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Analysing Changes in Land Use and Land Cover (LULC) For C81 Catchment of the Free State, South Africa

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***Abstract* -** The purpose of the study is to analyse changes in land use and land cover (LULC) from 1990-2018 in the C81 catchment of the Free State, South Africa. It is important to understand the changes of LULC on the catchment and evaluate its impact on environmental aspects. Changes in LULC were examined using remote sensing, and aeronautical reconnaissance coverage geographic information system (ArcGIS). The LULC data was obtained from the South African National Land Cover (SANLC) project. The results of the net change from 1990-2018 with 35 classes of LULC show that the most reduced are forest plantations which decreased from 57.65% to 1.02%, and low shrublands which decreased from 17.08% to 0.16%. However, the most expanded are grasslands which increased from 17.74% to 54.30% and cultivated agriculture which increased from 1.11% to 37.32%. The transition shows that the majority of the LULC changes occurred in grassland with an annual rate of change of 1,31% and forest plantation with an annual rate of change of -2,02%. These changes in LULC may be attributed to population increase, the severity of drought and floods, water scarcity for irrigation, and climate change effects. Grasslands to forest plantations were recorded with the highest changes, which indicated that the area is dominated by agricultural activities. However, plantations or woodlots to wetlands recorded the lowest changes, which indicates low rainfall in the study area for the period under review. Integrated LULC management of this catchment is, therefore, a necessity for the mitigation of environmental degradation.

***Keywords*:** Catchments, GIS and remote sensing, land use land cover (LULC), wetlands, grasslands, Environmental degradation

1. Introduction

The rate at which land use is changing globally and locally is astounding; these changes include the conversion of natural vegetation to crops and forest plantations, natural vegetation loss due to bush encroachment and overgrazing, soil erosion, alien plant invasion, and increased urbanization [1]. Land-use change refers to a process by which human activities transform the natural landscape, referring to how the land has been used, usually emphasizing the functional role of land for economic activities [2]. Land cover is any physical and biological covering of the earth's surface such as water, vegetation, soil, and artificial structure [2]. Therefore, the conversion of land use from grassland to afforestation is being driven by demand for fiber, wood, and new efforts for ecosystem restoration which alters the earth's systems through climate change, the disturbance of water and nutrients use which are expected to further increase land use change globally [4].

Understanding the causes of land-use changes has progressed from a simple depiction to a considerably more complex understanding that includes situation-specific interactions among many components on various geographical and temporal scales [3]. As a result, land use is influenced by biophysical and socioeconomic factors [6]. This statement by [4] is supported by [5], who stated that biophysical factors such as soil, climate, topography, and vegetation, mostly affect the runoff of a particular catchment, as well as socio-economic drivers that may affect land-use change, such as population increase and the level of its influence, affect runoff of a particular catchment. However, the agricultural activities in the catchment of C81 have been highly modified because of anthropogenic activities such as population growth, and changes in food and energy demands [6].

The impacts on land-use change are negative as they are associated with continuing to increase food production and fiber production, using resources efficiently, in wealth, and well-being [5]. The negative impact of land-use change is also observed through the structural factors and behaviours associated with the demand, technological capacity social relations affecting demand and capacity, and the nature of the environment are the complex interactions distinguished by land-use change [2]. It is further reported by [5] that the downstream land-use change has an off-side effect and upstream users could bring a significant on-site effect on the catchment’s water resources. Reference [7] argues that the reduction in agricultural expansion on natural forests and the diverted lands urgently needs protection for our forests and to fight the global climate crisis.

