

Sustainable Environmental Management: A Case of Assessment of Land Degradation Using Space Technologies in Longido District, Arusha Tanzania

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Abstract: This study was conducted to assess land degradation in Longido District, Arusha, Tanzania using remote sensing techniques. Biophysical degradation indicators i.e. land use/land cover, land productivity level and soil erosion were used. Specifically, Landsat Satellite images of 1995 and 2015, together with soil data and digital elevation model were applied. Land cover maps of the study area over the study years were produced by supervised classification method. Soil erosion was assessed using RUSLE (Revised Universal Soil Loss Equation) model producing soil erosion map of Longido district, the inputs into the RUSLE model were rainfall, erosivity factor, soil erodibility factor, slope steepness and slope length factor, cover management factor and support practice factor. Biophysical land degradation map was produced by applying weighted overlay technique whereby soil erosion was given more weight followed by land use/land cover of 2015 and land productivity level of 2015. The findings show that about 38% of Longido district areas are highly vulnerable to land degradation which is above the international allowable level. It is being concluded that Longido District is at high risk of failure to sustain livelihood of and resilient for its communities, the earth in general, so it is timely for the district authorities to take steps towards mitigating further land degradation. It is being recommended that sustainable conservation and management strategies as well as policies must be affected by district authorities including farmers and pastoralists to improvise land degradation friendly cultivation and grazing methods.

Key words: Environmental degradation, anthropogenic activities, land degradation, biophysical factors.

1. Introduction

Most of anthropogenic activities produce adverse environmental effects. Such activities include construction of communication infrastructure e.g. highways, airports, power plants, farming, livestock keeping, mining and so on. With concern for environmental effects of such activities in mind, many countries have developed their national management policies. The purpose of the environmental policy is forging harmony between anthropogenic activities and the environment with the view of protecting the environment, indeed land degradation. Among other things this entails protection of ecosystems, biodiversity and the landscape. Land degradation, is an

aspect of ruining the landscape, as such, it contributes to environmental degradation. Land degradation is a phenomenon continuously occurring in many part of the world and its impacts are getting worse with time. Developing countries are severely affected, leading to soil erosion, drought, deforestation, salinity, famine and so on. Factors leading to land degradation include prolonged agriculture, overgrazing, excessive rainfall and so on [1].

Land degradation in most of developing counties has become a major threat and development constraint of mainly rural livelihoods. About 40%-75% of the world's agriculture land's productivity is reduced due to land degradation. This has adverse impacts on livelihoods of most of the population in rural areas [2]. This is mostly attributed to both anthropogenic activities and climate variability. It is estimated that

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65% of Africa’s agricultural land is degraded due to either soil erosion or chemical or physical damage and 31% of the continent’s pasture land as well as 19% of its forests is degraded [3, 4]. In Africa, overgrazing has for so long time been considered as the primary cause of land degradation, though now, it is thought that rainfall variability and long-term drought are more important determinants of land degradation [5].

Land degradation can be assessed by either socio-economic indicators or chemical indicators or biophysical degradation indicators. Biophysical indicators include land use/land cover, soil erosion and land productivity [6]. Longido district in Arusha Region in Tanzania, is one of seven districts in Tanzania experiencing drought and soil erosion [6, 7]. Other districts are Simanjiro, Same, Mwanga, Rombo, Ngorongoro and Monduli. Longido district is occupied by pastoral Maasai tribe, excessively engaged in livestock keeping as the main source of income, also a part of the population is engaged in small-scale

subsistence farming growing maize and beans. Due to prolonged drought seasons, over 90% of households in the district have lost their livestock. In efforts to address the problem of lack of communal grazing areas, the district authorities recommended adoption of indigenous browse pasture species due to their role ability in sustaining feeding resources for the benefit of livestock feeding during critical times [8].

2. The Study Area

Longido district is located between longitude 36° to 37.3° east of Greenwich and latitude 2.2° to 3.1° south of the equator. It covers an area of 7,900.33 km² and has the population of 123,153 people according to 2012 population census of Tanzania. About 90% of the district area is grazing land. The motivation for selecting this district for assessment of land degradation is because it experiences severe drought and soil erosion. The location of the study area is indicated in Fig. 1 below.

