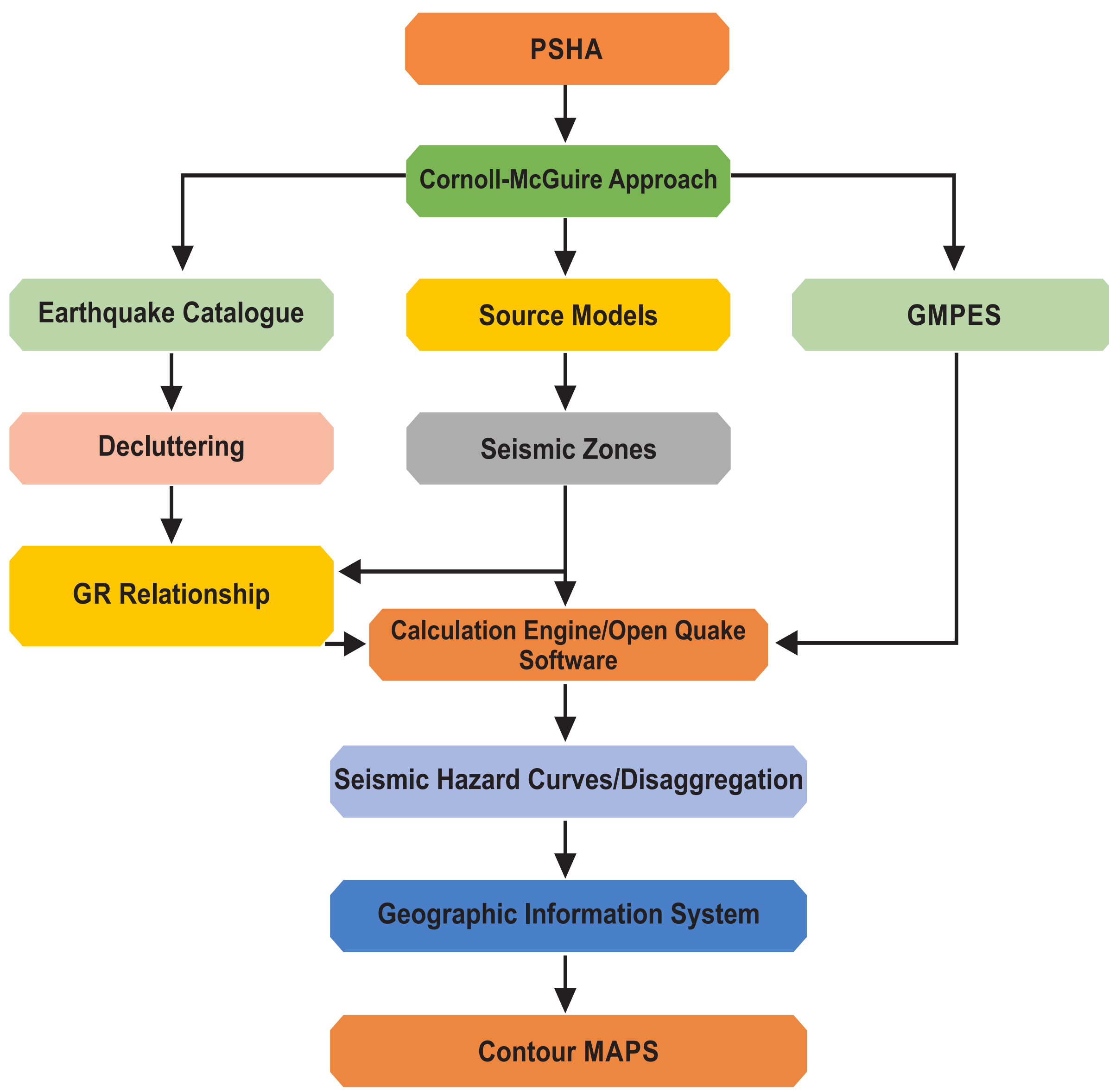
The model utilized earthquake catalogs from PMD, USGS, and ISC, along with PGA values for return periods ranging from 95 to 2475 years. It also incorporated DEM and fault-line data to accurately represent the region's seismic and geological characteristics.

Model Calibration and Validation

The model was calibrated using historical seismic data to ensure accuracy. Validation was performed by comparing simulated PGA values with those observed in past earthquake events.

Model Output

The model outputs include hazard curves, uniform hazard spectra, and seismic hazard maps showing Peak Ground Acceleration (PGA) and spectral acceleration for various return periods. These aid in assessing seismic risk and guiding earthquake-resilient infrastructure planning.



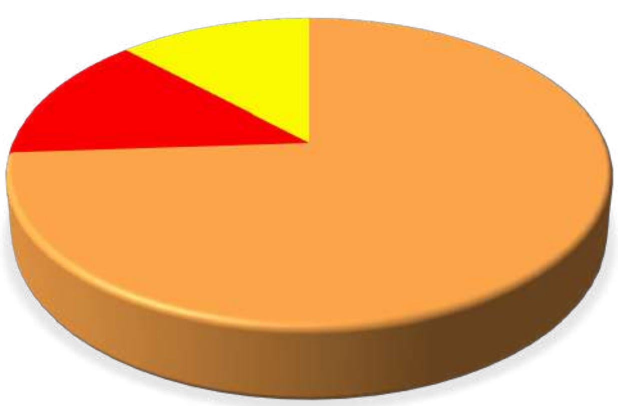
Imagesource:dawn.com

Seismic

Earthquakes in Pakistan result from the tectonic interactions of the Indian, Eurasian, and Arabian plates, posing a significant threat to life and infrastructure, particularly in high risk areas. To address this ongoing risk, a Probabilistic Seismic Hazard Assessment (PSHA) was conducted for return periods of 95, 475, 975, and 2,475 years. This assessment produced peak ground acceleration (PGA) maps across various spectral periods, offering critical insights into earthquake intensity and ground shaking potential.

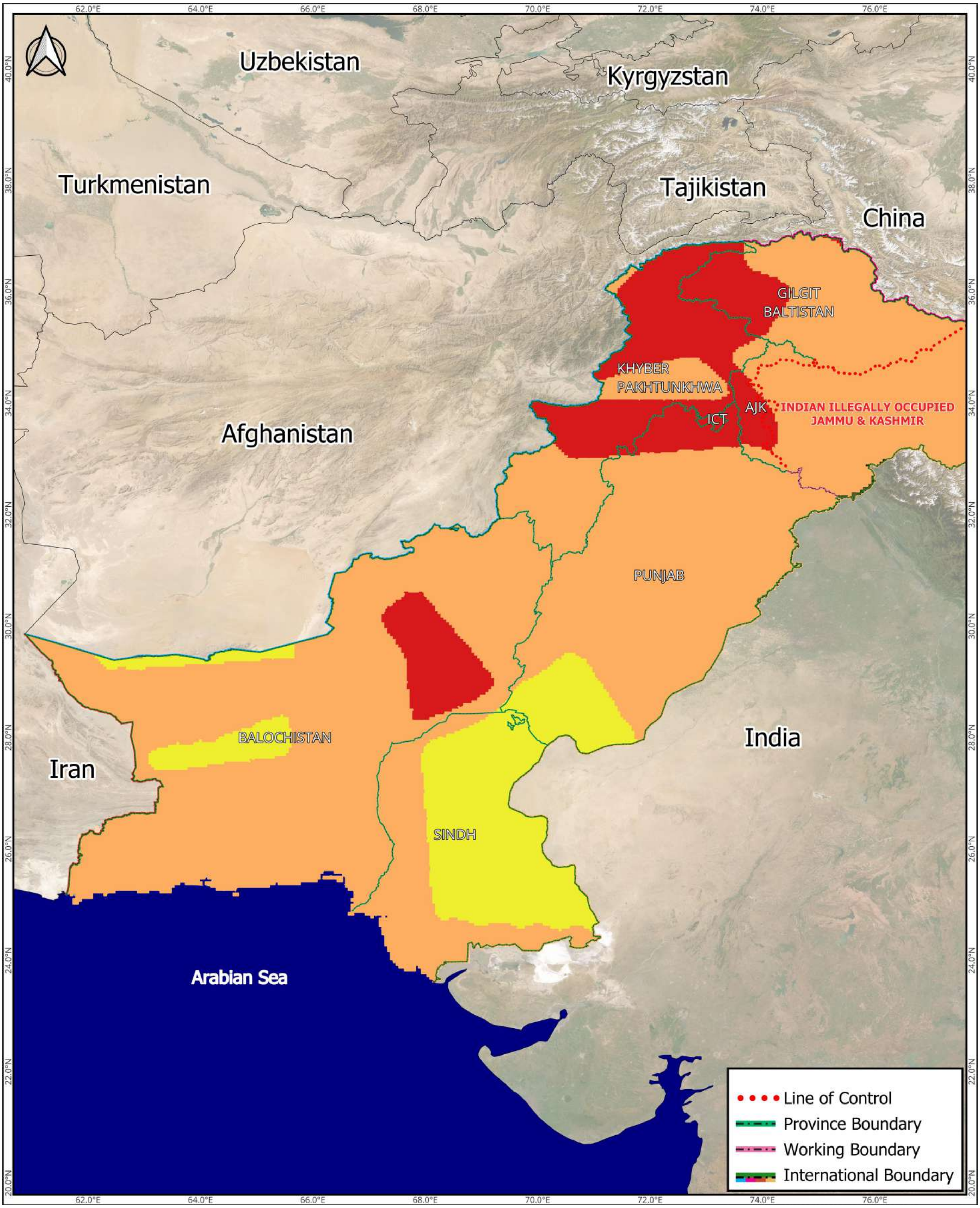
Imagesource: dawn.com

Potential PGA Classes (%)



PGA Classes

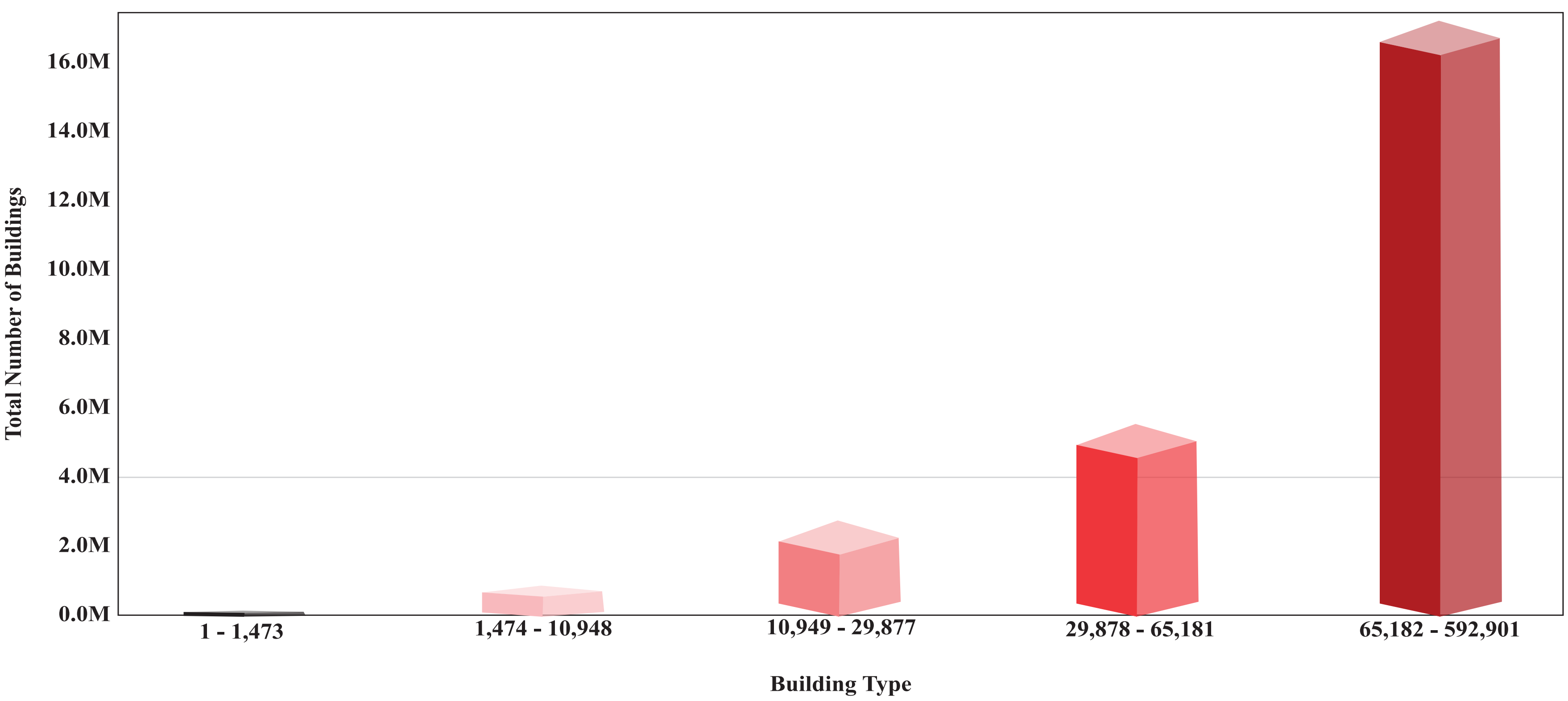
	Severity Class	Area (sq. km)	Percentage
(orange)	Very Strong	725,345.70	73.99
(yellow)	Strong	133,307.65	13.58
(red)	Severe	121,691.13	12.42

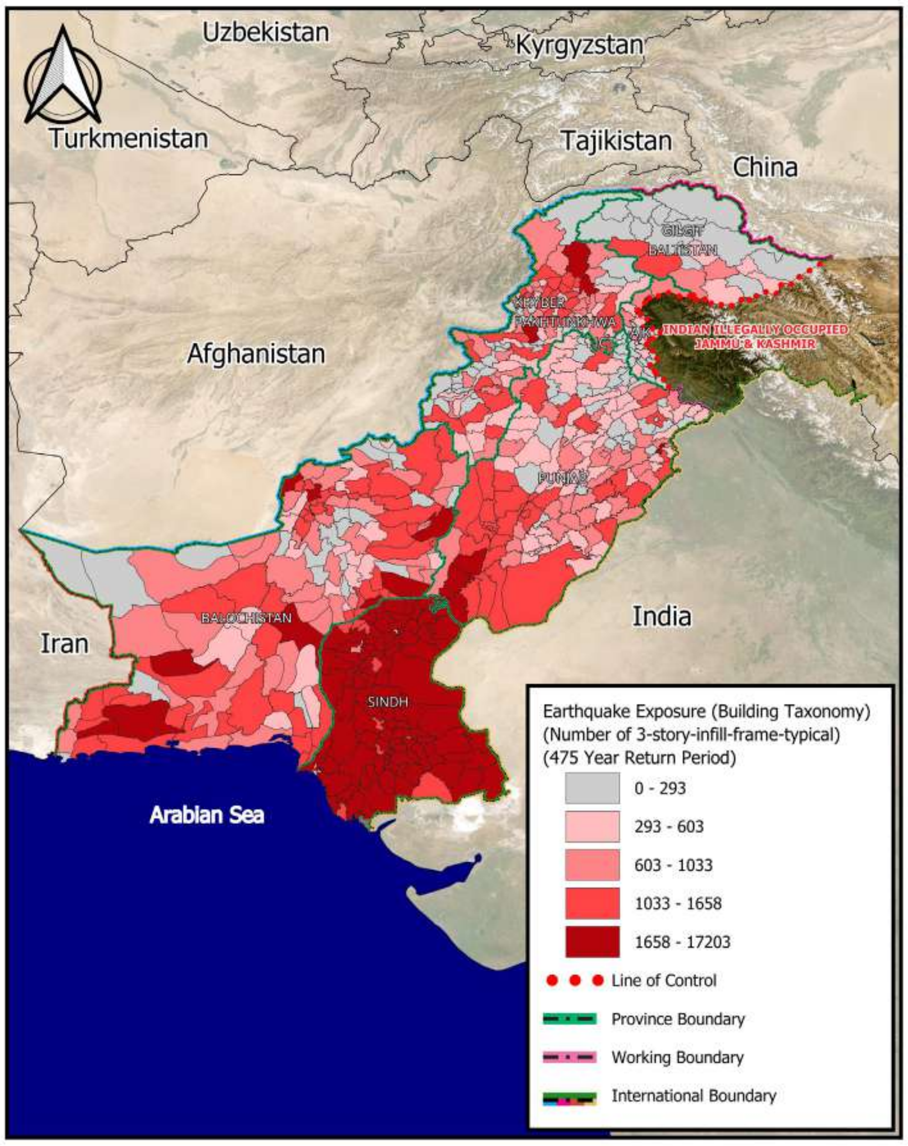

Uzbekistan
Kyrgyzstan
Turkmenistan
Tajikistan
China
GILGIT
BALTISTAN
KHYBER
PAKHTUNKHWA
ICT
AJK
INDIAN ILLEGALLY OCCUPIED
JAMMU & KASHMIR
Afghanistan
PUNJAB
BALOCHISTAN
Iran
India
SINDH
Arabian Sea
Line of Control
Province Boundary
Working Boundary
International Boundary

