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# Multi-temporal Satellite Images Analysis for Assessing and Mapping Deforestation in Um Hataba Forest, South Kordofan, Sudan

***Emad H.E. Yasin[1,2], Om Habiba Kamil[2], and Budi Mulyana[1,3]***

[1]*Faculty of Forestry, University of Sopron, Bajcsy-Zsilinszky ut. 4, 9400, Sopron, Hungary*
[2]*Faculty of Forestry, University of Khartoum, Khartoum North, 13314, Sudan*
[3]*Faculty of Forestry, Universitas Gadjah Mada, Yogyakarta, Indonesia*

**Abstract.** Deforestation is a problem in Sudan, despite the increasing awareness of deforestation and its consequences. Consequences are related to increased emissions of greenhouse gases, water pollution, and loss of biodiversity. However, consistent, and accurate information on the current state of the forests is scarce. Therefore, in order to effectively intervene to support and maintain existing resources, a better understanding of the processes taking place in the country and the negative impact on those resources is required. The objective of this study is assessed and map Land use Land cover (LULC) change and analyze the anthropogenic factors causing it in Um Hataba forest, South Kordofan State. The study utilized two-free cloud images (TM 2000 and Sentinel-2 in 2018), field surveys, and questionnaires to analyze the decrease in forest cover. The results indicated there were a decrease in vegetation cover on wadis (clay soil) from 20.98% in 2000 to 15.85% in 2018 and vegetation on sandy soil decreased from 30.29% in 2000 to 30.13% in 2018. While mixed shrubs and grassland increased from 28.60% in 2000 to 33.20% in 2018 of the total area under study and the rainfed agricultural area increased from 20.13% in 2000 to 20.82% in 2018. The expansion of mechanized rain-fed agriculture, tree felling and woodcutting, poor grazing activities, and building construction are the main causes of deforestation and forest degradation. The findings of this study can be used to develop proper forest rehabilitation programs and management plans that consider the needs of the communities who utilizing the forest.

**Keyword:** Landsat Images, Deforestation, LULC, Antrhopogenic Factors, Um Hataba Forest

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## 1 Introduction

Tropical forests are biodiversity-rich habitats, on the globe because they host diversity flora and fauna species, provide a diverse range of ecosystem goods and services to local communities, as well as maintain a variety of ecological functions [1]. The forest resources have significant

*Corresponding author at: Institute of Geomatics and Civil Engineering, Faculty of Forestry, University of Sopron, Bajcsy-Zsilinszky ut. 4, 9400, Sopron, Hungary
E-mail address: emad.yasin823@gmail.com

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impact on Sudan's society, economy, and environment [2]-[3]. Deforestation, on the other hand, is threatening Sudanese forests, which is primarily driven by energy needs and land clearance for agricultural expansion. Furthermore, these resources are distributed in an unbalanced manner (i.e., the majority of the remaining forests are concentrated in the south, whereas the northern part of Sudan has poor and sparse woody formations). There has been a concentration of people in that area, and demand for forest goods and services is at an all-time high [4]. There are Some communities still rely solely on illegal timber harvesting and resale for daily survival, and they have a limited understanding of the root causes of widespread forest degradation in developing countries [5]-[6].

Forest resources are vital, and Sudan's forests are under huge pressure to meet subsistence needs such as fuelwood, fodder, and land-use changes as the population grows. Forest conservation is particularly important in Sudan, where forest resources are extremely crucial for ecosystem balance and people's livelihood [7]. The forest cover in Sudan has witnessed a substantial decrease in the last decades as reported in a plethora of literature. [8] Reported the total forest cover of Sudan to be 23.57 million ha, 21.826 million ha, 20.954 million ha, 20.082 million ha, and 19.21 million ha in 1990, 2000, 2005, 2010, and 2015 respectively. [8] Observed that there has been a consistent reduction in total forest cover in Sudan yearly. The figure attributed to 2015 constitutes about 10.3% of the country’s landed area of 186.665 million ha. Therefore, there is an urgent need to arrest further loss of Sudan forest cover [9]. Except for appropriate intervention policies that engendered effective management practices to checkmate excessiveness of the drivers of deforestation and forest degradation, it may be impossible to check the menace of forest cover reduction in Sudan [9]. In this respect, forest cover in Sudan has witnessed considerable changes in the last decades as reported in many reports [8, 10].

