Analyzing Changes in Land Use and Cover (LULC) in the Quetta Valley Over Four Decades (1990-2020) Using Geospatial Techniques

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LULC changes have profoundly impacted environmental conditions, socio-economic development, and resource management in various regions. This study examines LULC changes in Quetta Valley, Baluchistan, Pakistan, over the past four decades (1990-2020) using geospatial techniques. The observed transformations primarily result from rapid urbanization, agricultural expansion, and population growth. LULC changes were analyzed using geospatial data from Landsat satellites, employing GIS and remote sensing (RS) methods. The findings indicate a steady increase in urban areas, with built-up land rising from 3.4% in 2000 to 7.17% in 2020, reflecting ongoing urbanization trends. This urban expansion has been accompanied by an increase in agricultural land, especially between 2010 and 2020, driven by the need to enhance food security. Vegetative cover has shown fluctuations, influenced by climatic variations and changing land management practices. Although barren land remains the predominant land cover type, its proportion has decreased slightly over time. These trends highlight the growing need for sustainable urban planning, effective agricultural management, conservation efforts, and integrated land management strategies. Policymakers should consider these LULC changes and their underlying causes when developing policies to ensure careful land use development and resource management, thereby promoting long-term environmental and socio-economic stability in Quetta Valley. This investigation provides insights into the dynamics of LULC changes and offers recommendations for sustainable land use planning in the region.

Keywords: Land Use and Land Cover (LULC); Urbanization; Geo-spatial Techniques; Sustainable Planning; Resource Management.

Introduction:

The rapid transformation of land use and land cover (LULC) presents a significant challenge in environmental science, particularly in regions experiencing accelerated ecological and socio-economic changes. Quetta Valley, a critical area in Baluchistan, Pakistan, has undergone substantial LULC changes over recent decades. These transformations, driven by urban expansion, agricultural activities, and socio-political factors, have profound implications for both the local environment and community [1]. Understanding these dynamics is crucial for developing effective sustainable development strategies [2]. Recent studies have employed geospatial techniques to monitor and analyze LULC changes. Remote sensing and Geographic Information Systems (GIS) have proven to be invaluable tools for researchers and policymakers, providing accurate, timely, and comprehensive data essential for understanding land transformations [3]. Numerous studies have demonstrated the effectiveness and adaptability of these techniques across extensive geographical areas, highlighting their importance in LULC research [4].

Recent advancements in geospatial technology have significantly enhanced the accuracy and applicability of land use and land cover (LULC) analysis. Innovations in satellite imaging, data-processing algorithms, and analysis software have greatly improved the ability to detect and quantify land changes. These technological developments provide more detailed analyses, enabling researchers to identify the factors driving changes and assess their environmental impacts. Consequently, there is a growing body of literature utilizing these technologies to tackle complex environmental issues [5]. Despite these global advancements, there is a notable lack of region-specific studies focused on the Quetta Valley. This research aims to address this gap by employing advanced geospatial techniques to examine LULC changes in Quetta Valley from 1990 to 2020. The study seeks to elucidate the spatial and temporal dynamics of land use and cover in the region, providing a comprehensive understanding of these transformations.

The structure of this research is organized as follows: The methodology section details the data sources and geospatial techniques utilized in the study. The results section presents the findings from the LULC analysis, highlighting significant changes and trends. The discussion interprets these findings in the context of local environmental and socio-economic factors, while the conclusions summarize the main results and their implications for future research and policy. The primary objectives of this study are to quantify the changes in LULC in Quetta Valley over the past forty years, identify the key driving forces behind these changes, and assess their environmental impacts. Additionally, this paper aims to offer novel insights into the application of geospatial techniques for regional LULC analysis, providing a model that can be replicated in similar settings. The relevance and accuracy of this work are underscored by its integration of the latest literature and technological advancements, offering valuable information for sustainable land management and policy development in Quetta Valley.