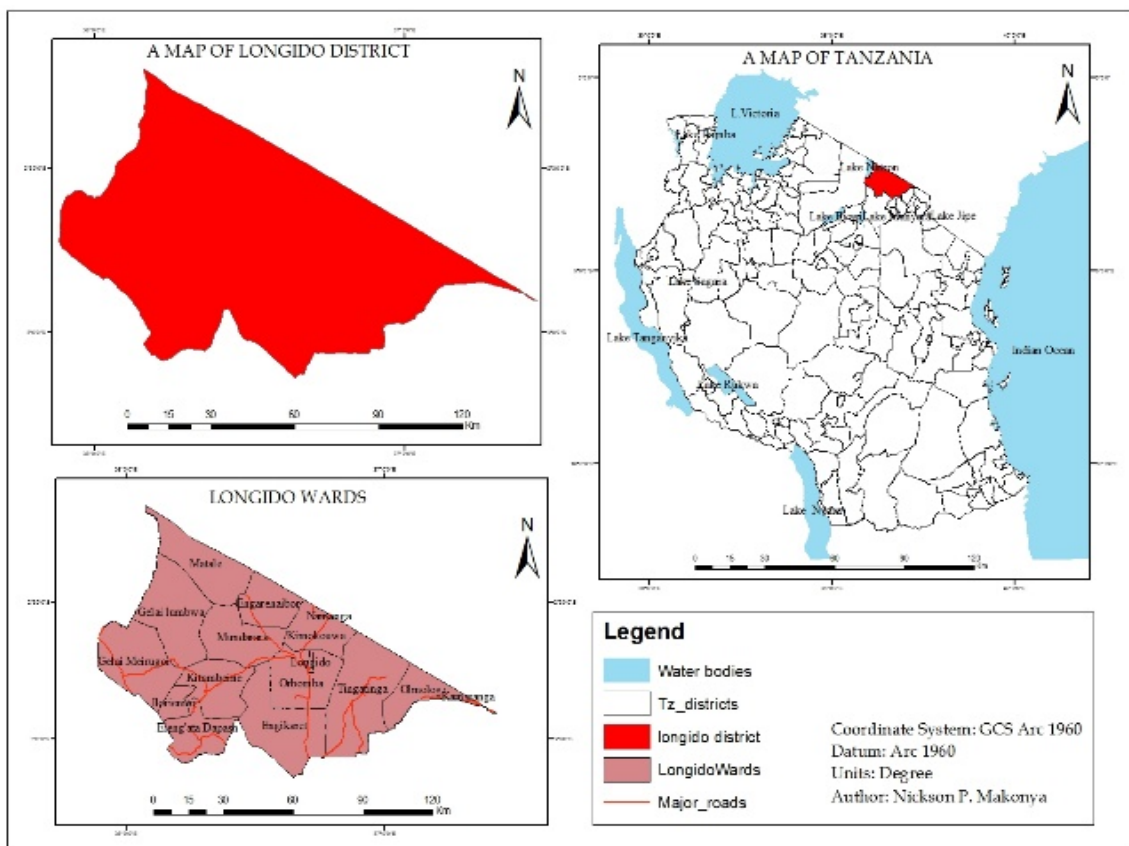


Fig. 1 Location of the study area.

3. Problem Statement

Longido district, in Arusha, Tanzania is affected by both drought and soil erosion leading to land degradation. Land degradation impacts have affected both farmers and pastoralists in the district (with 95% of communities engaged in livestock keeping and 5% engaged in farming as their main livelihood strategies). Some of the damages of land degradation include loss of vegetation cover, loss of soil fertility, and drying up of shallow wells, seasonal rivers, dams and swamps [9]. The extent of damages of land degradation in Longido district has not been assessed hitherto. The aim of this study was assessing the extent of land degradation in Longido district for a decade specifically i.e. 1995-2015 with a view of acquiring information to be used as evidence in proposing policy interventions and/or guidelines to mitigate the effects of land degradation in Longido district and other districts and eventually the national level at large.

4. Methodology

This study was based on biophysical land degradation indicators, which are land cover/land use changes, soil erosion and land cover support practice and land productivity assessment.

4.1 Land Cover/Use Changes & Assessment

Land use/land cover changes have impacts on a wide range of environmental and landscape attributes including the quality and quantity of water, land and air resources, ecosystem processes and functions and the climate change through greenhouse gas fluxes and surface effects. The land use/land cover pattern of a region is an outcome of natural and socio-economic factors and their utilization by man in time and space. The change in land cover occurs even in the absence of human activities through natural processes whereas land use change is a result of manipulation of land cover by human being for multiple purposes

applications such as search for food, search for wood for use as of energy, logging, search for pasture, leaf, littering, search for medicinal herbs, raw materials [10] and so on.