The annual forest cover change between 1990 and 2015 accounted for -0.8% [8]. While a global data set on changes in forest cover was recently released and made freely available for each country [11]-[12]. It has been criticized that there is a lack of accurate and consistent information in different vegetation types at the local scale. Even so, it remains a respected source of forest cover in areas where local information is severely lacking. For example, spatially explicit forest cover information for Um Hataba forest is scarce, particularly in recent decades. Nonetheless, illegal selective logging, uncontrolled grazing, and slash-and-burn agriculture are causing significant forest degradation and deforestation in this dryland forest. Furthermore, as reported in a plethora of literature, these activities have had a significant impact on underground water and soil properties. [13]-[15] These activities may have caused LU/LC changes in the area that were relatively diffuse and small-scale. Regrettably, reserved forests in the study area are being dramatically cut indiscriminately in order to meet the needs of visitors for urbanization and income generation. Demand for land has increased, resulting in gradual deforestation of the watershed. Many unauthorized residential buildings have been established, and various types of agricultural activities are now taking place in a reserve forest. Illegal timber harvesting, illegal wood cutting for firewood, and so on. That is why conducting research in the study area is necessary. Something must be done; we must comprehend the scope of the exploitation, estimate the trend, identify the factors of deforestation, and begin to forecast future events if nothing is done.

GIS and Remote sensings are very powerful tools [16], widely accepted, and they're having an increasing impact on forest degradation studies' monitoring. It entails gathering data about an object, area, or phenomenon from a distance, then analyzing data collected by a device that isn't in contact with the object, phenomenon, or investigation area. For forest cover mapping and monitoring, remote sensing data with sufficient spatial and high-resolution satellite datasets are valuable and reliable resources [17]. Change detection can be accomplished by analyzing remote sensing data from various epochs. Monitoring of forest destruction can be done using time changes analysis. The knowledge gained from this data serves as the basis for decisions making in the efforts to address against deforestation [18]. Therefore, the objective of this study, assess and map Land use, land cover (LULC), and their temporal changes and analyze the anthropogenic factors causing the change. In Um Hataba forest, South Kordofan State, Sudan was determined utilizing multi-temporal satellite images, ground truth data, Geographic Information System (GIS) integration, and other information collected by questionnaire.

## 2 Research Method

### 2.1 Study area

This study was conducted in Um Hatabah forest is in Dilling locality, South Kordofan, Sudan, which is located between (latitudes 12° 3’ 0” and 12° 49’ 0” N and longitudes 29° 49’ 30” and 30° 5’ 30” E. It covers an area of about 7,872 Km2, mostly useful for agriculture and grazing activities (Figure 1). The weather in the Um Hataba forest Reserved. Forest is characterized by high temperatures ranging from 20˚C at night and 35˚C in the day. The annual rainfall range from 400 mm and 676 mm in the northern southern parts of the locality, respectively [19]. The soils are ferruginous tropical red soils that have been associated with basement rocks. The vegetation in the study area varies according to rainfall patterns. The average annual rainfall is 372 mm, and the vegetation is poor to moderate, with Acacia trees and short grasses and shrubs [20]-[21]. The average annual rainfall is 712 mm, with denser Acacia and other trees vegetation [22]. Therefore, this region was chosen as one of Sudan's class two (moderately desertified) States due to its geographical location in the dry regions category. It had fair good of vegetation cover, but it was severely degraded due to irrational mechanized farming, extensive woodcutting, overgrazing, and overmining of land resources [23].

