Discover Sustainability

Case Study

Investigation of changes in land use/land cover using principal component analysis and supervised classification from operational land imager satellite data: a case study of under developed regions, Pakistan

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Abstract
Monitoring and understanding Land Use/Land Cover (LU/LC) is critical for sustainable development, as it can impact various environmental, social, and economic systems. For example, deforestation and land degradation can lead to soil erosion, loss of biodiversity, and greenhouse gas emissions, affecting the quality of soil, air, and water resources. The present research examined changes in (LU/LC) within the underdeveloped regions of Balochistan and Sindh provinces, which are situated in Pakistan. In order to monitor temporal variations of LU/LC, we employed Geographic Information System (GIS) technique, to conduct an analysis of satellite imagery obtained from the Landsat 8 Operational Land Imager (OLI) during the time period spanning from 2013 to 2023. In order to obtain an accurate LU/LC classification, we used principal component analysis (PCA) and a supervised classification approach using the maximum likelihood algorithm (MLC). According to the results of our study, there was a decrease in the extent of water bodies (– 593.24 km^2) and vegetation (– 68.50 km^2) by – 3.43% and – 0.40% respectively. In contrast, the area occupied by settlements in the investigated region had a 2.23% rise, reaching a total of 385.66 square kilometers. Similarly, the extent of barren land also expanded by 1.60%, encompassing a total area of 276.04 square kilometers, during the course of the last decade. The overall accuracy (94.25% and 95.75%) and K value (91.75% and 93.50%) were achieved during the year 2013 and 2023 respectively. The enhancement of agricultural output in Pakistan is of utmost importance in order to improve the income of farmers, mitigate food scarcity, stimulate economic growth, and facilitate the expansion of exports. To enhance agricultural productivity, it is recommended that the government undertake targeted initiatives that aimed at

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enhancing water infrastructure and optimizing land use to foster a sustainable ecological framework. Integrating the sustainable ecological framework provides a foundation for informed decision-making and effective resource management. By identifying areas of urban expansion, agricultural intensification, or alterations in natural LU/LC, stakeholders can design targeted conservation strategies, mitigating potential environmental degradation and promoting biodiversity conservation. In conclusion, the integration of GIS and Remote Sensing (RS) may effectively facilitate the monitoring of land use patterns over a period of time. This combined approach offers valuable insights and recommendations for the judicious and optimal management of land resources, as well as informing policy decisions.

Keywords Land use/land cover · Under develop region · Principal component analysis · Supervised classification · Operational land imager · Environment

1 Introduction

People migration from rural to urban areas [1–3] and fluctuations in land surface temperature (LST) and land use/land cover (LU/LC) [4–6] have had negative effects on crop health. Recent studies [7–9] suggest that these environmental modifications have resulted in 3.2% reduction in food security per capita. Green plant cover could potentially affect climate and land surface fluxes at both global and regional scales [10, 11]. Climate change alters terrestrial ecosystems and vegetation [12]. As plant cover has a significant impact on the energy cycle, hydrology, soil, and climate [13], it is imperative to explore its role in the context of post-industrialization LST rise related to global warming [14, 15]. Vegetation cover is crucial in describing human activities, fluctuations in the terrestrial ecosystem, soil dynamics, hydrological processes, and the context of regional and global climate change [16]. The LU/LC classification study in the under develop region (Sindh and Balochistan provinces) is intricately linked with broader environmental and societal challenges, integrating critical aspects like LST, foot security, and global warming issues. The accurate assessment of LU/LC plays a pivotal role in addressing global warming concerns, as changes in LU/LC directly impact the regional climate and contribute to temperature variations [17]. Additionally, the study area, characterized by a diverse landscape of urban centers, agricultural regions, and natural ecosystems, necessitates a nuanced consideration of foot security concerns. The intricate balance between urban expansion, agricultural activities, and the preservation of natural habitats directly influences the livelihoods and security of the local population [18, 19].

