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Land-Use Land-Cover Change Detection Using Geospatial Techniques in Zalingei, Central Darfur, Sudan

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Abstract

Using remote sensing for land use and land cover (LULC) is essential for systems that help people make decisions because it gives valuable information about space and time. A study was conducted in Zalingei, Sudan, to analyze the changes in LULC over 30 years from 1991 to 2021 using multi-temporal Landsat images. Thematic Mapper (TM) and Operational Land Imager (OLI) were classified using the supervised classification method. The pictures were divided into four groups based on how the land was used: residential areas, bodies of water, vegetation cover, and bare land. Results showed that the residential area increased by 20.74% while the water body increased by 2.32%. However, the vegetation cover decreased by 0.7%, and bare land decreased by 22.37%. The changes were caused by people, which shows how vital good land management practices and involvement from the local community are for reducing LULC change. So, to reduce LULC change in the study area, proper land management practices and active participation from the local community are needed. The study concluded that remote sensing technology is an effective tool for assessing and mapping land use and land cover changes and providing valuable information for decision support systems.

Keywords: LULC, Anthropogenic activities, Change Detection, Zalingei.

1. INTRODUCTION

Rapid and significant changes in land use and land cover are occurring globally, with few areas remaining unaffected, primarily in remote, rural regions [1], [2], [3]. The implications of these changes on ecosystems at various scales are a growing concern [3], [4], [5], [6], [7]. Historically, human activities have dramatically transformed landscapes, particularly in tropical regions [8], [9], [10]. While proper planning is crucial for sustainable agricultural development, uncontrolled changes have led to reduced wetlands and lost natural vegetation, exacerbated by population pressures and poor land management, contributing to widespread land degradation [11], [12], [13], [14].

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Urbanization trends have shifted more people into cities, reducing the land available for agriculture [15]. This transition, combined with the activities of real estate developers, places forests and farmlands at risk. Understanding the dynamics of agricultural land change is vital for future planning and mitigating negative impacts [16], [17]. Additionally, natural disasters and geomorphic hazards, such as rivers changing course, significantly influence land cover patterns, heightening the risk of substantial property and human losses.

Remote sensing technology has become a critical tool for monitoring the Earth's surface, offering a way to gather data without physical presence. This technology has proven effective in detecting urban growth and changes using Landsat images [18], [19], [20]. Continuous improvements in satellite imagery and the use of multi-temporal data enhance our understanding of land cover changes over time, as demonstrated in several studies [21], [22], [23], [24]. However, comparing images from different times can produce varying results due to seasonal changes in vegetation growth [25], emphasizing the need for consistent seasonal data collection to ensure accurate land cover change detection [26], [27], [28], [29].

Remote sensing and GIS have become indispensable for tracking changes in land use and cover, including shifts in agriculture, landscape transformation, land degradation, and desertification [30], [31], [32], [33]. With the increasing degradation of land and water resources, identifying and monitoring these changes are crucial. Various methodologies, such as multi-temporal composite image change detection, on-screen digitization, vegetation index differencing, and post-classification change detection, have been developed to analyze these shifts accurately [36], [37], [38], [39], [40], [41]. This study focuses on the fertile valleys and slopes of the savannah and the Marra Mountains, using Landsat imagery from 1991 to 2021 to analyze land use and land cover changes, and to identify spatial and temporal patterns over this period.

2. METHODS

2.1. Study area

The Zalingei area in Central Darfur state, Sudan, lies between latitudes 12° 42' 576" N and 13° 08' 055" N, and longitudes 23° 39' 761" E to 23° 25' 835" E (Figure 1). The altitude ranges from 890 m to 1121 m above sea level [42]. The region lies in the semi-arid Savannah zone, influenced by the elevation of the Jebel Marra massif. It is situated in a low-rainfall woodland savannah with annual rainfall ranging from 350 to 900 mm, and is marked by seasonal flooding. The temperature varies between 30 °C and 35 °C [42].