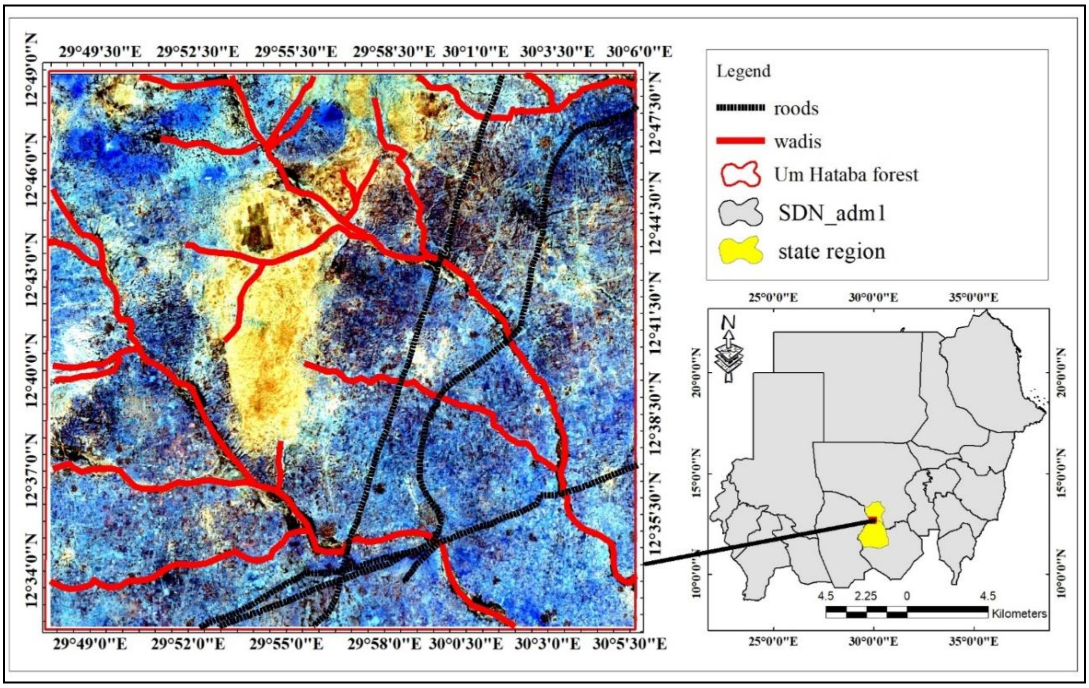


**Figure 1** The study area (Um hataba forest in south Kordofan State, Sudan)

## 2.2 Material and Methods

To identify the LU/LC changes, remotely sensed data were used, where satellite images have chosen from the Landsat 5 and sentinel 2. These images were clear of cloud cover and freely downloaded from the United State Geological Survey website (GloVis) at the path of 175 and row 52. Consequently, two satellite images were used with spatial resolution 30 and 10 m (Table 1), where Landsat 5 and Sentinel-2 images were downloaded for years 2000 and years 2018 respectively. Landsat and Sentinel images were selected purposely because of their geographical cover ability and temporal availability. The study applied an integrated approach for data collection and analysis (Fig. 2). It is based on remote data as well as other field information concerning the different land use activities during the research period.

**Table 1** Landsat 5 TM and Sentinel-2 that Used in LULC Determination of the Study Area

| Satellite/Sensor | Path/Row | Acquisition date | Spectral Bands | Resolution (m) |
|---|---|---|---|---|
| Landsat 5 TM | 175/52 | 26/12/2000 | 1, 2, 3, 4 | 30 |
| Sentinel-2 | 715/52 | 28/12/2018 | 2, 3, 4, 8 | 10 |

Source (GLOVIS; 2000; 2018)

ERDAS Imagine 2014, ArcMap 10.7, and Microsoft Excel 2016 software were used in the analysis and processing of the satellite images, as well as in computing the areas of land use and land cover changes, as well as their percentages and changes. Accordingly, image calibration, geometrical, and atmospheric correction were completed, as well as layer stacking and the composite bands tool to convert each year's bands (1, 2, 3, and 4 for TM, and 2, 3, 4, 8 for sentinel-2) into a single-layer file (preprocessing and enhancement).Sub-scenes were then clipped. Following that, for the LU/LC classification of acquired Landsat images from 2000 and Sentinel-2, supervised classification was used, with the Maximum Likelihood Classifier. Finally, each image's accuracy was assessed systematically using ground truth and Google Earth, as well as prior knowledge of the area under investigation, by calculating user and producer accuracies, overall accuracy, and Kappa coefficients, and then the error matrix of the land cover classification; the results revealed that the overall accuracy and kappa coefficients represented for each classified image were greater than 85 % for all images. SPSS Version 24 was used to analyze social survey data on deforestation drivers.

