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Organized By

GEOLOGICAL SURVEY OF PAKISTAN

CONTENTS

FOREWORD

It is with great pleasure to publish the Abstracts Volume of the First International Conference on Geological Hazards, organized by the Geological Survey of Pakistan (GSP) on May 27-28, 2025. This landmark event represents a significant step forward in our collective efforts to understand, monitor, and mitigate the increasing challenges posed by geohazards in Pakistan and across the region.

Pakistan lies within one of the most tectonically active zones of the world; earthquakes, landslides, and related geological hazards continue to threaten lives, infrastructure, and sustainable development. In this context, the role of scientific research, cross-disciplinary collaboration, and evidence-based planning cannot be overstated. Recognizing this need, GSP convened this conference as a platform for dialogue between national and international experts, researchers, policymakers, and stakeholders who share a common commitment to reducing the risks posed by natural hazards.

The research presented during the conference reflects the depth and diversity of ongoing research in the areas of earthquake studies, slope stability, application of modern techniques to face challenges, impact of climate change on geohazards, mitigation strategies, and related fields. The presence of esteemed international participants enriched the discussion with global perspectives and cutting-edge methodologies, while national experts highlighted the unique geological conditions and challenges faced by Pakistan. This exchange of knowledge has not only strengthened scientific understanding but has also paved the way for future collaborations aimed at enhancing resilience and disaster preparedness.

The abstracts compiled in this volume stand as a testament to the dedication, hard work, and innovative spirit of the contributors. They offer valuable insights for researchers, practitioners, and decision-makers, and will undoubtedly serve as a useful resource for shaping future research priorities and national hazard-management strategies.

I extend my sincere appreciation to all the participants, invited speakers, organizing committees, and supporting institutions whose efforts made this conference a success. I am confident that the ideas shared and the partnerships forged here will continue to advance our mission of safeguarding communities through robust geological research and effective hazard management.

On behalf of the Geological Survey of Pakistan, I am honored to present this publication and look forward to continued progress in our collective endeavor toward a safer and more resilient Pakistan.

(Adnan Alam Awan)
Director General
Geological Survey of Pakistan

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INTRODUCTION TO THE CONFERENCE

The Geological Survey of Pakistan (GSP), an attached department of the Ministry of Energy (Petroleum Division), successfully organized the International Conference on Geological Hazards in Pakistan on May 27-28, 2025 at Margala Hotel, Islamabad. The conference was well attended by leading geoscientific experts and distinguished representatives from national and international organizations involved in geohazards and related studies. During nine technical sessions, over 50 national and international experts/speakers presented their research work covering the following conference themes:

- **Research on Seismic Hazard Assessment and Mitigation in Tectonically Active Regions: Geological Insights and Challenges in Global and Regional Perspective**
- **Application of Geospatial Technologies (GNSS and InSAR Data) in Plate Tectonics (Earthquake Studies)**
- **Building Codes of Pakistan: Methods, Analysis & Fault Line Database**
- **Sustaining GNSS CORS Network: Challenges, Innovations and Future Strategies**
- **Climate Change Impact on Mass Movement / Landslide Hazards**

Lt. Gen. Inam Haider Malik, (Hilal- E - Imtiaz (Military) Chairman, National Disaster Management Authority (NDMA), Islamabad graced the occasion as Chief Guest. Dr. Sajjad Ahmad, Director General GSP inaugurated the conference with his opening remarks and welcome address, while Deputy Director General/Project Director/conference convener Mr. Adnan Alam Awan presented the conference introduction and objectives, outlined the country's geohazard scenario and emerging challenges.

The conference participants unanimously agreed on the need of working together in the field of geological hazard assessment, a gap was also identified in the geosciences cooperation across the country that can be addressed through some legislative process and the participants also agreed to initiate necessary interventions to advance the research programme for earthquake and landslides hazard assessment in the country with a focus on priority areas.

The following two agenda items have been unanimously agreed by the conference participants during the closing session:

1. **Working Together and Developing Partnership in the Field of Geoscientific Studies Leading to Disaster Risk Reduction (DRR) in the Country**

A consensus and agreement of joining hands and working together in the field of seismic and mass movement hazards assessment in the country has been developed. Necessary steps, MoUs/LOC among the stakeholders for data sharing, capacity development and launching joint research programs is crucial for geoscientific input and agreed by all stakeholders. It was agreed that both in the pre and particularly in the post phases of any disaster, priority intervention should be working together and developing partnership in the field of geoscientific studies leading to Disaster Risk Reduction (DRR) in the country:

2. **A GAP in the Disaster Risk Management (DRM) Cycle to be Addressed Through a Legislative Process**

The conference participants discussed and agreed that there exists a specific gap in the Disaster Risk Management cycle, where necessary legislative process is required to manage the redundancy in the research work and duplication of efforts in any specific geographical area across the country. In the disaster-prone areas, sometimes both in the pre and post disaster phases, the geoscientific and specific studies are carried out by different organizations without any inter coordination and sharing of results after the completion of study with the concerned authorities and stakeholders. It was agreed that a National Geohazard Data Center/Pool (NGDC) need to be developed, that may keep record of all the disaster related studies in any area of Pakistan and same National Geohazard Data Center/Pool may issue NOCs for any future studies related with the Disaster Risk Reduction and Management themes proposed by any public sector organization, academia/university, international organization and other related private sector organizations in the country. The Geological Survey of Pakistan (GSP) may act as a secretariat for the National Geohazard Data Center/Pool and National Disaster Management Authority (NDMA) with the role and responsibility to initiate and supervise the whole process and providing the framework for the new proposed legislative process as above.

Seismic Gaps on Plate Boundaries: Knowledge Gaps in Society's Response

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The geographic setting of Pakistan is one of environmental instability: flooding frequents 20% of its agricultural lands, landslides in its mountains can cause transient lakes whose catastrophic breach exposes downstream communities to considerable risk, rising sea levels threaten to consume 1% of its land area, and 40% of its land area is visited by moderate and occasionally catastrophic earthquakes. While it is relatively easy to quantify these risks, the implementation of a successful strategy to mitigate their effects remains a challenge.

Pakistan's earthquakes result from the convergence of the Arabian and Indian plates with a promontory of the EuroAsian plate. Convergence velocities rise from 30 mm/yr in the west to 40 mm/year in the east, and at a fundamental level determine the productivity of earthquakes throughout Pakistan. Along the Baluchistan coast, great thrust earthquakes (M8) occur at intervals estimated to be as long as 670 years, but since three potential segments for these massive events remain unbroken one might anticipate ***M****8 earthquakes every 200 years, the most recent having occurred in 1945. In central Pakistan, from Karachi to the latitude of Peshawar, the sinistral Chaman Fault system hosts a complex sequence of strike-slip faults and thrust faults with magnitudes up to* ***M****7.7. Except for the segment near Chaman which is currently sufficiently mature for imminent failure, the recurrence between the largest of these earthquakes is unknown historically and remains to be evaluated by paleoseismic trenching, a renewal interval of ~200 years is considered conservative. In the past 200 years, three* ***M****>7.5 events have occurred on one or other of these faults, hence a <60-year recurrence interval for major earthquakes between Karachi and Islamabad very probably lies in Pakistan's future. A similar pattern is present In Pakistan's northern provinces where thrust faults again dominate, and three major earthquakes have occurred in the past two centuries.*

Beyond statistical studies base on limited data, our best guess for the location of the next damaging earthquake is where its recent absence has followed an historical abundance (i.e. a seismic gaps and prolonged quiescence). Although earthquake hazards cannot be controlled, earthquake risk is man-made and manipulable. Earthquakes don't kill people, buildings do. Since engineers know how to construct buildings that can survive the most powerful earthquake shaking, in principle, earthquake disasters could be largely eliminated. That disasters will continue is due to a disconnect between what we know, and how and where we apply earthquake resistant construction.

Currently earthquake resistant design is mandatory for civic structures: schools, bridges, power stations, banks, high rise buildings. Notably absent in this list are mandatory building codes for dwellings in villages, towns and low-cost residential apartments where most people live. A conservative estimate is that 100 million Pakistani residents are at risk from earthquakes. Until earthquake resistance is applied to their homes, future earthquakes are guaranteed to be future disasters.

Current Tectonics of Pakistan, 25 Years of Cooperation Between the Geological Survey of Pakistan and ISTerre

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After an initial field mission in August 2005, collaboration between the Geological Survey of Pakistan and Isterre began after the earthquake of 8 October 2005 with the installation and measurement of a GNSS network dedicated to the study of post-simismic deformation induced by this earthquake. This network was re-measured and extended in January 2006 and again in August 2006 and March 2007, with the installation of a dense network stretching from the Himalayan foreland to the Karakorum, with a special focus on the Nanga Parbat Massif. This network was remeasured by the Geological survey in 2008, 2009, 2010, 2012 (total remeasurement), 2017, 2018 - 2019 (total remeasurement and densification of the network in the Nanga Parbat Massif) and 2022 (total remeasurement).

These measurements have made it possible to quantify the post-seismic deformation following the 2005 earthquake and to identify the main driver of this deformation as being the afterslip. Recently, these GNSS measurements have been reinforced by InSAR quantification of the post-seismic deformation (Envisat and sentinel1), which should make it possible to specify the importance of the afterslip in the seismic balance of the Balakot-Bagh fault, the site of the 2005 earthquake.

By quantifying the velocities from the Himalayan foreland to the Karakorum, it was possible to demonstrate southward displacement velocities of up to 12 mm/year in the fixed Indian plate reference frame. These observations and a synthesis of the data on the geometry of the Main Himalayan Thrust have enabled us to propose a coupling model along the MHT. This model identified a significant coupling of the displacement along the southern part of the MHT, which may therefore be affected by very strong magnitude earthquakes, decoupling zones in the Salt Ranges and the Potwar Plateau and deformation of the Nanga Parbat, characterised by a westward overthrust of this Massif. These data were supplemented by a quantification of the deformation of the Salt Ranges and the Potwar Plateau by InSAR. These data have enabled us to establish the dominant role of the Massif salt level forming the detachment level of this region and to propose the existence of a horizontal extrusion of salt at the level of the Salt Ranges.

The current deformation of Nanga Parbat has also been quantified not only by GNSS but also by InSAR. This InSAR study required the development of a dedicated atmospheric correction model, given the very large differences in altitude in the area studied. The GNSS & InSAR results, together with the available focus mechanisms, confirm the existence of very strong Massif surrection of up to 5 mm/year and the co-existence of westward thrusting of the Massif on the Koshitan and normal faults also identified by published microseismicity studies and geomorphology.

TECHNICAL SESSION

RESEARCH ON SEISMIC HAZARD ASSESSMENT AND MITIGATION IN TECTONICALLY ACTIVE REGIONS;

GEOLOGICAL INSIGHTS AND CHALLENGES: GLOBAL AND REGIONAL PERSPECTIVES

Upgradation Of the Tectonic Map of Pakistan: Implications for Seismic Hazard Analysis

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The tectonic framework of Pakistan plays a critical role in understanding regional geology and assessing seismic hazards. The widely referenced 1982 tectonic map of Pakistan has served as a foundational tool for geoscientific research for several decades. However, advancements in remote sensing, digital mapping, and the availability of high-resolution geological and geophysical datasets necessitated a comprehensive revision. This study presents an upgraded tectonic map of Pakistan, developed using modern GIS techniques, detailed fault analysis, and precise structural mapping. The updated version integrates geological data from 1:50,000 scale GSP maps, remote sensing imagery (including Sentinel and Google Earth), digital elevation models (DEMs), and various published and unpublished tectonic and geological sources. A critical part of the update involved rectifying and realigning polygon boundaries with visible surface features and fault traces. Faults that were previously generalized or absent have been redefined based on satellite data and recent field validation. One of the major improvements in this updated version is the subdivision of larger tectonic units into smaller, well-defined tectonic blocks, including refined representations of island arcs, marginal belts, fold and thrust zones, and magmatic arcs. This restructuring offers a more accurate interpretation of the regional tectonic setting and crustal deformation zones.

Furthermore, seismic data from the last 25 years has been plotted and analyzed to examine earthquake frequency, magnitude, and depth distributions across different tectonic zones. The integration of seismicity with the updated tectonic framework has led to the preparation of a seismotectonic map of Pakistan, highlighting zones of high activity, active fault systems, and areas of thrust, strike-slip, and subduction-related movement. The upgraded tectonic and seismotectonic maps provide an essential foundation for seismic hazard analysis, infrastructure planning, and further geoscientific research. This work represents a significant step forward in understanding the complex tectonics of Pakistan and their implications for geological risk mitigation.