According to the intergovernmental panel on climate change (IPCC) Report 2013, a rapidly rising climatic system deleteriously affects farming methods and plant life [20, 21]. Due to high rates of evapotranspiration and minimal precipitation, plant development in dry places is very reliant on the availability of water [22–26]. To accurately detect changes in vegetation patterns, researchers have turned their attention to study of plant phenology, vegetation cover and biomass [20, 27–32]. These days, change analysis relies heavily on remote sensing (RS) satellite data [33, 34]. Over the past few years, RS data from sources like Landsat images have emerged as the dominant data sources for a wide range of change analysis applications [35–37]. This preference is attributed to their inherent advantages, including repetitive data acquisition, a comprehensive synoptic perspective, and a digital format amenable to computational processing. Furthermore, satellite imagery has been used for development and monitoring purposes in semi-arid and arid environments, as well as for LU/LC change analysis [38–41] with varying degrees of success. Likewise, GIS techniques are employed to examine the effects of population density, terrain slope, distance to roads, and contiguous land use on LU/LC changes [42–44].

Integrating RS data with GIS is a powerful tool for statistically measuring urban sprawl and representing urban growth on a typically large geographical scale [45, 46]. Because of its ability to simultaneously measure a large area, satellite RS is now widely used to evaluate the biophysical properties of land surfaces, as well as to understand better and monitor landscape development and processes [47, 48]. Organizing, visualizing, and analyzing digital data is made easier thanks to the GIS revolution, which facilitates the detection of changes [49–51]. Bashir and Ahmad [52], Chen et al. [43], and Abdo [53] have highlighted the growing importance of long-term studies of RS vegetation dynamics to the study of global ecology. In addition, Ige et al. [54] and Mia et al. [55] note that RS is increasingly being utilized to detect seasonal variations in plant life. Applied RS is maturing into a reliable resource for assisting people in their efforts to solve ecologically-related challenges on a global, national, and regional scale [56]. An essential part of RS is keeping track of the substantial changes in vegetative indices and other agronomical relevant physical factors [57–59] throughout time. According to many studies [60, 61], the RS is an effective tool for keeping tabs on the health of a plant population and documenting how much of it there is using more affordable and flexible field measuring techniques. An increasingly pressing issue in the global climate change study is the detection and dynamics of vegetation and the mechanisms that drive them. Several satellite-based studies have reported changes in plant growth that are relevant to a changing climate.

Pakistan's agricultural industry is still the country's most vital source of income, jobs, and international trade. Pakistan's agricultural industry is under increasing pressure due to the country's rising urban population and the associated rise in demand for a wider variety of foods [62]. Agricultural growth dropped from an annual average of over 4% between 1970 and 2000 to around 3% despite receiving substantial governmental funding with cooperation from development partners. Water-efficient, high-value agriculture is negatively impacted by political parties dispute on land use development, which is defined by poorly targeted subsidies and poorly functioning agricultural markets. Land usage and water resource damage are exacerbated by climate change's effects on plant cover, surface temperature, and natural disasters, including floods, heat waves, and earthquakes [63]. Therefore, main objective of this research's is to identify LU/LC changes in the under develop region (UDR) lie in between Balochistan and Sindh provinces of Pakistan during the last 10 years (2013–2023) using principal component analysis and supervised classification from Operational Land Imager (OLI) satellite data. As per author's knowledge, there is no study existed in literature to present LU/LC variation in UDR. Also, Investigating Changes in LU/LC by combining principal component analysis and supervised classification from Operational Land Imager satellite data [38, 39, 41, 42, 51]. Addressing the multifaceted challenges posed by LU/LC dynamics, global warming concerns, foot security, and related issues in the study area demands a methodical and integrated approach. The methodology will involve a combination of advanced RS techniques, including Principal Component Analysis (PCA) and supervised classification algorithms, applied to OLI satellite data. By leveraging these tools, we aim to enhance the accuracy of LU/LC mapping, providing detailed insights into the temporal variations of urban, agricultural, and natural land cover categories.

2 Materials and methods

2.1 Study area

Pakistan's geographical features include a diverse variety of landscapes, extending from the southern shoreline along the Indian Ocean to the northern mountain ranges including the Karakoram, Hindukush, and Himalayas. The provinces of Sindh and Punjab are situated in the northwestern region of the Indian plate, whereas the provinces of Balochistan and a significant portion of Khyber Pakhtunkhwa are located inside the Eurasian plate. The Eurasian plate mostly encompasses the Iranian Plateau from a geological perspective. Pakistan shares its borders with China to the northeast, India to the east, Afghanistan to the northwest, and Iran to the west. The geographical location of the nation situates it in close proximity to many highly volatile international boundaries, notably the contentious Kashmir dispute with India, which has been a recurring catalyst for military hostilities. The Khyber Pass and the Bolan Pass, situated along its western border, have traditionally served as conduits for migratory movements between Central Eurasia and South Asia. The study area lies in between 67.92° E and 28.41° N which consist of 12 cities (Dera Bugti, Sui, Chattar, Lehri, Dera Murad Jamali, Tamboo, Jhat pat, Jacobabad, Thul, Tangwani and Kandh Kot) as shown in Fig. 1. The climatic of study area is characterized as arid to hyper arid (hot desert) type.