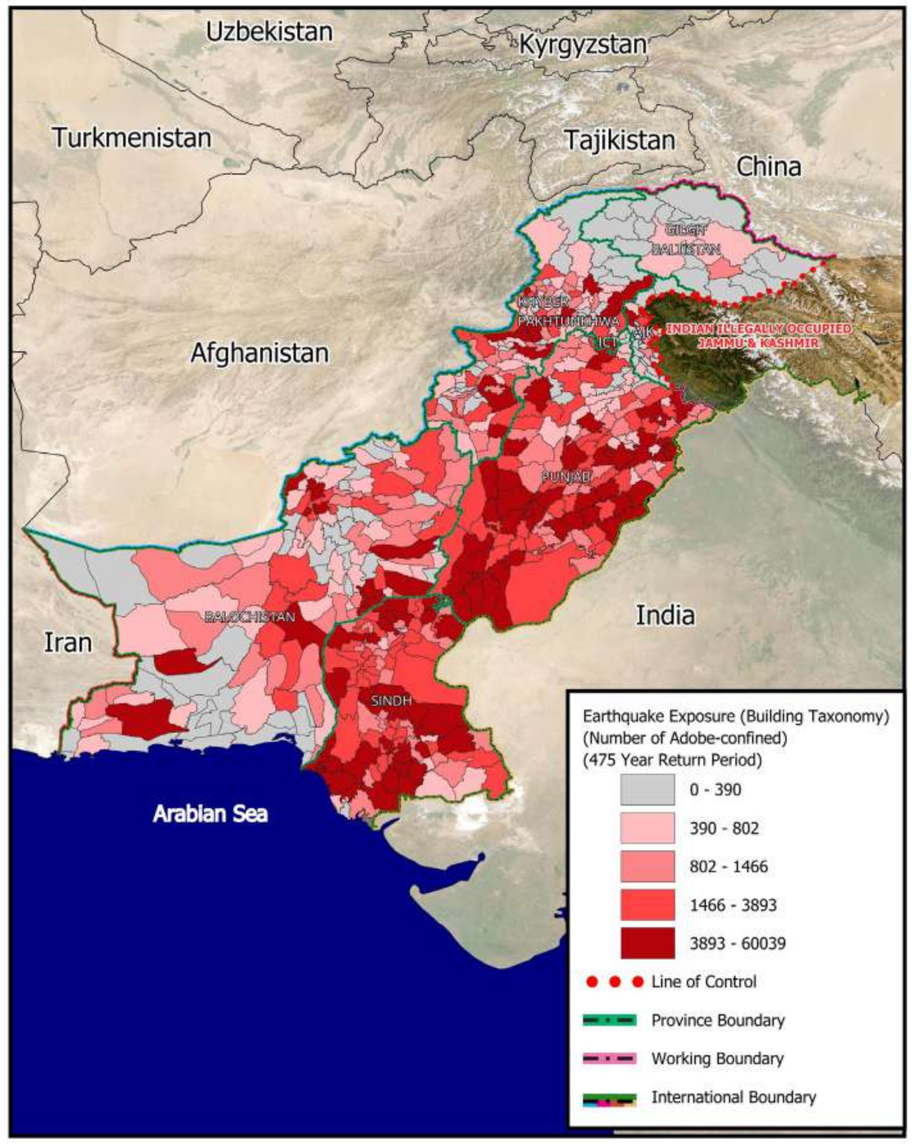
Seismic

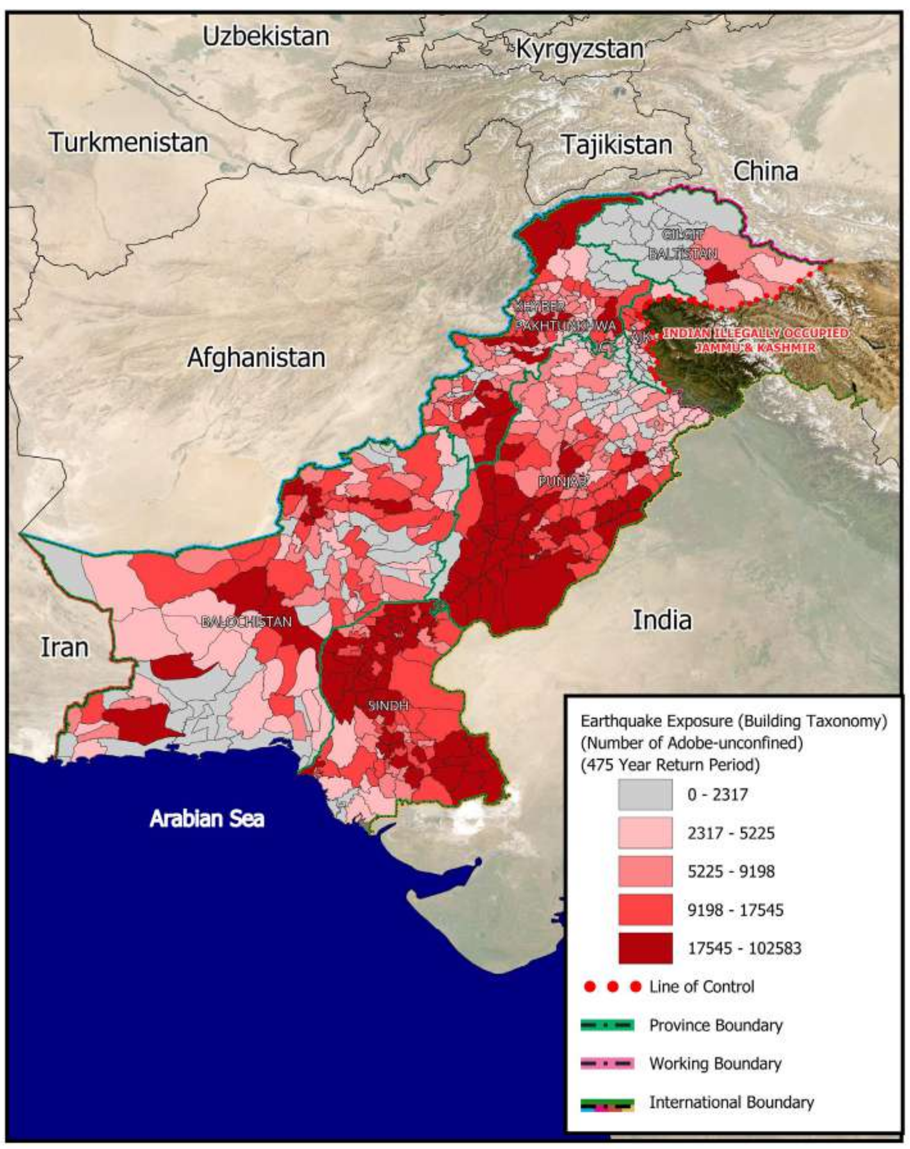
The exposure of builtup areas to seismic hazards in Pakistan was assessed using Peak Ground Acceleration (PGA) values, ranging from Low (PGA: 0.05 - 0.08) to Severe (PGA > 0.32). This classification helps identify regions with varying levels of seismic risk, enabling targeted risk management and resilience strategies for urban development in areas most at risk. This approach also aids in prioritizing infrastructure strengthening and implementing building codes to enhance seismic resilience in vulnerable areas.

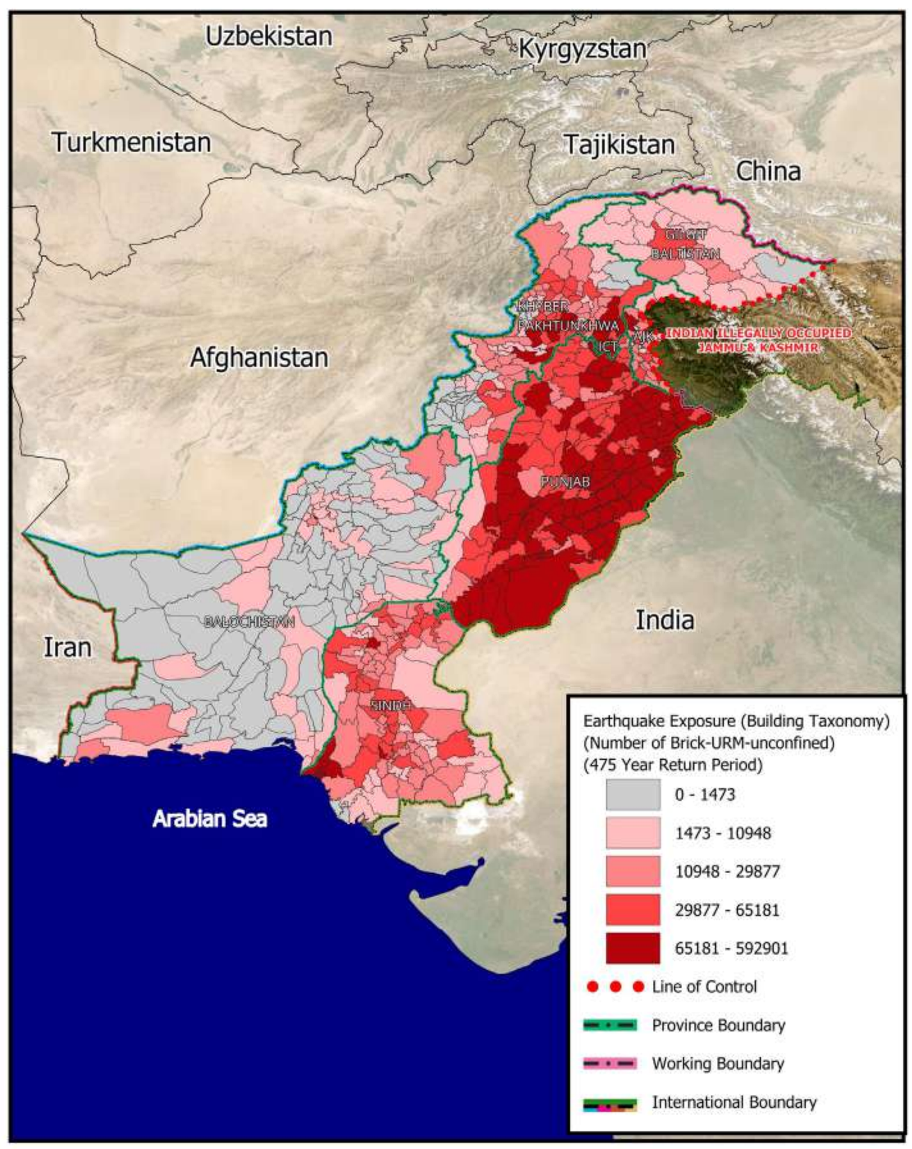
Seismic Exposure




Uzbekistan
Kyrgyzstan
Turkmenistan
Tajikistan
China
Afghanistan
Iran
India
Arabian Sea
BALOCHISTAN
SINDH
PUNJAB
INDIAN ILLEGALLY OCCUPIED JAMMU & KASHMIR
Earthquake Exposure (Building Taxonomy)
(Number of 3-story-infill-frame-typical)
(475 Year Return Period)
0 - 293
293 - 603
603 - 1033
1033 - 1658
1658 - 17203
Line of Control
Province Boundary
Working Boundary
International Boundary


Uzbekistan
Kyrgyzstan
Turkmenistan
Tajikistan
China
Afghanistan
Iran
India
Arabian Sea
BALOCHISTAN
SINDH
PUNJAB
INDIAN ILLEGALLY OCCUPIED JAMMU & KASHMIR
Earthquake Exposure (Building Taxonomy)
(Number of Adobe-confined)
(475 Year Return Period)
0 - 390
390 - 802
802 - 1466
1466 - 3893
3893 - 60039
Line of Control
Province Boundary
Working Boundary
International Boundary


Uzbekistan
Kyrgyzstan
Turkmenistan
Tajikistan
China
Afghanistan
Iran
India
Arabian Sea
BALOCHISTAN
SINDH
PUNJAB
INDIAN ILLEGALLY OCCUPIED JAMMU & KASHMIR
Earthquake Exposure (Building Taxonomy)
(Number of Adobe-unconfined)
(475 Year Return Period)
0 - 2317
2317 - 5225
5225 - 9198
9198 - 17545
17545 - 102583
Line of Control
Province Boundary
Working Boundary
International Boundary

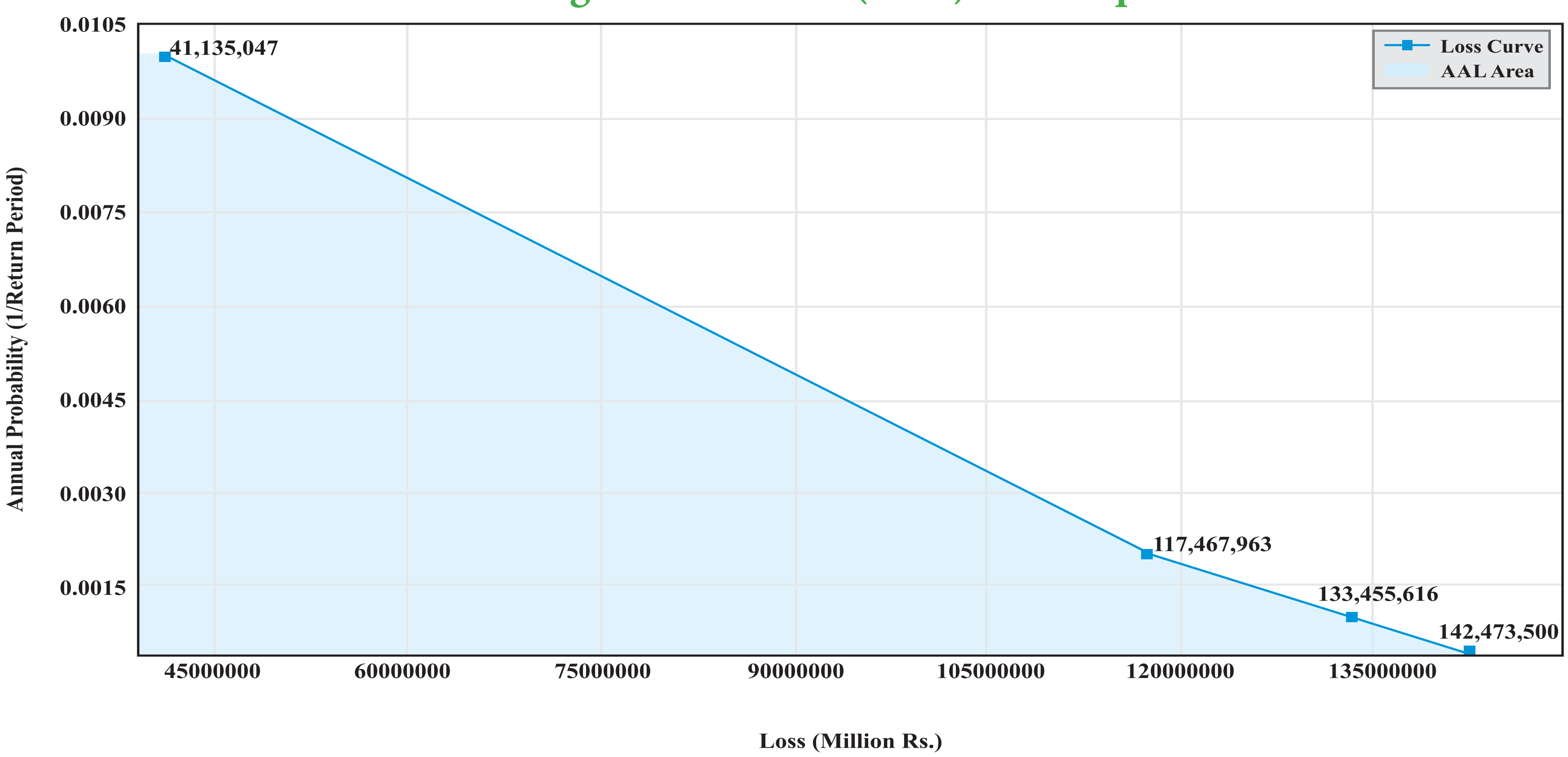

Uzbekistan
Kyrgyzstan
Turkmenistan
Tajikistan
China
Afghanistan
Iran
India
Arabian Sea
BALOCHISTAN
SINDH
PUNJAB
INDIAN ILLEGALLY OCCUPIED JAMMU & KASHMIR
Earthquake Exposure (Building Taxonomy)
(Number of Brick-URM-unconfined)
(475 Year Return Period)
0 - 1473
1473 - 10948
10948 - 29877
29877 - 65181
65181 - 592901
Line of Control
Province Boundary
Working Boundary
International Boundary

