

ADDIS ABABA UNIVERSITY



COLLEGE OF NATURAL AND COMPUTATIONAL SCIENCES

SCHOOL OF EARTH SCIENCES

Department of Remote Sensing and Geoinformatics



IDENTIFICATION OF DEGRADED RANGELAND AREAS, AND
REHABILITATION SITE ANALYSIS FOR FEED SPECIOUS GROWTH: THE
CASE OF BORANA RANGELAND, OROMIA REGION, ETHIOPIA

By: - Belachew Tsehay

ID: GSR/7287/13

Addis Ababa
February 2023



ADDIS ABABA UNIVERSITY
COLLEGE OF NATURAL AND COMPUTATIONAL SCIENCES
SCHOOL OF EARTH SCIENCES

Department of Remote Sensing and Geoinformatics

By: - Belachew Tsehay

ID: GSR/7287/13

Advisor: Dr. Biniam Tesfaw

A Thesis Submitted to the School of Graduate Studies of Addis Ababa University, In Partial Fulfillment of the Requirements for the Degree of Masters of Science, Specialization in Remote Sensing and Geo- Informatics

Addis Ababa University

Addis Ababa

August 2022

ADDIS ABABA UNIVERSITY
GRADUATE PROGRAMMES

This is to Certify that the thesis prepared by Belachew Tsehay Tarekegn, entitled:
Identification of Degraded Rangeland Areas, and Rehabilitation Site Analysis for Feed Specious
Growth: The Case of Borana Rangeland, Oromia Region, Ethiopia submitted in Partial fulfillment of
the requirements for the Degree of Masters of Remote Sensing and Geo-informatics complies with
the regulations of the University and meets the accepted standards with respect to originality and
quality.

Signed by the Examining Committee:

Examiner

_____ Signature _____ Date ____/____/____

Examiner

_____ Signature _____ Date ____/____/____

Advisor

Dr.Binyam Tesfaw Signature _____ Date ____/____/____

Head,

School of Earth Sciences Signature _____ Date ____/____/____

Acknowledgement

First, I would like to thank ‘Almighty God for providing me with all the energy and patience to make it possible, to initiate and finish this work successfully.

I would like to express my greatest gratitude to my advisor Dr.Binyam Tesfaw his unreserved support while I do this research project. He guided me, encouraged and advised me on every aspect of the research work when I need. He is kind and friendly to advice and support my work on the field and provision of data of the study area.

Special thanks goes to Dr. Tibebu Kassawmar for his support in the provision of data that I could not find from other institutions.

Sincere appreciation goes to my fellow partners and instructors in supporting me throughout my study especially Tewodros Kassahun and Taye Teshome who have been supporting me all the time.

My grateful thanks go to Habtamu Sewnet, a Ph.D. candidate at the Space Science Observatory Research center who has been supporting me in all aspects whenever I need. I have honest respect and appreciation for his unreserved support for me.

I would like to acknowledge ESSA (Earth observation and environmental sensing for climate-smart sustainable agro pastoral ecosystem transformation in East Africa) project funded by European Union DG International Partnerships under DeSIRA (Development of Smart Innovation through Research in Agriculture) programme for supporting me in budget to conduct my research project.

I am also obliged to thank the national meteorological institute and Agricultural research institute of Ethiopia for providing me required data from their respective organizations. Especially, Ashenafi Ali of the Ministry of Agriculture who supported me in providing specific data on my study area.

I would also like to pass my special thanks to Dr. Tulu Besha, Director General of Geospatial Information Institute for encouraging me to continue my study, supporting my research work, and handling my office issues as well as, Mulualem Yeshitila for taking over my roles on behalf of me.

Lastly, my deepest gratitude goes to my beloved family (my wife and children) for sacrificing their time of joy and support for the sake of my success. Without their patience, understanding and love it would have been impossible to finish this work.

Belachew Tsehay

July 2022

Contents

Acknowledgement.....	iii
List of Tables.....	viii
List of Figures	ix
List of Acronyms.....	ix
Abstract	xii
CHAPTER ONE	1
1. INTRODUCTION	1
1.1. Background of the Study.....	1
1.2. Problem statement	3
1.3. Objectives.....	4
1.3.1. General objectives.....	4
1.3.2. Specific objectives	5
1.4. Significance of the study	5
1.5. Scope and limitations of the study	5
1.6. Organization of the Thesis	6
2. REVIEW OF LITERATURE.....	7
2.1 Pastoralism and Lowlands in Ethiopia	7
2.2 Contribution of Livestock to the Ethiopian Economy	7
2.3 Farming System and Management of Livestock and Rangelands in Borana.....	8
2.4 Types of Rangelands and Extent of Rangeland Degrations in Borana Zone	8
2.5 Major Drivers of Rangeland Degradation.....	9
2.6 Impacts of Rangeland Degradation on Soil Properties	10
2.6.1. Impacts on Soil Quality	10
2.6.2. Impacts on Soil Erosion	11
2.6.3. Impacts of Rangeland Degradation on Vegetation	12
2.7 Indigenous and Scientific Approaches to Improve Rangelands.....	13
2.8 Land Suitability Analysis	14
2.9 Mapping and Assessment of Rangeland Degradation.....	14
2.10 Application of Remote Sensing and GIS for Rangeland Management.....	15
2.11.1. Remote Sensing for Land Use Land Cover Mapping.....	15
2.11.2. Remote Sensing for Vegetation Analysis Using NDVI.....	16
2.11.3. Application of GIS for Soil Erosion and Deposition Analysis	17

2.11.4.	Application of GIS for Soil pH Mapping	17
2.11.5.	Application of GIS for Land Degradation and Site Suitability Analysis.....	18
CHAPTER THREE	20
3.	MATERIALS AND METHODS	20
3.1	Description of the Study Area.....	20
3.1.1.	Biophysical Characteristics.....	21
3.1.1.1.	Climate	21
3.1.1.2.	Topography	23
3.1.1.3.	Soil	23
3.1.1.4.	Vegetation	24
3.1.2.	Socio-Economic Characteristics	25
3.1.2.1.	Human and Livestock Population	25
3.1.2.2.	Farming System and Livelihood	25
3.2	Data Collection.....	26
3.2.1.	Satellite Data.....	26
3.2.2.	Soil Data.....	26
3.2.3.	Climate Data	26
3.2.4.	Ground Truth Data.....	27
3.3	Software and Materials.....	27
3.4	Methods of Data Analysis	27
3.4.1.	Vegetation Degradation	29
3.4.1.1.	Digital Image Preprocessing	29
3.4.1.2.	Vegetation Analysis Using NDVI.....	29
3.4.1.3.	Image Classification.....	31
3.4.1.4.	Accuracy Assessment of LULC Classification	32
3.4.2.	Soil quality assessment	33
3.4.3.	Soil Degradation Assessment due to Erosion and Deposition.....	34
3.4.3.1.	Rainfall Factor (R-Factor) Analysis.....	36
3.4.3.2.	Soil Erodibility (K-Factor) Analysis	36
3.4.3.3.	Cover Factor (C-Factor) Analysis	37
3.4.3.4.	Topographic Factor (LS-Factor) Analysis	38
3.4.3.5.	Overall Erosion-Deposition Analysis.....	39

3.4.4.	Rangeland Degradation Assessment.....	41
3.4.4.1.	Multi-Criteria Decision Analysis of Degradation	41
3.4.4.2.	Criteria Weighting (Pairwise Comparison of the Factors).....	43
3.4.4.3.	Aggregation of Rangeland Degradation Criteria Weights	44
3.4.5.	Land Suitability Assessment.....	45
3.4.5.1.	Factors of Site Suitability for Rangeland Rehabilitation	45
3.4.5.2.	Multi-Criteria Decision Analysis of Site Suitability	46
3.4.5.3.	Pairwise Comparison and Weighting of the Criteria	48
3.4.5.4.	Aggregation of Site Suitability Criteria Weights	49
CHAPTER FOUR.....		50
4.	RESULTS.....	50
4.1	Vegetation Degradation assessment.....	50
4.1.1.	Results of NDVI	50
4.1.2.	Vegetation Change between 2002 And 2012.....	51
4.1.3.	Vegetation Change between 2012 And 2021.....	52
4.1.4.	Vegetation Change between 2002 And 2021.....	52
4.1.5.	LULC Assessment of the Study Area.....	54
4.2	Soil Quality Assessment.....	56
4.3	Soil Degradation Assessment due to Erosion and Deposition Using USPED Model	57
4.3.1.	Rainfall Erosivity Assessment	57
4.3.2.	Soil Erodibility to Erosion (K-Factor) Assessment	58
4.3.3.	Land Cover Susceptibility to Erosion (C-Factor) Assessment	59
4.3.4.	Topographic (LS-Factor) Assessment	60
4.3.5.	Overall Soil Erosion and Deposition Assessment	61
4.4	Rangeland Degradation Assessment Factors (Criteria)	63
4.4.1.	The LULC Cover Factor (C-Factor)	63
4.4.2.	Soil Quality (pH) Factor	64
4.4.3.	Soil Degradation due to Erosion and Deposition Factor	65
4.4.4.	Aggregated Rangeland Degradation Assessment	66
4.5	Site Suitability Results for Rangeland Rehabilitation.....	67
4.5.1.	Soil Suitability	68
4.5.2.	Site Suitability Criteria	71

4.5.3. Overall Land Suitability Assessment for Rehabilitation	74
CHAPTER FIVE	75
5. DISCUSSION.....	75
5.1 Rangeland degradation.....	75
5.1.1. Vegetation Degradation	75
5.1.2. Livestock feed Degradation	76
5.1.3. Soil quality (pH) Degradation.....	77
5.1.4. Soil Degradation due to Erosion and Deposition.....	77
5.1.5. Overall Rangeland Degradation.....	79
5.2 Rehabilitation Site Suitability	80
5.2.1. Soil Suitability	80
5.2.2. LULC Suitability	80
5.2.3. Rainfall suitability.....	81
5.2.4. Slope Suitability.....	81
5.2.5. Temperature Suitability	81
5.2.6. Overall Land Suitability.....	81
6. CONCLUSION AND RECOMMENDATIONS	83
6.1 Conclusion	83
6.2 Recommendations.....	84
REFERENCES	86
APPENDICES	99
APPENDIX 1	99
APPENDIX 2.....	100
APPENDIX 3:.....	103
APPENDIX 4	105
APPENDIX 5	106
APPENDIX 6.....	107

List of Tables

Table 3. 1: Data Summary	27
Table 3. 2: NDVI Index values	31
Table 3. 3: Land use/Land Cover Types description	32
Table 3. 4 Soil pH Standard	34
Table 3. 5: C – Factor Values	38
Table 3. 6 Erosion-Deposition values	40
Table 3. 7 Land Degradation Rating	42
Table 3. 8: Summary of rangeland degradation analysis	45
Table 3. 9: Factors of suitability and their relationship with suitability	46
Table 3. 10 Forage Suitability Classes	47
Table 3. 11 Weighting Factor Rates for Forage growth Site Suitability	48
Table 4. 1: Vegetation Condition of the study area in the three Periods	51
Table 4. 2: GCPs Used for each of the LULC class	55
Table 4. 3 Area Coverage of LULC of the Study Area	56
Table 4. 4: Soil pH Class Value and Area Coverage	56
Table 4. 5 Summary of Area coverage of Erosion/Deposition Factors based on erosion susceptibility	61
Table 4. 6: Erosion and Deposition Values and impact Level	62
Table 4. 7: LULC Area Coverage and Level of Degradation	64
Table 4. 8: Soil Erosion and Deposition Area Coverage and Level of Degradation	66
Table 4. 9: Area Coverage and Level of Rangeland Degradation	67
Table 4. 10: Area Coverage of Soil Suitability	70
Table 4. 11: Area Coverage and Level of Suitability Criteria for Rangeland Rehabilitation	71
Table 4. 12: Suitability Area Coverage of the Rangeland	74

List of Figures

Figure 3. 1 Location of the Study Area.....	20
Figure 3. 2 (a) Mean Annual Rainfall; (b) Monthly average Rainfall	22
Figure 3. 3 Monthly Average Temperature	22
Figure 3. 4 Elevation Map of the Study Area	23
Figure 3. 5 Soil Types of the Study Area.....	24
Figure 3. 6 Data Analysis Work flow Diagram	28
Figure 3. 7: Image Preprocessing Workflow	31
Figure 3. 8: Summary workflow diagram of LULC Classification	33
Figure 3. 9: Summary of Soil Quality Assessment Workflow	34
Figure 3. 10: Summary workflow Diagram of Soil Degradation Assessment	40
Figure 3. 11 Criteria weighting flow diagram	43
Figure 3. 12: Summary Workflow Diagram of Suitability Analysis	49
Figure 4. 1: Vegetation Change between 2002 and 2012	51
Figure 4. 2: Vegetation change between 2012 and 2021	52
Figure 4. 3: Vegetation change between 2002 and 2021	53
Figure 4. 4 (a) NDVI Map of 2002; (b) NDVI Map of 2012.....	53
Figure 4. 5 NDVI Map of 2021	54
Figure 4. 6 Vegetation Change in three Periods	54
Figure 4. 7 LULC Map of the Study Area	55
Figure 4. 8: Soil pH level Map of the Study Area	57
Figure 4. 9: Rainfall Erosivity (R-Factor) map of the Study Area	58
Figure 4. 10: K-Factor Map of the Study Area.....	59
Figure 4. 11: Cover Factor Map of the Study Area	60
Figure 4. 12: Topographic Factor Map of the Study Area.....	61
Figure 4. 13: (a) Erosion - Deposition Map; (b) Erosion–Deposition Map (Enlarged Scale)	62
Figure 4. 14: LULC Degradation Map	63
Figure 4. 15: Soil Quality (pH) Degradation Map of the Study Area.....	64
Figure 4. 16: Soil pH Level of Degradation	65
Figure 4. 17 (a) Erosion-Deposition Degradation; (b) Erosion-Deposition Degradation (magnified)	66

Figure 4. 18 Overall Degradation Map of the Study Area.....	67
Figure 4. 19: Soil Suitability Graph.....	68
Figure 4. 20 (Left) Soil Depth Suitability Map; (Right) Soil Texture Suitability Map.....	69
Figure 4. 21 (Left) Soil pH Suitability Map; (Right) Soil Organic Carbon Suitability Map.....	69
Figure 4. 22 (Left) Soil Total Nitrogen Suitability Map; (Right) Overall Soil Suitability Map.....	70
Figure 4. 23 (Left) Soil Suitability Map; (Right) LULC Suitability Map.....	72
Figure 4. 24 (Left) Slope Suitability Map; (Right) Rainfall Suitability Map.....	73
Figure 4. 25 Temperature Suitability Map.....	73
Figure 4. 26 Suitable Site for Grass Seeding/Reseeding in the Study Area.....	74

List of Acronyms

AHP	Analytical Hierarchy Process
CSA	Central Statistics Agency
DEM	Digital Elevation Model
ETM ⁺	Enhanced Thematic Mapper Plus
FAO	Food and Agriculture Organization
GCP	Ground Control Point
GDP	Gross Domestic Product
GIS	Geographic Information System
GPS	Global Positioning System
ICPALD	Inter-Governmental Authority for Development (IGAD) Center for Pastoral Areas and Livestock Development
ILRI	International Livestock Research Institute
LCCS	Land Cover Classification System
LULC	Land Use Land Cover
MCDA	Multi Criteria Decision Analysis
MOLF	Ministry of Livestock and Fish
NDVI	Normalized Difference Vegetation Index
NIR	Near Infrared
OLI	Operational Land Imager
pH	Power of Hydrogen
QGIS	Quantum GIS
RUSLE	Revised Universal Soil Loss Equation
SRTM	Shuttle Radar Topographic Mission
USLE	Universal Soil Loss Equation
USPED	Unit Stream Power Erosion and Deposition
UTM	Universal Transverse Mercator
WLRC	Water and Land Resource Center

Abstract

Livestock production is mainly dependent on the productivity and sustainability of the rangelands' capacity to supply feed for the livestock. However, in recent times the Borana rangeland is unable to sustain supply enough feed to the livestock because of the degradation of the rangeland. Remote Sensing and GIS techniques are of paramount importance to investigate degradation hotspots and select suitable rehabilitation sites for sustainable rangeland. Therefore, this research aims to assess and identify degraded areas as well as suitable sites for rehabilitation in Borana Zone using Remote Sensing and GIS Techniques. The data used in this paper are Landsat 7ETM+ and Landsat 8 OLI Satellite images of 2002, 2012 and 2021, elevation, soil, and climate data. Land Use Land Cover (LULC) degradation, soil degradation due to erosion and deposition, and soil pH degradation were considered as rangeland degradation indicators. LULC, soil (soil depth, soil texture, soil pH, soil OC, and total Nitrogen (TotN)), elevation, rainfall, and temperature factors were used for suitability analysis. Weighted overlay analysis, and Multicriteria decision Analysis (MCDA) method supported by Analytical Hierarchy Process (AHP) were applied to identify the degraded areas and suitable sites for rangeland rehabilitation. The result of the study indicates that 6.33% of the rangeland cover is highly degraded. Whereas, 46.98%, which is the majority of the rangeland, has a moderate degradation level. The marginally degraded area covers 18.97% of the total rangeland while 27.70% of the total rangeland has no or very low degradation. With respect to suitability, the highly suitable site selected covers an area of 7.9%, while the majority of the study area (81.4%) is moderately suitable. The result shows that 10.7% of the area has a marginal contribution for rangeland rehabilitation. Whereas, negligible amount (0.002%) of the rangeland is not suitable. The findings indicate that there is a high risk of conversion of the moderately degraded areas into a highly degraded condition and hence, it is important to Consider degradation protection measures and rangeland restoration sooner.

Key words: Rangeland, Degradation, Suitability, Analysis, NDVI, USPED

CHAPTER ONE

1. INTRODUCTION

1.1. Background of the Study

Pastoralism is a cultural source of revenue, where its base is a widespread use of rangelands, that is practiced in arid and semi-arid dry land areas (Abduselam, 2019). In Asia, china has 400 million hectares area of rangelands out of which, 313 million hectares is pastureland (Han et al., 2008). Thus, according to Han et al, (2008), china is second in the world, next to Australia. In central Asia (Kirgizstan), rangelands cover 49% out of the total land of the country (Carol Kerven and Odessa Centre, 2006). Pastoralism in the Sahel region is the major and most important source of economy in which 50 million people in the region are dependent on it for their livelihood (Haan et al, (2014).

Pastoralism in Ethiopia is the backbone of most people living in the arid and semi-arid low land areas. Pastoralists (Abduselam, 2019; Teshome & Ayana, 2016) occupy about 61%-65 % of the total area of the country. Concerning the amount of livestock and area coverage, the Somali in the eastern and the southern part of Ethiopia cover 53%, the afar in the Northeast 29%, and the Borana in the south covering 10% are the dominant pastoralists although there are pastoralists in different parts of the country that contribute the remaining 8% of the livestock population (Solomon, 2006). The pastoralists of Ethiopia are estimated to Cover an area of 590,000 km² - 780,000km² (48% -65%) and most of the rangelands are located in drier areas with an altitude below 1500m of elevation (Yeneayehu et al.,2018; African Development Fund, 2000).

The Borana plateau is one of the best remaining pastoral areas in Africa (Gemedo et al., 2006; Leykune, 1991 cited in Fekadu, 2009). It occupies an area of about 95 thousand km² in southern Ethiopia (Fekadu, 2009). The livelihood of the dominant ethnic, the Borana, mainly depends on extensive livestock production predominantly cattle and a small number of small animals, camels, and donkeys. The Borana rangeland area is environmentally heterogeneous with annual or perennial grasses, suitable for cattle grazing; bushes and trees proliferate in other areas, particularly species of acacia. These bushes are suitable for the browsing of camels and small stock (Fekadu, 2009). However, he added that in recent times, the productivity of the rangelands in the Borana zone, which is one of the zones in the Oromia Region, is decreasing due to many reasons.

The deterioration of the rangelands in Borana is becoming critical in terms of the loss of perpetual grass at the cost of increasing unpalatable forbs (Musa et al., 2016). Different studies of rangelands of

Ethiopia show that bush encroachment, conversion of rangeland to Cropland, shortage of rainfall, wood harvesting, human population pressures, and over-grazing by livestock are the major causes of degradation (Musa *et al.*,2016; Teshome & Ayana, 2016). Overgrazing-induced soil compaction that prohibits the porosity of the soil for water and air results in degradation of the soil, which in turn reinforces the expansion of bush encroachment (Amaha et al, 2012). Amaha et al (2012) stated that a large livestock population created overstocking, overgrazing, and too much woodcutting resulting in soil erosion. Musa et al., (2016) added that because of these and other reasons like climate change and rigorous human activities, pastoralists in arid and semi-arid areas of the study area have faced tremendous problems. The rangeland communities of Borana are increasingly involved in crop cultivation as an alternative means of livelihood, which significantly degrades the grazing area (Abera et al., 2017). Cultivated land, bare lands, and permanent settlement area increased. While woodland vegetation is decreasing, except in the mountains which are slightly increasing (Yeneayehu et al., 2018). Yeneayehu also stated that soil erosion also is among the rangeland degradation factors, which reduce feed production. In addition, Sintayehu et.al, (2006) stated soil chemical properties were investigated, it is observed that it had less organic matter in the bush encroached areas and is more compacted than in grassland areas reducing water infiltration. These results point to the deterioration of grassland and forage production to feed the livestock. One of the modern techniques of rangeland management is the assessment of rangeland pattern changes and degradation levels, which contribute better by far than traditional ones (Teshome & Ayana, 2016).

Rangeland rehabilitation is a rangeland ecosystem management and conservation method, which is applied over degraded rangeland to return an ecosystem to its sustainable community. The major objective of the management and restoration of the rangelands is to encourage palatable productive perennials since they are important for livestock production and environment protection (Saco et al., 2006 as cited in Yeneayehu et al., 2018). The degraded rangelands can be preserved and restored using several methods among which are, differed grazing to reduce overgrazing, cutting and removing encroached bush, seeding and reseeded, applying indigenous knowledge of the community, and the prescribed fire to regenerate the vegetation and grassland (Yeneayehu et al, 2018). Moreover, to improve the productivity of rangelands, reducing the alkalinity and acidity of the soil through fertilization can be considered (Amaha et.al 2012). Amaha et al also stated that as there is higher rangeland degradation, there exists soil erosion. Hence, it is essential to Control soil erosion for better grassland productivity.

To restore the degradation, Land suitability analysis is important to bring together the diverse information from different streams of science and analyze using various criteria to determine the suitability of land (Desalegn, 2009). Dessalegn added that in Ethiopia, current land use practice is not based on suitability analysis; therefore, it is required to use land in the most balanced and productive way. This is investigated through the land's limitations of productivity for its intended use. There for, analysis of vegetation dynamics and its degradation level as well as, analysis of soil degradation caused by erosion, and its chemical property to understand the productivity level is essential.

1.2. Problem statement

Borana Zone located in the southern Ethiopia's low land, which is characterized by erratic rainfall and high temperature, is negatively affected by significant deficiency of crop production, and hence, livestock production is the way of life (Fekadu, 2009). However, recently rapid population growth demanding an increase in livestock numbers to meet the livelihood of pastoralists, which in turn led to pastureland degradation for natural grazing. Overgrazing due to an increase in livestock number, increasing land use conflicts, and bush encroachment are the problems accountable for rangeland degradation. Conversion of grazing lands and forestland to Cultivation, which in turn leads to vegetation degradation, is a common practice and a threat to livestock production and natural resources. As vegetation degradation increases, soil's chemical and physical properties will change in terms of nutrient contents and soil texture, which again lead to soil degradation (Amaha et al, 2012). These conflicting issues led to the fast depletion of rangeland resources and loss of grazing land, affects the productivity of livestock. This deteriorating productivity of the livestock resulted in a negative effect to generate the required amount of income for the pastoralists and in turn, affected their lives. As a result, it necessitates properly utilizing the land as well as rehabilitating the degraded rangeland to make it productive and ultimately for the betterment of the pastoralists' livelihood.

This problem was identified from the gaps in previous studies conducted in the Zone at different times (Yeneayehu et al., 2018; Bedasa, et al., 2014; Abera et al., 2017; Fekadu, 2009). The main causes of rangeland degradation for example in Yabelo woreda are overgrazing, bush encroachment, conversion of rangeland to Cropland, and deforestation (Yeneayehu et al., 2018; Fekadu, 2009; Dessalegn, 2009). These conditions again cause vegetation degradation, increase soil erosion, decrease soil nutrients, lead to more degradation of the rangeland, and cause to reduce productivity (Amaha et. al 2012)

Dessalegn (2009) stated that assessment of the trends of land cover changes using satellite images and locating suitable areas for livestock production using spatial models in GIS would be essential to

improve grazing land for livestock productivity. Accordingly, assessment and mapping of vegetation degradation using remote sensing and analysis of soil erosion threats and soil property degradation using GIS are essential. To get the maximum benefit out of the land, proper assessment, management and use for specific purposes are inescapable. In addition, restoration of the degraded rangeland to its initial state will be a remedy for the improvement of palatable grass. The restoration of degraded grazing land can be done through indigenous grass reseeding and is necessary to apply it (Yeneayehu et al., 2018). Bedasa, et al., (2014), experimented and showed in their study that there is a possibility and feasibility of growing indigenous grass through reseeding which resulted in a highly productive indigenous grass for livestock feed. Therefore, in order to rehabilitate the degraded rangeland, the first activity is to assess the level of degradation of the rangeland in terms of soil properties, soil erosion condition and vegetation degradation, and the second is selection of appropriate sites for rehabilitation. Among rehabilitation techniques, are conservation of the areas by enclosure and grass reseeding using improved or indigenous seeds. Hence, it is of principal importance to identify areas, which are degraded, and suitable site selection for improved seed growth to rehabilitate the degraded rangeland as well as, to enhance the resilience of the rangeland ecosystem.

A GIS and remote sensing-based vegetation and soil degradation analysis as well as site suitability analysis for grass reseeding in the degraded areas has not been conducted in the area before. However, a related study of suitable site selection for livestock production by Dessalegn, in 2009 and Fekadu, in 2009 was conducted in the Yabelo area. In their analysis, they considered slope, rainfall, land use/land cover, soil, and temperature factors to be taken for suitability analysis, which can also be used for this study. In this study, identification and mapping of the degraded rangeland areas and analysis of suitable sites for growing palatable species for the rangeland restoration and abundance of feed will be done using a geospatial data analysis technique.

1.3. Objectives

1.3.1. General Objective

The main objective of this study is to assess the degradation level of the borana rangeland and further explore suitable sites for rehabilitation.

1.3.2. Specific Objectives

- To assess and map Rangeland degradation of the Borana Zone
 - To assess and map the nature of vegetation degradation over the last two decades
 - To assess and map soil chemical and physical degradation of the rangeland by analyzing the soil acidity and alkalinity as well as soil erosion and deposition
 - To prepare a composite map that could depict the overall rangeland degradation
- To produce potential rangeland rehabilitation suitability map that could guide planting of improved grass species for rehabilitation of degraded rangeland

1.4. Significance of the Study

Borana zone of Oromia regional state is one of the three major pastoral areas in Ethiopia. However, its long-time rangeland management practice is weakening from time to time. As a result, its pastureland is diminishing from time to time and livestock is suffering with the deficiency of enough feed. This study there for, is conducted to assess the level of the borana rangeland degradation. The study will help the Borana pastoral area stakeholders get understand the underlying causes of rangeland degradation and its effects on rangeland productivity. Consequently, they can devise mechanisms to improve the rangeland productivity. In addition, the study support the pastoralists through recommending suitable sites to rehabilitate with indigenous feed species for their livestock feeding. Moreover, it helps rangeland managers, Zone administrators and environmentalists manage the rangeland and make decisions based on properly analyzed geospatial data. Beyond the rangeland community and stakeholders, this study will provide information to the scientific community to extend their research in the study area or anywhere in Ethiopia.