The agricultural sector is directly dependent on rainfall and evapotranspiration and sensitive to drought and water scarcity, and the impact of drought affects this industry negatively. For example, drought has affected agricultural production by crop yield reduction and the water quantity available for irrigation decreased [8]. More often drought always starts with water scarcity for domestic and agricultural use, thus affecting streams, soil moisture, groundwater, ecosystems, water bodies, wetlands, and human action [9]. Climate change is a reality, whereby it taking place is just a matter of time and farmers are mostly affected by undergoing dry and wet periods in the future thus the increase in climate events specifically drought has affected and damaged the world over the years [10]. There is an unquestionable connection between drought, climate change, and food security [11]. The world has been affected by the overall increase in the occurrence and the severity of drought and it was reported that it caused the death of more than 11 million people and has affected more than 2 billion people [12].

On all spatial and temporal ranges, LULC alteration is widely acknowledged as a significant cause of environmental change. Forest fragmentation, earth-atmosphere interactions, and biodiversity loss are all severely impacted by LULC shift [13]. Additionally, by affecting runoff, soil loss, and stream flow, it is one of the causes contributing to local environmental disturbance [14]. These factors make it significantly important for regulating the environment to model the dynamics of LULC. The Andassa watershed, the research area, is well-known for being the most productive region in the nation and the source of the Blue Nile River. Therefore, determining the rate and procedure of LULC changes, which have both national and global relevance, is crucial.

For example, this study is investigating the LULC in South Africa, Thabo Mofutsanyane District Municipality in the Free State Province. This is because Thabo Mofutsanyane District Municipality has a very large comparative advantage in the agricultural sector, the tertiary sector made the largest Gross Value Added (GVA) contribution at 72.3%, with community services being the largest contributor at 29.4%. In addition, the primary sector agriculture had the largest contributor at 11.5%, and in the secondary sector, manufacturing at 7.6% [6]. The district is next to Lesotho, which shares a border to the south, and had a population of 739305 people in 2019, up from 736812 in 2018. The district's annual growth rate has been 0.5 percent, which is lower than the provincial (0.6 %) and national rates (1.5 %) [6]. GIS is used in adaptable situations to gather, manipulate, and extract data, also to display spatial information, and this can be used for decision-making [15]. The integration of remote sensing with the GIS is also used for land use planning and modelling [16].

The purpose of this study is to analyze changes in land use and land cover (LULC) for the Free State C81 catchment of South Africa from 1990-2018. It is important to understand the changes of LULC on the catchment and evaluate its impact on environmental aspects. Understanding the factors for such changes is necessary for the management of LULC modifications to be successful. As a result, integrated LULC management of this catchment is therefore a necessity for the mitigation of environmental degradation.

2. Methods

2.1. Study Area

The study area is the C81 catchment located in the Eastern Free State, under the Thabo Mofutsanyane District Municipality. The municipality lies between latitude -27.945 and 28.783 longitude. It is a semi-arid region with a dispersed habitation pattern that covers a catchment area of 1657882.700 hectares (ha) as presented in Fig 1. The catchment has an average annual rainfall of 690mm, with minimum temperatures of 1.0 o C occurring in July, and maximum temperatures of 26.5 °C occurring in December. The C81 catchment is situated within the Vaal and Orange River basins which are also water management areas with common climate and hydrological characteristics. The C81 catchment has the highest percentage of clay soil texture which is suitable for conservation.