2.2 Landsat remote sensing data collection

The United States Geological Survey's (USGS) website (earthexplorer.usgs.gov) provided the 30 × 30 m spatial resolution, 0% cloud cover Landsat RS satellite images used to determine LU/LC change detection which included areas of vegetation, bare soil, settlements, and water bodies. The specifics of the gathered Landsat satellite data are listed in Table 1.

2.3 Classification method

Several distinct bands make up a Landsat picture. Bands 1 through 7 of Landsat-8 were employed to assess LU/LC change detection. Xu et al. [64] reported that Landsat images were geo-referenced, layer stacked (which involves creating multiband images from individual bands), mosaicked the images to merge the two stacked sets, and subsequently extracted the study area using ArcMap 10.7.1. According to Adefisan et al. [65] looked at all the satellite data by labeling each pixel with a unique signature. The Landsat photos from 2013 and 2023 were used to train a supervised classification approach (the maximum likelihood algorithm) that generated the ultimate LU/LC maps. Training samples were chosen by

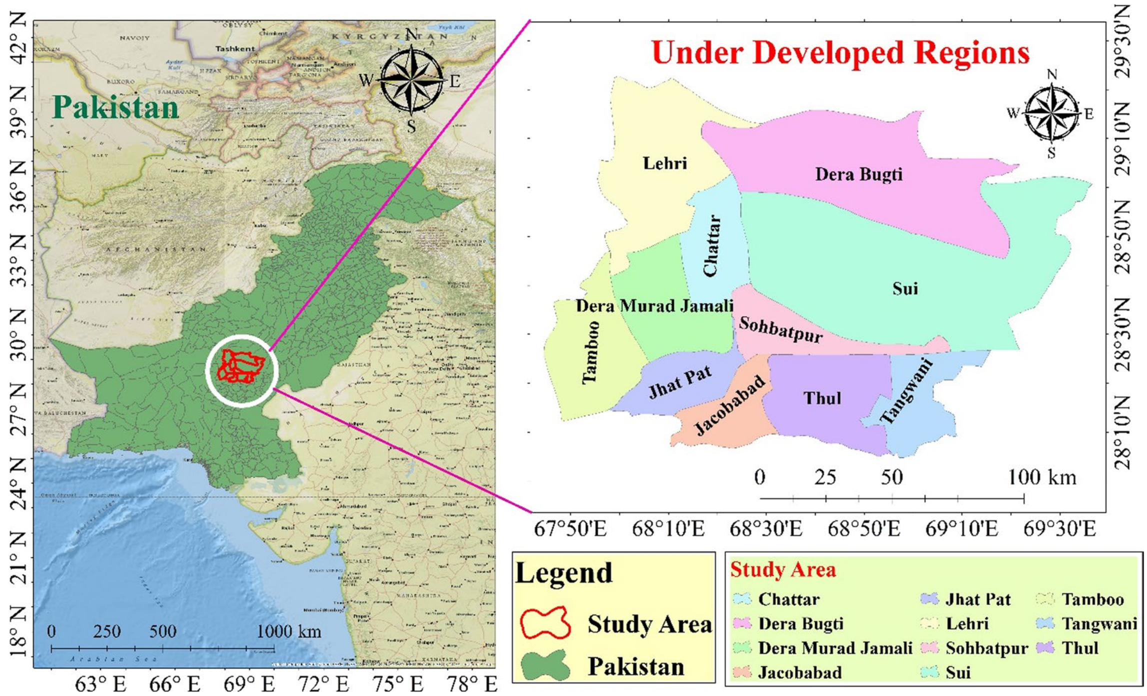


Fig. 1 Geographical location of study area (under developed regions, Pakistan)

Table 1 Collected Landsat satellite data details

Date	Earth sun distance	Scene center time	Sun azimuth	Sun elevation	Satellite (sensor)	Path/row	Resolution (m)	Cloud cover (%)
23-05-2013	1.0124777	05:57:58.39Z	108.62	69.20	Landsat 8 (OLI)	152/040	30	0
19-05-2023	1.0115967	05:57:58.39Z	108.62	69.20	Landsat 8 (OLI)	152/040	30	0

