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GEOSPATIAL ANALYSIS OF VEGETATION AND SOIL TYPE DYNAMICS USING REMOTE SENSING AND GIS IN PAKISTAN

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ABSTRACT

This study aims to evaluate the dynamics of vegetation, soil types, and their inter-relationship through the analysis of normalized difference vegetation index (NDVI) and soil data in Pakistan. The data utilized spans from January 2014 to December 2018 and is sourced from the MODIS-derived NDVI data product, MOD13A3, acquired from the USGS site. The MODIS product plays a crucial role in assessing NDVI at various temporal scales, including monthly, seasonal, annual, and intra-year analyses. In addition, soil maps were generated by utilizing secondary data and digitizing the information through ArcGIS 10.3, providing a comprehensive foundation for the investigation into the interplay between NDVI and soil types in the specified region. For a comprehensive analysis, randomly generated points were employed to extract values from five years of MODIS NDVI images. A total of 3,200 random points were systematically generated for precise value extraction purposes. Subsequently, the datasets resulting from this meticulous process were subjected to thorough analysis using Excel spreadsheets. This approach establishes a robust foundation for scrutinizing and understanding the correlation between normalized difference vegetation index (NDVI) and soil types within the specified study area. The analysis revealed higher NDVI values in 2015, contrasting with lower values in 2018. The years 2014, 2016, and 2017 exhibited medium NDVI values. Notably, loamy soil types consistently displayed higher NDVI values. The overall inter-year NDVI trend indicated higher values during the post-monsoon season, while the monthly average NDVI remained lower in the pre-monsoonal months. This observed NDVI pattern could be harnessed to improve crop production and inform effective management strategies.

KEYWORDS: MODIS-NDVI, MOD13A3, Soil in Pakistan, Vegetation in Pakistan, Cropping, Food.

1. INTRODUCTION

At all conceivable geological levels, vegetation is helpful to the earth, climate, biological system, and environment. It controls the development of

a few biogeochemical cycles, the most significant of which are carbon, nitrogen, and water. This is fundamental for all types of life (Brandt et al., 2015; Qi et al., 2019; Schlüter et al., 2022). Farming and greener regions generally have a positive job on well-being and nature, and they could utilize it even to decrease the illness rate. Moreover, as well as further developing air quality and propelling clinical information, side-of-the-road vegetation can assist with enhancing the street, raising property estimation, lessening temperature, and surface hydrology and stream of the water (Xiong et al., 2021; Ding et al.,2021; Zheng et al., 2022).

Vegetation associations are likewise critical for an assortment of air, normal, and environmental perspectives. It additionally affects soil characteristics like volume, discipline, and land surface. For the real environment and monitoring environment, vegetation in all designs, as well as harvests, woods, and natural and man-made impacts, are basic. The worth of vegetation to the individuals who are encircled by it and delicate to it can't be accentuated. Plants and creatures track down food and asylum in biomes and timberlands, and vegetation types affect greenery overall. Plant communities and environments give food and haven to plants and creatures, and vegetation types influence verdure nature overall. Normal vegetation game plans and their mixes are impacted by climatic vulnerability and dangers.

Different examinations have been made considering the association between climate and vegetation, and the pace of vegetation use records. Since vegetation established a connection between soil, water, and air in the typical habitat by altering the general water cycle, carbon cycle, significant trades, and normal quality, we can anticipate a significant improvement in altering the general water cycle, carbon cycle, significant trades, and normal proficiency. When it comes to monitoring farming operations, which face unique challenges that aren't seen in other observatories, the utilization of remotely sensed information is essential (De Castro Oliveira, 2021). They are influenced by a variety of other factors, including the type of soil, in addition to the physical view.