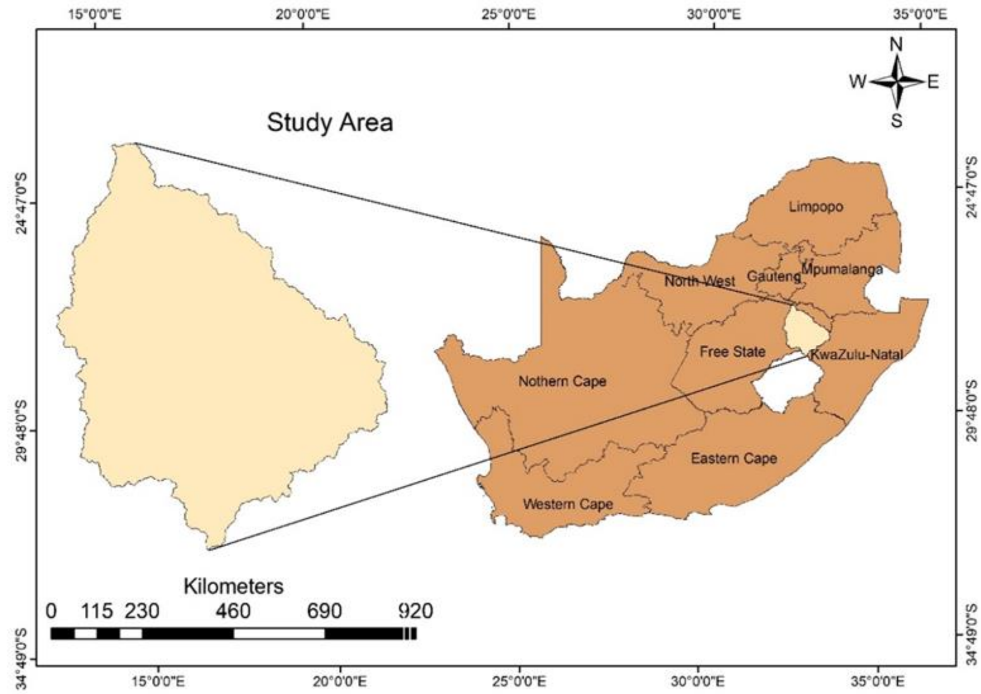

Fig 1. Location map of the study

2.2. Data and methods

The topography of the study area was defined by the digital elevation model (DEM) that was downloaded (Source: https://earthexplorer.usgs.gov/, accessed on 20 April 2021) which is used to describe the elevation points for the given area at a specific spatial resolution of 30 m. Fig 2 outlines a schematic representation of how the data analysis was implemented. The South African National Land Cover (SANLC) project data source was used for the period 1990-2018 [17]. The digital satellite image was used to analyse the dynamics of LULC changes over a period of 1990-2018 in C81 catchment captured in South Africa [17].

These years were selected to detect the possible change occurring at long-span. The LULC datasets were semi-automated where spectral modelling procedures were used to generate, derived, and defined the basic components such as water, bush, grassland, bare ground, and water. These semi-automated land-cover mapping techniques offered a more efficient alternative to conventional classification techniques such as analyst-assisted pixel-based classifiers, allowing rapid production of standardized, yet informative land-cover information and classification. This provided the necessary standardized references from which landscape changes could be determined and quantified [17].

The LULC maps for 1990-2018 were created. LULC data for 1990 were derived from Landsat images at a 30 m special resolution whereas 2018 used Sentinel-2 images at a special resolution of 20 m. This LULC data for 1990, which covers the entirety of South Africa, is displayed in a map-corrected, raster format and is based on 30x30m cells, which are like the source data's source Landsat 8 multi-spectral imagery's picture resolution. Each data cell has a single code that, after analysis of the multi-date imagery collected throughout that image frame, represents the dominant land-cover class (by area) within that 30x30m unit [17]. These images were then resampled at 30 m for compatibility and comparability with those of the 1990 LULC. The 2018 raster format was resampled using raster processing under a data management tool in the aeronautical reconnaissance coverage geographic information system (ArcGIS) from 20m to 30x30m.

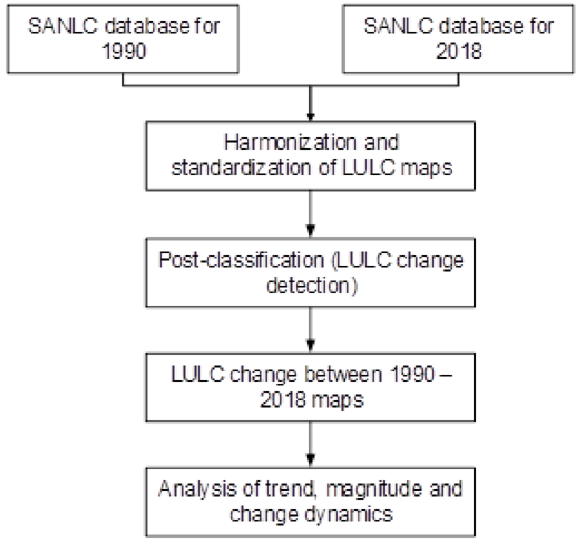

Fig 2. Schematic representation of LULC change analysis.