1.5. Scope and Limitations of the Study

Scope of the Study

The focus of this study is the Borana zone of the Oromia regional state of Ethiopia. This area is chosen because of the challenges subsequently the society is facing is managing rangelands. Although rangeland degradation assessment comprises various issues, the present study considers: 1) Vegetation degradation and 2) Soil degradation by analyzing soil chemical and physical properties.

The scope of the work is assessment of the overall rangeland degradation through the analysis of different factors. Besides, the focus of this study is to identify suitable sites for the rehabilitation of the degraded rangeland through examining different criteria for suitability.

Limitation of the Study

In most cases, USLE/RUSLE models have been used to analyse the impact of soil erosion over a certain area. There are many studies applied in different countries to assess the soil erosion impact using these models. However, studies to estimate the risk of soil erosion-deposition using the USPED model is limited and lack a sufficient amount of literature. However, a thorough investigation and understanding of the available limited literatures was done to analyse the erosion-deposition condition to mitigate the limitation.

1.6. Organization of the Thesis

This thesis is organized into six chapters. The first chapter presents the introduction part of the study including the background of the study, statement of the problem, objectives of the study, significance of the study, scope, and limitation of the study. The second chapter describe literature review which give emphasis on concepts about pastoralism in Ethiopia and especially in borana, contribution of the livestock to Ethiopian economy, rangeland degradation extents, factors of rangeland degradation, impacts of rangeland degradation on soil and vegetation, approaches of improving rangelands, land suitability analysis for rangeland rehabilitation, applications of GIS and remote sensing in rangeland management. Chapter three mainly focuses on the data, materials and analysis methods needed for the research. The fourth chapter explains about the results including NDVI results of vegetation degradation, LULC assessment of the study area, assessment of soil quality, soil degradation results due to erosion-deposition, a composite result of rangeland degradation and suitable sites for rehabilitation. The fifth chapter clarifies the main discussion on vegetation degradation, soil degradation, LULC degradation and discussion about the suitable sites for rehabilitation. The closing chapter presents conclusions and recommendations.

CHAPTER TWO

2. REVIEW OF LITERATURE

2.1 Pastoralism and Lowlands in Ethiopia

Pastoralism is a specialized form of natural resource management and a dominant source of revenue, adapted to ecosystems characterized by variable and volatile agro ecological resources of the rangelands (Yimer, 2015; Birch, 2018). Yimer added that spatial and temporal difference in rainfall distribution and structure is the major description of low lands. In the lowlands, the period of rain in different years is different in pattern and the annual average rainfall amount in the North - South is 600mm and East-West is 2000mm (Mengesha, 2020). The dry season diminishes the productivity of the rangeland and causes livelihood in the pastoral community miserable (Adugna & Aster, 2021). Lowlands have a large area of rangelands and are located in a topography lower than 1500m elevation (Birch, 2018; Fekadu, 2009). According to Dessalegn (2009), the lowlands of Ethiopia take 60% of the total area of the country. These low lands of the country help grow woodland vegetation like Acacia and Terminalia species, grasslands, and herbs (Mengesha et al., 2020).

Even if there are other small groups of pastoralists in the country, the Somali, the Afar, and the Borana are the major pastoralists in Ethiopia (Solomon, 2006). Ethiopia has 52 million cattle, 24.2 million sheep, 22.6 million Goats, and the remaining others, of which 65% - 73% are located in the lowlands (MoLF & ILRI, 2017).

2.2 Contribution of Livestock to the Ethiopian Economy

The livestock sector is contributing 20% of the GDP of the country and 20% of its foreign exchange to the national economy (Panel, 2020). Direct products (meat and milk) of the livestock have a share of 35% of the GDP of agriculture while its share increases to 45% when indirect service values (tilling services, transport, sale for cash, etc.) are considered (ILRI and MoLF, 2017). Its export contribution to the national livestock development is about 11% (ICPALD, 2013). In addition, it also benefits 80% rural people in terms of providing farming and transport services, financial services, credit substitution, and insurance (ICPALD, 2013). It provides protein-rich foods, and easily liquidated assets as an income source and for transport (ILRI and MoLF, 2017). During the limited crop production season, the semi-arid areas of southern Ethiopia are engaged in livestock production to fulfill the food requirement of pastoralists and agro-pastoralists and make cash and foreign currency for the country (Adugna & Aster, 2021).

2.3 Farming System and Management of Livestock and Rangelands in Borana

The livelihood of the Borana mainly depends on extensive livestock production predominantly cattle, sheep, goats, camels, and donkeys but also produce some crops (Solomon et al, 2011; Fekadu, 2009). Rangeland degradation mainly due to frequent drought and other factors led to the death of livestock and consequently scarcity of food for pastoralists forced them to go for crop cultivation (Sintayehu et al 2006). The beginning of crop production to fill the gap in food sources forced them to Change their lifestyle from pastoralists to agro-pastoralists and continue to grow crops in some areas. Crops help pastoralists to escape selling their livestock to buy food, especially during drought season (Tilahun et al (2017). Besides, crop residuals from Maize and Teff are palatable and used for livestock feed. Accordingly, pastoralists in Borana continue to produce some crops like maize, beans, and wheat (Solomon et al, 2011). Because of this, the Borana pastoralists are turning the rangeland from pasture to agriculture in a continuing manner (Tilahun et al 2017). Though the Borana rangeland is suitable for livestock rearing, there is poor management of agricultural and rangeland resources (Solomon et al (2011). To maintain the productivity of rangelands and fulfill feed requirements, pastoralists mobilize in two forms to the area where enough resource (pasture and water) is available in the form of temporary regular mobility (“Godaanssa Fooraa), and (“Godaanssa Warraguda”) permanently during drought and conflicts (Lasage et al, 2010). Mobility of herds, traditional institutions (elected elders or hereditary leaders, customary rules), herd splitting by age, sex, and range enclosure, which are locally called “Kaloo”, is the famous local practices applied for rangeland management (Dika, 2016). Dika added that the mobility of herds helps for the production of livestock as well as managing pastureland depending on the rain, water, and forage availability of the host area. Besides, customary institutions determine the resource access conditions; herd splitting helps different livestock groups graze separately and “Kaloo” helps to maintain feed for drought season.

Pastoralists in the Borana zone also use prescribed fire, hand cutting of unwanted wood, enclosures, fallowing, and reseeded techniques to maintain the productivity of rangelands (Yeneayehu, 2018). Yeneayehu added that, woodcutting and firing help to prevent bush encroachment and help regeneration of the seed to improve feed productivity while enclosure helps to Control overgrazing.

2.4 Types of Rangelands and Extent of Rangeland Degradations in Borana Zone

Rangeland is Land on which the native plant mainly grasses, grass-like plants, forbs, or shrubs are used for current and future grazing and browsing in the customary environment for the production of

livestock and wildlife (Allen et al., 2010). Rangelands are different types including prairies (grasslands, savannas, and shrubs), grasslands (grass and forbs), steppe, pampas, shrub land (grass, herbs, and geophytes), woodlands, savanna, a desert with maximum rainfall of 250mm, and Tundra, rangeland with dwarf shrubs (Gautam, 2020). Pastoralists in Ethiopia are faced with serious risks in the Afar region about the 409,678-hectare area along rivers is used for investment, one million hectares is encroached by bush and a significant amount of land is used by parks (Ykhanbai et al, 2014). Similarly, in the Borana zone of the Oromia region, bush encroachment by acacia mellifera and acacia drepanolobium are an ever-growing current problem (Yeneayehu, 2018).

The deterioration of the rangelands in Borana is becoming critical in terms of the loss of perpetual grass at the cost of increasing unpalatable bush (Musa et al., 2016). Different studies of rangelands of Ethiopia show that bush encroachment, conversion of rangeland to Cropland, shortage of rainfall, wood harvesting, human population pressures, and over-grazing by livestock are the major causes of degradation (Musa et al.,2016; Teshome & Ayana, 2016). Overgrazing due to overstocking leads to soil erosion and soil compaction that compaction prohibits the porosity of the soil for water and air result degraded soil productivity, which in turn reinforces the expansion of bush encroachment (Amaha et al, 2012). The rangeland communities in the study area are increasingly involved in crop cultivation as an alternative means of livelihood, which significantly degrades the grazing area (Tilahun et al., 2017). Cultivated land, bare lands, and permanent settlement area increased. While woodland vegetation is decreasing, except in the mountains which are slightly increasing (Yeneayehu et al., 2018). In addition, soil chemical properties show less organic matter in the bush encroached areas, and are more compacted than in grassland areas (Sintayehu et.al, 2006).

2.5 Major Drivers of Rangeland Degradation

According to studies in different parts of Ethiopia, major rangeland degradation causes are heavy grazing, repeated drought, crop cultivation, bush encroachment, scarcity of rainfall amount over each season, improper use of land resources, and erosion (Teshome & Ayana, 2016; Tilahun et al., 2017; Dawit & Mebrate, 2015; Musa et al.,2016). Rangeland degradation decreases plant productivity, vegetation cover, and species diversity (Yeneayehu, et al., 2018). When rangeland is degraded, the level of vegetation cover reduces; the composition of grass and grass-like species changes, meaning that annual grass replaces perennial grass; the soil will be eroded due to overgrazing and substantial woodcutting (Han et al., 2008).

Overgrazing is a factor, which is an ever-persistent driver of soil degradation in pastoral areas (Coppock 1994). Overgrazing according to Coppock is caused by an increase in population that demands an increase in livestock to meet livelihood needs that again clash with the limited grazing land. An increase in livestock number due to population growth in turn leads to intensive grazing that damages the rangeland ecosystem (Yeneayehu et al, 2018). Hence, Overgrazing is the major threat to land degradation where the vegetation and soil are deteriorating in the rangelands (Fatunbe and Dube, 2008; Yong-Zhong et al, 2005).

The other ever-growing driver of rangeland degradation is bush encroachment which is characterized by a spread of plant species to the rangeland that does not occur before (Yeneayehu et al, 2018). It is becoming a major reason for the rangeland deterioration in the area as *Acacia brevispica drepanolobium*, *acacia mellifera*, and *Commiphora* are encroaching the area that is becoming very difficult for grazing because of the prickles of the bush that hurt livestock (Coppock 1994; Terefe et al, 2011; Yeneayehu et al, 2018). The bush encroached area in turn destroys the palatable indigenous grass and other herbaceous plants (Desalegn, 2009; Fekadu, 2009).

Since the rainfall pattern is insufficient and highly variable for crop farming, pastoralism is the major mode of economic activity for the livelihood in the pastoral area (African Development Fund (ADF), 2000). ADF stated that when there is relatively better rainfall specifically at the margins of the intermittent rivers, agro-pastoralism is becoming increasing though the pastoralist economy is predominantly dependent on livestock production. Consequently, the conversion of rangelands to Crop cultivation is increasing and Rangeland is deteriorating. According to a study by Sisay et al (2020), bush encroached rangeland and crop farming in the Borana zone show an increase b/n 1986 and 2016. This led to a decrease in forest and shrub land while bush encroachment and crop cultivation are increasing with the cost of forestland. Climate change is affected by a consequence of heightened temperature and lowered rainfall in southern and eastern Ethiopia starting in 1996 (Yeneayehu et al, 2018). Fekadu, (2009) confirmed the idea that rainfall in the Borana Zone is inadequate for the growth of grass as well as filling the ponds in drought season, and this together with overgrazing is devastating the rangeland.

2.6 Impacts of Rangeland Degradation on Soil Properties

2.6.1. Impacts on Soil Quality

Soil pH is the acidity or alkalinity of soil that affects plant growth ranging from most acid (0) to most alkaline (14) and neutral (7) (Lake, 2000). According to the United States Department of Agriculture

(USDA, 1998), pH values ranging from 6.5 – 7.3 is neutral, from 5.5 - 6.5 are medium acidic, and from 7.3 - 8.5 are medium alkaline whereas, soil pH values from 4.5 – 5.5 are strongly acidic and >8.5 are strongly alkaline. When the vegetation decreases from its state of outstanding condition to reduced condition, soil alkalinity increases because of the accumulation of more calcium and sodium contrary to magnesium (Amaha et al., 2012). A serious rangeland degradation in an area will have an increased soil pH in the area (Fatunbi and Dube, 2008). Overgrazing changes the soil characteristics of organic matter (OM), organic carbon (OC), sodium(K), potassium (P), nitrogen(N), electric conductivity (EC) bulk density, and soil pH (Pellant et al., 2005; Wang et al., 2021). A higher soil pH was detected in the grasslands of china continuously overgrazed which led to rangeland degradation (Yong-Zhong et al, 2005). In the areas where lengthy drought due to high temperature and inadequate rainfall is experienced, rangelands are mostly faced with salinization driven by a higher rate of evapotranspiration (Bolo et al., 2019). The higher content of sodium and calcium ions in the soil means there is a strong relation with soil pH, and pH is related to Chemical and physical conditions as well as the structure of the soil (Hillel, 1998). For example, Getachew et al, (2007) stated that rangelands of Yabelo woreda that are bare land cover have lower soil pH while ranches have large exchangeable K and Mg. The soil pH value of the study area mainly covers from 7.1 to 8.6 (Mohammed & Omar, 2021).

2.6.2. Impacts on Soil Erosion

Soil erosion is the detachment, movement, deposition, and draining out of the soil by water and wind in a faster or slow process (Balasubramanian, 2017; Telkar & Neha 2018). However, the principal source of land degradation that drains top soil is water-induced erosion (Nigussie et al, 2015; Tegegne & Biniam, 2017). Soil erosion is one of the main soil degradation processes deteriorating soil fertility and removal of seeds by runoff (Lal, 2015; Stolte et al, 2016). Land use and soil type as well as soil conservation mechanisms are the determining factors of soil loss (Tegegne & Biniam, 2017). There is a higher risk of erosion in rangelands where conversion of forestland to Cropland and settlement is high, as well as near the boundaries of vegetated and cultivated lands (Yared et al, 2020). In the study conducted in the Somali rangelands of Ethiopia, the minimum soil erosion was observed in the excellent vegetation condition while the maximum was in the poor vegetation condition (Amaha et al 2012). They also stated that Grass and forbs have better water run-off control and soil erosion protection capacity than woods and trees. Consequently, overgrazing, overstocking due to an increase in livestock population, and woodcutting are considered the major causes of soil erosion in the rangelands.

Erosion can be of different forms such as sheet erosion and rill erosion of which sheet erosion is an erosion that washes away thin homogeneous top organic content rich soil during the rainy season (Telkar & Neha, 2018). Telkar and Neha added that such erosion is caused by the loss of vegetation to intensive grazing, deforestation, and cultivation to protect the soil. They also stated rill erosion as uniform removal of topsoil ends and channelization begins on a shallow surface in an overgrazed, bare area, and freshly cultivated loosened surface. Soil erosion results from the deformation of soil texture and changing of soil nutrients and a decrease in moisture retention capacity (Bolo et al, 2019). In its severe forms, soil erosion results in the formation of gullies alongside (Amaha et al., 2012). However, such soil erosion can be reduced by the abundance of soil organic matter that enhances the porosity, infiltration, and water storage of the soil to bind the soil particles together (Mitchell, 2010).

2.6.3. Impacts of Rangeland Degradation on Vegetation

Vegetation degradation is a decrease of natural vegetation characterized by rangeland degradation, which is a shift in plant species composition, declined production capacity, poor land cover, and soil erosion (Yeneayehu et al, 2018). Rangeland degradation indicates the incapability of the rangeland to provide the expected products and services to feed the livestock (Niguse & Gizachew, 2014). Rangeland degradation is a decrease in the production of flora and fauna that leads to the reduction in the rank of natural vegetation (Yeneayehu et al, 2018). Borana rangeland mainly is threatened by the loss of persistent grasses and increase in the unpalatable bush, expansion of crops, and settlement with the cost of vegetation cover of the rangelands (Oba and Kotile, 2001). Desertification, which is the result of land degradation, is mainly caused by the alteration of the patterns of vegetation due to overgrazing that changes the structure and density of vegetation patches in semi-arid areas (Saco et al, 2006). Consequently, the vegetation change of the Yabello area was at a vigorous state where forest cover was changing at an alarming rate with significant magnitude in the previous times (Sisay et al, 2020). The vegetation pattern and composition of the Yabello forest, woodlands, and shrublands have been faced with a substantial problem due to intensive grazing and browsing by livestock, crop farming, woodcutting, settlement, and other human interventions. Hence then, Forest has to be protected as it is the major land cover that contributes to building a climate-resilient ecosystem to maintain environmental changes (Sisay et al, 2020).

2.7 Indigenous and Scientific Approaches to Improve Rangelands

The major objective of the management and restoration of rangelands is to encourage palatable productive perennials since they are important for livestock production and environment protection (Saco et al., 2006). Destocking, prescribed fire, cutting and removing of the encroached bush, intermittent grazing, ripping and grass reseeding could be applied to rehabilitate the degraded rangeland (Dawit and Mebrate, 2015; Yeneayehu et al, 2019). Dawit and Mebrate added that these methods are useful since original species will not give their benefit if plants are overgrazed which reduces the majority of biodiversity-ecosystem. Lasage et al (2010) stated that pastoralists in the area use a mobilization strategy to restore the rangeland by avoiding overgrazing. They also use controlled fire, hand cutting of the unwanted bush, using the enclosure to protect the pasture, and fallowing of the overgrazed pasture (Yeneayehu et al., 2018).

Therefore, in areas with significant vegetation degradation, grass seeding and reseeding using a quality seed type is a highly recommended and successful method for rangeland restoration (Way et al., 2009). Production of forage through cultivation by using well-developed seeds was experienced in turkey since 2000 (Dengiz et al, 2016). A grass-reseeding method is a tested and promising method of rehabilitating degraded rangelands in Borana zone Dugda Dawa woreda (Bedasa et al, 2014). Bedasa et al (2014) added that seeding was conducted in the rainy season of Dugda Dawa woreda adjacent to Yabelo from March-June 2007 and 2009 and the highest recovery was observed. This grass cover obtained using this mechanism got appreciation from the local community and was verified to be a good rehabilitating method. Zowe (2009) reinforced this idea that the highest recovery was observed from reseeding the indigenous grass seed as long as there is enough rain greater than 300mm.

Moreover, to improve or restore the productivity of rangelands, reducing the alkalinity and acidity of the soil through fertilization can be considered (Amaha et.al 2012).

Different field studies indicated that natural vegetation patterns contributed to the stabilization of the ecosystem through efficient reduction of land degradation that helps the ecosystem to rehabilitate from disruption (Saco et al., 2006). Saco et al added that the system becomes inefficient to trap runoff and leads to the loss of valuable water and nutrients that reinforces the degradation. Amaha et al (2012) stated that it is essential to Control soil erosion induced by higher rangeland degradation for better grassland productivity.

A Scientific approach such as Land suitability analysis is important to bring together the diverse information from different streams of science and analyse using various criteria to determine the

suitability of land for rangeland restoration (Desalegn, 2009). Desalegn added that in Ethiopia, current land use practice is not based on suitability analysis and is required to investigate the land's limitations of productivity for its intended use. There for, analysis of vegetation dynamics and its degradation level as well as, analysis of soil degradation caused by erosion, and its chemical property to understand the productivity level is essential.

2.8 Land Suitability Analysis

The purpose of land use planning is to survey climate, soils, vegetation, and other aspects to decide on land use and to put resources in a way that benefits the user (FAO, 1976). Land for livestock feed production is one of the land use types where it is dependent on forage cultivation and production (Dengiz et al, 2016). According to (FAO, 1976), Land suitability is the relationship between land mapping units and the appropriateness of a specific land unit for a specific purpose. FAO also stated that land suitability is classified as highly suitable (S1), moderately suitable (S2), marginally suitable (S3), currently not suitable (N1) and permanently not suitable (N2) based on the severity level of the limitations of the land use. Dengiz et al (2016) modified these suitability classes to make the number of orders to be four by merging the currently not suitable (N1), and permanently not suitable (N2) into unsuitable (N). Suitability analysis is conducted based on the important requirements of land suitability. Among the many requirements of suitability for plant growth, physical and chemical factors including soil type, soil texture, soil depth, soil organic carbon(OC), soil total nitrogen (N), soil pH, rainfall, temperature, and slope are considered for the suitability analysis (Dengiz et al, 2016). Based on the review in this study, the Borana rangeland is degraded in terms of expansion of agriculture, conversion to barren soil due to overgrazing and drought, erosion, encroachment of unpalatable bush, and increase of soil pH. Rehabilitation of the degraded rangeland through selection of suitable sites for grass seeding through site analysis is important.

2.9 Mapping and Assessment of Rangeland Degradation

One of the modern techniques of rangeland management is the assessment and mapping of rangeland pattern changes and degradation levels (Teshome and Ayana, 2016). So far, a significant number of studies have been conducted to map and assess bush encroachment and species degradation. Consequently, Graw (2016) did an assessment and mapping of bush encroachment and woody vegetation in Africa using Landsat and MODIS data to generate large-scale and small-scale maps respectively. In the study, field data of encroaching bush was applied to train the computer and to

identify it on the imagery. A study was also Conducted by Zemenu (2009) to map and assess the magnitude of expansion of the bush in the Borana zone of the Oromia region in Ethiopia using Landsat 7ETM⁺ data and supervised classification together with separability analysis. Zemenu in his study identified a significant increase in the area coverage of the expansion of bush encroachment between 1986 and 2003. Liao et al (2018) also Conducted an assessment of bush encroachment using field data to train the non-parametric classifier for supervised classification together with time series NDVI analysis.

Oldeland (2010) assessed bush encroachment using field data in central Namibia to identify prosopis juliflora and acacia reficiens bush types. They applied field data to identify species composition using hyperspectral vegetation indices and gradient analysis.

Overstocking, wood harvesting for fuel and construction, wild forest fire, and bush encroachment damaged the grass species in the Bale Mountains and Borana rangelands (Mekbebe et al, 2022). They also identified that invasive bush damages and destroys other inherent species and the ecosystem by competing for important resources helpful for their growth and survival. Intensive grazing deformed the concentration, area coverage, and variety of grass and herbage species in the rangelands (Yeneayehu et al, 2019).

2.10 Application of Remote Sensing and GIS for Rangeland Management

2.11.1. Remote Sensing for Land Use Land Cover Mapping

Information on land use and changes in land use is a major requirement for better use of land (Anderson, et al., 1976). GIS and Remote Sensing (RS) are fundamental modern tools for the assessment of rangeland degradation, monitoring, and evaluation as well as for assessing time-based changes (Masoudi et al., 2018). Remote sensing helps to acquire spatial data and accurately measure the vegetation cover to estimate the impact of bush and weeds (Hunt et al., 2003). LULC change detection is the application of multi-temporal remote sensing data to extract information and detect LULC change (Nigus, 2021; Lilesand et al., 2015). Mgalula (2016) assessed vegetation using satellite images and analysed the nature and magnitude of LULC change in the Borana Zone. The area is changing in terms of LULC especially the grasslands and forest cover and understanding was created to know the factors affecting the security of pastoralists and to plan natural resources management (Sisay, 2019). Remote sensing supports mapping and monitoring rangeland since the repeated visit of an area by satellites enables one to get data that shows the changes in the area observed (Desalegn, 2009). As a result, the

rangeland degradation level and the land use pattern will be analysed and a restoration mechanism will be developed using the change trend map of the area using Remote sensing data. Remote sensing provides data with a variety of temporal, spatial, and spectral resolutions to help differentiate grass biomass for grazing and to prepare classified LULC maps for the development of rangelands (Fekadu, 2009).

2.11.2. Remote Sensing for Vegetation Analysis Using NDVI

While analyzing, monitoring, and evaluating the rangelands of Africa, Asia, and the United States GIS and RS with Normalized Difference Vegetation Index (NDVI) were the most useful tools applied (Espach et al., 2009; Thenkabail and Gamage, 2004; Booth and Tueller, 2003; Hunt Jr et al., 2003). Normalized difference vegetation index (NDVI) is the ratio of the difference in Near Infrared (NIR) and Red reflectance for vegetation analysis (Lillesand et al., 2015). Lillesand et al stated that the result of spectral signatures of vegetation shows high if the NIR is higher than Red and low otherwise indicating the non-vegetated areas like water, bare soil, construction materials, and ice. After the computation of the images, vegetation areas will have high NDVI values since the NIR reflectance is high and low values for the low reflectance of the visible wavelength (Teshome, 2011). When a need arises to assess vegetation cover and condition in terms of quantity and quality, meaning that original species disappear and other species like unpalatable bush appear, the NDVI integrated with remote sensing is an ideal tool (Marie et al, 2021). According to Marie et al (2021), this tool helps to assess the vegetation condition based on remote sensing data for sustainable rangeland management.

Teshome (2011) applied NDVI-based change detection through the image differencing method to see the changes in the greenness of vegetation in Borana. He then identified that the image had resulted in positive and negative values in areas where vegetation change was observed and zero or close to zero in the areas where there were no changes between images of different dates. Teshome also stated that once the change detection is done, the magnitude of change could be determined by using image statistics. Marie et al (2021) proved that the application of NDVI for the analysis of vegetation spectral reflectance index is suitable and justified to estimate the productivity of rangelands. However, in their study, Marie et al (2021) recommended the need to verify the result using field data for the acceptance and accuracy of the vegetation indices before applying it to the specific monitoring purpose. Similarly, vegetation cover was assessed in the semi-arid rangelands of Iran using satellite data from all vegetation indices and confirmed NDVI for its accuracy in predicting rangeland degradation (Masoudi et al, 2018).

2.11.3. Application of GIS for Soil Erosion and Deposition Analysis

Farming on steeper slopes in a rain-fed agriculture together with the absence of protective measures results in soil erosion (Hurni et al., 2010). Soil loss induced by water erosion can be analysed using RUSLE (Wischmeier and Smith, 1978). Alelgn et al, (2021) applied the RUSLE model for water-induced soil erosion analysis since it is simple and friendly with remote sensing and GIS tools to integrate data in a computer environment. Analysis of soil erosion risk of grazing and agroforestry areas of Brazil was conducted using RS and GIS tools and the result indicated that those areas are associated with high erosion risk (Bolo et al, 2019). The RUSLE model was applied to investigate the annual soil loss of a watershed to compute the model's parameters erosion risk and intensity maps (Farhan and Nawaiseh, 2015). Moreover, they applied it with the incorporation of terrain, elevation, slope, and Land use/land cover for the investigation of the influence of these factors on soil erosion in the GIS environment. However, with the absence or limitation of soil conservation interventions, the RUSLE model overemphasizes the soil erosion risk estimations (Stolte et al, 2016).