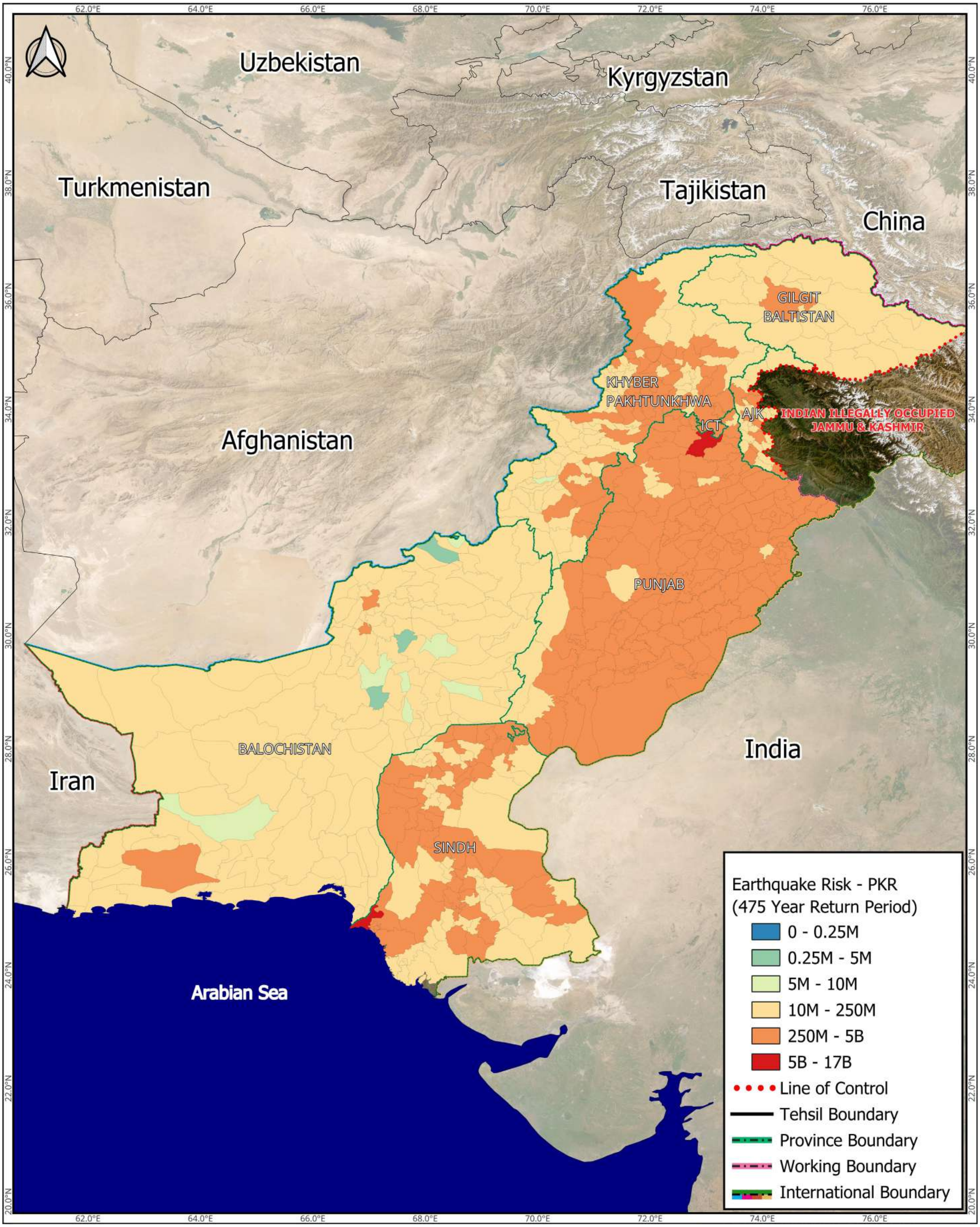
Seismic

Earthquakes pose a major risk to life, infrastructure, and the economy in Pakistan, especially in seismically active regions. The risk arises from both the high hazard level due to tectonic activity and the vulnerability of poorly constructed buildings and dense urban areas. Probabilistic Seismic hazard assessment(PSHA) Data , including peak ground acceleration(PGA) maps, helps to identify the areas at higher risk which estimate potential losss ranging from 0-17 billion. This information is crucial for risk reduction strategies, emergency Planning, and building resilience.

Imagesource: freeimages.com

Average Annual Loss (AAL) - Earthquake





Uzbekistan
Kyrgyzstan
Turkmenistan
Tajikistan
China
GILGIT BALTISTAN
KHYBER PAKHTUNKHWA
AJK
INDIAN ILLEGALLY OCCUPIED JAMMU & KASHMIR
ICT
Afghanistan
PUNJAB
BALOCHISTAN
India
Iran
SINDH
Arabian Sea
Earthquake Risk - PKR
(475 Year Return Period)
0 - 0.25M
0.25M - 5M
5M - 10M
10M - 250M
250M - 5B
5B - 17B
Line of Control
Tehsil Boundary
Province Boundary
Working Boundary
International Boundary

Geo-Physical Hazards - Landslides

Landslides occur due to a combination of geological and hydrological factors, often triggered by rainfall or seismic activity. They lead to loss of life, damage to infrastructure, and disruption of transportation networks. Landslides are frequent in hilly terrains, especially during the rainy season.
Landslide susceptibility was assessed using the Weights of Evidence (WoE) model, incorporating factors like slope, land use, and rainfall. Hazard maps were created for different rainfall scenarios. The outputs include landslide susceptibility maps for three risk levels: low, moderate, and high.

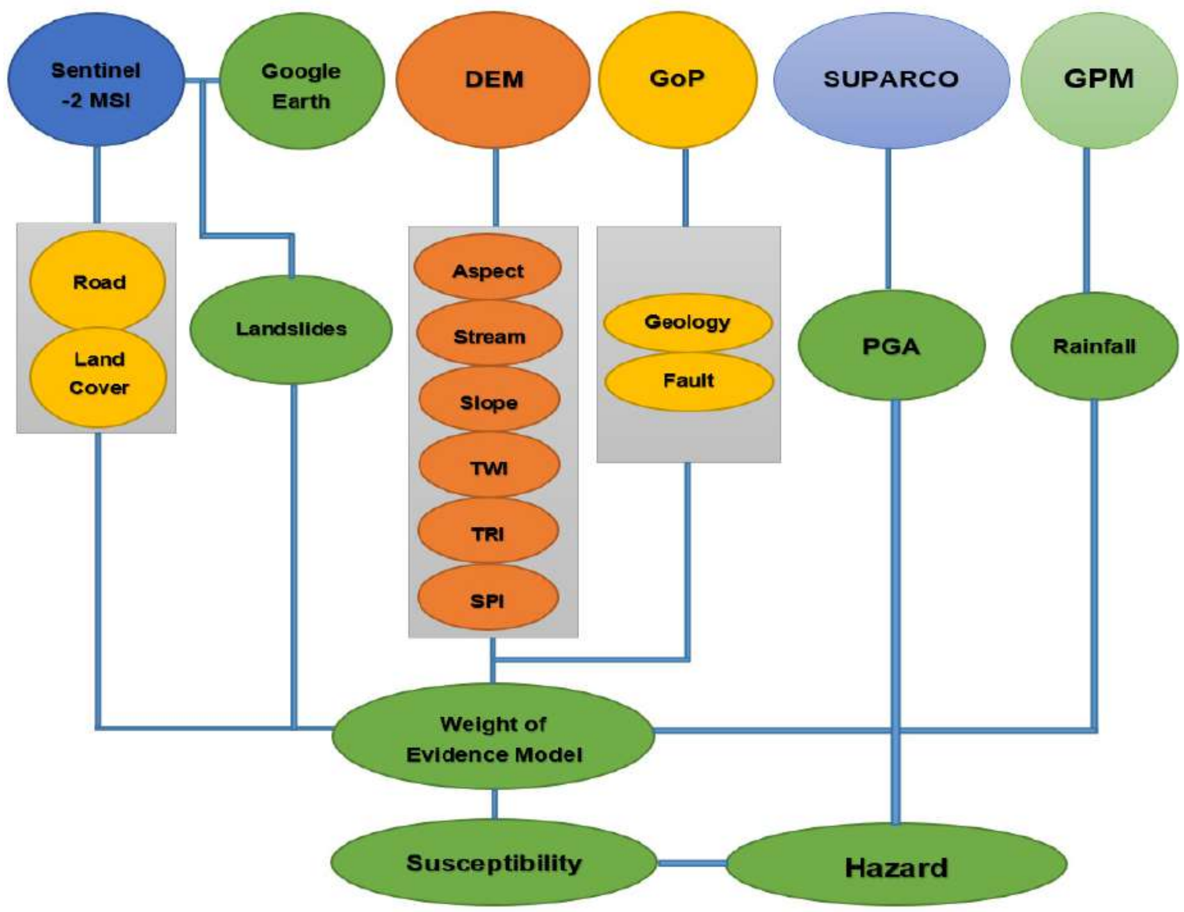
Weight of Evidence (WoE) Model

Landslide susceptibility and hazard assessments involve analysing a combination of landslide data and various controlling parameters to determine the likelihood of landslides occurring. The Weight of Evidence (WoE) Statistical Model was utilized in this process to assess landslide susceptibility and hazard. To calculate landslide hazard assessment, triggering factors, mainly precipitation and seismic parameters (Peak Ground Acceleration), were used.
The WoE model is a data driven model based on the Bayesian method and used prior and conditional probabilities. In this method, the prior probability wass determined based on past landslides without additional information. The prior probability was calculated by dividing the number of pixels with landslides by the total number of pixels in the map. As additional information about each causative factor was obtained, the prior probability was modified into a conditional probability. This approach helped in quantifying the spatial relationship between landslide occurrences and contributing factors.

Data Inputs

The following data layers used in the WoE Statistical Model:
• Slope, aspect, elevation, distance to streams, and curvature, have been derived from the Digital Elevation Model
• Geological maps were utilized to create detailed lithology maps and assess the proximity of areas to fault lines
• Sentinel-2 satellite imagery was employed to generate maps showing distances from roads and landcover types
• Mean of the 5 years rainfall records (2019-2024)

The ROC curve was generated by correlating the landslide validation dataset with the susceptibility map produced by the model. This curve plots the true positive rate (sensitivity) against the false-positive rate (specificity), providing a clear picture of the model's ability to correctly predict landslide occurrences at various threshold levels. The cut-off value or threshold was determined to find the optimal balance between sensitivity and specificity. The validation dataset ensured the accuracy of the WoE model output. Based on ROC curve results, landslide susceptibility was categorized into three levels: low, moderate, and high.



Model Calibration and Validation

The landslide susceptibility model was validated using the Receiver Operating Characteristic (ROC) curve, a statistical tool that helps assess the performance of predictive models.

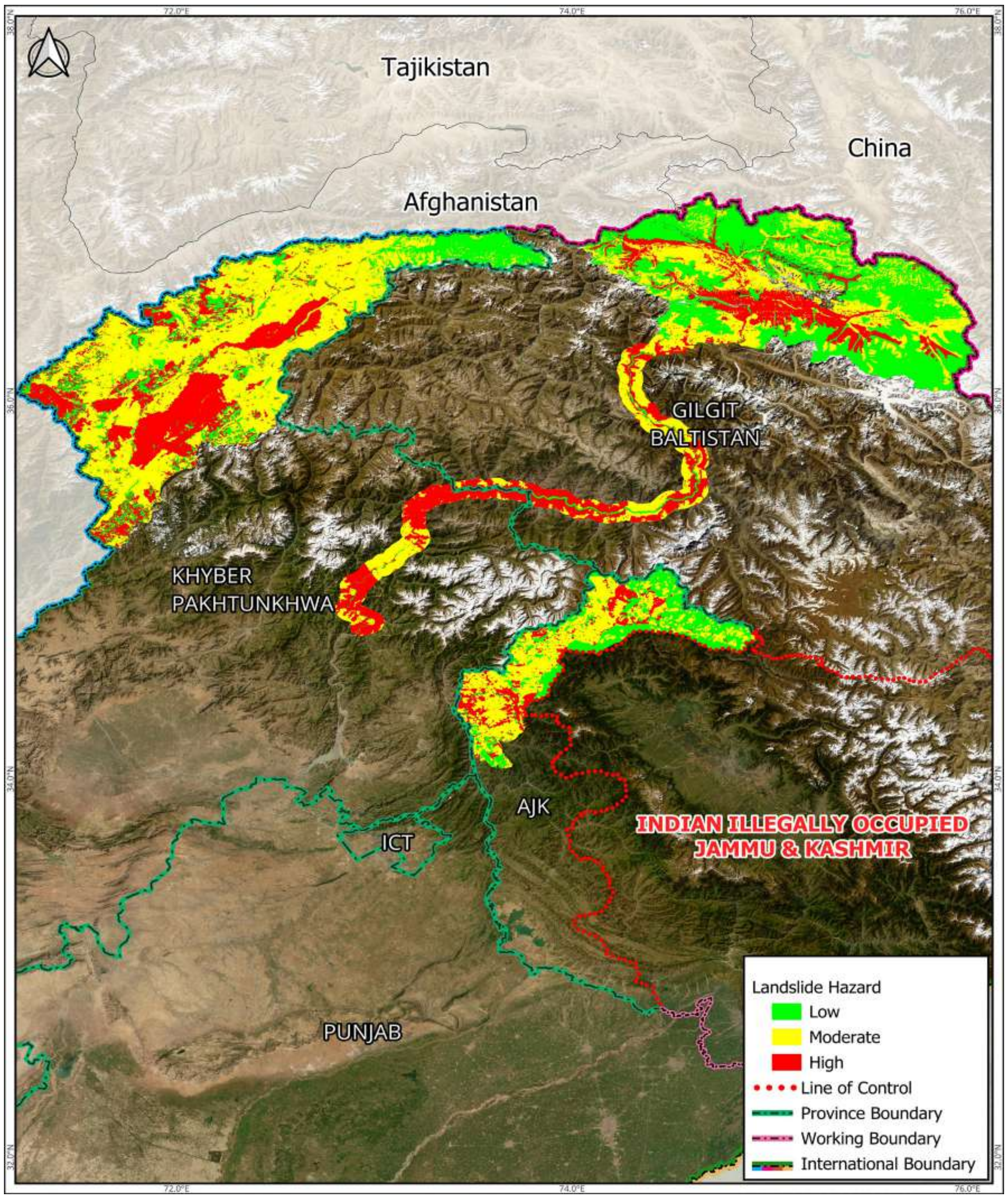
Model Output

The model outputs include landslide susceptibility maps categorized into low, moderate, and high risk zones. These maps quantify spatial probabilities of landslide occurrence based on contributing factors.