The LULC classes were grouped into 10 new classes. Table I indicates that 1990 had 72 classes and 2018 had 73 classes. Class name reduction is based on the major changes that happened over the years in the catchment area. The legends were harmonized and standardized to enable comparison (Table I). Finally, evidence for the study was gathered through ArcGIS mapping and ground truthing. After the LULC maps and legends were harmonized, a post-classification method for LULC changes analysis was completed next.

Table I. Standardized LULC classes for changes between 1990 and 2018.

Class_Name	New Class_Name	1990	2018
Bare ground	1	40-41	25-31
Build-up	2	42-72	47-67
Cultivated agriculture	3	10-31	32-46, 73
Forest plantation	4	4, 32-34	5-7
Grassland	5	7	12-13
Low shrublands	6	8-9	8-11
Mining	7	35-39	68-72
Water bodies	8	1-2	14-21
Wetlands	9	3	22-24
Woodlands	10	5-6	0-4

Source (land-cover map reports and legend at https://egis.environment.gov.za/ , accessed on 20 April 2021)

Post-classification is a simple method for determining LULC changes that involve comparing the extent and areas of LULC classes between two periods or point in time, which is also known as bi-temporal change detection [18]–[20]. This provides the direction of change from one point in time to another point. In this study, the year comparison was 1990-2018. The detection change matrix and statistics were generated using a ha/year formula. The rate of change (ha/year) equation no (1) described by [21]:

$$R\Delta\ (\frac{ha}{year}) = \frac{Z-X}{W} \quad (1)$$

3. Results and discussions

The C81 watershed boundary was delineated from the DEM (Fig.3.) Firstly, the DEM was produced using four DEM tiles from earth explorer (Source: https://earthexplorer.usgs.gov/, accessed on 20 April 2021). ArcGIS was used to produce a 30m x 30m pixel-aligned resolution DEM which was formulated to describe the study area. More so, the DEM shows the different elevations within the catchment. The upstream of the catchment (highlighted in blue color) has an elevation of

3291m and the downstream elevation is 1475m which is where the outlet is located. The C81 watershed was delineated with features as shown in fig 3.