Material and Methods:

Investigation Site:

Study Area Selection:

Quetta, the capital of Baluchistan province in Pakistan, serves as the focus of this study (see Figure 1). The Quetta Sub-basin spans an area of 603 km², located between latitudes 30°00' to 30°30' N and longitudes 66°40' to 67°15' E [6]. The Quetta Valley is characterized by a semi-arid climate and diverse topography, with land use encompassing urban, agricultural, and natural covers. As a key economic hub, the valley has witnessed substantial population growth in recent years. Quetta City, with a population exceeding 3.0 million, is currently facing significant challenges due to its limited water resources, which are expected to become a critical issue in the near future. Situated at an average elevation of 1,680 meters (5,510 feet) above sea level, Quetta is notably the highest major city in Pakistan (see Figure 2).

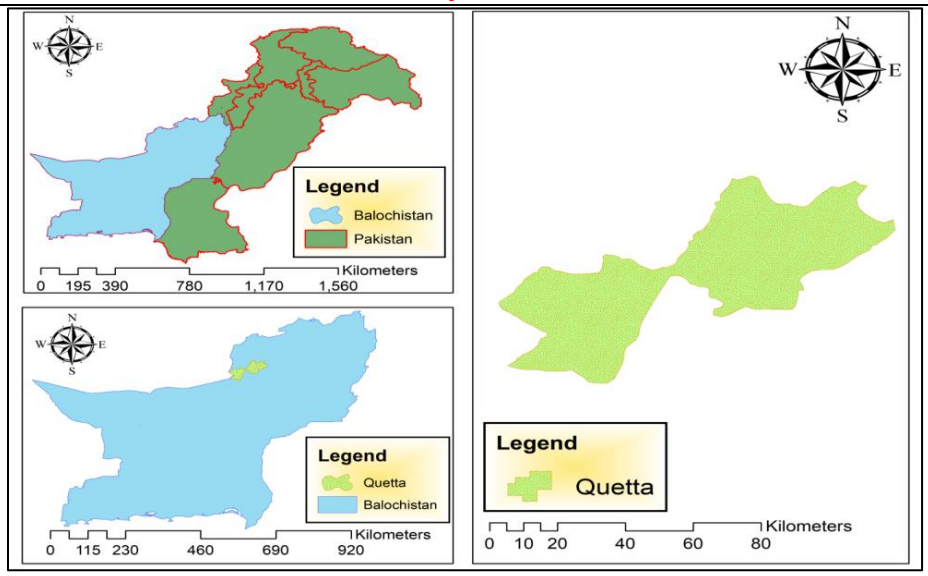

Figure 1: Location Map of the Study Area

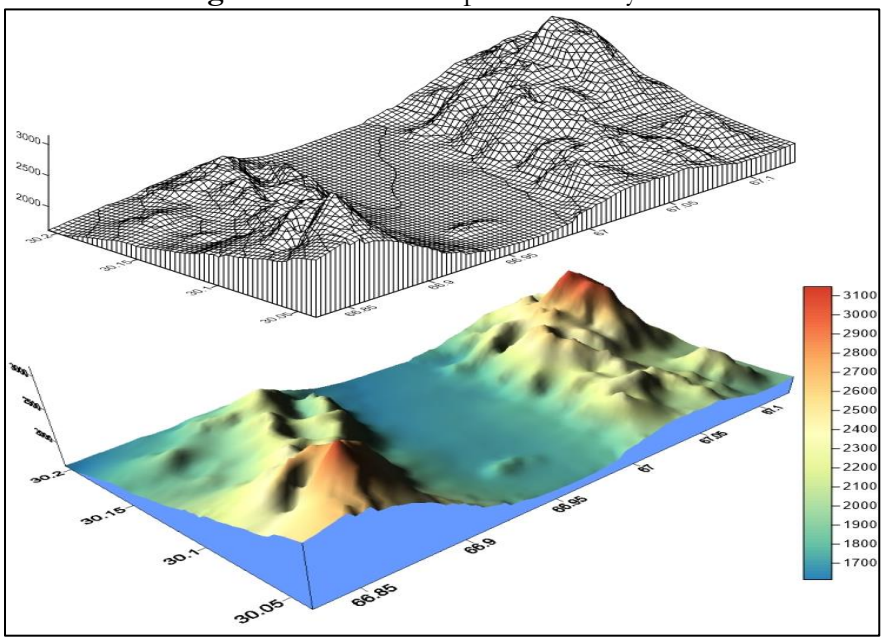

Figure 2: Elevation Map of Quetta Valley

Climatology:

