Green energy transition: Rare earth elements mineralization in the carbonatites of Pakistan

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Green technologies are a key part of meeting the world's goal of decarbonization. Rare Earth elements (REEs), a component of green technologies, are very important for a fossil fuel-free society and are essential components in electronics, vehicles, homes and in energy supplying infrastructure. Given the strategic importance of REEs, there is a need to explore them using the latest technologies, essential, for the green energy transition. In Pakistan, REEs and other strategic element bearing minerals are found in peralkaline rocks and pegmatites. Peralkaline rocks occur in the Khyber Pakhtunkhwa province, with carbonatites being the main types. The carbonatite bodies in this region are explored as a case study. Geochemical and isotopic studies confirm rift-related and post-collisional partial melting settings for the Koga and Sallai Patti carbonatites respectively. The Sallai Patti carbonatite hosts REEs mineralization but is not economically significant due to the early crystallization of apatite, which reduces the REEs content in the melt. Therefore, carbonatites rich in apatite are not conducive to economic REEs mineralization. Based on this study, it is recommended to apply the same approach to other carbonatite bodies in the province to assess the promising prospects of REEs.

Ophiolites concept and evolution example from Muslim Bagh ophiolite complex, Balochistan, Pakistan

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Ophiolite studies are one of the leading topics that gathered a large number of geoscientists recurrently and these studies have played an important role in the progress of shaping opinions on the plate boundaries. The ophiolite concept started from the famous Penrose Definition of 1972 and then evolved through time by creating a stock of novel information on the topic until the Second Penrose Meeting on Ophiolites was conducted in 1998. Shortly, the scientific understanding of ophiolites had undergone a remarkable transformation since 1972. Later, it was defined and classified with some new and mandatory Ophiolite sequence to be preserved. The 1000 km^2 Muslim Bagh ophiolite complex ophiolite segments having a very preserved: 1) ophiolite sequence; from a thick mantle peridotite and dunite that grade upward to crustal section and are structurally underlain by the metamorphic sole rocks, and 2) a subduction-accretion- complex of Bagh complex that underlies the ophiolite sequence. The ophiolite complex is overlain by the rocks of the Flysch Belt rocks, and thrusted over the Indian platform sediments. Several past and present workers reported the Muslim Bagh Ophiolite Complex as an intrusive and extrusive complex. Based on field studies, limited laboratory studies, geochemistry, and age dating, it was interpreted to be formed in an oceanic ridge setting and a back-arc basin environment. Based on this data, the Muslim Bagh ophiolite yields crystallization age 80.2 ± 1.5 Ma and emplacement (K-Ar) age 80.5 ± 5.3 showing that this ophiolitic complex was young at the time of emplacement. The presence of a crustal section with less well-developed sheeted dyke complex and geochemical signatures transitional between Island Arc Tholeiite (IAT) and Normal Mid Oceanic Ridge Basalt (NMORB), with harzburgitic mantle rocks and the presence of huge chromitite deposits; all confirm the supra-subduction zone setting for the Muslim Bagh ophiolite.

Mineral Sector in Pakistan: National Policy, Sways and Challenges

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Pakistan is bestowed with numerous varieties of mineral resources spread across the country, providing a pier for a mineral-based economy. Currently, 92 minerals have been found among these 52 are mined commercially with a collective 68.52 million tones production capacity yearly and are, therefore, playing a vital role in the economy of the country. It is expected that there will be approximately 2 to 3% annual increase in the production. In Pakistan, for mineral exploration, the legal and regulatory framework at federal, provincial and tribal levels is governed by several laws, regulations, and government agencies. The exploitation and trade of minerals contribute significantly to government revenue through taxes, royalties, and foreign exchange earnings which certainly provide support in stabilizing the country's balance of payments and sustainable economic growth. It creates employment and provides assistance to improve the living standard of habitants and ultimately the GDP of the country. The progress of the mineral sector enthralls domestic and foreign investment, leading to the transfer of technology, expertise, and best practices. Likewise, the construction of infrastructure such as roads, railways, ports, and power plants are also strengthening the growth of the mineral sector in the country. Mineral-based industries including cement, steel, ceramics, chemicals, fertilizers, etc. rely mainly on the raw materials for their manufacturing processes. Thus, a robust mining sector supports the industrial base to expand and become more diverse. Beyond all of these sways, Pakistan still faces a lot of challenges, such as regulatory reforms, political unrest, infrastructural development, environmental sustainability, workforce shortages, and lack of community involvement creating hurdles in the growth of the mineral sector. To acquire the full benefit of the mineral-based economy, these issues must be addressed and resolved. To tackle these issues, the government, business community, and civil society must work together to implement comprehensive reforms that will improve the investment scenario, provide incentives to miners, upgrade

infrastructure, simplify regulations, encourage sustainable mining practices, and fund R&D organizations. The involvement of academia and other research organizations will cater problems associated with the identification, exploration and exploitation of new mineral horizons in more convenient way.

Infrared Spectroscopy of Natural, Synthetic and Treated Rubies

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The widespread availability of chemicals, raw materials, and equipment capable of controlling multi-stage pressure and temperature conditions has made distinguishing treated and synthetic gems from their natural counterparts increasingly challenging. Traditional methods reliant on physical and optical characteristics often fall short in such scenarios. However, recent advancements in non-destructive analytical techniques, including EDX-SEM, XRD, RAMAN, AFS, LA-ICPMS, NMR, and FTIR, offer promising avenues for differentiation. For instance, identifying diamonds treated under high pressure and temperature solely through physical and optical properties poses significant risks and challenges. However, techniques like AFS and FTIR provide reliable means for differentiation. Similarly, the detection of beryllium diffused ruby and sapphire is facilitated by LA-ICPMS and WDX-XRF. FTIR, which measures the vibration energy of atoms within crystals, gemstones, and minerals, offers intricate fingerprint information crucial for identification purposes. Whether dealing with synthetic, pressure-treated, or temperature-treated loose or mounted gems, FTIR proves invaluable in differentiation. To evaluate the efficacy of FTIR in gemstone identification, we conducted tests on five natural, five synthetics, and five treated ruby specimens, obtaining distinct lattice vibration infrared spectra. These spectra effectively distinguished synthetic and treated rubies from their natural counterparts.

Petrography and Geochemistry of Sandstone of the Kamlial Formation, Islamabad Expressway Section, Islamabad, Pakistan

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The Miocene Rawalpindi Group including the Kamlial and Murree formations and the Quaternary deposits are exposed along the Express Highway Islamabad near Korang Bridge. Previously established geological map has been modified during this study which also shows the Quaternary Pothwar clay deposits. This section belongs to the Miocene Murree Formation. The Kamlial Formation, which is the focus of this study contains abundant quartz, which is fractured and oriented as micro-lenses along with K-feldspar such as microcline, micro-perthithe, orthoclase and sanidine, and albite to andesine plagioclase feldspar indicating felsic plutonic and volcanic rocks protoliths. Besides, the presence of pyroxenes and amphiboles also indicate mafic volcanic and/ or plutonic rocks source. Traces of garnet, epidote, chlorite, biotite, muscovite, vermiculite may show metamorphic origin of the clasts. The preferred orientation of the grains and bending in mica indicates that the formation has undergone through deformation due to shearing. Based on geochemistry, the sandstone of the Kamlial Formation is mainly litharenite which shows fluvial depositional environment. It illustrates recycle oceanic island arc tectonic origin and provenance of Himalaya and the Kohistan Island Arc.

Remote sensing-based prospects for the exploration of metallic minerals in North Waziristan, Pakistan

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Mineral exploration plays a vital role in a nation's economic growth and sustainability. However, security concerns pose significant challenges to conducting exploration surveys in areas with substantial mineral reserves in Pakistan, particularly in certain regions of Khyber Pakhtunkhwa (KPK) and Baluchistan Provinces. This study focuses on the utilization of remote sensing techniques and GIS tools for the delineation of metallic mineral outcrops in the North Waziristan region of KPK Province. Landsat 8 satellite imagery data was acquired to perform this study and processed using ENVI and ArcGIS software. Radiometric and Atmospheric corrections were applied to the data, followed by various analysis techniques including stacking, band ratio, unsupervised classification, and normalized difference vegetation index (NDVI) in a GIS environment. The study approach based on expert knowledge of distinctive spectral reflectance values to identify different natural surficial materials facilitates the identification of common metallic minerals surface deposits, which exhibit distinctive pale red and red- pinkish color shades compared to other natural materials in the region. Unsupervised classification aided in creating different classes based on reflectance values of the same groups for mineral exploration prospects. Resultant maps indicate surface traces of pyrite, galena, chalcopyrite, hematite, and magnetite as dominant minerals in different parts of the study area. NDVI classification maps and the Hill Shade map assisted in assessing area accessibility and land use, including water bodies, built-up areas, digital terrain, and various vegetation types. The study outcomes show that the Shawal region emerged as a potential area, exhibiting significant metallic mineral diversity, primarily hematite and magnetite. This region is recommended as a suitable training site for conducting field-based mineral exploration surveys in close proximity. Overall, the study results are promising and require ground-truthing which is an

essential aspect of remote sensing-based research. The study emphasizes effectively utilizing remotely sensed data to delineate target areas before commencing comprehensive field-based exploration surveys in such regions. Additionally, the study recommends the use of multiple remote sensing data sources, including ASTER and hyperspectral imageries, for more comprehensive results.

Beneficiation and Geochemical Evaluation of Coal and Associated Rare Earth Elements in Cherat Area, District Nowshera, Pakistan

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The economic potential of the Paleocene coals in the Cherat region of Pakistan remains largely untapped, as detailed studies on their major and trace element compositions, as well as rare earth elements (REEs) upgradation have been limited. The study focused on examining the geochemical characteristics of existing coal deposits in Bakhtai, Shahkot, and Naguman areas and exploring their potential for enhancement using the froth flotation technique. Additionally, the research aimed to determine the economic abundance of rare earth elements in the coal samples of 10 coal mines from this area. The geochemical analysis including REEs determination and comprehensive proximate analysis were conducted to assess coal quality. The detailed proximate analysis included the evaluation of volatile matter, moisture content, ash content, fixed carbon, Gross Calorific Values (GCV). The geochemical analysis of the gangue samples following coal washing showed higher concentrations of major oxides such as SiO_2, Al_2O_3, Fe_2O_3, TiO_2, and K_2O, while CaO, P_2O_5, and Na2O had lower concentrations. Trace elements (Cr, Ni, Co, Cd, Zn, Pb, and Cu) were found in very low concentrations (<1ppm). After applying the Froth Flotation technique, the overall coal quality was improved. Among the REEs contents (ppm) an enrichment in Yb, Gd, Er, Sm, Ho, Tm, Eu, Tb, and Dy and depletion in Y, La, and Pr was noticed in the raw coal samples as compared to the average Chinese and US coal standards. While an enrichment in Yb and Y and depletion in in Er, La, Pr, Sm, Gd, Dy, Ho, Eu, Tb, and Er occurred in gangue as compared to the average Chinese and US coal standards. In conclusion, the processing techniques applied to the coal samples in this study have shown promising results in upgrading the coals from Bakhtai, Shahkot, and Naguman areas. The data obtained will be valuable for industries such as energy, power, coal exploration, and cement manufacturing.

Evaluation of Kirthar Limestone for Manufacturing Calcix Pellets; An Alternative to Traditional Petroleum-Based Plastics

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The evaluation of Kirthar Limestone as a resource for producing Calcix pellets offers a comprehensive examination of its geological properties and chemical composition. The study addresses the pressing issue of plastic pollution, particularly in developing nations like Pakistan, and underscores the necessity of seeking alternatives. It outlines the environmental impact of plastic waste and emphasizes the benefits of Calcix pellets derived from limestone compared to traditional petroleum-based plastics. The manufacturing process of Calcix pellets highlights its simplicity, energy efficiency, and reduced carbon emissions compared to conventional plastic production methods. Cost analysis indicates that Calcix pellet production could be a cost-effective and economically viable alternative to plastic manufacturing. Kirthar Limestone of Eocene age, abundantly available in Pakistan, is deemed suitable for producing Calcix pellets based on geological and chemical analyses. The study examines the presence of various elements such as Al_2O_3, SiO_2, CaO, MgO, and Fe_2O_3 and their impact on pelletization. CaO is the main component of limestone which helps in the pelletizing process as a high amount of CaO leads to the polymerization process. All the samples of the study area have a high amount of CaO. Furthermore, MgO content is also desirable for manufacturing limestone pellets as high magnesium contents tend to be sticky. The study also discusses trace element analysis, identifying nickel as a potential concern due to its higher content in some samples.

Petrology of the chromite bearing ultramafic rocks in Allai area of Kohistan, Pakistan

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The Allai area of Kohistan (AAK), Khyber Pakhtunkhwa province of Pakistan comprises ophiolitic mélange of the Main Mantle Thrust (MMT), hosting rocks of the Indian continental plate and the Neo-tethyan oceanic crust. To the north of the MMT lies the Kohistan Island Arc and to the south the Indian continental plate. The present research study deals with metallic mineral prospecting for chromite in the area of investigation. Based on fieldwork and laboratory data including petrography, XRD and XRF analyses, the rocks of the area are identified as dunites, pyroxenites, serpentinites, meta-gabbros and meta-basalts. The rocks clearly show deformation in terms of shearing, mylonitization and anastomosis, due the tectonic activity. Besides other mineral constituents, the presence of alkali amphibole in meta-basalts may corroborate alkaline affinity of the rocks or the presence of blue schist in the mélange zone. Geochemistry shows that mafic rocks of the area are tholeiitic and the ultramafics rocks as cumulates. There seems single magmatic source composition for the mafic and ultramafic rocks. On the basis of major elements chemistry tectonic division, the meta- gabbroic rocks show (Mid-Ocean Ridge Basalt) MORB affinity. The chromite mineralization is restricted to dunites only, which form in layers, and as disseminated and fracture-filled grains. The fracture-filled grains are secondary whereas layering and dissemination is primary, related to magmatic crystallization. The XRF analysis reveal 18 wt.% chromium in one rock, which is not economically viable. Further detailed field and laboratory study is suggested to find out economic potentiality of chromite and other metallic minerals in the area.

Salt Lake deposits of Thar desert: Source of Trona, Halite, Gypsum and a hope for Lithium-bearing minerals

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Pakistan is such a blessed country where all types of natural resources are present; some of which are being exploited whereas, others need to be exploited for the economic growth of the country. Among these natural resources; the deposits of diverse nature are also found bearing good potential of strategic mineral concentrations such as the REEs including lithium ores. Along with these mineral resources, the evaporites are also noteworthy being the natural source of different metals including lithium, which can easily be processed with low cost. Different kinds of evaporites are reported from various regions of the country i.e., Chagai district of Balochistan province and Sanghar, Shaheed Benazirabad, Umarkot and Tharparkar districts of Sindh province. The salt lakes of these evaporites are diverse in size, shape and mineral contents due to varied sources of such salt/evaporite deposits. The present study is aimed at the proper mineral characterization and possible source of these Salt Lake deposits/evaporites of Quaternary to Recent age. During fieldwork, representative samples were collected from salt lakes in Thar desert for analyses using X Ray Diffraction (XRD) and Energy Dispersive Spectroscopy (EDS) techniques. Thin laminations of different evaporites having the thickness of a few centimeters and at places encrustations from a few centimeters up to 2 feet were observed. The XRD results indicate that the evaporites of the salt lakes of Thar desert are of diverse nature. In Taulka Nangar Parkar, the major salt is halite (NaCl) along with some concentration of gypsum ($CaSO_4.2H_2O$) and polyhalite; while the lakes of Sanghar, Shaheed Benazirabad and Umarkot are rich in Trona along with halite and gypsum. The current XRD and EDS results do not show any presence of lithium-bearing minerals but it is possible that lithium-bearing salts in minor quantity could be embedded because salt

lakes of similar nature are the good producer of lithium in different regions of the world. Therefore, detailed studies are required for investigating the lithium bearing minerals of economic potential in the extended areas of these salt lakes.

Mineralogy and Organic Geochemistry of lunar meteorite Gadamis-003

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The current research investigates the lunar meteorite, Gadamis-003 discovered in the Ghadamis Basin, Libya in 2021. This certified meteorite, listed in the Meteoritical Bulletin Database is scarcely explored, therefore, a pilot study was conducted to examine the extraterrestrial sample using equipment and resources available within Pakistan, and making a modest contribution to the top emerging area of astrobiology. A detailed micrographic report was generated through microscopy and SEM/EDX analysis. Comprehensive petrography and elemental analysis revealed major minerals like anorthite (plagioclase), pyroxene, and olivine, alongside accessory minerals such as magnetite and ilmenites. A comparative study considering thin sections of the Apollo mission samples highlighted mineralogical similarity of Gadamis-003 with the Apollo 16 mission samples. It also revealed the possible locality of the sample, i.e., in proximity with lunar highlands, though its geochemical province is yet to be confirmed. The study also documented detailed sample-handling procedures that included trackable sub-sectioning used for the reconstruction of the recovered lunar meteorite sample for trailing the geochemical composition of the original site of the sample on the Moon. The powdered fragments of the lunar meteorite underwent biosignature investigation using gas chromatography-mass spectrometry, revealing traces of organic compounds classified as aldehydes and ketones. However, a thorough analysis of organic chemistry is necessary to characterize the detected compounds and verify their isotopic delta values. This work is fundamentally intended to serve as a groundwork for future studies aiming to spur the curiosity of local researchers.

Geochemical Analysis of Miocene Jhill Limestone in Sona Pass Area for Steel Industry

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This study focuses on assessing the suitability of Miocene Jhill Limestone for industrial applications, particularly in the steel industry. The study area, situated in the west and northwest of Karachi City, Sindh province, Pakistan, near the coast of the Arabian Sea, features exposures of Nari and Gaj Formations, consisting of limestone, shale, and sandstones. Limestone, a sedimentary calcareous rock predominantly composed of calcite, holds significant importance in various industries due to its versatile properties. Geochemical analysis of prepared samples was conducted using X-ray fluorescence spectrometry (XRF). Chemical analyses revealed high CaO content ranging from 49.87% to 53.41%, with an average of 51.96%, indicative of the presence of calcite. Additionally, Al_2O_3 content varied from 0.58% to 1.2%, averaging at 0.778%, suggesting the presence of clay minerals. Fe_2O_3 values ranged from 0.64% to 1.43%, with an average of 0.996%, while SiO_2 values ranged from 2.09% to 4.02%, averaging at 2.8%. The results indicate that the Jhill limestone exhibits high purity and elevated CaO content, making it economically viable for use in the steel industry.

Petrochemical Investigation of Sulfide Mineralization and Host Rocks of Kusham Area, Upper Chitral, Pakistan

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The Kusham region of upper Chitral contains sulfide mineralization in the form of ~5 cm thick mineralized quartz veins. These veins are primarily limited to the Wakhan Formation's meta-greywackes bed near its contact with the Sarikol Shales. Based on petrographic, geochemical, and field characteristics, the rocks in the research area are classified as Fe-rich shales and meta-greywacke. The meta-greywackes, primarily composed of angular to sub-angular quartz, mono- crystalline, alkali kaolinized and alkali sericitized feldspar, and matrix, are immature, fine-grained, and compact rocks of poorly sorted. The rock has undergone low-grade metamorphism and has quartz veins that are mineralized and barren, arranged in various directions. The primary ore phases found in mineralized quartz veins are sphalerite, chalcopyrite, and galena. Fine-grained ore phases are found as inclusions, whereas coarse- to medium-grained ore phases are prevalent. The oxidation products are hematite, olivenite, plattnerite, and limonite. The intergrowth textural nature of sulfide minerals (sphalerite, galena and chalcopyrite) implies that they have been precipitated simultaneously. On average, the meta-greywackes have the following compositions in wt%: SiO_2, TiO_2, Al_2O_3, Fe_2O_3, and MnO of 72.89, 0.8, 13.39, 0.93, 0.04 respectively. On the other hand, the average trace element values for Cu=145 ppm, Pb=1530 ppm, Zn=530 ppm, Ni=29 ppm, Cr= 30 ppm, Co=33 ppm, Cd=11. The Fe-shales exhibit average wt% concentrations of SiO_2, TiO_2, Al_2O_3, Fe_2O_3, MnO, MgO, CaO, Na_2O, K_2O, and P_2O_5 as 53.8, 0.32, 14.6, 13.3, 0.50, 2.31, 3.73, 0.74, 2.48, and 0.09 respectively. The average trace element values are: Cu=58 ppm, Pb=100 ppm, Zn=206 ppm, Ni=23 ppm, Cr=50 ppm, Co=61, Cd=2 ppm, and Ag=7 ppm. The mineralized quartz veins are substantially enriched in Pb, Cu and Zn, with average concentrations of 71427, 3195 and 746 ppm,

respectively. The average concentration of Ag is high, at 71 ppm, although the amounts of the other trace elements are rather low. Majority of the samples include Au in concentrations below the revealing limit (0.05 ppm), although insufficient have Au in minor amount (<0.72 ppm). The solution of hydrothermal yields an important role in the creation of mineralized quartz veins and nearby alteration of wall rock, which resulted in the enrichment and depletion of various chalcophile elements from the host rock. During the fluid interaction, the altered rocks gained a considerably higher amount of Cu, Pb, and Zn, with just a modest increase in Cd and Ag. The hydrothermal solution could be magmatic or metamorphic metalliferous fluid; nevertheless, field factors strongly favor the contribution of metamorphic fluid.

Geophysical Characterization and Prospective Assessment of Copper Ore in Waziristan Complex

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The Waziristan complex, spanning over 500 km², formed during the Paleocene to early Eocene interval, featuring ultramafic rocks, gabbros, sheeted dikes, pillow lavas and pelagic sediments. It constitutes a typical ophiolite suite, hosting various economic minerals like copper, gold, chromite, and azurite. Copper mineralization in the area includes native and sulfide types, occurring as veins, veinlets, stringers, and rims around fragments, often associated with cupriferous breccia. The study employs integrated geophysical techniques, including gravity, magnetic, resistivity, and induced polarization (IP) surveys, to assess copper and associated ores within the Waziristan complex. Data collection involved 81 gravity and magnetic stations, leading to data acquisition along 3 IP and resistivity profiles across the project area. Analysis of the data revealed a Complete Bouguer Anomaly (CBA) with a total relief of 10.3 mGal and a Total Magnetic Field Anomaly (TMFA) indicating a total magnetic anomaly of 10749.7 nT. Gravity maps showcased southeast-northwest trending linear gravity highs, alongside north-south trending anomalies, while the magnetic maps displayed east-west trending linear magnetic highs. Notably, a shift in gravity and magnetic anomalies was observed, with southeast-northwest gravity highs correlating inversely with magnetic highs. Elliptical magnetic lows surrounded by highs emerged as key indicators for locating copper ore bodies. Additionally, resistivity and IP modeling identified zones of low resistivity and high chargeability, suggesting anomalous geological features at varying depths and distances. Based on these findings, a borehole depth of 150m is proposed at a location characterized by high gravity, low magnetic and low resistivity values, and high chargeability.

Integrated Geophysical Survey for Mineral Exploration at Prospect-05, Shinkai Site, Muhammad Khel, North Waziristan

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This research provides the results of integrated geophysical survey consisting of electrical resistivity and induced polarization methods at prospect-05 at Shinkai site, Muhammad Khel, North Waziristan for the exploration of minerals and ore bodies. Vertical electrical sounding (VES) was conducted at ten locations distributed randomly covering all prospective areas. The 2-D survey of the proposed prospect (P-05) site, comprising 10 survey lines, was also conducted to scan the area completely. The VES (1-D) investigations remained useful as the anomalous zones were hit at probes 1, 4, 5, 6, 7, 8, and 9 at different depths. The VES indicated good electrical contrast between different rock formations and ore bodies. In VES, the resistivity data is also processed separately for better understanding of subsurface geology. The 2-D investigations were conducted for detailed subsurface investigations through a grid of parallel and perpendicular lines with a spacing of about 90-110 meters among survey lines depending upon topography. The depth target of more than 250 m was achieved through use of pole-dipole electrode configuration. The 2-D investigations yielded successful results as subsurface anomalous zones are delineated under the 2-D lines 1, 2, 3, 4, and 7 at varying depths, also confirmed by VES probes 6, 8 and 9 falling near the 2-D lines 1 and 4. The VES investigations yielded that either the conductive body is continuous with large size or there exist more than one body in the area at the varying depth of 25-130 meters form general ground surface. The volume of resistivity/conductivity and chargeability anomalies are calculated for low, moderate, good, and strong mineralization. Eight points are recommended for exploratory boreholes drilling at different locations in the exploration area.

Economic Evaluation of Placer Gold Along Khair Abad-Nizampur transect, Indus River Khyber Pakhtunkhwa, Pakistan

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This study aims to conduct an economic evaluation of placer gold deposits along the Indus River, specifically focusing on the Kahi and Darwazgai sites in District Nizampur. The Atomic Absorption Spectroscopy (AAS) analysis indicates that gold concentrations in the samples range from 1.83 to 18.09 ppm. X-ray Diffraction (XRD) analysis of the pan concentrates reveals that quartz, magnetite, ilmenite, hematite, anorthite, and albite are the primary mineral phases associated with gold, suggesting a complex mineralogical environment that could impact the processing techniques used for gold extraction. Furthermore, rare earth elements (REEs) are also detected in economical concentrations with xenotime and monazite as the main phases. The SEM examination of gold grains in the Indus River reveals a wide range of sizes and forms, with most grains exhibiting rounded shapes and some being sub-rounded. Platy grains, a common feature, display evidence of folding during river transport and characterized by fold hinges, scratches, and drags. Comparisons with previous studies indicate that the heavy minerals, including gold, are likely transported from deformed and uplifted rocks in the Himalayas. Potential sources include porphyry and epithermal-type mineralization or fault-hosted veins, which could guide future exploration efforts. This research identifies feasible placer gold sites, underscoring the potential for exploration and exploitation. Such activities could significantly enhance the socio-economic conditions of the region by creating jobs and stimulating local economies. The research findings endorse advance exploration, mining, and the development of appropriate processing techniques for the commercial extraction of gold and associated heavy minerals including REEs at the south of the study area along Indus River.