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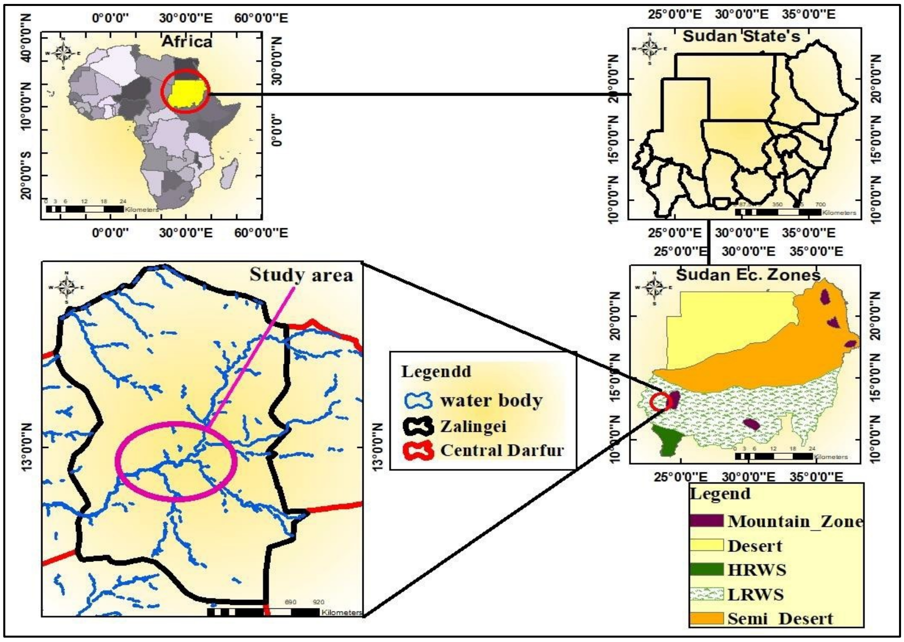

Figure 1. Location of the study area.

2.2. Data collection and analysis

Multi-temporal Landsat images and remote sensing data were used to identify LU/LC shifts. Landsat sensors were used to collect satellite images, and those images were then downloaded from the USGS GloVis database (path 172, row 51). Landsat 8 (OLI TIRS) images 2021 were compared to Landsat 5 (TM) images from 1991 for this study. Geographic scope and temporal accessibility led to the selection of Landsat images (Table 1). Based on remote sensing data and additional field information on land use activities during the study period, an integrated approach was taken for data collection and analysis in this study (Figure 2).

Table 1. Utilized Landsat Images in Determining LULC Change

Satellite/Sensor	Pass/Raw	Data of acquisition	Spatial resolution	Used bands
Landsat TM	172/51	28/1/1991	30 m	B1-B7
Landsat OLI	172/51	1/1/2021	30 m, 15 m	B1-B7

The study employed various methods to collect, process, and analyze data, including remote sensing techniques, ground-truthing surveys, and field observations. We selected two satellite images for analysis: the Landsat 5 Thematic Mapper (TM) 1991 and the Landsat 8 Operational Land Imager/Thermal Infrared Sensor (OLI/TIRS) 2021 (Table 1). These images were chosen based on minimal

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cloud cover (less than 10%). Then defined the coordinates and boundaries of the study area using Google Earth Pro and downloaded images from the USGS GloVis database (path 172, row 51).