Vegetation also relies on agricultural management and climate-determining factors. Every aspect has a significant effect. Additionally, a project's viability can shift over time. Future requirements must be met, as stated by the Food and Agricultural Organization (FAO) (Horn et al., 2021; Zhang et al., 2022; Krakauer et al., 2023). According to Xue & Su (2017), data from remote sensing can be used to address future issues and guarantee global food security. The majority of the 795 million people in the world, including small-scale ranchers and fishermen, struggle to survive daily (Augustin et al., 2016; Fears et al., 2019; Peng, et al., 2023). Since Pakistan's populace is expected to be roughly 207 million individuals, food security and nourishing

circumstances are a subject of concern (Gross et al., 2000; Tanumihardjo et al., 2019; Hussain & Karuppannan, 2023). Food crops, as well as their accessibility and cost, defy various difficulties. Consequently, vegetation management and monitoring are frequently required. Crop yield instability should be checked to give an early admonition framework to food the board and starvation (Kazemi et al., 2023).

The research gap or problem statement that motivated our study is the need for a comprehensive understanding of the relationship between the normalized difference vegetation index (NDVI) and soil types in the environmental landscape of Pakistan. Despite the significance of both NDVI and soil types in ecological and agricultural studies, there exists a lack of detailed investigations into their specific correlation within the context of Pakistan. This research is particularly crucial for the environmental landscape in Pakistan due to several reasons. Firstly, Pakistan's diverse topography and climatic conditions create a unique ecological setting where the interplay between vegetation and soil is intricate and essential for various ecosystems. Understanding the correlation between NDVI and soil types can provide valuable insights into the health and dynamics of vegetation in different regions.

Secondly, Pakistan faces environmental challenges, including land degradation and water scarcity, which directly impact agricultural productivity. A deeper understanding of the relationship between NDVI and soil types can contribute to more informed land management practices, aiding in sustainable agriculture and natural resource conservation.

Moreover, the findings of this study can have implications for land-use planning and environmental monitoring. By elucidating how different soil types influence NDVI values, the research can guide policymakers in making informed decisions regarding land development, afforestation initiatives, and the overall management of natural resources. This research addresses a critical gap in knowledge regarding the correlation between NDVI and soil types in Pakistan. The significance lies in its potential to enhance our understanding of the environmental landscape, support sustainable practices, and contribute to informed decision-making for the benefit of both ecosystems and communities in the region.

2. MATERIAL AND METHODS

2.1. Study Area

Pakistan is a large country in South Asia with a diverse landscape and large population. It currently ranks sixth in terms of population. The area covers nearly 881,913 square kilometres (340,509 sq mi) (Figure 1). There are all seasons and beautiful peaks with watersheds that feed the river year-round

with significant monsoon rains. In general, conditions are favourable for large-scale agriculture in the upper and lower Indus plains. In general, the climatic conditions are dry. Most of the land is fertile, but poor water conditions limit yields and yields.

Figure 1. Pakistan (study area).

2.2. Arid derived soil type in Pakistan

Widespread drought characterizes Pakistan, serving as the primary climatic indicator that influences the country's soil composition. Despite being rich in essential nutrients, Pakistani soils notably lack nitrogen. The soil is formed from two types of parent materials, each exhibiting mixed geochemistry, and encounters with bedrock introduce additional materials. Limestones constitute the predominant rock type, with lime-free soil materials extracted in various locations, often from granite. The breakdown of stones releases diverse salts, contributing to the substantial desalination of the soil. The distinctive properties of Pakistani soil types are attributed to the source materials and the processes involved in their formation. Alluvial soils are formed by the accumulation of debris from watercourses. The sands of the desert have turned into separate areas. Residual soils with alluvium, loess, and other soils were created by the slope of mountains with higher slopes

and levels. Accordingly, Pakistani soils can be divided into six types: floodplain alluvial soils, Bar Highland alluvial soils, Piedmont Lowland alluvial soils, desert soils, Potwar Plateau alluvial soils, and Western Hills alluvial soils.

2.3. Soil data and MODIS NDVI DATA

The GIS data was generated through the amalgamation of secondary sources and soil maps. ArcGIS 10.3 software played a pivotal role in computing land type and area. The MODIS NDVI is a globally applicable product with a 1 km resolution utilized monthly.