Long Term Integrated (Multi-Agent) Modeling of Power Sector Under Sustainable Development Pathway

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The study involved a detailed analysis of existing energy models and uncertainties attached to the energy systems. To address energy security and climate change challenges, long-term energy plans for least cost electricity generation (OPT) and demand management for household sector (DSM) were devised. This includes sustainable policies that represent Nationally Determined Contributions (NDCs), mix of efficient and conventional technology and appliances, and targets for renewable energy. The power supply scenario (SSM) exhibits different energy supply policies with lowest socio-economic and environmental impacts. On the basis of analysis of current and historical policies and energy consumption patterns, macro-economic modeling was carried out for the period 2011-2050, using the Long-range Energy Alternative Planning modeling tool. Results indicate that electricity generation sector is expected to continue posing more global warming than any other sector if the current scenario prevails such that the environmental emissions will quadruple the current global warming potential in 2050. Therefore, the SSM alternatives were further compared to analyze their potential with and without externality cost of environmental emissions. Results of optimization of SSM show that wind, solar and hydel power plants are the most economic options with respect to their fuel inputs whereas residual oil based plants cost very high due to their consumption of expensive imported furnace oil. Though natural gas and coal are locally available, their mining and extraction charges are costlier than renewable resources. For a holistic decision on the most suitable scenario, a cost benefit analysis of these scenarios was performed in terms of societal perspective. This sustainability evaluation leads to formulation of a least cost electricity generation mix (OPT) for Pakistan which included the supply target of 10% renewable electricity till 2025. Conventional market valuation and benefits transfer approaches were used for economic analysis of demand side

policies. It was found that the “efficient water heating” scenario for demand management in household, offers the maximum energy-saving potential (up to 270 M.TOE) whereas “efficient space cooling” is the lowest-cost scenario. To achieve the best-fit mitigation scenario (MIT), targets for renewable energy supply were also incorporated. Findings were weighed against the reference scenario (REF), which reveals a huge GHG reduction under DSM. Moreover, the cost required to implement MIT is estimated to be US $ 3.4 billion/ton of carbon dioxide-equivalent, less than the REF. The resultant policy set features a best-fit sustainable management plan in terms of its energy saving potential, social cost, and environmental impacts. Hence, the findings of this study are extremely important for developing countries, in order to meet their energy related GHG targets, especially NDCs.

Unconventional hydrocarbon prospects: A study of the Cambrian- Eocene rocks of the Salt Range, Upper Indus Basin, Pakistan

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The Salt Range area of the Upper Indus Basin of Pakistan is potentially rich in conventional as well as unconventional hydrocarbon reservoirs but rising prices and declining hydrocarbon production merit paying serious attention to the exploitation of the unconventional reservoirs. In the Salt Range area of the Upper Indus Basin of Pakistan, the Cambrian-Eocene strata are potential candidates for producing unconventional hydrocarbon reservoirs. The previous investigations related to the Cambrian-Eocene stratigraphy, sedimentology and source rock analysis are lacking the detailed analysis of the potential gas reservoirs in the Salt Range area of the Upper Indus Basin. In other parts of the world, particularly in North America, the use of advanced stratigraphic and geochemical techniques in the Barnett Shale has resulted in the exploration of more than 13,500 gas wells. The progression in the US gas industry and substantial investment in shale gas exploration has been noted. We expect that the use of advanced analytical techniques in evaluating unconventional hydrocarbon source rock potential will provide a formidable base for the exploitation of the existing gas reservoir potential of the study area. In this study the Precambrian-Tertiary strata of the Indus Basin, Pakistan is analyzed for their unconventional hydrocarbon prospects. The potential organic-rich shales were collected from five key stratigraphic sections. These rock samples were evaluated through geochemical analyses using Total Organic Content (TOC) and Rock-Eval Pyrolysis techniques, mineralogical analysis using X-ray diffraction (XRD) and nano-porosity evaluation using Scanning Electron Microscopy (SEM). Different geochemical parameters were plotted in different cross-plots to determine the TOC, kerogen type, level of maturity and migration history of the hydrocarbons. The analyzed samples show thermally immature, mature and post-mature organic contents. The organic content found in most organic-rich shales was Type III kerogen, capable of generating gas while the occurrence of rare Type

I kerogen shows oil-bearing organic content. Most of the samples have poor genetic potential and few samples show a very good genetic potential. The integration of source rock geochemistry, mineralogy and SEM data suggests that the Pre-Cambrian Salt Range Formation, Permian Wargal Formation, Cretaceous Lumshiwal Formation, Paleocene Patala Formation and Eocene Nammal Formation are ductile and not suitable for fracking. As the Cambrian Baghanwala Formation, Permian Chhidru Formation, Triassic Mianwali Formation and Jurassic Datta and Shinawari formations are semi ductile, these formations are also not suitable for fracking. Nevertheless, the Permian Sardhai Formation and Triassic Tredian Formation are brittle in nature and suitable for fracking. Finally, the Cambrian Kussak Formation, Permian Tobra, Dandot and Warchha formations, Jurassic Samana Suk Formation and Cretaceous Chichali Formation are brittle in nature and are suitable for fracking.

Khyber Pakhtunkhwa Oil & Gas Potential, Future Resources and Operational Constraints for Exploration Activities'

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Khyber Pakhtunkhwa (KP) represents a new geological frontier with significant proven oil and gas potential, currently contributing approximately 45% of the nation's crude oil, 13% of its natural gas, and 42% of LPG from just five blocks within the province. With a success ratio of 1:2, KP stands as a highly prospective area, drawing the involvement of over ten national and international Exploration and Production (E&P) companies. Recent high-impact oil and gas discoveries by OGDCL, MPCL, and Al-Haj Enterprises in and around the Merged Districts further underscore the region's potential. Khyber Pakhtunkhwa Oil & Gas Company Limited (KPOGCL) serves as the provincial holding company, wholly owned by the Government of Khyber Pakhtunkhwa in accordance with Clause 4.1.3(6) of the Petroleum Exploration Policy, 2012. As a joint venture partner in nine exploration blocks alongside renowned oil and gas companies such as OGDCL and MPCL, KPOGCL holds shares ranging from 2.5% to 20%. While the Baratai Block is currently in production, other blocks remain in the exploration phase. Additionally, KPOGCL has applied for and signed a Petroleum Concession Agreement (PCA) for an exploration block named "Miran" where it will operate with 100% working interest. It is anticipated that the PCA for the Miran Block will be finalized by the Ministry of Petroleum in May 2024.

Organic Geochemistry of the Early Jurassic Datta Formation: Implications for Source Rock Evaluation, oil-oil and oil-source Correlation in the Potwar Sub-Basin, Pakistan

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An extensive geochemical study is conducted to evaluate source rock potential of Datta shales in the Potwar Sub-basin through TOC measurement, Rock Eval pyrolysis, organic petrography, and biomarkers analysis. The study examines the source input, environment of deposition and thermal alteration of organic matter along with oil-source correlation using core/well-cuttings data of Toot-17 well. The results indicate that a significant percentage of Datta shales samples show fair to good potential and early to late mature stage having Type-III kerogen with vitrinite as a dominant maceral. However, a fraction of Datta shale with HI values less than 50 mg HC/g TOC has Type-IV kerogen and predominantly inertinite macerals. The biomarker composition analysis and microscopic investigation indicate that primarily terrestrial organic matter was deposited in a marine environment under relatively suboxic conditions. Stereo-isomeric composition of steranes and terpanes indicate that the samples are thermally mature, falling in late oil window. Furthermore, Pr/nC17 and Ph/nC18 values indicate that the samples are not biodegraded. The star correlation diagrams for oil-source correlation exhibit significant similarities between crude oil and Datta shale samples, thereby suggesting Datta shales as source for the oil.

Paleo-Environmental and Stratigraphical Analysis of the Turonian Red Beds, Northern Kirther Range, Pakistan

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During the Cretaceous period in the Tethys Ocean, redox conditions fluctuated between oxic and anoxic conditions, leading to the deposition of Cretaceous oceanic red beds (CORBs) and black/grey shale (oceanic anoxic events), respectively. The former comprises pelagic shales, marls, and fine-grained limestones characterized by a reddish coloration, whereas the latter comprises black shales. In the Kirther Range of the Lower Indus Basin, a unique alternation between red pelagic limestone (RPL) and black shale was observed. Petrographic, mineralogical, geochemical, and stratigraphical analyses were conducted on the red beds to understand their genesis, stratigraphic contexts, and paleo-environments. Petrographic analysis revealed three distinct microfacies within the red pelagic limestone: 1) planktonic foraminiferal wackestone/packestone, 2) planktonic foraminiferal wackestone, and 3) planktonic foraminiferal packestone. The identification of these microfacies indicates that the sedimentary environment is a deep open marine system. Three planktonic foraminiferal biozones have also been identified: Whitinella archeocretacea Partial Range Zone, Helvetoglobotruncana helvetica Total Range Zone, and Marginotruncana sigali Partial Range Zone. The age of the red beds is dated to be early to late Turonian. The RBL, similar to the Goru Formation in the Murree Brewery Section, has been found in several locations across the Tethys Ocean, mainly on the European side. These locations include the Chuangde section in Tibet, China, which represents the Eastern Tethys Ocean; the Vispi Quarry section in Italy; and the Buchberg section in Austria, which represent the Western Tethys. Additionally, the Unas section in Turkey represents the Middle Tethys. Under an optical microscope, red

pigment is observed scattered in the matrix and/or inside the shells of foraminifera. Mineralogical investigations conducted using X-ray diffraction (XRD) confirmed that the red coloration observed in RPL originated from hematite. Three geochemical endmembers classified the Murree Brewery red beds as calcareous (Ca-CORBs) based on the predominant presence of CaO compared to SiO_2 and Al_2O_3. The major elements Al_2O_3, SiO_2, Fe_2O_3T, MgO, K_2O, TiO_2, P_2O_5, and Na_2O were significantly depleted in RPL compared to the average shale composition, with enrichment in MnO attributed to local hydrothermal sources. The geochemical indicators for redox and productivity, including Ni, Co, Cr, Zn, and Cu, showed low values, suggesting that the depositional conditions were oxic and oligotrophic.

One Dimensional (1D) maturity modeling of Lower to Middle Jurassic Petroleum System of Indus Basin, Pakistan

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1D maturity modeling of the Lower to Middle Jurassic in the Indus Basin, Pakistan is carried out to know the burial history, petroleum system, thermal history, paleo-heat flow, source rock maturity, and hydrocarbon generation and expulsion capacities of source rock. The wells across the Upper Lower Indus Basin are selected to carry 1D modeling with the help of Petromod (PM) basin modeling software. Data for the software analysis were adopted from the established literature and public-domain databases. Besides geochemical analysis, well logs, outcrop stratigraphic logs and well sections data were acquired to determine lithostratigraphy, eroded or non-deposited sections and true stratigraphic thickness for performing petroleum system modeling. The stratigraphic thicknesses of Lower to Middle Jurassic are based on current work and the information regarding the stratigraphy of Indus Basin and the erosional durations of its strata are obtained from published data. The mean value of TOC and HI are put together along with the information of precise layers, time of erosion, chronological ages, and definite kinetic model in one-dimensional modeling of the petroleum system. Besides these, the latitude of the basin, the temperature of global mean surface temperature (SWIT), paleo depth of water (PWD) and flow of heat (HF) are the most important requirements, which explain the boundary condition in the basin. The output result includes; the burial, depth, and time plots, these are used to model the hydrocarbon zoning throughout the burial history and estimate the quantities of oil generation. The kinetic models for kerogen type II were applied in the PSM to evaluate the relative retention capability of the Lower to Middle Jurassic shales. The paleo-temperature history is found out through the Ro % model, and the Tissott and Welte (1984) methods are used to simulate the hydrocarbon generation history.

Unveiling Diagenetic Evolution and Reservoir Characterization of Kingriali Formation, Paniala Section, Khisor Range Pakistan

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The dolomite from 105m-thick Kingriali Formation in the Paniala section, Khisor Range was sampled, and 48 representative samples were randomly collected. Current petrographic observations and geochemical analysis indicate that the most prevalent dolomitization process in the formation involves the replacement of limestone with dolomite. This implication is supported by matrix-selective dolomitization, overgrowth of crystal leading to overdolomitization, cementation of dolomite, mold and vug development, the existence of calcium sulfate cement, two distinct dolomite populations, and the formation of saddle dolomite. Three primary stages of the dolomitization process are depicted in the study leading to the formation of a densely packed low porosity replacive dolomite. Finally, neomorphism modifies this phase into RD-II replacement dolomite during progressive dolomitization. The petrographic observations are zipped into eight distinct microfacies. Stable isotope analysis ($\delta^{13}C$ and $\delta^{18}O$) of selective samples from each microfacies was carried out to support petrographic and geochemical data for decoding the origin of dolomite and the nature of dolomitizing fluids. The isotopic analysis of $\delta^{13}C$ and $\delta^{18}O$ in samples MKD-2, MKD-5, and MKD-6 shows a decrease in $\delta^{13}C$ and an increase in $\delta^{18}O$ values, indicating dolomitization influenced by slightly warmer basinal brines and meteoric water. Conversely, MKD-1, MKD-4, and MKD-8 show consistent marine signatures in their isotopic ranges. It suggests that during the late Permian to middle Triassic interval,

seawater-derived brines with high levels of Fe, Mg, and radiogenic strontium were heated as they followed through clastic sediments. This process likely played a role in replacing the precursor limestone in the Kingriali Formation. Also, meteoric water is key in modifying dolomitization phases and inducing dissolution processes. Petrophysical analysis reveals significantly high porosity and permeability values, which are believed to result from various modifications of shallow marine limestone into current dolostone. The formation of molds and vugs can be attributed to several processes, including the breakdown of calcite at shallow depths, the replacement of unstable carbonate minerals on a mole-for- mole basis, and fractures resulting from active tectonics and burial compaction. Investigating the reservoir properties, we find that the 3D porosity spans a range of 8.62% to 16.73%, while the 2D porosity varies from 2.16% to 30.37%. The values of air permeability range from 0.064 to 30mD, and the liquid permeability exhibits values within the range of 0.037 to 27.2mD. These distinctive characteristics closely resemble those of a promising hydrocarbon reservoir.

Lithofacies-based depositional environment and Reservoir Characterization of the Lumshiwal Formation, Surghar Range, Pakistan

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Rock samples from the Lumshiwal Formation exposed in Pannu Nala and Karandi Nala have been collected near Malla Khel area in Surghar Range for analyzing its depositional environment, geochemistry, lithofacies and reservoir potential. The lower contact of the Lumshiwal Formation with the Chichali Formation is transitional, and it is unconformably overlain by the Paleocene Hangu Formation. The thickness of the formation at the study area is 190m. Field investigation suggests that the formation is thinning in an easterly trend along the EW transect of the Surghar Range. The formation is composed of fine to medium-grained sandstone mostly, though a few sections exhibit medium to coarse grains, almost devoid of fossils. Belemnite fossils were noted in the lowermost layers of the formation. Sandstones within the Lumshiwal Formation are categorized as sub- arkose to arkose arenite based on their modal composition, with some samples designated as lithic arkose. Based on the lithofacies studies and geochemical studies (XRD studies), the depositional environment for the Lumshiwal Formation is Transitional that is ranging from Deltaic to shallow marine. Furthermore, the formation shows enrichment in carbonaceous material, with coal seams observed at multiple intervals. Overall, the formation exhibits general porosity, permeability, and moderate cementation, displaying characteristics indicative of the potential reservoirs for hydrocarbon accumulation within the region.

Formation mechanism of Cambrian oncoids: Evidences from the Miaolingian Zhangxia Formation, North China Platform

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Oncoid is the type of microbial carbonate that exhibits characteristics of coated grains with a size relatively larger than ooids. It also depicts successive lamination formed through microbially-mediated calcium carbonate precipitation similar to stromatolites. This study is intended to investigate the formation mechanism of Cambrian oncoids from the Miaolingian Zhangxia Formation exposed in the Shanxi province of north China. Currently, a bed of oncoidal limestone in the uppermost part of the fourth-order subsequence in the Zhangxia Formation is considered for petrographic investigation. The oncolite, graduating from oolitic limestone, exhibits the fabric of both stromatolites (laminated) and ooids (coated grains) on a large scale. On the other hand, at a smaller scale, it shows plentiful twisted and non-twisted calcified filamentous cyanobacteria in the cortexes and matrix of the oncolite. These features of the oncolite offer tangible signatures of the direct or indirect role of filamentous cyanobacteria in the development of these oncoids. The oncoids of the Miaolingian Zhangxia Formation provide a classic instance of organo-mineralization, involving a complicated calcification process of extracellular polymeric substances (EPS) in the cyanobacteria-dominated microbial mats.

Exploring the geothermal potential in the Himalaya-Karakoram Orogenic belt of northern Pakistan

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Northern Pakistan, situated within the collision zone of the Indian and Asian plates, encompasses the Himalaya, Kohistan, and Karakoram regions, hosting numerous hot springs linked to the Himalayan Geothermal Belt stretching 3000 km along the Himalayas. Understanding the magnitude of terrestrial heat flow and characteristics of potential heat sources in this belt is crucial across geoscientific domains. However, geothermal exploration in this remote area faces challenges due to limited data, with only two decades-old geochemical analyses of hot springs available. The absence of reliable geophysical data and petrophysical parameters hinders understanding the lithosphere's thermal state, essential for geothermal modeling. This study aimed to evaluate geothermal resources in the Himalaya-Karakoram region of Pakistan at a reconnaissance level, offering baseline data and pinpointing zones for future detailed exploration. Employing a multi-method and multi-scale approach, the study commenced with a regional- level investigation using remote sensing, geological mapping, and literature review to analyze tectonic mechanisms, structural features, surface temperature patterns, and hydrothermal alterations. Ground-based measurements of radioelement concentrations were conducted using a portable gamma spectrometer, complemented by laboratory analyses (XRD, optical and cathodoluminescence microscopy, XRF, and ICP-MS) of altered and unaltered samples to determine mineralogical, petrological, geochemical, and petrophysical properties. Remote sensing results confirmed high lineament density, thermal anomalies, and hydrothermal alteration near hot springs and suture zones. Hydrothermal alteration detected via remote sensing

was validated by XRD analysis, laying the groundwork for subsequent field investigations. Radiogenic heat production was found to be high in the Nanga Parbat Massif (> 4 μWm^{-3}), moderate in the Karakoram batholith (2 – 4 μWm^{-3}), and low in the Kohistan-Ladakh batholith (< 2 μWm^{-3}). Geochemical analyses unveiled peraluminous S-type gneisses and granites in the Nanga Parbat Massif, syenitic to granitic compositions with REE-rich allanites in the Karakoram batholith, and calc- alkaline I-type granitoids with REE and radiogenic element depletion in the Kohistan-Ladakh batholith. The granitoids and gneisses exhibited weak to moderate alteration of biotite, K-feldspar, and plagioclase, intensifying towards intensely deformed zones. The genesis of hot springs is attributed to high geothermal gradients from elevated radiogenic heat production and exhumation, accessed by meteoric waters through deep faults. The Nanga Parbat region, central Karakoram, and eastern Karakoram are identified as potential geothermal targets for detailed investigations, with hydrothermal and hot-dry rock geothermal play types proposed in these areas. Short to long-term strategies for geothermal resource development are outlined, prioritizing the cost-effective and expeditious development of hot spring sites for direct-use applications. Despite existing financial and technical hurdles, the region's geothermal prospects offer substantial promise. This study's findings provide crucial data for comprehending the region's geothermal dynamics on a broader scale and lay the groundwork for future geothermal exploration endeavors.

Repeating Lithological Diversity of Clastics, Carbonates and Evaporites as Herald of Depositional Instability: An outcrop-based interpretation of Nari Formation from Northern Ranikot Anticline, Sindh, Pakistan

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We systematically analyzed the vertical stacking of lithofacies and made high- resolution outcrop-observations and interpretations of the Nari Formation from Northern Ranikot Anticline, Sindh, Pakistan. A total 65m thick sequence of Nari Formation from top Kirthar Formation (Upper Eocene) to base Manchar Formation (Neogene, Siwalik Group) is measured in the study area. Interbedded strata of limestone, gypsum, gypsiferous shale, oxidized shale, cross-bedded sandstone and oxidized sandstone were identified. Abundant fossils were identified in limestone, which include worm burrows, echinoids, gastropods, pelcypods, turritella and larger benthic foraminifera, particularly discocyclina. Orientation of gypsum laminations and veins were also noted to understand their syn-depositional or post-depositional relationship with other lithologies. Paleo- current data of elongated fossils and cross-bedding in sandstone was also recorded to interpret current direction and hence paleo-slope during the deposition of Nari Formation. Nari Formation has transitional lower contact with Kirthar Formation. Lower 35m of the Nari Formation in study area consists of four distinct lithofacies associations, which are ramp-deposited limestone facies, sabkha-deposited gypsiferous shale and gypsum facies, flood plain-deposited variegated shale facies and delta/fluvial -deposited thick and cross-bedded sandstone facies. Upper part of the formation is dominantly composed of delta/fluvial-deposited oxidized and cross-bedded sandstone facies. This lithological diversity indicates a wide range of depositional environments ranging from shallow-marine ramp, sabkha to deltaic and fluvial settings. Majority of the bedding planes in the study area are erosional in nature, indicating frequent emergence and erosion episodes. Paleo- current analysis indicates dominant paleo-

flow direction towards NW. Besides the vertical lithological diversity, Nari Formation also exhibits lateral variations in lithology. Present interpretations propose that the study area was initially part of Nari Sea that was opening to the west. The study area experienced gradual emergence due to regression caused by uplifting of northern and western margins of Indian Plate. Therefore, marine fossiliferous limestone was replaced by evaporite gypsiferous shale and gypsum, which in turn were replaced by deltaic and fluvial oxidized and cross-bedded sandstone.

Multiphase Dolomitization of the Shogram Formation, Devonian Platform Carbonates: Insights from Field, Petrography and Geochemistry

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The Shogram Formation, regarded as Devonian platform carbonates, within the Karakoram-Hindukush tectonostratigraphic basin is intensely dolomitized. The dolomitized bodies, varying in size and shape, are accompanied by tabular bodies of dolomite-cemented breccias and networks of dolomite veins. Three types of matrix dolomite can be categorized through field observations and petrography. It is evident from the overall results that the dolomitization occurred through a polyphase process involving hydro-fracturing, dissolution of the host rock, and subsequent dolomite precipitation. These dolomites exhibit distinct stable oxygen isotopic signatures, i.e., dolomite-1 and dolomite-2 display oxygen isotopic signatures similar to the Devonian carbonates, while dolomite-3 shows depleted oxygen isotopic signatures. Strontium isotopic signatures reveal similarities between dolomite-1, dolomite-2 and the Devonian signatures, while dolomite-3 and cement dolomite exhibit more radiogenic signatures. Fluid inclusion analysis suggests elevated temperatures (170 to 230°C) for the dolomitizing fluids, indicating a fossil hydrothermal system. This process is likely driven by the episodic expulsion of over pressured fluids through fault and fracture systems. Dolomite-1 and dolomite-2 are interpreted to have formed in shallow burial or near-surface conditions. Moreover, dolomite-3 and dolomite cement are interpreted to be hydrothermal. The hydrothermal system likely stems from deep- rooted faults, implying substantial faulting activity during the deposition interval of Devonian Shogram Formation. This study contributes significantly to understanding the complexities of dolomitization processes and their geological implications in similar geological settings.

Insights into Fluid Flow Mechanisms in Low Porosity Reservoirs

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Monitoring the dynamics of subsurface fluids has been a major focus of research in geotechnical and geological engineering in the recent years. This phenomenon is particularly noticeable in the analysis of unconventional oil and gas reservoirs, such as low-porosity sandstone, where variations in the fracture length and complicated distribution of pores make the task difficult. In this case, the pore network exhibits a heterogeneous structure that includes both stiff and soft pores, leading to pore-scale creation of heterogeneous porous media. Furthermore, there is a frequent patchy saturation in the fluid distribution inside these rock pores, which is defined by patches that have diameters larger than the wavelength scale; they, however, remain smaller than the individual pores. These changes also affect the heterogeneity of the rock, which causes wave-induced flow in the low- porosity sandstone at the micro- and mesoscopic levels. Recent research challenges the conventional understanding of fluid flow characteristics by demonstrating the possibility of micro-flow in the seismic and acoustic frequency ranges. However, a detailed grasp of the velocity and frequency characteristics at various frequencies is necessary to fully understand these occurrences, particularly in the context of velocity dispersion and attenuation research. Current research highlights the non-uniform characteristics of subsurface porous medium in all forms and sizes, indicating potential connections between wave-induced flow at the meso- and microscale. Soft pores, contrary to stiff ones can dramatically change the saturation modulus. These changes then affect the mesoscopic-scale viscoelastic response of porous media in a wide range of frequencies. Considering these results, developing a fluid flow mechanism that creates velocity correlations over a variety of frequency ranges in low porosity sandstone while accounting for heterogeneities at the pore- and mesoscopic scale is imperative.

Preparation of Green Nano catalyst and Its Application in Biodiesel Production from *Melia azedarach* Seed

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Biodiesel is a sustainable fuel which is often made from vegetable oils and animals fats. In this study, oil extraction and its conversion into biodiesel is done by transesterification using nanocatalyst. The solvents n-hexane for oil extraction was used on nonedible seed oil like M. azedarach for further analysis and investigations. The impact of oil to methanol molar ratios (1:3, 1:6, 1:9 and 1:12) at varied temperatures (70, 80, 90, 120 and 140° C), catalyst amount (0.3, 0.5, 0.7, 0.9 and 1g) and reaction temperature (1hr, 2hrs, 3hrs and 4hrs) were analyzed. Melia azedarach yielded 93% biodiesel in 1:12 molar concentrations and 80°C temperature with 0.7g of catalyst amount in three hours. The synthesized biodiesel was characterized using FTIR technique which confirmed synthesis of biodiesel. For nanoparticle characterization X-ray diffraction, FTIR, and scanning electron microscopy were performed on synthesized TiO_2 nanoparticles. These findings confirmed that the selected nonedible seed oil "Melia azedarach" can be used as a sustainable energy source for commercial/ industrial scale production of biodiesel.