4.2 Land Productivity Level and Assessment

Land Productivity is the state of the earth's vegetative cover and its development over time is perceived as a representation of land productivity and its dynamics, it reflects integrated ecological conditions and the impact of natural and predominantly anthropogenic environmental change. Assessment of land productivity typically relies on the multi-temporal and thematic evaluation of long-term time series of remotely-sensed vegetation indices, computed from continuous spectral measurements of photosynthetic activity. The analyses of trends and changes in land productivity are a methodology to detect areas with persistent and active declines in primary productivity pointing to on-going land degradation rather than areas which have already undergone degradation. NDVI (Normalized Difference Vegetation Index) is widely associated with assessment of the net primary land productivity through the use of remotely sensed data [5].

4.3 NDVI

NDVI is the ratio of the difference between the NIR (Near-Infrared Band) and the R (Red Band) and the sum of these two bands is stated in Eq. (1) below.

$$NDVI = \frac{NIR-RED}{NIR+RED} \quad (1)$$

where NIR is reflectance in the NIR and RED is reflectance in the visible R. The NDVI ratio is based on the fact that green vegetation reflects less visible light and more NIR, while sparse or less green vegetation reflects a greater portion of the visible and less NIR. NDVI combines these reflectance characteristics in a ratio so it is an index related to photosynthetic capacity. The range of the value obtained is between -1 and +1, only positive values

correspond to vegetated zones such that the higher the index, the greater the chlorophyll content of target [11].

4.4 Soil Erosion

Soil erosion is a process of modifying biophysical environment involving soil, climate, terrain or topography, ground cover and interactions between them. Important terrain characteristics influencing soil erosion are: slope, length, aspect and shape. Impact of slope and aspect play a major role in runoff mechanism. More slope, implies more runoff and thereby reduces infiltration. The runoff generated from slope will find a path to nearby areas leading to erosion of soil as the velocity of the runoff increases. Soil erosion is a natural geological phenomenon resulting from the removal of soil particles by water or wind, transporting them elsewhere, while some human activities such as agricultural practice, conversion of forest to agriculture etc. would increase the rate of erosion [12]. It is noteworthy that soil erosion assessment is based on evaluation and combination of pertinent factors.

In this study, soil factors were combined to

compute the soil all of which depend on land loss using the RUSLE (Revised Universal Soil Loss Equation) model. Inputs into model were: land use/land cover maps of the study area as generated from can satellite images, management practices, soil types and properties. The RUSLE mathematical model is given in Eq. (2):

$$A = R \times K \times LS \times C \times P \quad (2)$$

Where:

- A = annual soil loss;
- R = rainfall erosivity factor;
- K = soil erodibility factor;
- LS = slope length and steepness factor;
- C = cover and management factor;
- P = support practice factor.

RUSLE model can be integrated with remote sensing and GIS (Geographic Information System) techniques in assessing of soil erosion risk and vulnerability. The parameters of RUSLE model were estimated from the rainfall data, DEM (Digital Elevation Model), soil type and land cover. All the data sets were integrated through weighted overlaying. The logical flow of research activities is shown in Fig. 2 below.