Whereas, the USPED modeling strategy is suggested when detailed engineering computation is not required, and for effective planning purposes (Morgan 1995). This type of modeling is applied to know just the relative strength or intensity of the erosion patterns and not to compute the real sediment dynamics (Morgan, 1995; Arebbei, 2020). According to Warren et al (2019), the USPED model is a modification of the USLE/RUSLE models by Moore and Burch in 1986 and applied by Desmet et al in 1995 and Mitasova et al (1996). It is a model applicable to estimate the sediment transport capacity of erosion (Liu et al, 2007; Arebbei, 2020). Liu et al (2007) stated that soil erosion would be highly minimized if the shape of the terrain is less suitable for erosion and if there is enough vegetation. The application of this model is useful for the assessment of soil erosion and sedimentation risk and the identification of hot-spot areas through the analysis of plentiful data available (Mitasova and Mitas, 1999; Warren et al, 2019). Warren et al (2019) also stated that the USPED model computes both the erosion and deposition with transport capacity change across a grid cell. Therefore, the USPED model is suitable to apply in the rangelands to assess soil erosion treatments.

2.11.4. Application of GIS for Soil pH Mapping

Applying RS and GIS for Soil pH mapping is essential to show the spatial distribution of areas with acidic soil for the application of lime to reduce acidity (Chabala, 2014). He analysed the spatial representation and mapping of acidic soils using ordinary kriging geostatistical methods in a GIS environment. Soil alkalinity and salinity are the factors of soil deterioration and are important to

process and map these factors both spatially and temporally (Bai et al, 2016). GIS and RS are applied to develop the spatial model and to evaluate the soil characteristics like soil fertility, physical index, and chemical index (Abdullatif et al, 2021). Similarly, an Inverse Distance Weighted (IDW) method was applied to determine the cell values using a weighted combination of sample points (Mustafa, 2011). Mustafa added that this method uses to Control the advantages of known points of interpolated values result point distance. There for, GIS is an essential tool for the analysis of soil pH and mapping it spatially.

2.11.5. Application of GIS for Land Degradation and Site Suitability Analysis

GIS is a powerful and ideal scientific tool to analyze data and integrate different attributes and helps create databases to manage resources as well as to analyse spatially variable data and generate results for decision and planning (Amiri et al., 2012; Berhanu & Suryabhadgavan, 2015).

An integrated application of Remote Sensing, GIS, MCDA, and Analytical Hierarchy Process (AHP) is applied for the generation of a composite land degradation map (Alelgn et al, 2021). Furthermore, an integrated application of GIS, MCDA, and analytical hierarchy process was applied for the preparation of a suitable site map. Satellite image, DEM, climate data, soil data, and land use land cover data are among several data sets used to produce independent factor maps for land degradation and suitable site selection by integrating GIS with MCDA (Zolekar and Bhagat, 2018; Alelgn et al, 2021). GIS is a powerful tool to do land suitability analysis using Multicriteria Decision Analysis (MCDA) to select suitable sites (Nguyen et al., 2015). Mugiyo (2021), applied a GIS-based MCDA for suitable site analysis to identify appropriate areas for agriculture in South Africa. Fekadu (2009) also applied GIS for the identification of suitable sites for livestock production in the Yabelo rangeland of Ethiopia. Rangeland grazing suitability scheme can be developed using GIS by integrating topographic data, rainfall data, Remote Sensing data, and water resource data (Nahom, 2015).

Therefore, thematic layers (factors) related to land degradation or land suitability are going to be categorized into measurement scales depending on the weights given based on Analytical Hierarchy Process (Morales et al., 2021). Among different techniques integrated with MCDA for making decisions, the AHP method is the well-known method for land degradation as well as suitable site selection analysis in the field of natural resources (Alelgn et al, 2021; Mustafa, 2011). The weighted overlay is a procedure for applying a common measurement scale of values to different inputs based on their influence to Create an integrated analysis to define the suitable site. MCDA evaluates through classifying decision alternatives against criteria (Hajkowicz, 2007). Several land quality indicators

were processed and analysed using spatial MCDA in the RUSLE model to spot land degradation or suitability (Alelgn et al. 2021; Prakash, 2003). In this study, MCDA is applied in a USPED model to analyse and identify sites with erosion and deposition, to identify the overall land degradation risk and, to select suitable sites for reseeded to rehabilitate the rangelands.

CHAPTER THREE

3. MATERIALS AND METHODS

3.1 Description of the Study Area

The study area is located in the Borana zone of the Oromia Region, Ethiopia that includes Yabelo and parts of Arero, Dugda Dawa, Dire, Dehas, Dilo, and Teltele woredas (Figure 3.1). Yabelo, the town of Borana zone, is found 570 km south of Addis Ababa along Addis – Moyale road, to the border of Kenya and Ethiopia. The study area is located between 4°30'56" and 5°24'36" North, and between 37°44'15" and 38°36'05" East which is extracted from a satellite image and has a total area coverage of 13,801 km² based on the project area definition. The site was selected because it is one of the pastoralist areas famous for annual perennial grasses and trees in the lowlands of the Borana zone. The pastoral communities of this Zone are the most vulnerable to poor economic conditions because of the rangeland degradation that could not accommodate the livestock population, which is the major source of the economy.

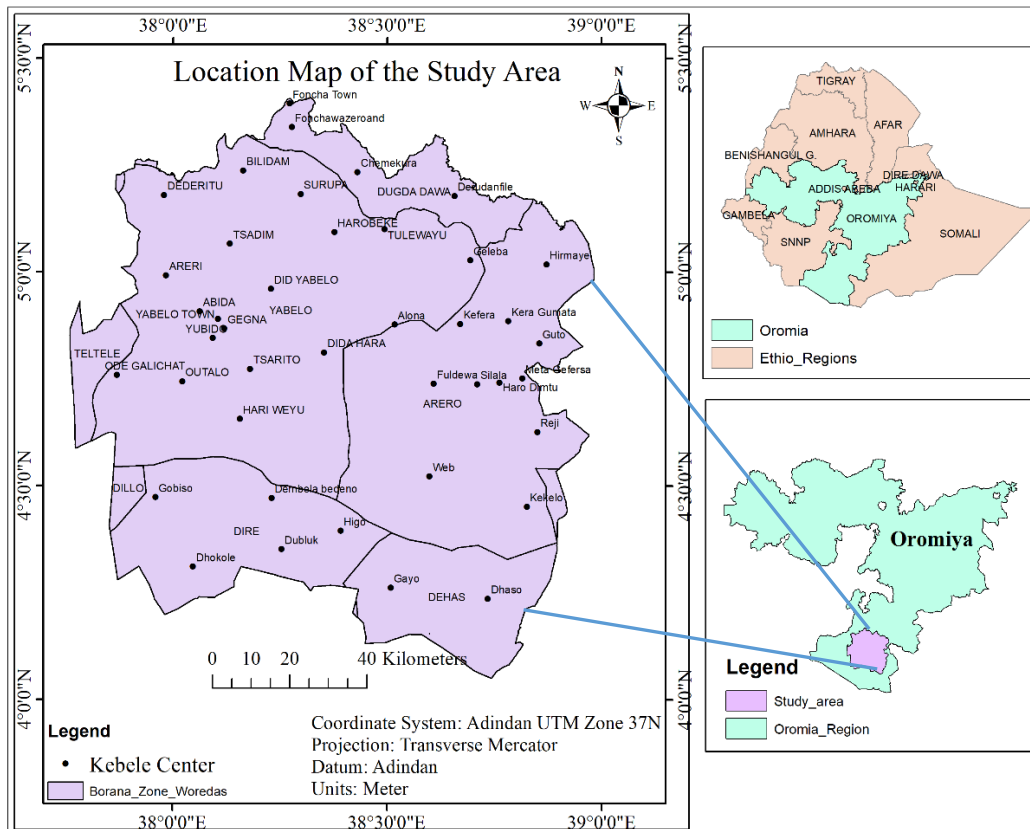


Figure 3. 1 Location of the Study Area

3.1.1. Biophysical Characteristics

These characteristics include the climate, vegetation, soil, and topography. These characteristics are important in the assessment of the rangeland condition of Borana zone. Biophysical characteristics are used as the indicators of the rangeland degradation as well as, highly important in the identification of suitable sites for rangeland rehabilitation.

3.1.1.1. Climate

The climate of the study area is required in this study to investigate whether it supports the growth of palatable vegetation for livestock or not. Through mapping and analyzing the climate, it is possible to see the degradation level of the rangeland. The increase in temperature and a decrease in rainfall amount is the source of drought. Whereas, an increase of rainfall above the required amount is the source of soil erosion due to run-off created by the high rainfall. Abundance of enough rainfall and temperature indicates the suitability of the area for vegetation plantation as well as, for rehabilitation. The climate of arid and semi-arid areas of the Ethiopian lowlands is characterized based on the elevation of the area (Fekadu, 2009). The rainfall in the lowlands is different in different seasons as well as in the range of years (Mengesha, 2020). The rainfall in the study area has an erratic and variable nature and most areas receive different amounts of rainfall. The study area has a semi-annual monsoon-type rainfall where 60% of the main rainfall is expected and obtained during the March to May (Ganna) season (Yeneayehu et al, 2018; Elias et al, 2015). Whereas, short showers of rainfall are received during the season from September to November (Hagaya) when heavy cloud with mist is happening (Sisay et al, 2020).

Yeneayehu et al (2020) classified the climate of the study area as a hot-arid climate characterized by a mean annual temperature ranging from 27°C to 29°C and an annual average rainfall of 450mm barren with little vegetation. The hot semi-arid climate has a temperature of 18°C to 27 °C and annual mean rainfall of 410-820mm characterized by sparse and short edible grass. The tropical rainy climate has a temperature of 18°C and rainfall amounts from 680-2000mm, which is characterized by tall grass mixed with trees. The warm temperature climate has altitudes from 1750-3200 and heavy rainfall and forest are the features of this climate.

According to the data collected from the woredas' meteorological stations obtained from the National Meteorological Institute of Ethiopia, the study area's annual rainfall amount ranges between 443mm in the Eastern part and 917mm in the Northern part. The mean average monthly rainfall ranges between 13mm to 158mm. The average temperature of the study area ranges from a minimum mean monthly 21.74 °C to a maximum mean of 26.02 °C. The study area's high temperature is a phenomenon of dry

and windy seasons (Yeneayehu et al, 2018). Figures (3.2, a) and (3.2, b) below show the mean annual and monthly rainfall and (3.3) mean monthly temperature of the study area respectively.

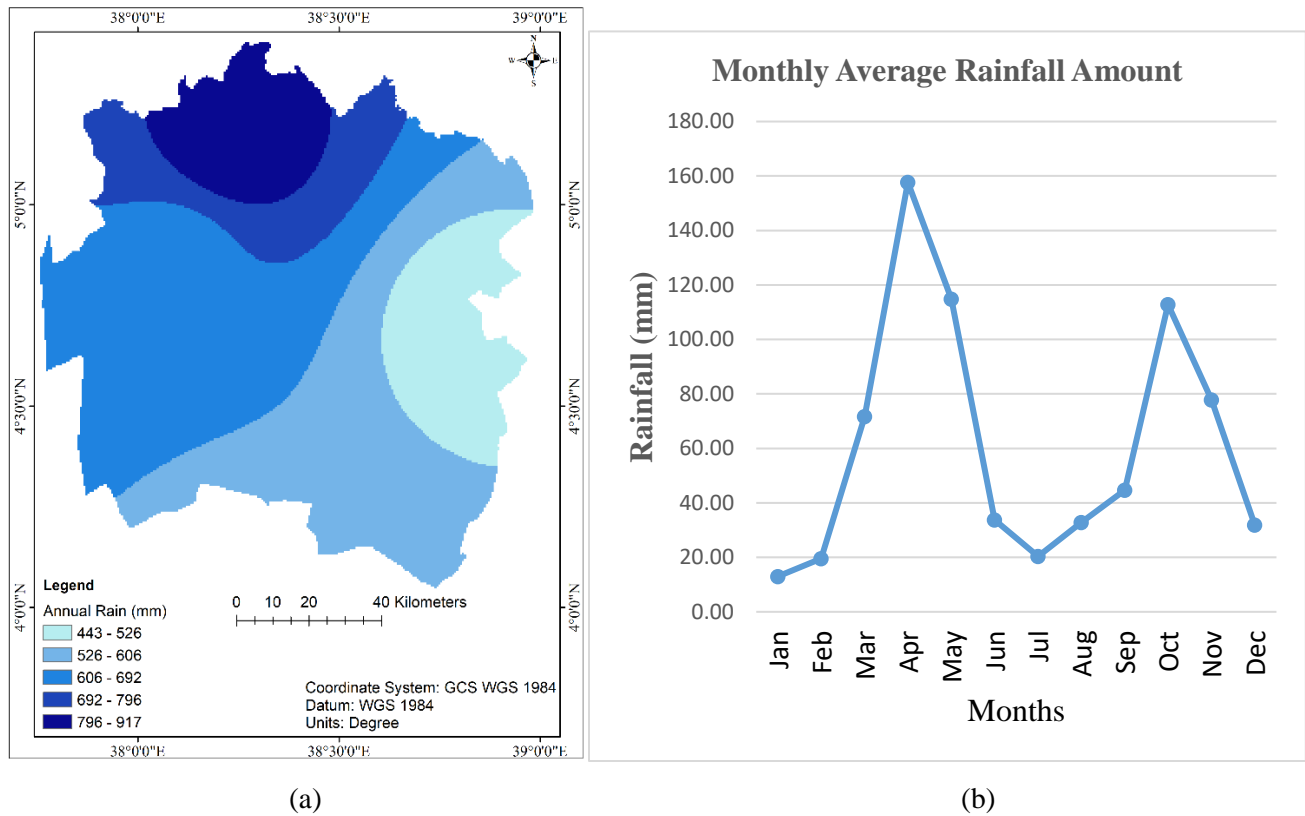


Figure 3. 2 (a) Mean Annual Rainfall; (b) Monthly average Rainfall

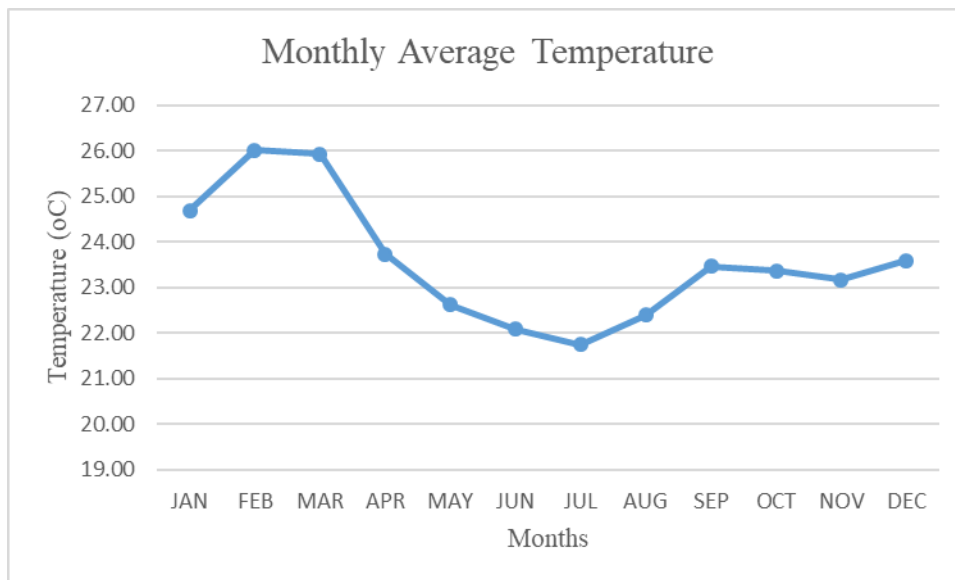


Figure 3. 3 Monthly Average Temperature

3.1.1.2. Topography

Topography gives information about the gradient of the terrain which intern helps to analyse the contribution of topography for erosion and deposition that causes land degradation. Steep slope indicates the existence of high erosion leading to land degradation. It helps to identify less erodible or gentle topography with less erosion for grass reseeding. The altitude of the study area taken from the digital elevation model of 30m resolution ranges from low 873m to high 2,361m (Figure 3.4). Areas in the Northeast, Southeast, and Center-West are considered to be in the low elevation region. Whereas, those areas ranging from South to North are considered to be from medium to high altitude ranges. Mountainous areas, which are occupied with forest cover, are located in the South and Northeastern boundaries of the study area and the Northwestern part.

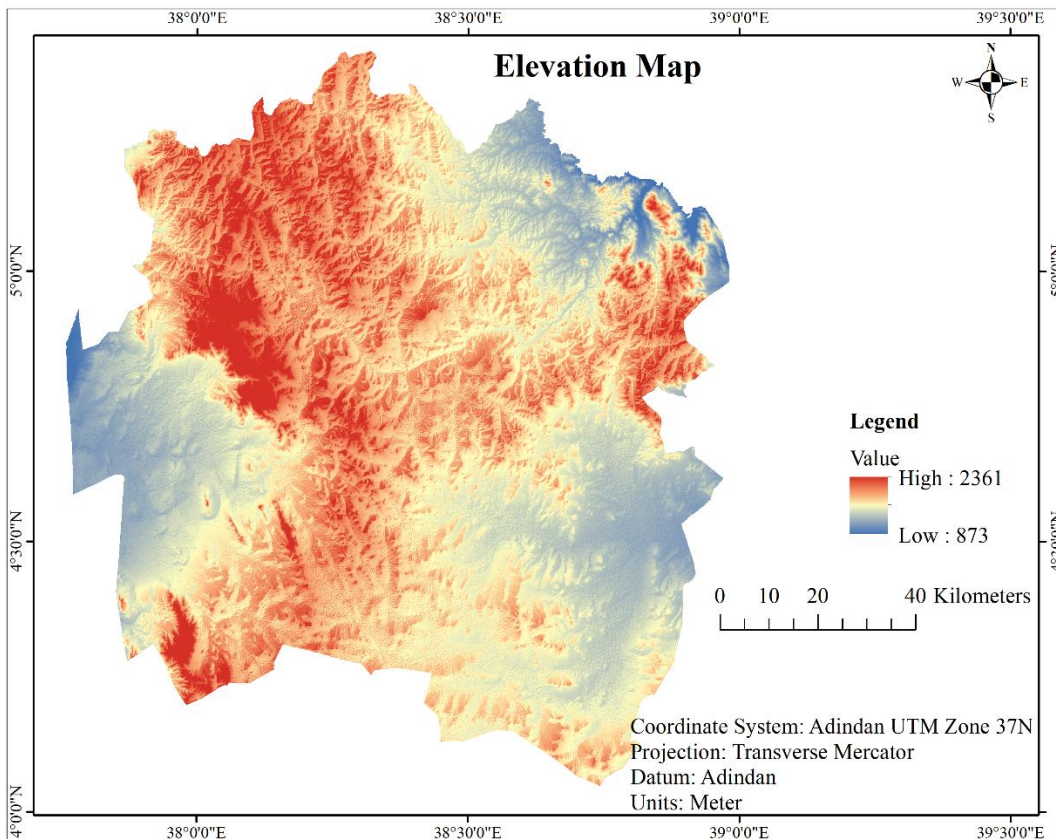


Figure 3. 4 Elevation Map of the Study Area

3.1.1.3. Soil

Soil is one and major biophysical indicator of land degradation expressed in terms of degradation due to erosion, and degradation in terms of chemical properties. Therefore, it is applied as one factor for land degradation assessment as well as suitable site selection based on soil fertility for planting and growing grass species. Depletion of its nutrient contents indicate land is degraded, and its nutrient

abundance indicates suitability for rehabilitation. The soil types in study area according to data from Water and Land Resource Center (WLRC) of Addis Ababa University are Vertic Andosols, Rhodic Nitisols, Pellic Vertisols, Lithic Leptosols, Lithic Leptosols, Haplic Calcisols, Fibric Cambisols, Eutric Fluvisols, Distric Cambisols, Chromic Luvisols, Chromic Cambisols, Calcic Vertisols, Calcic Solonetz, Calcaric Fluvisols and Calcaric Cambisols. Among these fourteen types of soils, some are available to a very low spatial extent (Yeneayehu et al, 2020). According to soil type data from WLRC, chromic Cambisols cover about 41% of the area, 21% Chromic Luvisols, and 11% account for Lithic Leptosols. The three types of soils cover a total area of 73%. The rest 11 types of soils account for a minimum of 0.2% up to a maximum of 8.9% a cumulative of 27% area coverage. The bushland of the Borana Zone has more sand and, less silt and clay than the grassland area (Sintayehu et al 2006). (Figure 3.5) below illustrates the soil types of the study area.

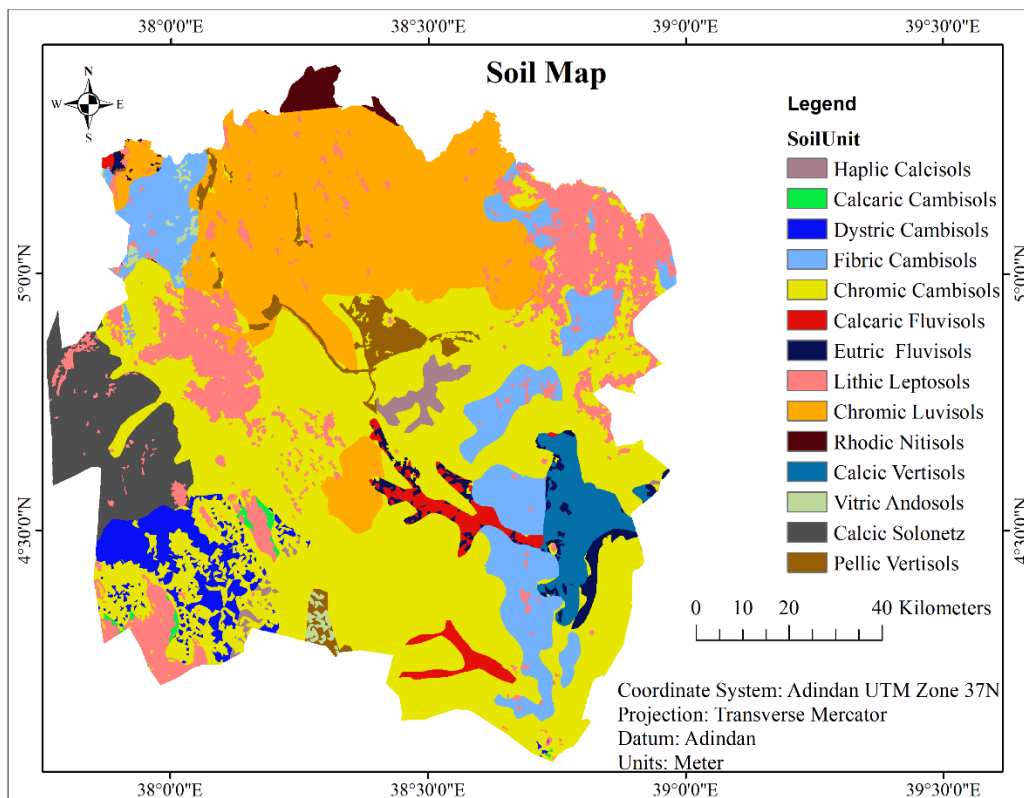


Figure 3. 5 Soil Types of the Study Area

3.1.1.4. Vegetation

The existence of vegetation is the indicator for the availability of pastureland for livestock. The vegetation condition of the study area whether it is dense, sparse or no vegetation indicates the availability or non-existence of palatable feed for livestock. Therefore, assessment of rangeland degradation in this study is dependent on the vegetation condition. According to Yeneayehu et al,

(2020), there are four regions of vegetation in the area. Among these, the first holds mixed deciduous woodland and savanna, Junipers woodland and savanna, and different types of acacia woodland and savanna. The second region is the grassland region with different types of grasses available within woodland and savanna, is located in the lower elevation areas, and covers a larger area of the zone. The third region, which is the steppe region, is located up to 1400 elevation with an average annual rainfall of 500 mm and contains sparse deciduous shrubs and short acacia with small leaves up to 4m in height. The fourth region is the natural and manmade forest, which covers large area. Commiphora, prosopis juliflora and Acacia mellifera, Frankincense, and like are the most abundant types of species in the study area (Mohammed & Omar, 2021). Savanna herbaceous vegetation and grassland as well as evergreen and semi-evergreen bushland and shrubs in its northern part characterize the study area (Yeneayehu et al, 2018). Bushlands and thickets, which cover major parts of the lowlands, are dominated by Acacia and Commiphora species (Gemedo, 2006).

3.1.2. Socio-Economic Characteristics

3.1.2.1. Human and Livestock Population

The study area is composed of different ethnic groups including Borana Oromo, Geri, Somali, Guji Oromo, Amhara, and Konso (Fekadu, 2009). The total population according to CSA (2019) estimate was 143,331. Out of the total population, 50.33% (51,418) were male and 49.67% (50,748) were female. Pastoralists in Borana are herding cattle in large, goats and sheep for their food source as well as camels and donkeys for transport (Fekadu, 2009). The proportion of livestock in the Borana zone is cattle 44.1%, goat 35.7%, camel 3%, sheep 14%, donkey 3% (CSA, 2015/2016). According to CSA estimate, the amount of livestock in number and its contribution by type to the total livestock in the Borana zone is cattle 1,081,553, Goats 876,139, Sheep 343,674, Camel 75,622, Donkey 73,762, Mule 2,102 and Horse 874.

3.1.2.2. Farming System and Livelihood

Extensive livestock production predominantly cattle, sheep, goats, camels, and donkeys but also produce some crops is the livelihood of the Borana mainly depends on (Solomon et al, 2011; Fekadu, 2009). The beginning of crop production to fill the gap in food sources forced them to Change their lifestyle from pastoralists to agro-pastoralists and continue to grow crops in some areas. Crops help pastoralists to escape selling their livestock to buy food, especially during drought season (Tilahun et al (2017). Besides, crop residuals from Maize and Teff are palatable and used for livestock feed. Accordingly, pastoralists in Borana continue to produce some crops like maize, beans, and wheat

(Solomon et al, 2011). Because of this, the Borana pastoralists are turning the rangeland from pasture to agriculture in a continuing manner (Tilahun et al 2017). Though the Borana rangeland is suitable for livestock rearing, there is poor management of agricultural and rangeland resources (Solomon et al (2011). To maintain the productivity of rangelands and fulfill feed requirements, pastoralists mobilize in two forms to the area where enough resource (pasture and water) is available in the form of temporary regular mobility (“Godaanssa Fooraa), and (“Godaanssa Warraguda”) permanently during drought and conflicts (Lasage et al, 2010).

3.2 Data Collection

3.2.1. Satellite Data

The acquisition of relevant, quality descriptive geographic data is the most important input for the successful completion of this study. Spatial and non-spatial as well as primary and secondary data are required. Spatial data from organizations that are engaged in producing fundamental and thematic datasets as well as, from different websites were collected. Whereas, associated non-spatial data such as population data that could substantiate the spatial data were collected from CSA. For this study, satellite-based datasets like cloud-free Landsat 7 ETM+ of the year 2002 and 2012 as well as, Landsat 8 OLI image of the year 2021 were downloaded for LULC classification as well as to utilize it for periodic vegetation analysis using NDVI of 2002, 2012, and 2021. SRTM DEM data of 30m spatial resolution downloaded from open source and used to drive slope and aspect of the area for soil erosion and deposition analysis as well as, site suitability analysis. Besides, google earth data was also used for classification accuracy assessment.

3.2.2. Soil Data

Soil datasets were used for the analysis and mapping of soil acidity and its susceptibility to erosion. Consequently, it is used to weigh and identify the type of soil suitable for grass germination and growth. Hence then, it is included in the Multi-Criteria Analysis process for grass reseeding site selection. This soil data in spatial and tabular form with its physical and chemical properties were collected from the Ministry of Agriculture (MoA) and WLRC of Addis Ababa University.