Unraveling the Dolomitization Puzzle: Insights from the Cambrian Ambar Formation, Peshawar Basin

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The Ambar Formation, a Cambrian carbonate sequence within the Peshawar basin, is characterized by extensive dolomitization. Tabular bodies of dolomite- cemented breccias and networks of dolomite veins accompany dolomitized bodies of varying sizes and shapes. Field observations and petrography reveal three distinct types of matrix dolomite. Dolomite-1 is stromatolitic, Dolomite-2 is oncoidal and bedded, and Dolomite-3 is replacive saddle dolomite. Analysis indicates that dolomitization occurred through a complex process involving hydrofracturing, dissolution of the host rock, and subsequent dolomite precipitation. The dolomites exhibit distinct stable oxygen isotopic signatures, with Stromatolitic Dolomite and Oncoidal Dolomite showing similar signatures to the Cambrian carbonates, while Replacive Saddle Dolomite displays depleted oxygen isotopic signatures. Strontium isotopic signatures reveal similarities between Dolomite-1, Dolomite-2, and the Cambrian carbonates, while Dolomite-3 and cement dolomite exhibit more radiogenic signatures. Fluid inclusion analysis suggests elevated temperatures (135 to 215°C) for the dolomitizing fluids, indicating a fossil hydrothermal system. This process is likely driven by the episodic expulsion of over-pressured fluids through fault and fracture systems. Dolomite-1 and Dolomite-2 are thought to have formed in shallow burial or near- surface settings, while Dolomite-3 and dolomite cement are seen as having a hydrothermal origin. This hydrothermal system is likely linked to deep-seated faults, suggesting considerable fault activity during the Cambrian Ambar Formation. This study offers valuable insights into the complex processes of dolomitization and their geological implications in similar contexts.

Preliminary Geology of the (Khanozai) Karezat Quadrangle, District Pishin, Balochistan, Pakistan

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The (Khanozai) Karezat Quadrangle (KQ), situated 70 km northeast of Quetta, covers Khanozai and its surrounding areas. The region comprises distinct zones, the Urak Basin (south), the ultramafic, gypsum, and Jurassic basins (middle), and the Kakar-Khorasan Back Arc basin (northwestern) portion. The terrain is dominated by rocks of Jurassic to recent/subrecent, structurally divided into three domains of Tungi-Ahmadun Syncline, Khanozai-Torkhula Ophiolite Segment and Murgha Zikriazai Flysch Segment. The Tungi-Ahmadun area predominantly characterized by the Urak Group, ranging from Miocene to Early Pleistocene. Notably, the Urak Group comprises Uzdapasha, Shinmati and Urak formations. The Urak Group is thrusted by the Jurassic Alozai Group to the north and the Cretaceous Parh and Bibai formations to the south. In the southeastern corner, it contacts the Jurassic Loralai, Cretaceous Sembar and Eocene Shaheed Ghat formations. The Khanozai-Torkhula Ophiolite Complex is predominantly occupied by the Jurassic Singwar and Loralai formations of the Alozai Group. The ultramafic intrusion holds significant potential for chromite, forming part of the Muslim Bagh Ophiolite Complex. The Murgha Zikriazai Flysch Segment comprises Eocene Nisai Formation, Oligocene Murgha Faqirazi Shale Member and Oligocene-Miocene Shaigalu Sandstone Member of the Kajok Formation. The Nisai Formation consists of fossiliferous limestone and shale at the base, multicolored shale in the middle, and medium to thin-bedded fine-grained sandstone, shale, and brecciated cliff-forming limestone in the upper part. The central part is covered by alluvial deposits of the Pleistocene Bostan Formation and recent to sub-recent material. In the northern Khanozai region, potential hydrocarbon structures exist near the Karez Haji Dadullah and Murgha Zikhazai areas. Geophysical surveys are recommended in this region to delineate subsurface sequences for assessing hydrocarbon potential.

Depositional setting and sequence stratigraphic analysis of Lakhra Formation, Lower Indus Basin, Pakistan

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The current study focuses on the paleoenvironmental and sequence stratigraphic analysis of the Upper Paleocene-Lower Eocene Lakhra Formation, exposed in Laki Range of the Lower Indus Basin, Pakistan. The formation is previously analysed for biostratigraphy, but has never been analysed for depositional setting and sequence stratigraphy. Based on filed and petrographic observations, two distinct lithofacies (i.e., bioclastic sandstone lithofacies and shale lithofacies) and one microfacies (i.e., foraminiferal bioclastic packstone MF-1) are identified. The lithofacies and microfacies suggest the formation to have been deposited in a middle ramp to outer ramp slope (turbidite) setting. The studied rock units show deposition in a total time period of 55-56 million years, which is comparable to the eustatic third-order cycle (2.1 Ma). The depositional sequence in the studied sections represents a partial cycle including lowstand system tract (LST) and transgressive system tract (TST). These facies represent depositional cyclicity and have preserved trackable sea level changes and associated facies variations, controlled by the local shift in sea level and the associated tectonics. The study provides valuable information regarding the depositional framework in the Lower Indus Basin and changes in the depositional pattern associated with the Himalayan orogeny in the proposed time interval.

Cretaceous Anoxic Intervals Preserved in Parh Formation, Mughal Kot, Pakistan

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The trace element analysis of warm Cretaceous periods found in the Parh Formation at the Mughal Kot Section has been addressed in this work. The Cenomanian-Turonian oceanic anoxic event (OAE) was identified in the Mughal Kot section based on biostratigraphy and microfacies, correlated with the earlier OAEs reported elsewhere. Black shales, which are deposits with abnormally high levels of organic materials deposited in them, are a defining feature of the OAEs. The evolution of planktons across the OAEs during the Cretaceous was driven by shifting environmental conditions. These OAEs are responsible for the significant biotic and sedimentological changes seen in various Cretaceous strata. Test- secreting plankton showed higher rates of diversification and extinction near OAEs in various regions across the world. The Weissert and Selli event (OAE1a) in the early Cretaceous and the Bonarelli (OAE2) event in the late Cretaceous are two major OAEs from the Cretaceous period that have been extensively documented in literature. The evolution of planktonic foraminifera has been influenced by changes in the environment during the OAE2. The prevalence of OAE in the studied area indicates that these events occurred frequently worldwide. The depositional environment of the organic rich (Cenomanian–Turonian) intervals preserved in the Parh Formation is the outer ramp setting, evident by the microfacies details. Anoxic water conditions suggested by the abundance of both the organic matter and pyrite, represents an OAE. The elevated concentrations of the trace elements are the main cause of extinction of organisms, suggested by the geochemical analysis along these organic rich intervals. Other possible explanations include oceanic circulation, nutrient fluxes and ocean acidification. The concentration, toxicity and effects of trace elements on marine biota has been addressed in this study in detail.

Renewable Energy Resource Potentials in Pakistan: The Way Forward

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Pakistan is bestowed with plenty of renewable energy resource potentials that includes wind, water, geothermal etc. It is time to better exploit these resources in an efficient way so that maximum benefit is provided to society for sustainable development. As per statistics, Pakistan's total installed power generation capacity is 43,775 MW, of which 59% of energy comes from thermal (fossil fuels), 25% from hydro, 7% from renewable (wind, solar and biomass), and 9% from nuclear (NEPRA). Wind energy is one of the main source, which can be exploited efficiently. According to Pakistan Meteorological Department, Pakistan's coastal belt at 60km (Gharo-Keti Bandar) and 180 km long, with an exploitable potential of 50,000MW of electricity generation through wind turbines. As per report of the World Bank, Pakistan possesses a solar power potential of 40 GW and has set a goal to achieve 20% of its electricity from renewable sources by 2025. Another potential source of energy is shallow- and deep-seated geothermal energy resources, where large bodies of deep-seated reservoirs are found in Gilgit-Baltistan. According to Pakistan's geothermal profile, the country can potentially generate around 15,000 megawatts of power to meet its power challenges. In conclusion, using the renewable resource potentials, Pakistan can not only overcome energy deficiencies but also play its important role in reducing greenhouse gas emissions.

Ground Penetrating Radar (GPR) in Exploration Geophysics: Principles, Applications and New trends

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Ground Penetrating Radar (GPR) is a noninvasive geophysical method that is commonly used for imaging near surface features. GPR is quick, easy and quite reasonable to straight, and measured data have highly perpendicular and straight resolutions. GPR could be used for many applications including geotechnical and engineering as it could provide early warning for engineers from civil sector to yield proper securities before arising any situation like catastrophic. GPR could also be used for identifying cavities within sedimentary rock. GPR uses high frequency waves of electromagnetic to plot different lithologies or subsurface objects yielding electrical properties of different nature. Ground Penetrating Radar is commonly dragged along an earth surface using a wheel cart, the transmitter antenna sends pulses of electromagnetic high frequency energy to enter into the earth, a part of the GPR waves are send back to the ground upon encountering an interface with materials contrast in dielectric permittivity. Underground structural features are detected by determining the two-way travel time and amplitude of this reflected energy to the receiver antenna. Limestone with dry nature is a promising source that allow GPR signal to penetrate and gives image of karstic cavities. Due to the electrical permittivity contrast in between the air-gap and the surrounding host rock, this give strong reflections of radar signals. GPR could be measured in different configurations including common- offset, common midpoint and as radar tomography between boreholes. GPR could be used for many other applications including geological and hydrogeological investigations (e.g. mapping of bedrock topography, groundwater levels, glacial structures, and landslide), Environmental Studies (e.g. groundwater pollution, salt water intrusion, hydrocarbon leakage, landmines, unexploded ordnance (UXO), and landfills); engineering and geotechnical investigations (e.g. constructions, foundations, tunnels, utilities, dams, pavements, road beds, railway embankments,

piles, bridge decks, underground storage tanks, and reinforcing bars). GPR is considered as one of the best tools for detection of cavities, tombs, and archaeological targets. GPR could also be used for forensic investigations. The GPR depth of investigation increases with low frequency antenna, high transmitter power and high receiver sensitivity. However, the depth of penetration decreases with high electrically conductive materials like clays and saline water or highly conductive contaminants. In general, GPR is an efficient practice in the documentation and classification of near surface structures. GPR results not only inform us about existing structures, but also warns of potentially hazardous situation like sinkholes and landslides. The presentation will provide background about the principles, applications, restrictions, and appropriateness of the Ground Penetrating Radar process for examining the subsurface and new trends in GPR equipment and field measurements.

Assessing seismic risk on a local scale in Muzaffarabad city, Northern Pakistan through the integration of satellite data and field observations

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Earthquakes are one of the most devastating and catastrophic natural calamities, often leading to extensive losses in infrastructure and human lives. This research introduces an integrated approach for evaluating seismic risk, encompassing factors such as seismic hazard, vulnerability, coping capacity, and resilience within the earthquake-prone region of Northern Pakistan. Utilizing high- resolution satellite imagery alongside thorough field surveys, the study generated detailed building footprints along with information on building types. Twenty- eight distinct sub factors, covering aspects of seismic hazard, physical, social, and economic vulnerability, and response and recovery capabilities, were employed to construct a comprehensive seismic risk map. Overcoming limitations in available factors by leveraging abundant vulnerability data at the local level, the assessment yielded a detailed high-resolution risk analysis, pinpointing areas highly susceptible to seismic hazards. Employing ArcGIS grid technology and the Analytical Hierarchy Process, the seismic hazard map reveals that the high and very high hazard classes covered an area of 3 km2 (10.7%) and 0.9 km2 (3.2%) respectively. Similarly, vulnerability map identified 1.8 km2 (6.4%) and 0.5 km2 (1.8%) of the total area as exhibiting high to very high vulnerability. The final seismic risk map delineated villages such as Chella Bandi, Dhanni Mysiba, Makri, Dherian Syedian, Ranjata, Baila Noor Shah, Taami, Middle Gojra, Lower Gojra, Rasheed Abad, and Upper Chattar as falling into the high-risk category. Additionally, areas including Pilot, the Madina Market area, Shahnara, and Domail villages were classified as very high risk, covering an area of 1.8 km2 (6.4%). These results inform the formulation of building codes and

land-use plans, ensuring elevated building standards in regions prone to seismic activity. Critical structures within designated hotspots become focal points for infrastructure design and retrofitting initiatives to enhance their seismic resilience. Emergency response plans can be tailored to address potential impacts in high-risk regions, facilitating efficient and focused crisis management strategies. Furthermore, these findings contribute to public awareness campaigns, insurance schemes, and community engagement programs aimed at mitigating overall damage from seismic events.

Development of SPT-N and Correlated Shear Wave Velocity Profiles Database for Pakistan

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This study spearheads efforts to develop a Pakistan-centered comprehensive and open-access SPT-N and correlated Vs profiles database. The initiative aims to create an impactful Vs profile repository that ensures the accurate prediction of ground motion acceleration during an earthquake. The database is built on specific entry requirements, such as in-situ SPT-N measurements, precise location data through geodetic coordinates and elevation, and additional information on geotechnical logs, penetration resistance data, and groundwater tables. A suite of SPT-N and Vs correlations are selected from the literature to develop corresponding Vs profiles. These data inclusions enhance the overall database and make it suitable for complex site response analysis across all the provinces of Pakistan. About 350 profiles have already been collected as part of the study, and a data model prototype has been developed to ensure efficient data storing, processing, and retrieval. A web-based interactive platform with downloadable SPT-N and Vs profiles and additional data will be established to create an ultimate database. The project serves to update the geotechnical and earthquake engineering community. It will become a vital source for open-access VS profile databases and potentially influencing seismic hazard mitigation strategies in Pakistan and beyond and becoming a valuable resource for researchers.

Active Strike-slip Faulting in the Southern Kirthar Fold Belt, Pakistan: An Integrated Interpretation of Remote Sensing Data Field Data and Earthquake Characteristics

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The mechanism of foreland-vergent strike-slip deformation, independent of folding, in the foreland fold belt is poorly understood. This work establishes the existence of such foreland-vergent active strike-slip faults, detached deeper than folds and their kinematics in the Southern Kirthar Fold Belt (SKFB), Pakistan. SKFB is the southernmost continuation Himalayan-Suleiman-Kirthar orogenic belt, which developed due to continent-continent collision Plate with Eurasian Plate. Kirthar Fold Belt is located adjacent western margin of the Indian Plate represented by the Ornach-Nal-Chaman Fault System (ONCF). It is bounded Sindh monocline to the east and Suleiman fold belt in the north. In the south-west Kirthar Fold Belt passes into the Offshore SW-NE trending Murray Ridge. Present study area is located in the southeastern front of Kirthar Fold Belt. In this work we utilized Digital Elevation (DEM) of Shuttle Radar Topographic Mission (SRTM) and Landsat 8 imagery, both with ground resolution of 30 m. These satellite imageries provided indispensable insights regarding identification of structural landforms, such as ridges, valleys, lineaments and drainage. The remote sensing analysis was then integrated with available geological maps of different scales to refine and update the regional geology. The areas of structural anomalies, such as sharp breaks in stratigraphic contacts, deviations in structural trends, elevation profile and drainage pattern were visited for their ground-truthing and then marked on updated geological map along-with locations of earthquake epicenters 50 years. This integrated approach enabled us to

identify two generally E-W trending active strike-slip faults and associated second-order faults. Kinematics of these faults was tested through strain ellipsoid analysis, which proved their structural configuration. The southern strike-slip fault has right-lateral (dextral) sense of movement as "Karachi-Keenjhar Boundary Fault (KKBF)" as it passes through Karachi city and Keenjhar Lake. This fault is characterized by alternate releasing and restraining bends. Releasing bends consists of lakes and sag-ponds, while restraining bends consists of ridges. The northern strike-slip fault has left-lateral (sinistral) sense of movement as "Dureji-Lakhra Fault (DLF)" as it passes through Dureji and Lakhra areas. DLF fault, left step-over north of Thano Ahmed Khan city. This step-over bends the NS trend of Kambhu anticline to NE-SW. Both DLF and KKBF run nearly parallel and have curved map fault traces, concave. These faults also justify the surface structural configurations, which were previously not understood. More than 10 earthquake hypocenters are located at the depth of 10Km, which are interpreted as the depth of detachment for strike-slip faults. Previously, thin-skinned folding detached from top Jurassic and Lower Cretaceous sequences in the depth range of 3.5 to 5 Km is reported. Therefore, strike-slip faults are interpreted to be detached deeper than folds. These faults accommodate differential east-vergent slip of Southern Kirthar Fold Belt and are developed due to east-ward drift sedimentary pile above a weak detachment.

Groundwater investigation using time-domain electromagnetic (TDEM) method in Alkhoud area, Oman: Implications for seawater intrusion

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Alluvial aquifer system along the coast of the Gulf of Oman fulfils one-third of the country's groundwater demand. However, such freshwater aquifers are threatened by the sea water intrusion. Surface geophysical method (Time Domain Electromagnetic (TDEM)) was used for the assessment of groundwater resources and sea water intrusion at Al Khoud area, Oman. The main objective of our work was to map the groundwater table of the alluvial aquifer, and resolve the interface between fresh and saline water. Geophysical soundings provided high resolution information on the spatial distribution of the salt water intrusion, aquifer zones, their thicknesses and lithological units. The coastal aquifer can be characterized by gravels, and clayey gravels. Thus, TDEM proved to be an effective geophysical technique with relatively large depth (>70m) detection capability as compared to other tools for assessment of freshwater resources and mapping sea water intrusion.

Cenozoic Tectonics and Paleogeographic Evolution: Insights from Southeast Tibet Plateau and Northern South China Sea Margin

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Tectonic processes strongly influence the drainage system for transportation of sediments and pose challenges in investigating dominant mechanisms and paleogeographic reconstructions. This study examines the Cenozoic tectonic and paleogeographic evolution of the Southeast Tibet Plateau (SETP) and its connection to sediment deposition in the northern South China Sea margin (NSCSM). Through a case study drawing parallels with the Himalayan region in the north of Pakistan as a source and the offshore Indus Basin as a sink, we aim to understand sediment transportation dynamics. Multiproxy data, seismic profiling, geophysical investigation, and numerical simulations are employed to quantify the impact of tectonic processes on sedimentation patterns in both regions. Badlands simulations and flexurally interpolated backstripping model the tectono-sedimentary evolution of the NSCSM, revealing the integrated response of surface processes and deep dynamics. The SETP is recognized as a source region, characterized by uplifts and erosion that supply sediments to the NSCSM. Tectonic and deep dynamics control basin architectures, which isostatically adjusted accumulation with the source region. Erosional events due to uplifts in the SETP, flexural thickness of lithosphere and dynamic topography significantly influence sedimentation changes in the NSCSM. A proposed conceptual model links the tectonic evolution of the SETP as a source to sediment deposition in the NSCSM as a sink, shedding light on the complex interplay between tectonic and sedimentary processes in these regions. Eocene is identified in this paper as a period of low deposition ascribed to its low source topography, thinned lithosphere, and extension. However, since the Oligocene, there has been an increase in the cumulative thickness of sediments, which has

strengthened the lithosphere, leading to the isostatic adjustment of the higher topography of SETP. In contrast, during the Miocene, the loss of the source-sink connection resulted due to the cessation of the SCS opening and intense magmatic activity. Subsequently, the rotation of the Philippine Sea Plate, Taiwan's orogeny, and the rise in SETP topography reactivated several pre-existing faults and weakened the lithosphere of NSCSM for offshore sedimentation.

Evaluating Fold-Thrust Structures and Hydrocarbon Potential in the Western Marwat-Khisor Ranges and Sheikh Badin Hills, North Pakistan

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The Marwat-Khisor mountainous belt of the Himalayan frontal ranges is a south-vergent fold-thrust strap that protrude south to southeastward into the northwestern Punjab foredeep. It is characterized by east-west to northeast trending parallel to en echelon, plunging structures mostly asymmetric to overturned and dominantly southeast vergent. The frontal foothills of the Khisor Range and Sheikh Badin Hills encompass the latest partially emergent thrust fault named Khisor and Sheikh Badin Frontal Thrust. The outcrop appearance and its extrapolation to the subsurface of the structural fabrics proposes a thin-skinned structural configuration for the progression of the Marwat-Khisor Range where the cushion surface for the frontal ramp being sited within the Jhelum Group rocks of Cambrian age at an estimated depth of 4~5 km. The structural enhancement of the Himalayan frontal ranges is primarily attributed to tectonic processes originating from the north and transferring southward. This tectonic mechanism is observed along a disconnected surface at the base of the Cambrian Khewra Sandstone. Along this décollement horizon the thrust sheet comprising the Khewra Sandstone is exposed at the surface and juxtaposed to the sediments lying south-eastward and belonging to the Punjab foredeep. Thrust tectonics often initiate subsequent to the deposition of molasse sediments, as these rocks become involved in the latest phase of thrust faulting. The forefront of the Khisor Range represents the newest and most dynamic zone of tectonic activity in the northwestern segment of the Himalayas, with geological disturbances progressing towards the southern axis. In the region near Dhupsari, the boundary of the Khisor Thrust delineates the northwestern edge of the

Punjab foredeep, predominantly consisting of marine sediments from the Permian to Triassic periods. The geologic succession observed in the area under investigation shows substantial similarities to the stratification seen in the Surghar and Salt ranges, albeit with a few distinct variations. The Khisor Range's Permian sequence is made up of rock layers from the Nilawahan and Zaluch groups. Overlying the Nilawahan Group is the Sardhai Formation and at the base of the Zaluch Group lies the Amb Formation. The Sardhai Formation has been measured to be over 40 meters thick, mainly composed of blackish-gray to black, carbon-rich shale. In contrast, the base of the Amb Formation is characterized by a dark gray, carbon-rich, and calcareous shale with a thickness exceeding 20 meters. The configuration of the structural forms and the stratigraphic sequence within the Khisor Range point to the northwestern Punjab foredeep being a promising zone for hydrocarbon resources, given the considerable thickness of carbon-rich shale strata in both levels, making them potential sources of hydrocarbons. The study area also contains other prerequisite parameters imperative for the building of a hydrocarbon kitchen, such as a trapping system along with a reservoir, seal, and overstrained horizons.

Balanced cross-section across the Ziarat Block, western Sulaiman fold belt and hydrocarbon exploration

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In order to understand foreland deformation in the western fold-and-thrust belt of Sulaiman ranges, Pakistan, subsurface seismic reflection and well data was acquired while mapping a balanced-cross-section. Interpretation of seismic profiles show the geometry of a petroleum play as vergence of asymmetrical hinterland folds and foreland folds. The Triassic age detachment folds (~6 km depth in the pelitic strata) are located over the tip of blind thrusts of flat-ramp and flat-ramp-flat geometry. Whereas, the decollement floor thrust (~11 km depth in the Triassic strata) was interpreted with stacked duplexe s covered by a passive roof-thrust of hinterland vergence in Ghazij strata of Eocene age. The deformation is represented by passive-roof duplex with presence of a monocline and absence of an emergent thrust with duplicated strata between floor and roof thrust in the foreland. The balanced cross-section reveals deformation of intraplate in series of frontal duplex at the hanging-wall. The deformed balanced cross-section of 33 km was restored to an original length of ~71 km with 54% shortening in the foreland. About 12 km (17%) of the overall shortening is marked by an out-of-sequence blind hinterland-vergent thrust. The geometry and kinematics of deformation based on this study serves as an example of complex foreland deformation for successful exploration and exploitation of hydrocarbons.

Geophysical investigations of a potential landslide area in Mayoon, Hunza District, Gilgit, Baltistan, Pakistan

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The Mayoon landslide in the Hunza District has become a growing concern, particularly in recent years, due to its sudden activation and rapid movement. This area is highly susceptible to earthquakes, classified as zone 3 with peak ground acceleration values ranging from 2.4 to 3.2 m/s^2 according to the Building Code of Pakistan, owing to frequent seismic activity. Previous earthquakes have displaced foliated rocks southward and contributed to the opening of bedrock joints. Loose, unconsolidated material covers the landslide's head and body, displaying fractures of various sizes. To assess the subsurface of the Mayoon landslide, non-invasive geophysical methods, namely Ground Penetrating Radar (GPR) and Electrical Resistivity Soundings (ERS), were utilized. The subsurface was interpreted as a two-layer model. The upper layer (L-1) is characterized by reflections and highly variable resistivity, indicating loose, heterogeneous, fragmented material deposited over the existing bedrock, likely from glacial activity. The lower layer (L-2) displays hyperbolic reflections and intermediate resistivity, indicative of foliated metamorphic bedrock containing faults/fractures. The depth extension of these faults/fractures is uncertain due to signal decay with depth in GPR. Intermediate resistivity within L-2 suggests weathering and foliation of the bedrock. Reflections within L-1 directly above fractures/faults indicate potential movement. A bright reflection between the layers signifies the presence of a debonded surface. The combination of loose material in L-1 and debonding poses a significant hazard for landslide generation during intense rainstorms or earthquakes, highlighting the importance of proactive measures to mitigate risks in vulnerable areas.

Electrical Resistivity Tomography and Ground Penetration Radar Techniques for the delineation of Paleocene coal seams along the Main Boundary Thrust belt in Cherat area, Pakistan

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In this study, Electrical Resistivity Tomography (ERT) and Ground Penetration Radar (GPR) surveys were conducted in the Cherat coalfield, located along the Main Boundary Thrust (MBT) in the most prevalent coalfield of Khyber Pakhtunkhwa (KP), district Nowshera. The results of the ERT and GPR profiles indicated varying resistivity values and depths of coal seams. Specifically, in the Cherat region, the resistivity of coal seams ranged from 600 to 1200 ohm-m at a depth of 11 meters and from 500 to 900 ohm-m at a depth of 20 meters. The location and depth of coal-bearing zones were validated by comparing them with existing stratigraphic profiles of coal mines. ERT and GPR profiles were conducted along already explored coal mines to identify resistivity ranges and locate coal seams in the area. Following the structural trends of the Hangu Formation, similar surveys were conducted in nearby areas to delineate coal seams and recommend potential sites for new coal targets. Based on the ERT and GPR profiles, wide ranges of resistivity values were encountered for coal seams in unexplored areas. For instance, at a depth of 8 meters, the resistivity of the coal-bearing zone ranged from 400 to 1200 ohm-m, and in profile 4, it varied from 300 to 1100 ohm-m at a depth of 25 meters, suggesting potential coal prospects. Our results highlight the efficacy of geophysical and geological techniques in providing valuable information for identifying potential coal zones in unexplored regions.