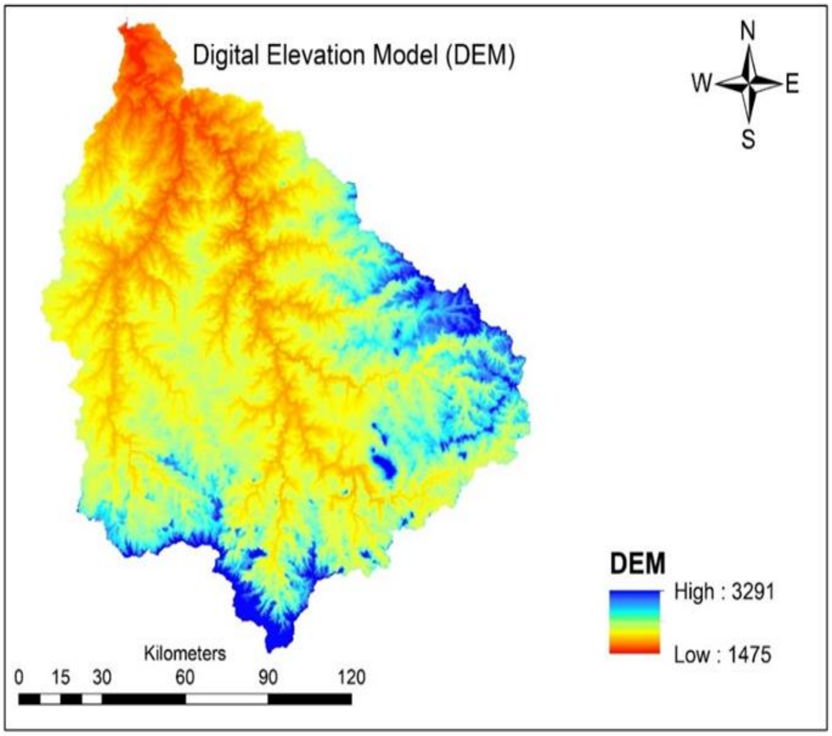

Fig 3. The digital elevation system (DEM) of the study area (Source: https://earthexplorer.usgs.gov/, accessed on 20 April 2021)

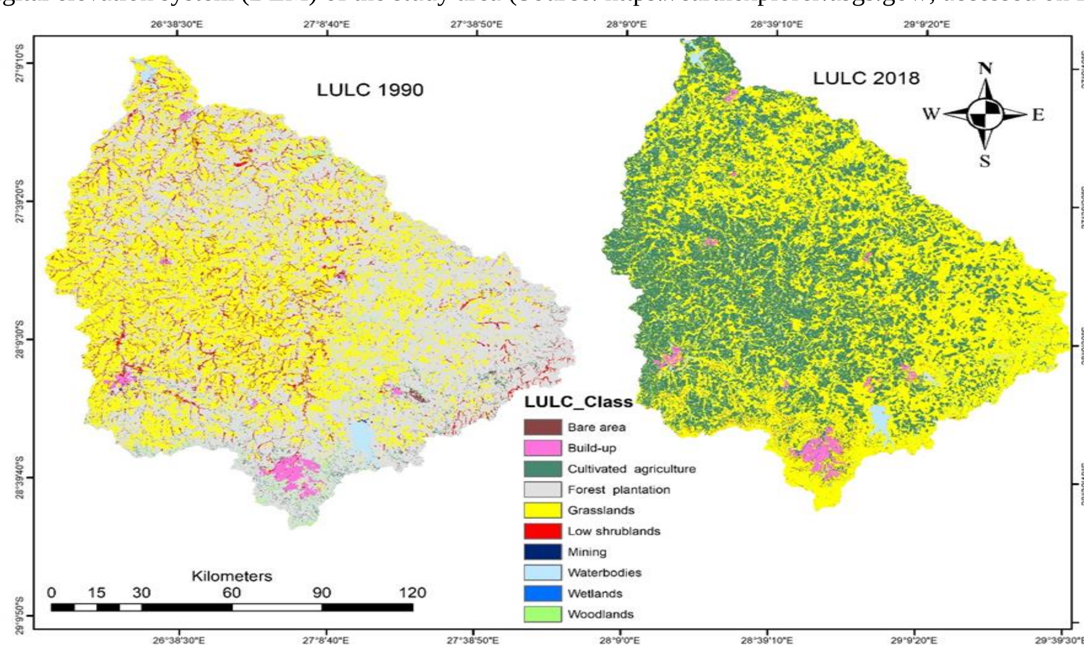

Fig 4. LULC map from South African Land Cover for 1990-2018.

Table II shows the LULC classes, coverage of the area in hectares, percentage, and the rate of change for a period of 28 years. The LULC classes were reduced into 10 classes based on the major changes that happened over the years in the catchment area for both 1990 and 2018. The negative rate of change indicates a decrease in LULC class, where forest plantation decreased from 57.65 to 1.02% with a rate of change of -2.022, and low shrublands decreased from 17.08 to 0.16% with a rate of change of -0.604, these were the major decline in LULC classes. A positive rate of change stipulates an increase in LULC changes, grassland increased from 17.74 to 54.30% and cultivated agriculture increased from 1.11 to 37.32% with a rate of change of 1.306 and 1.293 over 28 years respectively.