3.2.3. Climate Data

The climate data from rainfall stations of Yabelo, Mega, Moyale, Teltele, and Hageremariam stations is collected from the National Meteorological Institute of Ethiopia. Accordingly, monthly and annual temperature and rainfall data for 20 years were collected and applied for analysis.

3.2.4. Ground Truth Data

Data about vegetation types and crop coverage was collected using GPS and attribute information in a descriptive form and used for training the software during image classification accuracy assessment after classification as well as for the erosion and deposition susceptibility analysis. Therefore, Sample positional and descriptive data of each land use/land cover type was collected and documented.

Table 3. 1: Data Summary

Serial No.	Name	Data type		Source	Resolution	
		Primary	Secondary		Spatial	Temporal
1	LS 7ETM+		>>	USGS https://www.earthexplorer.usgs.gov/	30m	2002 & 2012
2	LS 8 OLI		>>	https://earthexplorer.usgs.gov/	30m	2021
3	SRTM DEM		>>	https://www.portal.opentopography.org/	30m	
4	Soil		>>	MoA & WLRC	Point data	
5	Climate data		>>	Meteorological institute of Ethiopia	Point data	20 years
6	Ground truth data	>>		Field survey	>>	2021

3.3 Software and Materials

For satellite image processing, classification, and NDVI analysis, ERDAS IMAGINE 2015 V15.1 and QGIS software packages were used. Whereas, for rangeland degradation and land suitability analysis using the Multi-Criteria decision analysis (MCDA) method and for mapping purposes, Arc GIS 10.8 software was employed. EasyAHP application was used for weighting the criteria of rangeland degradation and site suitability analysis. Microsoft Office and Visio packages had been utilized for the preparation of reports and workflow design. Hand-held GPS was also used for sample field Ground Control Points data collection.

3.4 Methods of Data Analysis

Materials like Input data and processing software identification and collection is the most important component in the processing and mapping of vegetation dynamics, soil properties, erosion and deposition susceptibility assessment, and overall rangeland degradation analysis as well as the selection

of a suitable site. Consequently, relevant and time series satellite images, digital elevation models, climatic, and soil data types were collected from different sources and utilized. Image Classification, vegetation analysis, soil property analysis, erosion and deposition analysis, and site suitability analysis were conducted using acquired software packages. Within this process, different tools and procedures like supervised image classification, NDVI analysis to see the vegetation change, MCDA using AHP for weighting the criteria of rangeland degradation as well as suitable site selection. The use of the spatial analysis tool in the ArcGIS environment was tremendous to Create various types of intermediate and final results. Finally, the results of the analysis were interpreted and discussed. The below diagram shows the data analysis process flow.

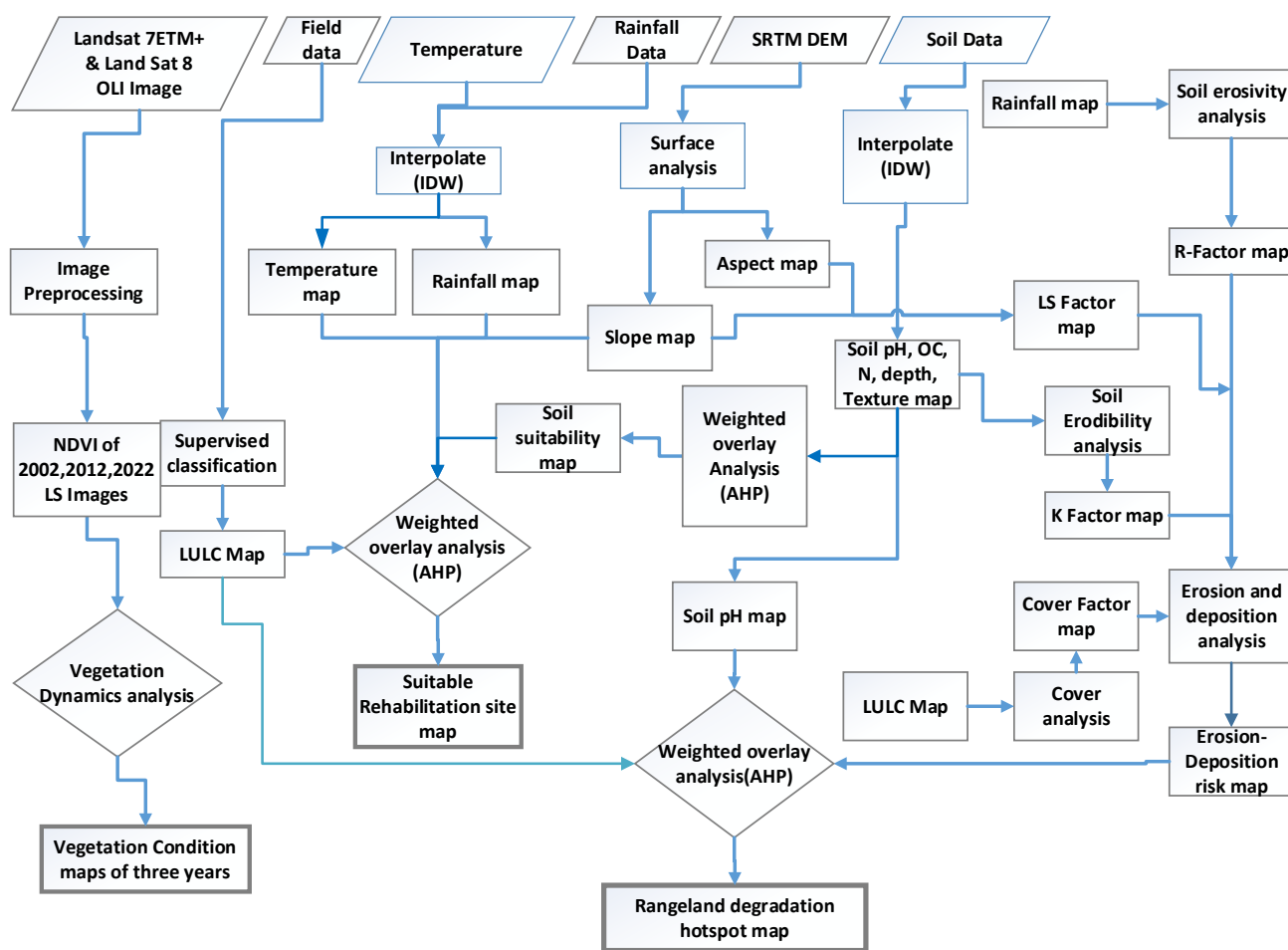


Figure 3. 6 Data Analysis Work flow Diagram

3.4.1. Vegetation Degradation

3.4.1.1. Digital Image Preprocessing

Image preprocessing involves the improvement of a distorted or noisy view of an image to better quality to apply further manipulations to the image (Lillesand, et al, 2015). Lillesand et al, (2015) also stated that image enhancement is an important image-preprocessing step that could help to boost visual identification of features and to extract more information from the image. Accordingly, raw satellite images that have poor feature identification capabilities due to Clouds and haze, poor brightness, and spatial and spectral limitations have been corrected for atmospheric effects using the SCP plugin preprocessing tool of the QGIS software. Landsat 7 ETM+ satellite images had scan line errors that created a gap or stripes caused by the incorrect functioning of the sensor. These gaps of scan line errors had been corrected and filled using the raster analysis “fill No data” tool of QGIS software. A histogram equalization technique was applied to improve the brightness of the images. Moreover, for the betterment of visual interpretation of features, pan-sharpening was done to improve the spatial resolution of the images using the 15m panchromatic images of both satellite sensors with the 30m Multispectral images. This enables the improvement of the spatial resolution of a 30m image to 15m spatial resolution that increases the distinguishable nature of each feature of classes better than the original low spatial resolution images.

As the satellite images are downloaded in the form of single bands, it is necessary to pile appropriate bands to Create one composite image from the individual bands. Such piling was done using the layer stack tool on the ERDAS IMAGINE software. Since the study area is covered by more than a single scene of Landsat images, two scenes of images were combined and a mosaic of the entire area was created. Moreover, the sub-setting of the mosaic images to fit it with the study area has been done using the study area boundary layer to make it ready for classification and various analysis activities in this study.

3.4.1.2. Vegetation Analysis Using NDVI

NDVI is one of the most commonly used indices applied for vegetation analysis (Lillesand et al, 2015; Faramarzi et al, 2018). NDVI is highly recommended to identify the nature and status of vegetation in an area. It is helpful to make a classification of land cover features using NDVI (Gandhi et al, 2015). Lillesand et al (2015) added that while there is high reflectance in the near-infrared (NIR) and low reflectance in the red Bands, it signifies the identification of healthy green vegetation, lower values indicate non-vegetated areas.

As mentioned in the image processing section of this study, satellite images of Landsat 8 OLI imagery were processed for radiometric, spectral, and spatial resolution corrections. For the Normalized Difference Vegetation Index (NDVI) analysis, three-year images at 10-year interval were downloaded. Satellite images for the years 2002 and 2012 of Landsat 7 ETM+ and Landsat 8 OLI image of the year 2021 were applied. Both Landsat 7 ETM+ as well as Landsat 8 OLI sensors have Near Infrared (NIR) and Red Bands appropriate for Vegetation analysis. In this analysis, Band 4 (NIR) and Band 3 (Red) of the Landsat 7 ETM+ and Band 5 (NIR) and Band 4 (Red) of Landsat 8 OLI images are used for generating NDVI maps of the three periods. NDVI is computed using the ratio of the NIR and Red bands of each image and provides values ranging between -1 and +1 (Mehta et al, 2021). Mehta et al stated that values between 0 and 1 represent vegetation density from sparsely vegetated to densely vegetated; whereas, values less than 0 represent non-vegetated areas like water, bare soils, rock, and sand. NDVI through categorizing the pixel values is applied to Classify an area of interest to its land use and land cover types (Sreelekha & Reddy, 2019). In this study, satellite images of the three years that are preprocessed are used to Compute the NDVI based on the equation:

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

Where, NIR = the near infrared reflectance in the Landsat 8 OLI of *Band 5* and Landsat 7 ETM + of *Band 4* and;

RED= is the red reflectance in the Landsat 8 OLI of band 4 and Landsat 7 ETM + of band 3

ERDAS IMAGINE and ArcGIS software were applied to generate and classify the values based on the thresholds. NDVI Values that have negative reflectance are water bodies; very low values lower than 0.1 are categorized as bare soil, snow, sand, and rock; Moderate values from 0.2-0.3 represent bushes/shrubs and grass; whereas, values from 0.6-0.8 are categorized as temperate and tropical rainforests (Ghandi et al, 2015). Mehta et al., (2021) in other words classified NDVI index values as water, barren land, sparse vegetation, moderate vegetation, and dense vegetation. Index values of both Mehta et al. (2021) and Ghandi et al, (2015) were useful for this study to describe the vegetation condition in terms of type and density of vegetation. There for, the NDVI-based assessment is conducted to see the vegetation change in terms of type and density and hence, Mehta et al (2021) index

values adapted from different researchers were more use full to Classify the vegetation condition and applied.

Table 3. 2: NDVI Index values adopted from Mehta et al, (2021)

No	Index value ranges	Vegetation type
1	< -0.046	Water
2	-0.046 – 0.25	Barren Land
3	0.25 – 0.35	Sparse Vegetation
4	0.35 – 0.50	Moderate Vegetation
5	0.50 - 1	Dense Vegetation

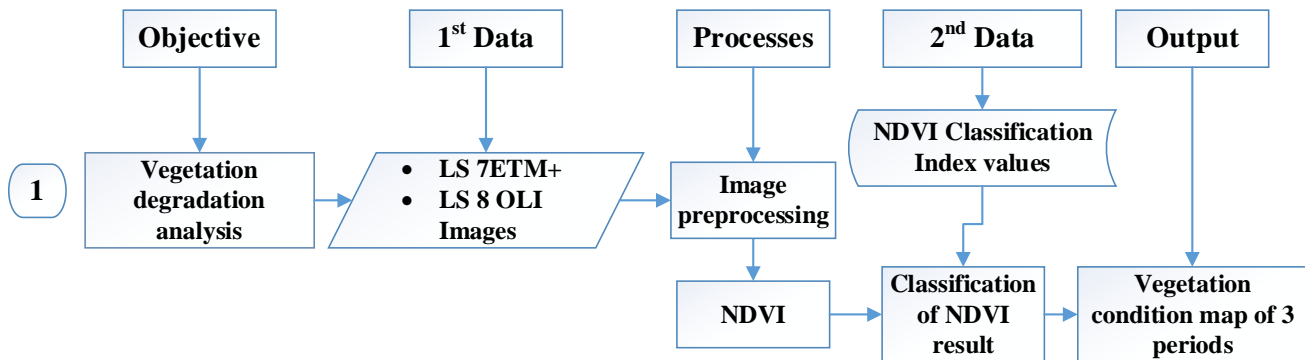


Figure 3. 7: Image Preprocessing Workflow

3.4.1.3. Image Classification

Image classification is the grouping of image pixels into land cover classes based on their similarity in reflectance value to specific land features (Lillesand, et al, 2015). Classification brings pixels with similar reflectance values to one and creates thematic classes of real-world objects. This thematic map of LULC is used as input for other types of geospatial analysis activities. Of the two major classification methods, unsupervised classification was done before the field visit operation to use it as a guide for field data collection. Whereas, supervised classification was conducted in ERDAS IMAGINE 2015 software using the Maximum likelihood classification algorithm. This algorithm is applied most commonly since it recognizes unique classes and reduces human errors (Michael et al, 2015). To supervise the computer, the user has to know the area to decide on the training sites. The user does classification based on the knowledge of the area through training of the computer using ground control points collected from the study area. Accordingly, the Landsat 8 OLI image of the year 2021 was classified by applying classification techniques and a LULC thematic map was produced. This map

will be used as an input for cover factor analysis in the identification of soil erosion susceptible areas as well as suitable site analysis for grass rehabilitation in the study area. In such a way, the Landsat 8 OLI image is classified in to eight classes namely: Bare Land, Bush Land, and Settlement area, Crop Land, Farm Land, Forest, Mixed Grassland, and Water body.

Table 3. 3: Land use/Land Cover Types description based on LCCS (2014) & Anderson et al (1976)

LULC Class	Description
Bare Land	Land that is poor ability to grow vegetation and area that do not have artificial cover as well as, has vegetation less than 1/3 of the total area
Bush Land	Refers to Land composed of open to Closed Bush 3 to 5m tall mainly Acacia mellifera (thorny Acacia species) plants which are not palatable by livestock
Settlement	Built-up areas, Other populated areas, Villages ,Open quarry mine areas and Landing Facilities
Rangeland	Rangeland historically has been defined as land where the potential natural vegetation is predominantly grasses, grass like plants, forbs, or shrubs
Crop Land	Refers to areas where the natural vegetation has been removed or modified and replaced by other types of vegetative cover like crops planted or cultivated with an intent to harvest
Farm Land	Tilled area not covered by seasonal and perennial crops and is planned to be sowed for the purpose of grain production
Forest	A land cover by tree vegetation and have a minimum of 0.5 hectares with trees higher than 5 meters and a canopy cover of more than 10 percent; or with a combined cover of shrubs, bushes, and trees above 10 percent (FAO,2018)
Mixed Grassland	Land cover is dominated by grass and herbs with scattered long trees and shrubs, forbs species, or herbal vegetation one-third of intermixture
Waterbody	Refers to land occupied by water such as Streams and Canals, Lakes, Reservoirs, Bays, and Estuaries
Shrub land	The class is composed of the main layer of natural shrubs with a cover from 10 to 100 % but characterized by less than 5m height of trees

3.4.1.4. Accuracy Assessment of LULC Classification

Land use and land cover map produced from satellite images obviously will have some sort of accuracy problems due to their nature of complexity and different reasons. The accuracy is dependent on the quality and suitability of images to identify the features, knowledge, and skill of the user, techniques applied to Classify images, and so on. There for, assessment of the classified image’s accuracy concerning the real situation is crucial. For the accuracy assessment, some of the data collected from the field were used to Compare and check the class values with reference values. Most commonly, a

classification error matrix (confusion matrix) or contingency table was used to check the accuracy of the classification result. The overall accuracy, user's accuracy, producer's accuracy, and kappa coefficient of a satellite image classification results is computed using the following formulas (Lillesand et al, 2015; Congalton, 1991).

$$\text{Overall accuracy} = \frac{\text{Total No.of pixels correctly classified}}{\text{Total No.of Pixels}} \times 100 \quad (2)$$

$$\text{producer's accuracy} = \frac{\text{No.of pixels correctly classified}}{\text{No. of test set pixels (column total)}} \times 100 \quad (3)$$

$$\text{User's accuracy} = \frac{\text{No.of correctly classified}}{\text{No.of test set pixels (row total)}} \times 100 \quad (4)$$

$$\text{Computation of kappa coefficient (k)} = \frac{N \sum_{i=1}^r x_{ii} - \sum_{i=1}^r (x_{i+} \cdot x_{+i})}{N^2 - \sum_{i=1}^r (x_{i+} \cdot x_{+i})} \quad (5)$$

The following workflow diagram depicts the process of LULC classification

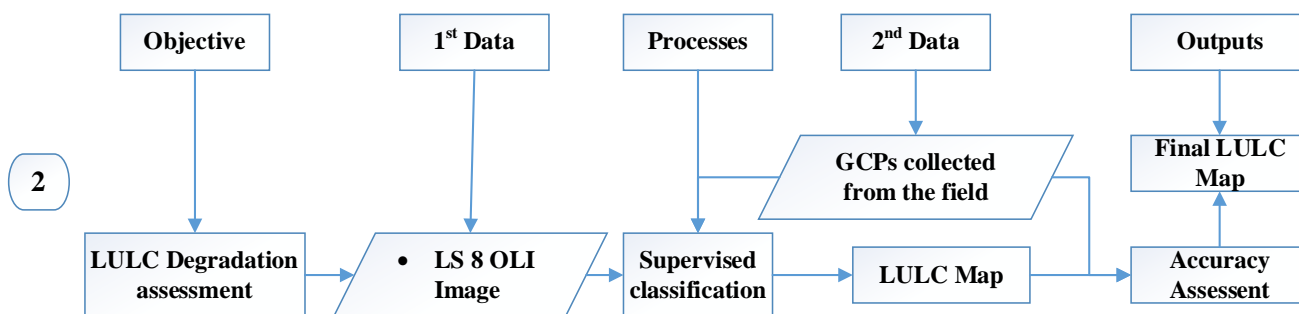


Figure 3. 8: Summary workflow diagram of LULC Classification

3.4.2. Soil quality assessment

Soil chemical quality based on acidity and alkalinity analysis is important to indicate the different chemical activities taking place within the soil (Mohammed & Omar, 2021). The soil pH data was used as input in the rangeland degradation analysis since it is one of the indicators of rangeland degradation together with LULC degradation and soil erosion. The acidity and/or alkalinity of the study area was mapped using 167 soil point data collected from MoA. Before classifying the soil to acidity and alkalinity, the soil point data was imported and converted to a shape file in Arc GIS software. Point based soil pH data was prepared and obtained as shape

file data and converted to a surface raster map through applying interpolation method using the IDW tool in the spatial analysis tools package. Eventually, the acidity and alkalinity map of the area was created based on the United States Department of Agriculture (USDA, 1998) Natural Resources Conservation Service classifications standard (Table 3.5). Based on (USDA, 1998) standard, the pH level of the study area was classified into five categories from very strongly to strongly acidic up to strongly alkaline.

Table 3. 4 Soil pH Standard adopted from USDA (1998)

Soil pH range	pH class level
4.5 – 5.5	Very strongly to strongly acidic
5.5 – 6.5	Moderately to slightly acidic
6.5 – 7.3	Neutral
7.3 – 8.5	Slightly to moderately alkaline
8.5 – 14.0	Strongly alkaline

The following graph shows the workflow diagram of soil quality (soil pH level) analysis.

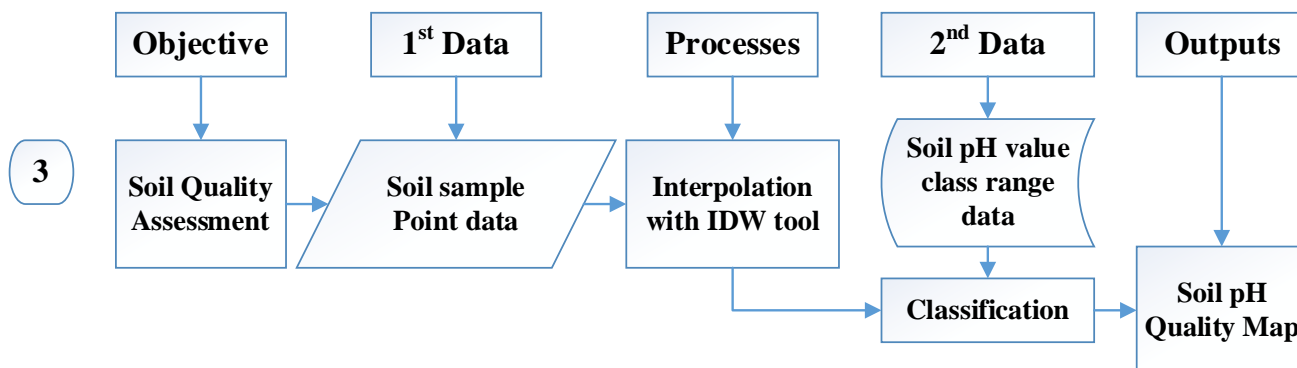


Figure 3. 9: Summary of Soil Quality Assessment Workflow

3.4.3. Soil Degradation Assessment due to Erosion and Deposition

Soil erosion quantity in tons per hectare per year in an area was computed universally by using USLE/RUSLE models (Wischmeier and Smith, 1978). These models do not predict sediment deposition, and hence, when there is a need to determine the susceptibility of both soil erosion and sediment deposition, the USPED model is applied (Warren et al, 2019). In this study, Soil erosion susceptibility in the USPED model is computed by analysing different soil erosion factors that are derived from the traditional USLE/RUSLE models. Annual Soil Loss (ASL) in terms of soil loss extent due to erosion is computed using USLE/RUSLE models by a formula (Wischmeier and Smith, 1978):

$$ASL = R K C P L S \quad (6)$$

Where: ‘R’ is the rainfall erosivity factor indicating the capacity of rainfall to erode the soil (R-Factor). ‘K’ is soil erodibility factor that shows the compaction level of the soil to be susceptible to erosion easily by rain (K-factor). C is the vegetation cover factor that restricts the detachment of the soil due to rainfall intensity (C-factor), and P is the management practice factor (P-factor). The USPED model, which is a modified USLE/RUSLE formula without additional experiments applied to analyse Erosion susceptibility to estimate net erosion and deposition relatively (Pistocchi et al, 2002; Mitsova & Mitsova, 1999; Liu et al, 2007):

$$TP = KcA^m (\sin b)^n \quad (7)$$

Where:

TP= is the transport capacity index

K= is the soil erodibility factor (K-Factor)

C= is cover factor (C_Factor) due to vegetation

A= the drained area (flow accumulation)

Sin b= is the slope angle; and m & n are coefficients of sheet and rill erosion respectively

The major difference between the USLE/RUSLE and USPED is to substitute and compute the topographic factor (LS) using the flow accumulation than the slope length in the former. The rainfall factor is considered in the erosion and deposition in the area where sheet and rill erosion is occurring even if there is an assumption that the erosion and deposition in the USPED model is constant (Pistocchi et al, 2002). The management factor ‘P’ is the practice of erosion reduction by using contour farming, strip-cropping, and terrace methods (Wischmeier and Smith 1978). The management factor ‘P’ is irrelevant and will have a value of one (1) as this factor is not considered in this model (Warren et al, 2019). USPED computes the availability of stream capacity to transport and deposit rather than estimating the actual amount of sediment in the area. The erosion type in the study area is observed to be more of a sheet and in some areas of the higher slope is a rill type of erosion hence the coefficients of m & n are assigned to a value of one (1). The transport capacity (∇T) divergence was computed with horizontal coordinates in addition to transport capacity (TP) index using a formula (Pistocchi et al, 2002; Warren et al, 2019):

$$\nabla T = d(TP \cos a)/dx + d(TP \sin a)/dy \quad (8)$$

Where: ‘a’ is the aspect angle of the landscape

3.4.3.1. Rainfall Factor (R-Factor) Analysis

To determine the sheet and rill erosion process, the rainfall erosivity factor (R-factor) is applied as one of the inputs for the soil erosion and deposition estimation. Rills and sediment deposits are connected with substantial storms, are a function of the highest intensities, and must include cumulative reasonable storms to determine annual soil loss (Wischmeier and Smith, 1978). Wischmeier and Smith added that the kinetic energy of rainfall is the source of rainfall erosivity, which in turn is quantified from the mean annual rainfall and 30 min rainfall intensity value. Rainfall erosivity is computed from the mean annual rainfall of the five stations of the study area using the following formula (Morgan, 1995).

$$\mathbf{R = EI30/1,000} \quad \mathbf{(9)}$$

Where, R rainfall Erosivity factor, in metric units; E is rainfall kinetic energy in Jm^{-3} and I30 is 30-minute rainfall intensity in mm/h. However, rainfall kinetic energy and 30 min intensity data were not available from the stations of the study area. Therefore, the erosivity factor (R) that was adjusted by Hurni (1985) to Ethiopia was used in computing the erosion and deposition susceptibility of an area. Accordingly, the average R factor was obtained from the mean annual rainfall of the five stations for the study area using the below equation (Hurni, 1985).

$$\mathbf{R = 0.55 * P - 4.7} \quad \mathbf{(10)}$$

Where 'P' is the mean annual rainfall in mm.

3.4.3.2. Soil Erodibility (K-Factor) Analysis

Soil erodibility is the rate of soil loss per erosion index per unit area (Wischmeier and Smith, 1978). It is the difference in the characteristics of some soil types to erode more easily than others due to the properties of those soils are even if all other factors are the same (Neitsch et al, 2000). Soil erodibility factor (K-factor) is the tendency of soil for erosion due to the nature and properties of the soil types in the area under investigation (Tsegaye, 2007). The K-Factor map of the study area as one major component of erosion and deposition analysis was computed using soil types and soil texture of the study area. Nine major soil types represent the soil data of Borana rangeland namely: Calcisols, Cambisols, Fluvisols, Leptosols, Luvisols, Nitisols, Vertisols, Andosols and Solonetz. These major soil types of the study area are subdivided into fourteen sub-soil types used for erodibility analysis.

According to Neitsch et al, (2000), the soil erodibility factor is computed based on the calculation of the percent composition of sand, silt, clay, and organic carbon of the topsoil as the topsoil the most

susceptible layer of the earth for erosion and deposition. Soil erodibility equations applied by (Neitsch et al, 2000) were used for this study and are stated below.

$$\mathbf{K} = f_{csand} \cdot f_{cl-si} \cdot f_{orgc} \cdot f_{hisand} \quad (11)$$

Where f_{csand} is a factor of low soil erodibility for coarse sandy soils, f_{cl-si} is a factor of low erodibility for high clay to silt ratio soils, f_{orgc} is low soil erodibility for high organic carbon content and f_{hisand} is a factor that minimizes erodibility for highest sand content soils. Each of the factors is computed as follows:

$$f_{csand} = (0.2 + 0.3 * \exp([-0.256 * m_s * (1 - \frac{m_{silt}}{100})]) \quad (12)$$

$$f_{cl-si} = (\frac{m_{silt}}{m_c + m_{silt}})^{0.3} \quad (13)$$

$$f_{orgc} = (1 - \frac{0.25 * orgC}{orgC + \exp[3.27 - 2.95 * orgC]}) \quad (14)$$

$$f_{hisand} = (1 - \frac{0.7 * (1 - \frac{ms}{100})}{(1 - \frac{ms}{100}) + \exp[-5.51 + 22.9 * (1 - \frac{ms}{100})]}) \quad (15)$$

Where m_s is the content in percent of 0.05-2.00 mm diameter sand, m_{silt} is the content in percent of 0.002-0.05 mm diameter silt, m_c is the content in percent of 0.002 mm diameter clay, and $orgC$ is the organic carbon content in percent of the layers.