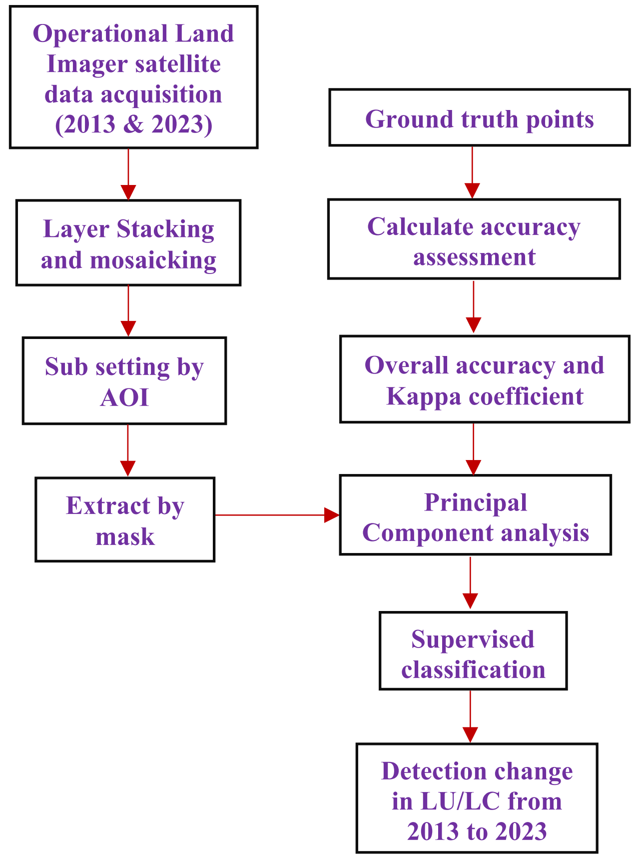
Here, Earth Sun Distance is in Astronomical Units (Day of year)

delimiting polygons around typical locations for each predefined LU/LC class [66]. The pixels inside these polygons were used to capture spectral signatures for the various land cover categories as determined by the satellite images. The PCA is a statistical technique widely employed in the field of remote sensing and image analysis to reduce the dimensionality of multivariate data while retaining the essential variability. In the context of satellite imagery and LU/LC studies, PCA is particularly valuable for transforming a set of correlated spectral bands into a new set of uncorrelated variables, known as principal components [64]. By utilizing PCA, redundant or less informative bands are minimized, allowing for a more efficient and simplified representation of the data. Step-by-step instructions for calculating LU/LC are shown in Fig. 2.

2.4 Accuracy assessment of LU/LC classes

Several studies [67–69] agree that error matrices best illustrate precision results. For example, the percentage of user accuracy (UA), producer accuracy (PA), and overall accuracy (OA) all account for random error [41, 70–74]. The accuracy and theoretical agreement of RS categorization may be estimated by evaluating the Kappa coefficient (K) values [75–78]. To ensure the robustness and accuracy of the LU/LC classification results, a validation process incorporating ground truth points or areas was implemented. Figure 2 illustrates the spatial distribution of validation points across the study area. A measure of the proportion of an error matrix's accurate values can be attributed to "true" rather than "chance" agreement [79]. The Kappa coefficient (k) values are an estimate of how well RS classification is correct and agree with reference data. Conceptually, k can be defined as:

Fig. 2 Stepwise procedure to determine LU/LC



$$OA = \frac{x}{y}. \tag{1}$$

$$k = \frac{OA - z}{1 - z} \tag{2}$$

where x represents number of sampling classes classified correctly; y shows number of reference sampling classes and z indicates chance assessment.

