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# GIS and Remote Sensing Based Land Degradation Assessment and Mapping: Case Study Adea Woreda

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***Abstract***
*Land degradation is an increasing problem in many parts of the world. Success in fighting land degradation requires an improved understanding of its causes, impact, degree and acquaintance with climate, soil, water, land cover and socio-economic factors. The present study aimed to assess the advanced of Remote Sensing (RS) and Geographic Information System (GIS) to quantify land degradation risk in Adea woreda. Remotely sensed data provide timely, accurate and reliable information on degraded lands at certain time intervals in a cost-effective method. This paper presents the effect of land-use changes on land degradation by utilization of remote sensing and GIS methods due to un wise agriculture and urbanization activities in the period 2000–2022. The analysis is based on the processing of Landsat 7 and Landsat OLI 8 satellite images from 2000 and 2022. In the analysis of satellite images, the supervised classification maximum likelihood method was used. The study demonstrated that about 42.77 % of the study area has undergone very high risk of degradation, whereas 44.26% of the area has undergone moderate degradation. About 12.50% of the total area was characterized by marginally degraded. The results indicated that the salinity, alkalinity and water logging are the main common degradation hazards of the Adea woreda.*

**Key Words:** Land Degradation, GIS, Remote Sensing, Soil Erosion

## Introduction

Land is the most valuable resource for production of food, fiber, fuel and many other vital goods required to meet human and animal needs. However, it is facing serious threats of deterioration due to inexorable human pressure and utilization incompatible with its capacity. Land degradation is considered one of the most severe global problems worldwide. According to land, degradation is increasing in severity and extent in many parts of the world, with more than 20% of all cultivated areas, 30% of forests and 10% of grasslands undergoing degradation [1]. Land degradation in general, indicates temporary or permanent decline from a higher to a lower status of productivity through deterioration of physical, chemical and biological aspects. From the ecological perspective, land degradation is realized as damage to the healthy functioning of land-based ecosystems [2, 3]. Stated that land degradation phenomena occur by a complex interaction between natural (e.g., soil properties and climate conditions) and human factors (e.g., over-grazing, overcultivation and deforestation). The main types of land degradation issues recognized in the Adea woreda include salinity, loss of vegetation cover, over exploitation, irrigation, sodicity, compaction and water logging as well as water erosion, which can be attributed to Koka dam.

Millions of hectares of land per year are being degraded in all climatic regions in the world [4]. In agriculture-based countries with a dependence on subsistence systems, the priority is to increase productivity to achieve food security [5]. The decline in land quality caused by human activities has been a major global issue since the 20th century and will remain high on the international agenda in the 21st century [6]. The accessibility of accurate and timely information on nature, extent and spatial distribution of land resources enables and rationalizes the decision-making processes of planners, policy makers and managers in a cost-effective and time efficient manner.

Land degradation can be examined in different ways, such as direct field observation and using remote sensing technology. In comparison to field methods, the remote sensing technique is more cost-effective and time-efficient in which a vast land area can be monitored using one image. A large number of researches have been carried out using different methods of remote sensing and geographic information system (GIS) to determine land degradation risk. Remotely sensed imagery is suitable for revealing land that has been affected by degradation to various levels [7]. Furthermore, remotely sensed data are effective in identifying and mapping land degradation risks and modeling soil loss [8-11]. GIS and remote sensing-based studies of land use /land cover change and land degradation analysis can be undertaken at different spatial scales to gives both qualitative (e.g., vulnerable areas) and quantitative information (e.g., soil loss rates). These research paper tries to examine the importance of GIS and remote sensing were employed to asses land use/land cover change and its environmental degradations for the preparation and implementations of sustainable land use management in the Adea woreda.

The aims of this study are temporal and spatial analyses of land degradation by using GIS and remote sensing to show dynamics in degraded land areas of Adea woreda between 2000 and 2022 in relation to land use/land cover change to counter land degradation. The specific objectives of this study were: (1) estimate the average annual soil loss of the woreda; (2) assess the risk of land degradation level depending on remote sensing and GIS techniques; (3) develop comprehensive and appropriate land degradation indicators.

## Literature Review

Land degradation is unprotected removal of the land through different ways whereas the surrounding livelihood is difficult to sustain of the degradation. It is mentioned as different description of idea. With regard as, land degradation and its attendant effects harshly influence on rural communities since a large number of rural communities are reliant on for their livelihoods on facilities derived from land-based ecosystems [12-14].