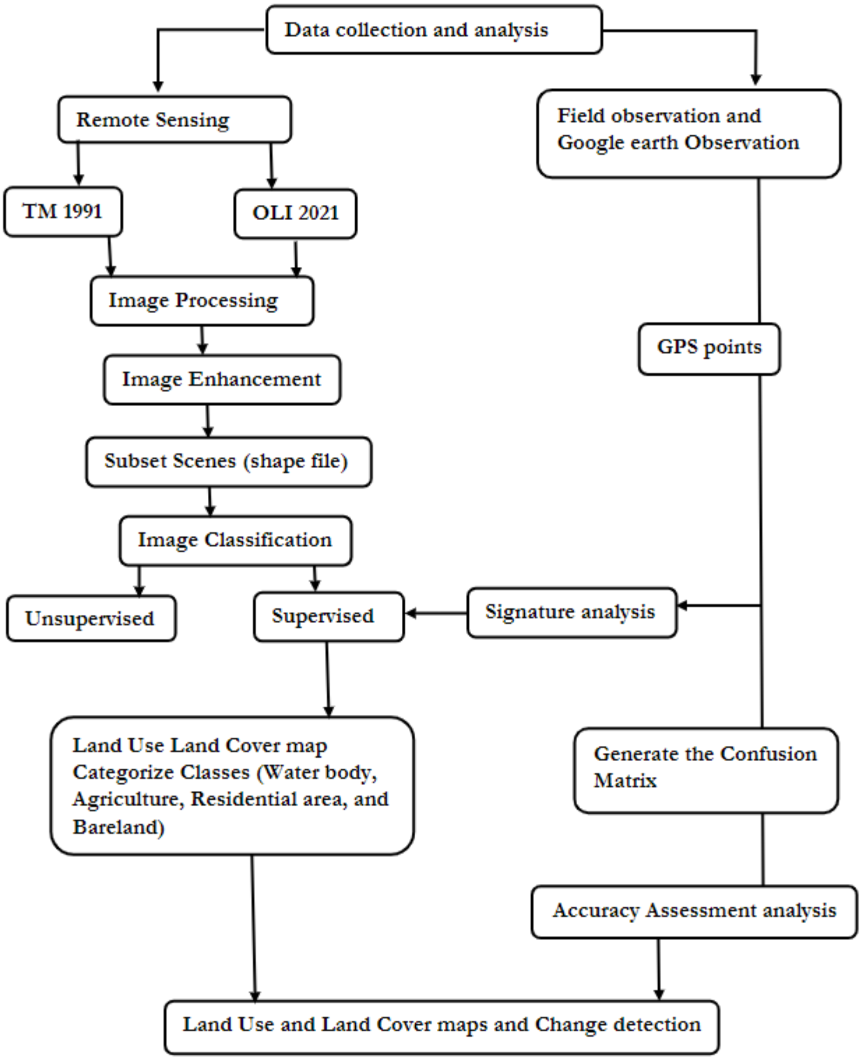

Figure 2. Schematic workflow used for LULC change detection.

To ensure clarity in distinguishing land cover classes, images were taken during the dry season (January). Then preprocessed these images wad done using geospatial analysis software (ERDAS Imagine 2014 and ArcGIS 10.7), downloading all bands, saving them as separate TIFF files, and combining them into a virtual

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raster. A false-color composite was created for visualization purposes, and a subset of this raster was clipped to the full study area extent, forming the training dataset for image classification. The images were projected onto the WGS 84/UTM Zone 35N coordinate system. We used unsupervised classification to differentiate land use categories and minimize mixed pixels. In the summer of 2021, the ground truth survey was conducted to validate land cover classes and assess classification accuracy. Then 200 random ground truth points were generated using ArcGIS 10.7 and visually interpreted these using Google Earth Pro. These points were recorded with GPS for field survey validation. We then applied supervised classification, creating training signatures for each land cover class based on visual interpretation, prior knowledge, GPS data, and Google Earth imagery. Then identified four land cover classes: Water body, Agriculture, Residential area, and Bareland. Then used the maximum likelihood classifier (MLC) to finalize the classification and conducted a change detection analysis using the trajectory matrix method to observe land use/land cover changes between 1991 and 2021. The changes, their percentages, and rates were calculated using Microsoft Excel 2016. After that systematically evaluated each image's precision, finding high levels of agreement (kappa coefficients over 85% for both images). The research methodology steps are outlined in (Figure 2).

3. RESULTS AND DISCUSSION

3.1 Land Use and Land Cover (LULC) resulted in 2021:

Using supervised image classification, we were able to categorize land cover into four distinct types: built-up areas, bodies of water, farmland, and undeveloped wilderness (Figure 3). Agricultural land made up 29.36% (2316.87 ha) of the OLI 2021 study area, while residential areas made up 40.48% (3202.29 ha), water bodies made up 10.85% (856.44 ha), and bare land made up 19.20% (1515.24 ha) (Figure 3 and Table 2).