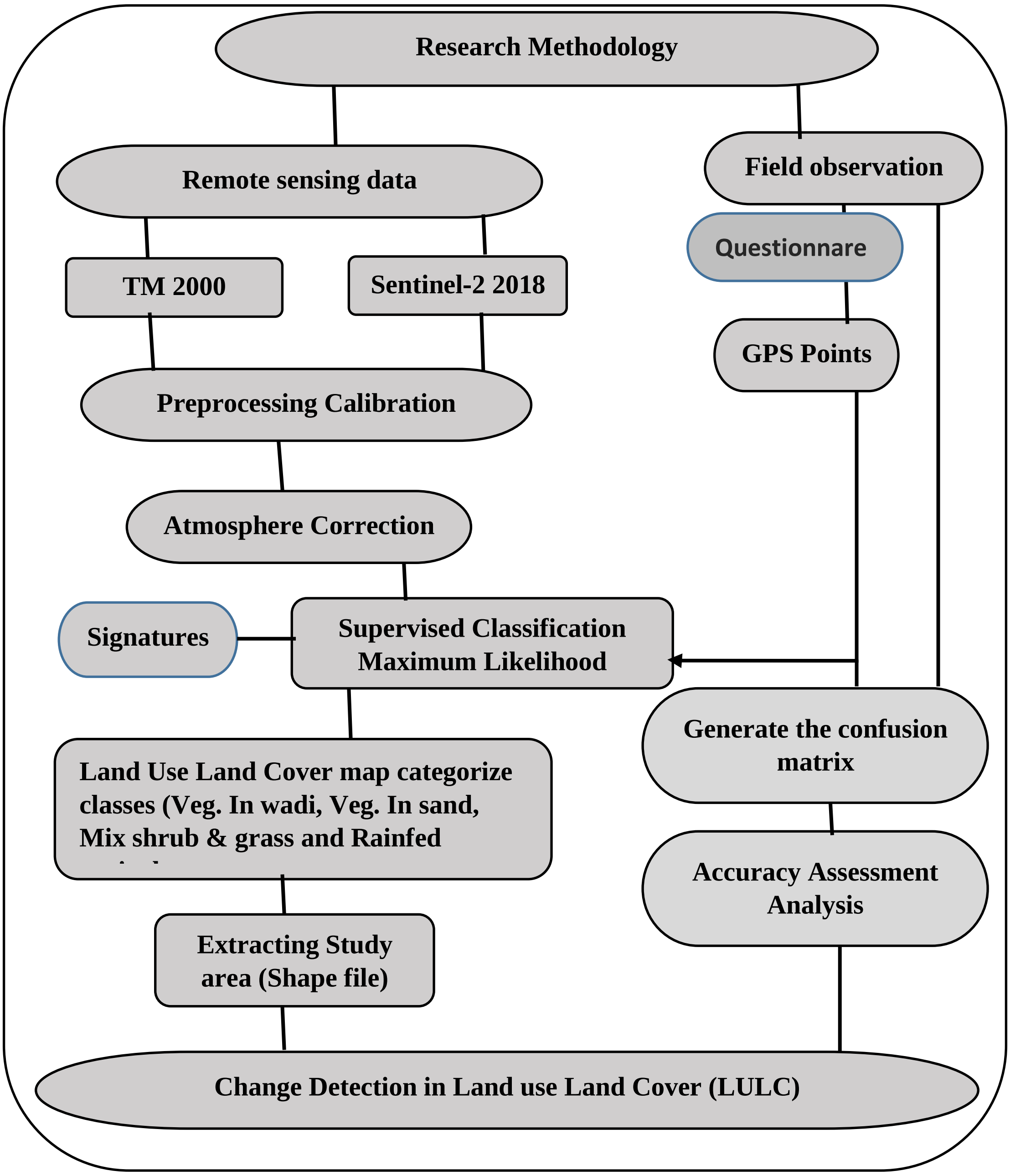


**Figure 2** Schematic workflow used for LULC change detection

# 3 Results and Discussion

## 3.1 LULC results in 2018

Four classes of land cover were depicted from supervised image classification. These classes: residential area, Waterbody, Agriculture, and bare land as shown in Figure 3. The result of the Supervised Classification of Sentinel-2 2018 showed that vegetation on wadis (clay soil) occupied 15.85% which represents (15,774.12 ha) of the total area, vegetation on sandy soil 30.13% (29,984.30 ha), and mixed shrubs and grassland 33.20% (33,032.88 ha) of the total area, while rainfed agricultural area occupied 20.82% (20,719.90 ha) of the total area. (Figure 3 and Table 2).