## Land Degradation Types and Processes

According to it is different interconnected land degradation process is occurred. There are four major land degradation types, each type of land is which can be sectioned by precise sub-set of degradation processes, these are soil degradation, vegetation degradation, water resource degradation and pollution (soil or water). However, to identify the land degradation type and process are the most important to be concerned about the vulnerability area of the watershed. Mostly it depends on soil degradation focused on other types of land degradation [15].

### Soil degradation

According to about the area of land estimated 20 million (over 15%) has degraded at a global level. The main causes are overgrazing, deforestation and unsustainable agricultural management. Some soil degradation processes are natural phenomena but they are worsened by all kinds of sustainable human uses. Soil degradation is expected to continue and probably accelerate if appropriate measures are not taken [16].

### Vegetation degradation

According to it refers to the growth reflectance of vegetation healthy condition of articulated through changes in its composition, structure and function. Also Van der Merwe 2005 targeted to vegetation is changeable in replying to pointed out that vegetation is dynamic in replying to existing environmental problems and these changing marked in variations in the distribution of vegetation types and changes in the growth periods of plant. The plant growth period frequent observation and measurement is significant for monitoring changes [17, 18].

### Water Resource Degradation

Ground water table lowering outstanding to minimize recharge and increased extraction, the amount of sediment load increased in watercourses and rivers as a result of increased 13 soil erosion in their catchment areas; reduced water storage capacity due to sedimentation of reservoirs; the ground water resource pollution and surface water pollution to the direct cause of human and animal wastes, agro-chemicals, industrial and mining wastes; and increased salt content of surface and ground water resources due to excess salt flushing from irrigated areas [18].

## Causes of Land Degradation

According to the cause of land, degradation involves multiple causal factors. These are the physical and human induced causes. The relations between the two systems determine the decline of resource management. The recognizes the causes of land degradation biophysical factors such as inappropriate land use, socio-economic factors such as lack of land management activities, access to markets, infrastructure, land tenure, institutional support income and political factors such as lack of incentives and political instability. Whereas in the corresponding argued that land degradation is a biophysical process focused by socio-economic and political causes in which hand to mouth agriculture, poverty and illiteracy people are the main causes of land and environmental degradation in Ethiopia [19-21].

## Materials and Methods

### Study Area

Adea woreda is located in the east shewa zone of the Oromia region at a distance of 48 km from Addis Ababa in the Great Rift Valley . The woreda geographically lies within 80 38' 47'' to 80 56' 52''N latitude and 380 53' 30''-390 11' 24''E longitude. The area coverage of the woreda are 936.41 square kilometers. According to 2007, national census reported a total population of the woreda are 130,321, of whom 67,869 were men and 62,452 were women. Adea has a high great rift alley the elevation of the area varies from 1680 -2867 m.a.s.l. According to the National Meteorological Services Agency Adea woreda gets maximum rainfall amount 1,220 mm and 1,050 mm minimum annually [22]. The highest mean maximum temperatures of the woreda about 26°C from February to May and 24°C from September to November and the lowest mean temperatures, of 23°C or lower between June to August respectively (Fig. 1).