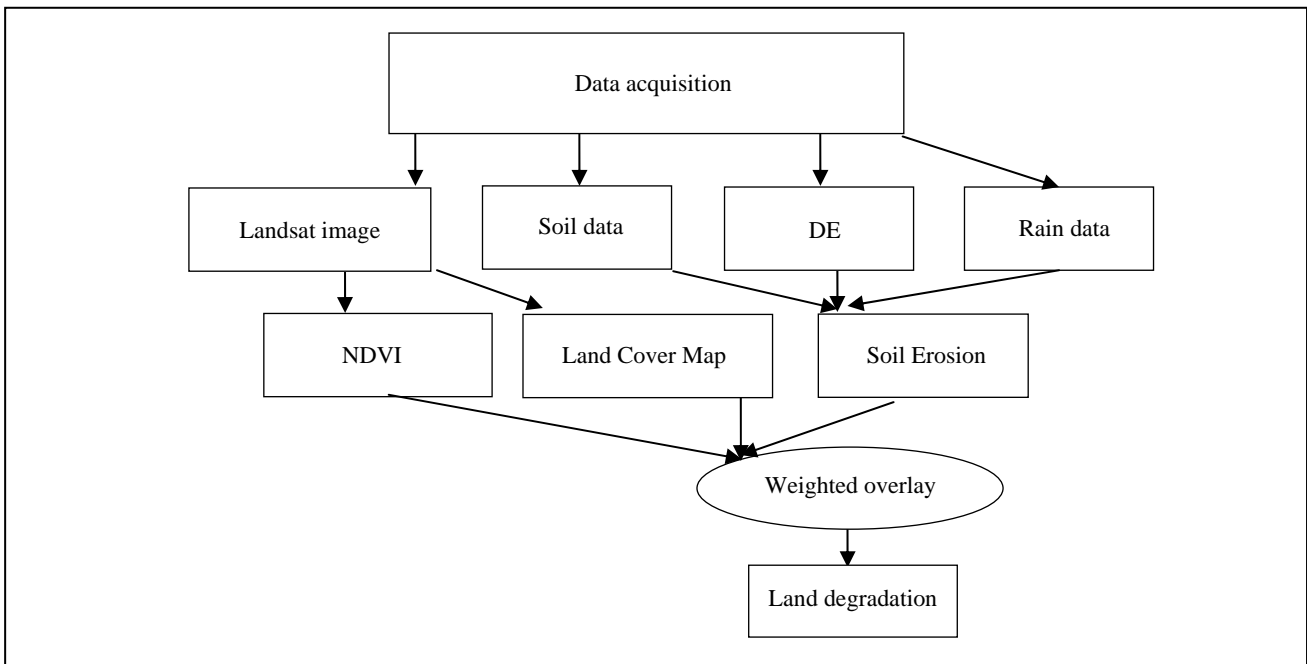


Fig. 2 Logical flow of research activities.

5. Data Processing and Results

This study involved processing of pertinent datasets generating products being inputs into the RUSLE Model for computing soil loss. Specifically, these were erodibility (K factor map) from soil data, rainfall erosivity (R map), land slope and steepness factor (LS factor map), cover management factor (C factor map), support practice (P factor map), soil erosion (annual soil loss map).

5.1 Soil Erodibility (K Factor Map)

This portrays the rate of permeability or penetrality of soil to water. Its computation involved knowledge of soil data types in terms of its percentage composition value of organic carbon, silt, clay and sand per pixel. Eq. (3) was used for calculating erodibility values.

$$K = \{0.2 + 0.3 \exp [0.0256 \text{SAN} (1.0 - \text{SIL}/100)]\} \times (\text{SIL} / (\text{CLA} + \text{SIL}))^{0.3} [1.0 - 0.25\text{C} / \text{C} + \exp(3.72 - 2.95\text{C})] \times [1.0 - 0.7(1 - \text{SNA}/100) / (1 - \text{SNA}/100) + \exp(-5.51 + 22.9(1 - \text{SNA} / 100))] \quad (3)$$

where,

SAN = sand soil %;

SIL = silt soil %;

CLA = clay soil %;

C = organic carbon %.

Inputs were the percentage of clay, silt, sand and organic carbon of each pixel of the soil data. The areas with high erodibility value were those characterized with high percentage value of sand and low percentage value of organic carbon content in the soil. The soil properties that were used to calculate the erodibility factor were obtained from literature as seen

in Table 1 below.

From which the following map showing soil erodibility factor map of Longido district was obtained.

5.2 Rainfall Erosivity (R Factor Map)

This indicates the power or the potential of a given storm event to detach or erode soil particles. For this study average annual rainfall from 1995 to 2015 has been used to estimate rainfall erosivity values (R) by using the following formula:

$$Ra = 0.0032(\text{Pa})^2 - 2.0474(\text{Pa}) + 1,348$$

where,

Ra = annual erosivity values in mega joule per millimeter hectare per hour per year (MJ/mm/ha/h/yr).

Pa = annual average rainfall amounts (mm).

In order to produce the average annual rainfall map of Longido District, rainfall data from 1995-2015 for about three meteorological stations and IDW (Inverse Distance Weighted) interpolation method were applied.

5.3 LS (Land Slope Length and Steepness Factor)

This reflects the influence of topography on soil erosion. A DEM of the study area was downloaded and processed in ArcGIS software generating LS factor map. The DEM processing involved extraction of slope in terms of degree values, followed by fill sink, flow direction and flow accumulation. Then Eq. (5) was applied in map algebra to obtain LS factor raster map.

$$\text{LS} = \text{Power} ("flow\ accumulation" \times \text{cell resolution}/22.1, 0.4) \times \text{Power} (\sin (\text{slope} \times 0.01745)/0.09, 1.4) \times 1.4 \quad (5)$$

Table 1 Soil properties and soil erodibility factor of Longido District.