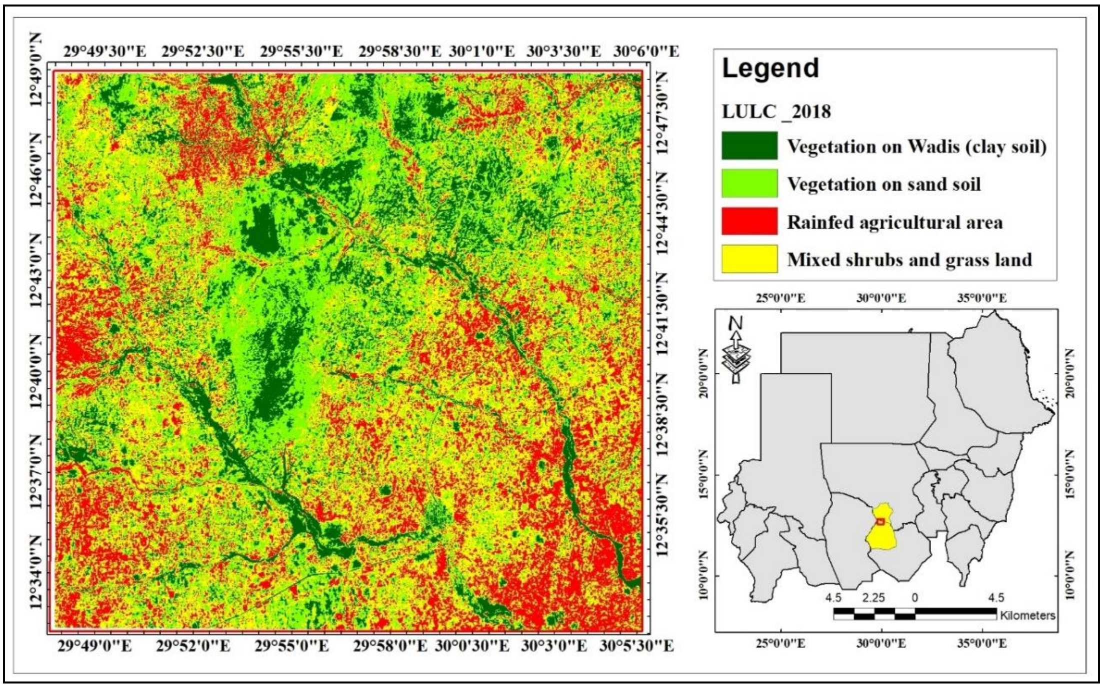


**Figure 3** Supervised classification map of Sentinel-2 2018

**Table 2** Distribution of LULC in the study area (ha) in 2021

| Class Name | 2018 | |
|---|---|---|
| | Area (ha) | % |
| Vegetation on wadis (clay soil) | 15,774.12 | 15.85 |
| Vegetation on sandy soil | 29,984.30 | 30.13 |
| Mixed shrubs and grass land | 33,032.88 | 33.20 |
| Rainfed agricultural area | 20,719.90 | 20.82 |
| Total | 99,511.20 | 100.00 |

## 3.2 Assessment of change detection (LULC during 2000-2018)

LULC changes are one of the most persistent and important sources of recent land surface changes around the world [24]-[25]. Thus, their identification provides the ground cover information for baseline thematic maps and establishes a baseline from which monitoring activities (change detection) can be carried out. In this study, and as depicted in (Figure 4 and

Table 3), and due to the human and environmental factors, LU/LC have witnessed considerable changes during the two study periods (2000-2018). It's clearly shown that there was a decrease in vegetation cover on wadis (clay soil) from 20,876.40 ha (20.98%) in 2000 to 15,774.12 ha (15.85%) in 2018 with the net of change of 5102.28 ha equivalent to (5.13%) and the annual rate of decrease 0.29% of total vegetation cover area per year, vegetation on sandy soil decrease from 30144.20 ha (30.29%) in 2000 to 29,984.30 ha (30.13%) in 2018 with the net of change 159.88 ha equivalent to 0.16% and annual rate of decrease 0.0089% of total vegetation cover area per year, Mixed shrubs and grass land increase from 28,459.00 ha (28.60%) in 2000 to 33,032.88 ha (33.20%) in 2018 with the net of change 4,573.89 ha equivalent to (4.60%) and annual rate of increase 0.26% of total mixed shrubs and grass land area per year and the rainfed agricultural area increase from 20,031.60 ha (20.13%) in 2000 to 20,719.90 ha (20.82%) in 2018 with the net of change 688.30 ha equivalent to (0.69%) and the annual rate of increase 0.038% of total rainfed agricultural area per year. In this line, a study conducted by [26] stated that deforestation, flooding, soil erosion, and unplanned urban and agricultural expansion are all factors that could cause LU/LC changes. The same study indicated that changes in LU/LC over time under different environmental, political, demographic, and socioeconomic conditions, which frequently change and have a direct impact on people who live near forests.