Table 2. The distribution of LULC in the study area (ha) in 2021

Class name	Area(ha)	%
Residential area	3202.29	40.58
Waterbody	856.44	10.85
Vegetation	2316.87	29.36
Bare land	1515.24	19.20
Total	7890.84	100.00

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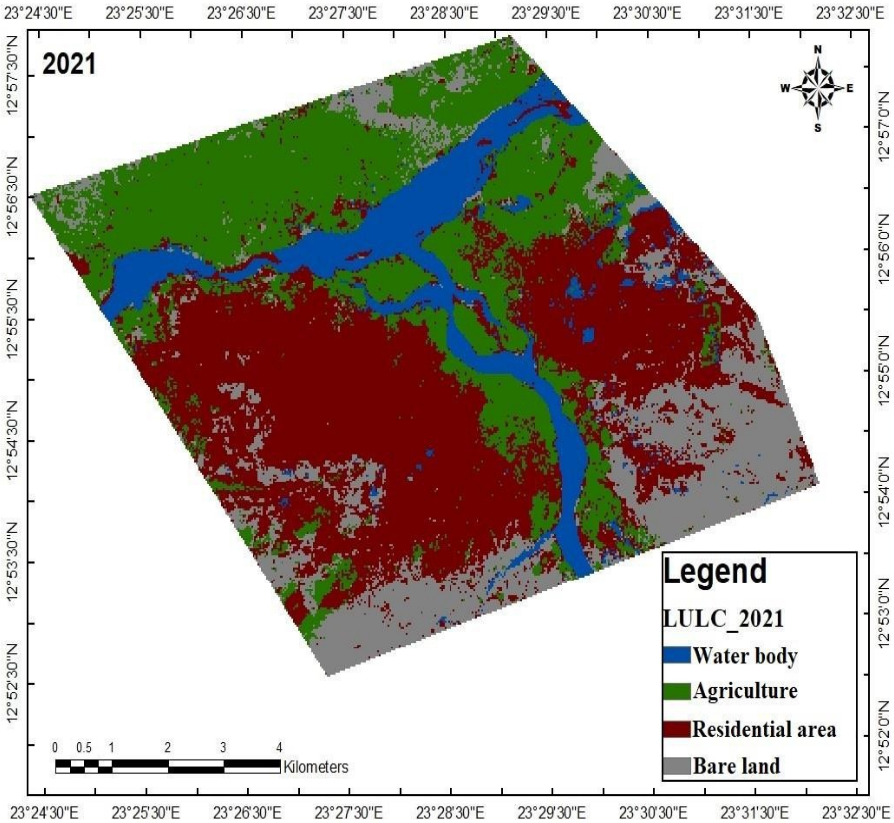

Figure 3. Distribution of LU/LC Classes detection in Zalingei in 2021.

3.2 Assessment of Change Detection

3.2.1 Land Use and Land Cover between 1991 and 2021

The comparison of classification results (Figure 4 and Table 3) shows that residential areas increased from 1565.64 ha (19.84%) in 1991 to 3202.29 ha (40.58%) in 2021, with a net change of 1636.65 ha (20.74%) and a yearly increase rate of 0.69%. This rise in built-up land was caused by the increasing population. On the other hand, water bodies increased from 673.11 ha (8.53%) to 856.44 ha (10.85%) in 2021, with a net change of 183.83 ha (2.32%) and a yearly increase rate of 0.08%. The reason for this increase may be illegal tree cutting and overgrazing, resulting in landslides and larger wadi areas. Agricultural areas decreased from 2371.77 ha (30.06%) in 1991 to 2316.87 ha (29.36%) in 2021, with a net change of 54.9 ha (0.705) and a yearly decrease rate of 0.02%. The main causes of this decrease were poor planning for residential, industrial, and commercial activities, and farmers shifting to other businesses for more income.

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Bare land declined from 3280.32 ha (41.57%) in 1991 to 1515.24 ha (19.20%) in 2021, with a net change of 1765.08 ha (0.705) and a yearly decrease rate of 0.75%. This reduction in agricultural land is harmful to human survival, and the current land-use pattern is different from thirty years ago. Land-use and land-cover (LULC) changes can be understood by analyzing satellite data, such as Landsat images, to determine the rate, pattern, and overall trend of changes. The relationship between population density and LULC changes can also be learned through population data and remote sensing. Hence, comprehensive analysis of land-use changes is crucial for better land-use planning and management.