The soil type layer of the study area was created from the soil type dataset available. The raster soil layer generated using the IDW method was converted to a polygon vector for the suitability of creating a soil erodibility factor map. Using the raster calculator of Arc Map 10.8, the percent composition of sand, silt, clay, and organic carbon was computed. The soil erodibility factor of the area was computed by multiplying the results of percentage compositions of sand, silt, clay, and organic carbon obtained from the computation of equations. Finally, the vector format K-Factor map was converted to a raster layer with a grid cell resolution of 30m using polygon to raster conversion tool from the spatial analyst tools to make it friendly with the other factors to compute erosion and deposition.

3.4.3.3. Cover Factor (C-Factor) Analysis

In the USLE/RUSLE soil erosion analysis equation, the Cover factor (C-Factor) is the ratio of soil loss from cropland in specified conditions to the corresponding loss from clean-tilled continuous fallow (Wischmeier and Smith, 1978). C-Factor ranges from 0 (reaching to Conservation systems) to 1 (non-conservation systems) based on erosivity and erodibility and measures the cumulative effect of the interrelated cover and management variables (Oliveira et al, 2022). According to Wischmeier and Smith (1978), areas with better coverage of crops or any other vegetation have lesser soil erosion

amount as compared to areas, which are bare or fallow for a certain period. Hurni (1985), indicated that a completely deforested except with the availability of eucalyptus trees and cultivated agricultural land have severe soil erosion damages.

In this study, LULC map of the study area was prepared from Landsat 8 OLI satellite image through a supervised image classification technique using ERDAS IMAGINE V.2015 software. Training the computer using ground truth data during supervised classification and for the assessment of the accuracy of the result. Major land use and land cover types of the Zone were identified through the observation of the area at the time of the field data collection period. Among those land use land cover types are crops of different types (Corn, Wheat, Sorghum, Teff, Barley), both natural and planted forest, bush (mainly *Acacia mellifera*), ranges of shrub types, grassland, acacia woodland, barren soil resulted from overgrazing, and dam water reservoir were identified. Classified land use and land cover thematic map of the recent year was used as input to Create a cover management (C- factor) map. Using the land use land cover map of the area, an equivalent Cover (C) value is assigned (Table 3.9 below) to each land use and land cover type of the rangeland. The soil erosion and deposition analysis in the USPED model, the final polygon C- factor map generated and converted to raster format with a resolution (cell size) of 30m is used.

Table 3. 5: C – Factor Values

No	Land Cover type	C-Factor Value
1	Bare soil	1 (Hurni,1985)
2	Settlement	0.05 (Birhan and Assefa,2017)
3	Bush	0.04 (Wischmeier and Smith,1978)
4	Crop	0.25 (Hurni,1985)
5	Water	0 (Chen et al,2019)
6	Forest	0.005 (Hurni,1985)
7	Grassland	0.05 (Hurni,1985)
8	Farm	0.60 (Hurni,1985)

3.4.3.4. Topographic Factor (LS-Factor) Analysis

The topographic factor in the USPED model indicates the effect of topography and is described within the interface between the slope (sediment transport capacity) and the aspect (flow direction) (Oliveira et al, 2022). Oliveira et al (2022) added that the flow accumulation (contribution area) which characterizes the flow of water at a defined location or grid cell is also used to Calculate the topographic factor together with slope and aspect. In this study, topographic factor was computed starting from the

generation of slope map using the slope function in the spatial analysis tools of Arc GIS environment, creating aspect map (direction of flow, direction of gradient vector) using the Aspect function, computation of the flow accumulation map and finally, computation of topographic component (LS-factor) of sediment transport capacity. The Shuttle Radar Topographic Mission (SRTM DEM) of 30m Grid resolution filled with the gaps is used as input to generate the flow direction. Similarly, the flow direction is applied to Create flow accumulation. Raster calculator of map algebra tool in the spatial analysis tools was used to Compute the topographic component of USPED-based erosion-deposition analysis using the below equation applied by Warren et al, 2019; Oliveira et al, 2022).

$$LS = A^m (\sin b)^n \quad (16)$$

Where A is the upslope contributing area per unit width, b is the slope angle, and m and n are constants that depend on the type of flow and the soil properties.

3.4.3.5. Overall Erosion-Deposition Analysis

Analysis of erosion and deposition was conducted using the factors affecting erosion and deposition of the study area. In the USPED model analysis, raster calculator, hydrology, and surface analysis tools were used intensively to generate each erosion and deposition factor's output. To generate the topographic component, sediment flows sediment flow in 'x' and 'y' direction, change in sediment flow and final net erosion and deposition computation were applied using ArcGIS steps that were provided online by Mitasova et al (2014).

Soil erodibility factor (K-Factor) map, Cover factor (C-Factor) map, rainfall erosivity factor calculated using the R factor equation) and the topographic factor of the study area was derived and used as input to generate the overall erosion and deposition map of the area. Sediment flow analysis was computed from the topographic factor, the rainfall, soil and land cover factors. Moreover, the divergence of sediment flow in the horizontal x and y directions was also analysed using the raster calculator tool in the spatial analysis tools. The changes of sediment flow in the x and y directions were computed using the slope and aspect generated from the sediment flow in the x-direction and y-direction. Finally, the relative net erosion deposition was computed using raster maps and summing up the sediment flow changes in the 'x' and 'y' directions. The result in raster map format displays categorized erosion and deposition values in negative and positive values. This shows negative values for erosion and positive values for deposition. The net erosion deposition is estimated using the equation below (Mitasova & Mitas, 1999).

$$ED = \text{div} (T \cdot s) = d(T \cdot \cos a)/dx + d(T \cdot \sin a)/dy \quad (17)$$

Where ‘s’ is a unit vector in the flow direction, ‘a’ (deg) is the aspect of the terrain surface, ‘dx’ and ‘dy’ are sediment flow changes (divergence) in the x and y directions.

Warren and Ruzycki (2022), through modification from their previous ranking method, rated and categorized erosion-deposition in to six categories as high erosion, moderate erosion, low erosion, low deposition, moderate deposition, and high deposition. Besides, Oliveira et al. (2022) added a stable category between erosion and deposition to indicate areas that have no or negligible erosion and deposition. The result of erosion-deposition in this study is categorized from high to low erosion and deposition categories using the above categorization.

Table 3. 6 Erosion-Deposition values adapted from Warren & Ruzycki, (2022); Oliveira et al., (2022)

Range (ton/ac/yr.)	Range (ton/ha/yr.)	Rank
<-10	< -24.7	High erosion
-10 - -5	-24.7 - -12.35	Moderate erosion
-4.99 – -0.1	-12.34 – -0.22	Low erosion
-0.09 – 0.1	-0.21 – 0.25	Stable
0.1 – 5.0	0.26 -12.35	Low deposition
5.01 – 10	12.36 – 24.7	Moderate deposition
>10	> 24.7	High deposition

The following figure depicts the workflow of the USPED analysis model to show soil degradation due to erosion - deposition.

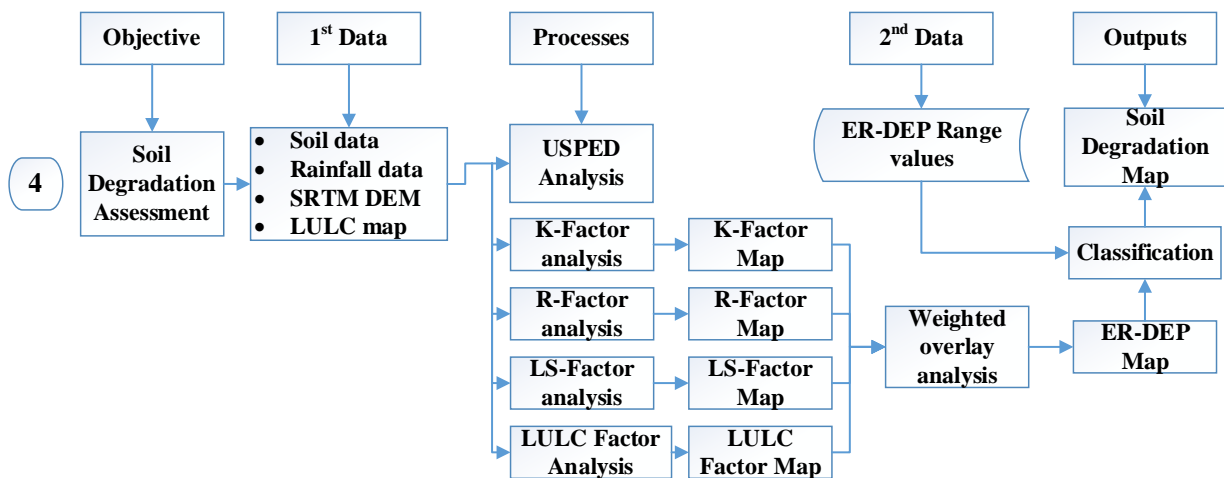


Figure 3. 10: Summary workflow Diagram of Soil Degradation Assessment

3.4.4. Rangeland Degradation Assessment

The study area was assessed for its rangeland degradation by the integration of three major degradation factors discussed in detail above. The integrated factors are LULC degradation data, soil chemical, and physical degradation data of the area, as well as, the multi-temporal vegetation data for vegetation degradation analysis. The sheet and rill erosion by the USPED model has sub-factors that determine the rate of erosion and deposition of the area. These sub-factors include soil erodibility factor, rainfall erosivity factor, topographic factor, and cover factor. Soil chemical properties was assessed for the acidity and the alkalinity (soil pH) of the rangeland. Accordingly, the soil pH map was considered for the assessment of chemical properties as the pH influences the rangeland productivity. The LULC factor map, soil chemical and physical properties factor maps in combination were analysed to Create a rangeland degradation map. Whereas, rangeland degradation in terms of its vegetation condition was assessed independently using the multi-temporal satellite images.

3.4.4.1. Multi-Criteria Decision Analysis of Degradation

MCDA method helps to assess the available data (criteria) to see the tendency of the study area for its degradation. This method compares some decision criteria and enables to generate the degraded rangeland sites. MCDA together with the AHP helps to weight, classify and rank the criteria so that each criterion was decided to be the most or the least important in the analysis of rangeland degradation. The vegetation degradation map resulting from the LULC classification was created in raster format using ERDAS IMAGINE software. The erosion and deposition factor map was created using component factors (K-Factor, R-Factor, C-Factor, LS-Factor) using the raster calculator tool in the spatial analysis tools of the ArcGIS environment. Soil pH factor map produced from point based soil pH data was prepared and obtained as shape files and interpolated to surface raster map using the IDW tool of the ArcGIS spatial analyst tool. All the datasets were projected into Adindan UTM zone 37N coordinate system, and reclassified based on four rangeland degradation classes.

3.4.4.2 Criteria Rating

Land degradation risk was categorized as very low, low, moderate, high and very high according to Zurayk et al (2001). Besides, Brabant (2010) also stated that the degree of land degradation diverges slowly from very low to very high depending on the levels of these distribution classes. Accordingly, the rating scale of rangeland degradation assessment was made based on this categorization method of degradation as No/Very low degradation (1), low/marginal degradation (2), medium/moderate

degradation (3), and high degradation (4) depending on the results of factors and environmental conditions of the study area.

Table 3. 7 Land Degradation Rating Levels adopted from Brabant (2010)

Extent class	Degree of degradation	Indicators
1	No/Very low	Soil erosion differ based on the soil type and topographic conditions. The area is generally uncultivated and covered with useful natural vegetation for livestock feed
2	Low (marginal)	Decrease in the depth of the humus layer but the soil is uncleared; A few sand deposits are noted in the field (clusters of grass, stones). Very little or no observable decrease in productivity.
3	Moderate	Reduction in the depth of the humus layer. Clusters of grass partially relocated; accumulation of fine sand and silt on the soil surface at sites conducive to such deposits.
4	High	Reduction of almost half of the depth of the humus layer. Substantial displacement of thickets of grass. Tree and shrub roots are exposed below the root collar. Many sand and silt deposits on lower parts of the field and riverbanks. Bare areas without vegetation are visible and encroached by Bushes. As much as a 50% decrease in feed productivity

3.4.4.3 Criteria Reclassification

The three criteria maps (LULC, erosion and deposition, soil pH) that are essential for identifying degraded rangeland areas were created from the datasets through reclassification of the criteria maps. Consequently, all the criteria maps of the study area were reclassified into four classes based on the rating scale of rangeland degradation. The reclass tool in the ArcGIS environment was used to reclassify the factors into these four categories (1-4) to standardize them to a common scale. Hence, rangeland degradation was rescaled as highly degraded (4), moderately degraded (3), marginally degraded (2), and not degraded or very low (1). All three criteria were reclassified based on these rating scales to make them standardized and comparable for a specific area degradation. Finally, each criteria map became ready for weighted overlay analysis to generate a rangeland degradation map.

3.4.4.2. Criteria Weighting (Pairwise Comparison of the Factors)

The weighting of the criteria was done to Compare the importance and relevance of one criterion over the other. For this study, a pairwise comparison matrix is applied to weigh and rank the criteria. This comparison and ranking of the criteria help to assign higher and lower values to the criteria depending on their relevance to rangeland degradation site analysis. Comparison of the criteria, normalization, weighting of the criteria, and computation of consistency ratio were the procedures conducted respectively. EasyAHP application embedded with ArcGIS 10.8 environment was applied to Conduct a pairwise comparison of the degradation criteria and to generate criteria weights as well as compute consistency ratio (CR) to see the consistency of criteria weights of one over the other. The weighting was conducted using the criteria that are considered factors of rangeland degradation. The process of weighing and standardizing the criteria was done iteratively until the consistency ratio reaches less than or equal to 0.1 using the workflow indicated in the diagram in Figure 3.7 below. APPENDIX (4) shows a pairwise comparison matrix, weights, and ranks of criteria for rangeland degradation analysis.

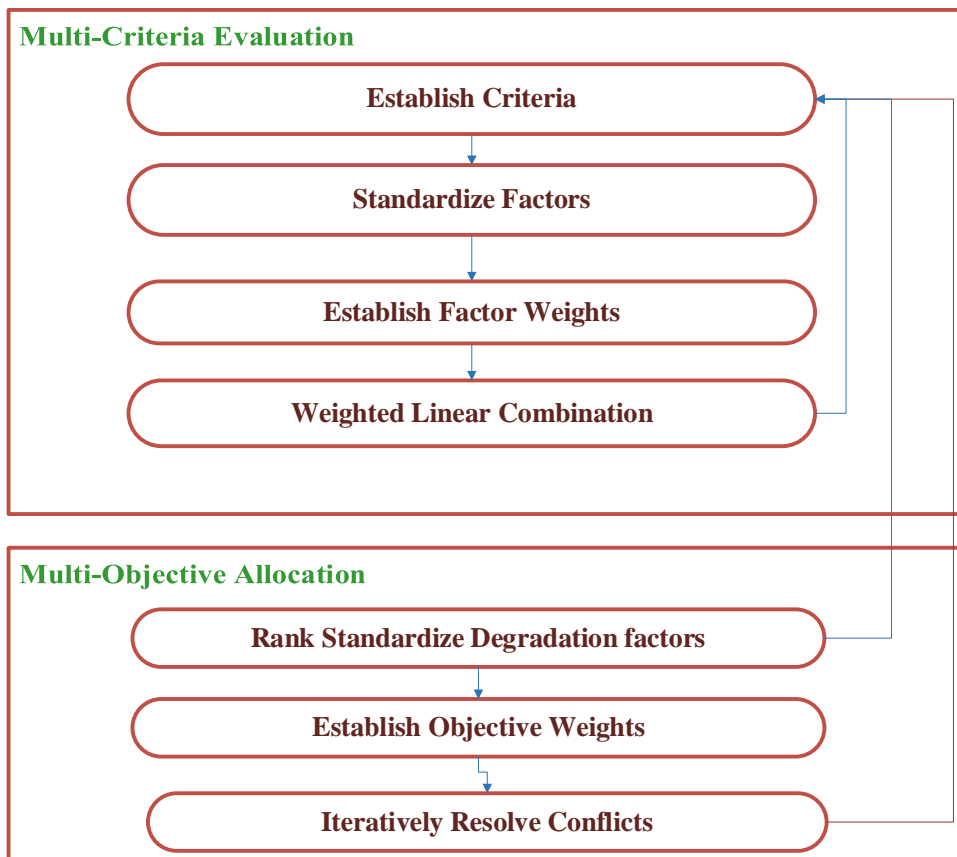


Figure 3. 11 Criteria weighting flow diagram adopted from Estoque (2011)

3.4.4.3. Aggregation of Rangeland Degradation Criteria Weights

The rangeland degradation in this study was planned to be assessed and determined through the combined effect of the rangeland degradation indicator/factor maps. These rangeland degradation factor maps are the LULC factor map, soil pH factor map, and soil erosion and deposition factor map. Accordingly, analysis of rangeland degradation because of soil degradation caused by erosion and deposition as well as degradation due to an increase in its pH level, degradation of LULC because of bush expansion, farm and crop expansion, conversion of land to bare soil due to overgrazing and drought was conducted. MCDA was done by providing weights to each of the three-rangeland degradation factors (criteria) using the AHP method developed (Wind & Saaty, 1980; Saaty, 1987). Weights were assigned to the vegetation degradation, soil pH, and soil erosion and deposition factors before conducting weighted overlay analysis. The AHP was also applied here to weigh the share of each land cover type in the LULC data before conducting a weighted overlay analysis. Reclassifying the factors was done using reclassify tool in the Arc GIS spatial analysis tool. Each factor was reclassified to a common scale of 1-4 before conducting a weighted overlay analysis. The weighting process involves a pairwise comparison of the values based on their importance by assigning intensity of importance from 1 to 9, which means 1 has equal importance of one factor over the other factor and 9 means extreme importance of one factor over another factor (Wind & Saaty 1980). Normalization of the values, calculation of consistency value, calculation of weighted sum, and calculation of consistency ratio were conducted. The LULC data and the rangeland degradation factors were weighted through this process and the rangeland degradation map was generated using Arc GIS 10.8 software spatial analyst weighted overlay tool.

Table 3. 8: Summary of rangeland degradation analysis

S/N	TYPE OF ANALYSIS	INPUT	SOFTWARE	METHOD OF ANALYSIS TECHNIQUE
1	LULC degradation assessment	<ul style="list-style-type: none"> • LULC map • Class's influence values 	Arc GIS 10.8	Reclassify based on the values
2	Soil chemical properties degradation assessment	<ul style="list-style-type: none"> • Soil pH map • Soil pH degradation level standard data 	Arc GIS 10.8	Reclassify based on the standard
3	Soil physical properties degradation assessment	<ul style="list-style-type: none"> • R-Factor map • K-Factor map • C-Factor map • LS-Factor map 	Arc GIS 10.8 software	<ul style="list-style-type: none"> • MCDA using AHP • Overlay analysis method
4	Vegetation degradation assessment	<ul style="list-style-type: none"> • Multi-temporal satellite images • NDVI Index values 	<ul style="list-style-type: none"> • Arc GIS 10.8 • ERDAS IMAGINE • QGIS 	NDVI Analysis method
5	Overall rangeland degradation assessment	<ul style="list-style-type: none"> • LULC degradation • Soil degradation <ul style="list-style-type: none"> ○ Soil chemical degradation ○ Soil physical degradation 	Arc GIS 10.8	<ul style="list-style-type: none"> • MCDA with AHP • Overlay analysis method

3.4.5. Land Suitability Assessment

3.4.5.1. Factors of Site Suitability for Rangeland Rehabilitation

The ultimate goal of the present study was to suggest reseeding sites of highly palatable rangeland vegetation species that are either degraded or extinct due to various pressures. Thus, reseeding to rehabilitate the degraded rangeland requires selection of appropriate suitable sites for a palatable forage species. Data that have been used for rangeland degradation analysis such as LULC, soil pH, rainfall, temperature, and slope generated from SRTM 30m DEM are input for reseeding site suitability analysis. In addition, soil organic carbon, soil texture, soil total nitrogen, and soil depth of the study area, which are very important factors for plant growth were used as criteria (Hamere & Teshome, 2018). A total of nine criteria were used to identify suitable sites for the rehabilitation of the rangeland through grass reseeding. The LULC map produced through supervised classification was applied as one factor of land suitability in this study. This factor includes forest, mixed grassland, bushland, water body, settlement area, cropland, farmland, and bare soil. This factor is an important factor since it

includes bushland cover, and the area converted to bare soil due to drought and overgrazing. These all need rehabilitation to increase palatable grassland.

The slope has a significant influence on the land suitability analysis as flat means less erosion and is suitable for rehabilitation and steep is more erosion, which is difficult to grow grass due to high rainfall-induced soil erosion of the area to rehabilitate. Rainfall provides soil moisture for seed germination and growth and substitutes the magnitude of moisture content lost due to evaporation to the atmosphere (Spittlehouse and Stathers, 1990). Therefore, precipitation is considered important criterion in land suitability analysis. The temperature has a considerable influence on plant growth since photosynthesis and respiration need temperature for their biochemical reactions.

Table 3. 9: Factors of suitability and their relationship with suitability

S/N	Factor	Source	Purpose of the factor	Relationship with suitability
1	LULC type	LULC map	To identify LULC trajectory	More bare soil is a higher source of re/seeding land
2	Soil type	Soil map	To identify soil nutrient content, pH and depth	Higher soil nutrient, neutral soil pH, and deep soil is highly suitable for re/seeding
3	Slope (%)	Slope map	To identify the course of gradient	Flat to near-flat gradient has lesser erosion and good for seed growth
4	Rainfall amount	Rainfall map	To identify suitable range of rainfall amount	Moderate rainfall is suitable for seed germination and growth
5	Temperature	Temperature map	To identify suitable range of temperature amount	Moderate temperature is suitable for seed germination and growth

3.4.5.2. Multi-Criteria Decision Analysis of Site Suitability

MCDA method helps to do assessment of the available data (criteria) in order to see the tendency of the study area for its suitability to grow grass for animal feed. This method compares several decision criteria and enables the generation of suitable sites. MCDA together with the AHP was applied to weight, classify and rank the criteria so that each criterion will be decided to be the most or the least important in the analysis of suitability. Most of Soil related datasets and climatic datasets, which were available in point data format, were converted to shape files and interpolated to a raster dataset using the IDW tool of the ArcGIS spatial analyst tool. Soil texture dataset that shows the twelve different

types of texture classes was available in shape file format and used in the analysis. All datasets were projected to Adindan UTM zone 37 coordinate system and reclassified based on the legumes plants growing site suitability analysis standard.

3.4.5.3 Criteria Rating

Appropriate rating scales of suitability criteria are prepared and adapted for the generation of land suitability maps (Dengiz et al., 2016; Amiri, 2009; Kalichkin et al., 2020; FAO, 1976). These rating scales were set as highly suitable (S1), moderately suitable (S2), marginally suitable (S3), and unsuitable (N). The suitability of each criterion as well as the aggregated soil suitability and overall land suitability rating was done based on these criteria rating scales.

Table 3. 10 Forage Suitability Classes adopted from Dengiz et al, (2016) and Amiri (2009)

Definition	Class
Highly suitable	S1
Moderately suitable	S2
Marginally suitable	S3
Unsuitable	N

3.4.5.4 Criteria Reclassification

The nine criteria maps that are essential for growing grass were created from the datasets through reclassification of the criteria maps. Consequently, all the criteria maps of the study area were reclassified into four classes based on the rating scale of suitability. The reclass tool in the ArcGIS environment was used to reclassify the factors into these four categories (1-4) to standardize them to a common scale. Hence, suitability was rescaled as S1 =4 (highly suitable), S2=3 (moderately suitable), S3=2 (marginally suitable) and S4=1 (unsuitable). All nine criteria were reclassified based on these rating scales in order to make them standardized and comparable for a specific land unit identification. Among all the factors, the mean monthly temperature of the study area has a different range as compared to the standard criteria range, which is identified as suitable for forage growth (Dengiz et al, 2016). However, the existing mean monthly temperature of the study area is classified into four classes based on the area mean monthly temperature to Create a study area criterion map. Finally, each criteria map became ready for weighted overlay analysis to generate suitable sites.

Table 3. 11 Weighting Factor Rates for Forage growth Site Suitability (Dengiz et al, 2016)

Factor /Criterion	Range of Suitability			
	Highly suitable (4)	Moderately Suitable (3)	Marginally Suitable (2)	Not Suitable (1)
Texture (Class)	SCL, CL,SL	L,SiL,Si	SC, SiC, SiCL	LS,S, C
OC (%)	>3	2.5 - 3.0	2.0 - 2.5	1.0 - 2.0
pH	6.5-7.5	6.0-6.5,7.5-8.2	5.0-6.0	<5, 8.2-9.0
N Total (%)	> 0.170	0.090-0.170	0.045-0.090	0.045
Soil Depth (cm)	>90: Deep	50-90: Medium Deep	20-50: Shallow	0-20
Slope (%)	0 - 2	2-6	6 – 12	>12
LULC (Class)	Bare soil	Farm land	Mixed grassland	Bush, water, settlement, crop, forest
Rainfall (mm)	450-650	350-450,650-850	300-350,850-1000	250-300,1000-1200
Temperature (°c)	14.9-18.4	14.4-14.9, 18.4-19.4	13.4-14.4, 19.4-20.8	12.4-13.4,20.8-21.3

S=Sand; C= Clay; L=Loam; Si=silt; CL= clay loam; SC= Sandy Clay; LS= Loamy-sand; SL=Sandy Loam; SiC=Silty Clay; SiL= Silty-Loam; SiCL=Silt-Clay-Loam; SCL= Sandy Clay Loam; (USDA, 1998)

3.4.5.3. Pairwise Comparison and Weighting of the Criteria

The weighting of the criteria was done to Compare the importance and relevance of one criterion over the other. For this study, a pairwise comparison matrix is applied to weigh and rank the criteria. This comparison and ranking of the criteria help to assign higher and lower values to the criteria depending on their relevance to suitable site selection. Slope, LULC, Rainfall, depth, texture, soil pH, temperature, soil OC, and soil TotN were ranked from 1 to 9 based on their relevance for the suitability analysis (Zolekar and Bhagat, 2018). Comparison of the criteria, normalization and weighting of the criteria, and computation of consistency ratio were the procedures conducted respectively. EasyAHP application embedded with ArcGIS 10.8 environment was applied to Conduct a pairwise comparison of the suitability criteria and to generate criteria weights as well as compute consistency ratio (CR) to see the consistency of criteria weights of one over the other. The weighting approach was done in two phases for the sake of ease of weighting. The first phase involves a weighting of the soil suitability factors (texture, OC, Total Nitrogen, depth, and soil pH) to generate the soil suitability map and to Consider soil factors in general as one criterion for site suitability analysis. Soil criterion will be involved in the site suitability analysis together with rainfall, temperature, LULC, and slope criteria.