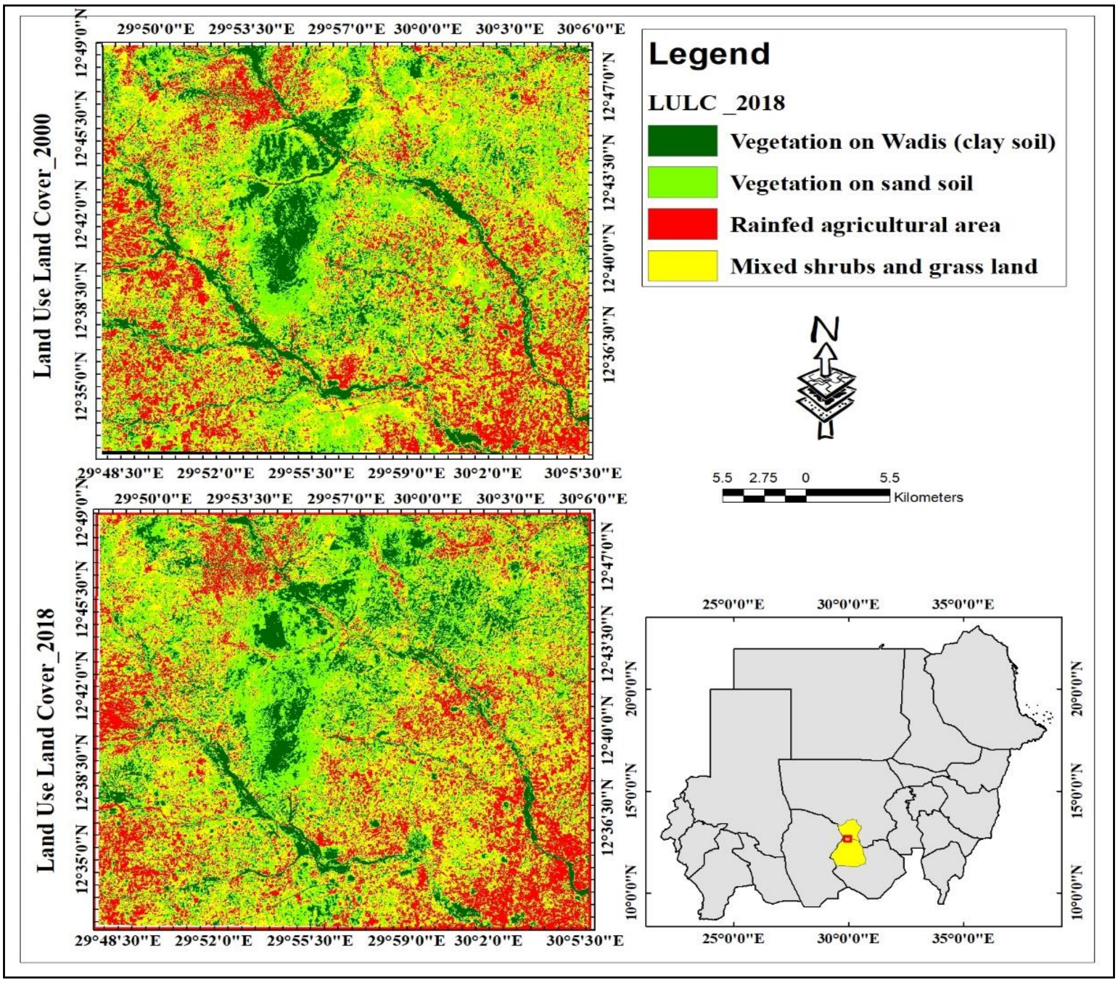


**Figure 4** LULC of TM 2000 and Sentinel-2 2018

**Table 3** Distribution of LULC in 2000 and Sentinel-2 2018 in the study area

| Class Name | 2000 | | 2018 | |
|---|---|---|---|---|
| | Area (ha) | % | Area (ha) | % |
| Vegetation on wadis (clay soil) | 20,876.40 | 20.98 | 15,774.12 | 15.85 |
| Vegetation on sandy soil | 30,144.20 | 30.29 | 29,984.30 | 30.13 |
| Mixed shrubs and grass land | 28,459 | 28.60 | 33,032.88 | 33.20 |
| Rainfed agricultural area | 20,031.60 | 20.13 | 20,719.90 | 20.82 |
| Total | 99,511.20 | 100.00 | 99,511.20 | 100.00 |

### 3.3 LULC trajectory matrix

LULC change is a complex pattern of interdependent processes involving various human activities, rather than just a simple and irreversible conversion from one type of land cover to another [27]-[28]. LULC change transition highlight the dynamic of successive changes that can be investigated through temporal series of remote sensing data [29]. Um Hataba Forest has been experiencing significant changes in terms of both space and time, particularly in recent years. The LULC transition matrices in Table 2 and the maps in Figure 4 below indicate how the forest has transformed from one class to a highly dynamic landscape. LULC transition matrices are a valuable tool to detect and analyze depletion of natural resources in semi-arid environments. [30]. Accordingly, matrix analysis tool provides a better understanding of the systematic Land Use Land Cover transitions [31]. However, change matrices for the classified LULC classes have been developed to show the overall change dimensions during the period 2000-2018. The output transition matrix is shown in Figure 5 and Table 4.