Fracture analysis of Jurassic to Eocene rocks exposed in the vicinity of Khanpur Dam, Lesser Himalayas, Pakistan

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In an area where compressional tectonics dominates, Fractures are usually formed due to tectonic stresses. Fractures occurring on dipping strata are typically categorized as extension fractures, release fractures, and conjugate fractures based on their relationship with the attitude of the exposed formations and the direction of tectonic stresses. To carry out fracture analysis, a detailed fracture data was collected across the Khanpur Dam area, which exposes Jurassic-Eocene formations, using the Circle Inventory and Scan Line methods. Various characteristics of the fracture sets, such as fracture density and maximum stress direction, were evaluated from the recorded data. Data from each station was used to determine the maximum stress direction (δ1) in the study area. The results show that the Lockhart Formation exhibits significantly higher fracture density compared to the Samana Suk and Margalla Hill Limestone formations. Consequently, the Lockhart Formation, Margalla Hill Limestone, and Samana Suk formations are listed in decreasing order of average fracture density. Out of the 22 stations, the δ1 at 13 stations is oriented in the NE direction, while the remaining 9 stations have it oriented in NW direction, indicating that regional compressional stresses in the study area predominantly align with the north-east and north-west directions.

Fracture analysis of Jurassic rocks of Nizampur basin, north Pakistan; Implications for tectonic evolution and reservoir potential

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This research presents a comprehensive fracture analysis aimed at assessing the reservoir potential and tectonic stresses influencing Jurassic rock formations. Stress orientation analysis indicates a prevalence of north-south compressional forces, resulting in diverse structural features such as folds, faults, joints, and fractures. Utilizing both 2D and 3D fracture models, we evaluated the permeability and effective porosity of these rocks. Three-dimensional Discrete Fracture Network (DFN) XIII Modeling revealed a deficiency of geometric and genetic coherence among fractures, notably impacting fracture permeability and porosity, particularly at anticlinal limbs. While Jurassic rocks exhibit significant permeability facilitating hydrocarbon migration, their suitability as reservoir rocks is questioned due to generally low fracture porosity. Nonetheless, localized zones with substantial fracture apertures hint at potential reservoir characteristics. Moreover, the decrease in fracture density and connectivity with depth underscores the need for further investigation, utilizing well data and DFN modeling, to better understand fracture interconnectivity in the subsurface.

Leachate plume mapping by using electrical resistivity tomography

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The leachate plume generated from a solid waste dump site comprises a hazardous mix of heavy metals and salts. The percolation of this leachate into the subsurface, contaminate the groundwater and pose a serious threat to both the nearby human population and the surrounding ecosystem. Therefore, immediate remediation measure required to mitigate its adverse effect. However, determining the exact dimensions of the plume and subsurface characteristics typically requires costly and environmentally unfriendly drilling methods. Therefore, alternative approaches are necessary to achieve effective remediation while minimizing environmental impact and resource expenditure. In this study an Electrical Resistivity Tomography (ERT) was applied to a test site to see its applicability to map the leachate plume. The motivation behind the use of this technique is that as leachate plume contains charge particles (heavy metals and salts), when it interacts with subsurface pore water it enhances the electric charge of soil (conductivity) and facilitates the flow of electric current. These anomalous conductive zones can be mapped through electrical methods. The data was acquired along the two ERT profiles. First profile was acquired adjacent to leachate accumulation point. We deliberately perform the short survey configuration in which each takeout was connected to the electrode and electrode spacing was chosen 1m to get the good resolution data, thereby enhancing our ability to discern the subtle variation in resistivity caused by the presence of the leachate plume. The resistivity value of leachate plume usually considers as (< 25 ohm.m), but it highly depends on leachate mineralization and subsurface geology. By analyzing the resistivity section enables us to confidently identify the leachate plume, characterized by its low resistivity zone (< 10 ohm.m). Second ERT profile was acquired on the top of waste

containing zone. By analysis the inverted section, a varying resistivity stratum with the thickness of 5m was observed. This varying resistivity is due to the heterogeneous nature of waste containing zone. Beneath the waste containing zone a low resistivity anomaly (< 10 ohm. m) was encountered and marked as a leachate plume that was extended up to the depth of 14m. To validate our results, soil samples were collected along each ERT profile. The chemical analysis of soil revealed relatively high level of elemental concentration in zones where ERT indicated the presence of leachate plume at shallow depth of 0.5m. The overall, results suggest that ERT has a potential to detect the leachate plume in the subsurface.

Seismic Hazard Assessment of Koragh-Paraith Hydropower Project at Mastuj River, District Chitral, KPK, Pakistan

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The Koragh-Paraith Hydropower project with a design capacity of 223 Mega Watt is proposed at Mastuj River in Chitral district, KPK, Pakistan. The project area lies in a historically active region of Eurasian plate close to Main Karakoram Thrust (MKT) and surrounded by gigantic Hindukush Mountain ranges. An active fault system is surrounding the project area which is confirmed by the historical and instrumental earthquake data collected for the present study. In the present study, deterministic seismic hazard assessment (DSHA) and probabilistic seismic hazard assessment (PSHA) for Koragh-Paraith Hydropower project is performed. In DSHA, maximum moment magnitude (Mw) and peak ground acceleration (PGA) values for several tectonic features (MKT, Reshun Fault, Trich Mir Fault and Hindukush Seismic Zone) affecting the project site are evaluated. The MKT and Reshun Fault are thrust faults while Trich Mir Fault is sinistral in nature. For tectonic features of the study area i.e., MKT, Reshun Fault, Trich Mir Fault and Hindukush seismic zone, the Mw is evaluated as 7.6, 7.5, 7.5 and 8.0 respectively by using the attenuation equation of Wells & Copersmith (1994). Similarly, the PGA values for these tectonic features are evaluated as 0.28g, 0.58g, 0.49g and 0.19g respectively. Moreover, in the procedure of PSHA, the seismic design parameters in accordance with the International Committee of Large Dams (ICOLD) guidelines are evaluated. For PSHA, the selected seismic source zones are Hindukush, Pamir, Kohistan and Himalayas. The PGA for Operating Based Earthquake (OBE), Design Based Earthquake (DBE), Safety Evaluation Earthquake (SEE) and Maximum Credible Earthquake (MCE) are determined as 0.20g, 0.29g, 0.33g and 0.60g to be used for the seismic resistant design of dam and its appurtenant structures.

Two-stage collision between Indian and Afghan plates: Evidences from geochemical signatures

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Trace elements and REEs concentration in the mafic ultramafic rocks of the dismembered units of the Waziristan ophiolites (Pakistan) were determined by ICPMS for petrogenetic implications. The lower NB/La ratio (<0.85), negative Nb and Ti anomalies, flat pattern of HFS-elements (Zr, Y) in the NMORB normalized spider diagram, enrichment of LIL-elements (Rb, Ba, Th, Sr) and depletion in Nb (<0.8 ppm) suggest addition of subduction component to the depleted mantle source for gabbroic and basaltic magmas. Tectonic discrimination diagrams i.e. Th/Y–Ta/Y diagram, Ti/Yb–Nb/Yb diagram, Ti/100–Zr–3*Y and Ti/100–Zr–Sr/2 diagrams show transitional character of gabbroic and basaltic rocks between Island Arc Tholeiite (IAT) and depleted mantle Island Arc basalt (NMORB) which is possible in low–pressure extensional environment directly above a subduction or a supra subduction zone. The ophiolite package structurally lying above the syn orogenic and forearc basin (trench–accretionary system) imply that emplacement initiation predates thrusting of the Late Cretaceous accretionary deposits on Indian Plate in Paleocene. These data show that the India–Afghan suturing completed in two tectonic events; i: Late Cretaceous ophiolite obduction and ii: Paleocene final closure (collision). The dataset further indicates that the mixed ophiolite and accretionary system originated in a subduction–accretion setting during two stage collision of the Indian-Afghan plates.

An Unfortunate Rock Slope Failure at Torkham Border Facilities: Some Overlooked Facts, Stability Evaluation, and Remediation

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On April 18, 2023, a massive rockslide occurred, burying a long queue of containers awaiting clearance at the Pakistan-Afghan border crossing. The rockslide resulted in the displacement of over 40,000 cubic meters of debris, burying 28 containers and tragically claiming the lives of 13 individuals. Additionally, the newly constructed road and bridge infrastructure sustained damage. This incident unfolded along a recently established road segment, spanning approximately 140 meters with a maximum elevation of 70 meters. The event prompted concerns regarding the stability of adjacent rock slopes sharing similar geological characteristics. Consequently, a comprehensive site investigation was conducted in July 2023 to assess the condition of the neighboring rock slopes and ascertain the underlying causes of the failure, which could pose risks to adjacent areas. The investigation encompassed engineering geological mapping, discontinuity surveys, geotechnical explorations, and laboratory testing to determine reliable parameters for subsequent stability assessments. Kinematic analysis revealed a predominant plane failure mode in the rock slope instability, attributable to unfavorable joint orientations concerning the cut slope. Specifically, the limestone beds exhibited a steep dip towards the slope face, juxtaposed with a near-vertical cut at the toe, predisposing the slope to substantial plane failures, particularly during periods of heavy rainfall. The failed slope served as crucial evidence informing subsequent analyses. Back-analysis of the failed slope was undertaken to validate and extrapolate parameters for the forward assessment of adjacent slopes. Subsequent limit-equilibrium analyses were performed under both flooded and seismic loading scenarios, revealing marginal Factor of Safety (FOS) values

insufficient to ensure long-term slope stability. Consequently, measures such as rock reinforcement and construction of retaining walls were incorporated into the analyses, resulting in satisfactory FOS values. Based on the analysis outcomes, recommendations were made for stabilization measures, including the installation of 6-8-meter-long rock bolts at 3-meter intervals, equipped with weep holes, alongside the construction of rubble concrete retaining walls. These stabilization measures are presently undergoing implementation to mitigate risks associated with slope instability.

A Review of Landslide Hazard Mapping and Development of Rockfall Hazard Rating System along CPEC Route in Northern Pakistan

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The Karakorum Highway (KKH) serves as a vital transportation link between China and Pakistan, traversing some of the world's most challenging terrain, characterized by complex geological forces including crustal closure, forcing compression, tectonic uplift, and fragile geological settings. Consequently, this region is prone to significant rock avalanches, deep-seated bedrock slides, and rockfall activities, posing potentially destructive consequences. Thus, conducting comprehensive studies on landslide hazard mapping and slope failure assessment is crucial for effective hazard mitigation. Initial efforts aimed at developing a comprehensive indigenous rockfall hazard and rating system along the KKH. Regional-level hazard maps, incorporating landslide inventories and susceptibility assessments, were prepared as a foundational step towards this endeavor. Utilizing anomalous topographic protocols and hillshade maps, the hazard mapping exercise effectively delineated various types of landslide-related features, including landslide complexes, translational bedrock slides, retrogressive slumps, and rock avalanches. These regional-level hazard maps laid the groundwork for the development of an indigenous rockfall hazard rating system covering a 285 km section from Thakot to Raikot bridge. The area was subdivided into 129 smaller sections based on local geological settings and rockfall potential. Field visits facilitated the measurement and estimation of various parameters to refine the Pierson (2005) model and develop a Rockfall Hazards Rating System tailored to the region's conditions. This modified version incorporated a novel parameter and upgrades from the Pierson model, as well as additional parameters from other rockfall hazard rating systems, reflecting local site conditions. The developed hazard maps demonstrated compliance with local site conditions and were deemed satisfactory for the selected areas. Additionally, a separate prediction

model was formulated for high-hazard sites in the Tatta Pani area, leveraging extensive laboratory testing and field validation exercises to predict rainfall-triggered rockfall. High-risk road sections were identified to prepare local risk maps and design safety barriers against rockfall hazards. This comprehensive study represents the initial step towards establishing an indigenous rockfall hazard rating system. Its aim is to assist local authorities in implementing cost-effective and sustainable mitigation measures for vulnerable rockfall hazard zones, while also formulating guidelines for an early warning system to mitigate associated risks.

Petrographic and Engineering Assessment of Coarse Aggregates from Thurly, Thore, and Khanbri Gravel Deposits along the Indus River: Implications for Concrete Applications

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This study investigates the alkali silica reaction (ASR) and alkali silicate reaction (AStR) potential of coarse aggregates sourced from Thurly, Thore, and Khanbri Gravel Deposits along the Indus River Terraces and Bed. Fifteen samples from each location were subjected to detailed examination of their engineering properties and chemical composition, in accordance with ASTM/BS/AASHTO standards for suitability in cement concrete. Petrographic analyses revealed promising physical and chemical properties consistent with international standards. However, Quick Mortar Bar Tests, as per ASTM C1260-01, produced conflicting results regarding ASR/AStR potential. While petrographic assessments and in-service behavior suggested potential reaction risks, the standard test indicated otherwise. Our findings challenge the adequacy of relying solely on ASTM C1260-94 for ASR/AStR assessment. Global studies echo this concern, highlighting limitations in strained quartz-bearing rocks and mylonites. Even materials like reconstituted microcrystalline acid to intermediate volcanics, and low-grade meta-argillites, and meta greywackes can yield misleading results. In conclusion, this research highlights the need for a comprehensive approach to ASR/AStR evaluation, considering both standard tests and petrographic insights to ensure accurate assessment of aggregate suitability for concrete applications.

Evaluating Tunnel Stability in Challenging Terrains: A Comprehensive Study of Geological Factors and Support Systems -The Lowari Tunnel Case

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Tunnel construction success hinges on navigating geological hazards, excavation techniques, and robust support systems. This study explores the intricate dynamics of these elements, emphasizing the need for sustainable tunnel infrastructure. Geological factors, including overburden depth, rock characteristics, and groundwater presence, significantly impact tunnel construction. Notable incidents, such as the Hanekleiv tunnel collapse, underscore the importance of precise tunnel face mapping in mitigating risks. Tunneling techniques selection depends on encountered strata, and controlled blasting is crucial for stress concentration prevention. Support systems, categorized into primary and secondary, play a pivotal role in ensuring stability. The Required Excavation Support Sheet (RESS) guides support installation after each blast. Focusing on the Lowari Tunnel in the Himalayan terrain, the New Austrian Tunneling Method (NATM) was employed. Extensive tunnel face mapping involved post-blasting assessments, identifying rock mass characteristics, and predicting deformations. Geological features, including color, texture, and luster, guided rock type identification. Excavation classes and support sheets were determined based on this mapping. Monitoring stations, strategically placed at 30 m intervals, employed 3D coordinate systems for precise measurements. The Lowari Tunnel, spanning 8.509 km, traverses diverse rock types with varying weathering conditions. Geological mapping identified rock mass behavior types, aiding in categorizing deformations. Incidents, such as cracking sounds and rock spalling, emphasized the impact of geological factors. Monitoring stations revealed inside (-) deformations dominating, validating NATM's efficacy. Geological

incidents at specific changes highlighted the need for strategic support. Shotcrete, rock bolts, wire mesh, and lattice girders constituted primary support. Shotcrete adhered to guidelines, with high strength attributed to admixtures. Rock bolts underwent pre- and post-installation testing, meeting specifications. Wire mesh and lattice girders passed quality tests, ensuring compliance with standards. The findings contribute to best practices, applicable across diverse terrains, prompting further research on support system performance and economic implications.

Stabilization of Expansive Soil: A Review

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Expansive soil, characterized by its high swell-shrink potential due to the presence of Montmorillonite mineral, poses significant challenges to infrastructure stability. Fluctuations in water content led to reductions in shear strength and volume change, resulting in various types of failures in infrastructure. This review paper provides an overview of different stabilization methods aimed at mitigating the detrimental impacts of expansive soil. Recent advances in stabilization techniques, including chemical and mechanical methods, as well as the innovative utilization of industrial wastes, are discussed in detail. Furthermore, the review emphasizes the sustainability aspects of various stabilization methods and offers insights into future research directions. The practical implications of these techniques for infrastructure development in expansive soil regions are also highlighted, underscoring the importance of effective soil stabilization in ensuring long-term infrastructure stability and sustainability.

To Study the Preparation, Properties and Uses of Light Weight Foamed Soils

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The construction industry seeks a versatile material for utilizing dredged soil effectively on-site. Lightweight foamed soil (LWFS) emerges as a promising solution, offering flexibility in strength, density, and thermal insulation at a cost- effective rate. LWFS comprises readily available ingredients such as raw soil, water, foam, and binder, making it a sustainable alternative to traditional building materials. This innovative soft soil treatment method, also known as Super Geo Material, presents numerous advantages over conventional options. LWFS demonstrates environmental friendliness and finds applications in various construction tasks, including road filling, retaining structures, and ground improvement. This paper provides an overview of LWFS, detailing its properties, applications, and preparation methods. By exploring the potential of lightweight foamed soil, this study aims to contribute to the advancement of sustainable construction practices and address the growing need for versatile materials in the construction industry.

Assessment of Construction Material Potential in the Vicinity of Nowshera Suburb, Pakistan

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The construction industry contributes over 10% to the country's GDP, and the assessment of geological materials for their suitability in construction is an emerging discipline within engineering geology. Rocks, regolith, and soil play crucial roles in various construction phases, serving as both dimension stone and processed aggregates. The study area lies within the Peshawar inter-montane basin of the Attock-Cherat Ranges, bounded to the south by the Khyber-Hazara fold and thrust belt and the Main Mantle Thrust fault to the north. The region comprises Precambrian to Quaternary sedimentary and meta-sedimentary rock units, along with fluvial deposits extensively exposed across different locations. The study focused on evaluating the potential of various rock formations as building and construction materials. Specifically, limestone from the Shahkot-Uch Khattak formation, quartzite from Misri Banda, and dolomitized/marmorized limestone from the Nowshera/PirSabak formation near the Nowshera suburb were examined. Petrographically, the mineral composition varied, with calcite constituting less than 90%, quartz less than 92%, and dolomite less than 5%, alongside traces of feldspar, mica, and ore minerals in different rock specimens. Chemically, limestone comprised over 90% $CaCO_3$, while quartzite exhibited a SiO_2 concentration of 79%. In terms of physical properties, the studied specimens demonstrated extremely strong to very strong unconfined compressive strength, very tough aggregate impact value, sulfate soundness loss of less than 6%, and water absorption below 0.36%. Based on their petrographic, chemical, and physical characteristics, the studied rock units generally conform to relevant international standards for building and construction materials. However, further investigation is required for quartzite to assess its susceptibility to alkali silica reactivity.

Gravelly soil liquefaction potential assessment on updated case history dataset using machine learning classifier

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Seismic soil liquefaction is a complex phenomenon that causes destructions to the environment, structures, and human life. Various studies have explored different approaches and procedures to construct predictive models for liquefaction in sandy soil over the years but have disregarded the possibility that gravelly soils could liquefy. However, the literature on seismic soil liquefaction in gravelly soils is still limited. Furthermore, the accuracy of predictive models is not well understood, and they are far from adequately addressing the problem of gravelly soil liquefaction. Consequently, predicting seismic soil liquefaction remains a significant challenge, and research on this area is ongoing. The aim of this research is to utilize machine learning techniques and a reliable database (comprising 234 case histories based on shear wave velocity tests from 17 earthquake-induced gravelly soil liquefaction events) to construct prediction models. These models will employ decision tree algorithms, including Random Tree, Logistic Model Tree, Random Forest, and Reduced Error Pruning Tree, to assess the potential for liquefaction in gravelly soils.

Stability & Risk Assessment Analysis for Deep Excavations – A review paper

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The rapid increase in underground construction has made deep excavation a necessity, presenting numerous challenges in terms of stability and associated risks. This study discusses these challenges based on the latest research findings. Finite Element Analysis is utilized to calculate safety factors for stability checks, while examining the relationship between excavation conditions and soil behavior, proposing a rigid block rotational failure mechanism. Another method explored is the Pipe Curtain method, which evaluates excavation stability under varying reinforcement types. A fitting accuracy of over 0.9 indicates improved stability in excavations. Soil arching techniques are employed in strutted excavations to optimize stability. Risk assessment and management are crucial aspects of deep excavations, considering the inherent dangers to human lives during construction. Dynamic risk assessment is emphasized, involving a model that selects risk factors to identify and mitigate instability throughout the project lifecycle. This methodological approach serves as a vital tool for ensuring the protection and control of instability-related disasters in deep excavation projects.

Geotechnical Evaluation and Sustainable Resource Management in Construction Projects Along Gabral River, Swat District

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The assessment of geotechnical properties and alkali-aggregate reactivity (AAR) in rock outcrops and borrow areas is vital for construction projects, ensuring material suitability and long-term durability. This study focuses on evaluating the petrographic examination and physico-mechanical properties of materials along the Gabral River in the Swat District, Pakistan, to determine AAR susceptibility. Various composite rocks, including diorites, granites, pyroxene granulites, garnet granulites, quartzites, slates, and green stones, were analyzed from borrow areas along the Gabral River. Through field and laboratory tests, their suitability for construction purposes was assessed. For coarse aggregates, two borrow areas, two quarry sites, and eight rock outcrops were identified. Similarly, two borrow areas were identified for fine aggregates. Petrographic analysis revealed a significant amount of deleterious content in the construction materials currently sourced for Kalam's construction activities, necessitating the use of slag cement for concrete production. However, important physico-mechanical parameters fell within permissible ranges according to international standards. The abundant alluvium present in the Gabral River, comprising sandy gravel with cobbles and boulders, was found suitable for use as coarse aggregates after appropriate processing. Sustainable management of industrial materials sourced from the river and its tributaries is essential to mitigate environmental and community impacts. This research contributes valuable insights into material selection and environmental sustainability in construction projects, highlighting the importance of thorough evaluation and responsible resource management.

Comprehensive analysis of mechanics of granitoids from the North- Western Himalayas, Pakistan

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This study explores the mechanical behavior of eight texturally diverse granitoids, including granites, granodiorites, and syenites, from the northwestern Himalayas, Pakistan, under diverse conditions. Mechanical tests, including rock triaxial test (RTT), rock direct shear (RDS), uniaxial compressive strength (UCS), and ultimate tensile strength (UTS), were conducted to examine the response of these rocks to various loading conditions and environmental factors. These tests aim to assess the behavior of the granitoids under different stress regimes and determine their mechanical properties under tension, compression, and shear. Observations from RTT reveal a notable correlation between confining pressure and rock strength. Applying confining pressures ranging from 2 to 10 MPa showcases a consistent trend, i.e., an increase in confining pressure corresponding to elevated rock strength. This trend is attributed to the closure of micro-cracks and enhanced interlocking of mineral grains under higher confining pressures, bolstering rock cohesion and resistance to deformation. In the case of RDS, fresh granitoids exhibit higher maximal and residual shear strengths, and a higher angle of internal friction, compared to highly weathered rocks due to intact mineral grains and fewer micro-fractures. Conversely, highly weathered granitoids show lower shear strength and angle of friction due to mineral degradation and increased micro- fractures. Additionally, fresh granitoids display a higher apparent cohesion, attributed to stronger mineral bonds and better particle interlocking. Moreover, the influence factors such as mineralogy, thickness, and surface roughness are found to have a significant effect on the shear strength of the studied granitoids. The UCS and UTS tests highlight the multifaceted impact of various factors on the strength properties of granitic rocks. Parameters such as grain size, texture, mineralogy, degree of weathering, and overall brittleness significantly shape the observed strength characteristics during testing. Fine-grained

granitoids, especially those with a higher quartz content, exhibit greater compressive and tensile strength compared to coarser-grained or highly-weathered granitoid. Additionally, fresher granitoid, characterized by lower degrees of weathering and brittleness, demonstrate enhanced mechanical properties in both compression and tension tests. The overall findings suggest a direct correlation between granitoid texture, mineral composition, and mechanical strength, emphasizing the significance of these factors in assessing rock behavior under load. This study provides crucial insights into the mechanical behavior of diverse granitoids, informing engineers and geologists in rock mechanics and geological projects.

Assessment of Slope Stability and Risk Mitigation Strategies for the Lohar Gali Landslide, Azad Jammu and Kashmir

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The Lohar Gali landslide poses a significant threat to the local community and travellers by blocking the main route to Muzaffarabad, the capital of Azad Jammu and Kashmir. Situated in a seismically and tectonically active region, the area exhibits several instances of landslides. This study focused on analyzing five topographic factors slope degree, aspect, contours, curvature, and elevation derived from a high-resolution DEM using ArcGIS 10.7. The findings revealed varying slope degrees from 0.1 to 60 degrees, with the steepest slopes exceeding 55° in the depletion zone. Additionally, the majority of the landslide faces southeast, followed by east. Utilizing these topographic factors and geotechnical investigations, slope stability analyses were conducted using the FLAC Slope and Slope/W module of GeoStudio software. The Factor of Safety (FOS) determined through Finite Difference, Ordinary, Bishop, Janbu, Spencer, and Morgenstern- Price methods ranged from 1.010 to 1.075, indicating that the slope is at risk of failure, with minor changes in intrinsic or extrinsic factors potentially leading to catastrophic events. Both methods predicted a planar failure surface. Further, a parametric study was conducted by varying slope angles, internal frictional angles, and phreatic levels to understand their impact on FOS. Observations revealed that increasing slope angles decreased FOS, resulting in slope instability, whereas higher internal frictional angles enhanced FOS and slope stability. Moreover, elevating water levels decreased FOS, exacerbating slope instability. These findings underscore the critical need for proactive measures to mitigate the risks associated with the Lohar Gali landslide and ensure the safety of the surrounding communities and travelers.

Evaluating the importance of the Geological strength index and susceptible zones in the mechanisms that trigger landslides in the Chukhayan-Kumrat Road area of Dir Upper, Pakistan.