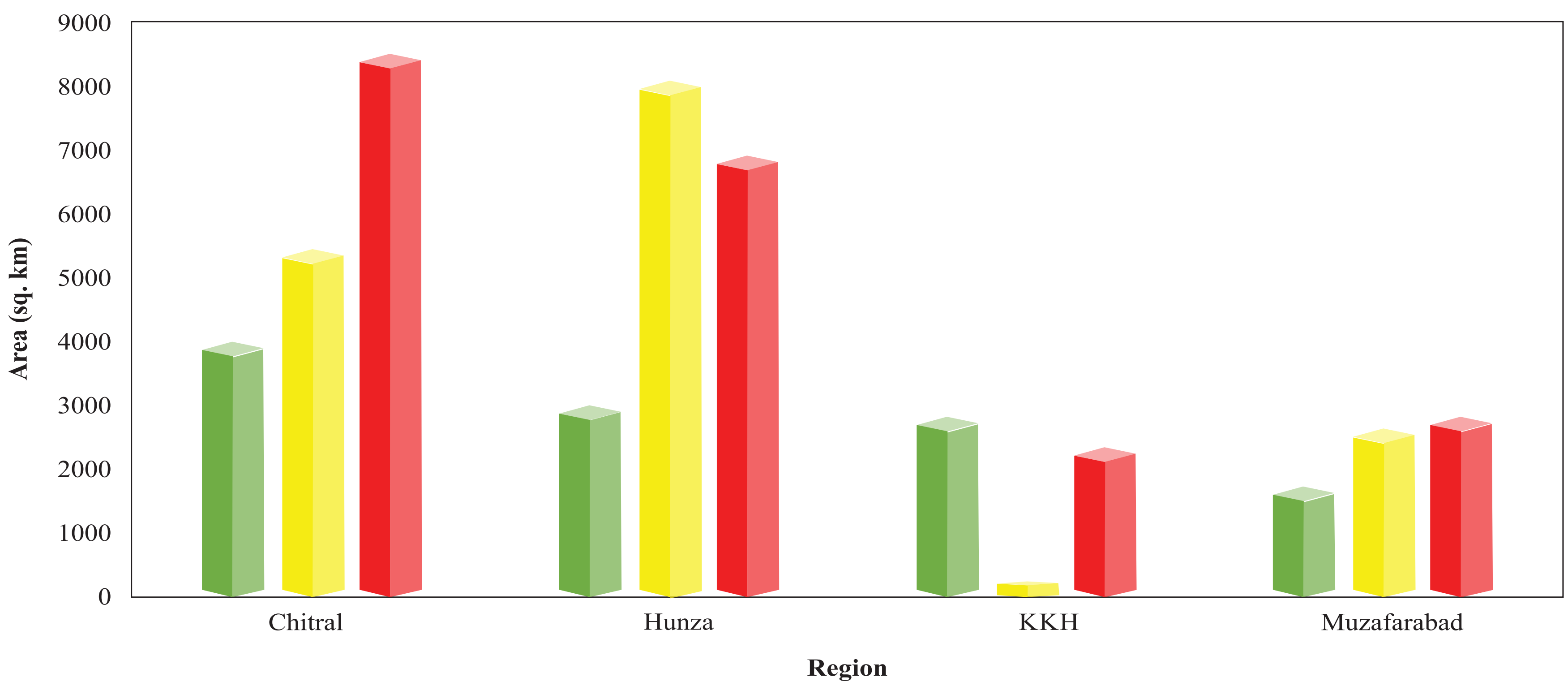
Imagesource: unsplash.com

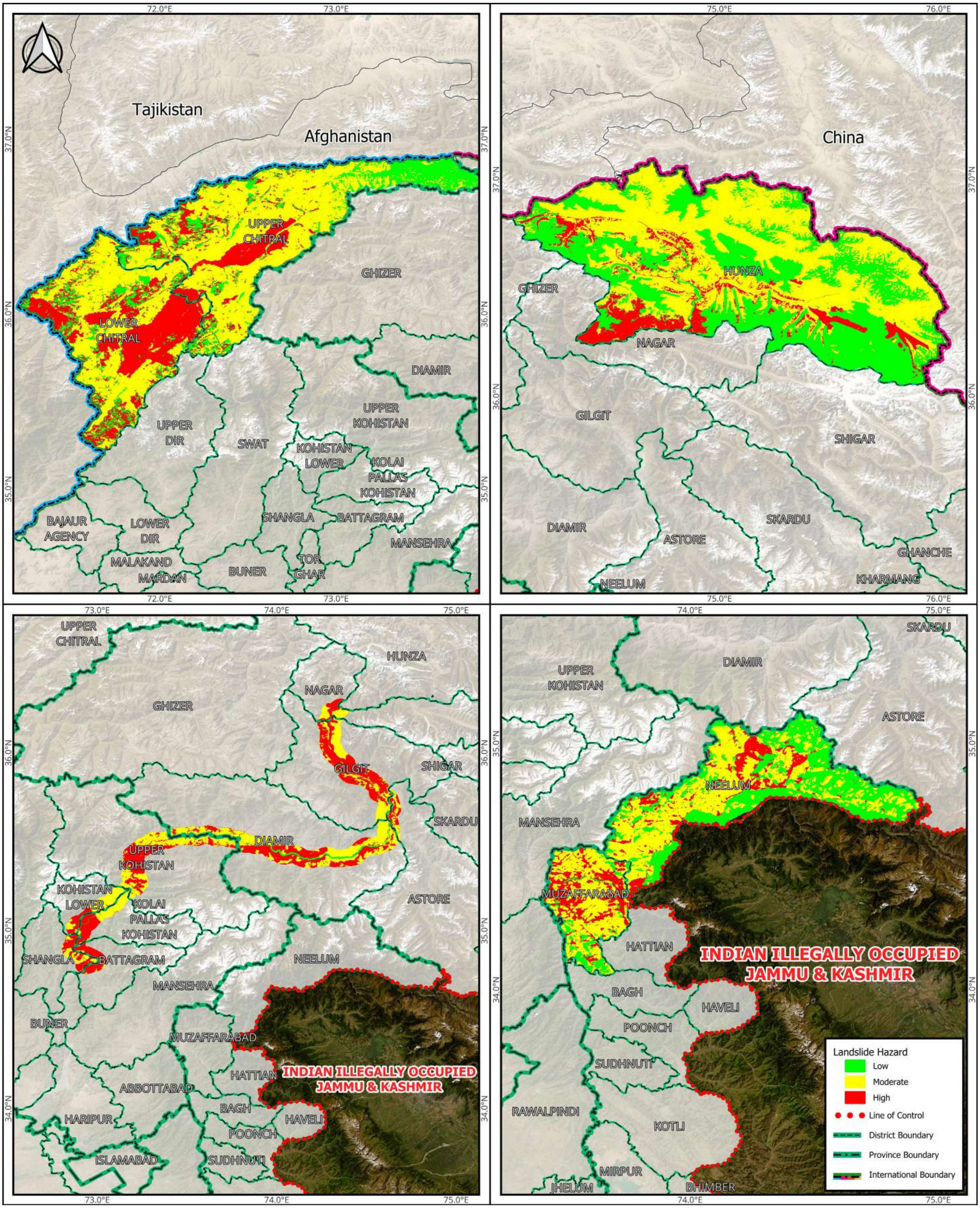
Landslides

Landslides in Pakistan, primarily triggered by intense rainfall or seismic events, are a major hazard, especially in northern regions and along the Karakoram Highway. Notable events like the 2005 Kashmir earthquake and heavy rains in 2024 led to significant fatalities and infrastructure damage due to landslides. To assess landslide susceptibility, the Weights of Evidence (WoE) model was employed, analyzing key factors such as topography, hydrology, land use and anthropogenic factors. Detailed hazard maps were generated, categorizing risk levels into low, moderate, and high, supporting mitigation efforts and informed land use planning.



Potential Landslide Hazard Classes

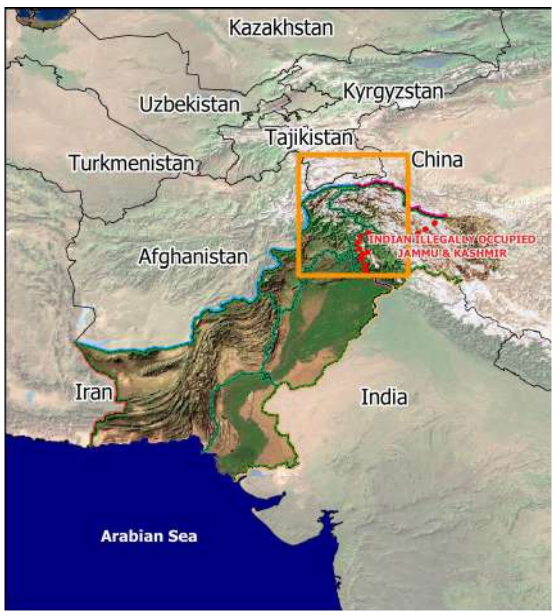




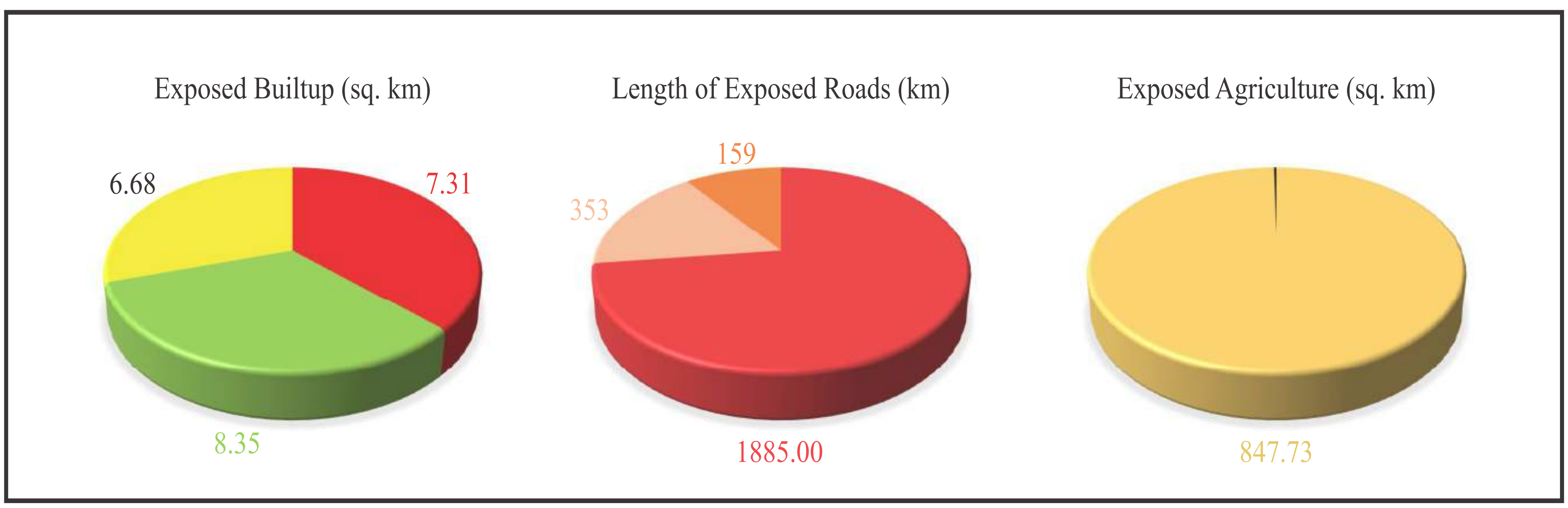
Tajikistan
Afghanistan
UPPER CHITRAL
LOWER CHITRAL
GHIZER
DIAMIR
UPPER KOHISTAN
UPPER DIR
SWAT
KOHISTAN LOWER
KOLAI PALLAS KOHISTAN
BAJAUR AGENCY
LOWER DIR
SHANGLA
BATTAGRAM
MANSEHRA
MALAKAND
MARDAN
BUNER
TOR GHAR
China
HUNZA
NAGAR
GILGIT
SHIGAR
ASTORE
SKARDU
GHANCHE
KHARMANG
NEELUM
MUZAFFARABAD
HATTIAN
BAGH
HAVELI
POONCH
SUDHNUTI
ABBOTTABAD
HARIPUR
ISLAMABAD
RAWALPINDI
KOTLI
MIRPUR
JHELUM
BHIMBER
INDIAN ILLEGALLY OCCUPIED JAMMU & KASHMIR
Landslide Hazard
Low
Moderate
High
Line of Control
District Boundary
Province Boundary
International Boundary
72.0°E
73.0°E
74.0°E
75.0°E
76.0°E
34.0°N
35.0°N
36.0°N
37.0°N

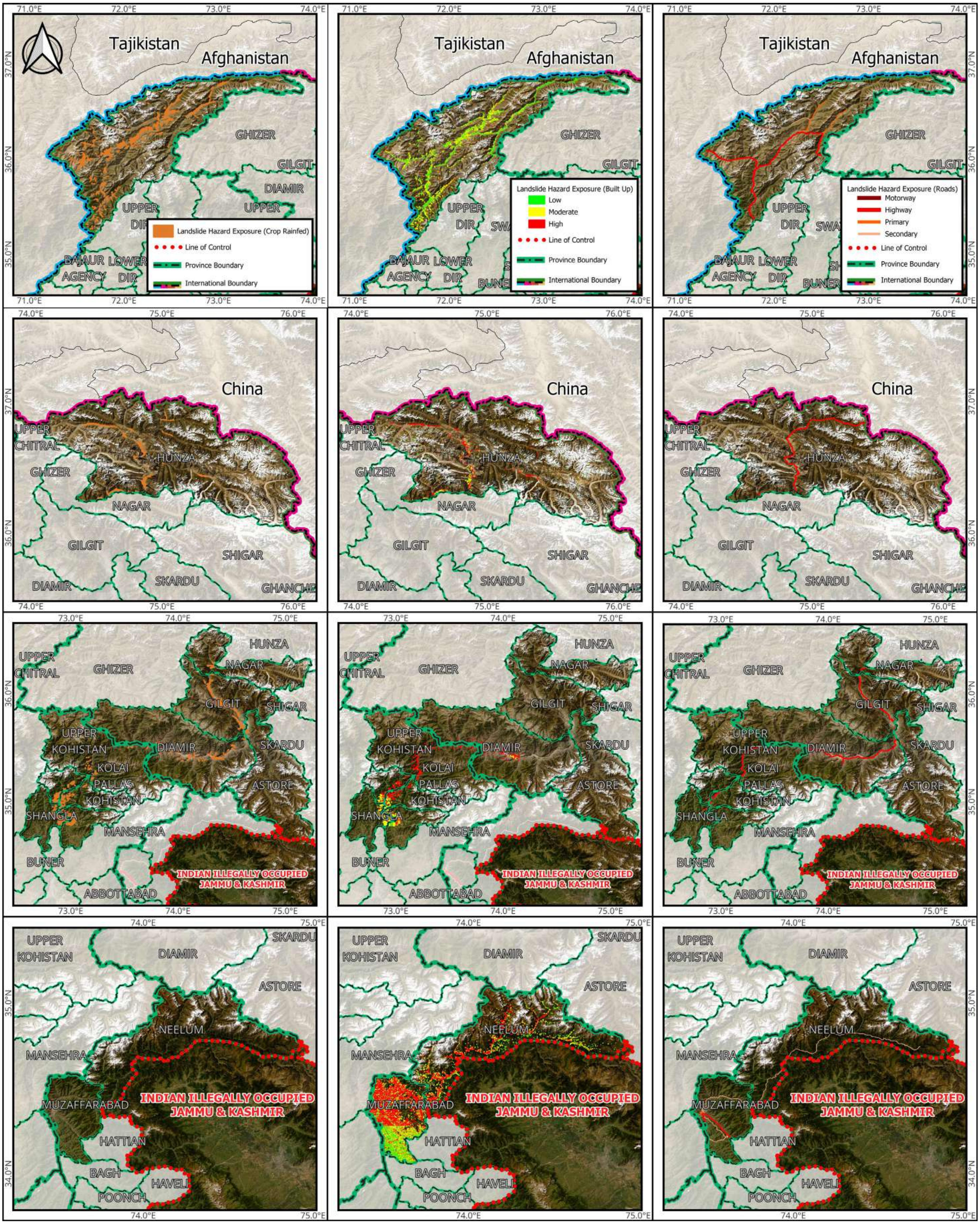
Landslides

The Landslides significantly impact agriculture, builtup areas, and roads. In agriculture, they destroy crops, erode soil, and damage irrigation, reducing productivity. Builtup areas face risks of structural damage, loss of life, and economic losses, especially where consturction occurs on unsatble slopes. Roads are often Blocked or destroyed by landslide, disrupting transportations, isolating communities, and increasing repair costs. These sectors are highly exposed, particularly in hilly and poorly planned regions.