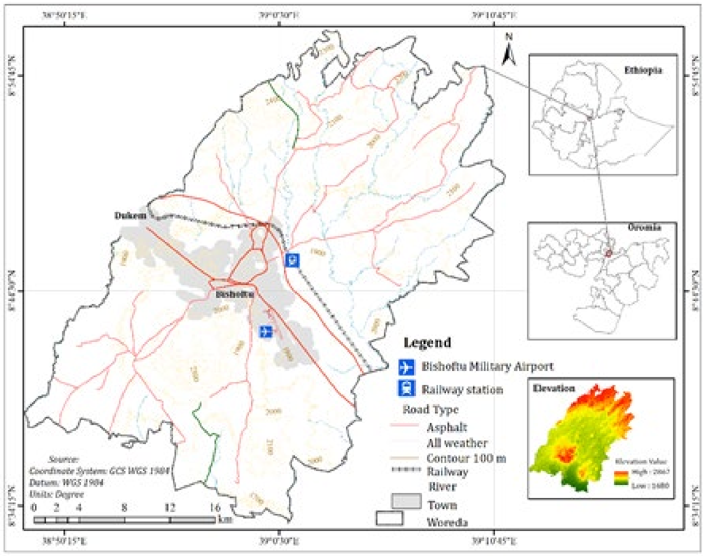

**Figure 1:** Location Map of Adea Woreda

## Methods and Data Used

The most common methods used to assess land degradation are expert opinions, land users' opinions, field monitoring, observations and measurement, modelling, estimates of productivity changes and remote sensing. The methods have been applied to different approaches, which use either qualitative or quantitative measures or both. The dataset for the study was collected from google earth. Landsat 7 ETM+ and Landsat 8 OLI satellite image with a resolution of 30 m was used for LULC classification, which was downloaded from the website: www.earthexplorer.usgs.gov. A geospatial analysis was employed for all variables of land degradation identification, which are rainfall, slope, land use land cover, and soil data by applying the basic image preprocessing techniques. The study used interpolation, regression, re-classify, and weighted overlay analyzing, combining, map algebra of GIS Spatial Analysis technologies to identified degraded areas.

## Satellite Data

The least-clouded multispectral and hyperactive spectral satellite images of the years 2000 and 2022 were procured from the United States Geological Survey (USGS, 2015; http: //www. usgs.gov) and Global Land Cover Facility (GLCF, 2015; http://www.glcf.umd.edu). Geospatial analysis technologies to identified degraded areas. The satellite data of the area was clipped from 168 path and 054 rows that, were preprocessed, manipulated, and analyzed by using Geospatial Packages (Table1.).

**Table 1. Details of the Satellite Images Used For Study**

| Spacecraft ID | Path & Row | Acquiring Date | Dataset Sensor ID | Attribute | Type | Location |
|---|---|---|---|---|---|---|
| Landsat 7 | 168/054 | 02-02-2000 | ETM+ | Earthsat- | GeoTIFF | Ethiopia |
| Landsat 8 OLI | 168/054 | 02-02-2022 | OLI_TIRS | USGS | GeoTIFF | Ethiopia |
| Geology Data | 1:250,000 | - | - | EGS | Shapefile | Ethiopia |
| Soil Data | 1:250,000 | - | - | FAO | Shapefile | Ethiopia |
| DEM | - | - | - | SRTM | GeoTIFF | Ethiopia |

## Software Used

Satellite image processing software, Earth Resources Data Analysis System (ERDAS) version 15 Imagine (Hexagon Geospatial formerly ERDAS, Inc.) and ArcGIS 10.8, ENVI 5.0 and Arc pro 2.9 (Environmental Systems Research Institute (ESRI) product) were used to process, classify, analyses and display the satellite images.

## Data and Methodology

Compared to the other methods of assessment of the current state of degradation, this indicator seems to be more significant, as land degradation is affected not only by erosion, but also by land deterioration and all environmental influences, for that matter. To show the current state of land degradation, several models including the FAO–UNEP model of desertification and the models of GLASSOD (Fig.2) have used this indicator [23-27].

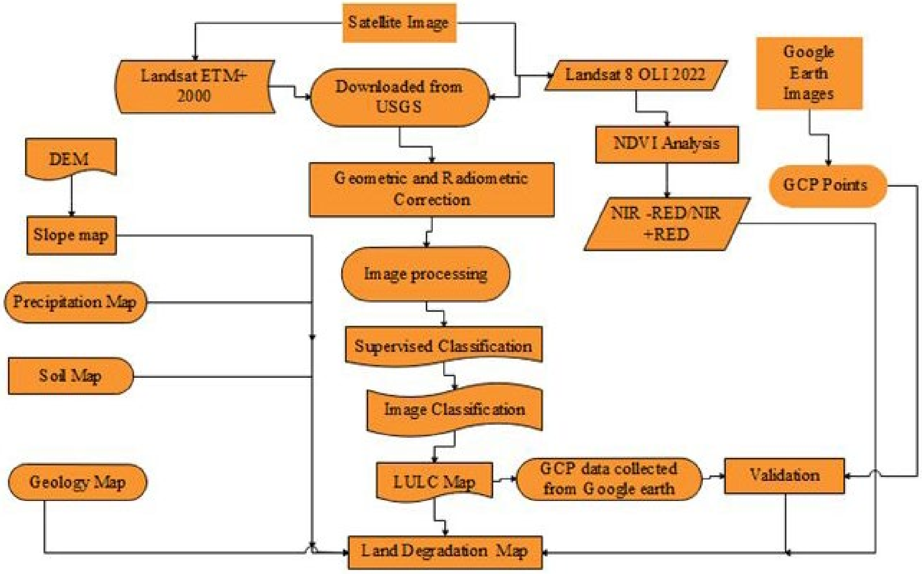

**Figure 2:** Methodological Flowchart

## Soil Map

The risk of water erosion is related to the type of soil, and its compaction, the particle-size distribution, the stability of soil aggregates and the organic components content. Generally, it is believed that the most susceptible to erosion and surface runoff are silty soils (especially loss soils) and sandy soils. According to some researchers, the general view of the greatest susceptibility to erosion of loss soils is not true. They think that the most susceptible to water erosion are soils developed from sand [28]. According to the most susceptible to erosion are sandy, then loamy, and finally clay materials (Fig.3).