2.4. Remote sensing derived vegetation assessment (NDVI)

The NDVI is one of the most commonly used indicators to evaluate large-scale vegetation greening and has been used in several studies. NDVI is a combination of the bright red and near-infrared spectrum reflected by vegetation (Equation 1). These two wavelengths are related to strong plant traits and photosynthesis. In this depiction of photosynthetic methods (infrared band), plants are reliably adapted to visible light (red band) and near-infrared light.

NDVI = (NIR RED)/(NIR + RED)…….Equation1

Vegetation is affected by precipitation, soil moisture, and soil or surface temperatures. Temperature, climate, and precipitation changes are the most likely causes of the effects of climate instability on plants. Nutrient cycling can lead to differences in the microbial and physiological activity of plants. Erratic rainfall can affect soil moisture balance. The main goal of the study is to map datasets such as NDVI and climate datasets and find relationships between them.

2.5. Procedure

Monthly NDVI imagery (MOD13A3) spanning five years, amounting to 60 rasters, was acquired. After conversion, resizing, and projection processes, grids were employed to generate monthly, seasonal, and yearly composite images. A total of 3200 sample points were strategically prepared, and value extraction was systematically applied to each raster, as illustrated in Figure 2. The culmination of these steps involved the creation of tables containing pertinent information on NDVI and soil types.

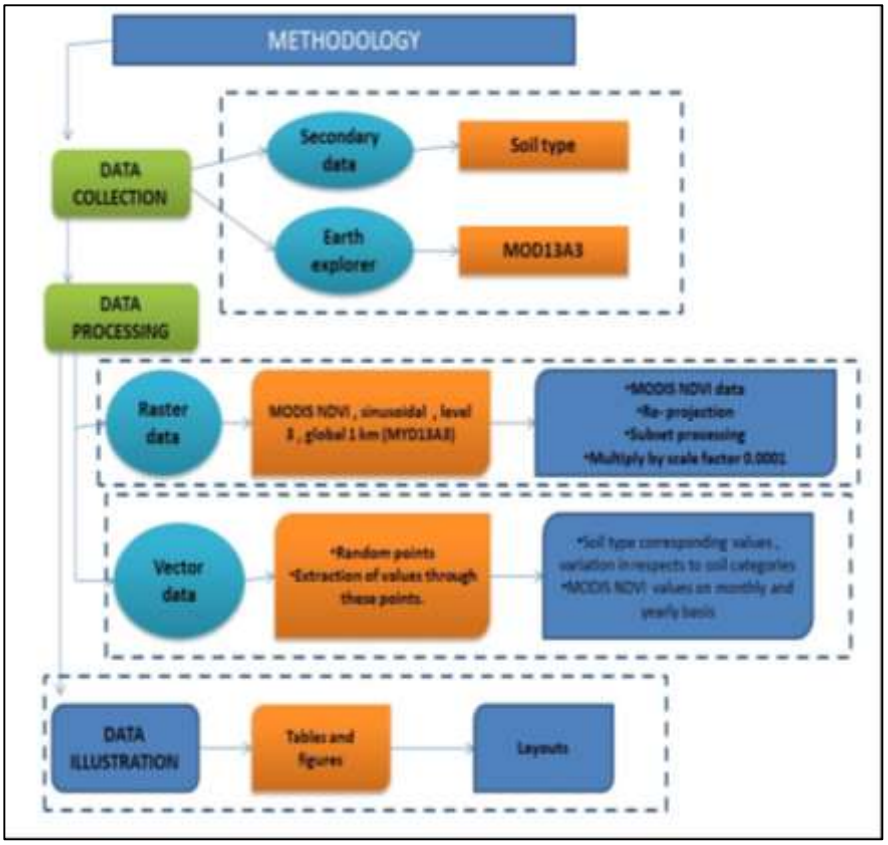

Figure 2. Flow chart of the study.