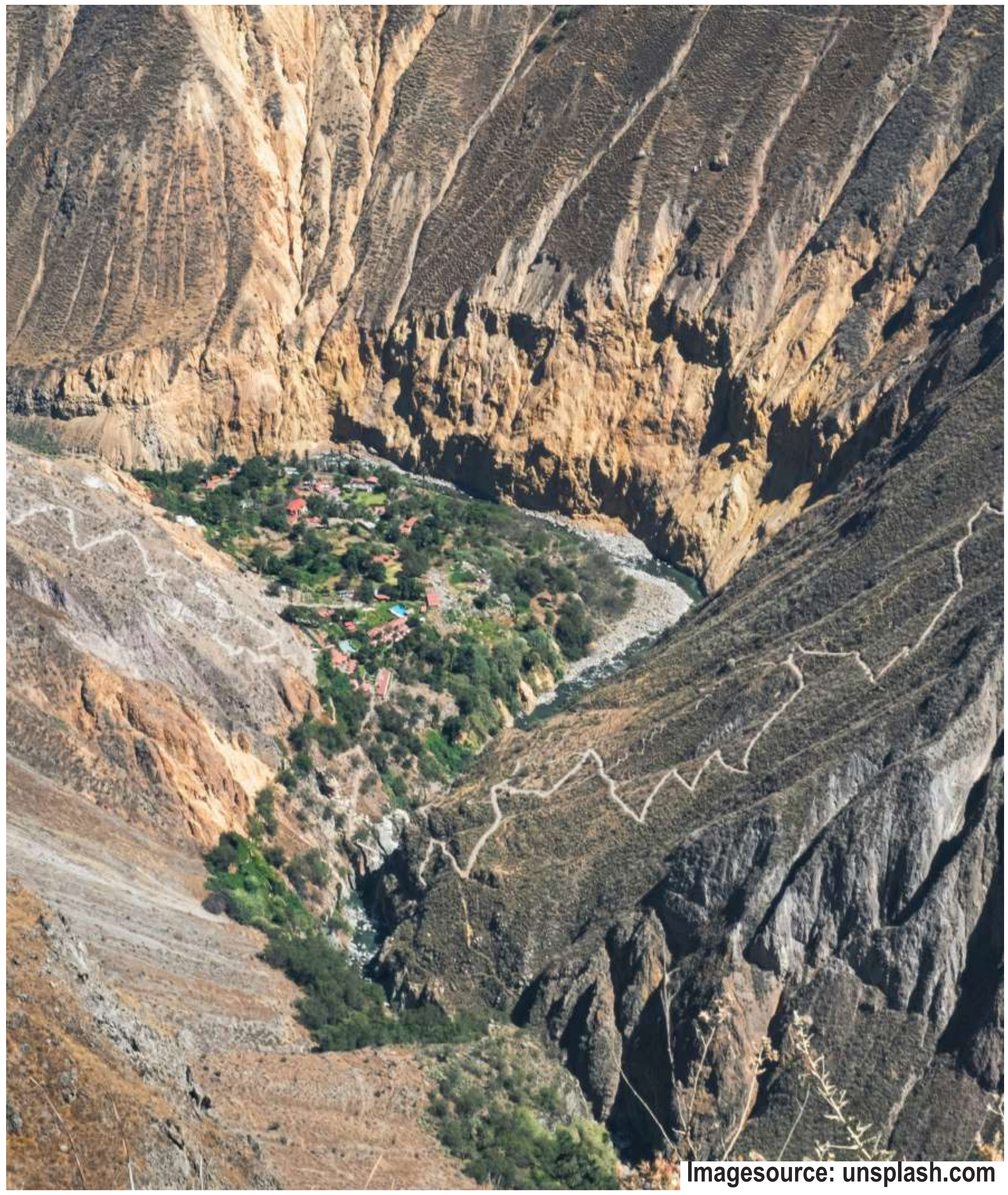
Potential Exposure of Key Sectors



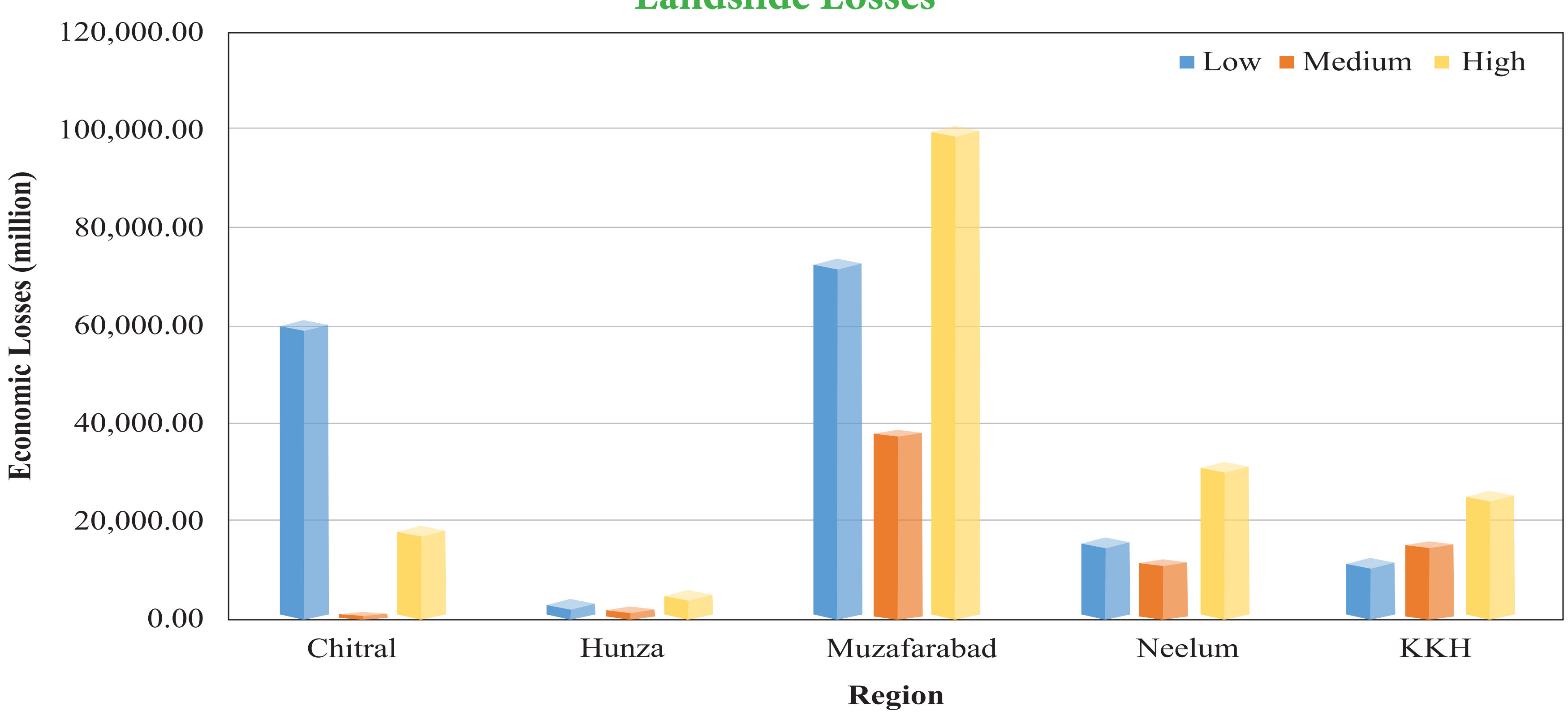

Tajikistan
Afghanistan
China
Landslide Hazard Exposure (Crop Rainfed)
Landslide Hazard Exposure (Built Up)
Low
Moderate
High
Landslide Hazard Exposure (Roads)
Motorway
Highway
Primary
Secondary
Line of Control
Province Boundary
International Boundary
GHIZER
GILGIT
DIAMIR
UPPER DIR
LOWER DIR
BAJAUR AGENCY
SWAT
BUNER
UPPER CHITRAL
HUNZA
NAGAR
SHIGAR
SKARDU
GHANCHE
ASTORE
UPPER KOHISTAN
KOLAI PALLAS
KOHISTAN
SHANGLA
MANSEHRA
ABBOTTABAD
INDIAN ILLEGALLY OCCUPIED JAMMU & KASHMIR
NEELUM
MUZAFFARABAD
HATTIAN
BAGH
HAVELI
POONCH
71.0°E
72.0°E
73.0°E
74.0°E
75.0°E
76.0°E
34.0°N
35.0°N
36.0°N
37.0°N

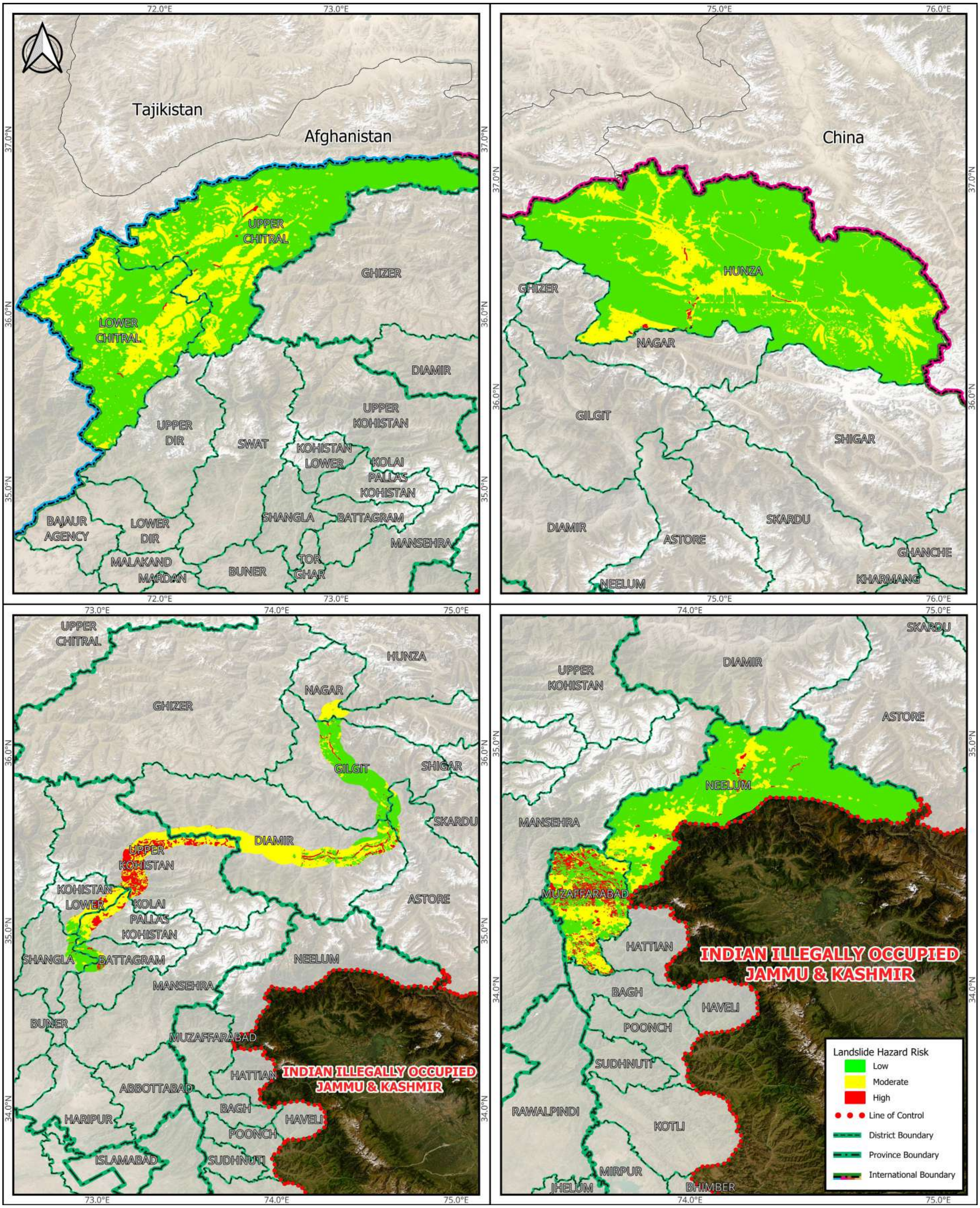
Landslides

This risk is influenced by a combination of factors including the susceptibility of the terrain to landslides, the triggering events, and the magnitude of the potential impacts on people, property, and infrastructure. Landslide risk is often conceptualized as the product of vulnera-bility and hazard This formulation helps in understanding the different components that con-tribute to the overall risk and in developing appropriate strategies to mitigate it. Hazard maps were created to classify risk into three categories: Low, Moderate, and High.



Landslide Losses




Tajikistan
Afghanistan
UPPER CHITRAL
LOWER CHITRAL
GHIZER
DIAMIR
UPPER KOHISTAN
UPPER DIR
SWAT
KOHISTAN LOWER
KOLAI PALLAS KOHISTAN
BAJAUR AGENCY
LOWER DIR
SHANGLA
BATTAGRAM
MANSEHRA
MALAKAND
MARDAN
BUNER
TOR GHAR
China
HUNZA
NAGAR
GILGIT
SHIGAR
ASTORE
SKARDU
GHANCHE
NEELUM
KHARMANG
MUZAFFARABAD
HATTIAN
BAGH
HAVELI
POONCH
SUDHNUTI
ABBOTTABAD
HARIPUR
ISLAMABAD
INDIAN ILLEGALLY OCCUPIED JAMMU & KASHMIR
RAWALPINDI
KOTLI
MIRPUR
JHELUM
BHIMBER
Landslide Hazard Risk
Low
Moderate
High
Line of Control
District Boundary
Province Boundary
International Boundary
72.0°E
73.0°E
74.0°E
75.0°E
76.0°E
34.0°N
35.0°N
36.0°N
37.0°N

Geo-Physical Hazards - Tsunami

A tsunami is a sequence of ocean waves with exceptionally long wavelengths and periods, often caused by large-scale disturbances beneath the ocean surface. These include underwater earthquakes, volcanic eruptions, landslides, or meteorite impacts that displace water and generate powerful waves. The Makran Subduction Zone (MSZ), offshore along Pakistan's southern coast, is a major tsunami threat. This tectonic boundary, where the Arabian Plate subducts beneath the Eurasian Plate, experiences frequent seismic activity. The potential for large earthquakes makes the area highly susceptible to tsunamis that could affect coastal communities. As such, the MSZ is a key concern for tsunami risk management in Pakistan, requiring focused monitoring and preparedness.

GeoClaw Model

The GeoClaw model is a specialized hydrodynamic tool designed to simulate geophysical flows, including floodwaters, storm surges, and tsunamis. It is part of the broader Clawpack (Conservation Laws Package) software for solving hyperbolic partial differential equations. GeoClaw excels at simulating flows over complex topography, such as coastlines, rivers, and urban areas, with a focus on coastal hazards and inundation modeling. In this study, GeoClaw is used to simulate the full lifecycle of tsunamis triggered by tectonic events, including initiation, propagation, and coastal inundation. Known for accurately modeling complex tsunami dynamics, GeoClaw is a preferred choice for real-world scenarios. The code has been validated through benchmarking studies, ensuring reliability in predicting tsunami behavior. Endorsed by the US National Tsunami Hazard Mitigation Program (NTHMP), GeoClaw is recognized as a trusted tool for tsunami hazard assessment. Its application in this study supports accurate prediction of tsunami impacts in regions like Pakistan, particularly along the Makran coast.

Data Inputs

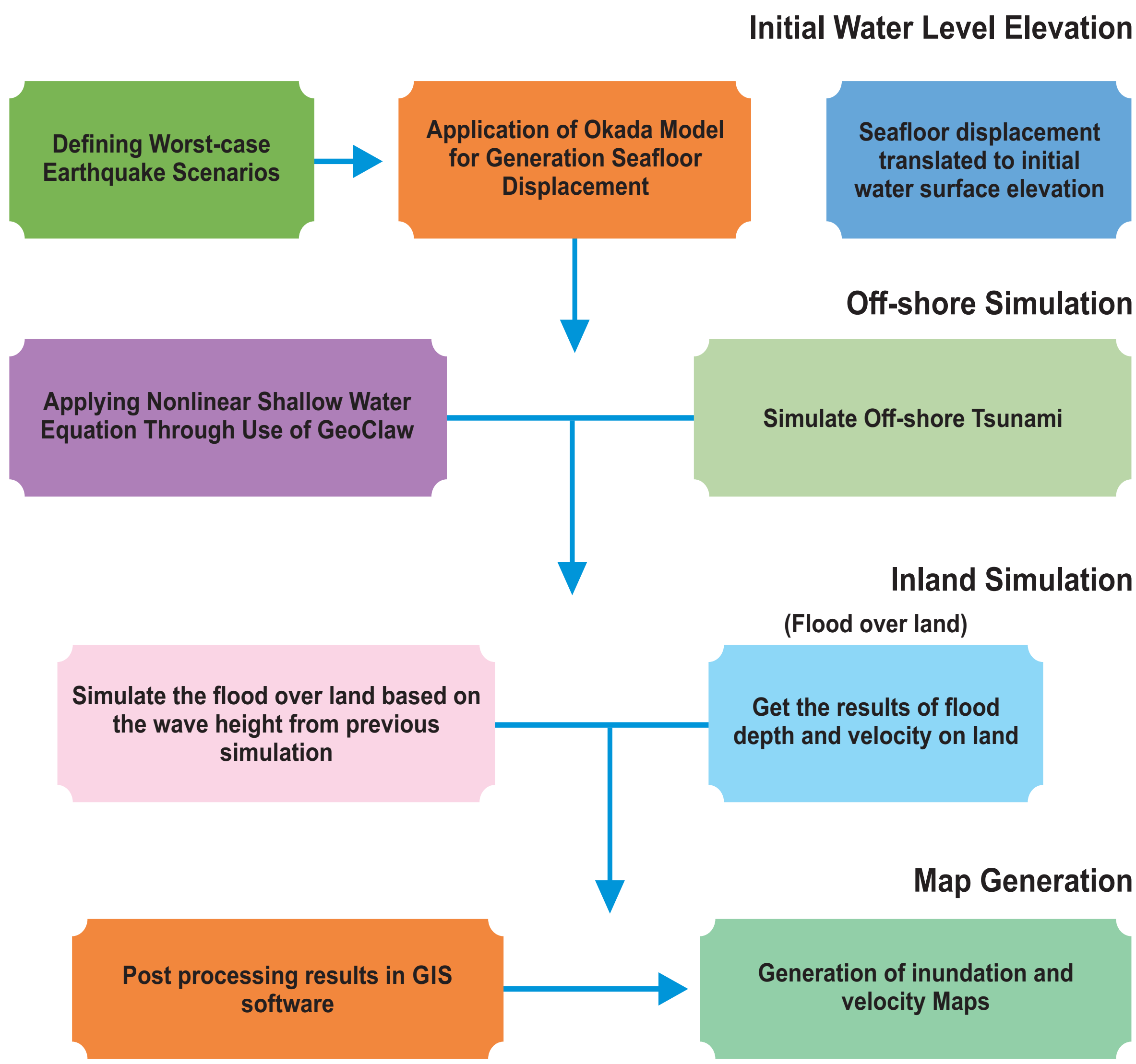
The model uses a Digital Elevation Model to capture topography, along with astronomical tide data to reflect tidal influences. Earthquake scenarios are used to simulate tsunami initiation and behavior.

Model Calibration and Validation

The simulations were carried out over a resolution of 30 m for all the cities under consideration for the studies. The total duration for which the simulations were carried out differs for the cities along the Makran coast and Karachi. The total duration of simulations for the Makran's coastal cities was six hours whereas for Karachi it was twelve hours. The longer duration for Karachi was chosen as it is further to the East of the Subduction zone as compared to the coastal cities along the Makran coast which vary from a few tens of kilometres to a few hundreds of meters.

Model Output

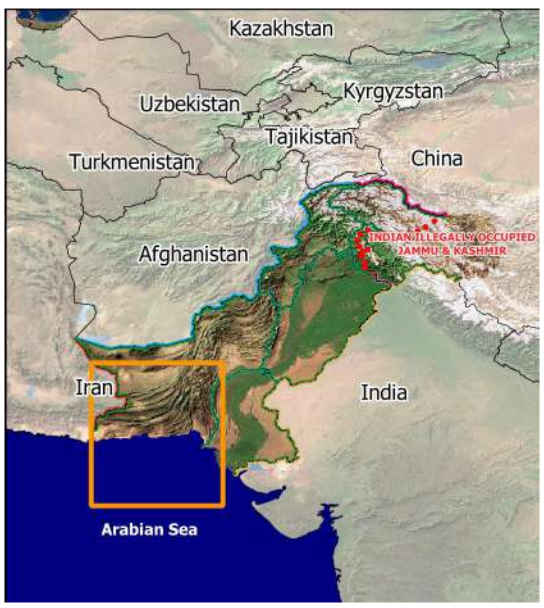
The GeoClaw model outputs include simulated tsunami wave arrival times, wave heights, and inundation extents for various coastal locations. These results help assess potential flooding and tsunami impact levels. The model provides spatially detailed hazard maps and time-series data to support risk assessment, emergency planning, and early warning systems for areas like the Makran coast and Karachi.