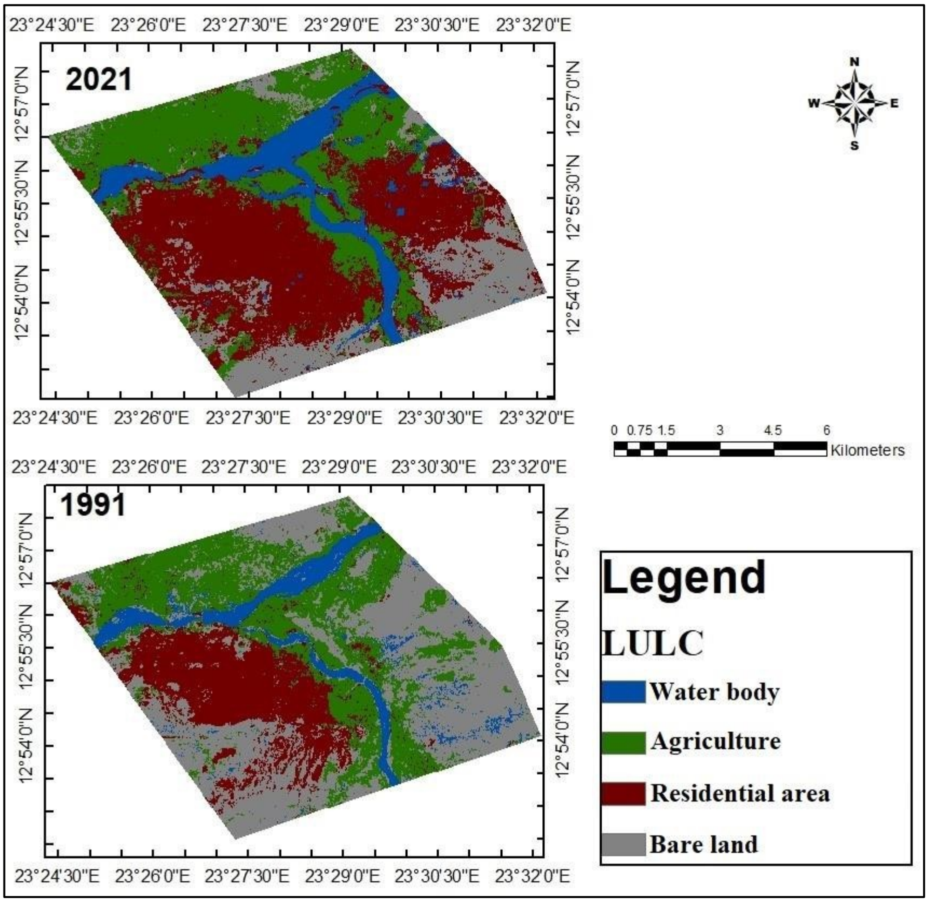

Figure 4. Maps of land cover change in Zalingei between 1991 and 2021.

Table 3. LU/LC Classes and their area in percentage for 1991 and 2021.

	1991		2021	
Class name	Area(ha)	%	Area(ha)	%
Residential area	1565.64	19.84	3202.29	40.58

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Waterbody	673.11	8.53	856.44	10.85
Vegetation	2371.77	30.06	2316.87	29.36
Bare land	3280.32	41.57	1515.24	19.20
Total	7890.84	100	7890.84	100.00

3.3 Land Use, Land Cover Trajectory Matrix 1991-2021

The LULC categories underwent changes, and their growth rates were linked to how fast they grew or declined. Table 4 displays how the LULC change matrix can reflect the total gains and losses from other categories. The main diagonal line in Table 4 indicates pixels that did not change over the specified period, while the other cells show pixels that underwent changes. The dimensional changes of categorized LULC from 1991 to 2021 were analyzed using the change in LULC matrices. The findings are presented in Figure 5 and Table 4.