The second weighting was conducted using soil, rainfall, temperature, LULC, and slope criteria that are considered factors of suitable site analysis. The process of weighing and standardizing the criteria was done in a similar methodology and flow to weight rangeland degradation criteria as indicated in the (APPENDIX_4) show pairwise comparison matrix, weights, and ranks of criteria for soil suitability and site suitability analysis.

3.4.5.4. Aggregation of Site Suitability Criteria Weights

Once the weighting and ranking of the criteria are completed, the next step is to Conduct an analysis of the criteria based on their weights or their contribution to the decision on suitable site identification. The weighted overlay analysis is conducted using the overlay tool in the ArcGIS environment. Weighted overlay analysis was conducted to generate a soil suitability map from its component criteria (Depth, Texture, pH, OC, and TotN). The component criteria were first scaled from 1 to 4 based on the scaling standards (S1, S2, S3, and N). Once the soil suitability map that is the soil criterion is created, then the final site suitability analysis was conducted in the same way. Consequently, an already scaled soil, slope, LULC, rainfall, and temperature criteria were used to Compute and generate suitable sites using the weighted overlay tool in the ArcGIS environment. Finally, the overall map that shows suitable sites for grass reseeding was created. The following figure shows the land suitability analysis workflow diagram for the identification of suitable grass reseeding sites.

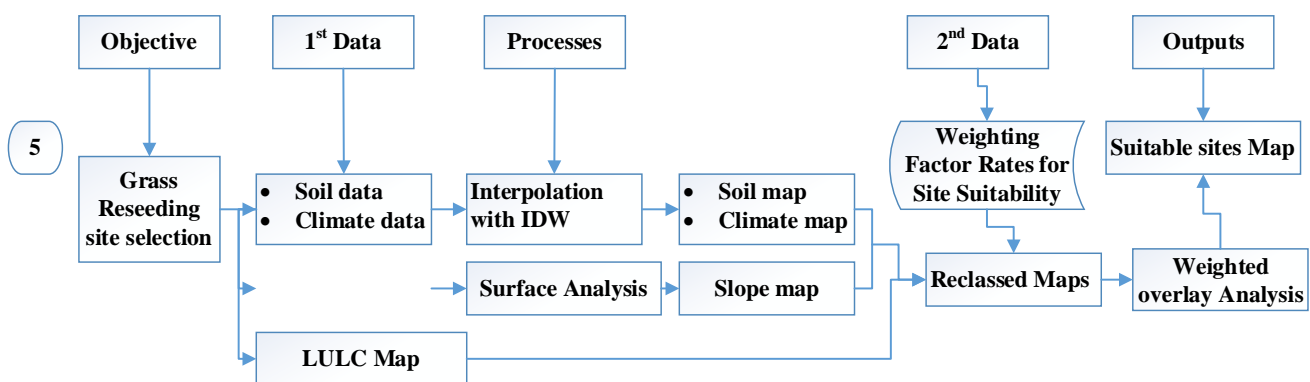


Figure 3. 12: Summary Workflow Diagram of Suitability Analysis

CHAPTER FOUR

4. RESULTS

The results section describes the results of the LULC classification, vegetation change using NDVI, soil erosion and deposition susceptibility, soil pH, rangeland degradation, and site suitable for the rangeland rehabilitation. The first part focuses on the presentation of vegetation changes on a temporal basis through analysis of NDVI for three periods of satellite images. The second part involves the LULC classification result of the study area. The third part involves the result of soil erosion susceptibility of the study area using the USPED Model in order to identify areas where the threat of erosion is anticipated. The fourth section deals with the result of the acidity and alkalinity level of the rangeland of the study area. The final and major part involves the presentation of results of rangeland degradation, and selection of suitable sites for grass reseeding to rehabilitate the rangeland.

4.1 Vegetation Degradation assessment

4.1.1. Results of NDVI

Vegetation maps of the study area (Figure E, F) were produced based on the NDVI result ranging between the thresholds of -1 and +1. The result of NDVI (Table 4.1) shows that the Non-vegetation area takes an area cover of 636.07km² (4.61%), 3,487.71 km² (25.27%), and 1,498.27 km² (10.86%) in 2002, 2012 and 2021 respectively. Sparse vegetation covers 493.93 km² (3.58%), 6,030.01 km² (43.69%) and 8,761.83 km² (63.48%) in 2002, 2012 and 2021 respectively. Whereas, moderately vegetated area has 90.90 km² (0.66%), 3,544.37 km² (25.68%) and 2,889.49 km² (20.93%) coverage in the three years respectively. The study area has a densely vegetated area coverage of 0.85 km² (0.01%), 734.44 km² (5.32%), and 647.64 km² (4.69%) in 2002, 2012, and 2021 respectively. Finally, water has the smallest area coverage as compared to other classes with coverage of 0.45km², 5.76km², and 5.06km² in 2002, 2012 and 2021 respectively.

Table 4. 1: Vegetation Condition of the study area in the three Periods

	2002		2012		2021	
	Area (km ²)	Area (%)	Area (km ²)	Area (%)	Area (km ²)	Area (%)
Water	0.54	0.004	5.76	0.04	5.06	0.04
Non_Vegetation	636.07	4.61	3487.71	25.27	1498.27	10.86
Sparsely Vegetated	3488.35	25.27	6030.01	43.69	8761.83	63.48
Moderately Vegetated	6631.42	48.05	3544.37	25.68	2889.49	20.93
Densely Vegetated	3045.93	22.07	734.44	5.32	647.64	4.69
Total	13802 km2	100%	13802 km2	100%	13802 km2	100%

4.1.2. Vegetation Change between 2002 And 2012

The result of the NDVI (Figure 4.1) shows that water has a significant increase by 5.22 km² (90.65%) from its state in 2002 with an area of 0.54 km² to an area coverage of 5.76 km² in 2012. Non-vegetation area (area covered with bare soil, sand, and built-up) increased from 636.07 km² coverage in 2002 to 3,487.71 km² (81.76%) in 2012. Whereas, sparse vegetation increased continuously by 3,488.35 km² from its state in 2002 to 6,030.01 km² (42.15%) in 2012. The moderately vegetated area has decreased from an amount of 6,631.42 km² in 2002 to 3,544.37 km² (46.55%) in 2012. The densely vegetated area showed a decrease from the condition in 2002 by 75.89% in 2012.

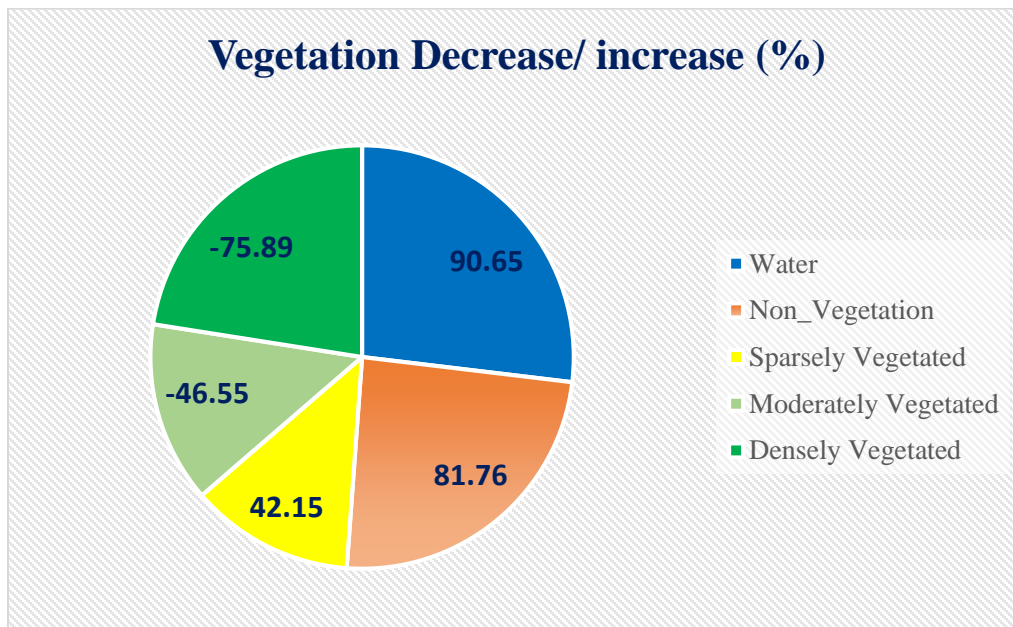


Figure 4. 1: Vegetation Change between 2002 and 2012

4.1.3. Vegetation Change between 2012 And 2021

The result (Figure 4.2) shows that water cover has decreased from the year 2012 by 12.15% in 2021. Non-vegetation area also shows a decrease of 57.04% in 2021 from its state in 2012. Whereas, sparse vegetation is observed as increasing by 45.30% within the last ten years from 2012 to 2021. Moderately vegetated and densely vegetated areas have shown a decrease of 18.48% and 11.82% from their condition in 2012 to 2021 respectively.

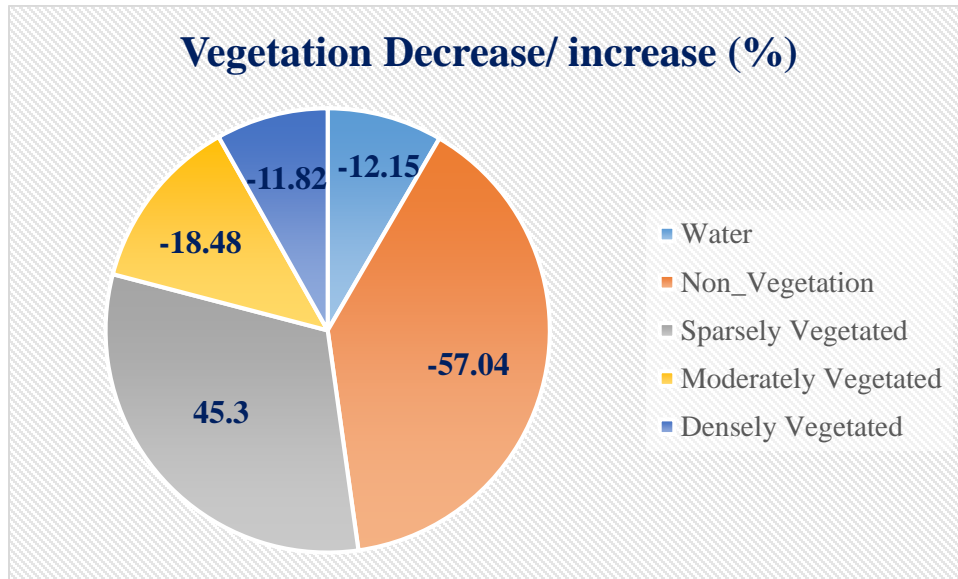


Figure 4. 2: Vegetation change between 2012 and 2021

4.1.4. Vegetation Change between 2002 And 2021

Water coverage that had 0.54 km² in 2002 increased to 5.06 km² in 2021 with an increase of 4.52 km² (89.33%) throughout the twenty years (Figure 4.3). Whereas, the substantial change observed within the last twenty years in the non-vegetation area has a continuous increase from its area coverage of 636.07 km² in 2002 to 1,498.27 km² in 2021 that is an increase of 57.55% in 2021. The sparsely vegetated area shows a continuous increase from its state covering 3,488.35 km² in 2002 to 8,761.83 km² in 2021 by an increase of 60.19%. Moderately vegetated area in 2002 that had 6,631.42 km² is covering 2,889.49 km² in 2021 and shows a significant decrease of 3,741.93 km² (56.43%) in 2021. The densely vegetated area that was very large in terms of area coverage (3,045.93 km²) in 2002 reached 647.64 km² with a decrease in area coverage of 2,398.29 km² (78.74%) in 2021. Figures (4. 4 (a) and (b)) as well as, Figure (4.5) show the NDVI maps of 2002, 2012 and 2021 respectively. Whereas, the two decades vegetation change is presented in (Figure 4.6) below.

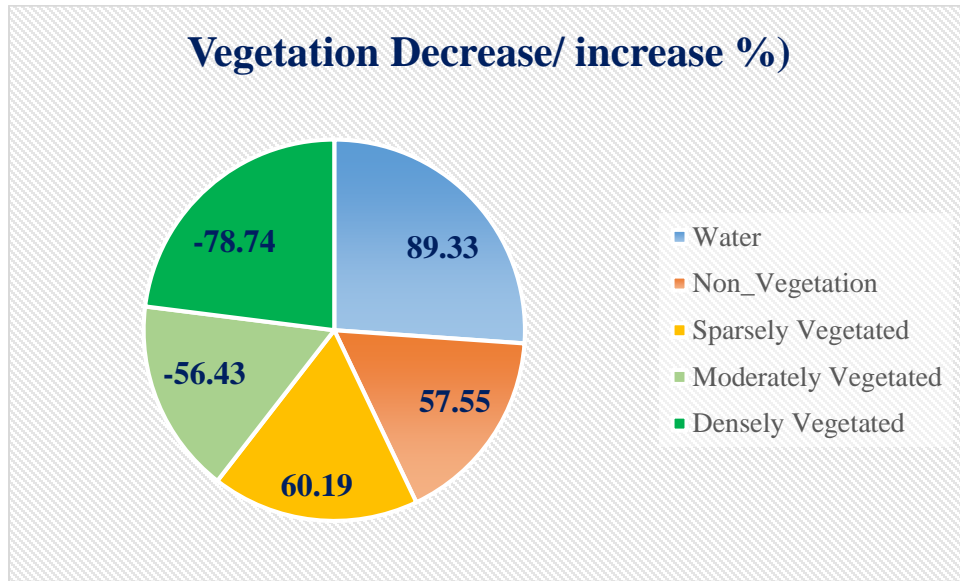


Figure 4. 3: Vegetation change between 2002 and 2021

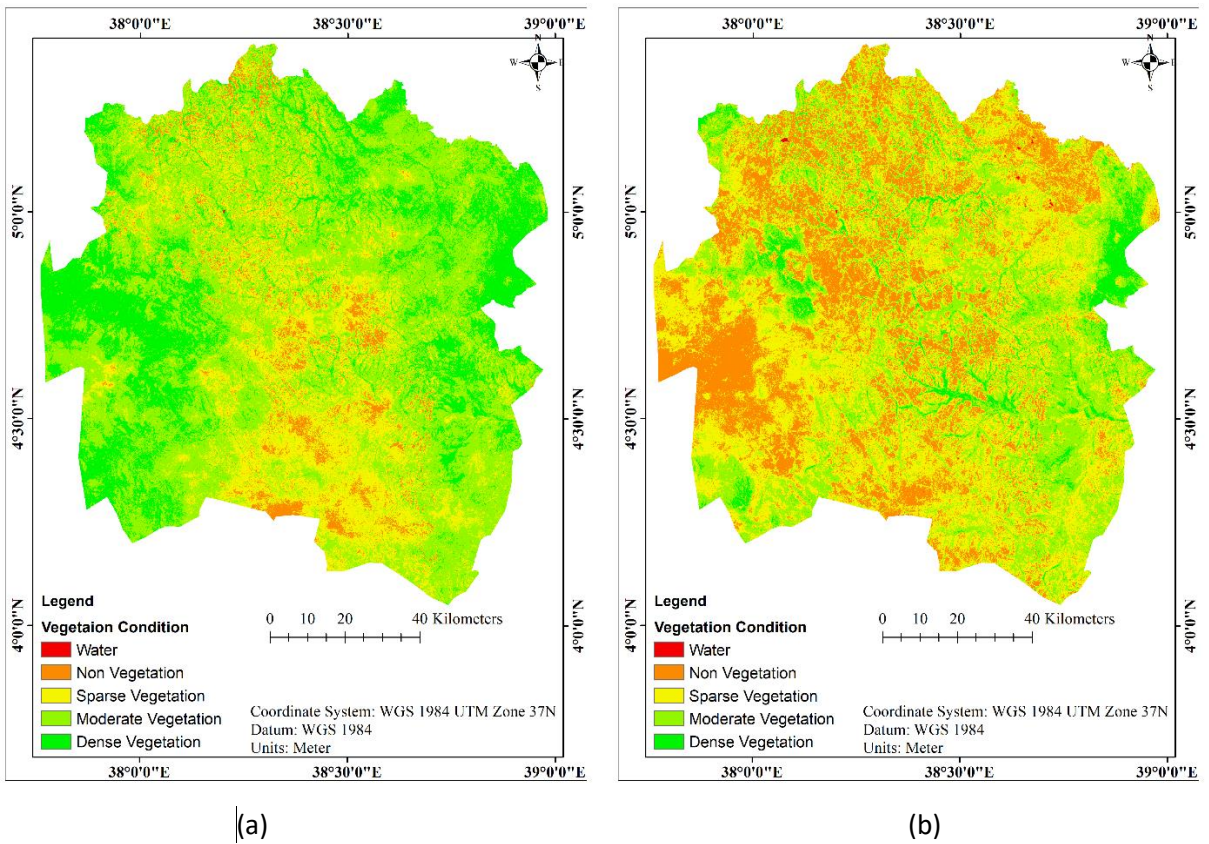


Figure 4. 4 (a) NDVI Map of 2002; (b) NDVI Map of 2012

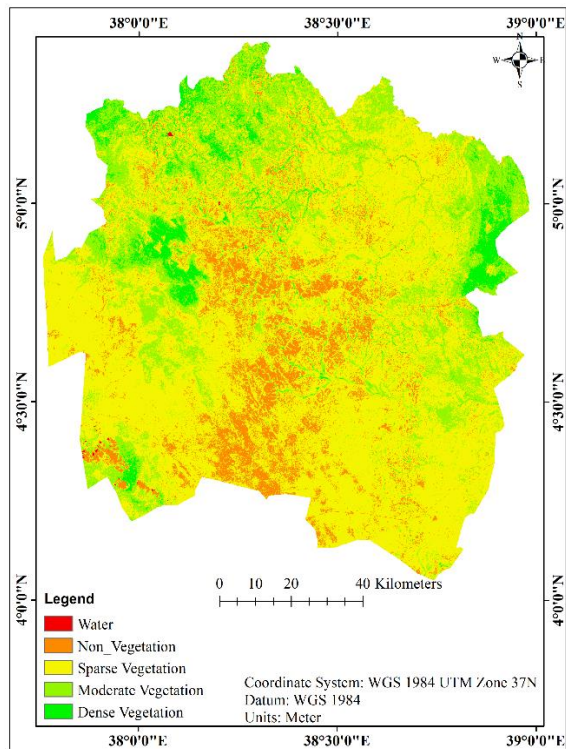


Figure 4. 5 NDVI Map of 2021

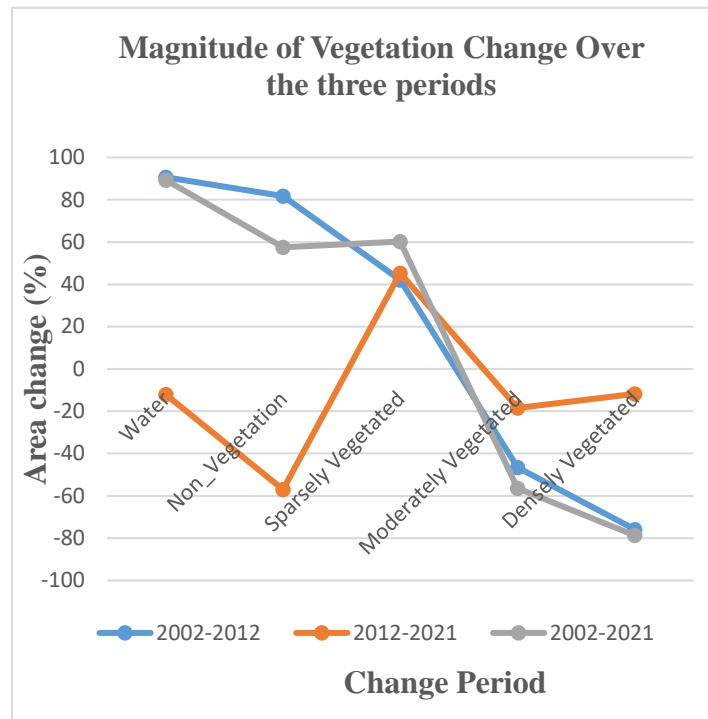


Figure 4. 6 Vegetation Change in three Periods

4.1.5. LULC Assessment of the Study Area

The LULC map (Figure 4.7) of the study area was generated from the supervised classification of the year 2021 Landsat 8 OLI image and an accuracy assessment was made based on the set criteria. Half of the total number of 107 GCPs (Table 4.2) collected from the field were used for classification and the remaining were used for accuracy assessment. The satellite image was classified into eight classes to produce and show the LULC map of the area. The overall accuracy of the classification result was 81.01% with Kappa Statistics of 0.77. The result shows that Bush has an area coverage of 4,976.6 km² (36.06%) and mixed Grassland (Grass, Shrub, and wood) has 4,640.82 km² (33.62%) of coverage (Table 4.3). These two Classes cover the majority of the study area and are the dominant cover types. The remaining area is occupied by Bare Soil that covers 1,643.02 km² (11.9%), Forest holds 1,023.39 km² (7.41%), Settlement area of 50.97 km² (0.37%), Agricultural area including Farm and Crop covers 1,465.47 km² (10.61%) and water has an area coverage of 1.09 km² (0.008%). The result of the classification shows that the area is mainly covered with bush followed by mixed grassland.

Table 4. 2: GCPs Used for each of the LULC class

S/N	LULC Class	No. of GCPs	Assigned Class value
1	Bush	18	1
2	Water	4	2
3	Settlement	11	3
4	Farm Land	12	4
5	Mixed Grass	19	5
6	Crop Land	12	6
7	Forest	14	7
8	Bare Soil	17	8
Total GCPs		107	8 classes

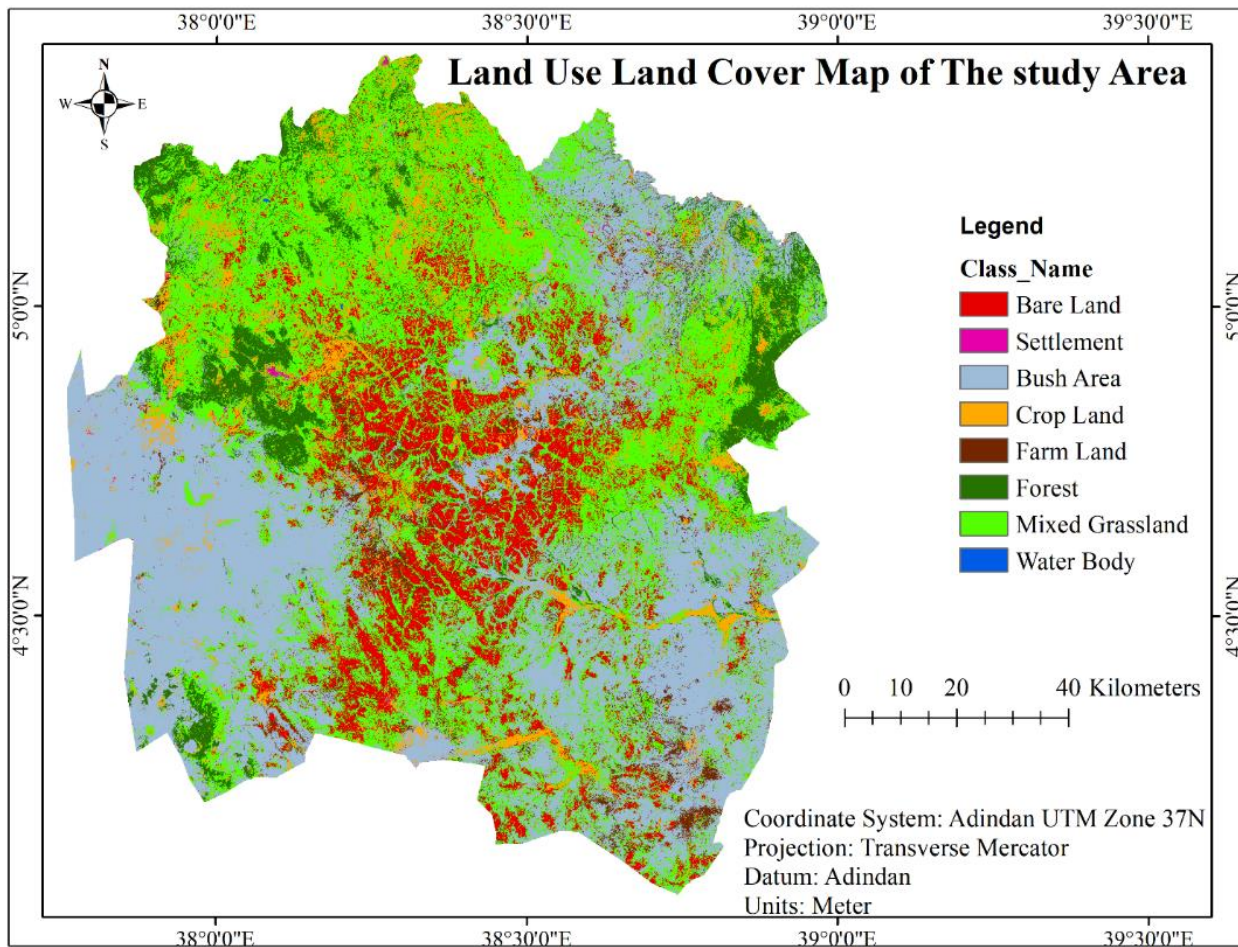


Figure 4. 7 LULC Map of the Study Area

Table 4. 3 Area Coverage of LULC of the Study Area

OBJECTID	Class Name	Area (sq_km)	Area (%)
1	Bush Area	4976.60	36.06
2	Water Body	1.09	0.008
3	Settlement Area	50.97	0.37
4	Farm Land	509.78	3.69
5	Mixed Grassland	4640.82	33.62
6	Crop Land	955.69	6.92
7	Forest	1023.39	7.41
8	Bare Land	1643.02	11.90
Total		13801.3587	100.00

4.2 Soil Quality Assessment

Soil quality in terms of acidity and alkalinity (pH) of the soil in the rangelands is one major indicator to assess the productivity of the rangeland. The soil pH of the study area is interpolated and mapped (Figure 4.8) based on the USDA (1998) soil pH standard. Accordingly, the result showed a total area of 91.24 km² (0.66%) and 494.33 km² (3.58%) is strongly acidic and moderately acidic soil types (Table 4.4). Whereas, the majority of the rangeland that includes 7,173.76 km² (51.98%) is neutral soil type. The remaining 5,871.81 km² (42.55%) and 169.91 km² (1.13%) of the rangeland are moderately alkaline and strongly alkaline respectively. Hence, it is evident that the majority of the area is neutral followed by moderately alkaline soil types.