Quetta Valley is characterized by a diverse environment with significant seasonal temperature variations. During the winter and spring, the region typically experiences rain and snowfall, which predominantly move westward. As the valley is outside the monsoon belt, summers are generally dry. Temperature averages in the summer range from 24°C to 26°C, autumn averages between 12°C and 18°C, winter temperatures are around 4°C to 5°C, and spring averages between 15°C and 20°C (see Figure 3). The lowest average monthly rainfall occurs in September, at 0.3 mm, while the highest monthly precipitation is recorded in January, at 56.7 mm [7].

Demography:

The population of Quetta Valley has experienced substantial growth from 1990 to 2020, significantly impacting land use and land cover (LULC). In 1990, Quetta's population was approximately 400,000. By 2000, it had risen to about 602,000, reflecting an annual growth rate of 3.08%. This upward trend continued, with the population reaching around 816,000 by 2010, driven largely by rural-to-urban migration in search of economic opportunities. By 2020, the

population had surged to approximately 1,100,000, with an annual growth rate of 2.80% (see Figure 4). This rapid population increase has spurred urban expansion, increased demand for housing and infrastructure, and led to the conversion of agricultural and natural lands into developed areas, underscoring the urgent need for sustainable land use planning.

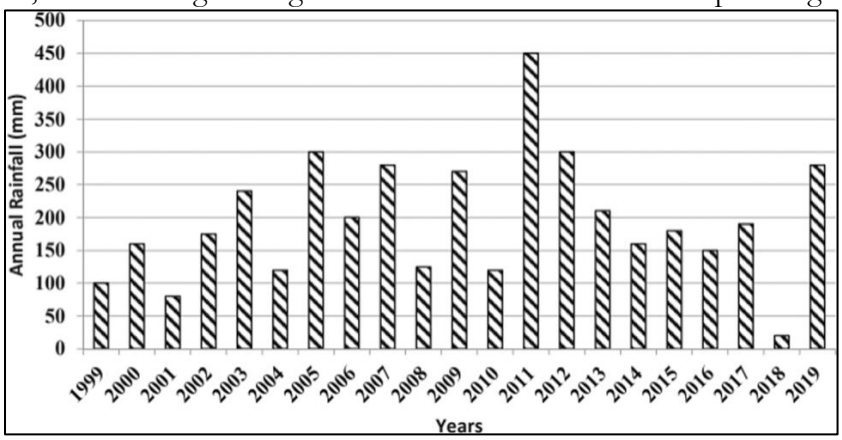

Figure 3: Annual rainfall data of Quetta Valley for the past 20 years

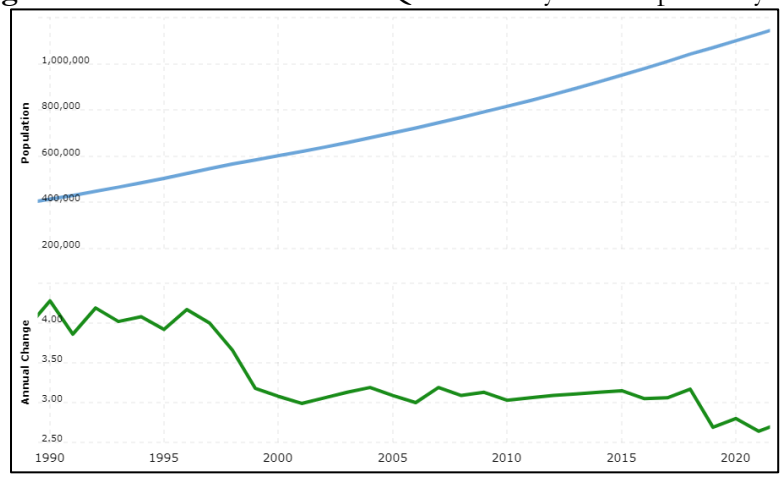

Figure 4: Population of Quetta Valley from 1990 to 2020

Materials and Methods:

- **Data Collection:**

Satellite Imagery: Landsat 7 imagery from 1990, Landsat 8-9 OLI/TIRS C2 L1 images from 2000 and 2010, and a Sentinel-2 image from 2020 were sourced from the United States Geological Survey (USGS) Earth Explorer (see Figure 5).