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This study conducts a complete analysis of landslide vulnerability along the 83.5- kilometer Chukyatan-Kumrat Upper Dir road in North Pakistan. Despite its vital importance in transportation and tourism, the region is plagued by recurring landslides caused by hydro-meteorological hazards, creating serious stability risks. This study uses a multidisciplinary approach to merge the Landslide Susceptibility Index (LSI) analysis with the Geological Strength Index (GSI) obtained from joint investigation of bed rock in order to better understand the intricate connections that underlie landslide occurrences. The research region consists of a variety of rock formations covered in residual soils, such as ignimbrites, volcanic ash, granodiorites, andesites, meta-rhyolites, spotted slates, and metavolcanics. Using the Landslide Susceptibility Index (LSI) map created using the frequency ratio technique, locations near road cuttings, fault lines, and mineralogically changed and sheared lithology are indicated as highly vulnerable to future sliding occurrences. The Geological Strength Index (GSI) and Rock Mass Rating (RMR) assessments divide jointed bed rocks into generally stable (zones 1 and 2; GSI 67-58, RMR classes II and III) and sheared and changed (zones 3 and 4; GSI 38-16, RMR class IV) segments, highlighting their respective susceptibilities. These zones have a slicken sided jointed structure that is mildly to heavily worn, which allows snow and precipitation to seep in. In addition to the impacts of precipitation and freeze-thaw cycles on the pores and joints of bedrock, the alteration process of minerals such alkali feldspar, biotite, chlorite, and hornblende further weakens the rocks and acts as a major trigger for future landslides. Overall, this research offers useful insights for landslide susceptibility mapping in comparable geological contexts and helps the Chukyatan-Kumrat area build efficient mitigation and preparedness methods.

Geotechnical Evaluation of Sand from Khar River for Fine Aggregate Application: A Case Study in Gadap Town, Karachi

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This study aims to assess the suitability of sand sourced from the Khar River, situated within the vicinity of Kirthar National Park, Gadap Town, for use as fine aggregate in construction applications. Eight random samples were collected from various locations along the Khar River. A number of physical and mechanical tests, including fineness modulus (FM), specific gravity, water absorption, bulk density, soundness, and petrographic examination, were conducted on the collected samples. The results indicate that the average fineness modulus (FM) of the sand is 3.6, with a specific gravity of 2.5 and water absorption rate of 0.5%. The bulk density of the sand was measured at 1659.95 kg/m^3. Petrographic examination revealed an off-white color and calcareous nature, with visible fossils present within the sand. Overall, the findings suggest that the sand from the Khar River is coarse in texture and may be suitable for use as a fine aggregate, particularly when blended with finer sand materials. This study contributes valuable insights into the geotechnical properties of the Khar River sand, informing decisions regarding its potential utilization in construction projects.

Evaluating Geothermal Energy Potential in Tattapani Springs, Azad Jammu and Kashmir, Pakistan: Integrated Geophysical and Geochemical Analysis Amid Environmental and Resource Challenges

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The Tattapani Thermal Spring in Azad Kashmir's NW-Himalaya region boasts a steady surface temperature of 60°C, attracting attention for its potential in geothermal energy. This integrated study combines geology, geophysics, and geochemistry to unravel its subsurface dynamics and assess its suitability for power generation. A thorough resistivity survey revealed four lithological units based on resistivity contrasts. High resistivity (>300 ohm-meters) indicated weathered dolomite/limestone, while low to moderate resistivity (80-200 ohm- meters) suggested clay and sandstone layers, possibly holding meteoric water. A low resistivity zone (20-80 ohm-meters) hinted at moderate hydrothermal alteration, and a very low resistivity zone (5-20 ohm-meters) pinpointed the geothermal spring. Thermal plumes (10-70 ohm-meters) detected at depths of 30-60 m indicated hot plume migration north-eastward, affecting fresher water (100-200 ohm-meters). Longitudinal conductance (0.95-15 mhos) and transverse resistance (20-300 ohm-m^2) peaked in the northeastern and northwestern regions. Fresh groundwater, mainly in sandstone (150-200 ohm-meters) and dolomite (≥400 ohm-meters), lay above the thermal plumes, vulnerable to contamination. Magnetic and gravity surveys revealed the spring's depth range of 30m to 60m, linked to deep-seated thermal convection cells tied to the Tattapani fault and Riasi thrust at greater depths. Recharge sources included surface runoff and the perennial Poonch River, with the heat source originating from Precambrian shield rocks sourced from the mantle. The spring emerges along a fault zone, bridging Cambrian

Abbottabad and Paleocene Patala Formations, serving as a conduit for thermal convection. This fault zone may interconnect with the Riasi thrust at deeper levels, suggesting a link to the mantle heat source. Vapor from the spring condenses upon mixing with groundwater at depths of 20-40 m, causing a temperature drop. Given the promising geothermal potential at deeper levels, the study advocates pilot drilling to 500 m for thermal assessments and geotechnical studies. This exploration, paired with gravity-based basin analysis, promises insights into Tattapani's thermal dynamics, paving the way for sustainable geothermal energy initiatives.

Landslide Mechanism Triggers Dir Upper, Khyber Pakhtunkhwa Pakistan: The Impact of Geochemistry and Geotechnical Properties

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The 83.5 kmr Chukyatan-Kumrat Upper Dir road is vulnerable to regular landslides caused by hydrometeorological risks, especially after the heavy rains and flooding in 2010. The landslide zones are composed of meta-volcanics, basaltic andesites, meta rhyolites, ignimbrites, volcanic ash, granodiorites, and spotted slates covered in residual soils. This study examines the geological features, geotechnical characteristics, and rock weathering of these regions. The study shows that large amounts of loose, weathered rock debris have accumulated due to the presence of the nearby Dir fault, and the exposed slopes exhibit polygonal stress fractures, joints, and fissures with steep inclinations exceeding 40° and heights exceeding 100 m. The slope material has a relatively low internal friction angle (28.520°–31.930°) and cohesiveness (4.154-5.95 kPa), while the bedrock's unconfined compressive strength (UCS) ranges from 10.75–41.51 MPa, indicating a weak to moderate-strong rock classification. The pH of the soil ranges between 3.1 and 4.2, and the presence of clay minerals suggests that the weathering conditions there encourage landslides. The hydrothermal alteration during low-grade metamorphism of the meta-volcanic rocks in the region has led to the creation of chlorite, smectite, monmorillonite, and zeolites as a result of chemical weathering, according to thin section and X-ray diffraction analysis. In addition, the content of quartz has increased due to physical deterioration. The study comes to the conclusion that a number of landslide incidents in the Chukyatan-Kumrat area are caused by the slope geometry, low shear strength of slope materials with strain-softening properties, and environmental factors like rainfall, snow melting, freeze-thaw activity, and slope base cutting for road development. Massive loading in the form of houses also plays a role in these events. The study's conclusions could useful in creating preparedness and mitigation plans that are suitable for slope protection in the study region and its environs.

Structural Geology and petrography of the Karora Hydropower Tunnel

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The 2580 m long Karora Hydropower Tunnel (KHP), is located about 20 km S of the Indus suture zone (ISZ) or Main Mantle Thrust between the Kohistan island arc and Indian plate. The tunnel passes through the Early Proterozoic Besham group of basement metasediments and heterogeneous gneisses, and deformed and undeformed granites and pegmatites, of which the deformed varieties are intruded by mafic dykes metamorphosed to amphibolites. Some 1230 m length of the tunnel exposes granitic gneisses, 550 m graphitic schists, 290 m amphibolites, 120 m dioritic rocks, 145 m hornblende leucogranite and simple pegmatites, and 135 m highly sheared rocks; the remaining ca. 100 m is occupied by pyroxenites, hornblendites, metagabbroids and chromitite. The pyroxenites and hornblendites are coarse-grained. The pyroxenites consist essentially of diopside (80-90 vol%), with small amounts of orthopyroxene, olivine, serpentine, chlorite and opaque grains. Hornblendites are monomineralic (90-96% Hbl), with small amounts of pyroxene, epidote, chlorite and magnetite. Samples of the chromitite are made up of chrome spinel (70-80%), olivine (>15%), small amounts of serpentine, magnesite, chlorite, and taces of pyroxene. The studied ultramafic rocks in the tunnel show remarkable petrographic similarity with the ultramafic rocks forming the lower part of the Jijal complex in the hanging wall of the ISZ, the gabbronorites are similar to the gabbronorite relics in the garnet granulites of the Jijal complex, whereas the dioritic and orthopyroxene-free gabbro-diorites resemble those of the amphibolite belt just north of Patan. Since such mafic- ultramafic rocks have not been reported from the Besham group, therefore, these rocks have probably been derived from the southern Kohistan arc. They may represent remnants of a possible nappe which may have extended at least 20 km south of the ISZ and presently enclosed in the Besham group as a sandwich.

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Estimation of rock mechanics from the intrinsic characteristics: A time- and cost-effective approach

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The intrinsic properties of rocks including size, shape and mutual arrangement of mineral grains, are effectively used in deciphering the geological events and deformational history of rocks. A series of experimentation has been executed on multiple rocks suites from the large- and small- scale construction projects in northern Pakistan, to use these intrinsic properties in addressing the mechanical nature of rock. The primary rock suites considered for this study include granite, granodiorite, dolerites, limestones, quartzites, gabbronorite, amphibolite and granulites. These rocks are investigated due to their stability in variety of conditions as well as their wide range of applications in multiple engineering operations. Detailed hand specimen and petrographic examination of these rocks provide ample understanding on their respective textural distinctions. Petrographic examination after the mechanical testing of rocks have also been conducted for some rock types to investigate the propagation of novel stress-induced fracturing and their interaction with mineral grain boundaries. The statistical comparison is made between the mechanical nature and textural relations of rocks which yields important insights. The grain size and shape, grain boundaries relations, variation in grain size within a rock, alignment and recrystallization of mineral grains are important characteristics to be controlling the mechanical nature of rocks. All the mentioned features collectively contribute to govern the mechanical response of rocks.

Climate change causes water resources scarcity or mismanagement in Pakistan

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The present study provides an assessment of future water availability over the Upper Indus Basin (UIB) Pakistan, discussing the influencing factors of hydrology such as Monsoon & Winter Rainfall Changes and shift, Hydrological Cycle Changes, Temperature Changes and Glacier melting. All these factors are also affected by the teleconnection of oceanic phenomena like La Niña and Indian Ocean Dipole (IOD) etc. In Pakistan, mountain climates are changing, triggering changes in the headwater hydrology of the Indus River, necessitating research on the impacts of climate change on current and future water availability in the UIB. These factors are becoming increasingly important in the north of Pakistan in the future due to elevation dependent warming (the north warming faster than the south). The hydrological projections over UIB show likely increase the water availability in the future. However, changes in future flows show temporal variability. The results of the studies discussed in the study show that in summer, Pakistan will not face water scarcity in the future under the 21st century warming and Paris Agreement targets, given the efficient and timely management strategies in place of water storage in summer and use in winter. Hence, if not managed properly, such high flows at unexpected time of the year could pose a serious threat of flooding in downstream communities. Keeping this in view, the study provides good scientific evidence for policy makers to devise efficient policies to mitigate the threat of flooding/water scarcity and to ensure sustainable water management in the country.

Phytoremediation potential of *Centella asiatica* for heavy metals removal from wastewater

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Wastewater is generally generated from different sectors including industries, residential areas, hospital and educational institutes. Wastewater used for irrigation purposes, causes health risks and contaminates the food chain. Like other sector, higher education institutes, including Hazara University generated waste water. It is important to treat wastewater prior to release in the nearby water bodies. This study was conducted to assess the potential of *Centella asiatica* for the treatment of wastewater. For this purpose, wastewater was collected from the outlet of Hazara University, Mansehra, plants were grown for one month. After exposure, plants samples and treated wastewater was collected and analysed for physicochemical parameters including heavy metals. Results showed that the concentration of total suspended solids (TSS), total solids (TS) and total dissolved solid (TDS) were reduced by 88%, 34%, and 35%, respectively in post-harvest water. Moreover, *Centella Asiatica* was able to remove 96% of the lead (Pb), 91% chromium (Cr), 90% Arsenic (As), 21% Cadmium (Cd), and 99% Iron (Fe) from wastewater. The concentration of heavy metals in roots/shoots of *Centella asiatica* followed the sequence: Cr>Pb>Fe>CD>As. The lower accumulation of heavy metals in roots/shoots is due to the presence of lower concentration of heavy metals in wastewater. The translocation factor (TF) for Cd, Pb, As and Cr was > 1 and BCF for Cr was > 1. From the present study it is clear that *Centella asiatica* has potential for the treatment of wastewater.

Potential of mineral waste from mines in Pakistan for carbon dioxide capture: considering the case of Baluchistan

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In the 21st century, environmental pollution has become a serious threat to biodiversity, human health, and the ecosystem. Particularly, anthropogenic activities significantly contribute to the release of CO_2 into the Earth's atmosphere, making atmospheric pollution due to CO_2 one of the grave concerns faced by humanity worldwide. Various sources trigger this, including the combustion of fossil fuels for electricity generation, transportation, industry, and other activities, releasing approximately 50 billion metric tons of global warming gases (GWG) annually. Additionally, mines (mineral exploration) are major contributors, both directly and indirectly. For example, BHP, an Australian multinational mining company, alone emitted over 3.4 Mt of GHG from iron and nickel mining sites in 2020. Moreover, mineral waste, often considered of less economic importance, accounts for approximately 2-6 Giga tons worldwide. Interestingly, it has significant potential for capturing CO_2 and sequestering it. Calcium, magnesium, and silicate rocks, in particular, are candidate materials for this purpose, which could have monumental environmental and economic benefits for the country. With particular reference to Pakistan, the Baluchistan province boasts plenty of mineral treasures that have stimulated the development of the mining industry, producing 1 Mt of mineral waste annually. This study employs several state-of-the-art techniques, including FTIR micro-spectroscopy with a powerful synchrotron source (IR beamline), to understand the CO_2 fixation process occurring in nature and to estimate the potential of natural minerals as CO_2 capturing and sequestration agents. Detailed X-ray fluorescence spectroscopy (XRF) was also carried out on numerous mineral waste samples collected from the Muslim Bagh District of Baluchistan, Pakistan. The analysis results of selected rocks and mineral wastes from the mines of Baluchistan showed promising trends in terms of CO_2 capture.

Contribution of Biotite weathering for arsenic pollution in the southern Indus Plain aquifers, Pakistan.

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Toxic levels of arsenic in groundwater pose a serious and widespread threat to human health and the environment, with approximately 150 million people worldwide being exposed to arsenic toxicity. In the southern Indus Plain, aquifers are naturally populated by arsenic, which is found in recent/sub-recent sediments primarily derived from the Himalayas and adjacent rocks during the Holocene period. Previous studies have indicated that the reductive dissolution of arsenic-bearing iron oxyhydroxides, facilitated by the microbiodegradation of organic matter, is a dominant mechanism for arsenic release. However, the source of arsenic in sediments remains poorly understood. The present study investigates the contribution of biotite leaching to the release of arsenic into groundwater. These investigations aim to improve our understanding of arsenic pollution in the Indus Alluvial Plain, with implications for developing effective mitigation strategies to ensure access to safe drinking water for the local population. Eight aquifer sand samples from the Matiari district of Sindh were collected for petrographic, scanning electron microscopy (SEM), and geochemical analysis. Petrographic and SEM studies revealed appreciable quantities of arsenic-bearing biotite in these sediments, along with its weathering products, including iron-rich chlorite and phlogopite. A Frantz Isodynamic Magnetic Separator was employed at different strengths to separate the magnetic and non-magnetic fractions in the aquifer sand samples (n=8). These fractions (n=19) were subsequently analyzed for trace elements, including arsenic, vanadium, chromium, nickel, copper, selenium, molybdenum, cadmium, lead, and uranium, using inductively coupled plasma mass spectrometry (ICP-MS) and atomic absorption spectroscopy (AAS). The results showed that arsenic concentrations in magnetic minerals

ranged from 8.6 to 51.7 µg/Kg, while arsenic concentrations in non-magnetic minerals ranged from 1.1 to 24.2 µg/Kg. The data indicated that high concentrations of arsenic are associated with the magnetic fraction found in the sediments. Arsenic is primarily derived from the FeOOH coating on the surface of magnetic minerals, and the dissolution of these coatings in a reducing environment result in the release of arsenic into groundwater.

Effect of pine needle leachate (*Pinus roxburghii*) on bedrock weathering and its role in soil development

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Pine needles, which are the fallen leaves of Chir pine (*Pinus roxburghii*), show slow decomposition due to their lignocellulosic complexities, because of which they are widely accumulated on the forest floor as biomass. The interaction of biomass and water can change the chemistry of water through leaching, which can then percolate through soil and rock and affect both soil and bedrock. The study aims to analyze the effect of pine needle leachate on sandstone bedrock weathering and its effect on soil development. Microscopic analysis, such as petrography and scanning electron microscopy, was used for the mineralogical identification of bedrock. Different samples of Pine needle leachate were prepared in the laboratory under controlled conditions. Electrochemical parameters of leachate, such as pH, Electrical conductivity and salinity were measured. The elemental analysis of leachate was performed using atomic absorption spectroscopy (AAS). After seven days of leaching, colonization by decomposer fungi was observed and identified as *Aspergillus sp.* and *Penicillium chrysogenum*. Sandstone (Bedrock) of Kamlial Formation comprises quartz, plagioclase, orthoclase, muscovite and biotite. Pine needles have made the leachate more acidic, with a pH ranging from 4 to 6, and increased the electrical conductivity and salinity within the fourteen days of the experiment. Leachate has shown the liberation of cations from the sandstone and Pine needles such as k, Na, Ca, Mg, Mn, Zn and Cu. Results show that under controlled conditions, pine needle leachate shows high amount of release of cations as compared to pine needle litter on the forest floor. These cations once accumulated in soils can serve as sources of nutrients and can play pivotal role in the productivity of the soils.

Assessment of Ground Water Quality Index for Agriculture and domestic purpose of Taluka Sehwan, District Jamshoro

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Groundwater has become an important source of freshwater around the world, used for a variety of reasons such as home usage, agricultural irrigation, and industrial applications. The study was conducted in Taluka Sehwan, Sindh, Pakistan. Groundwater quality has decreased due to surface water intrusion from Manchar Lake into nearby groundwater. Manchar Lake poses a serious environmental risk due to regular direct influxes of contaminants. Most communities rely on groundwater for both drinking and agricultural needs. The study's purpose is to investigate groundwater quality for residential and agricultural use. Thirty samples were collected from the study area, and sixteen parameters were analyzed in the lab, including pH, electrical conductivity (EC), total dissolved salts (TDS), total hardness (TH), chloride (Cl), magnesium (Mg), calcium (Ca), potassium (K), and sodium (Na). The water quality index (WQI) and irrigation indices such as SAR, SSP, MH, and PI were calculated. The calculated values were zoned in the Geographic Information System (GIS) environment by the Kriging analysis method. The water quality index (WQI) has been applied to categorize the water quality, viz., excellent, good, poor, etc., which is quite useful to infer the quality of water to the people and policymakers in the concerned area. The WQI in the study area ranges from 35 to 213. The quality distribution within the study area WQI is only 13% deemed good, 23% poor, 7% very poor, 30% unsuitable, and 27% unfit. The overall WQI in the study area indicates that the groundwater is unsafe and non-potable, except for a few localized pockets (13%) area on the northern side. SSP was categorized as unsure (83%) or poor (13%) for irrigation. SAR: 10% excellent, 47% good, 33% allowable, and 10% unsuitable for agriculture. MH and PI are 70% excellent and 30% safe. The study area's water quality is poor, with moderate to good irrigation indices suitable for 70-75% of the area. Spatial analyses reveal low

concentrations in the north and high concentrations in the south, highlighting the area's heterogeneity. The policy should prioritize monitoring pollution, research on sources, and mitigation methods to prevent irreversible harm to the local ecosystem and communities.

Adsorption Potential of Modified Laterite-Based Nanomaterials for Fluoride Removal from Aqueous Solution

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Fluoride (F) is a persistent and non-biodegradable pollutant that accumulates in soil, flora, fauna, and human beings. It is most commonly found in groundwater and is considered to be one of the major environmental toxicological risks globally. Using small amounts of fluoride (<0.5 mg L-1) is good for dental health as it helps prevent tooth decay. However, having too much fluoride (>1.5 mg L-1) can harm teeth and bones, and may lead to other health issues. Globally modified natural minerals have been used for the removal of fluoride. In order to provide an affordable low-tech solution, local deposits of natural rock, such as laterite rich in iron and aluminum oxides, can be a less expensive alternative. Heat treated (HT), chemically treated (CT) and untreated laterite (RL) based nanomaterials have been used with different concentrations viz., 0, 1, 2, 5, 10, 20, 50 and 100 mg L-1 of F in 5 g of the adsorbent in 50 mL of the adsorbate solution. To see the effect of contact time, 5-gram sorbent has been added with 100 mg L-1 of F and then the contents were shaken on a reciprocating shaker for time intervals of 10, 30, 60, 120 and 180 minutes, respectively. Separately, experiments have been carried out at varying pH of 3, 5, 7 and 10 using 5 g of sorbent and 100 mg L-1 of F adsorbate solution. Likewise, effect of adsorbent dose has been tested using multiple doses of adsorbent like 0, 1, 2, 3, 4 and 5g in 50 ml of 100 mg L-1 solution of F. Batch experiment data was fitted to Langmuir and Freundlich adsorption models. Freundlich model fits the data well with adsorption intensity, β values were 0.56 for RL, 0.54 for HT, and 0.322 for CT. The adsorption capacity, Kf values were 878 L Kg-1 for RL, 928 L Kg-1 for HT, and 267011 L

Kg-1 for CT. Treated and untreated laterite showed high removal efficiency (99%) in the pH range 3 to 10. In Case of RL no significant change in removal efficiency was observed with increase in sorbent dose whereas HT and CT showed increase in removal efficiency with increase in dose of sorbent. Result of contact time on adsorption reveals that RL removal efficiency was achieved within the 10 min, while HT and CT showed high removal efficiency when allowed for 180 minutes of a contact time. This study concludes that laterite in raw form and after heat treatment can be used as F sorbent for treating F contaminated water. The efficiency of raw laterite for removing F from contaminated water increases many folds when treated chemically. Thus, this low cost modified sorbent can be an alternative to the expensive filtration systems.

Geochemical and Environmental Impacts of Coal Mines/Waste on Soil and Water in Tirah Valley, District Khyber

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To assess soil and drinking water quality deterioration in the Tirah coal mining area of Pakistan, the present study examines the environmental repercussions associated with coal mining activities. A total of 26 water samples, 31 soil samples, and 5 coal waste samples were collected from weathered soil and coal mines, respectively. These samples were analyzed for major and trace elements using atomic absorption spectrometer and ICPMS at the National Center of Excellence in Geology, University of Peshawar. Various methods, including descriptive statistics, correlation analysis, and pollutant quantification factor, were employed to process the results. For soil samples, an ecological risk assessment for several hazardous metals was computed. Groundwater samples from the Tirah coal mining area exhibited pH, EC, TDS, and salinity levels below the WHO-recommended guidelines. However, research on groundwater cations revealed that calcium and potassium levels exceeded WHO criteria. Analysis of heavy metals in water using ICPMS indicated that cadmium (Cd) and lead (Pb) levels surpassed WHO standards, with the HQ for Cd indicating high risk exposure in the area. Comparison of minor elements in soil with Bohn et al. (2001) showed that only cobalt (Co) was within regulatory limits, while concentrations of all other metals exceeded background values. Strong correlations among heavy metals were observed in coal waste samples, such as Cu-Pb, Co-Zn, Co-Cd, and Cr-Cu. The research area was found to be polluted with heavy metals (HMs), as indicated by pollution load index (PLI) values exceeding 1 for soil and coal waste samples. According to the study's findings, coal mining activities have impacted water and soil in the area, resulting in contamination. Heavy metals produced during blasting, quarrying, and crushing of coal-polluted soil in Tirah, District Khyber, directly affect vegetation and have significant effects on the local community and environment.

Geochemical and Environmental Investigation of Copper Deposit of North Muhammad Khel, Waziristan

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Copper, the third most consumed metal globally, has diverse applications, from phones to cars, owing to its alloys. Geochemically, copper-bearing materials fall into three categories: sulphur, oxide, and native copper metal ore, with sulphide being the most abundant. However, copper mining, smelting, and processing are associated with environmental issues like acid mine drainage and heavy metal contamination. The current study investigates the geochemical aspects of copper deposits in North Muhammad Khel, Waziristan, Pakistan, and their environmental impacts on agricultural soil, river sediments, and drinking water quality. Sophisticated instruments such as the Perkin Elmer Atomic Absorption Spectrometer (AAS-700) and the ICPMS (NeXion 350D), along with portable XRFs (Olympus DP-4050) and SEMs (JSM-IT100), were utilized for agricultural soil, river sediments, and drinking water analysis. Results showed elevated concentrations of heavy metals like Ni, Cr, Pb, Zn, and Cu in soil and sediment samples, with pollution indices indicating contamination. In drinking water, heavy metal concentrations were generally within WHO guidelines, except for Cd and Pb, posing risks, especially for children. SEM analysis revealed ore minerals such as Chalcopyrite and Pyrite for copper, and Pentlandite for nickel. Rock samples exhibited high concentrations of economically significant metals like Ni, Cr, Zn, Cu, Pb, and Mn, suggesting geogenic and anthropogenic influences. Economically significant mineral mining sites were identified, emphasizing the need for detailed geological surveys.