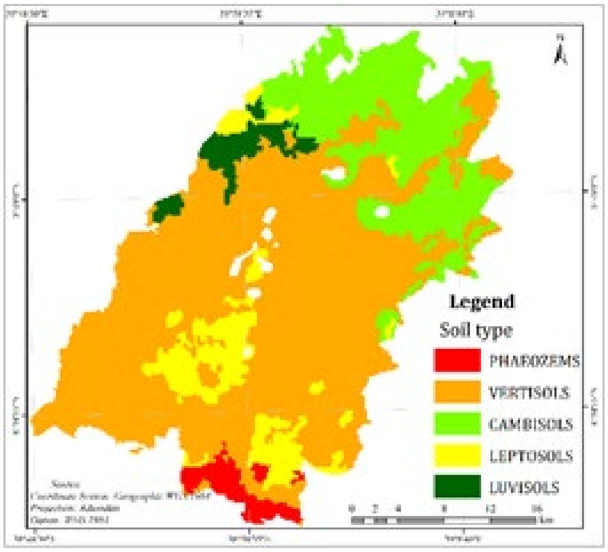

**Figure 3:** Soil Map of the Study Area

## Geology Map

Geologic degradation is a normal or natural erosion caused by geologic processes acting over long geologic periods and resulting in the wearing a way of mountains, the building up of flood plains etc. Accelerated erosion is much more rapid than geologic erosion. This type of erosion results primarily from the influence of man activities. Also, a natural catastrophe that exposes bare soil surfaces, like fires, contributes to this type of erosion. Many studies evaluate land degradation exclusively through remote sensing [29]. However, there is a limitation to explore all the different factors responsible for degradation. Degraded land identification through spectral indices also accounts for considerable criticism [30]. The different physiographic factors like geological formations, soil characteristics, relief features, slope characteristics and geomorphological formations determine the nature of land degradation in Adea Woreda (Fig.4).

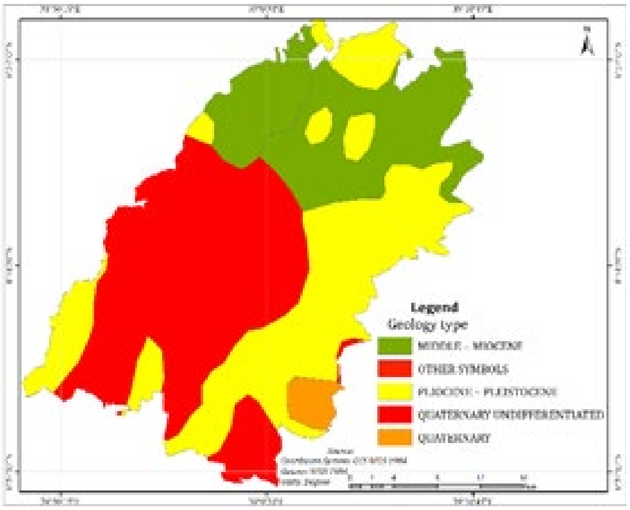

**Figure 4:** Geology Map of the Study Area

## Slope

Steep slope is assumed as a trigger of erosion. The steep slope will increase the number and speed of runoff so that erosion will be accelerated due to more transported and dissolved materials. Steeper slope will enhance the flow resulting a bigger power and amount of water to transport the soil. Increment of erosion on steep slopes is the result of the increment of surface runoff and also the reason for the decline of infiltration. Generally, slope class of 18-15%, 15-25%, 25-40% are assumed as a vulnerable area for erosion. Hence, these classes must have special attention and treatment (Fig.5).