Imagesource: unsplash.com

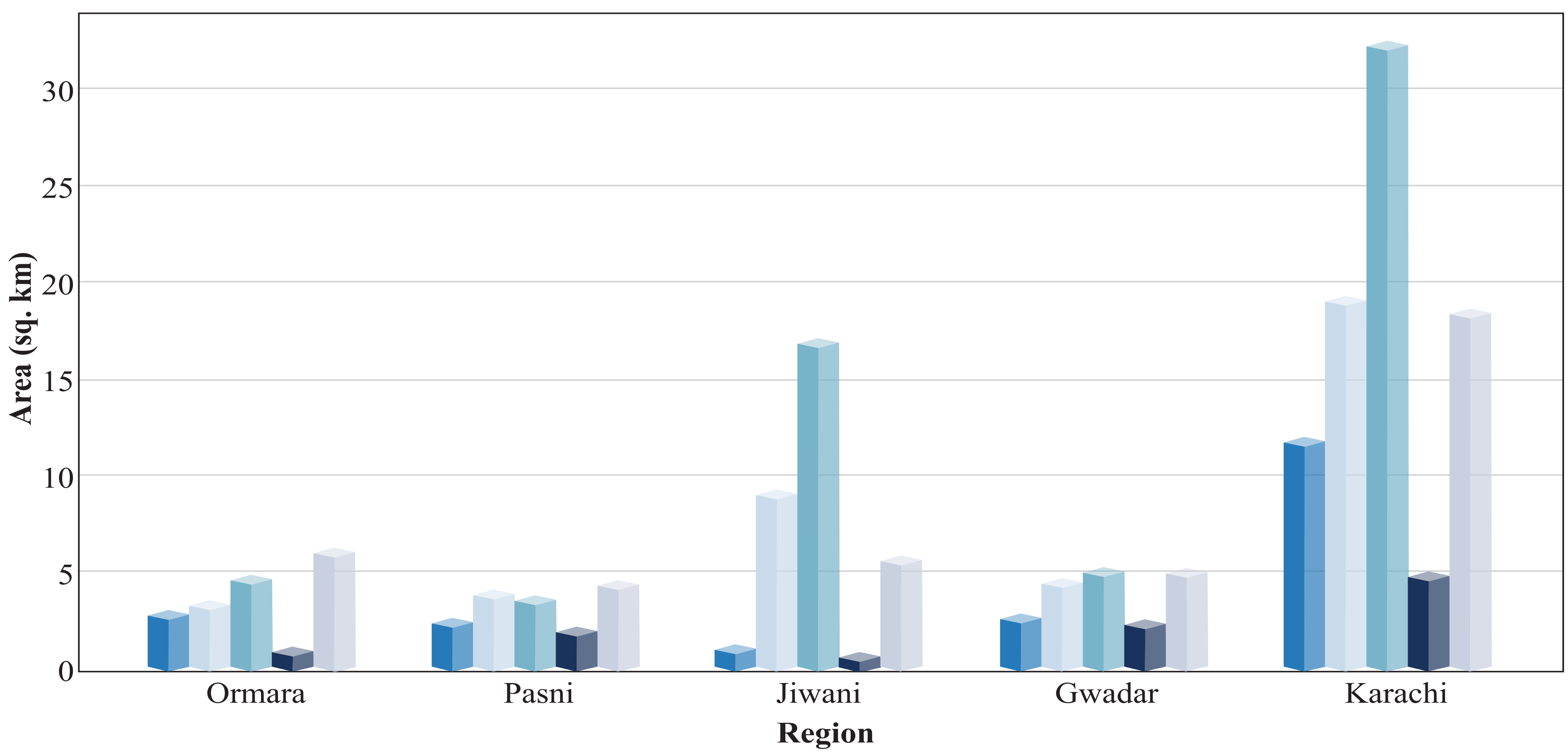
Tusnami

A tsunami is a series of ocean waves caused by disturbances like underwater earthquakes, volcanic eruptions, or landslides. The Makran Subduction Zone, off Pakistan's coast, poses a significant tsunami threat, as the Arabian plate slides under the Eurasian plate. This zone has a history of generating tsunamis, including a notable event in the mid-20th century. Scenario based simulation outputs were used to genertate detailed hazard maps categorizing on the basis of inland inundation due to tidal waves.



Imagesource: unsplash.com

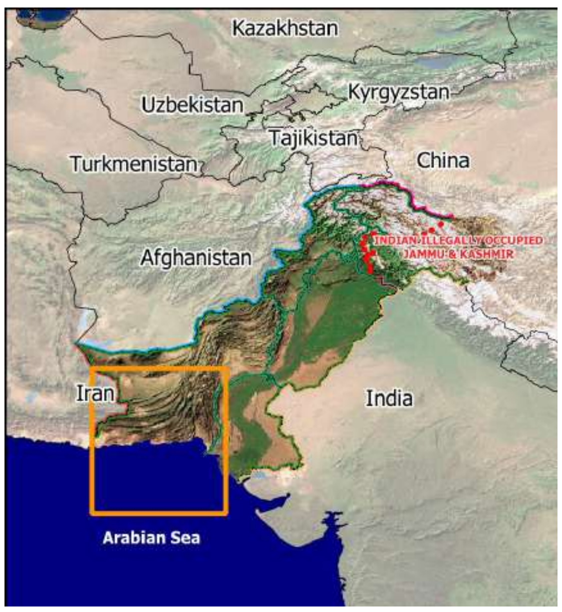
Potential Tsunami Hazard Classes



Ormara
Pasni
Gwadar
Karachi
Tsunami Hazard
(8.87 Moment Magnitude)
Very Low
Low
Moderate
High
Very High

Tsunami

Road networks and builtup areas along Pakistan's coastline face varying levels of tsunami exposure, from Very Low to Very High. Roads in urban centers and key infrastructure corridors are vulnerable to inundation, erosion, and damage, while highly exposed coastal settlements risk severe disruption. Identifying these zones is crucial for planning emergency response, optimizing evacuation routes, and enhancing resilience in tsunami prone regions.



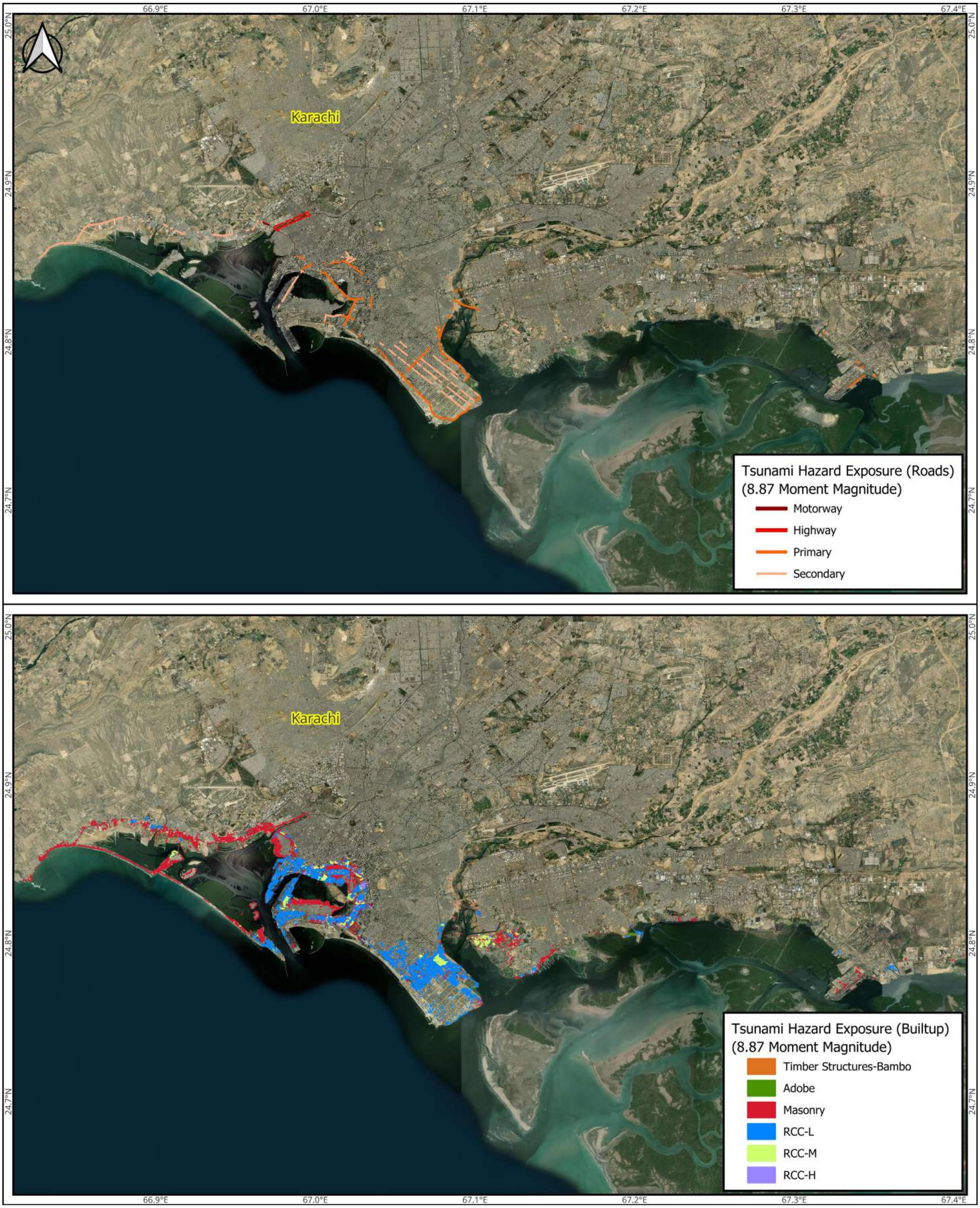

Imagesource: unsplash.com

Exposed Builtup

Typology	Area (sq. km)	Percentage
Adobe	0.0075	0.12
Masonry	2.5259	40.38
RCC-H	0.1586	2.53
RCC-L	3.0482	48.72
RCC-M	0.5155	8.24

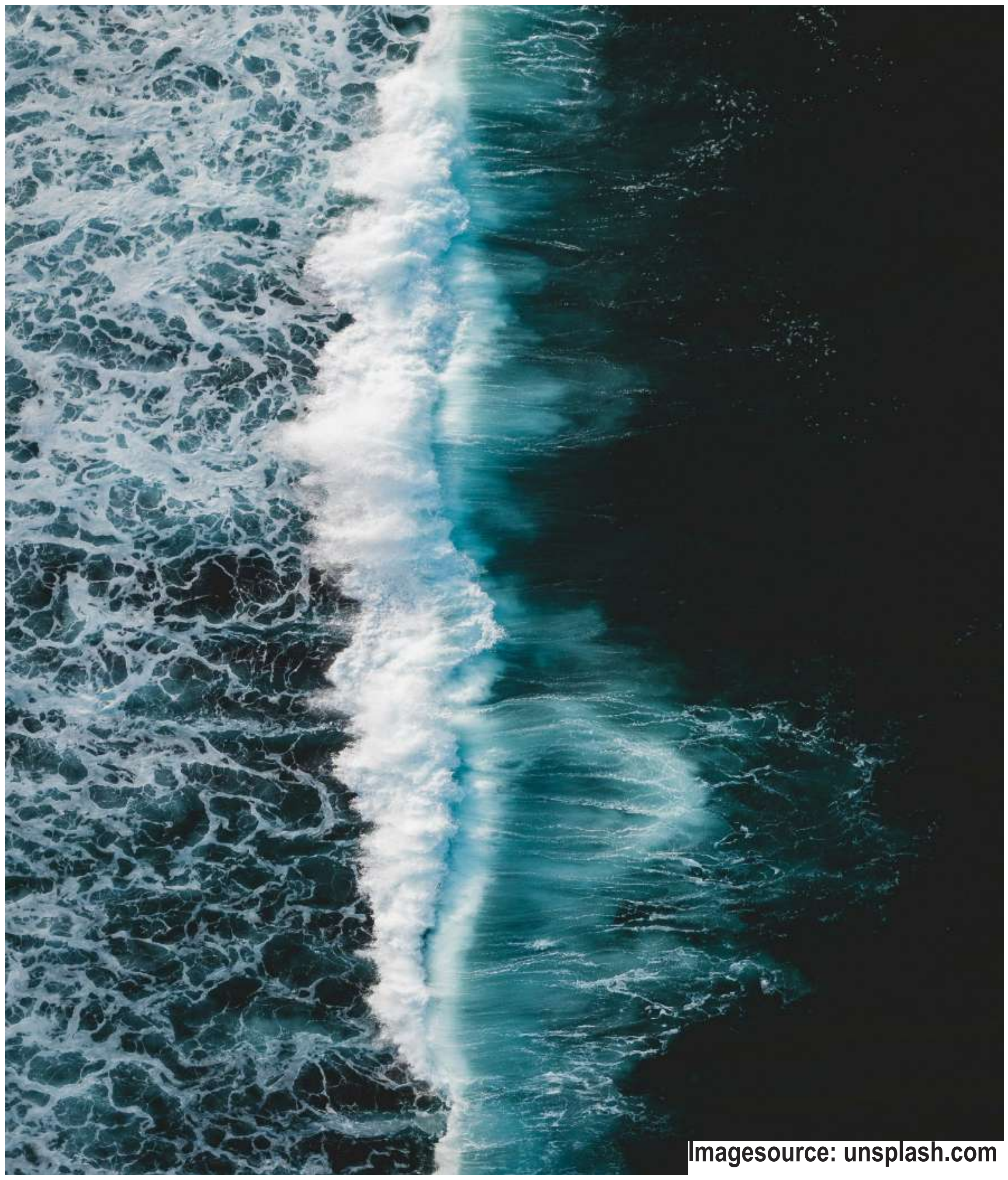
Exposed Roads

Road Type	Length (km)	Percentage
Motorway	0.248	0.22
Primary	50.692	45.23
Highway	2.934	2.62
Secondary	58.251	51.93


66.9°E
67.0°E
67.1°E
67.2°E
67.3°E
67.4°E
25.0°N
24.9°N
24.8°N
24.7°N
Karachi
Tsunami Hazard Exposure (Roads)
(8.87 Moment Magnitude)
Motorway
Highway
Primary
Secondary
Karachi
Tsunami Hazard Exposure (Builtup)
(8.87 Moment Magnitude)
Timber Structures-Bambo
Adobe
Masonry
RCC-L
RCC-M
RCC-H

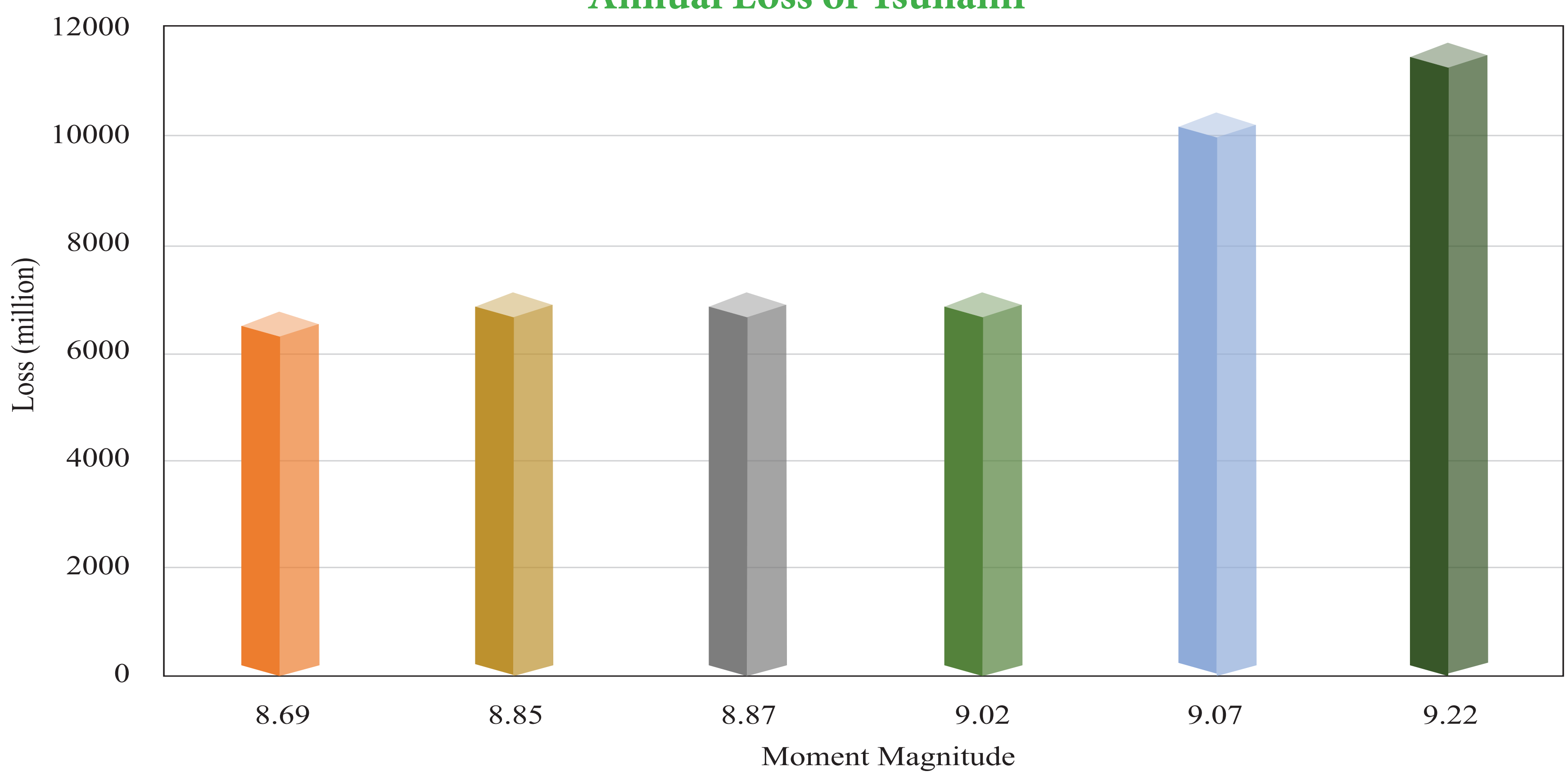
Tusnami

Tsunami hazard risk and loss assessment was performed using deterministic scenario based approach involving moment magnitude and the incurred accumulated losses of associated elements at risk; roads and builtup areas. Quantitative and qualitative risk assessment of risk depicts a comprehensive picture of vulnerable areas aiding in prompt and informed decision making.