Ancient Outburst Floods from The Kashmir Valley and Their Potential Influence on The Demise of The Indus Valley Civilization in Pakistan

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Hindu mythology relates that the Kashmir Valley was once a vast lake that was drained by the miraculous carving of a gorge through the Pir Panjal range by the grandson of Brahma. This narrow gorge hosts the River Jhelum and is the only outlet from the valley and its 15,000 km^2 area catchment. Although geological strata are inconsistent with the presence a long-lived former lake, a 1939 monograph by deTerra and Patterson quantifies the elevations of 88 ancient shorelines, some more than 200 m above the valley floor, many of which correspond to hillside benches visible in present-day satellite imagery. These transient shorelines have yet to be precisely dated, but those below 130 m have incised into 47 ka Kerewa sediments.
Two geological processes can be invoked to explain transient lakes in the valley. The first is the uplift of the bed of the Jhelum by thrust faulting during great earthquakes beneath the Pir Pinjal. These earthquakes would result in a shallow lakes (<10 m) whose duration would be controlled by the erosion of the bedrock stream bed through the Jhelum gorge. The second is the blockage of the path of the Jhelum by a landslide. This would result in short duration lakes of potentially considerable depth. One such impoundment event occurred in the ninth century that flooded low-lying parts of Srinagar to a depth of ~10 m reducing the area of arable land and increasing the price of rice for an extended period [doi.org/10.1007/s10518-013-9504-x]. Kalhana's Rajatarangini describes the engineered breach of this landslide, and traces of fused landslide breccia have been discovered near its probable location west of Baramulla. The lake volume impounded by this ninth-century event is estimated to be 14 km^3 based on the names of flooded Medieval villages in the valley. We calculate that following breach of the landslide it may have drained the valley in fewer than 3 days resulting in a 30 m high surge downstream to the Punjab. The size of transported mega-boulders in the bed of the Jhelum downstream from the dam are consistent with calculated 12 m/s peak flow velocities calculated for the ensuing flood, suggesting that lakes in Kashmir's prehistory, though they may have impounded volumes in excess of 200 km^3, may not have drained substantially faster than the ninth century breach [doi:10.3389/esss.2021.10040].
Present-day mean discharge rates for the Jhelum suggest that a transient lake with 200 m depth would have required a filling time greater than 100 years. Assuming that the catastrophic breach of this ancient landslide was similar to the Medieval landslide (3-7 days), the downstream consequences in the Punjab and lower reaches of the Indus Valley would have been severe, far exceeding those of the historical Indus outburst floods of 1841 and 1858. To place the flood in context, its estimated 460 km^3 volume exceeds that of most historical floods with the exception of the Lake Bonneville drawdown and other ice-age impoundments. Is there historical evidence for flooding in the plains of the Punjab from such a large-scale outburst flood?
It is well known that the Indus Civilisation, 5300 BP to 3300 BP, faced a constant threat from floods. In addition to evidence for the mitigation of "regular" monsoon flooding using elevated foundation levels and flood control dams, high-level flood deposits have been reported 10 m above occupation levels [www.penn.museum/sites/expedition/civilization-and-floods-in-the-indus-valley/]. At its height, the Harrapan Civilisation may have hosted 5 million people, however, a marked decline occurred c. 3900 BP. Subsequent to this time, the Late Harrappan period is characterized by the abandonment of the sophisticated urban infrastructure for which its towns and cities are famous, and a shift to rural occupation. These later settlements lie to the west and primarily to the east of the earlier settlements adjoining the Punjab river systems. Various mechanisms have been proposed for this decline – climate change, disease, warfare. One possibility, however, is that a disastrous flood from the Kashmir Valley incised through the nucleus of Harrappan society from the Punjab to the Arabian Sea, destroying its urban infrastructure, confounding its agriculture and disrupting its riverine communications. Though the timing and magnitude of such an event is at presently speculative (and has not been reported by archaeologists), a test of a Late-Harrappan flood is available to the present generation of geologists – to date Kashmir's abandoned shorelines and the high-level flood deposits of abandoned Harrappan cities, and to weigh their synchroneity.

GNSS (Cors & Campaign) Network of Pakistan Establishment, Challenges and Future Strategies

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The Earth is inherently dynamic, continually reshaped by geodynamic processes such as continental drift and plate tectonics. These processes drive the formation of mountain ranges, ocean trenches, earthquakes, and volcanic activity. The Indian Plate–Eurasian Plate collision, responsible for the Himalayan Mountain arc, is one of the most active tectonic boundaries on Earth, generating frequent moderate to major earthquakes.
Monitoring these processes is vital, not only for understanding Earth's deformation mechanisms but also for mitigating geohazard risks. Geospatial technologies, particularly remote sensing and geodesy, provide the precision and temporal coverage needed for such studies. Techniques such as Interferometric Synthetic Aperture Radar (InSAR) offer sub-centimeter accuracy, while Global Navigation Satellite System (GNSS) geodesy achieves millimeter-level precision. The Persistent Scatterer InSAR (PS-InSAR) method further enhances spatial coverage and reliability. Integrating Digital Elevation Model (DEM) analysis, PS-InSAR, and GNSS observations can significantly improve our understanding of active tectonics and surface deformation.
GNSS has transformed geodesy and geophysics by enabling the detection of subtle crustal movements at various spatial and temporal scales—essential for quantifying seismic strain accumulation and plate interactions. Over the past two decades, GNSS studies across the Indian Plate have constrained deformation rates for most major faults. However, GNSS is inherently point-based, requiring dense station networks to fully capture fault-scale deformation.
Geological Survey of Pakistan (GSP) has established its network right after the 2005 devastating earthquake. Seventy (70) control point was installed in the northern part of Pakistan along major fault line. Nine (09) campaigns have been carried out till 2022. In 2025, GSP has completed its CORS network by installing twenty (20) CORS receiver on outcrops based of tectonic division of Pakistan.
*Establishing a CORS network is a challenging task, especially when you have to cover large area with limited CORS. Site selection in hilly terrain, on best representative outcrop unit is always tricky. Multiple sites were selected using Remote sensing techniques and tectonic maps against each site. These sites, were finalize after ground fallow ups considering out crop conditions, masks angle, safety and internet availability. Power backup was design using multiple sources mechanism to provide uninterrupted 24*7 power supply. All these stations are located on the remote site, any*
human surveillance was not possible, so AI based security cameras were used to achieve this purpose.
Despite these advances, Pakistan's tectonic framework demands a denser GNSS infrastructure. Plans include the installation of 200 additional episodic sites and 20 new CORS stations to form a second network layer, enabling more comprehensive crustal deformation monitoring and supporting earthquake hazard mitigation strategies.

Present-Day Quantification of Seismic Coupling Along The D´ Ecollement Level Beneath the Potwar Plateau Region in Pakistan Western Himalaya

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Using GNSS horizontal surface velocities and Sentinel-1 interferometry line-of-sight velocities, we quantify the current velocity field of the Potwar Plateau Salt Range fold-and-thrust belt. From this velocity field indicating a creep of the Potwar Plateau along the Main Himalayan Thrust, we inferred a weak subhorizontal décollement level formed by a massive Precambrian salt layer. To the south of the Plateau, the Salt Range is uplifted along the Salt Range Thrust, conditioned by the presence of an inherited normal fault. The Kalabagh Fault, which forms the western boundary of the Salt Range and Potwar Plateau, exhibits a creep rate of 3.3 mm/yr. Numerical modelling enabled us to characterise the slip distribution and coupling along the faults, showing the presence of a large asperity along the décollement level beneath the Potwar Plateau and several asperities along the eastern part of this basal thrust. The model also indicated an alternation of coupled and decoupled zones along the Kalabagh Fault, suggesting that this strike-slip fault can be characterised by creep and the occurrence of earthquakes and/or slow slip events. Considering the lack of instrumental and historical large-magnitude earthquakes in this area, the Main Himalayan Thrust and Kalabagh Fault are likely to be affected by earthquakes of magnitude Mw larger than 7.5. A slip rate of 20 mm/yr is modelled along the southern and superficial parts of the Salt Range Thrust, which is larger than the 14 mm/yr slip rate along the Main Himalayan Thrust at depth. This observation suggests the existence of a southward flow of massive salt along the Salt Range Thrust.

TECHNICAL SESSION

APPLICATION OF GEOSPATIAL TECHNOLOGIES (GNSS AND INSAR DATA) IN PLATE TECTONICS (EARTHQUAKE STUDIES)

Geohazard Investigation and Analysis Using GNSS And Other Geospatial Technologies—Examples from Utah, USA

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Located at the intersection of the Middle Rocky Mountains, Colorado Plateau, and Basin and Range physiographic provinces, Utah's natural landscape is diverse and dynamic. Areas of geological hazards, including landslides and earthquakes, are widespread and overlap with areas of rapid population growth and expanding development, creating potentially costly challenges to the resilience of the state's communities and infrastructure. The Utah Geological Survey (UGS) uses a variety of geospatial technologies in a GNSS framework to characterize these hazards, including light detection and ranging (lidar), Interferometric Synthetic Aperture Radar (InSAR), and Structure from Motion (SfM). Utah now has statewide coverage of aerial-acquired lidar data (U.S. Geological Survey [USGS] quality level QL2 or better), allowing for identification and highly accurate mapping of even very subtle geomorphic features such as subdued landslide terrain and small fault scarps (min. ~0.25 m vertical offset). On a local scale, repeat acquisition of drone-based lidar data is being used to quantify movement rates and direction of landslides as well as rock glaciers. Using lidar, Quaternary fault scarps can be mapped with dramatically improved detail and spatial accuracy over traditional methods, in turn improving earthquake source data in the USGS's National Seismic Hazard Maps and the delineation of surface-fault-rupture special study areas by the UGS. Long-term GPS monitoring of known landslides near urban development and infrastructure helps in proactive landslide hazard mitigation, and InSAR is being used to identify and monitor large, slow-moving landslides in more remote areas. Additionally, InSAR is enabling basin-wide quantification of the magnitude and rate of land subsidence due to excessive groundwater withdrawal. Finally, digital photomosaics created using SfM software enable rapid, high-precision, and cost-effective logging of geologic exposures such as paleoseismic fault trenches. In addition to facilitating structural interpretation and accurate determinations of fault displacement, SfM 3D models allow researchers and students to virtually re-visit the exposure long after the trench has been backfilled. UGS geohazard information is compiled and made available in the Utah Geologic Hazards Portal (https://hazards.geology.utah.gov/), a GIS-based web map application, to facilitate the release of timely information to help mitigate hazard impacts, guide land-use decisions, educate the public, and provide foundational data for other researchers.

Seismic Coupling Quantified on Inferred Décollements Beneath the Western Syntaxis of The Himalaya & Current Tectonic Deformation of the Sulaiman Range (Pakistan) With InSAR

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Development of a slip coupling model along the MHT, estimation of possible moment magnitude for a major earthquake

We used episodic GNSS measurements to quantify the present-day velocity field in the northwestern Himalaya from the Himalayan foreland to the Karakoram Range. We report a progressive N-S compressional velocity gradient with two noticeable exceptions : in the Salt Range, where important southward velocities are recorded, and in Nanga Parbat, where an asymmetrical E-W velocity gradient is recorded. A review of Quaternary slip along active thrusts both in and out of sequence allows us to propose a 14 mm/yr shortening rate. This constraint, together with a geometrical model of the Main Himalayan Thrust (MHT), allows us to propose estimations of the slip distributions along the active faults. The lower flat of the MHT is characterized by ductile slip, whereas the coupling increases along the crustal ramp and along the upper flat of the MHT. The basal thrust of the Potwar Plateau and Salt Range presents weak coupling, which is interpreted as the existence of a massive salt layer forming an excellent décollement. In the central part of the frontal Salt Range, the velocities suggest the existence of a southward horizontal flux in the massive salt layer. Assuming that the measured coupling is similar to the long-term coupling, and noting the absence of very large historical earthquakes in the region studied, with the possible exception of the Taxila AD25 earthquake, this study leads to the conclusion that there is a risk of a very large earthquake of up to magnitude Mw 8.7 if a major earthquake occurs every 2,000 years.