3. RESULTS AND DISCUSSION

3.1. NDVI image for a year and over five years

The NDVI images for 2014, 2015, 2016, 2017, and 2018 were created using a combination of annual images (see Figures 3a to e and f). The highest NDVI values were observed in 2015, while the lowest NDVI values were observed in 2018, with average increases in NDVI observed in 2014, 2016, and 2017.

3.2. Soil map

Figure 4 shows a soil map produced from secondary informational sets and maps. Desert soil, playa, residual of potwar, tidal, saline, loamy, rock soil, and clayey soil are the main soil types found. Later estimates of soil type region have been made as follows: (Table 1).

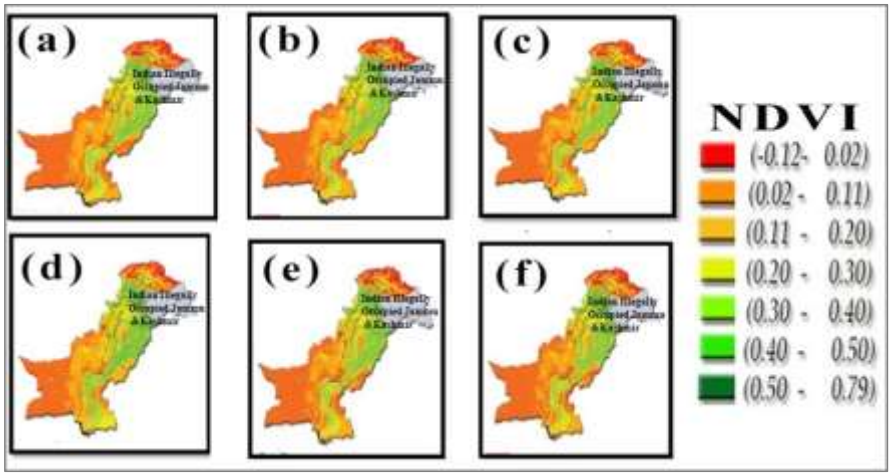

Figure 3. Aggregate NDVI annual composites (Jan to Dec): (a) 2014 (b) 2015 (c) 2016 (d)2017 (e) 2018(f)all NDVI Composite images 2014 to 2018 (Disputed Territory Final Status To Be Decided In Line With Relevant UNSC Resolutions).

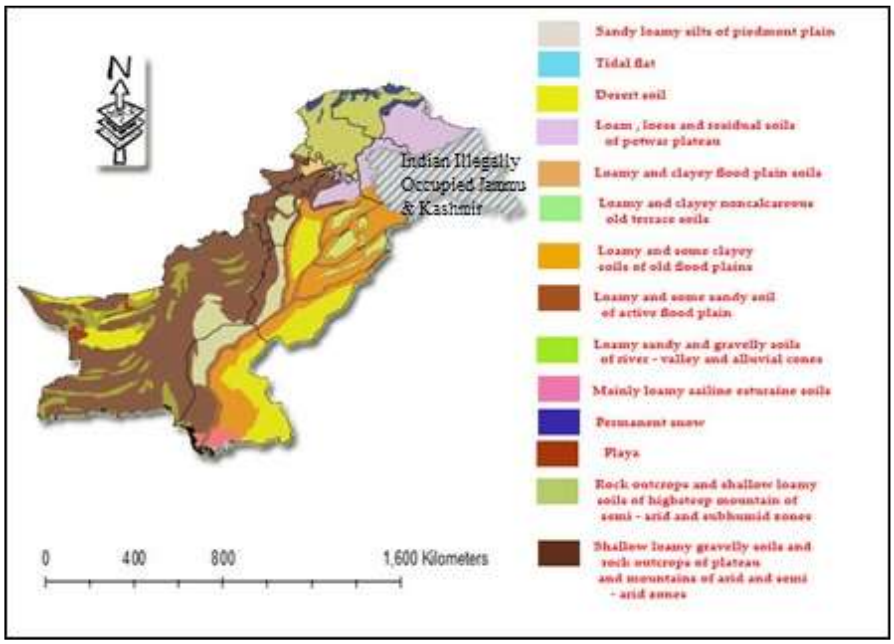

Figure 4. Pakistan Soil Types (Disputed Territory Final Status To Be Decided In Line With Relevant UNSC Resolutions).