Imagesource: unsplash.com

Annual Loss of Tsunami




Ormara
Pasni
Gwadar
Karachi
Tsunami Hazard Risk
(8.87 Moment Magnitude)
5M - 100M
100M - 1B
1B - 4.95B

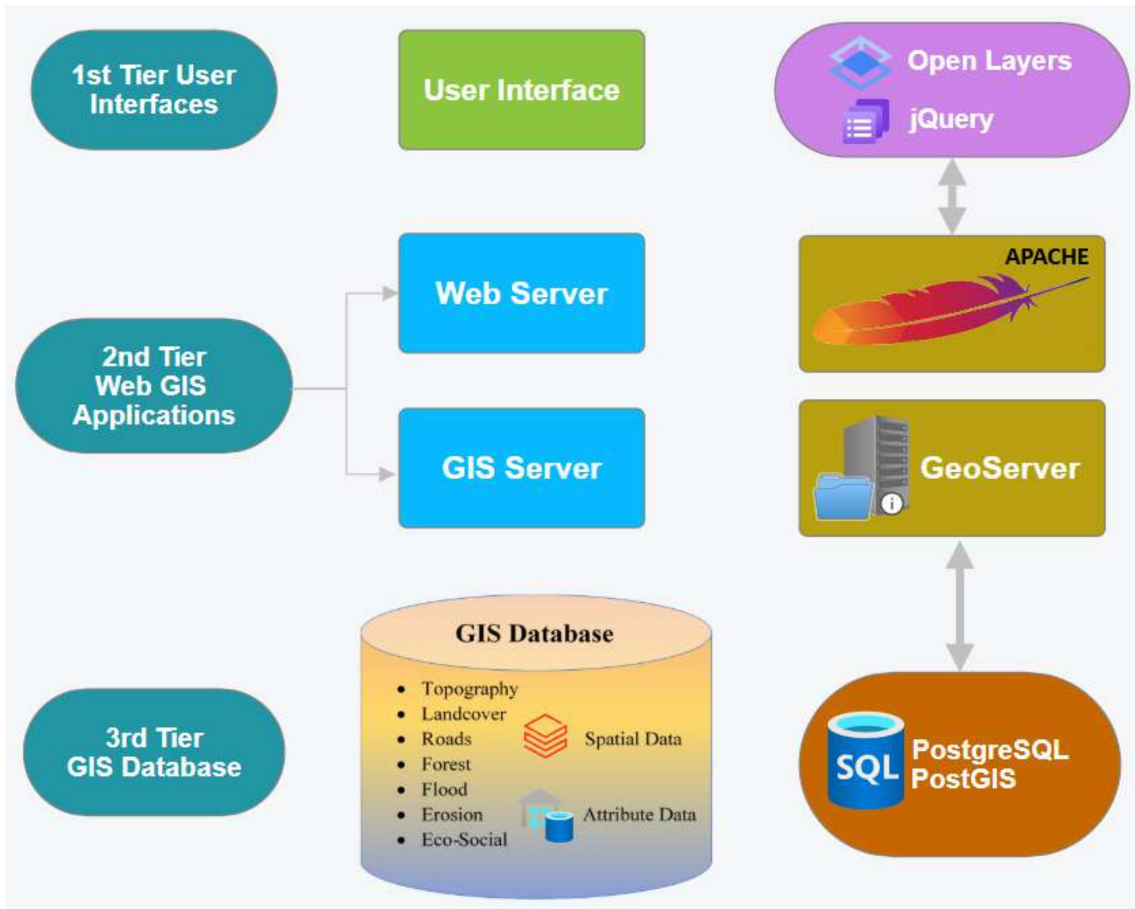

RIS
ASSESS

Imagesource: bootlabstech.com

Web-based Risk Calculator

The Web-based Risk Calculator is a revolutionary web-based platform designed to transform geospatial data visualization, analysis, and reporting. It serves as a comprehensive tool for users to access and share vast geospatial databases encompassing elements at risk and model results related to various hazards. The platform seamlessly caters to diverse users, including professionals in disaster management, urban planning, and environmental science, in real time. From national-level insights to granular tehsil-level data and analytics, it offers a spectrum of information crucial for informed decision-making. Its user-friendly interface ensures accessibility for all, fostering an interactive environment where users can engage with data effortlessly. The platform offers two specialized interfaces tailored to key stakeholders:

1. MoPD Interface
2. FFC Interface



Web Portal Architecture

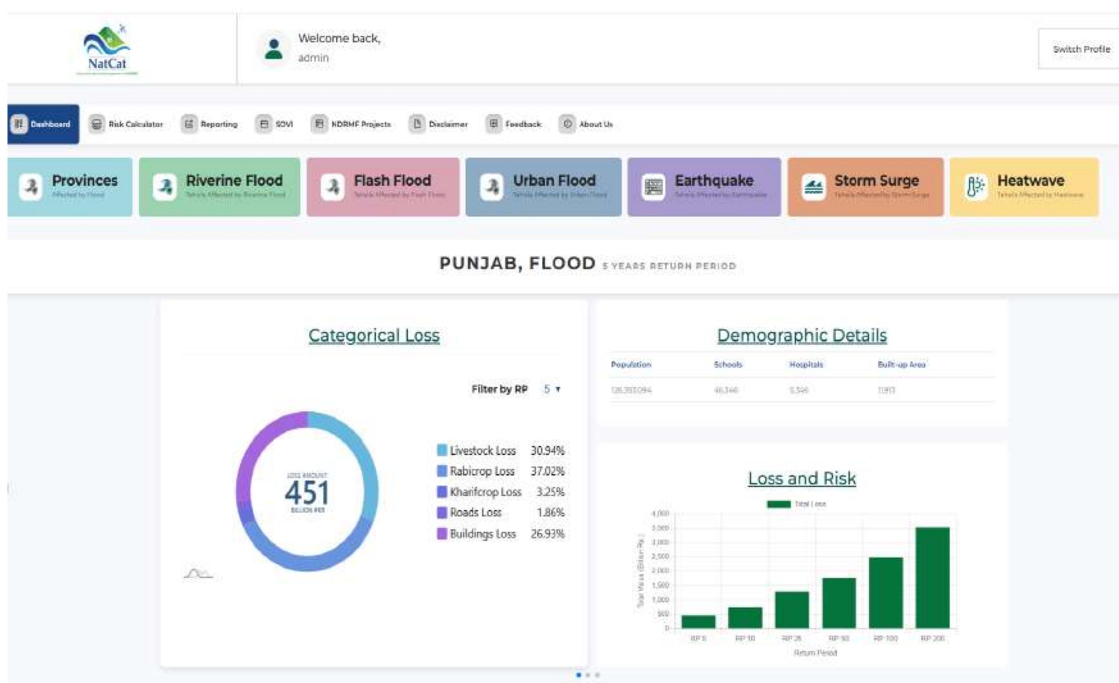
Key Functionalities

Explore Geospatial Datasets:
Users can explore and interact with various geospatial datasets related to hazards, exposure, vulnerability, and risk.

Management of Geospatial Datasets:
The platform allows for the efficient management of geospatial datasets, ensuring that users can update, query, and visualize data as needed.

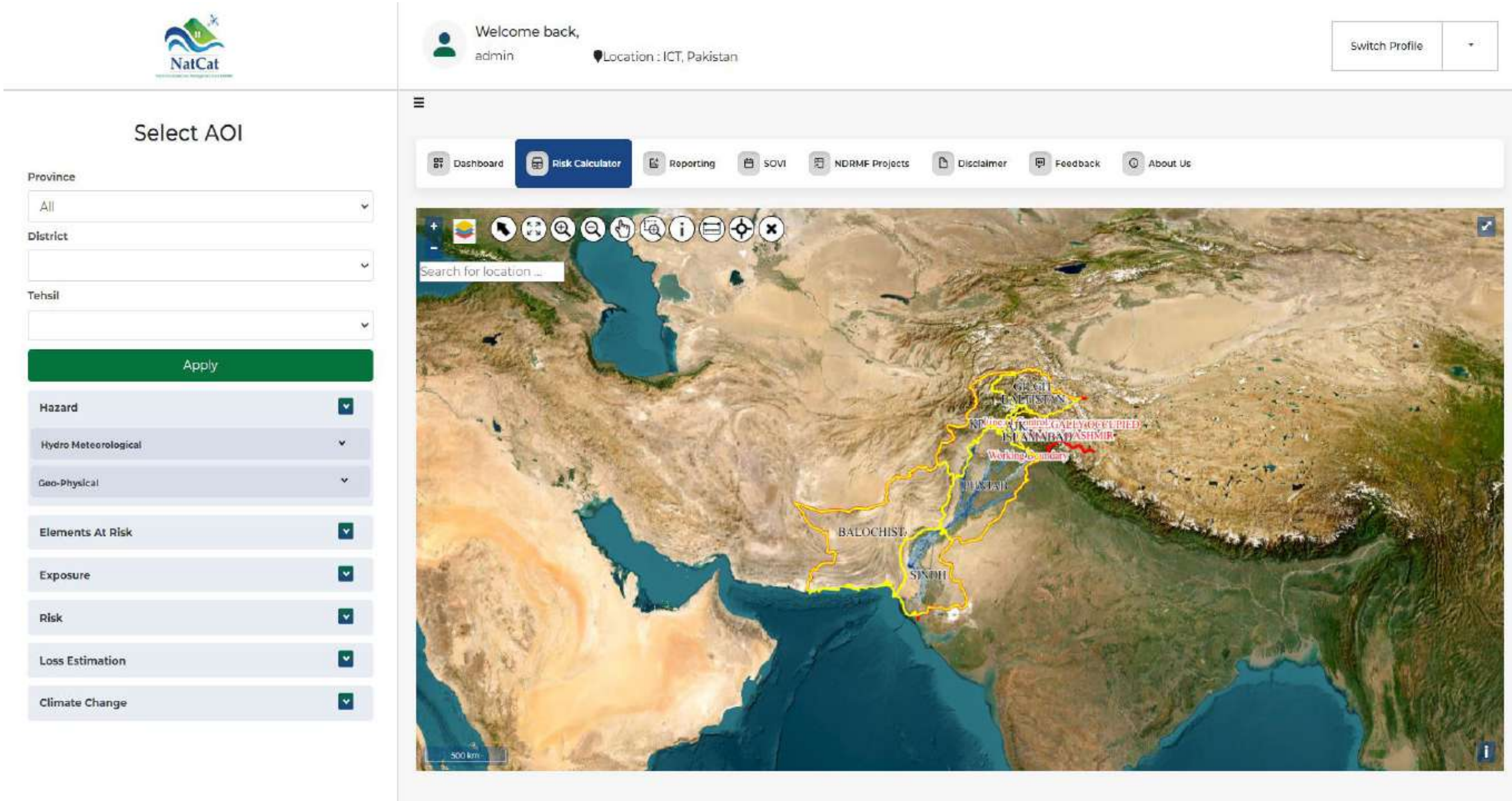
Visualization of Geospatial Datasets:
The Web-based Risk Calculator provides powerful visualization tools to help users understand complex data through maps, charts, and other graphical representations.

Reporting:
The platform includes features to generate detailed reports based on the data and analyses conducted, aiding in the communication of findings to various stakeholders.