Current deformation of the Sulaiman Range documented by InSAR

West of Pakistan, the relative displacement between the Indian and Eurasian plates is accommodated by a left-lateral transpression zone comprising the Chaman and Ghazaband faults and the Sulaiman Range. The current tectonic deformation of the Sulaiman Range is known only from some focal mechanisms and a few neotectonic studies. To document the present-day deformation of this area, we have performed an Interferometric Synthetic-Aperture Radar (InSAR) quantification of current tectonic deformation using the Sentinel 1 satellite. Velocity maps for the ascending and descending tracks enabled us to locate active faults affected by creep: the Harnaï and Kingri strike-slip faults, and the Gwal–Bagh thrust. We propose a numerical simulation that considers these faults as well as the level of detachment fold-and-thrust belt. Our results suggest the existence of out-of-sequence deformation along the Gwal–Bagh thrust, creep along the Harnaî and Kingri strike-slip faults, and slip along the basal décollement of the Sulaiman Range. The eastern part of the Sulaiman Range is characterized by a partitioning of the deformation with a left-lateral strike-slip along the N170° Kingri fault and an eastward thrust. In contrast, the western part is characterized by north–south compressive deformation associated with right lateral strike-slip on the Harnaï N120° fault.

The Role of GNSS Satellites in Earthquake & Natural Hazards Monitoring

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The earthquake (EQ) precursors through satellites data portray an image of the energy propagation from lithosphere to atmosphere and then ionosphere. The lack in previous papers has often observed about detail discussion on different precursors at various altitudes.
However, this study aims to investigate the anomalies at various altitudes associated with the Hotan China EQ (hypocentral depth: 10 km, latitude 35.595°N, longitude 82.416°E). The goal is to identify pre-and post-seismic anomalies statistically in the conjunction of wavelet transform. We have observed possible precursors in atmosphere such as variations in Aerosol
Optical Depth (AOD), Tropopause pressure (TP), Relative Humidity (RH), Latent Heat Flux (LHF) and Outgoing Longwave Radiation (OLR) in a window of 5-10 days before the seismic event. Moreover, the Total Electron Content (TEC) has also precursors during quiet geomagnetic storm conditions ($Dst \leq -40$ nt, $Kp \leq 3$) beyond the bound within 5-10 days. These findings highlight the potential of utilizing atmospheric and ionospheric parameters to detect seismic anomalies as EQ precursors for the improved EQ early warning systems.

TECHNICAL SESSION

APPLICATION OF GEOSPATIAL TECHNOLOGIES (GNSS AND INSAR DATA) IN PLATE TECTONICS (EARTHQUAKE STUDIES)

Pioneering GNSS Capacity: Establishing the Foundations for Innovation and Advancement

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Global Navigation Satellite Systems (GNSS) power a multi-billion-dollar global industry with applications across agriculture, transportation, disaster management, telecommunications, and space systems. Despite its strategic importance, Pakistan has lacked the technical capacity and infrastructure to fully leverage GNSS technologies.

To address this gap, the Institute of Space Technology (IST), Islamabad, launched Pakistan's first specialized MS program in GNSS in 2014, guided by the United Nations Office for Outer Space Affairs (UNOOSA). The program has since graduated over 50 professionals, produced more than 50 research theses, and contributed to over 100 publications. Practical exposure is provided through GNSS Winter Schools, technical workshops, and specialized training, enriching students' understanding and skills.

Strengthening this academic initiative, IST established Pakistan's first GNSS Research Laboratory under the National Center of GIS and Space Applications (NCGSA). The lab facilitates cutting-edge research in areas such as space weather and Ionospheric modeling, natural hazard monitoring, signal interference mitigation, and regional constellation design.

Beyond research, the lab plays a critical role in nationwide capacity building through training and outreach, helping to develop indigenous expertise and support a resilient GNSS ecosystem. These efforts are further amplified through IST's integration of GNSS research into the annual International Conference on Aerospace Science and Engineering, fostering innovation and collaboration across the space sector.

Application of Geospatial Technologies (GNSS and InSAR Data) in Plate Tectonics (Earthquake Studies)

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The Earth's ionosphere is closely coupled with the solar wind, magnetosphere, and the lower atmosphere. Ionospheric variations occur as a result of geomagnetic storms driven by an enhanced influx of solar wind and magnetospheric energy. On the other hand, lower atmospheric disturbances such as weather activities, volcanic eruptions, and seismic events also induce changes in the ionosphere. Driven by many of these external sources, the ionosphere exhibits complex variations at multiple temporal and spatial scales. Understanding these ionospheric variations, particularly their spatial structure, is a key research topic in the field of ionospheric space science. Furthermore, it has important application values for radio wave communication, satellite positioning, and navigation systems. The dual-frequency satellite-based measurements from Global Navigation Satellite System (GNSS) may provide feasible ways of studying and potentially detecting earthquake-related anomalies in the ionosphere. In this study, GNSS-based Total Electron Content (TEC) data are studied for three major M > 7.0 earthquakes in Nepal and Iran-Iraq border during 2015–2017 by implementing statistical procedures on temporal and spatial scales. Abnormal variations in Global Ionospheric Maps (GIMs) were also observed, which coincided with the diurnal TEC variations. It provides evidence of anomalous variations in TEC found on specific days at various temporal and spatial scales. Previous studies presented different time intervals of pre-seismic ionospheric anomalies, however, this study showed that earthquakes ionospheric precursors may occur within 5-10 days. The positive anomalies in TEC may be due to the existence of huge energy from the epicenter during the EQ preparation period.

Satellite-Based Identification of Active Faults in Balochistan: Safeguarding Infrastructure Along CPEC and Bri Corridors

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Balochistan, situated at the intersection of the Indian and Eurasian tectonic plates, is a seismically active region with substantial geological and strategic significance. The area plays a key role in large-scale development projects such as the China-Pakistan Economic Corridor (CPEC) and the Belt and Road Initiative (BRI). To ensure the safety and sustainability of infrastructure in this tectonically dynamic zone, it is essential to evaluate active fault lines. This research investigates prominent fault systems in Balochistan, with a specific focus on the Chaman, Ornach-Nal, and Ghazaband faults—known for triggering major earthquakes like those in Quetta (1935) and Awaran (2013). By integrating satellite imagery, digital elevation models (DEMs), geological records, and seismic data, we identified geomorphic indicators such as stream displacements, linear fault scarps, and disrupted alluvial fans that mark active tectonic movement. Fault slip rates and earthquake histories were analyzed to assess seismic potential. The study highlights the value of remote sensing tools, along with techniques like InSAR and ground-penetrating radar (GPR), in enhancing fault mapping and hazard evaluation for future works. It further recommends implementing real-time monitoring systems and probabilistic seismic hazard analysis (PSHA) to support risk-informed infrastructure development. The findings offer critical input for regional planning and contribute to disaster resilience strategies in seismically vulnerable areas.

Earthquake Probability Analysis and Active Stress Pattern Investigations in North Pakistan

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The Northern parts of Pakistan, coinciding with the Himalayan collisional zone is regarded one of the most seismically active regions in the world. The area is experiencing crustal compression since the Eocene due to the ongoing India-Eurasia collision. The ongoing N-S compressional stress regime in the region is well established, but local variations in seismicity patterns and stress conditions do exist in the area and encompassing these variations in the hazard related studies is crucial for better characterization of the area. The scope of current study covers the western margin of Himalayas with special emphasis on Hazara Kashimr Syntax, Nanga Parbat Syntax and Hindu Kush seismic zone. The objective is to carry out seismicity analysis by utilizing the available earthquake record. For this purpose, a regional seismicity catalogue is acquired from the Micro-seismic network operated by WAPDA in the region. The catalogue is processed and evaluated for temporal and spatial homogeneity in ZMAP software package. The analysis showed that the whole region has a recurrence interval of ~20 years for a magnitude Mw= 7.5 earthquake and ~60 years for Mw= 8.0 earthquake. The b-value maps showed that the area is characterized by significant spatial variations in b- values. The prominent high b-value regions identified in the study are along the Nanga Parbat syntaxis, Hazara Kashmir Syntaxis and Hindu Kush seismic zones suggesting heterogeneous stress conditions due to fault pattern complexity in these regions. The study area is subdivided into various subregions based on variations in seismicity patterns, fault gaps, variations in trends of major faults, and tectonic settings. Moreover, the focal mechanism solution catalogue is used to investigate the stress patterns and determine the principal stress orientations in the area using Michael's method. The result for stress tensor inversion showed that the region is dominated by compressional tectonics. Among subregions, Nanga Parbat syntaxis and Hazara Kashmir Syntax have considerable strike-slip components along their western and eastern bounding faults.

Inter-Seismic Coupling Modeling Using GNSS & InSAR Data: A Case Study from the Makran Area, Pakistan

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In Makran area, the Arabian plate subduct beneath Eurasian plate produces the world largest arc-trench gap system. This subduction zone, with a maximum convergence rate of 42mm/yr increasing from west to east, is highly active and has experienced many major earthquakes in the near past including 1945 Mw 8.1 tsunamigenic event. The differential convergence has divided the subduction zone into eastern and western parts with high and low seismicity, respectively. This suggests that the inter-seismic coupling may be present with variation across the plate interface. This study utilized satellite geodetic (GNSS and InSAR) data to investigate inter-seismic coupling and its distribution across the subduction interface.

Initially we utilized GNSS data, to test and model the number of fault patches across the subducting plate interface, i.e., three fault patches are the most suitable case for the Makran region. Furthermore, interseismic coupling of megathrusts and its distribution along different fault patches. The slip deficit rates estimated for three fault patches along the megathrust revealed that the whole subduction interface is coupled to some degree with variation along strike. In support of GNSS results, we also applied InSAR data set to investigate the locking behavior of the eastern Makran. InSAR data analysis and modeling reconfirms GNSS results; either plate interface locking is uniform or varies along strike of plate interface. The predicted model showed subsidence near the coastal region while uplifting landwards indicates consistency with InSAR observations. InSAR based slip deficit rate estimation indicates megathrust interface is coupled but varies in its strike direction. This estimated interseismic coupling and its distribution along the plate interface will assist in forecasting major earthquakes with subsequent tsunami in the coastal region of Makran.

Assessment of Potential Seismic Hazard Zones in The Gilgit-Baltistan Region of Pakistan Using Local and International Data Catalogs

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The Gigilt-Baltistan (GB) region is located in the seismic zone, which presents a major risk to the *population and the infrastructure. Significant work on seismic risk evaluation has not been undertaken previously based on the results of the true seismic monitoring approach and ground motion modeling techniques. Therefore, the current study is an attempt based on newly available seismological data and waveform modeling techniques to develop a new seismo-tectonic model near Gilgit city and the surrounding areas. The GB possesses a complex geologic and tectonic history where rocks of the two continental plates and a sandwiched island arc, along with two major tectonic boundaries, namely the Main Karakoram Thrust and the Main Mantle Thrust zones, are exposed. Frequent occurrence of strong magnitude earthquakes (Mw ≥ 6.0) in the region indicates a higher level of seismic risk to Gilgit city and the surrounding areas. Seismological data from the Pakistan Meteorological Department local seismic network have been used for knowing the crustal thickness and structure of the S-wave velocity underneath the Gilgit area. Primary wave receiver function analysis, H-K stacking, and inversion techniques are applied for this purpose. A new crustal model for S-wave velocity structure has been generated through waveform inversion. Results of waveform modeling show ~63 ± 2 km Moho crust thickness and a sedimentary rock layer at a depth of ~15 km beneath the Gilgit seismic station, respectively. The time-domain moment tensor inversion analysis has been applied to determine the source mechanism solution, providing convincing evidence of prevailing transpressive and transtensive stresses along several faults. Major seismic activities in the area are linked to the Nanga Parbat syntaxial region, which passes along the Main Mantle Thrust-Raikot active fault zone near Gilgit and Astore cities. For the risk assessment findings, firstly, ground motion shake maps using the SIGMA tool and GMT mapping software were generated. Later, the exposure of buildings, selected earthquake scenarios, and vulnerability information were provided as input parameters to the SELENA software to obtain potential damage and human and economic loss due to three scenario earthquakes. The first earthquake, Mw 7.0, induced maximum damage to the infrastructure with human casualties and injuries in the city of Gilgit. The second earthquake scenario, Mw 6.8, also resulted in high damage and casualties. However, the third scenario of Mw 6.3 caused maximum shaking with low damage to the infrastructure. Based on these scenarios, six building typologies are considered, among which RC-L, BrMsn, and adobe structures in Zone 1, Zone 5, and Zone 6 suffered maximum damage in both the first and second scenarios, indicating the vulnerability of these zones. The main reason for higher damage in these zones is the proximity of the earthquake source, the presence of buildings along the slope, poor BrMsn and RC-L structures, and, of course, higher ground motion. There was also observed influence of the unfavorable soil conditions, and trapping of seismic waves resulted in amplification in Zone 5 and Zone 6. The risk assessment study will help the people of the area to mitigate earthquake hazards more efficiently by adopting proper measures per recommendations related to pre- and post-earthquake scenarios. This study, besides the local population, will also help Pakistan and the China Economic Corridor (CPEC) counter earthquake hazards by adopting proper measures according to the earthquake zonation classification in the area of investigation.*