Ancillary Data: Topographic maps, demographic data, and historical records were gathered to support and enhance the analysis.

- **Preprocessing:**

Radiometric and Atmospheric Correction: Applied to maintain consistency across various time periods.

Georeferencing: Ensured precise alignment with ground features.

- **Image Classification:**

Supervised Classification: Applied the Maximum Likelihood Classification (MLC) algorithm to categorize the satellite images into distinct land use and land cover (LULC) classes: urban areas, agricultural land, vegetation, barren land, and water bodies.

- **Change Detection:** Compared classified images from various years to identify and quantify changes in land use and land cover (LULC).

Post-Classification Comparison: Compared classified images from different years to identify and quantify changes in land use and land cover (LULC).

➢ **Data Analysis:**

Spatial Analysis: Conducted within a GIS environment to visualize and analyze the spatial distribution and trends of land use and land cover (LULC) changes.

Statistical Analysis: Executed to quantify the extent and rate of changes, and to identify significant patterns and underlying drivers.

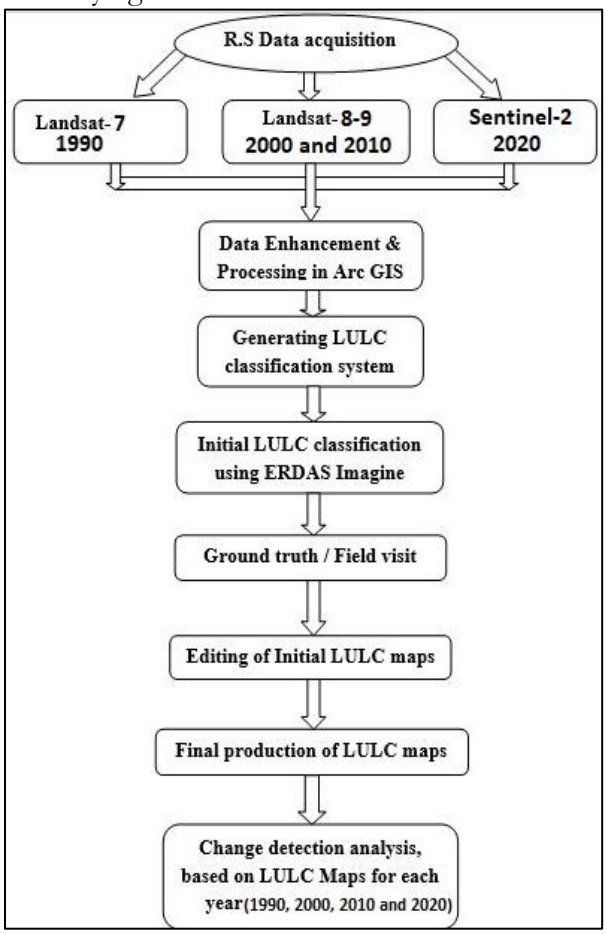

Figure 5: Flow chart of Land Use Land Cover Change Detection

Results and Discussion:

The analysis of land use and land cover (LULC) changes in the Quetta Valley from 1990 to 2020 reveals significant landscape transformations. LULC maps for 1990, 2000, 2010, and 2020 visually illustrate these changes and provide insight into the evolving dynamics of land use in the region.

LULC Changes in 1990: The 1990 LULC map highlights the dominance of barren land, which covered 63.71% of the total area, followed by trees at 25.04% and water bodies at 11.23%. This predominance of barren land reflects the semi-arid conditions of the Quetta Valley and the limited vegetation cover during this period. The presence of water bodies, although modest, indicates some level of water resources that could support restricted agricultural activities and natural vegetation (see Figure 6).