Table 1. Soil and area covered

Soil Types	Area in km2
Desert Soil	116025
Loam, Loess And Residual Soils of Potwar Plateau	62780
Loamy and Clayey Flood Plain Soils	4887
Loamy and Clayey Non calcareous Old Terrace Soils	20321
Loamy and Some Clayey Soils of Old Flood Plains	102493
Loamy and Some Sandy Soil of Active Flood Plain	37317
Loamy Sandy And Gravelly Soils of River Valley and Alluvial Cones	59550
Mainly Loamy Saline Estuarine Soil	8847
Permanent Snow	10911
Playa	2970
Rock Outcrop and Shallow Loamy Soils of High Steep Mountain of Semi-Arid And Sub Humid Zones	69089
Sandy Loamy Silts of Piedmont Plains soil	60070
Shallow Loamy Gravelly Soils and Rock Outcrops of PleatuexMountains of Arid And Semi-Arid Zone	317083
Tidal Flats	3656
TOTAL AREA	**875,999**

3.3. Soil type and NDVI variation

As information has been extracted from random points, soil contrasts and NDVI values change (Table 2). As far as NDVI is concerned, each type of soil and its time-sensitive characteristics make it limited. Average NDVI values of 0.40, 0.425, and 0.4 were found in loamy and clayey floodplain soils, loamy and clayey non-calcareous ancient terrace soils, and loamy and some clayey soils of old floodplains, respectively. The remaining soil types have low levels of NDVI values.

Table 2. Variability in Pakistani soil and NDVI annual average

Soil Types	2014	2015	2016	2017	2018	Average 5 (years)
Desert Soil	0.159	0.174	0.175	0.178	0.16	0.169
Loam, Loess And Residual Soils of Potwar Plateau	0.314	0.329	0.322	0.31	0.318	0.319
Loamy and Clayey Flood Plain Soils	0.393	0.423	0.392	0.4	0.415	0.404
Loamy and Clayey Non calcareous Old Terrace Soils	0.423	0.431	0.426	0.425	0.419	0.425
Loamy and Some Clayey Soils of Old Flood Plains	0.402	0.408	0.403	0.411	0.395	0.404
Loamy and Some Sandy Soil of Active Flood Plain	0.345	0.342	0.35	0.361	0.351	0.35
Loamy Sandy And Gravelly Soils of River Valley and Alluvial Cones	0.111	0.105	0.109	0.119	0.107	0.11
Mainly Loamy Saline Estuarine Soil	0.218	0.213	0.218	0.223	0.213	0.217
Permanent Snow	0.074	0.07	0.086	0.082	0.084	0.079
Playa	0.064	0.059	0.061	0.065	0.064	0.063
Rock Outcrop and Shallow Loamy Soils of High Steep Mountain of Semi-Arid And Sub Humid Zones	0.329	0.336	0.337	0.324	0.335	0.332
Sandy Loamy Silts of Piedmont Plains	0.249	0.261	0.258	0.258	0.246	0.254
Shallow Loamy Gravelly Soils and Rock Outcrops of PleatuexMountains of Arid And Semi-Arid Zone	0.178	0.189	0.179	0.173	0.173	0.179
Tidal Flats	0.148	0.153	0.149	0.162	0.153	0.153

3.4. BOX plot for trend and inter-annual variability

The bimodal peaks in the monthly estimate occur in the monsoon months of March-April and August-September (Fig. 5). Box plots from 2014 to 2018 show the inter-annual variability of the NDVI (Fig. 6). Overall, the highest mean vegetation value (0.273) was measured in 2015, while the lowest mean NDVI value (0.261) was measured in 2018.