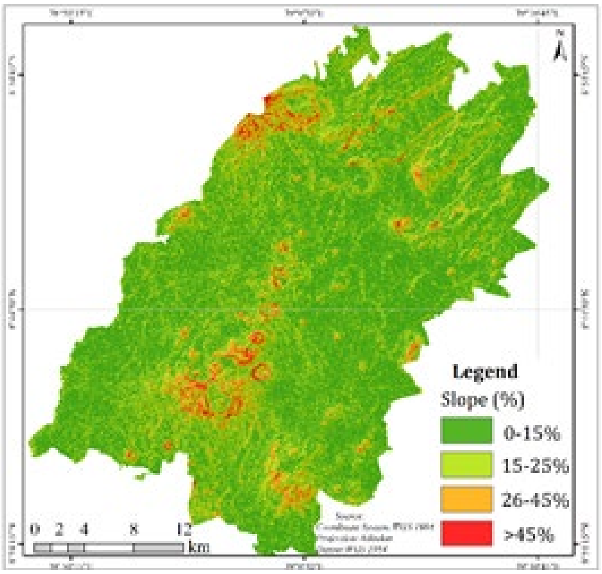

**Figure 5:** Slope Map of the Study Area

## Results and Discussion

### Land use/Land Cover Change Analysis

The result of this study showed that cultivated and built-up land had increased at a rate of 14.66% and 10.05 % respectively in the last 22 years (2000-2022). These changes were at the expense of waterbody, shrub and grass land (Table 2). In addition, farmers in the area are encroaching and cultivating sloppy and marginal areas, which aggravate land degradation. LU/LC changes are complex and interrelated that is the expansion of one land use type is at the expense of others In relation to this finding, recent unwise-based land use studies have showed that land use change is brutal and there has been agricultural land size expansion at the expense of natural vegetation cover lands and marginal areas without any appropriate conservation measures (Table 2).

**Table 2: LULC Changes of The Study Area between 2000 and 2022**

| Land use/land cover class | 2000 | | 2022 | |
|---|---|---|---|---|
| | Area (ha) | % | Area (ha) | % |
| Built-up Area | 4494.79 | 4.80% | 13908.22 | 14.85% |
| Farmland | 46223.83 | 49.36% | 59920.99 | 64.00% |
| Grassland | 28505.39 | 30.44% | 15618.51 | 16.68% |
| Shrubland | 13193.11 | 14.09% | 3317.75 | 3.54% |
| Waterbody | 1217.03 | 1.30% | 868.68 | 0.92% |
| Total | 93634.15 | 100% | 93634.15 | 100% |

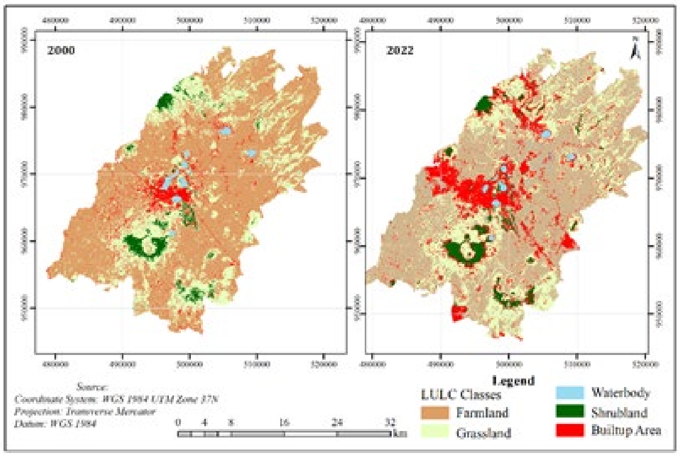

**Figure 6:** Land Use Land Cover Map of the Study Area

### Normalized Difference Vegetation Index (NDVI)

Normalized Difference Vegetation Index (NDVI): NDVI quantifies vegetation based on the difference between red (R) and near infrared (NIR) band values. Red (R) band refers to that which vegetation absorbs and near infrared (NIR) refers to that which vegetation strongly reflects. According to the NDVI equation is formulated as below NDVI always ranges from -1 to +1. However, there isn't an exclusive boundary for each type of land cover. High negative values of NDVI generally indicates that there is a massive possibility of water and if the values near to +1, there's a higher possibility of dense green leaves [31, 32]. However, if the NDVI is close to zero, it indicates that there are not green leaves and it might be an urbanized area (Table3).