Soil sample	Sand % topsoil	Silt % topsoil	Clay % topsoil	OC % topsoil	K values
I	58.9	16.2	24.9	0.97	0.1143
NE	68.4	10.5	21.2	0.6	0.1461
TO	38.2	36.6	25.2	3.02	0.0639
NH	6.4	29.8	63.9	4.04	0.0375
VP	25.1	12.2	62.7	0.68	0.0541
BC	40.1	21.5	38.4	1.44	0.0694
TM	31.2	39.6	29.2	3.95	0.06

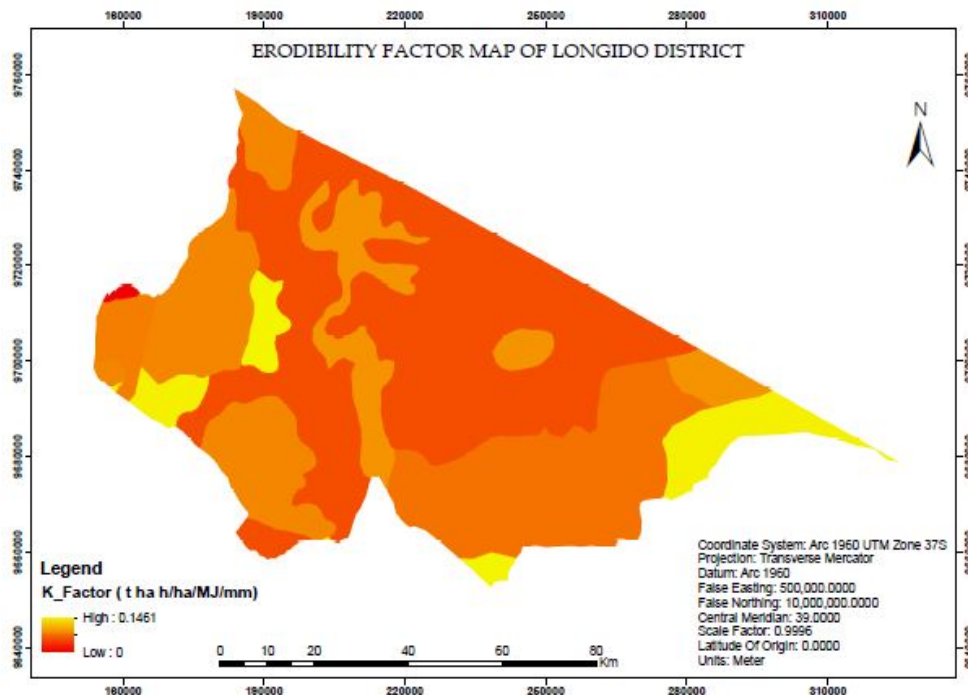


Fig. 3 Erodibility map of Longido District.

Table 2 Cover management factor (C) map of Longido District.

LULC type	C- Factor	Source
Forest	0.01	[14]
Bareland	0.6	[14]
Grassland	0.05	[14]
Agriculture	0.15	[15]
Shrubs & Hurbs	0.2	[15]
Settlement	0.03	[15]

5.4 Cover Management Factor (C)

Cover management factor is one of the important factors in RUSLE model that describes the effects of land cover management on soil loss. The C factor values used in this study were obtained from literature as indicated in Table 2.

Fig. 4 is the obtained cover management factor map of Longido district.

5.5 Support Practice Factor (P)

This captures effects of soil loss characteristics of the area under study. Due to lack of information on local indicative P values, the P values used in this study were obtained from literature. The values of P-factor vary from 0 to 1, the value of 0.1 is for

cultivated land on flat and gentle slopes whereby for other land uses the value is 1. The lower value indicates to be less susceptible to soil erosion. Table 3 shows the P values used in this study.

Fig. 5 is the support practice (P factor) map produced in this study.

5.6 Results

The output of this study was a map showing land degradation map degradation of Longido district obtained from weighted overlay of data emanating from biophysical factors in ArcGIS software. Soil, land cover and land productivity maps were assigned weights of 5, 2 and 3 respectively. The output was density sliced yielding the degradation map of Longido District as shown in Fig. 6.