Heavy metals contamination, distribution, sources apportion and Ecological risk assessment in the sediments of Dir-Kohistan, Khyber Pakhtunkhwa, Pakistan

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The sediments samples collected from different tributaries and River Punjkora of Dir-Kohistan and were analyzed for major and minor elements. The elemental concentration in the prepared sediment samples were measured by using atomic absorption spectrometry. The arithmetic means values for metals were found as 29460 mg/Kg, 26384 mg/Kg, 23473 mg/Kg, 15193 mg/Kg, 132868 mg/Kg, and 2369 mg/Kg, respectively for major elements Na, K, Ca, Mg, Fe and Mn. Similarly, an average concentration of minor elements was found as 158 mg/Kg, 48 mg/Kg, 100 mg/Kg, 22 mg/Kg, 87 mg/Kg, 69 mg/Kg, 25 mg/Kg and 294 mg/Kg, for Cu, Ni, Zn, Cd, Co, Ag, Cr and Pb, respectively. The distribution patter of major elements in sediments samples were found as Fe > Na >K > Ca > Mg> Mn while in minor elements arranged as Pb > Cu > Zn > Co > Ag > Ni > Cr > Cd. The potential ecologic risk assessment in term of contamination factor (CF), degree of contamination (Cd), pollution load index (PLI), geo-accumulation index (Igeo) and enrichment factor (EF) were also calculated. The CF data indicated very high contamination for Cd and Ag while low contamination factor for Ca, Ni, Zn and Cr. The degree of contamination in sediments samples were majorly contributed by Ag, Cd and Pb. Similarly, the PLI data indicated moderate category of pollution. The Igeo calculation data showed strong to very strongly pollution for Cd, very strongly pollution for Ag while rest of the elements indicated unpolluted to moderately polluted category of geo-accumulation index. More over EF assessment confirmed no enrichment for Ca, Mg, Mn, Cu, Ni, Zn, Co and Cr, minor enrichment for Pb; moderately sever enrichment for Cd and extremely severe enrichment for Ag. Enrichment factor analysis of ecological risk assessment further confirmed anthropogenic source of pollution for Ag and Cd while rest of the elements experienced geogenic sources of pollution in the study area.

Anaerobic Co-Digestion of Cow Manure with Food Waste Using Bio- Based Activated Carbon Modified Bentonite as Accelerant

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In this study, cow manure was co-digested with food waste through the process of anaerobic digestion using clay mineral bentonite and bio-based activated carbon as an accelerant. Bio-based activated carbon and bentonite may enhance anaerobic digestion through Direct Interspecies Electron Transfer (DIET) both contain metal oxides, for example, iron oxides. The objectives of the study were to check the sole as well as the combined effect of bentonite and bio-based activated carbon on biogas yield and digestate nutrients (NPK) contents. Anaerobic co-digestion of cow manure and food waste with a ratio of 3:1 with 30% inoculum (Intestinal fluids) was used in each digester. Different treatments were made using various concentrations of bentonite (2, 2.5, 3.0 g L^{-1}) and bio- based activated carbon (0.25, 0.5, 1.0 g L^{-1}) and combined bentonite and bio-based activated carbon (1+ 0.125, 1.25+ 0.25, 1.5+ 0.5 g L^{-1}). Biogas yield, volatile solids (VS), total solids (TS) reduction rate, and nutrient (NPK) contents of the digestate were measured. Treatment with 1 g L^{-1} bio-based activated carbon produced the highest cumulative biogas yield (417 mL g^{-1} VS) and treatment with 3g L^{-1} bentonite produced (409 mL g^{-1} VS) both had the highest amount of gas produced which are statistically similar in comparison to the control or reference group (240.11 mL g^{-1} VS). The treatment having bio-based activated carbon 1 g L^{-1} achieved the highest TS and VS reduction rates of 36.9 ± 0.54% and 38.4 ±0.29 %. The maximum COD removal rate was observed from the treatment containing bio-based activated carbon (1.0 g L^{-1}) i.e. (41 ± 0.31%) followed by (40.2 ± 0.29%) from the digester which contains the bentonite

concentration of 3 g L^{-1}. Nutrient (NPK) content was measured, the digestate containing 1 g L^{-1} bio- based activated carbon yielded the highest overall nutritional content of 5.73% followed by bentonite at 3.0 g L^{-1} at a percentage of 5.65% and the control group at 4.56%. It is concluded from the study that bentonite 3.0 g L^{-1} and bio-based activated carbon 1.0 g L^{-1} enhance biodegradation of organic waste through an anaerobic digestion process and digestate can be used as organic fertilizer.

Assessment of Soil Health on Agriculture in Kathor Area, Karachi, Sindh, Pakistan

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This study examines the intricate relationship between soil quality and agricultural productivity within the context of Kathor Village, Sindh. Recognizing the pivotal role of soil in influencing plant development, nutrient availability, and overall ecosystem health, our research aims to provide comprehensive insights into the multifaceted connections between soil properties and crop performance. Conducted in August 2023, the study focuses on a plain area southeast of Karachi City, characterized by sparse vegetative cover and exposed siliciclastic rocks. A total of 10 soil samples were collected from various agricultural fields, representing diverse vegetable crops. The physical and chemical properties of the soil were analyzed, including pH (as low as 3.5), Total Dissolved Solids (TDS), Total Organic Carbon (TOC) at 6.15%, major elements (H, Na, K, Ca, Mg, Cl, HCO_3, NO_3, SO_4), and trace elements (Cu, Fe, Ni, Pb, Co, Cr, Zn). These elements play crucial roles in maintaining soil moisture and structure, and supporting plant growth, while trace elements such as copper, iron, nickel, lead, cobalt, chromium, and zinc demonstrate their influence on plant functions and potential environmental consequences. Grain analysis revealed a medium-to-fine particle size, indicating potential nutrient-holding capacities in the soil. Furthermore, the study explores the impact of agricultural practices on soil health, considering factors such as fertilizers, manures, and pesticides used by farmers in the region. This detailed analysis of soil properties and their implications for crop research provides valuable insights into the complex interplay between soil characteristics and agricultural outcomes. The outcomes of this study can guide farmers and researchers in developing strategies for sustainable and resilient agriculture, ensuring the long-term productivity of agricultural systems in the Kathor area.

Groundwater Quality Assessment with WQI Technique: Comparative Report on Kathore Area, Malir District, Karachi, Pakistan

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The aim of this study is to evaluate the groundwater quality of the Kathore area using the Water Quality Index (WQI) measured through physicochemical parameters. For this purpose, a total of 11 groundwater samples were randomly collected from bore wells at depths ranging from 150 to 500 feet in the study area. The data revealed that the total dissolved solids (TDS) content of groundwater (mean: 891 ppm) is higher than the permissible WHO limit but within the limits proposed by Pakistan's National Standards for Drinking Water Quality, i.e., TDS <1000 is suitable for drinking purposes. Concentrations of Na (mean: 179 mg/l), K (mean: 15.7 mg/l), Ca (mean: 62 mg/l), Mg (mean: 115 mg/l), Cl (mean: 260 mg/l), HCO3 (mean: 296 mg/l), NO3 (mean: 6.41 mg/l), and SO4 (mean: 193 mg/l) were calculated, and 90% of the parameters are within the WHO guidelines for drinking water. TDS >500 but <1000 indicates that groundwater is slightly saline, indicating that agricultural activities in the area are influencing groundwater quality. The calculated value of the Water Quality Index (WQI = 64) indicates that groundwater in the Kathore area is not suitable for drinking but can be used for irrigation or industrial purposes. However, proper treatment of the available groundwater is required.

Estimation of biochar efficiency for the removal of cadmium, lead, and chromium from the coal waste-contaminated soil in Dara Adamkhel

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In Dara Adamkhel coalfield releases a huge amount of coal waste including coal gangue, coal slime, rocks, and soil, which is comprised of toxic trace elements and may cause diverse issues in the local environment. The current study was carried out for the investigation of pollutants deposited in soil, originating from the coalmines present in that study area, and its effects on crops specifically Corn and Lettuce, grown in the polluted soil. Near the coalmines, the soil usually contains harmful metals and substances transported by the runoff coming through the coalmines. The area near the coalmines is more prone to contamination. A total of 40 soil samples were collected from Dara Adamkhel for examining the toxic trace elements (TTE) such as Cd, Cr, and Pb. For the remediation of trace elements, pot experiments were applied for cultivating 20 corn and 20 lettuce samples in the contaminated soil. Afterward, these samples were treated with activated pyrolyzed biochar to limit the mobility and adsorption of toxic trace elements. To investigate the toxic trace metals, the soil was treated with acid and determined through an atomic absorption spectrophotometer (AAS). Before treatment, the average concentration (mg/kg) of Cr in soil was 47.71 ±20.4, Cd 5.86 ±2.1, and Pb 69.57 ±31.7. Conversely, after treatment, imposition of Cr was 20.72 ±8.5, Cd 3.37 ±1.2, and Pb 7.01 ±3.19 in mg/kg, while the average minimization of Cd, Cr, and Pb was up to 43 % Cr, 57% Cd, and 94% Pb through biochar application in Corn pots. Whereas, for the lettuce experiments, the minimization was 42% of

Cr, 76% of Cd, and 73% of Pb. The biochar application, in Corn and Lettuce crops was effective for the minimization of toxic elements in coal waste-contaminated soil. The trace element averages for Cr, Cd, and Pb in the Lettuce Crop pots were 47.65, 5.42, and 14.87 mg/kg respectively. In Corn Soil, Pb had the highest quantity followed by Cd and Cu before and after treatment. Lettuce Soil however exhibited the highest levels of Cr in samples that were cleaned. There was also a similar variation in elemental concentrations, which were lower than all other literature studies carried out to date. In the Corn pots before treatment, the trends of trace elements in the soil were Pb > Cr > Cd, while after treatment were Cr > Pb > Cd. Cr > Pb > Cd was signified in both contaminated and treated soil of Lettuce. It was found that Corn and Lettuce crops coupled with biochar had the potential to decrease the quantity of toxic elements from coalmine spoiled soil at an optimum level. The present study provides insights to using wood biochar for the rehabilitation of coal waste-contaminated soil. Whereas, its enviro-health effects on the surroundings cannot be undermined. The use of activated biochar limits the mobility of toxic trace elements as well as health effects.

Dendrochronology to reconstruct climate change in the moist temperate forest of Galiyat

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Moist temperate forests of Pakistan are under constant threat of climate change. Dendrochronology a study of annual growth rings of trees, and tree ring widths are dependent upon environmental/climate factors, therefore annual growth layers of trees can be used to reconstruct the climate change of the forest. The aim of this study was to use dendrochronological methods to reconstruct the last 165 years climate change and growth-climate change relationship. This was achieved by establishing a correlation between surface soil moisture and tree ring growth of Abies pindrow (Royle or Himalayan fir) growing in the moist temperate forests of Galiyat. Tree-rings are one of the important natural proxy, which have the ability to store all related information of climate, where they are confined. This climatic information might be local or regional therefore, knowledge of tree-rings study is crucial. Around hundreds of core tree samples were collected from Breast Height (BH) and were studied. The results of this study show that surface soil moisture data (SSMs) when correlated with tree ring growth for reconstruction only June was correlated with 0.201. It was observed that from 1917 was the wettest SSM whereas 1921 was the driest SSM. It is concluded from the present study that winter SSM proved to be the most important months for climate change and had an impact on tree ring in the Western Himalayas. This study revealed the contention that SSM is a very important parameter that can be used to reconstruct the climate change when correlated with tree ring growth. Thus, dendrochronology provides a detail information about the changes occurred in the tree ring growth during wet and dry seasons and the most abrupt change represent the extreme climate change may occur during the year.

Groundwater Estimation and Determination of its Probable Recharge Source in the Lower Swat District, Khyber Pakhtunkhwa, Pakistan by using Analytical Data and Linear Regression Algorithms

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Groundwater is used in all sectors and its over-exploitation enhance the burden on groundwater, moreover, the improper investigation, random selection of drilling sites will ultimately affect the quantity of groundwater. Groundwater estimation via actual field data and machine learning based approaches for feasible exploration sites in Lower Swat district were carried out. For this purpose, study area was divided into seven zone based on the lithology and distance from river Swat. Surface (river, canals) and groundwater (wells, springs,) samples were collected and analyzed for various physicochemical parameters including major and trace elements to find the probable recharge source in the flood plain area of Swat River. X-ray Fluorescence (XRF) analysis of the rock samples collected from the spring's host were also performed to compare its mineral constituents with the dissolved load of the analyzed groundwater samples. Analytical data interpretation reveals that the recharge source for groundwater in the flood plain regime is Swat River, while infiltration and percolation of rainwater act as a probable recharge source in the mountainous and elevated areas. Acceptable similarities were observed in the geochemical composition of the rock samples, spring's water samples and representative wells in their immediate neighborhood. A linear relationship was observed between the water table and distance from Swat River illustrates that water depth in wells increases with increasing distance from the main recharge source. Furthermore, predicted zones for potential water wells were marked in model wells by using linear regression algorithms of machine learning techniques.

Assessment of Groundwater Quality for Drinking and Agriculture Purpose in Nighawal Village, District Jamshoro, Sindh, Pakistan

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Nighawal village is a rural area in Sehwan, located in Jamshoro district where inhabitants rely on groundwater for domestic use and agricultural activities but the quality of water is unknown for its intended uses. Therefore, present study is aimed at assessment of groundwater quality for drinking and agriculture. For this purpose, groundwater (n = 21) samples were collected from various sites of study area. Data reveal that groundwater is slightly alkaline and spam around circum-neutral range (pH range: 7.2-7.96; mean: 7.46; stdev: 0.155) with a mean temperature of 29.48 °C suggesting the occurrence of alluvial aquifer as a hosting matrix. Eh varies in a narrow oxic range (range: 173-192; mean: 184.38 mV, stdev: 6.025mV). TDS content varied in a wide range (range 431-1110; mean: 773.95 mg/L, stdev: 213.95mg/l) where except two, all samples exceeded the WHO permissible limit (500 mg/L) and about one-fourth exceeded the Pakistani guidelines (1000 mg/L) for drinking purpose. Similarly, a wide range of hardness (470-980; mean: 680.95 mg/l, stdev: 165.103 mg/L) is observed where about 64% samples exceeded the WHO guideline value (500 mg/L) for drinking purpose. Interestingly, high hardness is mainly influenced by high sulphate content (range: 155-346; mean 275 mg/L, stdev: 53.016 mg/l). On the other hand, only three samples are found turbid (< 1 NTU) and within WHO permissible limit (5 NTU). Major cations and anions varied in the order of Na > Mg > Ca > K and SO4 > Cl > HCO3 > NO3. WQI value was found to be 72 indicating that groundwater falls in fair category for irrigation and industrial purpose but unfit for human consumption. PCA analysis revealed that both natural and anthropogenic factors are controlling the chemistry of water. It is concluded from present study that groundwater is of marginally acceptable quality which is mainly influenced by the high occurrence of sulphate. Detailed studies are required to explore the reason of high sulphate occurrence.

Liquid Crystal Biosensors Functionalized with Protein Probe for Heavy Metal Ions Detection

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Liquid crystals (LCs) represent a unique state of matter that exhibits property of both liquid and a solid crystal at a certain temperature range. Their ability to respond to external stimuli makes them an eye-catching material for sensing and detection application. LCs have been extensively exploited as sensitive components in the development of LC biosensors that rely on the principle that specific bimolecular interactions can disrupt the orientational order of LC molecules. This disruption triggers a detectable change in the LC's optical properties, allowing them for the sensitive detection. The use of LC based biosensors have been considered as an encouraging and convenient approach for heavy metal ions in water sample. As HMs ions possess significant threat to both aquatic ecosystems as well as human wellbeing and are toxic even in a low concentration probably carcinogenic and can amass in biological system causing harm to multiple organs. This research work aims to provide an effective method for detection of heavy metal ions based upon its interaction with protein, that will act as a ligand which will be immobilized on glass surface coated with UV modified Dimethyloctadecyl [3(-trimethoxy silyl) Propyl] ammonium chloride) (DMOAP) providing surface for interaction with heavy metal ions. This interaction will lead to change in aligning behavior of LC which will serve as base for detection of metal ions. The characterization technique for this biosensor will be UV-VIS spectroscopy, scanning electron microscope (SEM) to study there, surface, morphology and textural properties. Further study will be done on polymerized Optical Microscope (POM). This innovative bio sensing technique holds a great application in environmental monitoring, Industrial Quality control, medical diagnostic and food safety offering a sensitive and selective mean of detection for heavy metal ions.

Liquid Crystal-Based Enzymatic Biosensor for Detection of Lactic Acid

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Liquid crystals (LCs) are characterized by their unique mesophase, which combines the fluidity of liquids with the ordered structure of solid crystals. Their long-range orientational order and optical anisotropy enable LCs to change their alignment in response to chemical and biomolecular binding events transforming these interactions into amplified, measurable optical signals. This dynamic responsiveness is exemplified by 5CB (4-cyano-4'-pentylbiphenyl), a widely utilized nematic liquid crystal known for its rapid response to external stimuli such as surface topography, molecular configuration, pH levels, and temperature, making it ideal for biosensing. In this work, we introduce a novel lactate oxidase (LOx) LC biosensor that is particularly designed for the precise detection of lactic acid. This biosensor demonstrates how the enzymatic conversion of lactic acid to pyruvate and hydrogen peroxide can induce pH changes that significantly alter the alignment of 5CB molecules, thereby enhancing signal transduction. The biosensor assembly involves a functionalized coating of Dimethyloctadecyl [3-(trimethoxysilyl)propyl] ammonium chloride (DMOAP) and (3-Aminopropyl) triethoxy-silane (APTES) on a glass substrate. Glutaraldehyde is employed as a crosslinker to robustly immobilize the LOx enzyme on the coated surface, optimizing interaction with lactic acid. This interaction not only disrupts the LC orientation but also highlights the LCs' response to pH changes, enhancing the detection of optical signals. The biosensor structural and functional properties will be characterized using scanning electron microscopy (SEM), polarizing optical microscopy (POM), UV-VIS spectroscopy and other spectrometric techniques. This orientation sensitive design offers enhanced accuracy, demonstrating potential for widespread applications in clinical diagnostics, quality assurance in food

industry, bioprocess monitoring and environmental surveillance This research emphasizes the integration of biochemical method with LC technology paving the way for setting a new standard for biosensing functionality that enables precise, real-time tracking of lactic acid levels and is potentially leading to the development of portable, non-invasive diagnostic tool.

Groundwater evaluation for drinking and irrigation in Pakistan's mountainous terrain: hydro-chemical characteristics and health risks

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Renowned for its agriculture, livestock and mining, Zhob district, Pakistan faces the urgent problem of declining groundwater quality due to natural and human-induced factors. This deterioration poses significant challenges for residents who rely on groundwater for drinking, domestic, and irrigation purposes. Therefore, this novel study aimed to carry out a comprehensive assessment of groundwater quality in Zhob district, considering various aspects such as hydrochemical characteristics, human health risks, and suitability for drinking and irrigation purposes. While previous studies may have focused on one or a few of these aspects, this study integrates multiple analyses to provide a holistic understanding of the groundwater quality situation in the region. Additionally, the study applies a range of common hydro-chemical analysis methods (acid-base titration, flame atomic absorption spectrometry, and ion chromatography), drinking water quality index (WQI), irrigation indices, and health risk assessment models, using 19 water quality parameters. This multi-method approach enhances the robustness and accuracy of the assessment, providing valuable insights for decision-makers and stakeholders. The results revealed that means of the majority of water quality parameters, such as pH (7.64), electrical conductivity (830.13 μScm^{-1}), total dissolved solids (562.83 mgL^{-1}), as well as various anions ((mgL^{-1}) F^{-} = 0.55±0.42, Cl^{-} = 81.43±115, SO_4^{2-}=156.67±94.96, HCO_3^{-}=183.33±46.93, and NO_3^{-} = 2.61±2.24), and cations ((mgL^{-1}) Na^{+} = 61.87±38.79, Ca^{2+} = 65±39.06, Mg^{2+} = 34.89±25.2, and K^{+} = 3.57±2.14), were in line with drinking water norms. However, the water quality index (WQI) predominantly

indicated poor drinking water quality (range = 51–75) at 50% sites, followed by good quality (range = 26-50) at 37% of the sites, with 10% of the sites exhibiting very poor quality (range = 76-100). For irrigation purposes, indices such as sodium percent (mean = 31.37%), sodium adsorption ratio (mean = 0.98 $meqL^{-1}$), residual sodium carbonate (–3.15 $meqL^{-1}$), Kelley's index (mean = 0.49), and permeability (mean = 49.11%) indicated suitability without immediate treatment. However, the magnesium hazard (mean = 46.11%) and potential salinity (mean = 3.93) demonstrated that prolonged application of groundwater for irrigation needs soil management to avoid soil compaction and salinity. Water samples exhibit characteristics of medium salinity and low alkalinity (C2S1) as well as high salinity and low alkalinity (C3S1) categories. The Gibbs diagram results revealed that rock weathering, including silicate weathering and cation exchange, is the primary factor governing the hydrochemistry of groundwater. The hydro-chemical composition is dominated by mixed Ca–Mg–Cl, followed by Na–Cl and Mg–Cl types. Furthermore, the human health risk assessment highlighted that fluoride (F^-) posed a higher risk compared with nitrate (NO_3^-). Additionally, ingestion was found to pose a higher risk to health compared to dermal contact, with children being particularly vulnerable. The average hazard index (HI) for children was 1.24, surpassing the allowable limit of 1, indicating detrimental health effects on this subpopulation. Conversely, average HI values for adult females (0.59) and adult males (0.44) were within safe levels, suggesting minimal concerns for these demographic groups. Overall, the study's interdisciplinary approach and depth of analysis make a significant contribution to understanding groundwater quality dynamics and associated risks in Zhob district, potentially informing future management and mitigation strategies.

Mineral Characterization of Bentonites for Aflatoxin B1 Adsorption

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Aflatoxin, a class 1 carcinogen, comes in animal feeds via mold contamination in feed grains particularly through Aspergillus species. Aflatoxin is controlled by bentonite as a feed additive that is mostly imported in the country while sufficiently large clay deposits of medium to high quality with potential for use in feed industry are available. Limited research on the mineral details of the country's clay deposits have hindered their specified use. To study mineralogy in detail and determine their potential as aflatoxin binder for animal and poultry feed, 27 active bentonite quarries were sampled. Two commercial binders and three bentonites from China were included as reference. The mineral phases and structural characteristics were identified through XRD and Fourier transform infrared (FTIR), respectively while the Laser diffraction. Analyser was used for particle size distribution. Aflatoxin maximum binding capacity and strength was determined through adsorption isotherms and model fitting in the Langmuir equation. The organic carbon content, cation exchange capacity and pH of the clay suspensions were also measured. Structural modification of smectite was carried out through Al/Al-Fe pillaring and cations (Ca, Zn, Mg and Li) saturation coupled with heat treatments at 200 and 400 °C for improving aflatoxin selectivity. Based on the dominance of the minerals determined through XRD of the bulk samples, four clay mineral groups were identified and named as:(i) smectite, (ii) smectite-hydroxy interlayered smectite (HIS), (iii) HIS-smectite, and (iv) kaolinite. Smectite was dominant mineral with mica, kaolinite, and

quartz presence as minor minerals. The maximum aflatoxin adsorption capacity varied with the mineral purity and smectite dominance in each clay and was highest in smectite dominated clay quarries. Sorbatox® (kaolinite) had lower adsorption, 130 µg g-1 clay, while Toxisorb® (bentonite) had greater adsorption capacity of 665 µg g-1 clay indicating kaolinite, an ineffective binder for aflatoxin. The Al/Al-Fe pillaring in smectite enhanced aflatoxin adsorption by 65 % over unmodified smectite. The greater adsorption is related with the expansion of interlayer through pillaring. Smectite saturated with (Li, Mg and Zn) cations of comparable size, caused greater aflatoxin adsorption at 200 °C while larger cation (Ca) had greater adsorption at 400 °C. The study demonstrates feasibility of using local clays as aflatoxin adsorbent.

Comparative Adsorption of Aflatoxin B1 in Palygorskite, Sepiolite and Smectite

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Aflatoxin in feed causes aflatoxicosis in birds and livestock, and also poses health hazards to the consumers. Among the clays, smectite is extensively studied for aflatoxin removal though complete control relates to the complex gut conditions. Sepiolite and/or palygorskite possess specific tunneled structure, and are available in Pakistan but need testing as potential aflatoxin binders. The objective was to determine mineralogical characteristics and evaluate the indigenous palygorskite- sepiolite reserves for aflatoxin B1 control in poultry. Eleven clays and two commercial mycotoxin binders were sampled and processed for mineralogical analysis through X-ray diffraction, structural characterization through FTIR, particle size distribution by Laser diffraction, and morphology by SEM and compared with the reference clays from international repository. Aflatoxin B1 maximum binding capacity and binding strength were determined through adsorption isotherms and fitting to the Langmuir model for each clay. Heat induced structural changes were studied for the selected clays for consequent impact on adsorption of aflatoxin. The X-ray diffraction identified three mineral groups in the indigenous clays: (i) well crystallized palygorskite, (ii) palygorskite- smectite mix, and (iii) interstratified smectite (HIS/HIV) with moderate amount of mica and minor palygorskite. The palygorskite appeared to be formed through devitrification of volcanic ash under Mg rich saline conditions and in the third group mica appeared to be detritus. The FTIR suggested that palygorskite contained AlMgAl octahedral sites with zeolitic and coordinated water. Indigenous palygorskite had greater crystallinity and purity than the reference palygorskite indicated through sharp and intense 001 diffractions at 10.5 Å. In a physical mixture of

palygorskite and smectite, smectite was identified as montmorillonite with Al dominance in octahedral sheet through IR spectra. The IR band at 1190 cm-1, assigned to Si-O-Si bonding was related to inversion of apical O in the alternating ribbons, a characteristic of palygorskite that was present in indigenous palygorskite. Aflatoxin B1 isotherms and fitting to the Langmuir model suggested that aflatoxin adsorption increased with increasing smectite content in the mixed clays. The palygorskite and palygorskite-smectite mix (group i and ii) had comparable or higher adsorption than the commercial and reference clays. The heat treatments induced structural changes in the selected clays and structural collapse occurred through dehydration and dehydroxylation when heated at 400 °C and above. Simulated gastrointestinal fluid caused reduction in aflatoxin adsorption probably through the interference of pepsin and lower pH. Sepiolite had highest selectivity for aflatoxin B1 among the selected clays and had the lowest adsorption capacity for pepsin. The indigenous clay sources have the potential for use in the poultry feed industry to reduce hazards of aflatoxin B1 contamination.