Seismic Hazard Assessment of Kandiah Valley District Kohistan, KPK, Pakistan: A Key to Develop Earthquake Resistant Structure

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The accumulated stresses within the earth's crust build up due to the crustal deformation resulting from the movement of continental plates. These stresses are released along week zones in the form of earthquakes causing rupture of the crust. The threat to human activities from earthquakes appears in the form of geo-hazard, so, it is significant to require careful consideration in the design of structures. The goal of the earthquake - resistant design is to produce a structure that can withstand a certain level of shaking without excessive damage. The present research work is to develop the dam structure at Kandiah River in Kandiah valley, Kohistan district of Khyber Pakhtunkhwa province, Pakistan. The study area lies is the Kohistan Island Arc; a tectonically active region and sandwiched between Indian and Eurasian tectonic plates. This region has been subjected to many damaging earthquakes in the past. It is therefore essential that a study of tectonic and earthquake history of the region be conducted to determine the earthquake hazard to which the dam structure may be exposed. In this study, deterministic and probabilistic seismic hazard assessment (DSHA & PSHA) for the development of a dam structure has been carried out with the help of interactive computer modeling by using available geological and tectonic data and Instrumental as well as historical seismological data of the region surrounding the Kandiah Valley. In DSHA, maximum moment magnitude (Mw) and peak ground acceleration (PGA) values for several tectonic features (MMT, Kohistan fault, Chilas Complex fault and Kamila Strike-slip fault) affecting the project site are evaluated. For tectonic features of the study area i.e., MMT, Kohistan fault, Chilas Complex fault and Kamila Strike-slip fault, the Mw is evaluated as 7.5, 7.3, 7.3 and 6.7 respectively. Similarly, the PGA values for these tectonic features are evaluated as 0.10g, 0.11g, 0.50g and 0.24g respectively. Moreover, in the procedure of PSHA, the seismic design parameters are evaluated. For PSHA, the selected seismic source zones are Hindukush, Pamir, Kohistan, Western Himalayas, Eastern Himalayas and Hazara-Kohat-Potwar. The PGA for Operating Based Earthquake (OBE), Design Based Earthquake (DBE) and Safety Evaluation Earthquake (SEE) are determined as 0.18g, 0.27g and 0.31g to be used for seismic-resistant design of a dam and its appurtenant structures.

TECHNICAL SESSION

BUILDING CODES OF PAKISTAN; METHODS, ANALYSIS & FAULT LINE DATABASE

Seismic Data Catalogue Compilation for The Building Code of Pakistan-2021and its Implications for Seismotectonic Modeling and S.H.A

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The seismic data catalogue is one of the vital inputs in seismic hazard studies. Compiling a comprehensive and homogenous catalogue requires expertise and in-depth knowledge of the seismic data and active tectonics of the region. Comprehensive historical and instrumental earthquake catalogues were complied using various data sources. Each historical earthquake requires review of available historical data/reports and past published literature. The resulting historical catalogue is the most comprehensive and up-to-date catalogue for Pakistan. With the advent of modern instruments, instrumental seismic data has become available and have been collected from different national and international reporting agencies (such as PMD, CES, and USGS, ISC, EMSC, etc., respectively). Compilation of the instrumental seismic data catalogue of Pakistan was carried out using CompiCat software package by removing the duplicate events. The ISC-GEM catalogue was also utilized for event review. Missing hypocentral parameters of events were also utilizing different sources. Finally, the catalogues were described in moment magnitude (M_w) using magnitude conversion relations. The quality of the complied instrumental earthquake catalogue was assessed by the magnitude of completeness (Mc) using MAXC (Maximum Curvature) method. The main catalogue was then declustered using Matlab codes by applying several declustering techniques. Seismic hazard evaluation is very sensitive to the parameters of the seismic data catalogue. Therefore, it is recommended to conduct periodic S.H.A. to cater new data and to carry out S.H.A. after the occurrence of any major or destructive earthquake.

TECHNICAL SESSION

SUSTAINING GNSS CORS NETWORK; CHALLENGES, INNOVATIONS AND FUTURE STRATEGIES

Designing An Academic Cors-Network: Improving GNSS Coverage for Scientific Research and Practical Applications

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The demand for high-precision positioning services in Pakistan is growing rapidly across government, private, and academic sectors, particularly in surveying, construction, and geospatial applications. However, current standalone GNSS solutions offer only 5–10 meters of accuracy, insufficient for many critical applications; while single-base RTK setups suffer from limited coverage only of few kilometers. To overcome these limitations, this research proposes the design and development of an academic Continuously Operating Reference Stations (CORS) network, with the primary base station located at the Institute of Space Technology (IST), Islamabad and three additional stations hosted by different universities across the region. Each station will utilize multi-frequency, multi-constellation GNSS receivers paired with survey-grade, full-spectrum choke ring antennas capable of delivering centimeter-level accuracy. With inter-station distances under 30 kilometers, the network will enable Network Real-Time Kinematic (NRTK) services for high-precision GNSS corrections via NTRIP, ensuring continuous, reliable data access. This network will support a wide range of users, including academia, government, and the private sector, while also laying the groundwork for a national geodetic reference system. The continuous GNSS observations will contribute to geophysical research, such as monitoring tectonic motion, continental drift, crustal deformation, and active fault lines. The proposed regional network will serve as a prototype for future nationwide expansion, ultimately forming a comprehensive GNSS CORS-Network across Pakistan.

Fault System Sw, Pakistan: Insights from Geomorphology, Remote Sensing, Field Investigations, and Seismic Record Analysis

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The Chaman Transform Fault (CTF), a major tectonic boundary between the Indian and Eurasian plates, represents one of the most seismically active and structurally complex regions in Pakistan. Extending over 850 km along the western margin of Pakistan and Afghanistan, this left-lateral strike-slip fault system plays a critical role in accommodating oblique convergence between the two plates. This research investigates the neotectonic features and seismic behavior of the CTF within Pakistan, integrating geomorphological and remote sensing data, supplemented by field investigations and seismic data interpretation.
Recent neotectonic deformation is evident through features such as offset streams, fault scarps, shutter ridges, pressure ridges, en-echelon folds and linear valleys. Geodetic measurements from GPS and InSAR indicate significant crustal strain accumulation, with slip rates ranging between 18–28 mm/yr, emphasizing the potential for large-magnitude earthquakes. Structural segmentation along the fault suggests a complex interaction between transpressional and transtensional regimes, particularly in zones of fault step-overs and bends.
Seismological analysis indicates that the CTF accommodates a significant portion of the relative plate motion, with frequent moderate to strong earthquakes (Mw 5.0–7.5), highlighting the fault's potential for major seismic hazards. Historical seismicity, notably the 1935 Quetta earthquake (Mw 7.7), underscores the region's vulnerability.

The interaction of the CTF with adjacent fault systems, including the Ghazaband and Ornach-Nal faults, further complicates the stress regime, contributing to diffuse deformation across a broad fault zone. This research underscores the importance of continued neotectonic monitoring in the region, not only to refine seismic hazard assessments but also to better understand the long-term tectonic evolution of the India-Eurasia collision zone. The findings contribute valuable insights into the mechanisms of strain partitioning and crustal deformation within active continental transform fault systems.

The Impact of Tectonic Paleostresses on The Structural Evolution of Main Boundary Thrust (MBT) Along Western Limbs of Hazara, Pakistan

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Tectonic paleostresses associated with the Himalayan orogeny have had significant effects on the structural evolution of the Main Boundary Thrust (MBT) in the western limbs of Hazara, Pakistan. This study investigates how the brittle structural features and deformation patterns along the MBT have been influenced by modifications to paleostress orientations. The study region, that makes up part of the Lesser Himalaya and is bordered to the north by the Main Central Thrust (MCT) and to the south by the MBT, retains a great deal of evidence of brittle deformation triggered by thrust. Using the Win-Tensor initiative, the field data from 50 outcrops and upwards of 550 documented fracture orientations have been analyzed. Paleostress fields were subsequently reconstructed using the Right Dihedron Method. Approximately orthogonal to the MBT track, the data show a prevailing compressive regime with $\sigma 1$ running NNW–SSE. This orientation is consistent with a tectonic scenario where the MBT's structural design developed as a result of several thrust reactivations and stress reorientations. These results highlight how crucial tectonic paleostresses are in regulating the NW Himalayan thrust system's fault propagation and structural complexity.

Tectonic paleostresses generated during the Himalayan orogeny have profoundly influenced the structural evolution of the Main Boundary Thrust (MBT) in the western limbs of Hazara, Pakistan. The MBT, a major tectonic boundary separating the Lesser Himalaya from the Sub-Himalaya, has undergone multiple episodes of reactivation reflecting the interplay between India–Eurasia convergence and stress field modifications. Evaluating these paleostresses is essential for understanding thrust kinematics, fault propagation, and the geodynamic complexity of the NW Himalayan fold-and-thrust belt.

This study integrates detailed fracture analysis with paleostress inversion to examine brittle deformation patterns along the MBT. More than 550 fracture orientations from 50 outcrops were systematically documented using the circle inventory method, which quantifies fracture density, aperture, porosity, and spacing. Data were analyzed with Win-Tensor software, employing the Right Dihedron and rotational optimization methods to reconstruct reduced stress tensors. The results indicate a prevailing compressional regime with σ_1 oriented NNW–SSE, approximately orthogonal to the MBT trace. This orientation is consistent with Anderson's theory of faulting and reflects repeated thrust reactivation, transpressional adjustments, and out-of-sequence deformation.

The structural complexity documented in Hazara mirrors observations across the Himalayan arc, where polyphase deformation and variable stress regimes are common. Comparative studies demonstrate that paleostresses not only localize brittle failure but also govern thrust propagation and wedge mechanics. Integrating fracture mechanics, Mohr circle stress analysis, and paleostress inversion underscores the utility of geomechanical approaches in reconstructing tectonic stress histories.

These findings advance the understanding of MBT kinematics in western Hazara and emphasize the role of tectonic paleostresses in shaping foreland deformation. Beyond regional tectonic models, the results also have implications for seismic hazard assessment, given the continuing activity along the Himalayan frontal thrust system.

Establishing A First-Level Seismic Microzonation Model for Geohazard Risk Mitigation: A Step Towards Urban Resilience

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Seismic microzonation is a crucial step in evaluating site-specific earthquake hazards and formulating effective mitigation strategies, especially in urban environments prone to seismic activity. This study presents a first-level seismic microzonation framework designed to delineate zones based on relative seismic hazard potential using a combination of geological, geophysical, and geotechnical parameters. The methodology integrates Peak Ground Acceleration (PGA), soil classification, depth to bedrock, and shear-wave velocity (Vs30) to generate a composite hazard index. These parameters were first standardized and weighted, and then spatially processed in a GIS environment using raster overlay analysis to produce a seismic hazard zonation map. Each input layer was converted into a georeferenced raster surface, reclassified based on hazard potential, and aggregated using weighted linear combination techniques to produce the final index map.

The model was applied in a seismically active urban setting to assess its effectiveness in distinguishing zones of varying seismic vulnerability. Spatial analysis revealed a clear variation in seismic hazard levels across the study area, with high-risk zones correlating strongly with soft sediments, lower Vs30 values, and shallow bedrock depths. The resulting microzonation map highlights areas that may experience amplified ground shaking during future seismic events. This output provides a robust decision-making tool for urban planners, engineers, and emergency response authorities by enabling prioritization of retrofitting efforts and land-use regulation.

While the approach is based on generalized regional data and serves as a preliminary assessment, it can be refined with site-specific measurements to support higher-level microzonation in future studies. Moreover, the methodology is scalable and adaptable to other regions with similar geological contexts, including vulnerable areas in Pakistan. This study highlights the importance of integrating multidisciplinary datasets to enhance seismic risk assessment and lays the groundwork for advancing urban resilience through informed planning and infrastructure design.