Table 4. 4: Soil pH Class Value and Area Coverage

pH Level	Assigned Value	Area (km²)	Area (%)
Strongly acidic	1	91.24	0.66
Moderately acidic	2	494.33	3.58
Neutral	3	7173.76	51.98
Moderately alkaline	4	5871.81	42.55
Strongly alkaline	5	169.91	1.23
Total area		13801.05	100.00

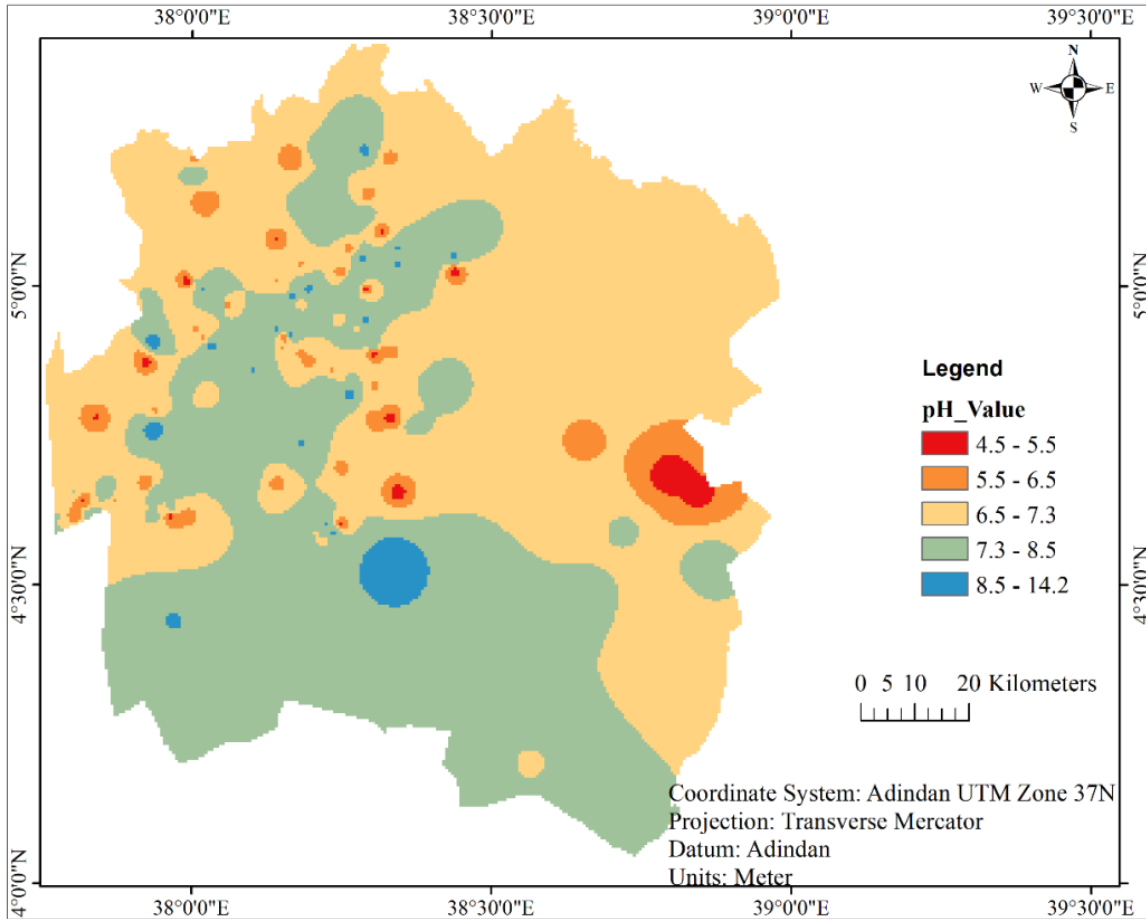


Figure 4. 8: Soil pH level Map of the Study Area

4.3 Soil Degradation Assessment due to Erosion and Deposition Using USPED Model

4.3.1. Rainfall Erosivity Assessment

Rainfall erosivity (R-Factor) shows the amount of rainfall that can affect the erodibility and transportability of the soil due to runoff. The rainfall erosivity map of the study area was generated from the five stations within and surrounding the study area. The result of rainfall erosivity factor value ranges between 239 and 499 where lower value means lower erosion, whereas, higher value means higher erosion (Figure 4.9). Lower power of rainfall in the study area ranges 239 – 285 and covers an area of 13.84% and low R-Factor ranges 285 – 329 with an area cover of 29.16%. A moderate power of rainfall ranges 329 – 376 and covers 35.36% area. Whereas, high values range from 376 to 433 with an area coverage of 11.4% and the higher values range between 433 and 499 with an area coverage of 10.61%.

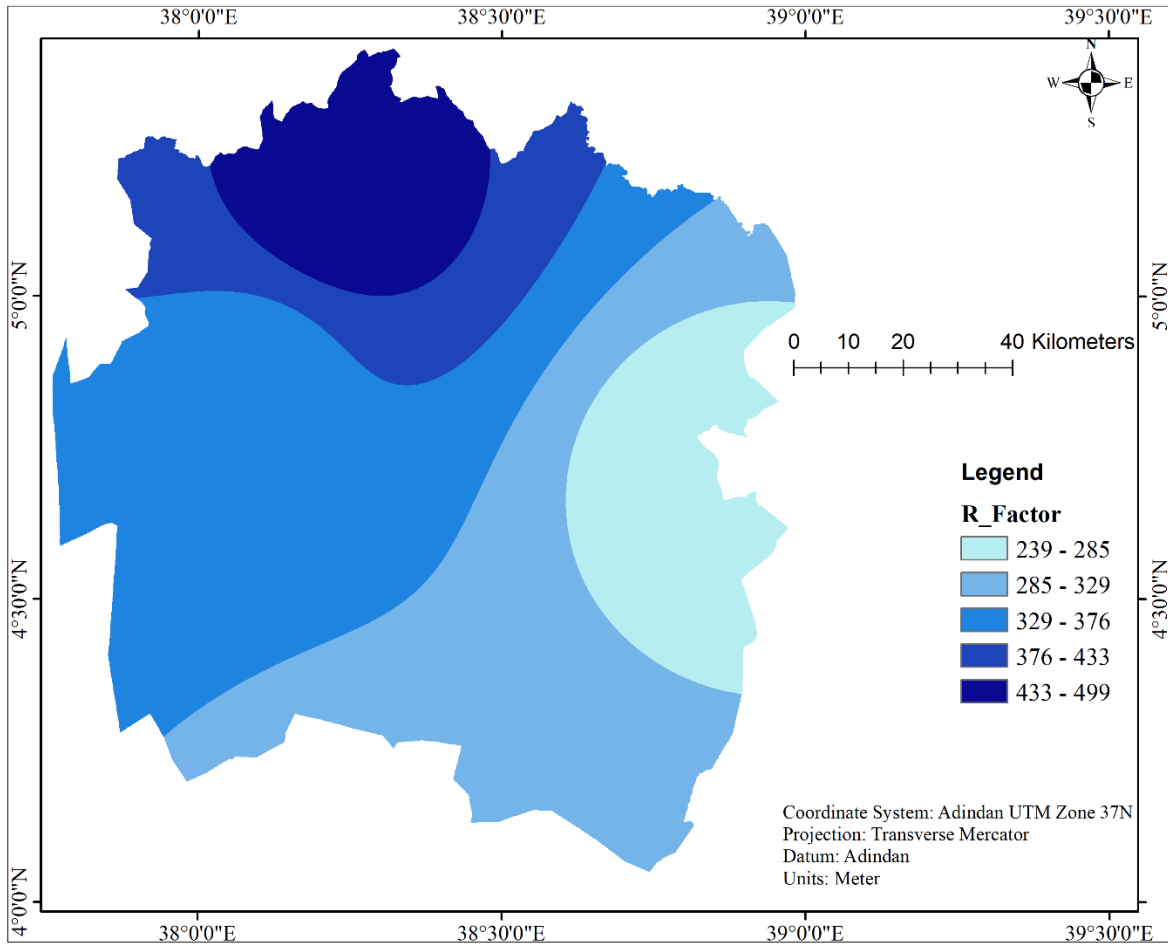


Figure 4. 9: Rainfall Erosivity (R-Factor) map of the Study Area

4.3.2. Soil Erodibility to Erosion (K-Factor) Assessment

Soil erodibility is characterized by the nature of the soil to be detached and transported easily by a runoff. The soil erodibility factor map was generated based on the structure, texture and organic carbon content of the soil in the study area (Figure 4.10). The soil erodibility of the study area is categorized from lower to higher susceptibility based on the result. Lower erodible areas have k-factor values less than 0.09 and cover 0.46% of the total study area whereas, low values range from 0.09 – 0.11 and have an area coverage of 0.98%. Moderate values range from 0.11 – 0.13 and cover 69.44% of the total study area coverage. High values of soil erodibility are observed at 0.13 – 0.15 and cover 24.7% of the total area. Whereas, higher k-factor values are ranging between 0.15 and 0.17 and have an area coverage of 4.42% out of the total study area.

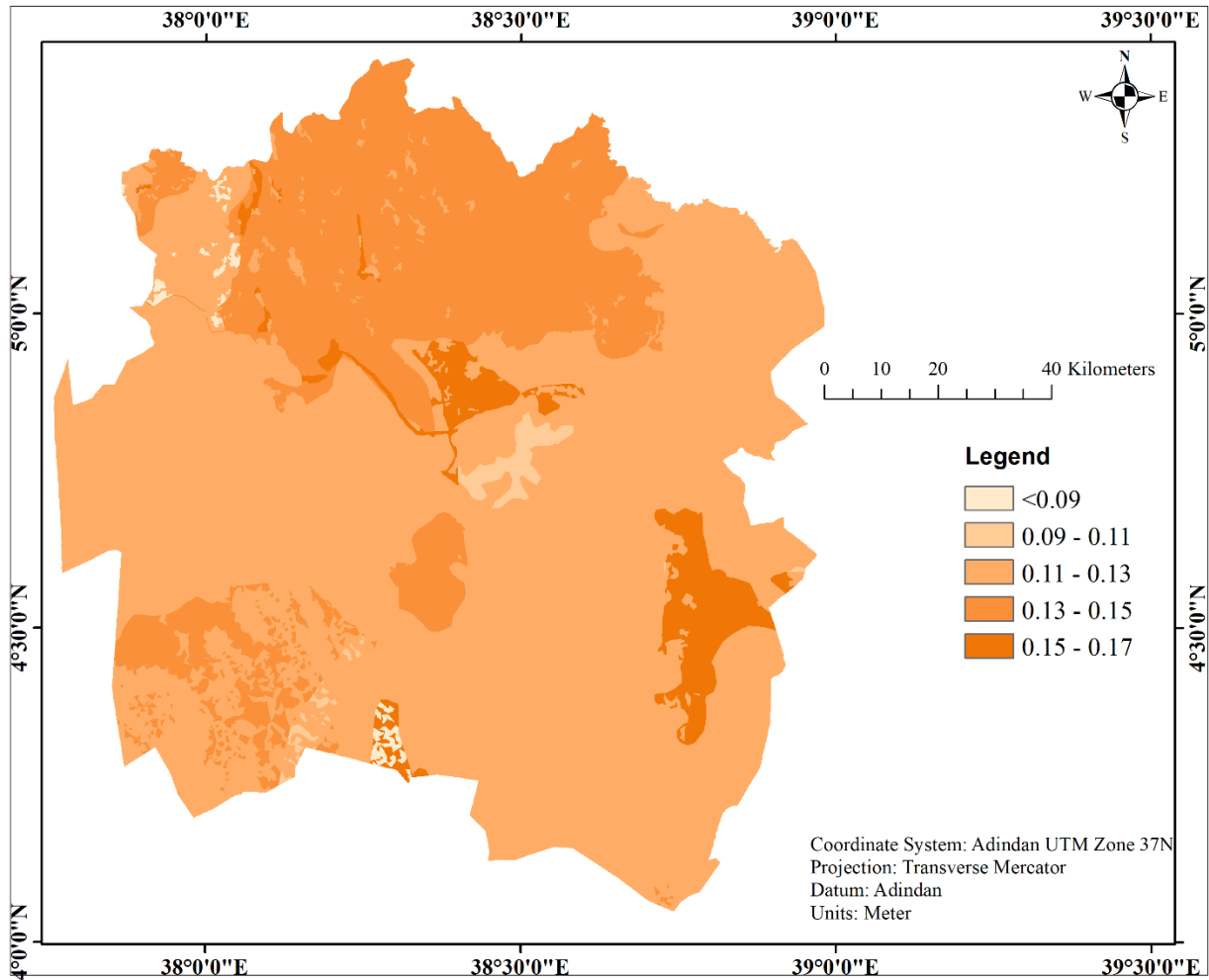


Figure 4. 10: K-Factor Map of the Study Area

4.3.3. Land Cover Susceptibility to Erosion (C-Factor) Assessment

The land cover vulnerability to erosion was labeled based on the cover factor value (C-Value) applied by different authors which is stated in the data analysis part of this study Table (3.5). From the cover factor result displayed in, the C-Factor value of the study area ranges between 0.005-1 (Figure 4.11). Values ranging from 0.0 – 0.001 are categorized as higher cover factor and are lower erodible in terms of cover and occupy an area of 0.8% of the total area. Whereas, high cover factor or low erodibility values ranging between 0.001 – 0.005 are covering an area of 2.07%. Areas with moderate erodibility cover factor values range between 0.005 and 0.2 and have an area coverage of 82.9%. High erodibility or low cover factor values range 0.2 – 0.6 and cover 5.32% of the total area. Lastly, cover type values ranging between 0.6 and 1 have lower cover factor or higher erodibility and cover an area of 8.9% of the study area.

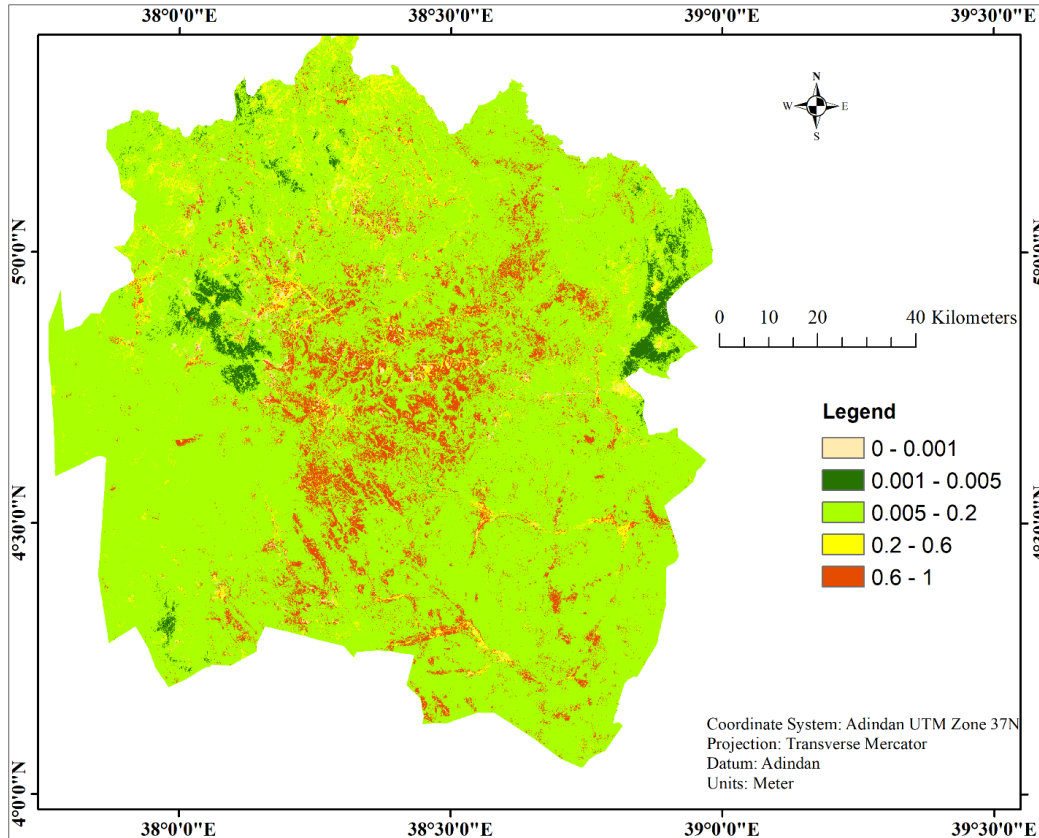


Figure 4. 11: Cover Factor Map of the Study Area

4.3.4. Topographic (LS-Factor) Assessment

The effect of topography on soil erosion is denoted by the topographic factor (LS-factor) which represents the ratio of soil loss at a standard of 9% steepness and 22.6m of slope length (Ganasri, 2015). The topographic factor is one of the components that have an impact on the soil erosion and deposition of the study area. The result of the topographic component ranges from 0 – 586 (Figure 4.12). The slope of an area can be classified into seven categories such as nearly level, gently inclined, moderately inclined, strongly inclined, slightly steep, moderately steep, and very steep (Ramirez et al, 2020). The topographic factor of the area is classified into five categories. Values ranging from 0 - 4.60 has no or lower erosion risk and 4.60 – 18.41 has a low risk of erosion. Moderate erosion is expected within the LS-Factor range of 18.41 – 43.72 and high risk is expected within a range of 43.72 – 101.26 topographic factor value. LS-Factor values ranging from 101.26 – 586.82 will result higher risk of erosion and deposition. The overall result of the factors of erosion-deposition is displayed below based on Alelign et al., (2021) classification from lower to higher in (Table 4.5).

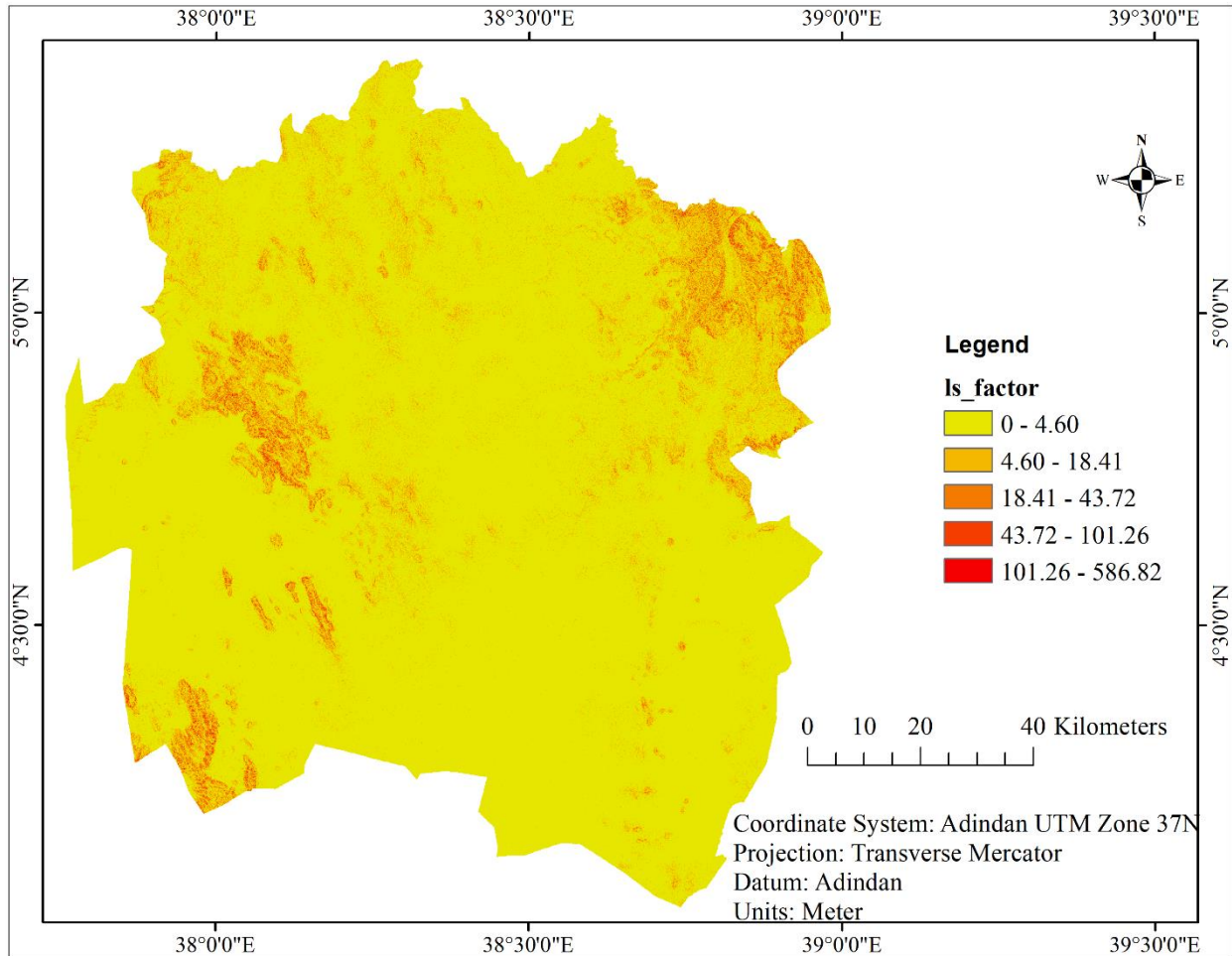


Figure 4. 12: Topographic Factor Map of the Study Area

Table 4. 5 Summary of Area coverage of Erosion/Deposition Factors based on erosion susceptibility

	K_Factor		R_Factor		C_Factor		LS_Factor	
	Area (km ²)	Area (%)	Area (km ²)	Area (%)	Area (km ²)	Area (%)	Area (km ²)	Area (%)
Lower	63.04	0.46	1860.28	13.48	111.02	0.80	11949.49	86.58
Low	135.68	0.98	4024.31	29.16	285.03	2.07	1476.52	10.70
Moderate	9582.27	69.44	4880.09	35.36	11439.91	82.90	322.89	2.34
High	3408.39	24.70	1572.74	11.40	734.20	5.32	48.69	0.35
Higher	612.12	4.42	1463.93	10.61	1231.40	8.91	3.90	0.03
	13801.50	100.00	13801.35	100.00	13801.5	100.00	13801.50	100.00

4.3.5. Overall Soil Erosion and Deposition Assessment

The overall erosion deposition is analysed using the results of the soil erodibility factor (K-Factor), rainfall erosivity Factor (R-Factor), cover factor(C-Factor), and topographic (LS-Factor) factors.

Warren et al (2019) classified the amount of expected erosion as follows. Positive values of the result indicate erosion whereas, negative values indicate deposition, and classified the magnitude of erosion and deposition level based on the following categories. Erosion (>24.7 ton/ha/yr.) is considered as high erosion, moderate erosion (12.35 – 24.7 ton/ha/yr.), low erosion (0 – 12.35 ton/ha/yr.), and stable (0). Similarly, low deposition (0 – 12.35 ton/ha/yr.), moderate deposition (12.35 – 24.7 ton/ha/yr.), and high deposition (>24.7 ton/ha/yr.) (Table 4.6). The result of the USPED model is classified based on the erosion and deposition classes (Figure 4.13 (a) and Figure 4.13 (b)). As can be seen on the map, high erosion and deposition is observed along hilly areas and rivers.

Table 4. 6: Erosion and Deposition Values and impact Level

Classified Value range (ton/ha/yr.)	Erosion and Deposition category
< -24.7	High Erosion
-24.7 - -12.35	Moderate Erosion
-12.34 - -0.22	Low Erosion
-0.21 – 0.25	Stable
0.26 - 12.35	Low Deposition
12.36 - 24.7	Moderate Deposition
>24.7	High Deposition

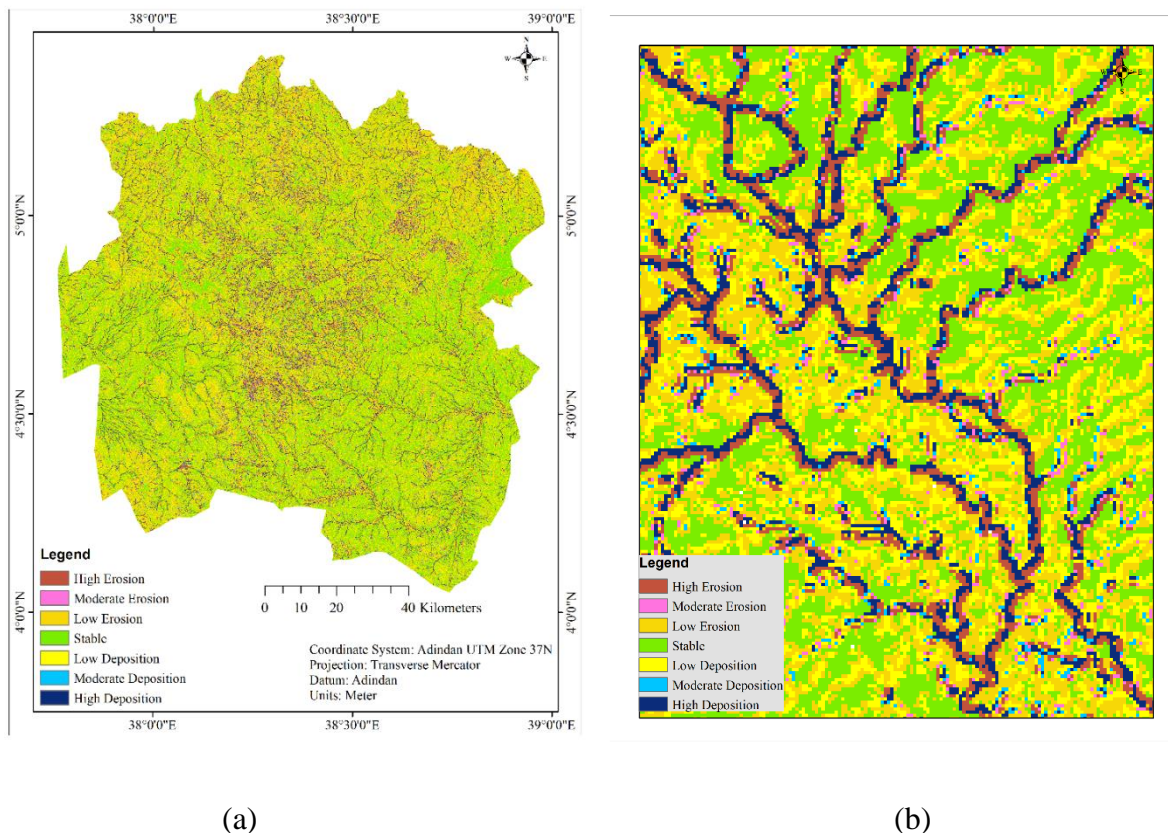


Figure 4. 13: (a) Erosion - Deposition Map; (b) Erosion–Deposition Map (Enlarged Scale)

4.4 Rangeland Degradation Assessment Factors (Criteria)

4.4.1. The LULC Cover Factor (C-Factor)

The LULC result categorizes water bodies, mixed grassland, and forest as the major source of livestock feed production and have a very low impact or not the cause of rangeland degradation. This category covers 5,683.44 km² (41.20%) of the rangeland area which is a significant cover of the total area next to Bush and bare soil covers. The second LULC class with negligible or marginal impact on rangeland degradation is the Settlement area that contains only 52.12 km² (0.38%) cover of the total area. Farmland and cropland expansion is considered the causes of moderate rangeland degradation even if the latter contributes crop by-products to be used to feed cattle. This category covers an area of 1,469.41 km² (10.65%) of the total rangeland which has a significant contribution to the rangeland degradation next to Bush cover and bare soil. The bush and bare soil cover of the LULC data shows the maximum area coverage of the rangeland containing 6,596.02 km² (47.81%). This cover type is considered the most rangeland-degrading factor and has a high impact on the degradation. Figure (4.14) and the Table (4.7) below display the area coverage of the rangeland degradation level of the LULC classes.