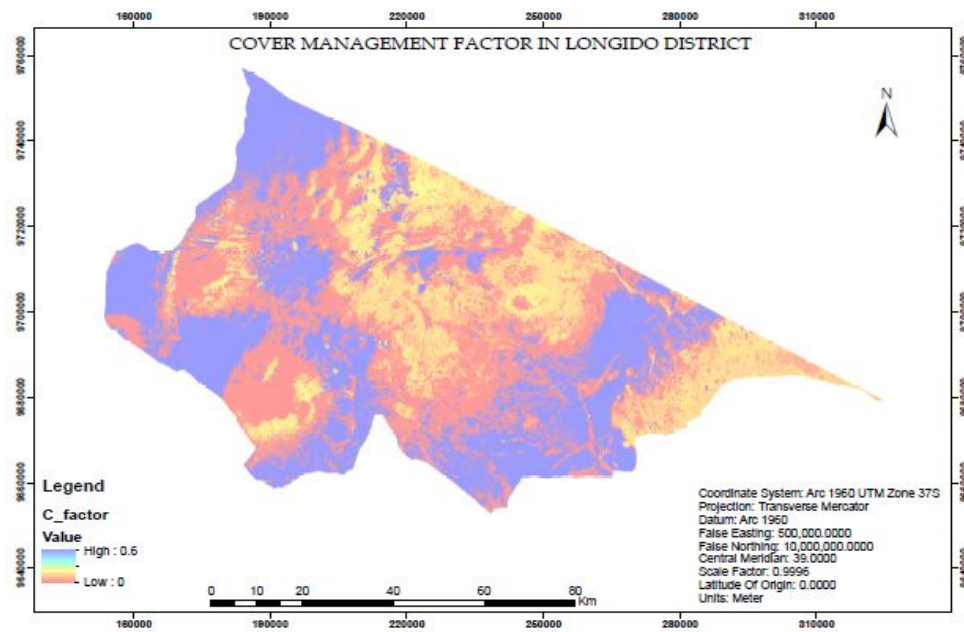


Fig. 4 Cover management factor map of Longido District.

Table 3 Support practice factor values.

Slope (%)	P factor
0-5	0.10
5-10	0.12
10-20	0.14
20-30	0.19
30-50	0.25
50-100	0.33
All	1.00

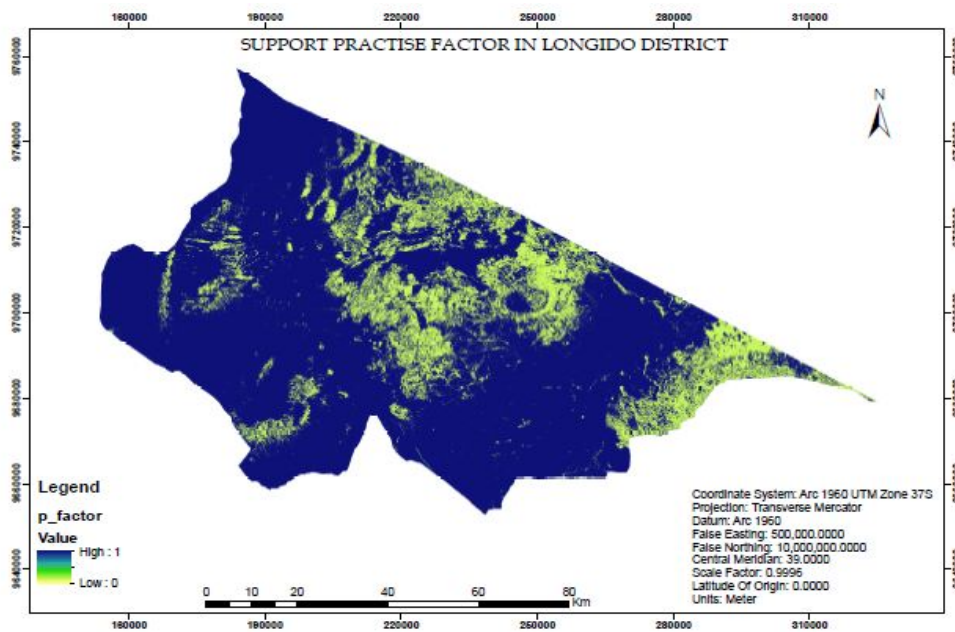


Fig. 5 Support practice factor map of Longido District.

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