**Table 3: NDVI Result of the Study Area**

| Statistics | 2000 | 2022 |
|---|---|---|
| Minimum | -0.663 | -0.071 |
| Maximum | 0.441 | 0.388 |
| Mean | -0.215 | 0.132 |
| Standard Deviation | 0.070 | 0.038 |

The statistics and visual observation of the NDVI images over the subsequent periods were evidence for land cover changes that may well indicate increased deforestation and land degradation in the study area. As it can be visually compared, the amount of green vegetation is falling. Taking the maximum value, it dramatically decreases from 0.44 in 2000 to 0.38 in 2022. To this effect, the standard deviation value decreases in certain value in 2000 image as compared to 2022 because of the change in vegetation cover (Table 3). Overall, there was an increase in the size of the land cover class classified as severely stressed area. Similar study conducted by the Lake Baringo catchment, Kenya, East Africa and in Dendi district case study, Ethiopia reported the decline of total vegetation cover and the increase of land degradation in the study periods. Similarly, a study by in Aberdares (Kenya) is also in agreement with the findings of this study, who stated that, a positive mean of stressed area in the period1987-2000 [33-35]. NDVI differencing is an indication of reduction in biomass within this period of study, which implies a decline in vegetation (Fig.7).

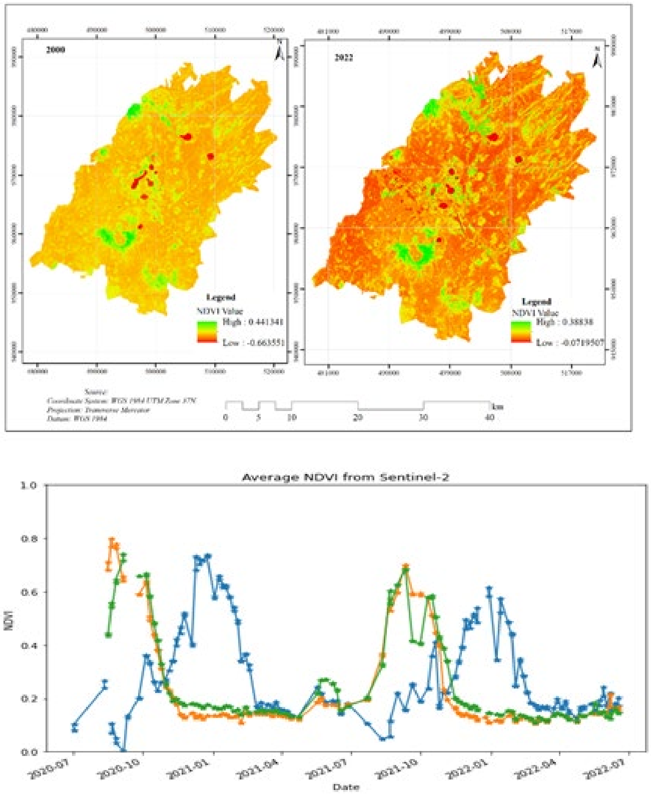

**Figure 7:** NDVI Map of the Study Area

### Accuracy Assessment

Accuracy assessment is a general term for comparing the classification to geographical data that are assumed true in order to determine the accuracy of the classification process. The fact that accuracy assessment is so important that it tells us to what extent the truth on the ground is represented on the corresponding classified image. In this study, accuracy assessment was done for the recent satellite image of Landsat OLI 8 2022, for which the ground truth data is likely corresponding. An overall accuracy was calculated by summing the number of pixels classified correctly and dividing by the number of pixels. Thus, an overall accuracy of 96.92% with a Kappa coefficient of 0.95% was achieved (Table 4).

**Table 4: The accuracy assessment Land cover Landsat OLI 8 2022**

| **Classified Data** | **Reference Data** | | | | | | |
|---|---|---|---|---|---|---|---|
| | **GL** | **Shl** | **W** | **BU** | **Fl** | **RT** | **User A** |
| Grassland | 47 | 0 | 0 | 0 | 2 | 49 | 95.92% |
| Shrubland | 0 | 1 | 0 | 0 | 0 | 1 | 100.00% |
| Waterbody | 0 | 0 | 2 | 0 | 0 | 2 | 100.00% |
| Built up Area | 1 | 0 | 0 | 21 | 0 | 22 | 95.45% |
| Farmland | 1 | 0 | 0 | 0 | 55 | 56 | 98.21% |
| CCT | 49 | 1 | 2 | 21 | 57 | 130 | |
| Producer A | 95.92% | 100.00% | 100.00% | 100.00% | 96.49% | | |