3 Results

Several LU/LC categories were used for the supervised categorization of the research region in the years 2013 and 2023 (Table 2). In 2013, the area covered by water was 966.75 km^2, followed by barren land at 11,320.87 km^2, and finally by vegetation at 2423.07 km^2, with the area covered by human settlements at 2586.72 km^2. Furthermore, Table 2 revealed that 14.01% of the research area was covered by vegetation, whereas 14.95% was covered by human settlements, 5.59% by water bodies, and 65.45% by bare land (Table 2). Similarly, the area covered by vegetation was 2354.56 km^2 (13.61%), while the area occupied by settlements was 2972.38 km^2 (17.18%), Water bodies accounted for 373.51 km^2 (21.6%), followed by barren land at 11,596.91 km^2 (67.04%) in 2023 year. From 1993 to 2023, barren land and human settlements grew by 1.60% and 2.23%, respectively. Changes in LU/LC have been seen, particularly in the proportion of water bodies. Vegetation coverage has declined by 0.40% and net change in water bodies was calculated as − 3.43% due to poor water infrastructure. Since the primary source of income in the study area is fish, the expansion of settlements has also been one of the primary causes of the decline in vegetation areas and the decline in water resources. Figure 3 indicates LU/LC change in studied region from 2013 to 2023. In addition, Fig. 4 indicated the LU/LC change detection in UDR.

Table 2 Aerial distribution of LU/LC class in UDR, Pakistan from 2013 to 2023

LU/LC Class	2013		2023		2013–2023	
	Area (km^2)	Area (%)	Area (km^2)	Area (%)	Change (km^2)	Change (%)
water	966.75	5.59	373.51	2.16	− 593.24	− 3.43
vegetation	2423.07	14.01	2354.56	13.61	− 68.50	− 0.40
settlements	2586.72	14.95	2972.38	17.18	385.66	2.23
barren land	11,320.87	65.45	11,596.91	67.04	276.04	1.60
Total Area	17,297.41	100.00	17,297.41	100.00	0.00	0.00

3.1 Accuracy assessment of LU/LC classes

Table 3 presents an evaluation of accuracy for different LU/LC classes, during the years 2013 and 2023. Average user accuracy was 95% for water, 97.50% for vegetation, 76.25% for settlements, and 86.25% for bare soil. The average levels of producer accuracy for the four LU/LC categories were very similar: 97%, 76.77%, 94.44%, and 94.09%. Table 3 displays producer and user accuracies and a trend of total accuracy and K values over time. The best overall accuracy (90.63%) and the highest K value (88.24%) were achieved in 2023. Both OA and K values (88.63% to 90.63%) in this investigation are acceptable [80–84].

4 Discussion

Researchers used RS and GIS to create maps of LU/LC in the research region based on the perspectives of local farmers. Because of the profound effect that changes in LU/LC have on regional climate, understanding changes in LU/LC changes is crucial for making informed decisions during planning and development of future planning regarding agriculture production and water resources. For this reason, we use the most recent period (2013–2023) data for LU/LC change detection. Our findings show that the percentage of water bodies declined to -3.43% between 2013 and 2023. From 2013 to 2023, barren land and human settlements grew by 1.60% and 2.23%, respectively. Vegetation coverage has declined by 0.40%.