Table II. Coverage and change rate of different LULC classes in the study area during the period 1990-2018.

Class Name	**1990**		**2018**		**28 Years**	
	ha	**%**	**ha**	**%**	**Change in ha**	**Rate of change**
Bare ground	237.24	0.01	18237.63	1.10	18000.39	0.039
Build-up	14917.18	0.90	24042.58	1.45	9125.40	0.020
Cultivated agriculture	18380.49	1.11	618721.78	37.32	600341.28	1.293
Forest plantation	955629.24	57.65	16868.83	1.02	-938760.41	-2.022
Grasslands	294091.67	17.74	900218.83	54.30	606127.16	1.306
Low shrublands	283085.37	17.08	2711.36	0.16	-280374.00	-0.604
Mining	79.60	0.00	379.90	0.02	300.30	0.001
Waterbodies	868.53	0.05	17515.99	1.06	16647.46	0.036
Wetlands	116.83	0.01	45895.48	2.77	45778.65	0.099
Woodlands	90352.15	5.45	13349.55	0.81	-77002.59	-0.166

Soil is a major contributor to the agricultural sector. The catchment has 4 soil properties, with clay as the highest followed by loam, clay loam, and water respectively (Fig 5). A soil's ability to function within an unmanaged or managed ecosystem limits, support plant, and animal productivity, maintain or improve the quality of water and air, and support human health and habitation is known as its soil quality. The state of the soil's ability to operate in response to management within a certain environmental context is reflected in its quality [22].

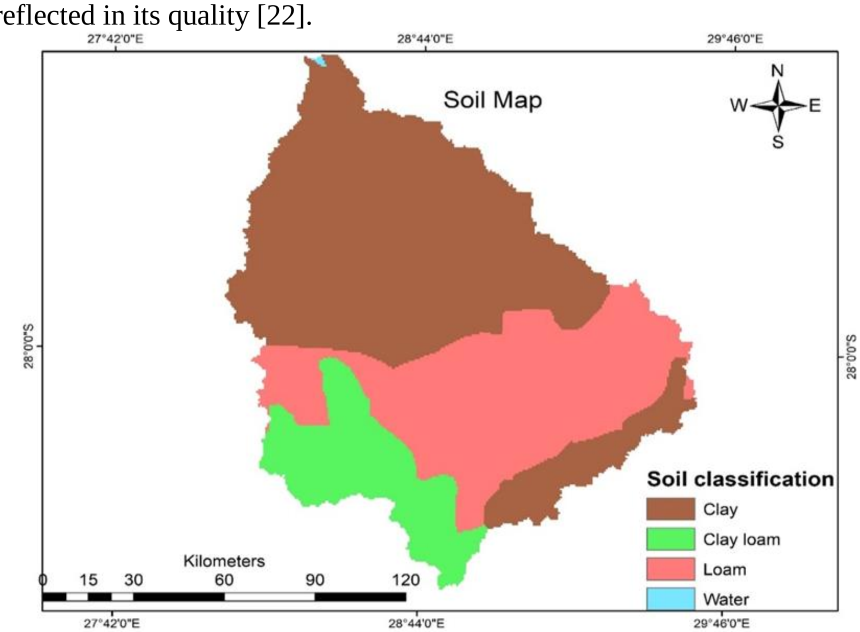

Fig 5. Soil Classification map

Clay is the highest soil texture type in the catchment. Due to its negative surface charge, it has a greater capacity to absorb cations and certain nutrients, which is imperative for the health and quality of the soil [23]. The amount of clay has a great effect on the biological and chemical processes of the soil due to its strong effect on the flow of water, air, and nutrients in the soil [24]. It is common knowledge that soil organic carbon is a function of numerous soil physical properties, including bulk density, aggregation, total porosity, moisture content, atterberg limits, and dispersion clay [25]. Clay is a great soil property texture which is very good for cultivated agriculture which is shown prove about the catchment because it has the highest increase in cultivated agriculture. In short, the catchment's soil is suitable for agriculture.