LULC Changes in 2000:

By 2000, the LULC pattern had undergone significant changes. The map reveals a notable increase in built-up areas in and around Quetta City, which now comprise 3.4% of the total land cover, indicating rapid urbanization. Barren land remains the dominant land cover type, accounting for 88.7%, with the remainder consisting of trees. The rise in built-up areas reflects population growth and urban expansion, while the introduction of shrublands suggests shifts in vegetation patterns, likely driven by land management practices and climatic conditions (see Figure 7).

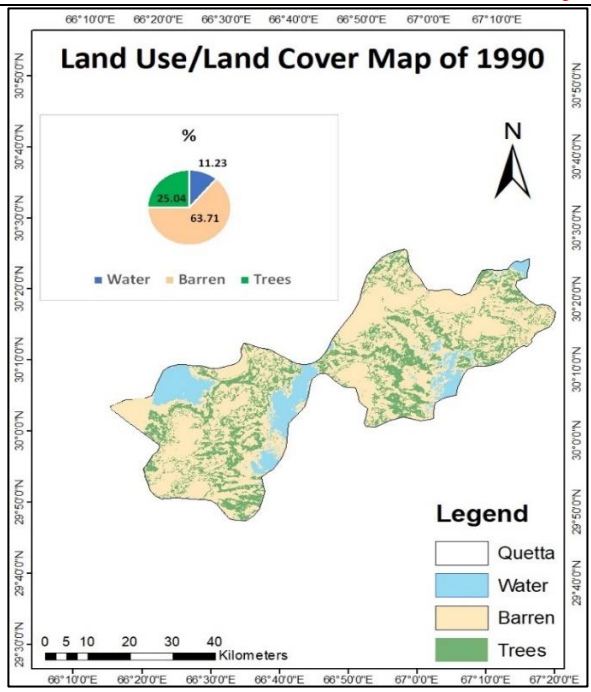

Figure 6: Land use and land cover map of Quetta valley of 1990

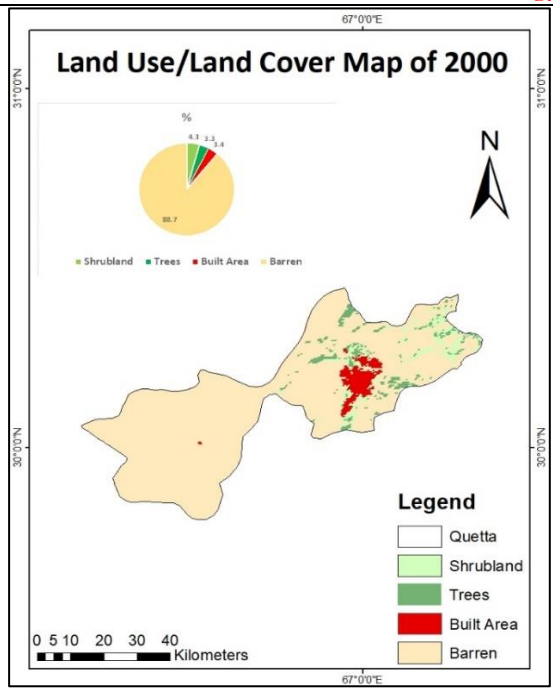

Figure 7: Land use and land cover map of Quetta valley of 2000

LULC Changes in 2010:

The 2010 LULC map shows continued urban expansion, with built-up areas increasing to 7.8% of the total land cover. Barren lands remain predominant at 76.2%, but there is an increase in shrubland to 12.5% and trees to 3.4%. Additionally, agricultural activities have become more apparent, with crops occupying 0.005% of the area. These changes reflect ongoing urbanization and agricultural intensification, likely driven by the need to accommodate a growing population and support economic activities (see Figure 8).