Integrated Seismological and Geodetic Analysis of Moderate Earthquakes in The Northern Potwar Deformed Zone, Pakistan

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Between December 2024 and April 2025, a sequence of moderate earthquakes (Mw 4.8–5.2) occurred in the Northern Potwar Deformed Zone (NPDZ), producing significant shaking in Islamabad–Rawalpindi. This study presents the first integrated seismological–geodetic assessment of these events using broadband waveforms and GNSS observations from newly established Trimble Alloy stations. Three main earthquakes are analyzed: (i) a Mw 5.2 strike-slip event near Kharian–Jhelum (December 2024), (ii) a Mw 4.8 thrust event on the Rawat Thrust (February 2025), and (iii) a Mw 5.1 oblique-slip event along the Main Boundary Thrust near Hazro (April 2025). Moment tensor inversion of local broadband data, supported by finite-fault modeling, indicates predominantly transpressional kinematics with a persistent NNW–SSE compressional axis, consistent with India–Eurasia convergence. GNSS velocities (May 2024–Feb 2025) derived from GAMIT/GLOBK processing reveal ~36–45 mm/yr northward Indian Plate motion with localized strain accumulation along frontal thrusts. Ground motion records show peak ground acceleration (PGA) of 0.22 m/s² in the Islamabad Basin, enhanced by Quaternary alluvium. Coulomb stress transfer analysis suggests that the December 2024 Jhelum earthquake may have advanced failure on the Rawat Fault, while dynamic triggering from the March 2025 Mw 7.7 Myanmar earthquake likely modulated seismicity across the NPDZ.
These results highlight the critical role of moderate earthquakes in accommodating distributed deformation, basin amplification effects on ground motion, and the necessity of integrating seismic and geodetic monitoring to improve seismic hazard assessment in northern Pakistan.

InSAR Time Series Analysis: A Case Study of The Locked Zone of the Chaman Fault in Nushki Area, Pakistan, to Describe the Fault Behavior

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*Chaman Fault is strike-slip structural boundary that separates the weste
rn boundary of the Indian plate and the eastern boundary of the Eurasian Plate. It is known for its potential seismic hazards. This research aims to forecast these hazards using the mintpy time series technique by calculating the average velocity of motion transects and point displacement time series in its locked zone, Nushki area. Interferometric synthetic aperture radar (InSAR) technique measures the ground surface deformation, therefore enabling the estimation of fault movement. In this study, Sentinel-1A Single Look Complex (SLC) ascending images spanning the dates July 2018 to June 2023 have been used. InSAR time series analysis, based on small baseline subset (SBAS) and mintpy time series analysis method, has addressed the challenges of unwrapping errors, tropospheric delays, and topographic noise and generated the raw phase time series. Further, this approach produces noise-reduced average velocity, motion transect velocity and point displacement time series. The results reveal an average velocity of motion transects along the Nushki locked zone is ± 0.6 mm/year across 10 km. Additionally, the point displacement time series is -0.2 ± 0.7 mm/year. Moreover, the findings of this work indicate that the southern part of the Chaman fault is inactive due to friction, leading to the accumulation of strain and suggesting a potential increase in seismic hazards in this area. Furthermore, this study offers valuable insights into the current state of the Chaman fault, contributing to a more comprehensive understanding of its behavior and supporting effective seismic risk mitigation strategies.*

<u>TECHNICAL SESSION</u>

CLIMATE CHANGE IMPACT ON MASS MOVEMENT/LANDSLIDE HAZARDS

Landslides In Pakistan: A Country Report

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Pakistan's northern mountainous terrain comprising Gilgit-Baltistan (GB), Khyber Pakhtunkhwa (KP) and Azad Jammu & Kashmir (AJK) are the landslide hotspot zones that lie in the key mountain ranges of Himalayas, Karakoram and Hindukush. Recent work by the Geological Survey of Pakistan (GSP) depicts the Himalayas as far more prone to landslides (at least major landslides) as compared to Karakoram and Hindukush. Parts of the Punjab and Balochistan provinces are also affected by the landslide phenomenon although lesser in intensity and frequency. Shallow, low angle landslides have been observed along the southern coastal belt but they constitute a negligible proportion in comparison with the north. In addition to the natural factors the anthropogenic activities like deforestation, improper road cuts, improper drainage and land encroachment are the main contributing factors. Coseismic landslides of the 2005 Kashmir Earthquake (including the catastrophic Hattian Bala Landslide), Attabad Landslide (2010), Gayari rock and ice avalanche (2012) and the Torkham Landslide (2023) are some of the major events in recent years. Losses due to landslides are generally under-estimated; for example, out of the total earthquake-related casualties (87,350) about 30% were associated with coseismic landslides including 1000 lives lost in a single landslide event (the Hattian Bala landslide). Economic loss due to landslides is not well-documented and under-estimated in Pakistan; only the realignment of the Karakoram Highway (KKH) due to a single landside event i.e., the Attabad landslide dam formation cost USD 275 million (Business Recorder, September 15, 20215). Landslides not only disrupt the infrastructure and communication network but also interrupt the socio-economic setup of the affected communities. Stream blockage and flooding due to landslide dams not only have long-lasting impacts on the sedimentation rate and landform of the area but adversely affect the storage capacity of downstream water reservoirs that are vital for the country. Shallow landslides dominated by the debris flow phenomenon are the emerging trend of mass movement under the influence of changing climate patterns in northern Pakistan. The state is encouraging in addressing the landslide issues in the country; the National Disaster Management Authority (NDMA) and other relevant state departments along with private organizations and academia are active towards disaster risk reduction (DRR) activities. Insufficient funds, low public awareness, limited coordination between national stakeholders, remote and inaccessible areas, underestimation of the landslide impact, and a visible gap between the recommendations and implementation are the main challenges in coping the landslides.

Lessons Learned from The Recent Earthquake-Induced Landslides and the 2005 Northern Pakistan Earthquake

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Recent earthquakes, such as 2005 Northern Pakistan Earthquake, 2008 Wenchuan Earthquake, 2009 Padang Earthquake, 2011 Tohoku Earthquake, 2015 Nepal Gorkha Earthquake, 2016 Kumamoto Earthquake, 2018 Hokkaido Earthquake, induced many landslides, which can be classified into several types. One of the important types is the landslides of young pyroclastic fall deposits which occurred in many locations by the 2009 Padang Earthquake, 2011 Tohoku Earthquake, 2016 Kumamoto Earthquake, and 2018 Hokkaido Earthquake. They were highly mobile and occurred in many numbers as clusters. Those landslides, however, are probably not serious in Pakistan because of the lack of the young pyroclastic fall deposits. Shallow landslides occurred on ridge tops and cliff shoulders, where earthquake shaking is amplified. Deep-seated gravitational slope deformation prepares for large-scale rockslides and shallow landslides on the surface portions of the deformed rock body. This type was particularly significant in the landslides induced by the 2005 Northern Pakistan Earthquake and would be expected to occur again.

Northern Pakistan Earthquake (Mw7.6), which occurred at 8:50 am on 8 October, 2005, induced many landslides along the earthquake fault, Balakot-Garhi (or BalakotBagh) fault, trending NW-SE for about 70 km. We studied landslides near the southeastern half of the fault, which runs in the Miocene Murree Formation consisting of alternating beds of sandstone and mudstone. Field survey and the interpretation of satellite images before and after the earthquake showed that many of the landslides induced by the earthquake were preceded by long-term gravitational slope deformation with several types; flexural toppling, buckling, and sliding. The Dandbeh slide (Hattian slide) with a volume of 27 million m3, one of the largest landslides by this earthquake, was a slide of the axial part of a downslope plunging syncline. It had been a complex of smaller elongated landslide bodies before the earthquake, and the lowermost slides were undercut by a stream, which seems to have rejuvenated because there are continuous slope breaks several tens of meters high above the riverbed. Many slope failures occurred along the upstream of the Jhelum River, which flows down near the earthquake fault; they occurred in the lower parts of large gravitationally deformed slopes. Most common deformation was flexural toppling, which occurred on slopes as large as 1 or 2 km^2 and made long downslope facing scarplets along the ridge tops. The deformation made many fractures within rock masses and made large volumes of debris, which failed. Another type was buckling; some buckled strata slid down catastrophically by the earthquake.

Investigating Landslide Hazards in The Kashmir Valley by An Empirical Approach Near the Main Boundary Thrust

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Northern Pakistan is vulnerable to landslides because of its distinct geotectonic setting and fluctuating topography, which continuously endangers infrastructure, human life, and the socioeconomic fabric of the area. In order to investigate landslide behavior along the Main Boundary Thrust (MBT) and assess its contribution to slope instability, this study focuses on a portion of the MBT's western limb. Kinematic analysis was used to find failure patterns in rock outcrops as part of field research to gather data on landslide parameters. Samples of soil were collected for Atterberg limit testing, and slope stability was evaluated empirically using the Q-slope method. The historical occurrence and behavior of landslides in the region were revealed through interviews with local residents. The findings from field observations, rock strength assessments by empirical method, terrain analysis, and soil testing indicate that the MBT along with associated factors such as spring water emergence, rock discontinuities, and human activities—significantly contributes to slope instability. Q-slope classification divides the slopes into uncertain, stable and unstable slope. Moreover, the anticipated increase in precipitation due to climate change is likely to further exacerbate landslide activity along the MBT. This risk is compounded by the expansion of human settlements on vulnerable mountain slopes, driven by population growth.

Climate Change and Landslide Hazards: A Case Study from Khushab District, Punjab, Pakistan

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The frequency of extreme precipitation events has increased, reflecting the severe effects of climate change in Pakistan. This research identifies rock slopes which can be potentially affected by the impact of extreme precipitation rates along the Khushab-Sakesar road in Khushab district. Numerous rock slope failures have been reported alongside the road during the monsoon period, leading to property damage and loss of life. To investigate slope failures, a systematic approach was adopted which comprised of slope failure data noted by locals, precipitation data of the research area, Detailed Line Survey, laboratory analyses, and Kinematic Analyses. Various sites have been identified based on the potential instability of rock slopes. The findings suggest that extreme precipitation patterns, especially in monsoon periods will result in the instability of rock slopes alongside the road.

The Role and Responsibilities of the National Institute of Disaster Management (Nidm): A National Think Tank

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The National Institute of Disaster Management (NIDM) in Pakistan, established in 2010 by the National Disaster Management Authority (NDMA), serves as a vital entity in addressing Pakistan's vulnerability to a wide spectrum of disasters, including natural ones like earthquakes, floods, droughts, GLOFs, cyclones, landslides, forest fires, heat waves, as well as man-made disasters. NIDM functions as a national think tank and knowledge hub, engaging in research, training, and capacity building programs. It collaborates closely with government agencies, NGOs, academic institutions, and the private sector to foster a coordinated and effective disaster management system. Since its inception, NIDM has made significant strides, impacting over 30,000 individuals through training programs, conducting research to inform evidence-based policies, and collaborating on disaster risk reduction strategies. Recognizing operational gaps highlighted by recent disasters, NDMA has restructured NIDM to focus on "Know Risks," "Know Early," and "Pre-emptive Preparedness." This remodeled NIDM engages in comprehensive disaster management aspects, collaborate with national and international academia, and establish a geohazard database while fostering collaboration with domestic and international universities to formulate "Global Best Practices". Additionally, initiatives like National Volunteer Corps, targeted at youth of Pakistan, will further enhance information dissemination and community engagement, fostering a proactive, knowledge-driven approach toward building a safer and more resilient future for Pakistan.

National Emergency Operations Center (NEOC), NDMA: Framework, Roles, Responsibilities, and Key Activities

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The strategic transformation of Pakistan's National Disaster Management Authority (NDMA) through the operationalization of its National Emergency Operations Center (NEOC), aiming to shift the national disaster management approach from reactive to proactive. Central to this transformation is the integration of multi-hazard early warning systems, real-time data streams, and AI-powered decision support tools.
A major feature of NEOC is its suite of Early Warning (EW) portals, including systems for floods, droughts, glacial lake outburst floods (GLOFs), and seismic hazards. These portals combine satellite-based rainfall data, river telemetry, vegetation health indices, soil moisture anomalies, seismic sensors, and infrastructure overlays to provide high-resolution risk intelligence. Built with support from national agencies such as PMD, SUPARCO, and FFD, the portals offer real-time dashboards, hazard forecasting, and impact-based advisories tailored to district and provincial authorities. Through these systems, NEOC manages a dynamic risk calendar, tracking climate- and geo-hazards over six-month cycles. This facilitates coordinated early action such as targeted evacuations, pre-positioning of supplies, simulation exercises, and rapid inter-agency communication. Backed by 270 satellite feeds and over 40 custom software applications, NEOC exemplifies a modern, anticipatory model for climate resilience and disaster preparedness in Pakistan.
The system exemplifies a forward-looking, integrated disaster risk management framework built on the principles of climate resilience and anticipatory governance. Central to this approach is NEOC's deployment of the National Common Operating Picture (NCOP) and Global Common Operating Picture (GCOP) — dynamic, data-driven situational awareness tools that consolidate real-time hazard, exposure, and vulnerability information. These platforms enable unified decision-making across federal, provincial, and district levels while incorporating global risk intelligence. By linking local risk dynamics to broader climate and geophysical indicators, NEOC ensures informed action at every level of response. This holistic framework not only enhances national preparedness but also aligns with global resilience strategies.