3.1. Waterbodies and wetlands

The waterbodies and wetlands increase slightly by 1.06 and 2.77%, respectively. There are a few dams in the Thabo Mofutsanyane District Municipality namely: metsimatsho dam, fika-patso dam. The amount of water in rivers, estuaries, dams, and lakes, among other bodies of water, is directly impacted by climate variability through precipitation, evaporation, and surface runoff. The distribution and alteration of water resources in space may have an impact on both human lifestyle and natural biological systems. Changes in the water resource systems may also have an impact on the local vegetation and amplify the effects of climate variability [26]. Taking everything into account, water-related investments can be made in a variety of ways to boost availability, quality, and efficiency of usage. As the world's population grows, more water will be needed for domestic and industrial uses, which will force many water-scarce regions to either import more food or produce more food with less water.

3.2. Cultivated agriculture, bare area, and build-up

The increase in cultivated agriculture from 1,11 to 37,32%. The increase is due to the agricultural sector being crucial in the catchment. The agricultural industry is critical for ensuring food security, and it also absorbs more labor than other economic sectors. Thabo Mofutsanyana District Municipality produces 90% of the country's cherry crops. There are many sunflower seed farms in its northern regions. A significant center for sunflower seed production is Tweespruit [6]. Due to the variety of land uses and agricultural practices seen in rural areas, there are a variety of economic options available.

People require on-the-ground instruction and ongoing supervision; the agricultural sector creates work for a lot of people in the area [27]. The main challenge is a delay in rains leading to a change of crops and reduced hectares, this results in high-stress levels leading to bank closure and farmers taking their own lives [28]. Climate change is affecting agricultural activities badly, due to the exceptionally high atmospheric demand, and evaporative losses in South Africa are already significant, ranging from 1400 to 3000 mm per year. Semi-arid environments are frequently caused by high evaporative losses paired with unpredictable rainfall. This is true in some cases even when there is enough rainfall. Evapotranspiration from crops, which is combined with evaporation, is used to calculate how much water a crop needs. An analysis to determine sensitivity shows that a 2°C temperature increase in the summer (January) will result in an increase in crop evapotranspiration of 3.5 percent, whereas the proportion is larger in the winter [29].

A change in catchment land cover will have a direct impact on the hydrological functioning of a catchment. In South Africa, irrigated agriculture consumes the most water, and this reliance on the water creates the greatest risk for all agricultural activities. Given the substantial agricultural industry, which is a key source of revenue and employment, as well as the hydropower generation in the Upper Orange watershed and mining, water availability is a crucial aspect in the growth of the Free State province [29]. Bare ground increased from 0,01 to 1.10%. The slight increase is linked to agricultural increase because most of the area is used for grassland and cultivated agriculture. The catchment's land is mostly agriculture which indicated that the area is dominated by a large comparative advantage in the agricultural sector, which proves the slight increase in a build-up area of 0,90 to 1,45%. The houses are scattered. The impact of low rainfall in the Free State province has contributed to the low average dam levels. For example, the average dam levels in the province are not at higher levels and are at 62.55%; the capacity of dams is at an average of 73.33%, which has affected the agricultural area estimated at 1,145,000 hectares that were planted in 2018/19 [30].

Thus, the municipality is currently experiencing issues of water scarcity with low quality; this problem can be expected to worsen because of drought, reduced runoff, and increased evaporation which continues to be experienced by this region [31]. Fig 4 and 5 demonstrate the changes which took place between 1990-2018. Although assistance is offered, beginning farmers have trouble getting information and assistance from the Department of Agriculture. People require on-the-ground instruction and ongoing supervision. It was strongly believed that only those who were genuinely interested in farming should be given the opportunity to purchase farms and that strict criteria should be utilized to identify aspiring farmers [27].