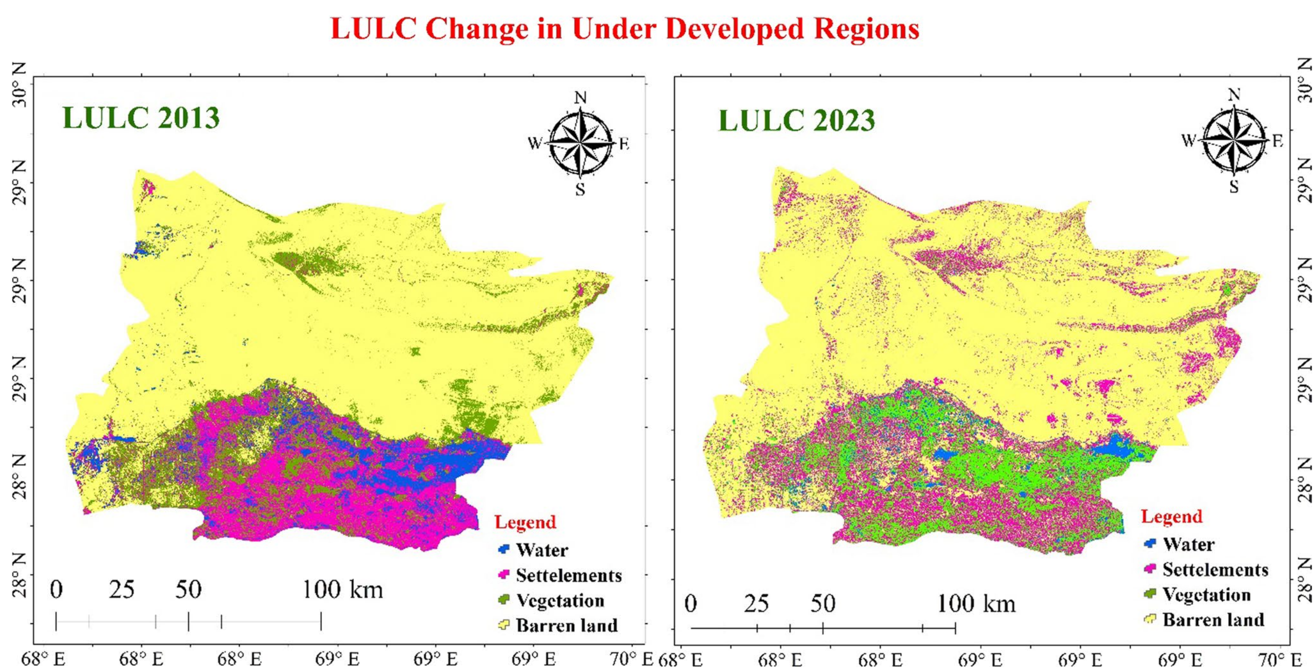


Fig. 3 LULC of the studied region of 2013 and 2023

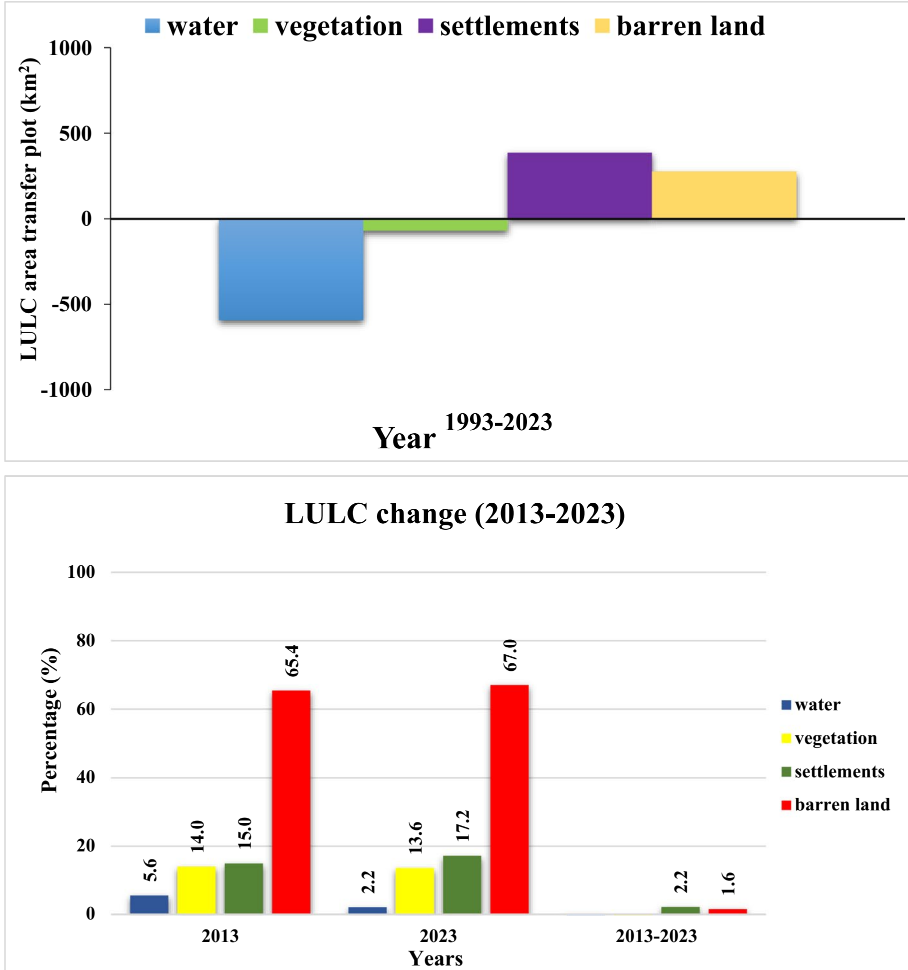


Fig. 4 Detection change in LU/LC over UDR, Pakistan for study period (2013–2023)

Table 3 Accuracy assessment of LU/LC classes in study area

Year	UA (%)				PA (%)				OA (%)	K (%)
	W	V	S	B	W	V	S	B		
2013	92	98	95	93	98	91.00	96	94	94.25	91.75
2023	94	96	97	98	95	89.00	94	98	95.75	93.50