Reactivated Landslide by the 2024 Noto Peninsula Earthquake Around Hattaro Pass, Central Japan

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The 2024 Noto Peninsula Earthquake (M 7.6) induced many landslides (Geospatial Information Authority of Japan/GSI HP). Recent developments in remote sensing technology such as InSAR and LiDAR have made it possible to reveal small displacements of less than ten meters to several ten centimeters that are difficult to find with the naked eyes for wide area (Kikuchi et al, 2024; Sato & Yagi,2024).
The study aims to clarify the slight lateral slide of the hilly terrain is repeatedly caused by the big landslide. The study site is located on a low-relief hill 200-250m asl on the western side of Hattaro Pass where landslide driving force is seemed topographically too small to move the hilly terrain (Fig.1). No large-scale landslides have been noted on the landslide inventory map issued from NIED. However, small up-hill facing scarps and narrow linear depressions running east-west were formed along the northern fringe of the hill before the earthquake in 2024, suggesting the hilly area were gravitationally slightly down-thrown southward before the event. Furthermore, LiDAR survey just after the earthquake clarified slight displacement was formed by the earthquake (Kikuchi et al, 2024).
The earthquake formed opening and cracks in the depression and caused humic deposits to appear. The authors collected two dating samples from the depression (Fig.2). They are a charcoal and a wood fragment. The AMS dating was performed at the Yamagata University High Sensitive Mass Spectroscopy Center. The calibrated age of these layers was 8-2 BC. These data imply the large earthquake of same scale occurred before 8-2 BC in this region.

Understanding Geological and Hydro-Meteorological Hazards for Effective Habitat Risk Mitigation in Northern Pakistan

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Northern Pakistan is marked by extreme topography, complex geological structures, and a dense fluvial network, making it one of the most hazard-prone regions in South Asia. Characterized by steep ridges, deep valleys, and glaciofluvial fan-based settlements, the region is increasingly vulnerable to a range of natural hazards, including landslides, debris flows, snow avalanches, glacial lake outburst floods (GLOFs), seismic activity, gully erosion, riverbank collapses, and flash floods. These hazards are being exacerbated by shifting climate patterns, resulting in increased frequency and intensity of damaging events. Recent examples underscore the severity of these risks: debris floods in Sherqila and Bubar have resulted in significant loss of life and property; a GLOF event in Shishper destroyed critical infrastructure including a major bridge on the Karakoram Highway (KKH); and in Chitral Valley, riverbank erosion has severely impacted road connectivity and bridge stability. Similar events in Karambar Valley, such as the debris flow in Immit village, have devastated agricultural land and damaged essential infrastructure including power stations and irrigation channels. Furthermore, numerous dormant but potentially catastrophic landslides such as those in Mayun, Nilt, and Reshit pose a persistent threat. These landslides, if reactivated, have the potential to replicate disasters like the Attabad landslide of 2010.

Although multiple agencies are engaged in hazard mapping and analysis, the absence of coordination among them has resulted in duplicated efforts, with various organizations often working independently in the same areas using limited and outdated data. This fragmented approach combined with insufficient access to advanced data acquisition technologies has led to assessments that are less meaningful and mitigation strategies that are largely reactive. These challenges are further compounded by the remoteness of the affected regions and the lack of long-term hydro-meteorological data, both of which hinder accurate flood modeling and effective risk reduction planning. To address these gaps, there is an urgent need for integrated, multi-disciplinary approaches that combine geological mapping, climatic modeling, and community-based assessments. Establishing a coordinated framework among academic institutions, government bodies, and non-governmental organizations is critical to improving the understanding and monitoring of hazard mechanisms, as well as the spatial and temporal variability driven by climate trends. Such collaboration will support the development of sustainable, data-driven, and cost-effective mitigation strategies to better safeguard vulnerable communities.

Tracing The Footprints of Climate Change on Mass Movements in Hunza-Nagar Valley, Karakoram: Implications for Hazard Assessment

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The Hunza-Nagar Valley, nestled in the geologically active Karakoram Range of northern Pakistan, is increasingly experiencing mass movements—particularly landslides—that are closely tied to the evolving impacts of climate change. This study aims to trace the footprints of climate change on the spatial and temporal patterns of mass movements in the region, highlighting how warming temperatures, glacial retreat, changing precipitation regimes, and permafrost degradation have altered slope stability over the past two decades. Using an integrated methodology combining remote sensing (e.g., Landsat, Sentinel), historical landslide inventories, climatic data, field surveys, and GIS-based spatial analysis, the study identifies climate-sensitive hotspots and assesses key triggering factors.

The results reveal a growing correlation between climate-induced changes—such as intense rainfall events, rising temperatures, rapid snowmelt, permafrost degradation, the formation of glacial lakes, sudden increases in stream discharge, and toe cutting along the base of unstable slopes—and the triggering of mass movements in climate-sensitive zones. Moreover, human activities such as road construction and slope modification have also interacted with climate-induced stressors to exacerbate hazard exposure in several settlements and infrastructure corridors. This case study offers critical insights into the cascading nature of climate change impacts on geomorphic processes in high mountain environments. It underscores the need for integrating climate projections into regional hazard zoning, early warning systems, and community-based disaster risk reduction strategies. As such, it contributes to both the scientific understanding and practical response mechanisms for enhancing resilience in climate-sensitive mountainous regions like Hunza-Nagar.

Urban Expansion and Risk Exposure Assessment Using GIS And Remote Sensing: A Case Study of Aliabad Town, District Hunza, Gilgit-Baltistan

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Urban expansion significantly reshapes city landscapes, affecting infrastructure, the environment, and quality of life. Geographic Information Systems (GIS) offer powerful tools for monitoring and analyzing these changes. This study uses GIS techniques to assess a 12-year urban expansion in Aliabad Town, Hunza, using building footprints as indicators of built-up areas. High-resolution Google Earth imagery from 2010 and 2022 was used to extract and compare building footprints. In addition, the expansion is evaluated in the context of risk zones identified through the Hazard Vulnerability and Risk Assessment (HVRA) method. Results indicate that the built-up area increased from 166,311 square meters in 2010 to 340,059 square meters in 2022, reflecting a growth of 173,748 square meters. Importantly, a substantial portion of new construction occurred within high-risk zones, highlighting the urgent need for informed urban planning.

Integrated Geospatial and Field-Based Assessment of Debris Flows in The Karakoram Range, Northern Pakistan

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Northern Pakistan is highly susceptible to debris flow hazards due to its unique geomorphological setting, including steep terrain, glaciated catchments, intense monsoonal precipitation, seismic activity, deforestation, and growing anthropogenic pressures. Accurate prediction of potential deposition zones from future debris flow events is essential for effective disaster preparedness, sustainable land use, and the protection of communities and infrastructure. Despite the increasing frequency and severity of such events, quantitative and high-resolution hazard assessments remain limited in this region, impeding robust risk mitigation efforts. This study presents a detailed, site-specific debris flow hazard, vulnerability, and risk assessment in Khalti village, Ghizer District, utilizing the Rapid Mass Movement Simulation – Debris Flow (RAMMS-DF) model. Unlike previous studies relying on empirical or single-scenario approaches, this research integrates multi-scenario, numerical modeling with systematic geospatial vulnerability analysis to better identify high-risk zones. High-resolution UAV-derived Digital Elevation Models (DEMs), ALOS PALSAR data, and extensive field observations were used to construct a comprehensive geospatial inventory of exposed elements and to enhance model accuracy in a data-scarce mountainous environment. Multiple potential initiation zones were modeled, with calibrated frictional parameters to simulate realistic flow behavior. The maximum simulated flow volume reached 193,717 m³, with a peak flow height of 13 meters and impact pressure up to 992.2 kPa, indicating substantial risk to settlements, roads, bridges, and agricultural lands. Among the modeled scenarios, Scenario 3 revealed the highest hazard and risk levels, emphasizing the importance of multi-scenario evaluations. The integration of high-resolution remote sensing, field-based data, and advanced numerical modeling offers a replicable framework for debris flow hazard and risk assessment in similar high-relief, data-limited regions. This research contributes significantly to the field of natural hazard assessment in the Hindukush, enabling more effective disaster risk reduction and climate-resilient land use planning.

Landslide Formation Mechanisms in Tectonically Active Regions of Northern Pakistan

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Assessing landslide hazards is crucial in highway engineering, particularly along challenging routes passing through the tectonically active regions. This study emphasizes the need for advanced, multidisciplinary methodologies to analyze the formation mechanisms and stability of complex landslides on the Muzaffarabad-Mansehra highway in Northern Pakistan. The main objectives include investigating slope failures, identifying triggering mechanisms in layered rocks, imaging subsurface geometrical configurations, and evaluating slope stability factors through field operations, remote sensing, geomorphological mapping, geophysical imaging, and kinematic analysis.

The results reveal that the foliated Hazara Formation is highly susceptible to geo-environmental conditions that can trigger landslides, as it is often dragged, buckled, and overhung due to the creeping faults. Geophysical surveys uncovered multiple layers with varying depths and thicknesses, illustrating the complexity of the landslide. Low resistivity zones indicate the presence of unconsolidated, water-saturated materials and sheared substances (0.325-1350 Ωm), while high resistivity zones correspond to overburden such as alluvium, boulders, and dry slate fragments (1510-26092 Ωm). Seismic refraction tomography showed low P-wave velocities (400-1800 m/s) in saturated overburdens and reworked blocks, with high-density rock fragments and massive boulders exhibiting velocities between 3000-5000 m/s. Both tomographic methods identified a fracture zone extending 30 m deep, posing significant risk for catastrophic events. The sliding surface was measured to be 25-30 meters deep at the crown and 45 meters deep in the main body, with kinematic analysis identifying wedge failure as the primary mode of failure along highway cuts.

These findings underscore the critical role of integrated methodologies in elucidating the mechanics of landslide hazards in the active tectonic regions. The results demonstrate the effectiveness of these approaches in identifying and mitigating the associated risks, thereby enhancing the safety and stability of roadway infrastructure.

Multi-Hazards Vulnerability and Risk Assessment in North Pakistan Using Open-Source Remote Sensing Data and Geoinformation Techniques

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The physical, tectonic, environmental and climatological settings coupled with the climate change in northern Pakistan, provide an favorable landscape for the frequent and damaging hazards mainly landslides, debris flows, GLOF and earthquakes. However, given the complex terrains and data-poor region, comprehensive multi-hazard, vulnerability and risk assessment are rarely achieved for effective disaster management. In this study, methodologies are developed to utilize the extensive field data, techniques and models for regional-scale landslide, debris flow, GLOF and seismic hazards and risk assessments. Manual and semi-automatic techniques are applied to develop multi-hazard inventories that are related to the physical and environmental settings; and potential triggers to acquire the susceptibility and hazard assessments. The elements at-risk database comprising of the settlement's footprints, typological information, communication network, landuse, critical infrastructure, and social vulnerability indicators are utilized for vulnerability assessment and eventually risk analysis. The morphometric analysis of the drainage basins and statistical models are useful for investigating the watershed susceptible to debris flows and for applying local scale simulation models. The element-at-risk features on the alluvial fan of the respective watersheds are analyzed for their exposure, vulnerability and risk analysis. Seismic site characterization maps are produced through field-based measurements of the shear wave velocities and relevant proxies such as the geology and terrain slope. The GLOF hazard and risk are accomplished for the high-risk glacial lakes. The integrated multi-hazard is analyzed with the element at-risk databases for the multi-hazard vulnerability and risk assessment. Considering the unprecedented devastation caused by the intense monsoon in 2022, dynamic and quantitative risk assessment and adaption/mitigation planning are critical for disaster risk reduction and therefore offer opportunities for collaboration for joint research studies on climate change impacts on dynamic multi-hazard risk assessment in the region.