3.3. Grasslands

Grassland increased from 17.74 to 54.30 over a period of 28 years. It proves that there is a relationship between the decline of low shrubland and the increase in grassland. Between these two environments, shrublands frequently exist, and their area expands rapidly as fire and grazing are curbed. Numerous ecological services are provided by it, including net primary material production, temperature regulation, soil and water conservation, windbreak and sand fixation, and biodiversity maintenance. Because more than 800 million people depend on grassland ecosystems for their livelihood, 5% of the world's bird species and 6% of its animal species are largely suited to grasslands, grassland ecosystems are irreplaceable in terms of biodiversity conservation and food supply [32]

Numerous ecological services are provided by the grassland ecosystem, including net primary material production, climate regulation, soil and water conservation, windbreak and sand fixation, and biodiversity maintenance [32]. Due to ongoing climate change, an escalating human population, and the resulting increase in agriculture, continuous and reliable monitoring of land cover/use and changes in land cover/use are required. Monitoring natural resources, ecosystem health, biodiversity, and the assessment of losses from natural and human-caused disasters are also made easier by it [33].

3.4. Woodlands, forest plantation, and low shrublands

Plantations for agriculture and forestry are significant economic endeavors that provide regional employment and societal advancement [34]. However, Plantations and other woods transpire more water than pastures, crops, and other similar land coverings, which is their main effect on water resources. To maintain water balance across the landscape, increases in evapotranspiration must be compensated for by concurrent decreases in the runoff, recharge, or water storage [35]. This is to support the decrease in forest plantations, woodlands, and low shrublands. These three LULC consumes a lot of water, and they have an impact on the water balance such as runoff and recharge. The catchment area experiences water scarcity so in the period of 28 years, these three LULC increased evapotranspiration which leads to reduced recharge or trees accessing groundwater stores and thus increasing discharge of that groundwater. Compared to agricultural land uses like cereals, pastures, and other crops, plantation trees consume more water per unit area per year, which reduces runoff and discharge in regions where they are dominant [34]

Although, the benefits of forests and trees for people and the environment include supporting livelihoods, supplying clean air and water, preserving biodiversity, and combating climate change. Due to its role in regulating critical ecological processes including nutrient intake, decomposition, and water availability, the soil is an essential component of the forest and woodland ecosystems. Foresters have historically evaluated the potential of locations to produce healthy forests using their understanding of the chemical and physical qualities of soil [36]. These changes result in population increase, the severity of drought and floods, water scarcity for irrigation and drinking, reduced runoff and increased evaporation. Catchment management is especially critical for climate change adaptation in a country with water scarcity like South Africa. Predicting land cover change may assist build resilience to expected climate changes through, for example, evidence-based water licensing [29].

4. Conclusion

This research analyzed the change of LULC in C81 catchment for a period of 1990-2018 using ArcGIS and remote sensing techniques. It can therefore be concluded that changes in LULC are important, for managing natural resources. The changes in LULC for the period of 1990-2018 were drastic as illustrated in Fig 4 and 5. The transition shows that the majority of the LULC changes are focused on an increase in grassland and cultivated agriculture, as evidenced by the rate of change of 2.31% & 1.31% respectively. These changes result in population increase, the severity of drought and floods, water scarcity for irrigation and drinking, reduced runoff and increased evaporation. Monitoring and management of the LULC in the catchment is very important so that biodiversity species can be saved and water as a resource can continue to be available. Grassland and cultivated agriculture recorded the highest changes, which indicated that the area is dominated by a large comparative advantage in the agricultural sector. However, in a country like South Africa where water is scarce, catchment management is essential for climate change adaptation. This is because the findings indicate that this area receives low rainfall. The benefits of forests and trees for people and the environment include supporting livelihoods, supplying clean air and water, preserving biodiversity, and combating climate change. More research will follow to investigate the impacts of LULC changes on the water resources of the study area using modelling. Management of this catchment is very important in relation to LULC.

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