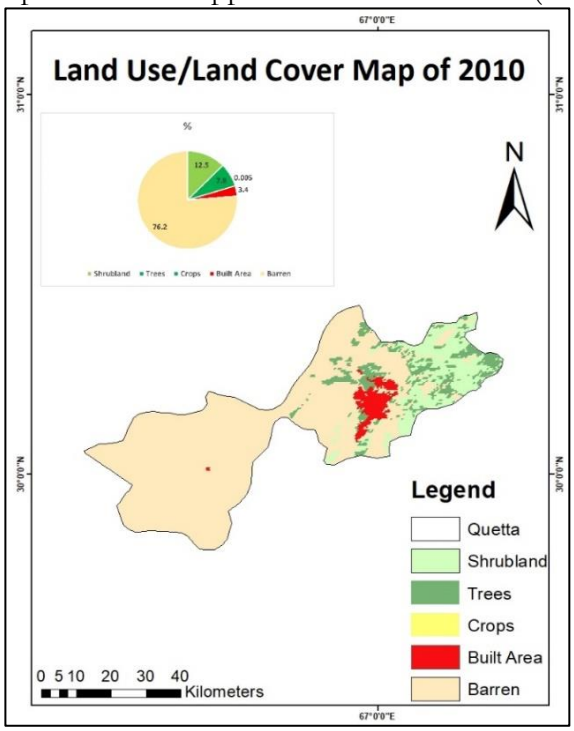

Figure 8: Land use and land cover map of Quetta valley of 2010

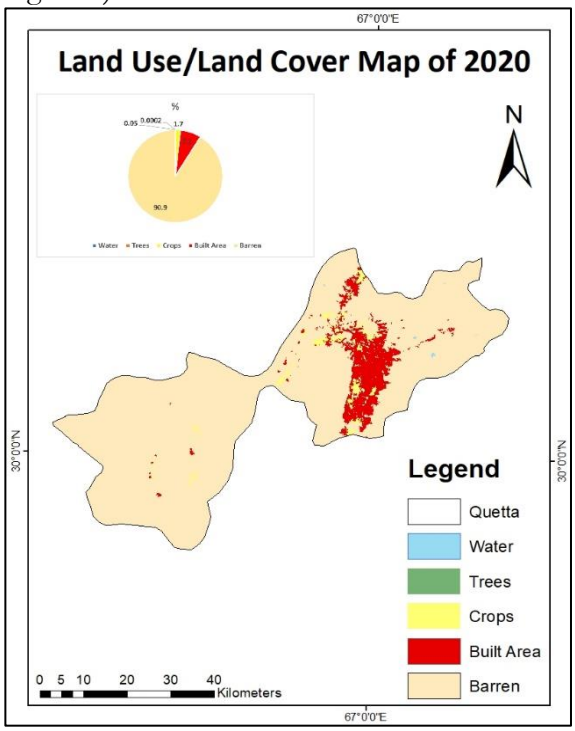

Figure 9: Land use and land cover map of Quetta valley of 2020

LULC Changes in 2020:

By 2020, the built-up area has significantly increased, covering 7.17% of the total land area. Despite this growth, barren land remains the dominant land cover at 90.9%, although it has decreased slightly compared to previous years. Trees now cover 1.7% of the area, while crops occupy 0.05%. The expansion of built-up areas underscores the ongoing urban development within the Quetta Valley. Additionally, the modest increase in agricultural land and the slight decrease in vegetation cover indicate a trend toward more intensive land use practices (see Figure 9).

The LULC analysis over the four-decade period from 1990 to 2020 reveals several critical trends:

Urban Expansion:

The urbanization gradient has significantly increased, particularly in and around Quetta city. This expansion is driven by rising population, economic development, and infrastructure growth. The built-up area grew from 3.4% in 2000 to 7.17% in 2020, reflecting an ongoing trend of urbanization.

Agricultural Activities:

Agricultural land, initially introduced and then expanded, increased significantly during the decade from 2010 to 2020. This trend indicates a rise in agricultural activities, likely driven by the need to meet the food demands of the rapidly growing population and ensure food security in the region.

Vegetation Cover:

The percentage of land covered by trees and shrubland has fluctuated throughout the study period. The initial introduction of shrubland in 2000, its subsequent expansion, and the varying proportions of tree cover suggest changes in vegetation patterns. These variations are likely influenced by factors such as climatic changes, land management practices, and potentially reforestation efforts.

Barren Land:

Barren land has consistently been the most dominant land cover category throughout the study period, although its proportion has gradually decreased over time. This enduring dominance highlights the semi-arid climate and limited natural vegetation characteristic of the Quetta Valley.