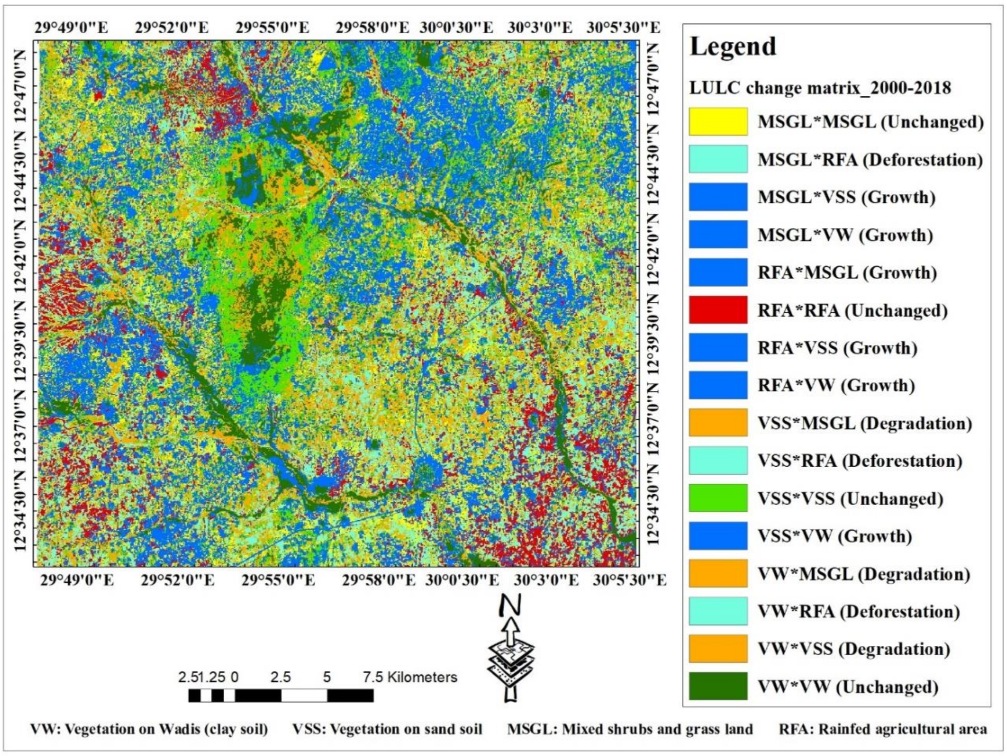


**Figure 5** Land use land cover change trajectory matrix 2000-2018

**Table 4** Land Use, Land Cover trajectory Matrix 2000-2018

| | | Year | 2018 | | | |
|---|---|---|---|---|---|---|
| | Class name | Vegetation on wadis | Vegetation on sandy soil | Mixed shrubs and grass land | Rainfed agricultural area | Total |
| Year | Veg. on wadis | 9,698.22 | 2,723.94 | 532.98 | 2,818.98 | 15,774.12 |
| 2000 | Veg. on sandy | 6,456.45 | 6,904.30 | 9,188.98 | 7,434.57 | 29,984.30 |
| | Mixed shrubs and grass land | 4,288.83 | 11,550.76 | 10,425.27 | 6,768.02 | 33,032.88 |
| | Rainfed agricultural area | 432.90 | 89,65.193 | 8,311.77 | 3,010.04 | 20,719.90 |
| | Total | 20,876.40 | 30,144.20 | 28,459.00 | 20,031.60 | 99,511.20 |

Figure 5 and Table 4 showed that only 9,698.22 ha of old vegetation cover on wadis remained of the total forest area of 20,876.40 ha detected in 2000. Between 2000 and 2018, forest conversion to rainfed agricultural land resulted in a total deforestation area of 432.90 ha. Mechanized rainfed agriculture is putting pressure on the remaining forest [32]. The lack of participation of people living in the surrounding areas in forest resource management is expected to aggravate the situation [33]. Vegetation cover degradation area between 2000 and 2018 was 10,745.28 ha resulting from vegetation cover on wadis conversion to vegetation on sandy soil which is a very fragile area (6,456.45 ha) and into mixed shrubs and grassland (4,288.83 ha). However, the gain into vegetation cover on wadis between 2000 and 2018 was 6,075.90 ha resulting from a change of vegetation cover on sandy soil (2,723.94 ha), mixed shrubs, and grassland (532.98 ha), and rainfed agricultural area (2,818.98 ha) into vegetation cover on wadis. which was due to the sound management activities that directed by refugees affected areas project, which was funded by the Higher Commission of Refugees of United Nations (UNHCR) and United Nations Sudano-Sahelian Office (UNSO). The total net gain, the difference between total deforestation (432.90 ha) and total vegetation cover expansion (6,075.90 ha) was 122.67 ha over eighteen years, resulting in decreasing the vegetation cover on wadis area from 20,876.40 ha in 2000 to 15,774.12 ha in 2018. Similarly, this table shows the dynamic change between other categories. The total area of Vegetation on sandy soil remaining since 2000 was 6,904.30 ha. Mixed shrubs and grassland on the other hand had an area of 10,425.27 ha remaining since 2000. All the values along the vertical column were representing rainfed agricultural and vegetation Sandy soil area converted to other land use categories. The values along the horizontal row represent land use categories converted to the rainfed agricultural area and Vegetation on Sandy soil, respectively.