Economic and Environmental Concerns of Himalayan Earthquakes with Example of Mw 7.6, 2005 Kashmir Earthquake

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The Himalayas represent one of the most active mountain system in the World. It has hazard of shallow (< 20 km) earthquake due to head-on collision of the Indian and Eurasian plates. The great earthquakes (> Mw 7.0) are located along the segments of the Himalaya arc with recurrence interval of ~ 300 Ma ±100 Ma. The devastating Mw 7.6, October 08, 2005 Kashmir earthquake occurred along the northwestern segment the Himalayas arc. Its epicenter was located about 26 km north of the Muzaffarabad with focal depth of about 11 km. The earthquake occurred along the active Balakot-Bagh fault (BBF) of the Himalayan trend (NW- SE) with a ground rupture of ~70 km and throw between 2-7 m. It was destructive with intensive ground-shaking, ground rupture, landslides, and building collapse over a vast region of 30,000 sq km. Most of the building in the town of Balakot, Muzaffarabad, Garhi, Chikar Khas, and Bagh located along the trace of the fault were destroyed with estimated economic loss of US$ ~5.1 billion and ~86,000 human lives, displacement of ~ 500,000 families, and loss of ~ a million jobs. As a matter of concern, this earthquake of relatively lower magnitude caused more deaths as compared to many great earthquakes of even higher magnitude along the Himalayan arc due to over-population along the active fault. Pakistan is seismically most active, due to the active convergent (Himalayas/Makran) and strike-slip Chaman fault systems, with examples of destructive earthquakes such as Mw 7.5, 6 June 1819 Run of Kutch Sindh with 3200 casualties, Mw 7.8, 24 September 1827 Lahore with ~1000 casualties, Mw 7.7, 31 May 1935 Quetta with 40,000-60,000 casualties, Mw 8.1, 28 November 1945 Pasni with

~4000 casualties, and Mw 7.7, 24 September 2013 Awaran Baluchistan with ~1000 casualties. These earthquakes raise concerns for identification and mitigation of future earthquake hazard to avert economic and human losses. This presentation is an attempt to create awareness about the earthquake hazard in the concerned quarters. Both, Government and Public are urged for safety measures with restricted development in the red zones, relocation of population away from the active faults, declaration of high-risk earthquake hazard zones as State Parks, establishment of museums for earthquake awareness/education, and construction of earthquake resistant buildings for sustainable development.

Environmental impact of biomarkers

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Biomarkers are natural product that are derived from the decay of terrestrial or marine or mixed vegetation, thus inherits the biological characteristics of the source from which it was derived. The presence of some of the hydrocarbon may become toxic to soil microbes and phytotoxic to plants. The aim of the study was to extract biomarkers from oil seep samples and understand their impact on the soil environment. For that purpose, oil seep and soil impregnated with oil was collected from the Kundal oil field. GC-FID chromatogram results indicate that Kundal oil seep was biodegraded. This is more likely because of absence of n- alkanes and isoprenoids in oil seeps, soil impregnated with oil and wastewater samples within the vicinity of oil field at Kundal. The presence of aromatic biomarkers indicates that the source of organic matter in oil seep is from marine algae or phytoplankton. Furthermore, organic matter is mature and of marine in nature as the ratio is slightly greater than terrestrial organic matter. The depositional environment is hypersaline and source rock is shale. Paleoclimate reconstruction from aromatic biomarkers indicate that the presence of triterpanes is of marine algae origin. This suggests that the climate was anoxic and anaerobic microbial degradation may have occurred under saline condition. Saline conditions are confirmed by the presence of gammacerane in the oil seep sample. Steranes like gammacerane has confirmed the input of eukaryotic marine phytoplankton in organic matter. This suggests that the paleoclimate was anoxic, anaerobic microbes were abundant and saline conditions prevails the formation of the organic matter of the Kundal oil seep.

Human (oral) health risks and dietary exposure assessment of potentially toxic trace elements in foodstuffs (vegetables and crops): A case study of Shangla, North Pakistan

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The current study depicted the potentially toxic trace elements (PTTEs) contamination and associated health (oral) risks in different foodstuffs (vegetables and cereal crops) in district Shangla, north Pakistan. The determined PTEs concentrations except lead (Pb) and chromium (Cr) in vegetables and crops samples were considerably found lower than the stated limited in international guideline for human consumption. Based on one-way analysis of variance (ANOVA) the concentration was significantly ($p < 0.05$) different in various types of vegetables and crops except that for manganese (Mn), copper (Cu), and nickel (Ni). The highest Cr and Pb contents were reported in vegetables samples, followed by cereal crops (T. aestivum, *O. sativa* and *Z. mays*). The data obtained on the basis of principal component analysis (PCA) two principal components (PCs) were extracted. The PC1 added 36.12% with greater factor loading (FL) on Ni ($r = 0.79$), Cr ($r = 0.64$), and Cu ($r = 0.69$) indicating mafic and ultramafic geogenic source of contamination. The human health risks indicated the following order for adults and children and in term of day-wise hazard quotient and intake: Pb>Mn>Cu>Cr>Ni and Pb>Mn>Ni>Cu>and Cr, respectively. The cancer risks factor (CRsF) for Ni, Cr, and Pb were found to be higher than the tolerance limit (< 10–4) in all vegetables and cereal crops. The findings of this study confirmed the human (oral) health risks (THQ>1.0) through the intake of vegetables and cereal crops among child population of the study area.

Estimation of Pozzolanic Activity of Scoria Rocks Using ASTER Remote Sensing

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Remote sensing, particularly through the Thermal Emission and Reflection Radiometer (ASTER) aboard the TERRA spacecraft jointly operated by Japan and NASA, presents a powerful means for gathering data essential for the targeted selection of scoria rock (SR) deposits. Leveraging informative radiance data captured by ASTER, reflective of various regions including those harboring SR, enables the conversion of radiance to reflectance. This study explores the correlation between the reflectance values at two effective ASTER Bands (B4 and B5) and the pozzolanic activity index (PAI) of ground SR samples measured within standard mortar mixtures. Through rigorous analysis, it is observed that SR samples exhibiting lower reflectance values are associated with higher PAIs, demonstrating a significant variation ranging from 91% to 100% at 28 and 90 days. By employing established mathematical correlation techniques, the reflectance values of distinct regions within the same geographical area as reported PAIs are derived and validated against existing data. The findings indicate a substantial agreement between the estimated and reported ranges of PAI values, affirming the efficacy of remote sensing methodologies in facilitating targeted SR procurement and correlating with critical material properties.

Developing Specialized Human Resources and National Capacity in Space Science and Technology for Socio-Economic Development of Pakistan

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This contribution unveils the pivotal role of the National Center of GIS & Space Applications, an initiative spearheaded by the Higher Education Commission of Pakistan to meet the emerging demands of space applications for the socio- economic development of Pakistan. The center is committed to promoting technological innovation and enhancing research and entrepreneurial capacities in the areas of space science, technology and its application including astronomy, astrophysics, small satellite development, global navigation satellite systems, spatial decision support systems, disaster management, water & forest resource management, geological applications of geographic information science and remote sensing, environmental studies, agriculture, and space education & awareness. The National Center encompasses a consortium of seven state-of-the-art research laboratories strategically distributed across seven renowned academic institutions of Pakistan equipped them with cutting-edge technology and skilled personnel. The NCGSA laboratories collectively contribute to a diverse array of research domains within GIS and space applications playing a crucial role in mentoring students and early-career professionals, fostering their talents, and setting the stage for future innovations. The National Center of GIS & Space Applications vigorously promotes collaboration both within Pakistan and globally, establishing partnerships with government agencies, academic institutions, and industry stakeholders to harness expertise and resources for significant research and innovation. Through these collaborative efforts, the center aims to not only contribute to the scientific community but also play a pivotal role in addressing global challenges in GIS and space exploration and shaping the future of space science & technology in driving the socio-economic growth of Pakistan.

Multi-Hazard Susceptibility Mapping Using Machine Learning, A Case Study of Hunza

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District Hunza are threatened by multiple hazards which pose significant threat to humans, buildings and infrastructure. The region has experienced numerous extreme climatic hazards including landslides, Debris flow, Seismic, Glofs, and Floods. Moreover, Hazards are usually studied separately and ignore multiple geo-hazards in the same area. Furthermore, this study produces multi-hazard Susceptibility map by integrating the (landslide susceptibility, Debris flow, Seismic, Glof, Floods hazard) for District Hunza, Northern Pakistan. Landslide, Debris flow, Seismic, and Glof hazard were collected from secondary sources. While the flash flood and riverine flood (Water level rise) hazards were developed using OpenLISEM and Global Mapper in this study. First, an equal number of hazard and non-hazard locations was digitized from each hazard map and then validated those randomly sampled locations in field. additionally, we have sub- divided the data by random partitioning technique into train-test chunks. 70% of these locations were randomly chosen for susceptibility map, while 30% were used for validation purpose. An intelligent learning machine called forest-based classification and regression model (RF) within an open-source R.4.3.3 software was utilized to estimates the importance of specific hazard. Then, the importance of each hazard was incorporated into-model for producing the multi-hazard susceptibility map. Finally, the spatial distribution of each hazard was assessed, and classified into nine classes named as: no hazard (8.83%), low + no hazard (58.57%), LS (12.53%), FF (6.06%), DF+FF (4.65%), FF+LS+DF (3.98%), SH+DF+LS+FF (2.87%), DF+LS+GLOF+SH (1.67%), and FF+RLR+SH+GLOF+LS+DF (0.80). The presented method will contribute to a Disaster risk reduction of disaster losses in District Hunza and will foster future efforts of harmonization of risk management strategies in the country.

Multi-hazards vulnerability and risk assessment in North-Pakistan, the challenges and way forward

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The physical, tectonic, environmental and climatological settings and anthropogenic activities coupled with the climate change in northern Pakistan, provide an ideal landscape for the frequent and damaging multi-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 available for effective disaster management. Methodologies are developed to utilize the available data, techniques and models for regional- scale landslide, debris flow, GLOF, 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 the settlement footprints, typological information, communication network, land use, critical infrastructure, and social vulnerability indicators are utilized for vulnerability assessment and eventually risk analysis. 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 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.

Site suitability analysis for the evaluation of adventure tourism along the proposed Kohsar Tourism Highway

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Tourism is a sector in which people travel to locations for professional or personal reasons. It is generally divided into many types depending upon where the tourists are travelling and for what purpose. This study focuses on Adventure tourism in mountains. Adventure tourism is among the rapidly growing types of tourism and a significant component of the tourism industry. Mountains are exceptionally alluring destinations for adventure tourism because they provide a variety of activities in landscape that is rich in both literal and symbolic representations of adventure. The goal of this study was to classify suitable sites for adventure tourism along the proposed Kohsar Tourism Highway into 3 categories; skilled adventure tourism (SAT), mass adventure tourism (MAT) and experiential adventure tourism (EAT). Skilled adventure tourism (SAT) is only for true adventure seekers that live for challenge and excitement for example zip-lining, bungee jumping, hiking and skiing. Experiential Adventure Tourism (EAT) comprises of participants that are eager to learn, enjoy and experience a connection with nature for example camping, multi-day hiking, bird watching and horse riding. Mass Adventure Tourism (MAT) is the type with least level of risk and low outdoor skills for example one-day hiking and biking. The evaluation factors include resource condition, ecological sensitivity, safety condition and difficulty condition. The results show that 16% of the study area has good resource conditions, most difficult conditions exist in 4.5% of the study area, 25.5% study area has safest conditions and high ecologically sensitive areas cover 4% of the study area. After the integration of these conditions suitability values of each condition were evaluated for different types of adventure tourism and categorized the study area into skilled, mass and experiential adventure tourism. 4.5 % of the study area is suitable for skilled adventure tourism, 53.7% is suitable for experiential adventure tourism and 40.8% is suitable for mass adventure tourism. Ayubia,

Khanspur, Riala, Changla gali, Chowain, Bhalgran, Mang, Kot, Pallandri, Cheeras and parts of Sehnsa Tehsil in AJK (Azad Jammu and Kashmir) are suitable for skilled adventure. Murree, Bhangal, Kuza Gali, Kohati, Mouri, Bhamrot Syedan, Beor, Bhagoon, Plahter, Kohatti, Dewal Shareef, etc are suitable for Experiential adventure. Moreover, a wide range of areas including Murree, Patriata, Ghora Gali, Samli, Angoori, Kahuta, Rawat, Mang, Panjar, Kotli Sattian, Lower Topa, etc. are suitable for Mass adventure tourism. This study has provided a framework for tourism scholars to look more into adventure tourism because despite being a newcomer to tourism industry it has a great potential for development, employment generation and economic prosperity for the local people.

GIS based site suitability analysis for the identification of potential skiing resorts in Gilgit Baltistan, Pakistan

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Tourism is the source of entertainment for those people who want to spend some quality time away from homes and is the source of their relaxation and pleasure away from their busy routines. Tourism has different types but the most famous type among tourists is adventure tourism. Skiing is also the part of adventure tourism which has become most famous winter sport and recreational activity among the tourists. Many countries are famous for having ski adventure tourism facilities. Although many northern areas of Pakistan have a great potential for ski adventure activities but in Pakistan skiing is not a well-known recreational activity. Gilgit Baltistan (GB) is the mountainous part of Pakistan which is famous for tourism because of its beautiful and natural scenic views. This study is based on the identification of suitable sites for the development of potential skiing resorts in GB using GIS. For this purpose, three main parameters include min and max. air temperature, slope and elevation of all stations of GB were analyzed followed by a weighted overlay analysis. The results showed that 18% area of GB is good for skiing while remaining 82% GB may not be good for skiing which means that development of suitable sites for skiing resorts is possible only in the identified 18% area of GB. The identified suitable area was further classified into vocational Ski resorts, Learning ski areas and ski areas for experienced skiers. The results showed that 18% areas are those which can be used for the construction of ski resorts for vocational purposes. 41% areas are those which can be utilize by tourists for learning purposes and 39% area can be used by those skiers who are expert in skiing activities. Route conditions of GB and suitable distance from major roads were also analyzed in this study. Moreover, the suitable sites for skiing were graded into highly preferred to least preferred scale on the basis of their distance from major roads (lying within 5km) and percentage of vocational, learning and experiential ski areas lying within each suitable skiing sites. This preference scale

will be helpful for tourists to choose which suitable site of GB they should visit for skiing on the basis of their interests. It has been concluded that Gilgit Baltistan has a great potential for the development of different types of ski resorts which have not been identified before. These findings can be helpful for government and local people to develop skiing resorts in GB and generate revenue by promoting skiing adventure tourism activities in GB.

Geospatial analysis for the identification of rainwater harvesting sites using SCS-CN technique in the Swat Basin, Pakistan

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Rainwater Harvesting (RWH) is considered to be a coherent approach not only for the conservation of abundant rainwater collected in a watershed but also to combat scarcity of water by providing an alternative of water supply reducing the pressure on ground and surface water resources. In addition, this method also aids in the mitigation of flood risks resulting from long and heavy spells of rainfall. The proposed study adopts a basin-wide that uses geographic information system (GIS) to identify specific locations for rainwater collection sites. By measuring rainfall runoff depth, the prospective RWH sites are found using the Soil Conservation Services-Curve Number (SCS-CN) approach. In order to ensure that there is land available for the construction of RWH structures, the proposed methodology is applied as a case study on the Swat basin, Pakistan. The analysis involved a number of thematic levels, including runoff depth, land cover/use, slope, and drainage density. Additionally, the geological settings, soil composition, and drainage stream features were also included. Land use/cover map was created using the online data of European Space Agency. Drainage density and slope were calculated from a digital elevation model. The aforementioned thematic layers are integrated in a GIS environment with weights corresponding to their importance to create a RWH potential map of the area. The resulting suitability map was divided into four potential zones, having 23%, 25%, 28%, and 24% area for high, moderate, low, and not suitable categories, respectively. The analysis revealed that all identified locations were distributed randomly throughout the study area, primarily on the western and central regions of Swat basin. As a result, the suggested methodology aids in locating potential locations for rainwater harvesting, setting a standard for future research on related topics in other places as well. The derived appropriateness will help decision- makers quickly identify potential locations for RWH structures to store water and address possible water shortage in the area.

Analyzing effects of environmental and climatic variables on snow- melt variability in Northern Pakistan using Deep Learning and Building Typology Data in The Himalayas of Northern Pakistan

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The rapid and unpredictable changes in snowmelt patterns in Northern Pakistan pose significant challenges for water resource management. This study employs deep learning models, specifically Feedforward Neural Networks (FNN), Convolutional Neural Networks (CNN), and Long Short-Term Memory Networks (LSTM), to analyze the temporal variations of snowmelt within the study region. The study utilized a dataset of 37 different climatic and environmental parameters from the Global Land Data Assimilation System (GLDAS), including temperature, precipitation, and humidity from 1948 to 2014, to train and validate the models for accurate snowmelt prediction. The performance of the deep learning models revealed significant insights. The FNN model demonstrated exceptional precision with an MSE of 3.51×10^{-5} and an R- squared value of 0.971. The CNN model, which processes spatial data more effectively, also showed high accuracy, with an MSE of 3.70×10^{-5} and an R- squared value of 0.971. Particularly notable was the LSTM model, optimized for sequential data, which recorded an MSE of approximately 5.28×10^{-5} and an R- squared value of 0.947. Storm surface runoff emerged as the most influential feature with an importance score of 0.8264 highlighting its significant contributions to Snow Melt predictions. These findings underscore the value of integrating deep learning techniques with climate datasets for hydrological predictions. By enhancing the accuracy of snow melt predictions, this research contributes to sustainable water management and supports climate action goals, aligning with SDG 6 (Clean Water and Sanitation) and SDG 13 (Climate Action). The methodologies and results provide a robust framework for ongoing research studies related to climate impact assessment and adaptive resource management.

Utilizing Remote Sensing Techniques and the Allen Coral Formula for Accurate Underwater Depth Estimation Along the Sindh Coast

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Measuring underwater depth is a crucial aspect in various engineering projects such as dam and bridge construction, where accurate depth assessment is imperative for ensuring structural stability and safety. Traditional methods for depth measurement often involve time-consuming and costly field surveys, which may pose logistical challenges, especially in marine environments. However, advancements in remote sensing technology offer a promising solution to this challenge, enabling efficient and cost-effective depth estimation. In this study, we leverage remote sensing techniques to calculate underwater depth along the Sindh coast, highlighting the significance of utilizing such methodologies in engineering applications. The core of our methodology lies in the calculation of underwater depth using a mathematical model based on below surface reflectance and predefined coefficients. This model utilizes the near-infrared and green bands from the remote sensing data to derive depth values, providing a comprehensive understanding of underwater topography. Additionally, we implemented the Allen Coral formula for calculating underwater bathymetry, which is a widely recognized and validated method in marine science and hydrographic studies. The Allen Coral formula incorporates spectral data from remote sensing imagery, such as the green and near-infrared bands, to estimate water depth accurately. To validate our results, we compare the calculated underwater depths with ETOPO bathymetry data, ensuring the accuracy and reliability of our depth estimation approach.

Evaluating the performance of various OSEB (One Source Balance) Models for estimating Evapotranspiration over a semi-arid region of Pakistan

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It is crucial to accurately estimate evapotranspiration ET as it plays a major role in water and energy balance. Changes in the climate and land cover can significantly impact the ET rate. Spatio-temporal variation in ET influences the patterns of water availability and impacts the ecosystem due to which it is very important to quantify ET in water-scarce regions. In Pakistan, there are very low footprints of meteorological station data. For this purpose, the Remote sensing techniques (Energy balance models) are proven cost and time-effective. In this research work, one source Energy Balance Models (S-SEBI) Simplified Surface Energy Balance Index and (METRIC) Mapping Evapotranspiration at high Resolution with Internalized Calibration were employed using Landsat 8 OLI/TIRS satellite imagery (from 2013 to 2020) to map the ET over the semi-arid district (Peshawar) of Khyber Pakhtunkhwa Peshawar, Pakistan. The obtained results were then validated with pan evaporation measurements of ET at the ground station provided by the National Agromet Center Islamabad, Pakistan. The modeled results show a very good correlation with ground-based station data in terms of the Pearson correlation coefficient r = 0.43 and 0.78 with a very slight deviation in terms of RMSD (Root Mean Squared Difference) exhibiting a value of 0.10 and 0.07 for S-SBI and METRIC, respectively. This study shows that the METRIC model is more effective compared to S-SEBI in calculating spatiotemporal ET over diverse regions with limited ground-based weather data.

Assessment of Active Landslides and Displacement Dynamics in Northern Hunza-Nagar District, Pakistan

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Hunza-Nagar district in northern Pakistan is constantly threatened by landslide activity due to its rugged terrain. The present study focused on the northern area of Hunza-Nagar, aiming to demarcate active landslides and analyze their temporal displacement dynamics. InSAR-based temporal monitoring was conducted using Sentinel 1 images from January 5, 2019, to January 15, 2023, with the LiCSBAS package. The study identified five active landslides: Hummari Bala Landslide (V1), Shabbir Abad Landslide (V2), Hakalshal Landslide (V3), Gojal Landslide (V4), and Nagar Landslide (V5), along with a previously reported active but now dormant Mayoon Landslide. The temporal displacement of these landslides reveals varying velocities (V1 =106.3 mm/yr, V2 = 115.7 mm/yr, V3 = 64.2 mm/yr, V4 = 41.2 mm/yr, and V5 = 52.2 mm/yr). These dynamic movements pose a significant threat, indicating an increased risk of future landslides. Consequently, mitigation of these landslide bodies is imperative to minimize potential damage in the area. The study also conducted a correlation analysis between temporal displacement, seismic, and rainfall data, revealing that seismic events and rainfall are the predominant factors contributing to the observed movements. These findings provide valuable insights into landslide dynamics in a vulnerable region, laying a foundation for proactive measures to mitigate hazards associated with large-scale landslides in the northern part of the Hunza- Nagar area.

Debris flow source-based susceptibility and propagation modeling: A case study from Garhi Habibullah to Balakot, Northwestern Himalayas, Pakistan

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Balakot is situated at the heart of the Hazara Kashmir Syntaxes. Characterized by high and steep slopes, active seismic zones, adverse climatic conditions, monsoon rainfall, and an active Bagh-Balkot fault, the region is highly susceptible to natural hazards. These include debris flows and landslides, which pose significant threats to both human life and infrastructure. Therefore, this study aims to achieve debris flow field-based inventory from Garhi Habibullah Khan to Balakot. A total of 12 debris flows were identified during the field. Later, the point-based inventory and delineation of sub-catchments were obtained using ArcMap. A total of 126 debris sources were marked through Google Earth Pro, contributing to debris flow channels. Subsequently, debris flow source datasets were randomly divided into two datasets. The first dataset comprised 70% (89) training source points and the second dataset comprised 30% (37) validation source points. Debris flow source-based susceptibility maps were prepared using a bivariate Statistical Index Model. The spatial database of nine causative factors was compiled using a 12x12 m Digital Elevation Model in ArcMap, including aspect, curvature, slope, elevation, lithology, rainfall, Topographic Wetness Index (TWI), fault buffer, and distance to stream. The propagation of debris flows was modeled using Flow-R software, and two propagation maps were generated using collapse material and susceptibility as source input. Flow-R results show low to moderate propagation and validate already propagated debris flows in the study area. The Receiver Operator Curve (ROC) validated the model's performance

through success and prediction curves. Results show that the area under the curve (AUC) for the bivariate Statistical Index Model was 83.4% and 84.1% for success and prediction curves, respectively. The outcome of this study will be beneficial in proposing solutions for the potential hazards and prevention of human life and infrastructure.

A GIS and Remote Sensing based integrated approach for Landslide Susceptibility Mapping of Gilgit River Basin

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Landslides are considered as one of the most catastrophic natural hazards in the world. The Northern Pakistan with its complex topography and active seismicity has a history of massive landslides which destroyed the infrastructure, blocked rivers and damaged communities. Landslide susceptibility maps are crucial for assessing risks and informed decision-making in planning safety measures, construction, and disaster management. This research focuses on the outcomes of statistical models in Geographic Information System (GIS) utilized for the generation of landslide Susceptibility maps using remote sensing data for Gilgit River Basin, Northern Pakistan. The input raster map layers were developed by considering the major landslide indicator groups i) Environmental factors which involves slope, aspect, slope curvature, elevation, lithology, vegetation index, distance to major river channel, and distance to active faults, ii) Causative features of rainfall and seismicity. The correlation between the identified landslide hazard zones and these factors was developed by integration of built-in GIS models such as Analytical Hierarchy Process (AHP), Weighted Overlay Index (WOI) and Fuzzy overlay method. The resultant Landslide Susceptibility maps classified the area of interest into very high, highly susceptible, moderately susceptible and less hazardous zones. By analyzing the finalized hazard maps developed by the three statistical approaches, it is observed that most of the high zones of hazard are existed either near the active fault or along the main Gilgit river channel. This study illustrates yet simple and straightforward but effective ways of producing such regional-level susceptibility maps which could serve as guide maps in order to perform detailed landslide hazard studies for planning of the infrastructure projects including embankment dams, highways, and bridges in the concerned areas.