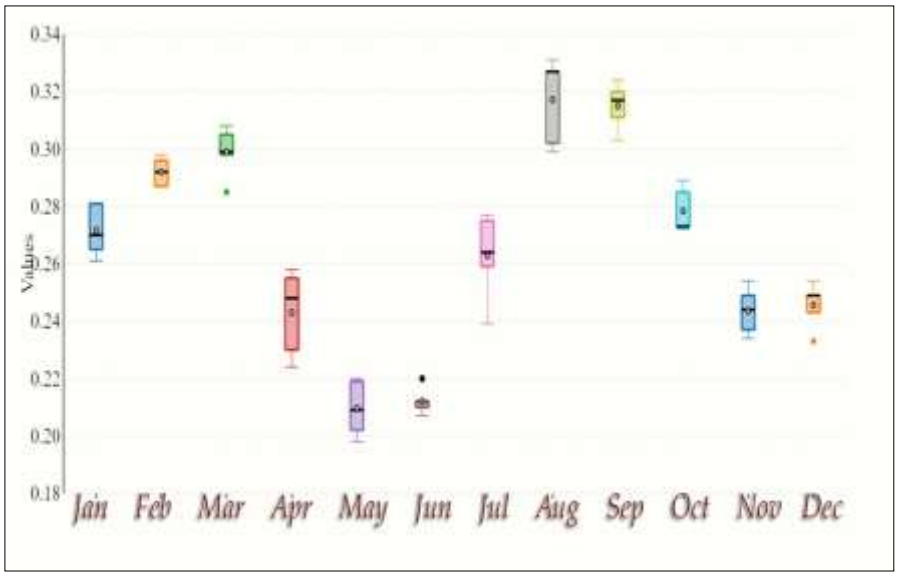

Figure 5: Average monthly variability of NDVI from 2014 to 2018.

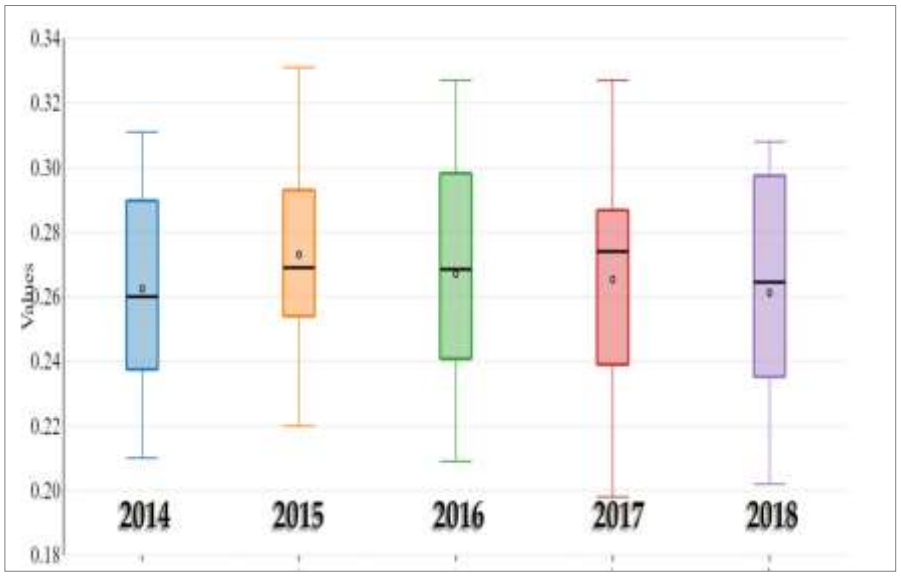

Figure 6: NDVI inter-annual variability from 2014 to 2018

This study involves the calculation of the Normalized Difference Vegetation Index (NDVI) using MODIS data (MYD13A3), assessing data variability on a monthly, seasonal, and yearly basis. Results indicate that the peak vegetative development occurred in 2015, while the lowest development was observed in the driest year, 2018. The years 2014, 2016, and 2017 are categorized as moderate, suggesting irregularities. Notably, during the monsoon season (July to September), substantial rainfall contributes to overall vegetation development, with August and September exhibiting the

highest growth. Post-monsoon, peak values are recorded in August and September, with an average vegetation NDVI of 0.327 in August and a minimum of 0.210 in May. The natural vegetation significantly contributes to animal production, crucial for local and global food security, particularly in the production of milk and meat. Given the relatively constant agricultural land area, the study emphasizes the need for increased food production from existing agricultural lands in Pakistan.