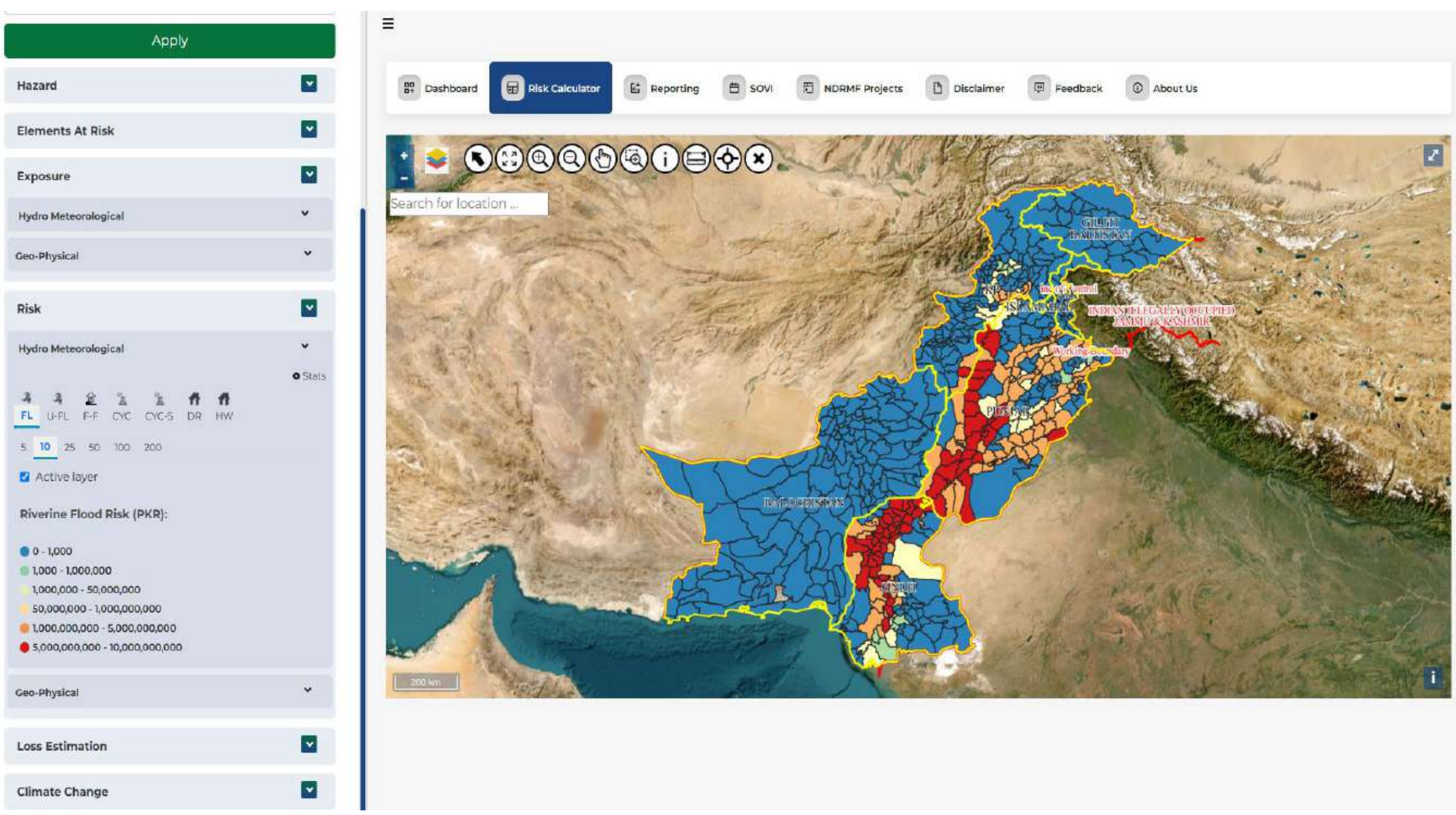


NatCat Dashboard

Web-based Risk Calculator

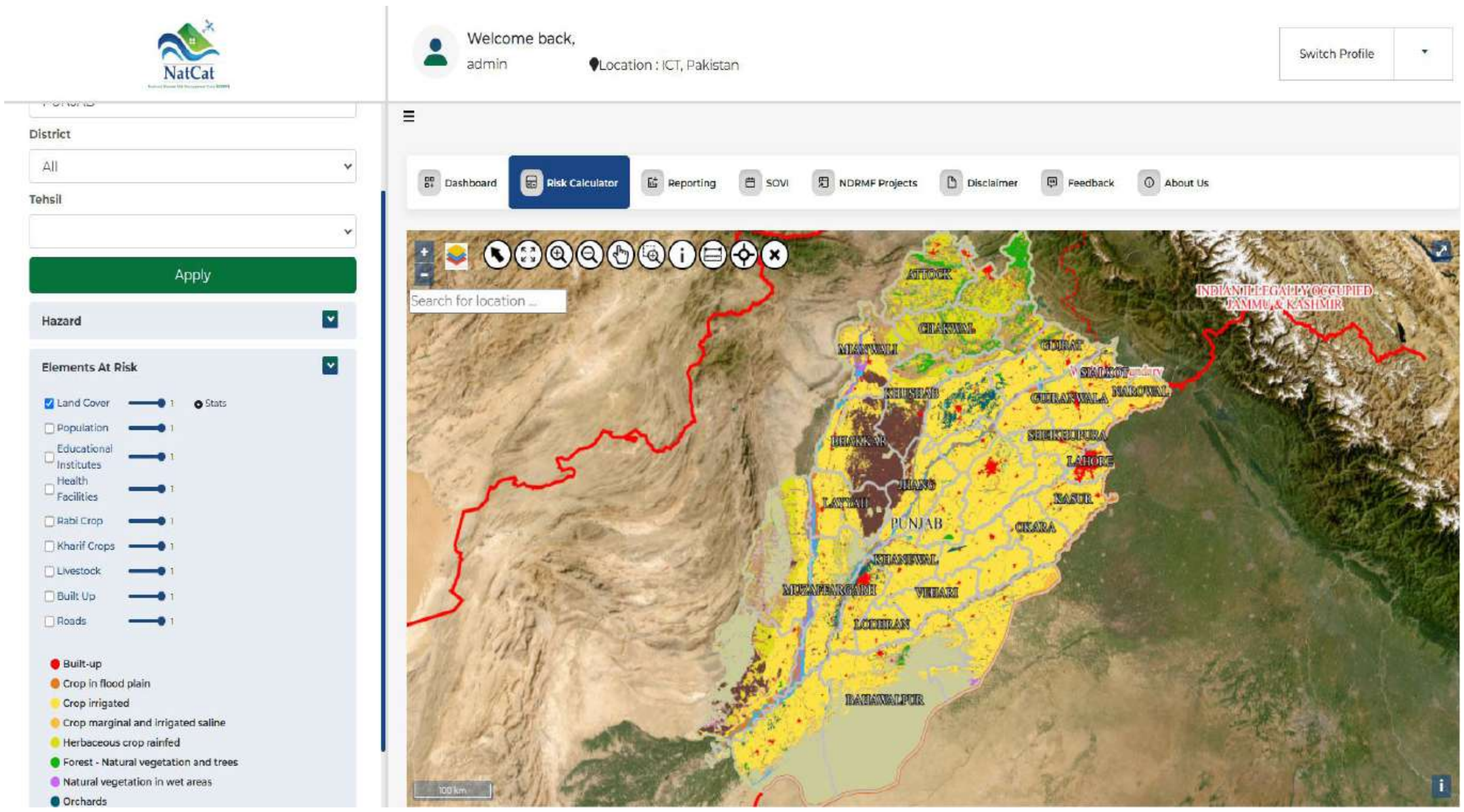


Web-based Risk Calculator Interface

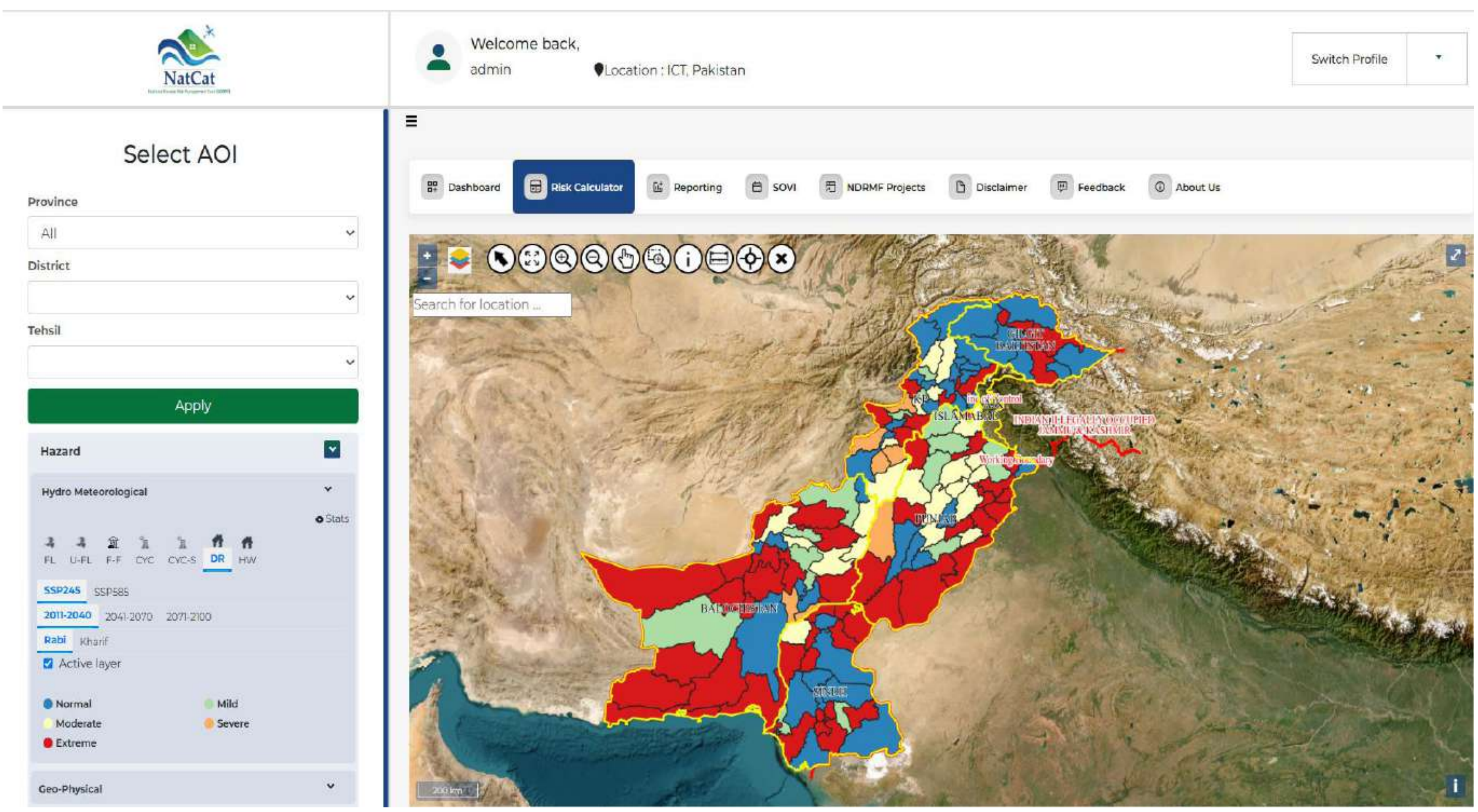


Flood Risk Map

Web-based Risk Calculator



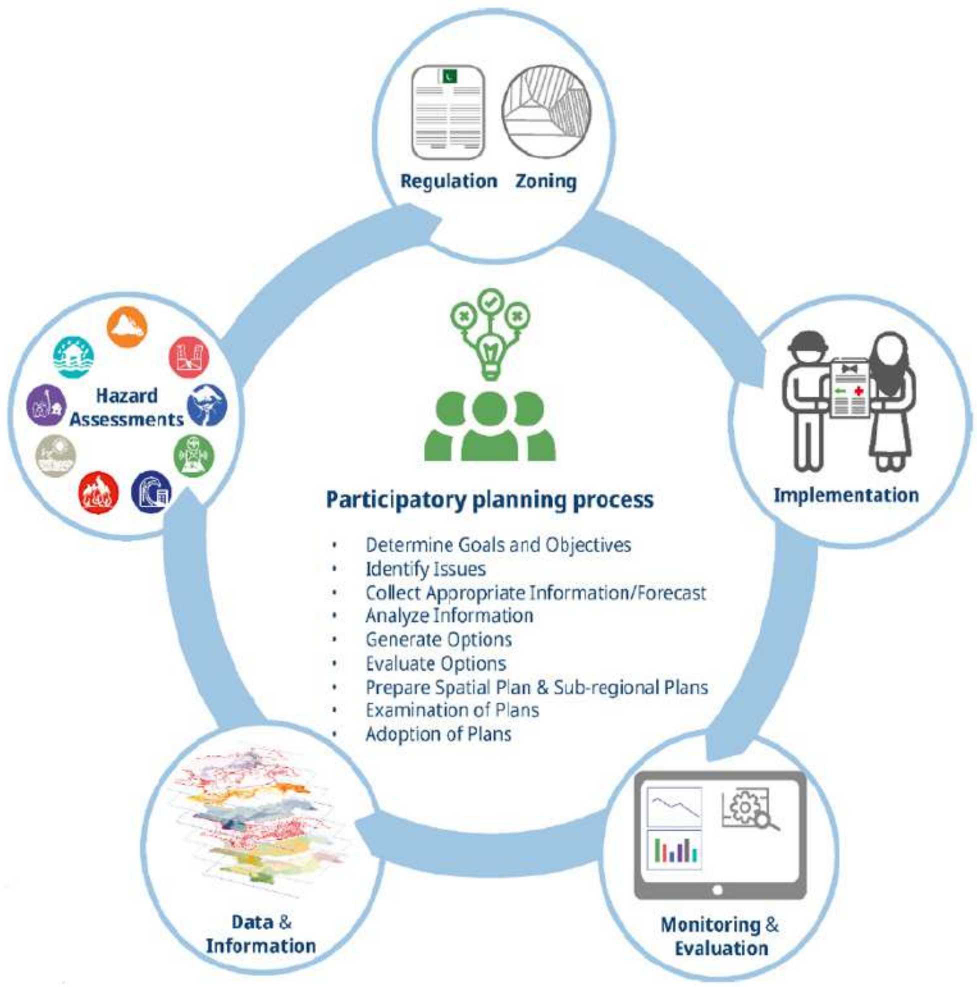
Landcover Classification of Punjab



Drought Hazard Map

NatCat Interface for MoPD&SI

The NatCat Risk Calculator includes a specialized interface for the Ministry of Planning, Development & Special Initiatives (MoPD&SI), owned by the National Disaster Risk Management Fund (NDRMF) and developed in collaboration with the Space and Upper Atmosphere Research Commission (SUPARCO). This interface serves as a pivotal tool supporting the Planning Commission of the Government of Pakistan and Provincial Planning & Development Departments. This innovative web application facilitates multi-hazard risk identification and management, playing a crucial role in informing strategic planning and infrastructure development initiatives. The primary purpose of the specialized interface for MoPD&SI is to harness historical data and spatial analysis techniques to comprehensively assess and prioritize resources for disaster risk mitigation across Pakistan. By integrating advanced analytics and modeling, the application aims to enable evidence-based decision-making processes for sustainable and resilient development strategies.



Spatial Planning Process

Key Functionalities

Multi Hazard Risk Identification: The interface enables users to identify and analyze risks associated with multiple hazards, providing a comprehensive overview of the potential impacts on different regions.

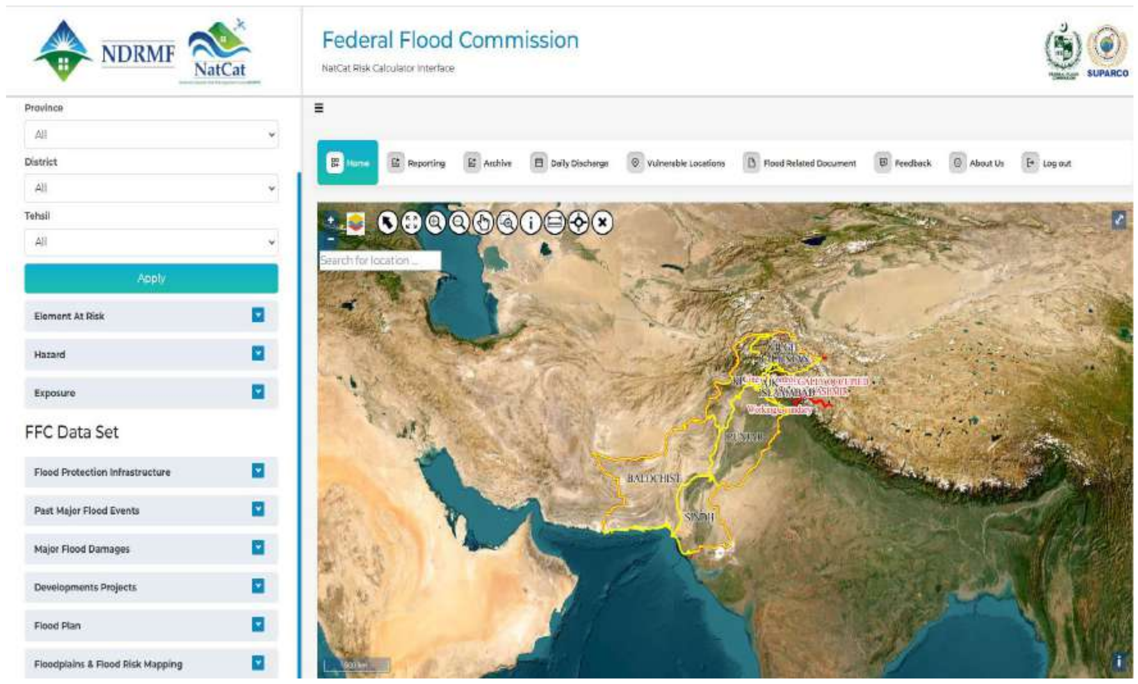
Strategic Planning Support: The interface supports the MoPD&SI in developing strategic plans for disaster risk reduction and resilience building, ensuring that resources are allocated effectively.

Infrastructure Development: The platform aids in planning and prioritizing infrastructure development projects that are resilient to natural hazards.

MoPD&SI Interface

NatCat Interface for FFC

The NatCat Risk Calculator, a collaborative creation by SUPARCO and funded by NDRMF, includes a ground breaking tool designed to support the Federal Flood Commission (FFC) in Pakistan. This specialized interface provides detailed flood hazard mapping, exposure analysis, vulnerability assessment, and risk identification. By leveraging cutting-edge technologies and geospatial data, the NatCat Model enables the FFC and associated stakeholders to make well-informed decisions, aiding in the effective management of flood risks, the development of robust flood mitigation strategies, and the construction of resilient water management infrastructure.



FFC Interface

Key Functionalities

Elements at Risk:
The module provides detailed information on the elements at risk, such as population, infrastructure, and critical facilities, allowing for targeted risk assessments.

Hazard Mapping:
The platform offers comprehensive flood hazard maps that visualize areas at risk, enabling more precise planning and response efforts.

Exposure Analysis:
The exposure analysis module helps quantify the potential impact of floods on various elements at risk, providing crucial data for risk management strategies.

Supporting Layers:
Additional layers, such as daily discharge data and topographic information, enhance the platform's ability to provide a detailed understanding of flood risks.

Tarbela Reservoir Discharge Hydrograph

Way Forward

Natural disasters have had a profound impact on Pakistan's population and economy, with major events including the 2005 Kashmir earthquake and the 2010 and 2022 floods, causing widespread devastation, economic setbacks, and long-term recovery challenges. These recurring catastrophes underscore the urgent need for systematic approaches to disaster preparedness and risk reduction. In alignment with the global shift from reactive to proactive strategies, under the Sendai Framework 2015–30, Pakistan has initiated the development of a Geo-referenced database for National Catastrophe (NatCat Model). This initiative supports planners, policymakers, and disaster managers in mitigating the effects of natural hazards on human lives and livelihoods. The NatCat model provides a probabilistic assessment of both hydro-meteorological and geo-physical hazards, incorporating elements of exposure, vulnerability, and potential loss across varying intensities and magnitudes. It evaluates risks to critical sectors, including built environment, landcover, agriculture, population, educational institutions, health facilities, livestock, and road infrastructure. Risk and loss estimation is a pivotal component in disaster management, planning, and insurance. Within disaster risk reduction, this includes the identification, analysis, and evaluation of potential threats that could hinder national development goals. Risk assessments are conducted through various methodologies, broadly categorized into qualitative, semi-quantitative, and quantitative approaches. NatCat adopts a comprehensive quantitative framework aggregating losses across plausible scenarios. Economic loss estimation in NatCat uses key metrics such as Probable Maximum Losses (PML) and Average Annual Losses AAL), offering (stakeholders a clear understanding of financial exposure under different hazard intensities. Valuation of key elements at risk is derived from Federal and Provincial Development Plans for FY 2022–23. Rehabilitation and reconstruction costs per kilometer of the national highway network were calculated using data from National and Provincial Highway authorities' PSDP and ADP schemes for the same year. In agriculture, support prices help stabilize farmer incomes and market behavior. For risk-loss estimation, provincial support prices from FY 2021–22 were used for wheat, cotton, and sugarcane. For rice, the prevailing market price was adopted due to no official support price. For livestock valuation, the average price per animal during Eid-ul-Azha FY2024 was applied across provinces, acknowledging limitations in consolidated data availability. By providing a unified, data-driven framework for multi-hazard risk assessment, NatCat is a foundational tool to guide strategic investments, strengthen institutional preparedness, and foster climate resilience. Its continued development and integration into national planning will be crucial for reducing vulnerabilities and securing sustainable futures for communities across Pakistan.

Recommendations

The Pakistan Digital Census (2023) by the Pakistan Bureau of Statistics (PBS) collected geo-coded data on housing and population characteristics. This data is vital for risk loss estimation and can be integrated into NatCat once publicly available.

The last livestock census was conducted in 2006, and since then, there have been significant changes and challenges affecting the livestock population. There is an imminent and urgent need to conduct a new livestock census, especially considering the severe impact of the two major floods in 2010 and 2022, which affected livestock extremely across various regions. Having updated and accurate livestock statistics is critically important, as it will provide essential data for planning, resource allocation, and recovery efforts. This updated information should also be incorporated into the NatCat to improve disaster risk assessment, management, and response strategies related to livestock.

Detail updated data collection of existing health facilities in all provinces, including information such as the premises area, total covered area, number of floors in each facility, number of rooms available, details of the health facility staff, total construction cost incurred, and the presence of allied facilities, is extremely important and must be carried on an urgent basis.

Likewise, detail updated data collection of existing educational institutes in all provinces, including the premises area, total covered area, number of floors, number of rooms, available teaching staff, construction cost, and all allied facilities, is highly important and must be undertaken at the earliest possible time with dedicated effort.

Building typology is the major economic feature contributing significantly to the reconstruction and rehabilitation cost; therefore, spatially accurate information and reliable data regarding building types, materials, and structural characteristics is necessary. It is therefore suggested to collect detailed and standardized information of building typology during the house census, as this enables authorities and planners to accurately estimate the potential risk and economic loss of buildings against various natural hazards.

Contact Information:

National Disaster Risk Management Fund (NDRMF),

5th Floor, EOBI House, 4 Service Road South,

Mauve Area G-10 Markaz G-10, Islamabad, 51000 Pakistan.

URL: https://ndrmf.pk

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