Climatic Trends and Glacier Dynamics in the Himalayan Region: A Case Study of the Astor Basin

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Glaciers in the Himalayan region are very important for a variety of biological, environmental, cultural and scientific reasons. The Himalayan region, spanning approximately 2000 km and containing hundreds of glaciers, covers an area of around 40,000 km² and the area under investigation is located in Astore valley, the Nanga Parbat region in northern Pakistan. Due to the difficult terrain, high elevations, and lack of spatio-temporal field measurements, estimating snout variation location, statistical analysis of climatic trends, and the equilibrium line altitude (ELA) of the majority of the glaciers are difficult tasks. Moreover, calculating the net variation in glacier mass loss or gain over a given period produces ambiguous results in the absence of climate data and a differentiating contour between the accumulation and ablation zones of the glacier. To assess the climatic pattern in the Astore Basin, a quarterly trend analysis was conducted on climate data, including temperature, precipitation, and river discharge. Furthermore, this study calculates ELAs using the accumulation area ratio (AAR; 0.6 ±0.5; utilized for high-altitude mountain glaciers) and the accumulation area balance ratio (AABR; 2.24 ±0.9; interval: 0.05 and 0.01). The results indicate that the Bazhin glacier has receded by 2.1 km², while the Chhongpher and Chongra glaciers have receded by 1.1 and 1.2 km², respectively. The largest retreat of the Bazhin glacier's snout position was 1595 meters; the Chhongpher glacier was 3260 meters; the Chongra glacier was 960 meters. The accumulation area of the three largest glaciers in the study region decreases as the annual AAR ratio rises from 0.4 to 0.8. We conclude that considering the greatest AAR and AABR values recorded between 5000 and 5600 meters above the sea level (masl), the biggest glaciers (such as Bazhin, Chhongpher, and Chongra) that extend from lower to higher elevations are probably more susceptible. Understanding the consequences of global warming and the possible repercussions for downstream communities requires research into glacier dynamics, ice melt, and the influence of temperature changes.

Investigating Glacial Dynamics in North Pakistan: A Landsat Perspective on the Karakoram Region

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The ongoing collision of Indian and Eurasian plates in north Pakistan is reflected by the development of mountain belts including Pamir, Karakoram, and the western Himalayas. These mountains are evolving with the development of tectonic geomorphology and crustal deformation with earthquake and seismicity. Karakoram is the most dynamic region on earth in terms of active high mountains and tectonic geomorphology with a remarkable fluvial and glacial system. The second largest glaciers outside the Polar region are accumulated in Karakorum, such as Baltoro, Hispar, and Batura glaciers. The present study is carried out to understand the Karakoram anomaly in active mountain ranges such as Karakoram in this climate change era. GIS data (Satellite images and DEM data) with field validation were analyzed to conduct this study. Glaciers are generally oriented in NW-SE direction, similar to structural trends. The results demonstrate that snow accumulation has reduced from 44.02% in 2002 to 27.75 % in 2017. In general, glaciation is reported in the Karakoram ranges however, the Shimshal Valley and other parts of the study area indicate retreating of glaciers. From the results of satellite imagery, the Hispar and Baltoro glaciers appear in an equilibrium state. Additional research could involve the integration of high-resolution satellite imagery and ground-based data to enhance the monitoring and understanding of glacier dynamics within the study area.

Integrated spaceborne HSI and field spectrometry for mapping different limestone facies, NE Kohat, Pakistan

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The evolution of remote sensing technology emerged as an efficient tool in geological investigation, particularly for mineral exploration and lithological mapping. The availability of numerous bands in the spaceborne hyperspectral imaging (HSI) is being adopted widely for such geological surveys. This study focuses on the capability of EnMap (i.e., hyperspectral satellite sensor) to differentiate different spectral facies of limestone outcrop. While the diagnostic spectral behavior for all carbonates remains consistent, certain elements either produce their own spectral features or influence the spectral response of carbonates. The two carbonates unit outcropped in the area are Kohat and Shekhan limestone. Field work was carried out across selective traverse, to observe on- ground textural behavior, collecting samples for petrology and geochemical analysis, and also to collect spectral data. Field investigation shows that both the limestone exhibits variety of textural and spectral behavior. Although the textural and spectral records of both units show identical behavior, but the iron related reflection curve in the region between 580-900 nm is more common in the Shekhan Limestone. The petrographic observations also confirm the relative higher percentage of oxidized mineralization in Shekhan Limestone. The Spectral Angel Mapper (SAM) classification successfully mapped these spectral facies, utilizing the image pixel's spectra as standard. The final classified map shows that the spectral facies are independent of stratigraphic order or age. The ferric facies are mapped in both the Kohat and Shekhan limestone, which is also observed in field spectral data. Additionally, field spectral records indicate ferric behavior for Kohat limestone at some locations, although it is prominent in Shekhan Limestone.

Debris flow hazard and risk assessment using morphometrics in Hunza watershed, northern Pakistan

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Debris flows are prevalent geohydrological disasters within the Karakoram terrain, primarily caused by heavy rainfall interacting with rugged topography and loose sediment. This research aims to provide a quantitative method to assess the risk of debris flow in a given area by examining the relationship between building vulnerability, fan exposure, and catchment hazards. The risk assessment procedure implemented in the study is organized into three essential steps. Hazard evaluation was carried out in third first stage using the normalized differential snow index (NDSI), precipitation, and causative factors, including slope angle, melton ratio, relief ratio, stream power index, topographic wetness index and drainage density. In the subsequent stage, five morphometric factors were used to estimate the exposure assessment: the fan area, the mean slope of the fan, the width and incision of the channel, and the distance between buildings and the channel. In the third phase, the vulnerability level was assessed at both regional and local scales, taking into account factors such as building type, foundation material, physical condition, and age. The results of the risk assessment conducted at the regional scale indicate that 0.91% of the area is extremely vulnerable to debris flow disaster. The results of local scale risk assessment of fans indicate that a high-risk zone comprising 530 buildings and a 2 km section of the Karakoram Highway (KKH). These findings highlight the importance of utilizing scientific risk assessment to inform preventive measures and mitigate debris flow hazards in the Hunza watershed.

Formation and Failure Mechanism of Pre-Historic and Historical Landslide Dams in Astore Valley (NW Himalaya, Pakistan)

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A landslide dam is a type of natural dam that forms when an earth mass or rock mass enters a river channel and results in its partial or complete blockage. When a river or channel is blocked by a sliding landslide, a landslide dam forms, creating a natural reservoir that overflows with water and/or sediments. The Astore valley has the characteristic feature of a narrow, steep landscape surrounded by high, uneven mountains with a high probability of landslide dams. The area is associated with the base of Nanga Parbat Haramosh syntaxes. Furthermore, the presence of active Raikot Fault is the diagnostic feature of the area. Four major formations of study area are Nanga Parbat Gneisses, Kohistan Batholith Kamila Amphibolite and Quaternary deposits. Landslide dams having differences in their construction, features and durability. Landslides dams occurred majorly in those regions which are seismically active zone, have volcanic activity and are glacially overstepped slope areas. Historical landslide dams identifying through satellite imagery and ASTER Digital Elevation Model (DEM) different geomorphic and topographic features like (Knick points, Thalweg, hummocky surface, bending river and balance of the stream passage along a valley) were recognizing through Arc GIS 10.5. For detailed investigation, we selected six landslide dams in the valley. Among the selected landslides the largest area was covered by the Gorikot landslide, which is 11.6 Km^2 area and the smallest one are Harcho landslide, which covers 1.2 Km^2 area. Several geomorphic parameters including total volume of the rockslide (Mm^3), volume of the rockslide dam, lake size (Mm^3), Drainage area of the rockslide in

kilometer2, and height of the maximum crest height of the rockslide, relief upstream of the point of blockage (HR=Emax−[Emin − HD]) (m), describes the rockslide dam and extreme altitude point in subsidizing catchment area (m), altitude of the rockslide dam (crest) (m), thickness of the dammed valley (m), local lengthwise slope of the waterway bed (°) were all studied during the construction of rockslide dams. A range of criteria were employed to define the stability or instability of landslide dams throughout time. II=log(VD/VL) and BI=log(VD/AC) are these indices, DBI=log (ACHD/VD), Basin index IA=log(HD2/AC), Back-stow index IS=log(HD3/VL), and Relief index IR=(HD/HR) Hydromorphic dam stability in one Log(VD/ACS) equals HDSI. Based on these indices Dion, Dashkin, Harcho, Darley landslides are unstable while Rattu and Gorikot are uncertain due to some indices and due to all others parameters were found unstable. Those factors which involves mainly in the instability of landslide dams are overtopping, pipe collapse, and slope failure are the three primary ways that enhance landslide dams failure.

Extracting clear ice surface of mountainous glaciers of Karakoram Range using Machine Learning for different Band Ratio compositions of OLI

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Glaciers of Hindu-Kash Karakoram Himalaya (HKH) significantly contribute to the earth's climate. However, the region needs more detailed knowledge about its glaciers. Specifically, the stability of glaciers in the Karakoram range of the Hunza sub-basin is a well-known anomaly. Therefore, monitoring its glaciers is needed to understand the dynamics of climate change in HKH. Glacier inventory is baseline data for monitoring, and the clear-ice surface is a quantifying parameter of glacier changes. Recently, Operational Land Imager (OLI), exploited with machine learning (ML), is highly recommended for glacier monitoring due to improved accuracy. Therefore, it is necessary to update the current status of glaciers in sub-basin using OLI and ML. This study aims to evaluate the current extent of clear ice in the sub-basin to examine stability and to explore the application of ML for extracting clear ice from OLI and assess accuracy. Random Forest classifier of ML set with minimum Root means square error (0.1 to 0.4), was used through SNAP environment. Results indicate satisfactory spatial distribution of clear ice in higher elevations (> 5000 meters) with 10 % area difference percentage exhibited in overall extent. However, 28 glaciers (area > 5 km2) showed variation in the extent and confirmed the localized heterogeneity. Overall accuracy (82% to 83%) and kappa coefficient values (0.64 to 0.65) confirm the significance of individual bands of OLI. It is concluded that the glaciers in the sub-basin have an overall stable clear-ice extent, except for variations in terminal ends. Whereas machine learning has a significant role in the automatic extraction of clear ice when exploited with the OLI.

Assessment of Flood Water Management Strategies in *Daraban* Watershed Using GIS and remote sensing

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The Daraban Zam is situated across the Khora River, about 13 km from Daraban town and 69 km from D.I. Khan city in the Khyber Pakhtunkhwa Province. The Daraban command area covers approximately 490 sq. km, with a longitude of 70.2011 and a latitude of 31.744. Heavy rainfall in the Daraban catchment area causes significant water flows in the Daraban command area, which also affects the river and nearby areas, ultimately resulting in flash floods. Assessing flood risk areas is a crucial aspect of flood management strategy. Storage of floodwater in various forms is an important component in reducing flood risks and protecting people and property from the damaging impacts of floods. The major objectives of this study were to assess the flood water potential in the Daraban watershed using satellite data, analyze the land use/land cover status of the catchment and command areas using GIS and remote sensing, and propose strategies for effective flood water management for agriculture and domestic use. Understanding how much water needs to be diverted or cut off from the study area is essential, as flood flow management techniques are developed based on the command area and the water potential generated from annual rainfall. For data acquisition, Landsat 8 imagery from 2013 and a digital elevation model with a spatial resolution of 30 meters for bands 1 to 5 and 7 were used. ArcMap 10.1 was used to determine elevation, slope, aspect, and water potential (annual rainfall, volume, and runoff) to develop suitable strategies for proper flood control. ERDAS Imagine 9.2 was used for the classification of both the catchment and command areas of the Daraban watershed. The results showed that the drainage of the Daraban command area flows from high elevation to low elevation. During heavy rainfall, water flows into the river near the Daraban command area, causing flash floods. The Daraban catchment area is at a high elevation, while the

command area is at a low elevation. The catchment area has a water volume of 24.1 million cubic meters (mcm^3), resulting in a runoff of approximately 6.266 mcm^3 (calculated as 24.1*0.26). The study concluded that a reservoir with a depth of 8 feet and covering 7 acres can be developed for proper water storage, fishing, crop raising, and other natural needs. This reservoir would contribute to the economy and social well-being of the people in its vicinity.

Estimation of runoff parameters by using Arc-GIS, HEC-RAS-GEORAS, and ground measurements of Teri-Toy River, Karak, NW, Pakistan

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River discharge estimation is an important parameter in hydrologic analysis and estimation of water resources, due to uneven distribution of gauge networks a severe challenge has been faced in its assessments, data sharing limitations, and to tackle these hardships, innovative and modern techniques has been established i.e., satellite and remote sensing data approaches. This study aims to estimate the river discharge by integrating remote sensing and ground measurements, achieving higher spatial and temporal resolutions. This study utilized remote sensing data including Digital elevation model, soil map, land use and land cover map, and ground measurements (gauge data) to estimate river discharge, velocity, and depth. It is interpreted that the peak flow velocity was recognized as 1.8 m/s and spatial distribution of velocity along the Teri-toye River is varied from 0.3 m/s to 1.3 m/s Maximum depth interpreted around 100 m in the upstream section and found decreasing upto few centimeters in downstream direction. River discharge decreases (from 2.26 to 0.28 m^3/s) towards downstream due to factors like water distribution in tributaries, infiltration, evaporation, and agricultural use. The novelty of this study is estimating river discharge with limited measurements, paving the way for assessing river properties over larger areas. Future research should assess the developed method (HEC-RAS-GEO-RAS) in estimating various properties of rivers under different hydrometeorological conditions.

Semi-Quantitative Landslide Risk Assessment in the Northern Pakistani Himalayas Using Remote Sensing and Building Typology Data

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In the Kaghan Valley, an area in northern Pakistan that is particularly vulnerable to landslides, this study suggests an integrated method to evaluate landslide risk, hazard, and vulnerability. In order to address the serious hazards that landslides pose to infrastructure, communities, and the environment, the study makes use of publicly available geospatial data in conjunction with semi-quantitative methodologies such as SMCE models. The study uses Google Earth Pro, high- resolution DEM, and satellite data to construct a full landslip inventory, which is subsequently confirmed through field surveys in order to develop a thorough understanding of landslide dynamics in the Kaghan Valley. A hazard map is developed by combining landslide-triggering factors with a susceptibility map generated using the WofE model. Due to limitations in temporal inventory data, hazard estimation relies on PGA and rainfall data, achieving an accuracy of 85% as assessed by AUC. In addition to hazard assessment, the study incorporates an extensive geographic database comprising building footprints, road networks, population data, and land cover information, obtained through remote sensing and field surveys. Vulnerability mapping encompasses various indicators across physical, social, environmental, and economic domains, analyzed through spatial multi-criteria evaluation techniques. For risk assessment, a semi-quantitative approach is adopted to classify relative risk levels into five categories: very low, low, moderate, high, and very high. The resulting landslide risk index map serves as a crucial tool for identifying hotspots and implementing effective risk mitigation strategies. Notably, the study's methodology stands out for its comprehensive integration of diverse data sources, enabling a holistic understanding of landslide risk in the Kaghan Valley.

A Comprehensive Approach: Remote Sensing and Geochemical Analysis for Mapping the Mafic Intrusion in the Arabian Shield

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The current research uses satellite imagery and Remote Sensing techniques in integration with field, petrographically and geochemical studies to identify the lithologies of Kamal layered mafic intrusion (KLMI) that is exposed in the Yanbu suture zone (YSZ) in northwest Saudi Arabia. This research uses Visible Near Infrared (VNIR) and Short-wave infrared (SWIR) of the ASTER image. To map the KLMI red, green blue (RGB) combination, decorrelation stretch (DCS), band ratios (BR), principal component analysis (PCA), minimum noise fraction (MNF), and spectral angle mapper (SAM) technique were used in integration with geochemical data. The FCC (False Color Composite) and DCS results show the hydrothermally altered zones; the BR differentiated the KLMI in dark red color from all other rocks. The PCA 135 and MNF 135 differentiated among the igneous, sedimentary, and metamorphic lithologies. The SAM results classify the KLMI and Nabat complex into the best correlation with the published map and geochemical results. The geochemical findings reveal a well-defined geological profile of Neoproterozoic rocks, including schists, gneisses, ophiolites, and various intrusive formations. The post-collisional nature of the KLMI is characterized by its un-metamorphosed and un-deformed state. The association of the KLMI with ophiolitic ultramafic rocks provides valuable insights into the geological evolution of the Yanbu suture zone. All the results were correlated with the published maps of the Ministry of Petroleum and Minerals, Saudi Arabia with a scale of 1: 250,000. The obtained data revealed that the overall accuracy is 78%, encouraging remote sensing to identify and map further suture zones. The results will help with local scale maping of the area and, eventually, aid in exploring valuable minerals.

Remote Sensing-based Mapping of Carbonate Lithologies in Northwest Mohmand District, Pakistan, Using Landsat 8 Imagery

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Marble, metamorphic rock rich in calcium carbonate ($CaCO_3$) and calcium magnesium carbonate ($CaMgCO_3$), has played a pivotal role in ancient civilizations and continues to be a significant resource for architectural purposes. The 19th-century surge in marble production led to its widespread use, with major quarries emerging in China, India, Italy, and Turkey. However, mapping and identifying marble deposits in remote and inaccessible regions remain challenging. This study introduces an integrated approach employing advanced remote sensing techniques to map carbonate lithologies in the Northwest Mohmand District, Khyber Pakhtunkhwa, Pakistan. Landsat 8 imagery is utilized alongside iterative adaptive reweighted regression (IARR), principal component analysis (PCA), minimum noise fraction (MNF), and spectral angle mapper (SAM) classification techniques. Data processing and analysis are conducted using the Environment for Visualizing Images (ENVI) software, with subsequent spatial analysis using geographic information systems (GIS), ArcMap, and Arc Scene software. Validation of the results is carried out through extensive fieldwork, X-ray diffraction (XRD), and petrographic analysis. The XRD and petrographic data validate the findings derived from the Landsat 8 imagery, confirming significant concentrations of dolomite and calcite, indicative of carbonate deposits. The implications of this study are particularly significant for Pakistan's marble industry, especially in Khyber Pakhtunkhwa, Punjab, and Baluchistan, where an estimated 300 million tons of marble reserves exist. Leveraging Landsat 8 imagery, this research aids in delineating valuable marble resources and provides recommendations for targeted exploration activities in the Mohmand area and beyond.

Land Sliding Susceptibility Mapping of Hazara Region, Pakistan

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The aim of this study is to carry out a detailed landslide susceptibility mapping using weighted overlay method in the Hazara Region, Pakistan. For this purpose, multiple datasets including slope, elevation, drainage density, lithological, soil, aspect ratio, active fault map, and land use/land cover (LULC) maps, are utilized to identify and assess various areas prone to landslide hazard. The Digital elevation model (DEM) is used to generate slope and aspect ratio maps, providing insights into terrain level characteristics crucial for landslide susceptibility assessment. The steeper slopes and specific aspects are marked as the most significant factors affecting and initiating the landslide occurrence. Similarly, the drainage density, calculated from hydrological data, is analyzed to identify areas with high water content, which are known to aggravate landslide risk. Moreover, lithological and soil type maps are integrated to identify zones that are characterized by weakly consolidated sediments and soil types marked by low cohesion and high permeability. Furthermore, the active fault map is compiled for the region from literature studies to identify structural weaknesses that may serve as preferential pathways for landslides. The LULC maps are analyzed to assess the impact of human driven activities on landslide. The intersection of these geospatial datasets by weighted overlay method in ArcGIS resulted in the hierarchical development of a susceptibility classes map for the region. The study area is categorized into low, medium, and high-class zones, delineating areas with differential degrees of landslide risk. The results of this study provide valuable insights for land use planning, disaster risk reduction, and informed decisive process to mitigate the impact of landslides in Hazara and similar mountainous regions.

Scenarios based debris flow hazard and risk evaluation in the Hindukush Mountain ranges, north Pakistan

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In mountainous regions worldwide, the occurrence of debris flows poses significant threats due to their intense velocity and forces, massive volumes of material, viscous flow, and long travel distance, resulting in causalities, infrastructure destruction, and destruction of ecosystems. Like other mountainous regions of the world, northern Pakistan is prone to debris flows because of its unique geomorphology, complex terrain, glaciers, rainfall pattern, deforestation, climatic variations, strong seismic activity, and human activities. Consequently, debris flows pose a serious hazard to human settlements and the environment in this region, where they could have catastrophic effects. As a result, anticipating the possible deposition regions of future debris-flow events in this region is crucial for risk reduction, emergency response, urban planning, and the protection of human and environmental assets. The current study involves a comprehensive assessment of debris flow hazard, vulnerability, and risk at a local scale in the village of Khalti in Ghizer district, located within the Hindukush Mountain ranges of northern Pakistan. The analysis involved employing Rapid Mass Movement Simulation (RAMMS), a 3D numerical simulation based on the Voellmy model, to model runout behavior. This allowed the estimation of crucial flow intensity parameters such as runout distance, velocity, elevation, and pressure along the path of propagation. For runout simulation, a very high-resolution DEM (digital elevation model) is used, which is a mosaic of UAV (unmanned aerial vehicle) generated and ALOS PALSAR DEM. Utilizing optimized frictional parameter values, a hazard assessment was carried out for two different potential release areas, each characterized by varying initial volumes. A hazard evaluation was

conducted using optimum frictional parameter values for two definite triggering blocks, each with different initial volumes. Moreover, a consolidated analysis was conducted to ascertain the likely runout distance and other flow intensity parameters for a range of potential scenarios that could emerge in the future. These results were exported to ESRI shape files for computing hazard maps. To evaluate vulnerability, the analysis incorporates data on elements at risk within the accompanying fan, encompassing factors such as the number of individuals, buildings, roadways, bridges, and agricultural and orchard lands. Multi-criteria analysis techniques were employed to ascertain the relative importance of each parameter in evaluating the vulnerability of each element to the debris flow. Risk maps are generated through the integration of potential hazard and vulnerability maps. The findings conclude that the debris flow scenario, which combines two release areas, exhibits the highest flow volume, vulnerability, and risk to exposed elements compared to the other scenarios.

An Integrated Approach for Potential Natural Aquifer Recharge Sites Demarcation in Panjkora River Basin, Pakistan

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Pakistan ranks fourth globally in terms of groundwater extraction. Its annual sustainable groundwater assets are evaluated at 55 billion cubic meters (BCM), but the groundwater withdrawal (annual) is 65 billion BCM. The majority of the water needed is obtained from groundwater resources, such as commercial tube wells and water bores. Finding natural aquifer recharge sites is therefore essential to provide the groundwater needed to address the water crisis. Therefore, the purpose of this study is to use fuzzy logic and the Multi Influencing Factor (MIF) method to find possible areas for natural aquifer recharging. Seven influencing factors (locally derived) water table, soil, slope, land use land cover (LULC), population density, elevation and drainage density are incorporated in this research in order to meet the stated purpose Fuzzy logic was used to standardize the aforementioned parameters, and maximum important factor (MIF) was employed to assess the components' relative importance. Lastly, factor maps were combined using the MIF and fuzzy logic techniques to identify natural aquifer recharge (NAR) sites in the Panjkora River Basin. Using both approaches, two distinct maps of appropriateness were created, and the maps were divided as: unsuitable, less suitable, moderately suitable, suitable and high suitable. The results indicate that 25% (MIF) and 30% (fuzzy logic) of the entire region is highly suited for natural NAR, while 20% (MIF) and 32% (fuzzy logic) of the study region was found to be suitable. Both the approaches can yield plausible results, nevertheless, the fuzzy logic suitability map has comparatively exhibited more accurate results. The study's findings are helpful to the concerned authorities and departments for planning NAR related campaigns in the study area and beyond.

Evaluating the Impact of Prime Minster Agriculture Emergency Program for Food Security and Sustainable Agriculture in Southern Khyber Pakhtunkhwa Pakistan

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Global food security is greatly dependent on the intricate and interconnected agricultural production systems. Despite being a lagging economic sector, agriculture accounts for 18.5% of the nation's GDP and employs 38.5% of the labor force. However, high-performing agriculture is essential for both economic growth and the reduction of poverty. The productivity of all major crops has stagnated over the past ten years, which has contributed to the agriculture sector's below-desired performance. The five traditional crops' total cultivated area has likewise mostly stayed constant. Pakistan's agriculture is seriously threatened by climate change, which also jeopardizes the nation's food security and water supply Due to its significance in establishing sustainable farming livelihoods and food security, groundwater utilization is a significant policy topic in developing countries. Pakistan's agriculture depends on the Indus basin, which is severely water-scarce because of climate change. There are two main dangers to the country's food and water security: inadequate irrigation techniques and a lack of policy changes. A resolution of the government is to increase the productivity of agriculture. In this connection the Prime Minister's Agriculture Emergency Program (PMAEP) has been initiated in 2018. The key objectives of the project are to bring maximum non cultivable land to best agriculture land, to conserve rainwater and to recharge aquifer. Water Conservation in barani areas the province is a huge project under the PMAEP where Soil and water conservation department constructed 1000 different structures to harvest rainwater. The purpose of this study is to find out the impact of water conservation structures in the region after the PMAEP and to find out how much

non-agriculture land were transformed to agriculture land. The Impact of the facilities were checked for the ground water potentially using MIF approach in GIS environment and supervised classification algorithm were used to find out the agriculture land use changes in KP after all the proposed sites were also marked for rainwater harvesting. The results revels that 4500 water recharge facilities were constructed in Khyber Pakhtunkhwa including Checkdams, Gullys, Waterponds, Water reservoirs and earthen ponds that can conserve rainwater and quickly recharge the aquifer while in Chitral, Abbottabad, DI khan and Kohat 10 no's of Watershed were constructed. The PMAEP have a positive role in groundwater recharge and for future food security. A total of 220-hectare scrub land were converted to agriculture land in different micro watersheds, while different slope areas were converted to terrace farming for best agriculture production.

Glacier Deposit-Based Zonation of Chitral valley, Northern Pakistan

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The District Chitral in the northern Pakistan is well-known for its diverse glacial- derived landscape, which has been formed over millions of years triggered by the different geological process. This study aims to classify and map glacial deposits in the Chitral Valley into distinct zones, providing an improved understanding of the region's geological history. The current zonation is based on detailed analysis of the characteristics and distribution of glacial deposits in Chitral Valley. These glaciers are mapped and classified into three distinct zones based on their location by utilizing remote sensing and GIS techniques. The results indicate that three distinct zones, Booni Zom, Terich Mir, and Broghil, have been identified based on unique glacial features. These zones are crucial as they serve as the origin points for major rivers that have shaped the valley's morphology. These zones correspond to various phases of glacial advancement and retreat. This study not only offers a framework for understanding the geological past of Chitral but also serves as a practical guide for assessing natural hazards and planning land use. Future research should focus on continuous monitoring and detailed analysis of these zones to enhance our understanding and preparedness for geological changes.