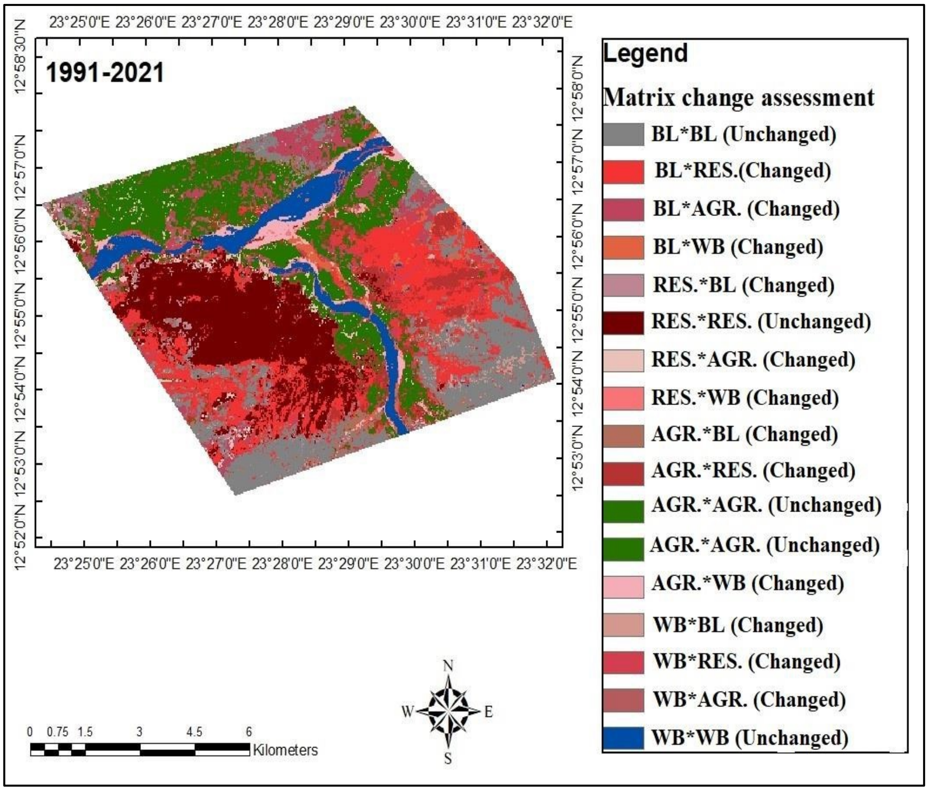

Figure 5. LU/LC change trajectory matrix 1991-2021

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Table 4. Land Use, Land Cover Trajectory Matrix 1991-2021

Class name	Residential area	water body	Vegetation	Bare land	Total
Residential area	1349.1	77.49	512.91	1262.79	3202.29
Waterbody	16.92	479.79	203.40	156.33	856.44
Vegetation	137.7	45.27	1506.78	627.12	2316.87
Bare land	61.92	70.56	148.68	1234.08	1515.24
Total	1565.64	673.11	2371.77	3280.32	7890.84

As shown in Figure 5 and Table 4, the total residential area in 1991 was 1565.64 ha, but only 1349.1 ha remained as old residential areas by 2021, resulting in a loss of 216.54 ha due to conversions to water bodies (16.92 ha), agriculture (137.7 ha), and bare land (61.92 ha). The total water body area in 1991 was 673.79 ha, but only 479.79 ha remained as old water bodies by 2021, with a loss of 193.32 ha due to conversions to residential (77.49 ha), agriculture (45.27 ha), and bare land (70.56 ha). In 1991, the total agricultural area was 2371.77 ha, but only 1506.78 ha remained as old agriculture by 2021, resulting in a loss of 864.99 ha due to conversions to residential (512.91 ha), water bodies (203.40 ha), and bare land (148.68 ha). In 1991, the total bare land area was 3280.32 ha, but only 1349.1 ha remained as old bare land by 2021, with a loss of 2046.24 ha due to conversions to residential (1262.79 ha), water bodies (156.33 ha), and vegetation cover (627.12 ha). The loss from each LULC category is indicated by the values along the vertical column, while the gain into each LULC category is defined by the values along the horizontal row.