*N.B Gl=grassland, Shl=shrubland, W= waterbody, BU= built-up area, Fl= farml*and

### Precipitation Analysis

Rainfall is the basic factor of detachment and transportation of soil due to raindrop impact and runoff primarily depends on the intensity and the amount of rainfall. However, in the study area, particularly in Ethiopia case there is no intensity data and hence, an empirical equation developed by Hurni (1985a) that estimates annual average precipitation 2000-2022) will be collected from the online resources. For this purpose, twenty-two years mean annual rainfall data was obtained from CHIRPS website. As depicted in Figure 7, rainfall is higher in the lowland parts of the study area, because in the upper part the rainfall characteristic is shower. Thus, the lower part of the area has higher erosivity values than middle and upper parts. The spatial distribution of the rainfall erosivity factor of Adea woreda ranged from 991.86 to 796.72 MJ mm ha−1h −1yr−1 (Fig.8).

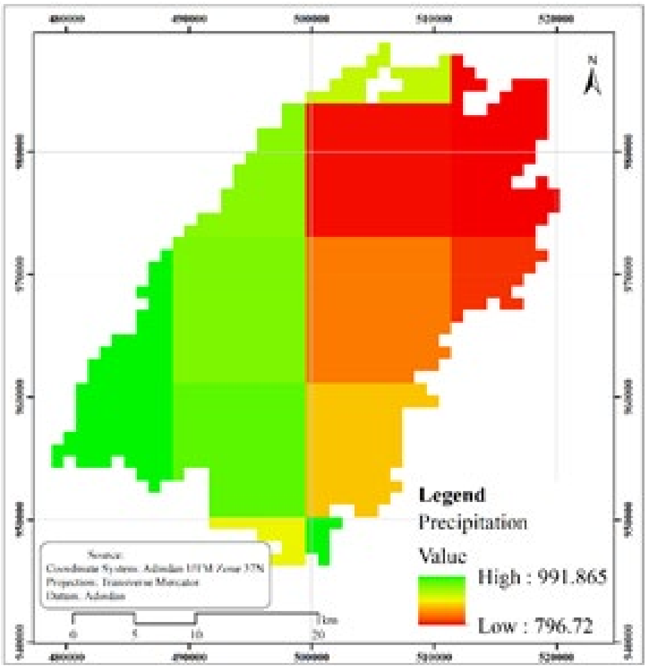

**Figure 8:** Rainfall Factor of the Study Area

### Land Degradation Assessment

Evaluation of the present status of land degradation in the FAO–UNEP model and the models of GLASSOD and ASSOD is emphasized in Eq. (1).

Degradation=*(CurrentDegradation)/(PotentialDegradation)*…………………………………. Eq (1)

The land degradation results indicate that much of the middle part of the study area has lost topsoil at a rate of 0 to 50 t ha−1yr−1, and that soil loss rates exceed 50 t ha−1yr−1 in upstream and downstream zones as well as in some erosion hotspot areas (Figure 8). As indicated in Table 5, about 0.003% and 42.77% of the study area experienced a very low and low soil loss rate, ranging from 0–5 t ha−1yr−1 and 5–15 t ha−1yr−1, respectively. The result shows that about 44.66% of the area experienced soil loss ranging from 15 to 30 t ha−1yr−1, which is characterized as a moderate erosion rate. Further, about 12.50% of the sub-basin lost topsoil with rates from 30 to 50 t ha−1yr−1, indicating high to very high soil loss rate. The remaining 0.048 % of the sub-basin was under severe erosion rate with soil loss exceeding 50 t ha−1yr−1. As shown in Table 5, the area under high to severe soil loss class covers about 42.77% area of the study area, found in most upper and lower parts in very steep sloped areas (Fig.9 & Table 5).

**Table 5: Annual Soil Loss Class and Risk Levels in the Adea Woreda**

| SN | Degradation Level | Assigned Value | Risk Level | Soil loss t/ha/y | Area(ha) | Percentage (%) |
|---|---|---|---|---|---|---|
| 1 | Low | 1 | Very Low | <5 | 0.303 | 0.003 |
| 2 | Severe | 5 | Very High | 5-15 | 38883.739 | 42.778 |
| 3 | Moderate | 3 | Medium | 15-30 | 40598.722 | 44.665 |
| 4 | Marginal | 2 | Low | 30-50 | 11368.631 | 12.507 |
| 5 | High | 4 | High | >50 | 44.267 | 0.048 |
| Grand Total | | | | | 90895.6659 | 100% |