Evaluating Landslide Susceptibility and Slope Failure Mechanisms Using Geospatial and Geotechnical Approaches: A Case Study from Nw Himalayas, Muzaffarabad, Pakistan

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Landslides are frequent geological hazards, particularly during the rainy season along road corridors worldwide. In the Himalayan region, this risk is significantly heightened due to steep slopes, high relief, active tectonics, fragile geology, and erratic monsoon patterns. In the present study, we have comparatively analyzed landslide susceptibility by employing integrated geospatial approaches, i.e., data-driven, knowledge-driven, and machine learning (ML), along the Neelum Valley road corridor of the Muzaffarabad district. The landslide inventory of this road corridor is developed to evaluate landslide susceptibility, and eleven landslide causative factors (LCFs) were analyzed. After statistical significance analysis, these eleven LCFs generated susceptibility models using WoE, AHP, LR, and RF. Distance from roads, landcover, lithological units, and slopes are considered more influential LCFs. The performance matrix of different LSMs is evaluated through the area under the curve (AUC-ROC), overall accuracy, Kappa index, F1 score, Mean Absolute Error, and Root Mean Square Error. The AUC-ROC for WoE, AHP, LR, and RF techniques along Neelum Valley road is 0.86, 0.82, 0.91, and 0.97, respectively. The LSMs are categorized into very high, high, moderate, and low susceptible zones. Based on the susceptibility results, the area of very high susceptible zone along Neelum Valley road, two case studies were selected for detailed kinematic analysis along with RMR and GSI assessments which indicated the planar and wedge mode of failures within poor to fair-quality rock masses. The study demonstrates that integrating geospatial and geotechnical techniques offers an effective approach for identifying and managing landslide-prone zones for mitigation and infrastructure planning along vulnerable sections of the Neelum Valley road.

Post-Formation Behavior of Hattian Landslide Dam and Post-Breaching Situation: Long-Term Shape Changes of Numerous Landslides Along the Balakot-Bagh Fault Activated in the 2005 Kashmir Earthquake and Their Impact on People's Livelihoods

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Countless landslides occurred along the 75 km-long surface rupture of the Balakot-Bagh fault, which appeared on October 8, 2005, during the Mw 7.5 Kashmir earthquake. These landslides included approximately 85 million m³ of debris mass that blocked two tributaries of the Karli branch of the Jhelum River, forming Karli Lake (the larger lake) and Tang Lake (the smaller lake). The dam was sustained for over 4 years and 4 months, and finally, the water of Karli Lake breached the northwestern part of the dam on February 9, 2010. In Muzaffarabad, where the earthquake exposed the bare slopes of the mountains behind the city, significant sediment flows buried thick the mountain streams that ran through the city. Such unstable sediment continued to be a serious threat to nearby residents. This presentation reviews the changes in these unstable soil masses and the responses of people.

A Process-Based System for Mountain Torrent and Debris Flow Early Warning and Risk Forecasting

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Mountain torrents and debris flows are widespread across mountainous regions, posing significant threats to urban development and infrastructure in these areas. The adverse impacts of these hazards are expected to intensify due to ongoing socio-economic development and the effects of climate change on the frequency and severity of events. This presentation introduces an early warning system built on hazard process simulation and integrated risk forecasting. The system identifies watersheds highly susceptible to mountain hazards by monitoring hazard-fostering conditions alongside real-time meteorological data. Within these targeted watersheds, the formation and movement of hazards are simulated, capturing key characteristics such as debris flow scale amplification and flash flood erosion. Risk assessments are conducted across the full disaster process—formation, movement, deposition, and disaster-causing stages. In contrast to traditional early warning systems that mainly rely on rainfall thresholds and expert judgment, this system is fully data-driven and process-based, requiring minimal human intervention. It offers more accurate early warning information and enhanced risk forecasting, supporting improved disaster response planning for government agencies. Currently being trialed in Liangshan Prefecture, Sichuan Province, China, the system successfully captured 102 out of 132 flash flood and debris flow events between 2022 and 2024, significantly enhancing the region's disaster resilience.

Scaling Resilience: UNESCO's Science-Based Approach to Disaster Risk Reduction in A Changing Climate

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As climate risks intensify, innovative and science-based approaches are essential to reduce disaster impacts and build resilience. This session will showcase how UNESCO is scaling practical solutions—such as AI-powered early warning systems, drone-based flood mapping, open science platforms, and low-power technologies—for risk reduction across diverse regions. Through real-world examples from Africa, Asia, and the Caribbean, participants will explore how UNESCO supports countries in transforming global DRR goals into inclusive, locally driven action.

Geological Hazards and Cultural Heritage: Traditional Knowledge as A Mitigation Strategy

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Geological hazards such as earthquakes and landslides (also due to floods) increasingly threaten cultural heritage sites and their related living/intangible heritage, especially in the context of accelerating climate change. In a country like Pakistan, characterized by complex terrain, tectonic activity, and fragile ecosystems, the risks to both tangible and intangible heritage are then amplified. This presentation explores how traditional knowledge can offer sustainable and context-sensitive strategies for mitigating these risks.

The presentation will first examine the geophysical threats affecting heritage sites in Pakistan, particularly in high-risk areas such as Gilgit-Baltistan, Balochistan, Sindh and Khyber Pakhtunkhwa. Earthquakes will be revisited as a critical moment that exposes the vulnerability of vernacular architecture; and the consequences of neglecting local risk mitigation knowledge. Landslide-prone heritage landscapes, often situated on unstable slopes or near active fault lines, further highlight the need for culturally rooted resilience.

Focusing on traditional construction methods, such as dhajji dewari (timber-laced masonry), dry-stone walling, and mud-plaster techniques, this presentation demonstrates how communities have historically adapted to seismic and geomorphological risks. These time-tested practices embody an understanding of local materials, topography, and environmental conditions that modern engineering often overlooks.

The discussion will emphasize the importance of integrating traditional knowledge into formal disaster risk management (DRM) and climate adaptation policies. It argues for participatory approaches that include local communities as key actors in both cultural heritage protection and hazard preparedness.

The presentation will draw on global references such as the "2011 Strategy for DRM in heritage contexts", which was developed under the framework of UNESCO World Heritage Convention, to integrate DRM into the management of cultural heritage, including both tangible and intangible heritage, recognizing that heritage is both vulnerable to disasters and also a source of resilience for communities.

Ultimately, this contribution advocates for a shift toward heritage conservation practices that not only protect structures, but also safeguard the embedded cultural knowledge systems that contribute to long-term resilience in the face of geological and climate-induced hazards.

Extreme of the Extremes: 2023 Türkiye-Syria Earthquake Disaster was Exacerbated by An Atmospheric River

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Strong earthquakes in mountain landscapes can trigger widespread slope failures, initiating chains of hydro-geomorphic hazards such as channel blockage, instability, flooding, and coarse sedimentation. These impacts disrupting ongoing response operations may be fueled and potentially amplified by extreme post-seismic precipitation delivered by atmospheric rivers (ARs), which can form continent-spanning corridors of concentrated moisture. Yet, such cases of ARs occurring in the aftermath of major earthquakes have remained unreported to the best of our knowledge. Here, we document the combined effects of seismic and precipitation extremes that perturbed the area struck by the February 6, 2023, Türkiye-Syrian earthquakes (Mw 7.8 and 7.6), the region's largest seismic sequence ever recorded. Strong ground shaking triggered thousands of landslides and was followed, 36 days later, by an exceptionally strong AR bringing severe precipitation with up to 183 mm in 20 hours. This rainfall induced yet more landslides, debris flows, and flooding, disrupting recovery efforts, affecting earthquake victims and temporary settlement areas, and claiming more lives. This unprecedented disaster highlights the need to revise rapid hazard assessment protocols to better account for hazard cascades arising from tightly timed seismic and weather extremes.

Emerging Risks of Landslide-Generated Tsunamis in The Arabian Sea

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Climate change has the potential to significantly increase the probability of landslide-generated tsunamis along the coast of Pakistan. Sea level rise, more frequent and intense cyclonic storms, and ocean warming may destabilize continental slopes by disturbing seafloor sediments and possibly dissociating gas hydrates. These changes elevate the risk of submarine landslides, which, if triggered, could generate localized yet destructive tsunamis, particularly in sediment-laden zones. However, the ability to realistically simulate such events is severely constrained by the lack of detailed bathymetric, geotechnical, and geomorphic data for the offshore region. The absence of high-resolution seafloor mapping and subsurface sediment properties impedes the development of accurate hazard models, leaving coastal communities vulnerable to under-assessed tsunami threats from submarine mass failures.
Recent tsunamis in the region, such as the 1945 Makran tsunami and the 2013 event, provide potential evidence of submarine landslides and mass movements, highlighting the emerging risks of landslide-generated tsunamis in the Arabian Sea. The significant destruction and loss of life caused by these events underscore the potential for widespread coastal damage and disruption should similar tsunamis occur in the future

Estimating Landslide Failure Surface and Volume Under Changing Climate Conditions: Insights from the 2023 Domeshi Landslide, Nw Himalaya, Pakistan

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Climate change intensifies cascading geohazards, with landslide events increasingly threatening infrastructure, populations, and ecosystems, particularly in mountainous regions. Global warming in the Himalayas is shifting monsoon patterns, increasing the frequency of landslides in areas with high annual rainfall. Modern techniques, especially machine learning (ML) and deep learning (DL) techniques, have substantially enhanced the ability to detect, map, predict and analyze landslides dynamics, outperforming traditional methods in managing complex datasets and uncovering hidden patterns. An essential factor in assessing landslide hazards is volume estimation, as it controls the propagation distance, affected area, and potential damage. However, estimating landslide volume remains challenging, particularly when the failure surface is concealed. This study investigates a case investigation of the massive Domeshi Landslide (August 2023) near Rara village, District Muzaffarabad, Pakistan, which occurred in two phases between August 1 and 4, 2023, lasting 96 hours with a 500-meter runout which caused the destruction of 22 houses, a major road, agricultural land, and infrastructure, displacing over 60 families. This affected site is located in the Sub-Himalaya as marked by intense deformation along the NS trending, left-lateral Jhelum Fault (JF). This study utilized a new Digital Elevation Model (DEM) based rapid method employing vertical spline profiles evaluated in MATLAB, to analyze the landslide failure surface and plot the 3D probable depth of the failure surface using a grid function. The resulted calculated volume of the Domeshi landslide failure surface is 2,563,258 cubic centimeters based on 12.5m resolution ALOS-PALSAR DEM data. The proposed method offers a rapid, accurate approach for estimating failure surfaces and supports improved stability of slope, hazard zoning and mitigation planning. Future studies may enhance accuracy by integrating high-resolution UAV-based DEMs.

POSTERS

Shallow Geophysical Approaches for Sustainable Urbanization in Earthquake-Prone Areas

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Sustainable urbanization in seismically active regions requires non-invasive and reliable methods to investigate subsurface conditions for urban development. This study employs shallow geophysical techniques to investigate soil conditions in a growing urban area near active fault zones. The geophysical investigations comprised of 20 Seismic Refraction profiles and 20 MASW profiles. The primary wave velocities (Vp) range from 400 to 2000 m/s, indicating layered subsurface materials from soft sediments to compacted deposits. Shear wave velocity values range from 356 to 711 m/s, with most locations classified as NEHRP Site Class C, suggesting moderately stiff soils. Bedrock depths vary from 9 to 45 meters, with deeper profiles in the majority of sites. These results highlight the significance of geophysical investigations in urban planning and emphasize the requirement for additional site response analysis to assess seismic amplification and achieve resilient infrastructure in earthquake-prone areas.

Emerging Neotectonic Activity and Induced Subsidence Hazards: A Case Study from Mountain Village of Watli (Choa Saidan Shah), Eastern Salt Range, Pakistan

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The eastern Salt Range of Pakistan field museum of geology, known for its complex geological setting and active tectonics associated with the Himalayan Foreland Thrust System, and is subjected to significant geo-hazard and geo-risks. This case study focuses on the Watli area (Choa Saidan Shah) located in the eastern Salt Range where recent incidents of ground subsidence have raised concerns over emerging tectonic activity and its implications for local infrastructure. On 4 September, 2024, a major subsidence event was observed in Watli, resulting in the deformation and complete collapse of the main road and severe damage to a nearby boy's school. Preliminary field visit and surveys, structural mapping, and lithological assessment indicate that the subsidence is primarily linked to the active subsurface dissolution of evaporitic formations, particularly salt and gypsum layers, which are inherently unstable under dynamic tectonic stress conditions. Salt also moves up when erosion of overlying layers takes place called salt tectonics. The presence of active thrust faults and huge fracture systems in the area has facilitated water infiltration, accelerated the dissolution processes and created underground caverns, sinkholes eventually leading to surface collapse. Additionally, anthropogenic factors such as increased groundwater withdrawal, location on very high angle slope and unplanned construction activity have further contributed to the destabilization of the subsurface layer. This case study highlights the interaction of neotectonics activity with fragile lithologies in triggering hazardous ground subsidence events, posing a direct threat to the local communities and infrastructures. These findings emphasize the urgent need of integrated geotechnical, hydrogeological and hazard assessment studies in the region to mitigate future risk. The Watli case represents an important example of how emerging tectonic processes can have immediate socio-economic impacts on communities in sensitive geological settings.