W water, *V* vegetation, *S* settlements, *B* barren land

Rising temperatures are an obvious indicator of climate change, making it imperative that adaptation programs be bolstered to their full potential in order to satisfy the fundamental requirements of the local population [85–87]. Hussain et al. [88, 89] point out that the easiest way to solve this issue is to decrease the number of response variables by comparing and contrasting the goodness-of-fit and values of various multidimensional models. Most of the research area's metropolitan areas are situated in the east and north, which makes the LU/LC more complicated, leading to the much inferior goodness-of-fit [90]. On the other hand, the implementation of PCA as a preprocessing step before supervised classification enhances the discernment of meaningful spectral variations, contributing to the accuracy of land cover change detection. The resulting change detection matrix from PCA-based classification offers a detailed evaluation of changes in LU/LC classes, presenting a different perspective on the landscape dynamics [91]. The reduction in data dimensionality through PCA assists in capturing subtle changes that may be overlooked in a conventional post-classification comparison, emphasizing its utility in addressing the complexity of LU/LC variations.

Extreme weather events, such as floods, droughts, and wildfires, explain how climate change might indirectly affect vegetation. Several environmental factors may negatively impact vegetation cover and production, including drought and wildfires [73, 92]. According to Khan et al. [23], the LST in a given region affects the degree to which LU/LC varies.

Adaptations to a changing climate, changes in LU/LC, and other factors may affect LST values [93–95]. To promote sustainable land use and effective natural resource management in the face of climate change, the RS technology may be utilized to monitor LU/LC change detection over time. Satellites are essential tools for collecting distant object data. In recent years, the role that long-term studies of RS vegetation dynamics have had in the study of global ecosystems has been more apparent. The RS has widespread use in spotting cyclical changes in plant life. Over time, we may anticipate functional RS to become a valuable resource for advancing humanity's ability to meet its global, regional, and local obligations in matters relating to the atmosphere.

5 Conclusion and future prospective

This study examined Land Use/Land Cover changes in Pakistan's marginalized Balochistan and Sindh provinces. For this purpose, we used Landsat 8 Operational Land Imager (OLI) satellite images from 2013 to 2023 to determine LU/LC changes. We employed combination of principal component analysis (PCA) and supervised classification technique for accurate LU/LC classification. Our investigation found that there was a decrease in the extent of water bodies (-593.24km^2) and vegetation (− 68.50 km^2) by − 3.43% and − 0.40% respectively. In contrast, the area occupied by settlements in the investigated region had a 2.23% rise, reaching a total of 385.66 square kilometers. Similarly, the extent of barren land also expanded by 1.60%, encompassing a total area of 276.04 square kilometers, during the course of the last decade. While the research encompasses a wide range of topics, it is important to acknowledge the several limitations that the authors have identified. Recognizing and addressing these limitations is crucial for interpreting the results with caution and guiding future research efforts in refining methodologies for more accurate and context-specific LU/LC assessments. In general, the diverse range of LU/LC patterns offer valuable insights into the condition of vegetation and agricultural productivity. Enhancing comprehension of the relationship between LU/LC and land surface temperature (LST) fluctuations might potentially yield advantages for land use planning and natural resource management. This understanding can aid in identifying areas of heightened production as well as regions susceptible to degradation, namely heat stress. The utilization of Geographic Information Systems (GIS) enables the rapid and cost-effective generation and integration of up-to-date data across diverse geographical areas, facilitating the incorporation of changes resulting from various management approaches. By doing a study of previous remote sensing satellite data, it is possible to create forecasts concerning potential vegetation issues on the Earth's surface in relation to future climatic conditions. The findings of this study will also provide valuable insights for policymakers in formulating decisions regarding the course of future economic development. Future studies should also consider the integration of socio-economic and cultural factors influencing LU/LC decisions [96], providing a holistic understanding of the drivers behind observed changes [97]. Engaging with local communities through participatory mapping or citizen science initiatives could contribute valuable insights into LU/LC dynamics and enhance the relevance of the research for community-specific sustainable development planning [98, 99]. Furthermore, exploring the potential of emerging technologies like unmanned aerial vehicles (UAVs) or drones [100] could offer a cost-effective and efficient means of collecting high-resolution data for specific areas of interest.

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Data availability The data that support the findings of this study are available on request from the corresponding author.

Declarations

Competing interests The authors have no conflicts of interest to declare.

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