### 3.4 Drivers of deforestation and forest degradation in the study area

Based on the socio-economic survey's result, most of the respondents affirmed the existence of deforestation and forest degradation due to the rampant forest dependents' needs and activities. For instance, energy, building materials, fodder, and other non-wood forest products are all gathered and collected from the forestland. Accordingly, in recent times, Due to a complex set of social, economic, and political factors, the Um Hataba forest has been severely deforested. The direct causes brought from questionnaires outcomes indicated large areas which have been cleared and transformed into mechanized farms inside and in the forest frontier where peoples are seeking farmland. Other reasons that stood behind forest degradation, were illegal cutting to meet fuelwood and building materials demand. For the respondents, the main sources of energy were firewood and charcoal, which were also mentioned as important sources of cooking fuel (see Figure 6). The majority of the fuelwood brought from the forest. Hence, despite the challenging conditions in the area and the grave threat of degradation/desertification, local peoples continue to put pressure on natural forests and planted trees [24]. According to [34] reported that, tree felling for firewood and charcoal production is a common practice in Sudan. The pressure is, however, greater in the areas surrounding urban centers [33].

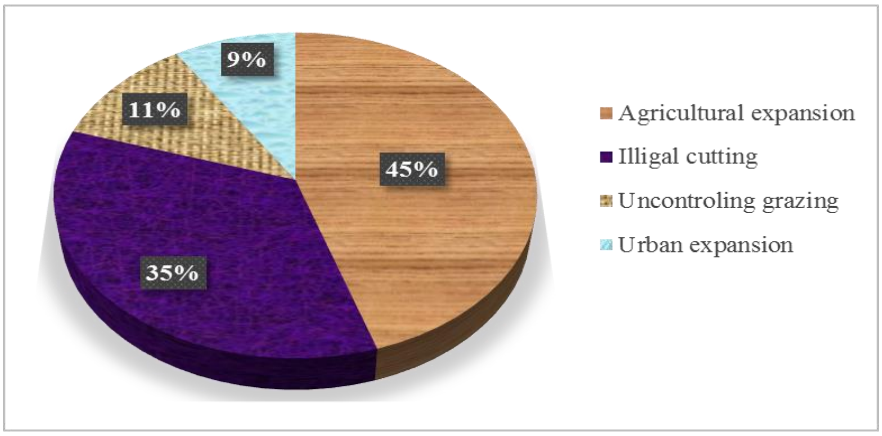


**Figure 6** Major Drivers of Deforestation and Forest Degradation

## 4 Conclussion

A combination of multi-temporal satellite images, GIS, ground inventory, and social survey was being used to assess deforestation in Um Hataba Forest. The study identified the spatial and temporal patterns of LULC changes in the forest, which will help and facilitate proper forest management and future rehabilitation plans. Thus, the study concluded that there were sizeable LU/LC changes during 2000-2018 with different trends and percentages. LULC analysis reveals that there is a decrease in vegetation cover on wadis (clay soil) from 20.98% in 2000 to 15.85% in 2018 and vegetation on sandy soil decreased from 30.29% in 2000 to 30.13% in 2018. While mixed shrubs and grassland increased from 28.60% in 2000 to 33.20% in 2018 of the total area and the rainfed agricultural area increased from 20.13% in 2000 to 20.82% in 2018 of the total area under study. These changes and alterations have been driven by Anthropogenic activities such as the expansion of rain-fed agriculture, wood cutting, poor grazing practices, and building infrastructure are the main underlying factors driving LULC changes in Um Hataba Forest. However, when compared to other factors, rain-fed agricultural practices were the most. Which all those factors have a role in deforestation and forest cover changes. Changes in forest cover are expected to have a significant impact on the forest's services, and if the current rate of deterioration continues, the forest's existence may be adversely affected. The FNC must prioritize protecting what remains of Um Hataba Forest, especially given the rapid degradation that has occurred over the last 18 years. However, there is no one-size-fits-all solution to this problem. As a result, policy initiatives should incorporate a variety of solutions, including agroforestry and agricultural intensification. It is also clear that encouraging local communities to participate in rehabilitation activities while taking their interests into account is an essential part of any successful rehabilitation program, as failure to do so will only result in restoration activities failing. The findings of this study can be used to develop proper forest rehabilitation programs and management plans that consider the needs of the communities who utilizing the forest.

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