3.4 Discussion

The results obtained from this study provide a comprehensive analysis of land use and land cover (LULC) changes in the fertile valleys and slopes of the savannah and the Marra Mountains, directly addressing the stated objective. By utilizing Landsat imagery spanning three decades, from 1991 to 2021, the research successfully documents and interprets the spatial and temporal patterns of change in the region.

Firstly, the supervised image classification clearly delineates the LULC into four main categories: residential areas, water bodies, agricultural land, and bare land. The detailed distribution of these categories in 2021 presents a current snapshot of the land cover, illustrating how the fertile areas are utilized and managed. The significant presence of agricultural land, constituting 29.36% of the area, highlights the ongoing agricultural activities in the fertile valleys, while the changes in water

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bodies and bare land provide insights into the environmental and land management practices over time.

The assessment of change detection between 1991 and 2021 is particularly telling of the spatial and temporal dynamics in the region. The substantial increase in residential areas from 19.84% to 40.58% points to intensified human settlement and urbanization, likely driven by the fertility and strategic importance of the valleys and slopes. The concurrent decrease in bare land from 41.57% to 19.20% further indicates a shift in land use from undeveloped to more actively managed or inhabited landscapes. These changes are critical in understanding how the pressures of population growth and development are shaping the land.

Moreover, the Land Use, Land Cover Trajectory Matrix provides an even more granular view of the changes, revealing the complex interchanges between different land types. This matrix not only confirms the general trends observed but also uncovers the specific interactions, such as the conversion of agricultural and bare lands into residential areas. This level of detail is essential for identifying the specific spatial patterns of change and understanding how different land use pressures interact over time.

The results directly answer the study's objective by providing a clear and detailed picture of how the land use and land cover have evolved over the last 30 years in the targeted fertile regions. The changes observed reflect the broader socio-economic and environmental dynamics at play, offering valuable insights into the patterns of development and natural resource management. This understanding is crucial for any future planning and conservation efforts aimed at preserving the fertility and ecological integrity of the valleys and slopes while accommodating sustainable human development.

Over all, the study's findings effectively map out the historical and current land use scenario, capturing the complex spatial and temporal changes in the fertile areas of the savannah and the Marra Mountains. These results provide a solid foundation for further research and informed decision-making, contributing significantly to our understanding of land dynamics in these ecologically and economically important regions.

4 CONCLUSION

This study utilized remote sensing and GIS technologies to conduct a comprehensive analysis of land use and land cover (LULC) changes in Zalingei over a 30-year period, from 1991 to 2021. Employing multi-temporal satellite imagery, the research not only provided an efficient and cost-effective means to track and document these changes but also demonstrated a high classification

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accuracy (greater than 85%). This high level of precision underscores the significant shifts observed in the region's LULC, most notably the substantial increase in residential areas by 20.74%, and the discernible reductions in agricultural and water body areas by 0.71% and 2.32% respectively.

The study's findings reveal that the expansion of residential areas and the corresponding decline in agricultural lands are indicative of a broader trend toward urbanization and changing land management practices. This transition, while offering development opportunities, poses challenges to agricultural sustainability and environmental health. Therefore, continuous monitoring and more nuanced, region-specific studies are necessary to fully understand the implications of these changes and to inform future land use planning and policymaking.

Looking forward, there is a critical need for a multi-faceted approach in research. Future studies should focus on unraveling the underlying causes driving these LULC changes, examining socio-economic factors, policy impacts, and environmental considerations. Additionally, an assessment of the effectiveness of current land use planning and management policies in Zalingei and Central Darfur is essential. This would help identify gaps, enable the development of more resilient and sustainable urban planning strategies, and guide innovative city development initiatives.

Moreover, further research should explore the broader implications of these land use changes on ecosystem services, biodiversity, and climate change. Understanding these relationships is crucial for developing integrated and adaptive management strategies that balance development needs with environmental conservation. This study lays a solid foundation for such future inquiries, offering valuable data and insights that can drive more informed and effective land use planning and governance in Zalingei and similar regions facing rapid environmental and socio-economic transformations.

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