Hypsometric Analysis of The Shyok Sub-Basin, Upper Indus Basin: Geomorphic Indicators for Seismic Hazard Assessment and Climate-Induced Landslide Susceptibility Using Geospatial Technologies

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Hypsometric analysis is a useful method for understanding the geomorphic evolution and geological development of river catchments, as well as determining the erosional potential of watersheds. In this work, hypsometric analysis was carried out on the Shyok Basin, a sub-basin of the Upper Indus Basin (UIB), to determine its geomorphic development phases and erosion vulnerability. Twenty-eight fourth-order sub-watersheds were identified, and hypsometric curves were created using SRTM-DEM data. The elevation-relief ratio approach was used to calculate the hypsometric integral (HI) in a GIS system. The HI values varied among the sub-watersheds, indicating a variety of geomorphic phases from juvenile to mature. None of the sub-basins reached the monadnock stage. The hypsometric curves were primarily upward convex forms, indicating young terrain with a high vulnerability to erosion, particularly incised channel erosion and mass movement. Statistical moments like as skewness, kurtosis, density skewness, and density kurtosis were also examined, which helped to validate the geographical diversity in erosion potential. A substantial positive connection (r = 0.76) was found between basin size and the hypsometric integral. These changes may be due to differences in tectonic activity, lithology, and rejuvenation processes between places. Furthermore, the hypsometric results are consistent with slope, aspect, land cover, and snow cover distributions, confirming the geographical patterns of erosion risk. The findings provide vital insights into the development of successful soil and water conservation techniques, particularly in the Shyok Basin's erosion-prone higher reaches. Implementing such methods would assist to reduce sediment discharge, save water resources, and improve the long-term management of this climatically and geomorphological fragile Himalayan watershed.

A GIS-Based Analysis of The Past 50 Years' Earthquakes in Pakistan

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Earthquakes are natural geological phenomena caused by the sudden release of energy in the Earth's crust, resulting in seismic waves that can potentially cause widespread damage and loss of life. Tectonic plate movements, especially along fault lines, are the primary drivers of earthquake activity. Relevantly, Pakistan, being located at the convergence of the Indian and the Eurasian tectonic plates, is a seismically active region and has experienced several devastating earthquakes throughout its history. The regions such as Balochistan, Kashmir, and Northern Areas of the country are particularly vulnerable due to active fault zones and mountainous terrain. Historically, Pakistan particularly over the past five decades has experienced numerous seismic events, resulting in significant human and infrastructural losses. The current study presents a comprehensive GIS based analysis of the earthquakes that struck Pakistan in past 50 years during the period from 1975 to 2025, by employing Python-based geospatial mechanisms along with data science tools. By integrating publicly available earthquake datasets (from USGS), the investigation not only identifies high-frequency seismic zones, analyzes magnitude trends, but also visualizes the temporal evolution of seismic activity across the country. Consequently, the results reveal persistent and significant seismic clusters along tectonic boundaries as well as along fault lines, especially in regions like Balochistan and northern Pakistan—having high-magnitude events recurrence in northern Khyber Pakhtunkhwa as well as in Azad Kashmir. Additionally, the results highlight seasonal patterns (variability) in earthquake frequency. Similarly, shallow earthquake prevalence was also observed. More importantly, the applied integrative approach demonstrates the utility of cutting-edge technology or tools for more effective seismic hazard analysis, but also supports improved decision-making for disaster preparedness and resilience planning. The findings further underscore the urgent and genuine need to enhance disaster preparedness strategies—both anticipatory and reactive—through improved early warning systems, seismic-resistant infrastructure, and the development of updated building codes for high-risk areas. Finally, the investigation not only highlights vulnerable regions but also provides actionable insights for seismic hazard/risk assessment and disaster preparedness in tectonically active regions like Pakistan. In future work, this analysis can be expanded to include machine learning models for earthquake forecasting and scenario-based planning for resilient urban development.

Using Unmanned Aerial Vehicles (Uavs) to Understand Landform Geohazard Sites in Hunza Valley, Pakistan

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Like many other mountainous areas, geohazards in the Hunza Valley are common and include glaciers and outwash floods, avalanches, rock falls, debris flows, earthquakes, landslides, and wind and snowstorms. However, in Hunza, the magnitude and frequency of these process events are enhanced because of the tremendous relative relief of the Karakoram landscape and high rates of downcutting by rivers and glaciers, together with frequent earthquakes, which create conditions in which slope failure and mass movements of rock and debris are widespread, making the potential for building collapse ever present. In particular, flooding and landslides are severe due to heavy rainfall and periods when exceptionally high temperatures induce rapid melting of glacier ice and snowpacks. Extreme rainfall in the valley destabilizes the numerous and extensive slope deposits, and the re-entrainment of these deposits results in the transport of large volumes of unconsolidated sediments downstream. Landslides also occur due to different factors, including tectonic active zones, weak rock structures (highly fractured, weathered, and jointed rocks that are prone to failure, especially during heavy rain and seismic events), steep mountain slopes with little vegetation, glacier retreat, and glacier lake outburst flood, glacier thawing and human activities (unregulated constructions on high-risk areas).

High-resolution drone imagery, processed using photogrammetry software to generate 3D digital elevation models and landscape reconstructions, can aid in understanding the mechanism of these geomorphic hazards and understanding landform changes in areas where geohazards have previously occurred, as well as in regions that are highly susceptible to future risks. In particular, 3D models will enable the documentation and analysis of the geomorphic impacts of glacier lake outburst floods (GLOFs), current landslide activity, landslide geomorphology, and mass movements. When these models are shared with local communities, they can help raise awareness about landform changes caused by geohazards in their region and empower communities to take preventative measures and respond effectively to emerging threats, contributing to long-term resilience and sustainability. Studies incorporating indigenous knowledge help bridge the gap between scientific research and community understanding. 3D landscape models will be showcased at public outreach events to educate the general public about the different types of landforms in the Hunza valley and their associated geohazards.

The Mw 5.9 October 2021 Harnai Earthquake: Insights from Field Observations and InSAR Analysis

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Recurrent shallow thrust earthquakes along active fault systems in the seismically active Balochistan region pose significant hazards, necessitating integrated geodetic and field-based investigations to better understand surface expressions and fault geometry. The northwestern Indian Plate margin has repeatedly experienced major earthquakes, including the Mw 7.0 Sharigh (1931), Mw 7.8 Quetta (1935), Mw 7.1 east of the Harnai Fault (1991), the 1997 Harnai, and the 2008 Ziarat events. This ongoing seismicity continued with a Mw 5.9 earthquake on October 7, 2021, at 03:01 AM (PST), which struck the Harnai District of Balochistan along the active Harnai-Khalifat fault zone [USGS; PMD]. The earthquake occurred at a shallow depth of ~9 km and was attributed to thrust faulting, situated in the TorKham Mountains (30.220°N, 68.015°E), approximately 15.2 km NNE of Harnai and 97.5 km east of Quetta. About 70 mud-and-stone houses collapsed or were severely damaged in Harnai, resulting in 20 deaths and over 300 injuries (PDMA, Balochistan). Field observations show that the earthquake ruptured a network of NW-SE and E-W oriented crevices and reactivated landslides within 40 km of the epicenter. Surface measurements indicate dextral movements, with landslides exhibiting mixed translational and rotational reactivation. Small Baseline Subset (SBAS) Interferometric Synthetic Aperture Radar (InSAR) time-series analysis of Sentinel-1A SAR data (ascending path 144, frame 93; descending path 78, frame 491) was used to investigate coseismic ground deformation. The cumulative Line-of-Sight (LOS) displacement showed uplift and subsidence patterns consistent with fault rupture geometry, ranging from −6.5 cm to +4.5 cm (ascending) and −7.5 cm to +8.2 cm (descending), respectively. InSAR coherence and incoherence maps revealed surface disruption due to fault rupture.

Development of GNSS by Using Artificial Intelligence for Disaster Monitoring in Pakistan

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The rapid advancement of technology has positioned Artificial Intelligence (AI) as a critical enabler in addressing contemporary challenges such as disaster monitoring and mitigation. Among these challenges, earthquake detection and monitoring stand out as urgent concerns, particularly in seismically active regions like Pakistan. The Global Navigation Satellite System (GNSS) has emerged as a vital tool for real-time tracking of ground movements, providing essential data for disaster response. However, conventional GNSS systems often face limitations in precision due to factors such as atmospheric interference, satellite geometry, and multipath errors. These shortcomings can reduce the reliability of earthquake detection when high accuracy is essential. To overcome these challenges, this study explores the integration of AI and machine learning with GNSS to enhance its accuracy and effectiveness for disaster monitoring in Pakistan.

The current work investigates how supervised and deep learning models, including neural networks, can process GNSS data to filter noise, correct errors, and detect seismic anomalies. Additionally, reinforcement learning approaches are considered for improving system calibration and predictive capacity. A scenario model is developed to demonstrate the use of GNSS data and AI algorithms for real-time earthquake monitoring, focusing on prediction of seismic magnitudes, locations, and impacts. Furthermore, the study presents an AI-driven methodology for identifying optimal GNSS station placement across Pakistan using geospatial data, active fault mapping, clustering algorithms, and regression models. This dual approach not only strengthens early warning systems but also enhances the strategic deployment of GNSS infrastructure.

The findings suggest that coupling GNSS with AI significantly improves earthquake detection accuracy and timeliness, supporting proactive disaster management. By advancing both monitoring and station deployment, this integrated framework can contribute to greater resilience and preparedness in Pakistan, setting a precedent for applying AI-enhanced GNSS systems in other disaster-prone regions worldwide.

Establishing 1st GNSS Observatory (IGO): Advancing Academic Research, Applications, And Innovation

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The International GNSS Service (IGS) operates a global network of GNSS stations that provide critical data for geodesy, precise positioning, ionospheric monitoring, space weather analysis, timing synchronization, and geodetic studies. Despite the wide-ranging applications and global significance of this infrastructure, South Asia—particularly Pakistan—remains underrepresented in the IGS network. To address this gap, the GNSS Research Laboratory of the National Center of GIS and Space Applications (NCGSA) at Institute of Space Technology (IST), Islamabad, has established the IST GNSS Observatory (IGO). Developed in collaboration with the Abdus Salam International Centre for Theoretical Physics (ICTP), Italy, the observatory is equipped with a u-blox ZED-F9P multi-constellation, multi-frequency GNSS receiver and a survey-grade antenna. Notably, as the only operational GNSS observatory at the latitude of Islamabad, IGO continuously collects and uploads high-quality GNSS navigation data to international databases. This contributes directly to the global IGS network and supports a wide array of applications including satellite orbit and clock determination, ionospheric monitoring & modeling and precision geospatial services. The observatory will also play a pivotal role in academic research, especially for the MS GNSS scholars at IST. Future work will include ionospheric modeling over Pakistan and the development of GNSS-based early warning systems for seismic risk mitigation.

Landslides In Complex Geological Formations: Geohazards Review of Kohala Muzaffarabad Road (S-2), AJK, Muzaffarabad

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Geohazards like landslides can cause severe property damage, loss of life, and disruption to social and economic systems, along with harmful environmental impacts. The 2005 earthquake's outcome still affects residents in Azad Jammu and Kashmir, highlighting the need for a thorough geohazard review along the Kohala-Muzaffarabad Road, which is the focus of this abstract. The study reveals that sandstone interbedded with shales poses significant risks for slope failures along the road. The Murree formation, made up of Sandstone and Shale, and the Hazara formation slates show significant folding due to tectonic processes. An active fault line along the Kohala Muzaffarabad road indicates geological instability. Shales, being loose, are prone to erosion, and during rainy seasons, sandstone becomes more susceptible to collapse. Landslide Hazards (LH) research examines slope types, geological features, soil and rock present in the area, and composition to analyze slope failures on roadways. A Risk Zonation Map categorizes vulnerability into classes from low to very high based on observed failure frequencies with the help of Hazard Risk Assessment Performa. The Muzaffarabad to Ambore section is classified as low to medium risk, while the Kulian-Dolai, Barora, Shahdara, and Kohala Barsala sections are identified as high-risk zones for landslides and slope failures. Laboratory experimental investigations involving soil sampling indicate that the clays possess high moisture content. The Plasticity Index of the exposed clays is characterized as slightly to moderately plastic, while grain size analysis reveals that 70-80% of the clayey material comprises fine particles that pass through a 200µm sieve. Rebound testing, particularly the Schmidt Hammer Test, was performed on Sandstone during fieldwork, demonstrating that the measured hardness of the Sandstone varied from weak to fair. Future study should include (GIS) based Landslide Susceptibility Mapping (LSM) and an Early Warning System to provide timely alerts and improve preparedness.

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