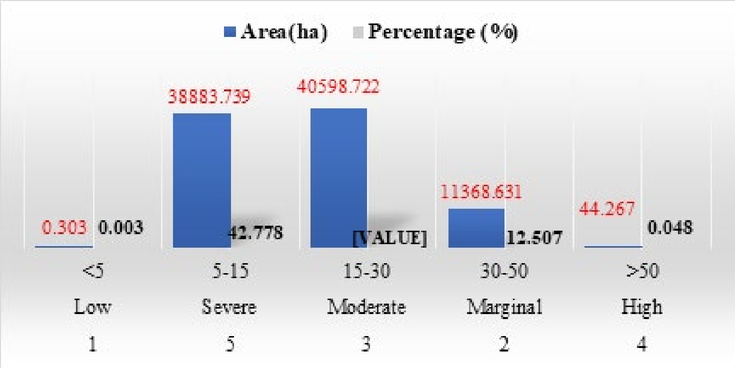

**Figure 9:** Land Degradation Result

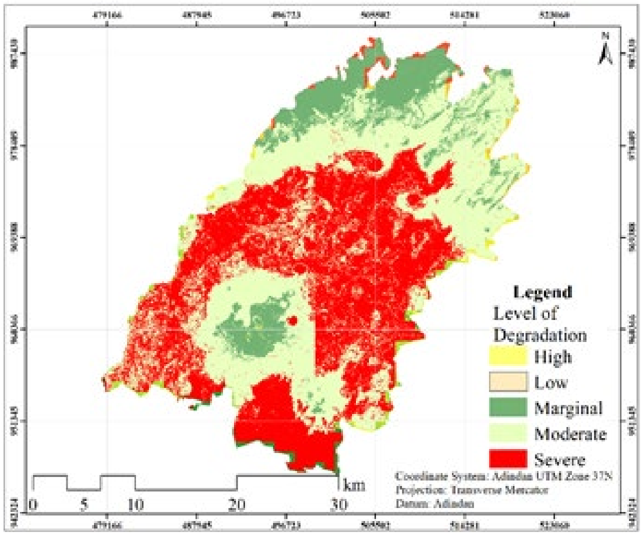

**Figure 10:** Land Degradation Map of the Study Area

A moderate degree of annual soil erosion was most frequently observed at 44.66 % of the sample points (Figure 8). The majority of the points with moderate erosion are located in farmland or built-up areas characterized by moderate to steep slopes with moderate deep to shallow soils and inadequate (less than 10 %) plant cover. The most important vegetation indicator was plant cover, negatively affecting soil erosion. Sample points with permanent plant cover higher than 50 % were adequately protected from soil erosion.

## Discussions

The different approaches described in the above sections provide extensive information about methods used to assess land degradation condition. The selection of a method depends on the goals and conditions under which it is applied. In this discussion, the main approaches are examined in relation to their applicability at different levels. Many researchers and scientists emphasize that assessing land degradation can be complex since more than one type of degradation may occur in any one place. The complexity makes it impossible to use the same tools, techniques and methods for assessing different types of degradation. Many methods have been improved and justified to gather as much useful data as possible.

Most studies conducted by the likes of trying to qualify the severity classes of the desertification map, first desert land was determined based on new definition derived from the UN definition of desertification. Globally land degradation occurred due to different factors or a combination of factors. Factors are affecting land degradation differently in different geo-climatic region.

In addition, the result of the study was found in line with the findings of According toanalysis and estimations, the highlands and rift valley area of Ethiopia has been affected by severe to moderate soil loss. In the same context different researchers indicated that, measured annual soil loss and land degradation from highlands of Ethiopia reaches up 243 t/ha/year and 300 t/ha/year from bare, built-up and agricultural lands [37-40].

## Conclusion

There is no single best method for assessing land degradation. The study has demonstrated that the severity and vulnerability of land degradation can be studied by harnessing technologies such as remote sensing and GIS. NDVI analysis has also showed the increased of land degradation between 2000 and 2022 images. These suggest the observed LU/LC changes are a cause for the observed land degradation. So, it is recommended to encourage farmers and decision maker to apply soil conservation practices like ditches, stone bunds, terraces in areas which highly affected by land degradation. This study expresses that Remote Sensing and GIS spatial modeling are useful tools in generating spatial and quantitative information on land degradation studies and risk assessment mapping.

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