Conclusion:

This study identifies significant changes in land use and land cover (LULC) in the Quetta Valley from 1990 to 2020 by comparing different time periods. It highlights the major landscape transformations driven by rapid urbanization, agricultural expansion, and population growth. The results reveal a consistent increase in urban areas, particularly around Quetta City, with the built-up area rising from 3.4% in 2000 to 7.17% in 2020. This trend underscores the region's ongoing urbanization, fueled by economic development and infrastructure growth. Additionally, the increase in agricultural land from 2010 to 2020 reflects efforts to enhance food security for a growing population. Vegetation cover, including trees and shrubland, fluctuated in response to climatic changes and land management practices. Despite these variations, barren land remained the dominant land cover, indicative of the semi-arid climate of the valley, though its proportion slightly decreased over time. These findings emphasize the need for sustainable urban planning, effective agricultural management, conservation efforts, and integrated land management strategies. Implementing such measures can help policymakers and planners balance development with conservation, ensuring sustainable LULC management and reducing environmental and socio-economic instability in the Quetta Valley.

Recommendations:

- **Sustainable Urban Planning**: Implementing guidelines to control urban expansion and promote sustainable urban development.

- **Agricultural Management**: This approach will foster long-term sustainable agriculture, mitigating land degradation and enhancing food security.
- **Conservation Efforts**: Programs aimed at conserving natural vegetation and biodiversity, along with reforestation efforts.
- **Integrated Land Management**: Developing integrated land use plans that incorporate environmental, economic, and social considerations when planning land use changes.

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Author's Contribution: Areeb Ul Haq is the first author and did all work related to methodology under the supervision of Abdul Latif Qureshi and Muhammad Afzal Jamali

Conflict of Interest: There are no conflicts of interest reported by the writers.

References:

[1] J. Hayat, S., Szabóa, Z., Tóth, Á., Mádl-Szőnyi, "MAR site suitability mapping for arid–semiarid regions by remote data and combined approach: A case study from Balochistan, Pakistan", [Online]. Available: https://www.acquesotterranee.net/acque/article/view/505

[2] N. Kakar, D. M. Kakar, and S. Barrech, "Land subsidence caused by groundwater exploitation in Quetta and surrounding region, Pakistan," Proc. IAHS, vol. 382, pp. 595–607, Apr. 2020, doi: 10.5194/PIAHS-382-595-2020.

[3] F. Dawood, M. M. Akhtar, and M. Ehsan, "Evaluating urbanization impact on stressed aquifer of Quetta Valley, Pakistan," 2021, doi: 10.5004/dwt.2021.27068.

[4] "NHESSD - Detection of Land Subsidence due to Excessive Groundwater Use Varying with Different Land Cover Types in Quetta valley, Pakistan Using ESA-Sentinel Satellite Data." Accessed: Jun. 10, 2024. [Online]. Available: https://nhess.copernicus.org/preprints/nhess-2017-234/

[5] W. Ahmad, M. Choi, S. Kim, and D. Kim, "Detection of land subsidence and its relationship with land cover types using ESA Sentinel satellite data: a case study of Quetta Valley, Pakistan," Int. J. Remote Sens., vol. 40, no. 24, pp. 9572–9603, Dec. 2019, doi: 10.1080/01431161.2019.1633704.

[6] S. M. Khair, S. Mushtaq, R. J. Culas, and M. Hafeez, "Groundwater markets under the water scarcity and declining watertable conditions: The upland Balochistan Region of Pakistan," Agric. Syst., vol. 107, pp. 21–32, Mar. 2012, doi: 10.1016/J.AGSY.2011.11.007.

[7] I. H. Durrani, S. Adnan, M. Ahmad, S. M. Khair, and E. Kakar, "Observed Long-Term Climatic Variability and Its Impacts on the Ground Water Level of Quetta Alluvial," Iran. J. Sci. Technol. Trans. A Sci., vol. 42, no. 2, pp. 589–600, Jun. 2018, doi: 10.1007/S40995-017-0235-8/METRICS.