Plants and natural products play a crucial role in providing the necessary energy and protein for human consumption. Notably, plant-based food production exhibits a carbon footprint comparable to that of mixed systems. According to Yue et al. (2023), vegetation and crops serve as significant carbon sinks, offering substantial potential for further growth. However, adaptation of vegetation to climate change is anticipated to be diverse, leading to potential fluctuations in production and variations in soil carbon storage, as indicated by studies conducted by Gonzalez et al. (2010), Shi et al. (2022), and Stamford et al. (2023).

In regions near rivers and at higher altitudes, the impact of soil erosion necessitates the implementation of effective soil conservation strategies. In response to changing environmental conditions, urgent adjustments in cropping patterns are essential to enhance productivity, as emphasized by studies conducted by De Castro et al. (2021), Xu et al. (2022), and Kogan (2023). These proactive measures are vital to addressing the challenges posed by evolving conditions and ensuring sustainable agricultural practices.

Following the analysis of results, a nuanced understanding of the correlation between the normalized difference vegetation index (NDVI) and soil types emerges, marking a significant contribution to the field of geospatial analysis. This study delves into the intricate relationship between NDVI and soil types within the environmental landscape of Pakistan. Integrating these key geospatial variables, our research provides a comprehensive temporal analysis using MOD13A3 data for five years. Leveraging advanced GIS techniques, including soil mapping and random point generation, the study identifies spatial patterns in NDVI and soil types, offering a nuanced perspective on their interaction. The findings hold practical implications for environmental management, guiding decisions in land-use planning and natural resource conservation. Additionally, the study provides insights for optimizing crop production strategies, contributing to the sustainable utilization of the region's resources. These contributions enhance the precision and depth of geospatial analysis, offering valuable insights for informed decision-making and sustainable practices in the unique environmental context of Pakistan.

4. CONCLUSION

This study focused on analyzing the annual vegetation trend through NDVI assessments, coupled with regional-scale soil mapping. The utilization of NDVI enabled an exploration of temporal and regional patterns in vegetation distribution, productivity, and dynamics. The identified dynamics elucidated through the study's NDVI assessments and regional-scale soil mapping, offer valuable insights for the examination of habitat degradation and fragmentation. Furthermore, these findings can contribute to understanding and addressing environmental disasters, such as droughts and wildfires, within ecosystems. The practical applications extend to cultivation planning and management, where the acquired knowledge can be leveraged for more informed and strategic agricultural practices. Soil and climatic conditions play an important role. In lowland areas, soil type has a significant and long-term impact on cropping patterns. The findings of this study suggest that NDVI holds significant promise as a valuable tool for terrestrial ecologists seeking a deeper understanding of various ecological aspects. The widespread adoption of NDVI indicates its potential utility in predicting the ecological impacts resulting from natural changes in the environment, as well as in assessing elements related to animal populations and settlements. This widespread acceptance of NDVI as a predictive tool facilitates a more straightforward analysis, enabling analysts to comprehend biological implications more effectively. The study underscores the pivotal role of NDVI in advancing ecological research and deepening our comprehension of intricate dynamics within ecosystems. The results reveal dual peaks in crop yields and vegetation, occurring in March-April and August-September. The observed annual fluctuations underscore the changing climate. Given Pakistan's substantial population and the consequent heightened food and security needs, understanding vegetation trends and patterns becomes crucial. The insights gathered from this study can be instrumental in adapting crop management strategies to effectively navigate and address challenges arising from evolving environmental conditions.

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