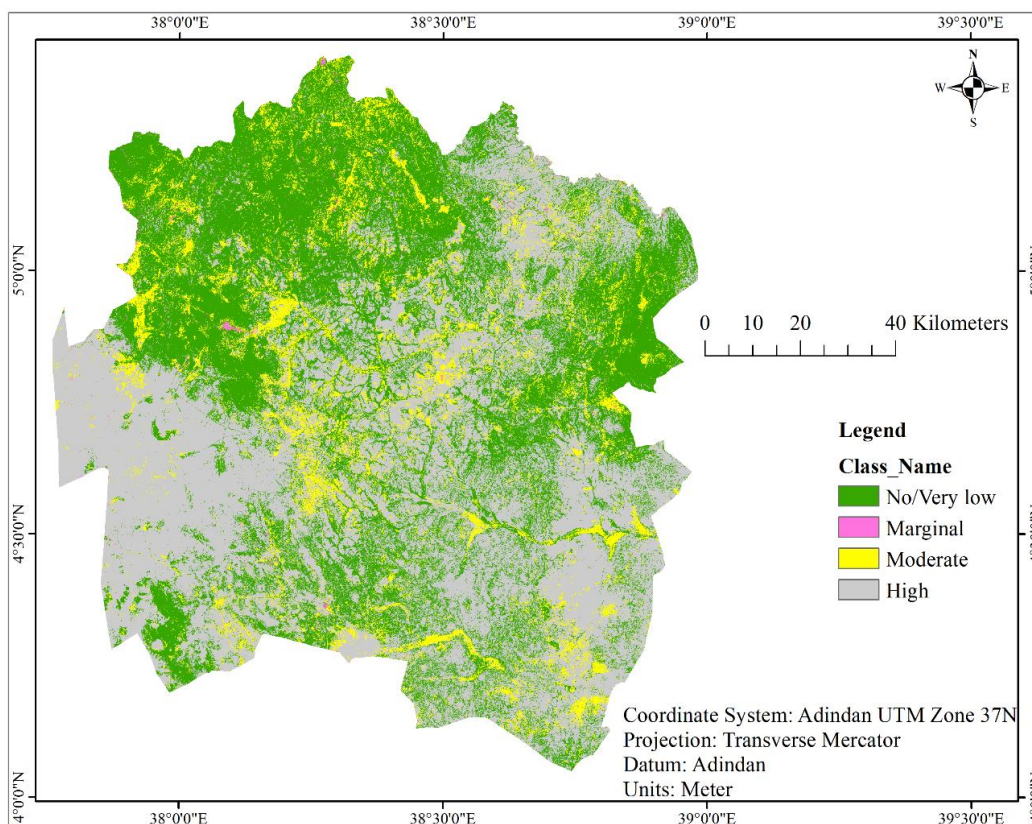


Figure 4. 14: LULC Degradation Map

Table 4. 7: LULC Area Coverage and Level of Degradation

LULC Class	Assigned Value	Degradation level	Areas (km ²)	Area (%)
Water Body/Mixed Grassland/ Forest Settlement	1	No/Very low	5683.44	41.20
Agricultural Land (Crop + Farm)	2	Marginal	52.12	0.38
Bush Area/Bare Land	3	Moderate	1469.41	10.65
	4	High	6596.02	47.81
Total area			13,801.00	100.00%

4.4.2. Soil Quality (pH) Factor

The result obtained from the soil classification indicates that more than half of the rangeland soil covering 7,496.31 km² (54.32%) has a very low degradation level or is not degraded (Figure 4.16). Whereas, 1,202.58 km² (8.71%) of the area coverage has a marginal degradation level. Area coverage of soil of 3,852.33 km² (27.91%) and 1,250.13 km² (9.06%) is moderately and highly degraded respectively. The soil in the east part of the study area has moderately to strongly acidic properties. The soil in the North and central part has mainly neutral properties while some parts of the center extending to the North show moderate to slightly alkaline property. The moderately to strongly alkaline properties of soils are mainly characterized by the soil types in the Southern part of the study area (Figure 15).

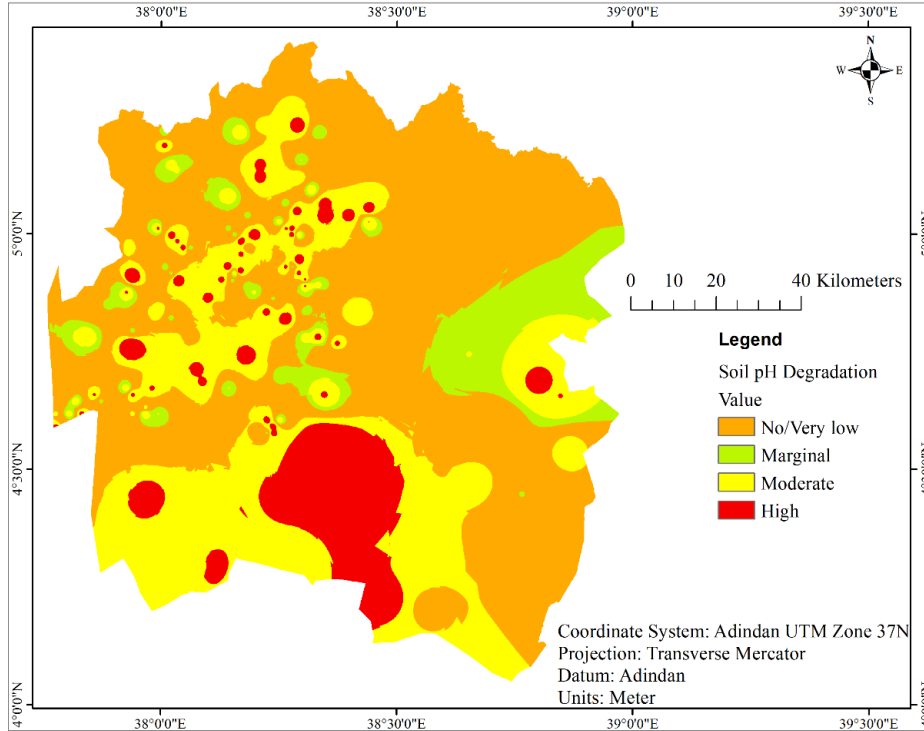


Figure 4. 15: Soil Quality (pH) Degradation Map of the Study Area

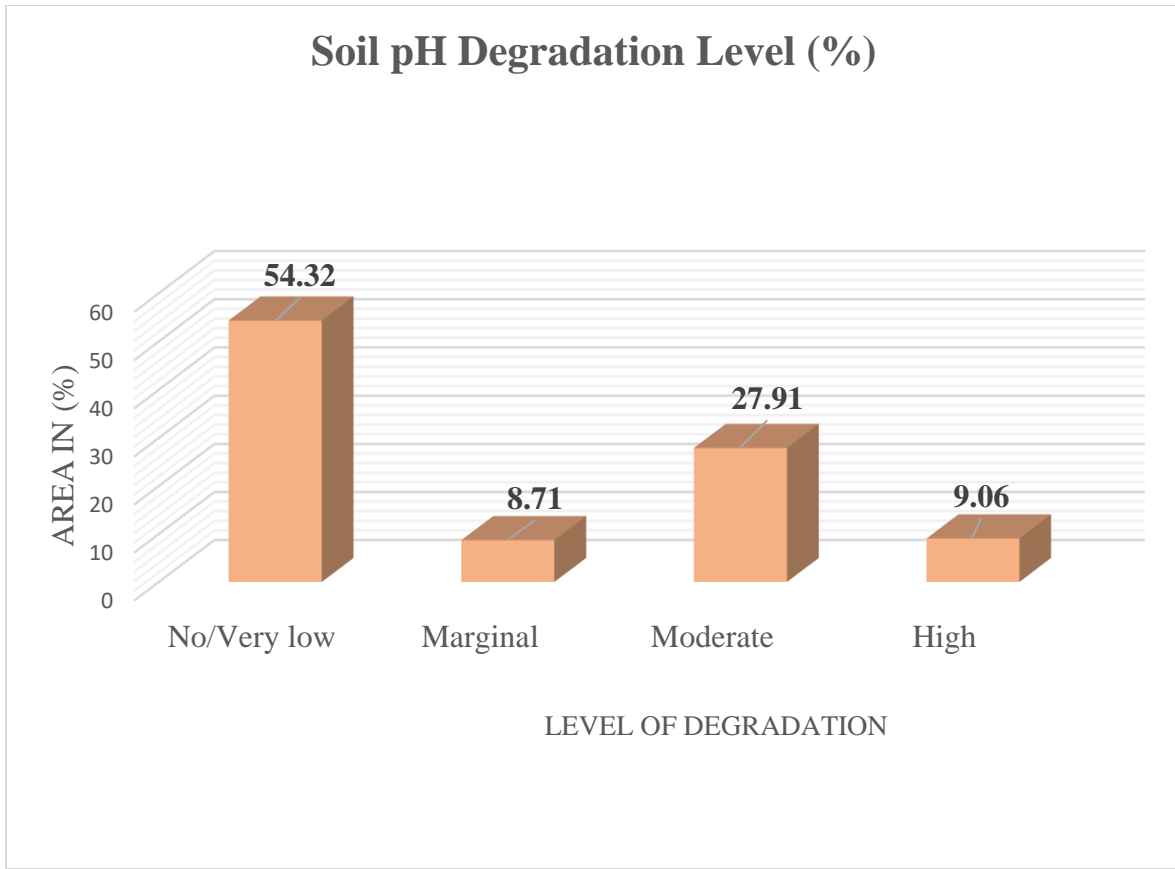
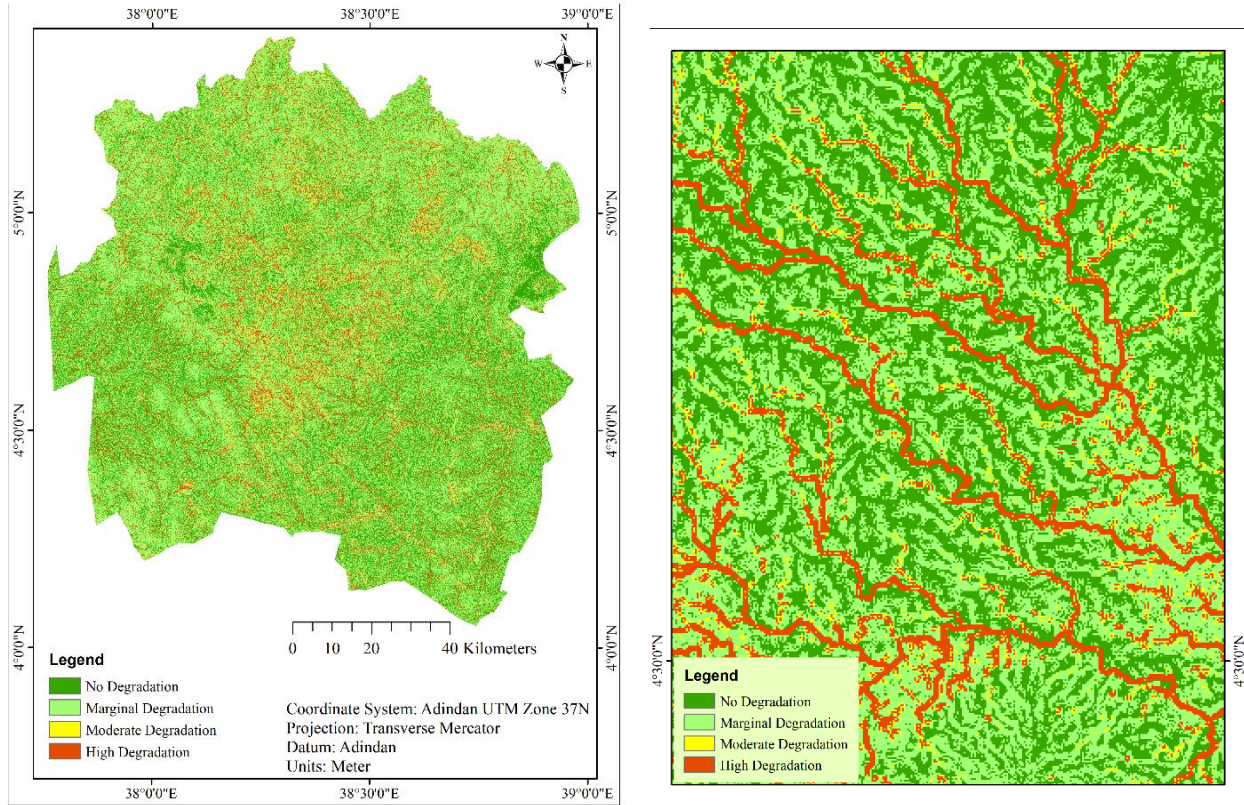


Figure 4. 16: Soil pH Level of Degradation

4.4.3. Soil Degradation due to Erosion and Deposition Factor

Concerning to erosion and deposition, the majority of the rangeland area 4,163.13 km² (30.16%) is not vulnerable to erosion and deposition threat (Table 4.8). Its erosion and deposition amount is between -0.21- 0.25 ton/ha/yr. and is considered as negligible degradation. Majority of the study area that covers 7,402.51 km² (53.63%) is marginally vulnerable to erosion and deposition. Its erosion and deposition amount is about 12.35 ton/ha/yr. An area of 679.00 km² (4.93%) and about 1,556.36 km² (11.28%) of the total area of the rangeland is moderately and highly vulnerable to erosion respectively. The moderately degraded area has an erosion and deposition amount 12.36 – 24.7 ton/ha/yr. whereas, the highly degraded area has a soil erosion and deposition amount greater than 24.7 ton/ha/yr. High erosion and Deposition is observed along the rivers and mountain beds (Figure 4.17 (a) and (b)).



(a)

(b)

Figure 4. 17 (a) Erosion-Deposition Degradation; (b) Erosion-Deposition Degradation (magnified)

Table 4. 8: Soil Erosion and Deposition Area Coverage and Level of Degradation

Erosion-Deposition	Assigned Value	Degradation Level	Area (km²)	Area (%)
Stable	1	No/Very low	4163.13	30.16
Low erosion & low deposition	2	Marginal	7402.51	53.63
Moderate erosion & deposition	3	Moderate	679.00	4.93
High erosion & deposition	4	High	1556.36	11.28
Total Area			13801	100.00

4.4.4. Aggregated Rangeland Degradation Assessment

The weighted overlay analysis result indicates that 3,823 km² (27.70%) rangeland is not degraded or has a very low degradation level (Table 4.9). Whereas, an area of 2,617.18 km² (18.97%) of the total rangeland is marginally degraded. These areas are located next to areas with no degradation. Rangeland with an area of 6,486.72 km² (46.98%) accounting for the remaining majority coverage of the study area is moderately degraded. The moderately degraded area mainly covers the southwestern, south

eastern, some parts of northern and southern parts of the study area (Figure 4.18). The remaining area that covers 874.62 km² (6.33%) of the total rangeland located in the south and central part of the study area is highly degraded. The overall rangeland degradation analyzed through weighted overlay analysis result is presented in Figure (4.18) below.

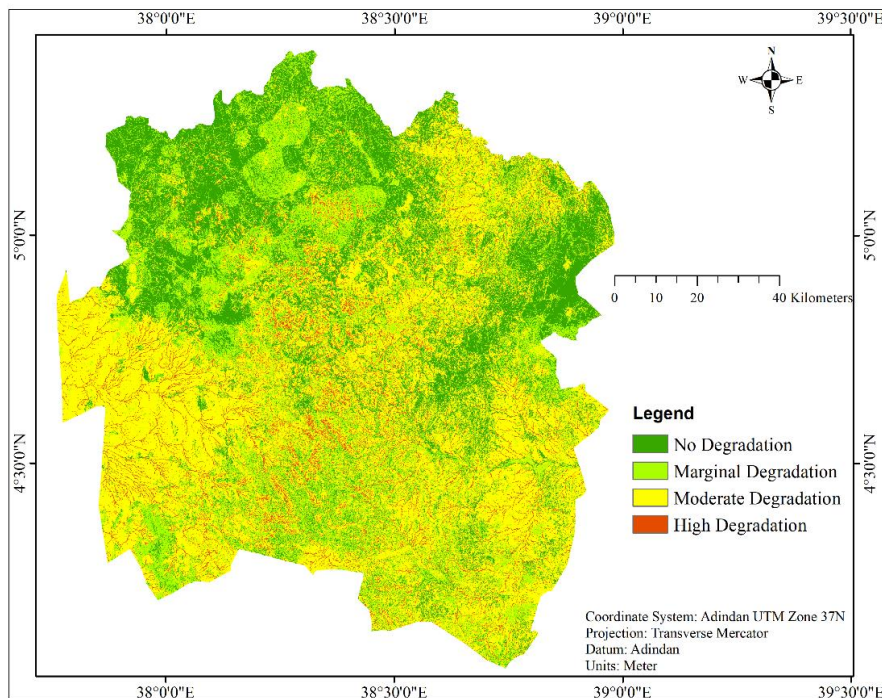


Figure 4. 18 Overall Degradation Map of the Study Area

Table 4. 9: Area Coverage and Level of Rangeland Degradation

Degradation Level	Value	Area (km ²)	Area (%)
No/Very low	1	3823.00	27.70
Marginal	2	2617.18	18.97
Moderate	3	6486.72	46.98
High	4	874.62	6.33
Total Area		13801.01	100.00

4.5 Site Suitability Results for Rangeland Rehabilitation

As stated in the analysis section of this study, the result of the weighted overlay analysis was indicated by the four categories of rangeland suitability classes namely: highly suitable (S1), moderately suitable (S2), marginally suitable (S3), and not suitable (N). The soil suitability as well as the overall site suitability of the study area were categorized based on this classification standard (specified in the method section).

4.5.1. Soil Suitability

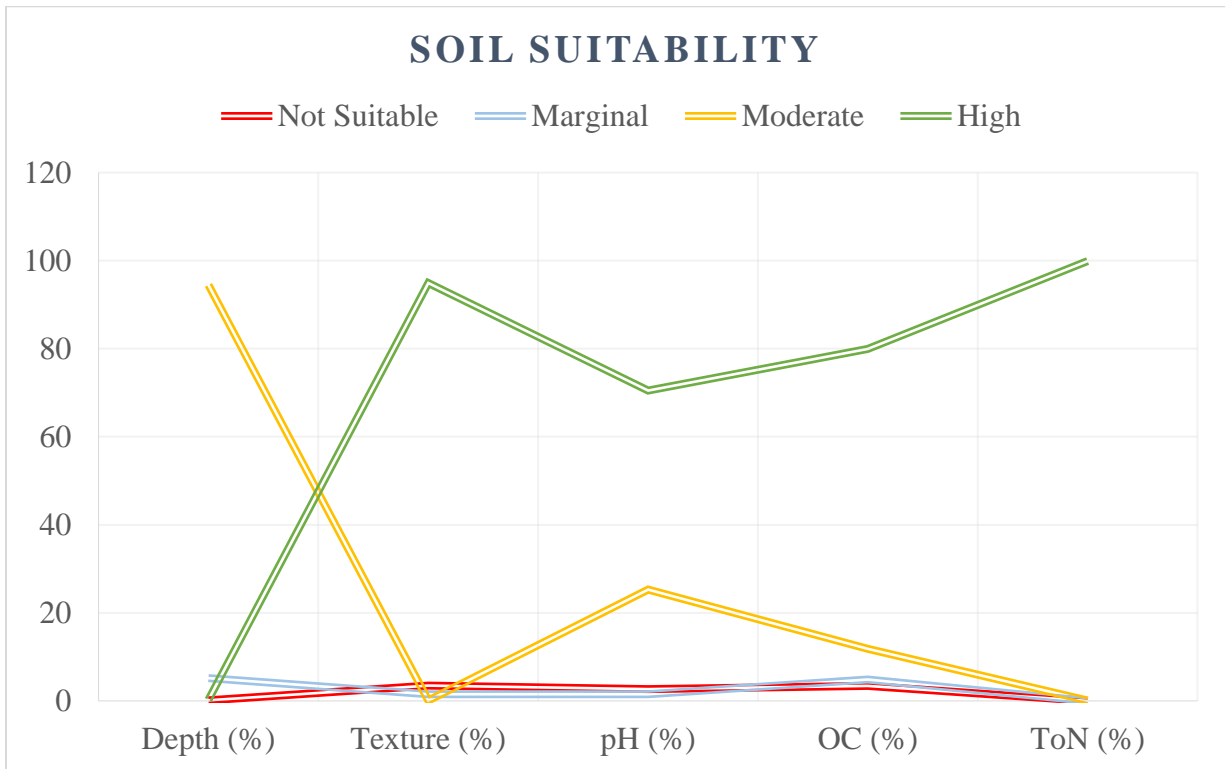


Figure 4. 19: Soil Suitability Graph

Soil suitability was analysed by combining five component factors of soil suitability including soil depth, soil texture, soil OC, soil pH, and soil Total Nitrogen. The result shows that 0.25% of depth, 94.90% of texture, 79.91% of OC, 70.48% of pH, and 99.90% of total nitrogen indicate high suitability of the soil (Figure 4.19 above). Whereas, 94.47% of depth, 0.09% of texture, 11.83% of OC, 25.32% of soil pH, and 0.09% of TotN are moderately suitable. The suitability of soil in the marginal class is a minimum that is 5.17% depth, 1.52% texture, 3.42% OC, 1.54% pH, and 0.01% total Nitrogen. The study area has only 0.11% depth, 3.48% texture, 2.66% pH, 3.42% OC, and 0% TotN area of soil that is not suitable for rangeland rehabilitation. (Figure 4.20), (Figure 4.21), and (Figure 4.22) below show the results of soil suitability.

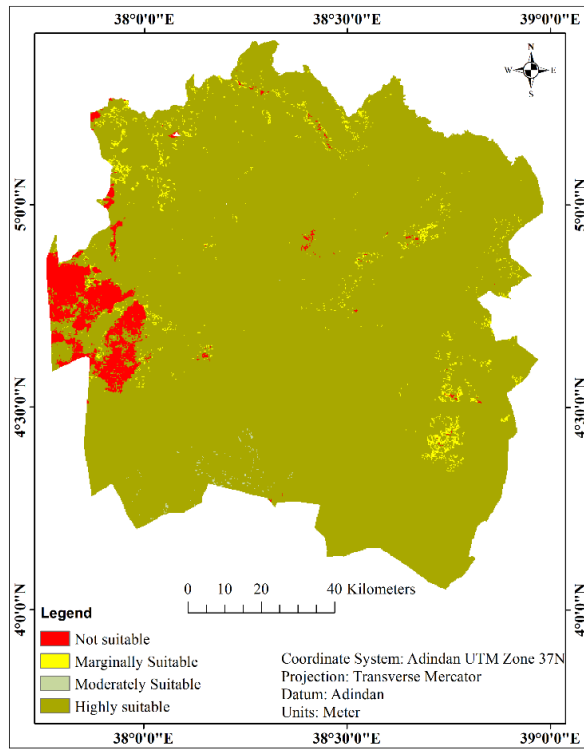
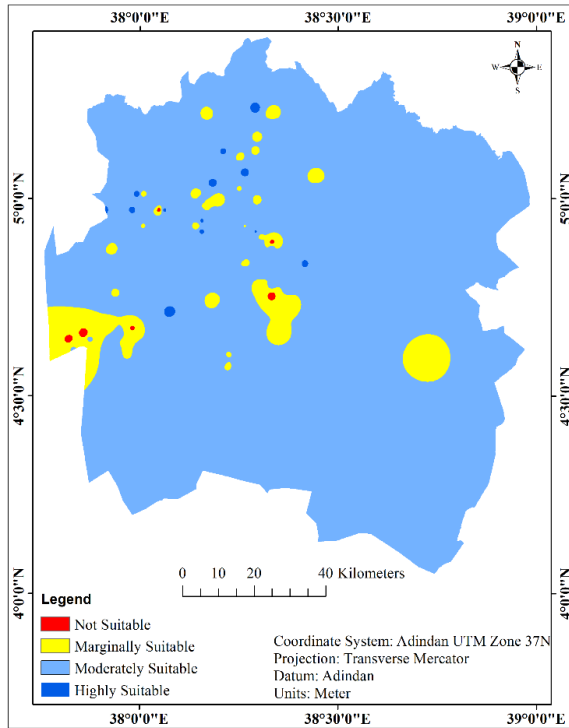


Figure 4. 20 (Left) Soil Depth Suitability Map; (Right) Soil Texture Suitability Map

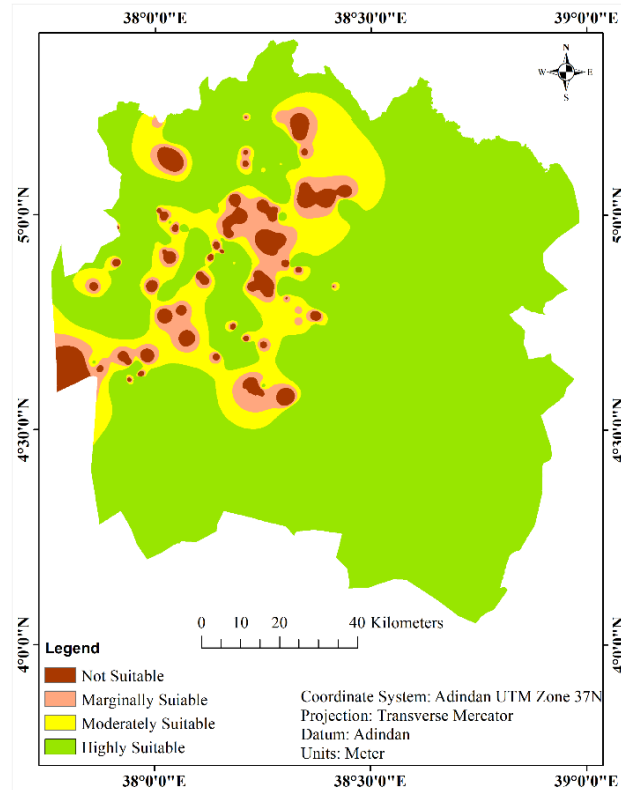
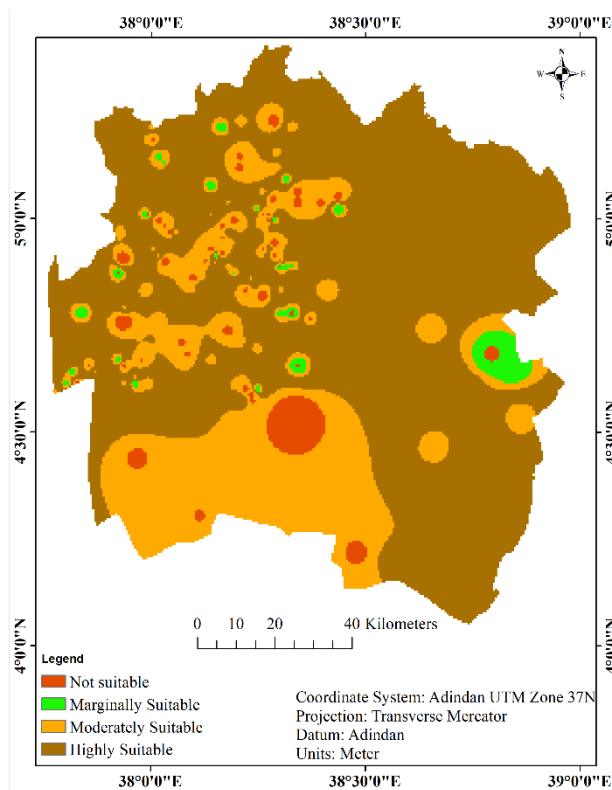


Figure 4. 21 (Left) Soil pH Suitability Map; (Right) Soil Organic Carbon Suitability Map

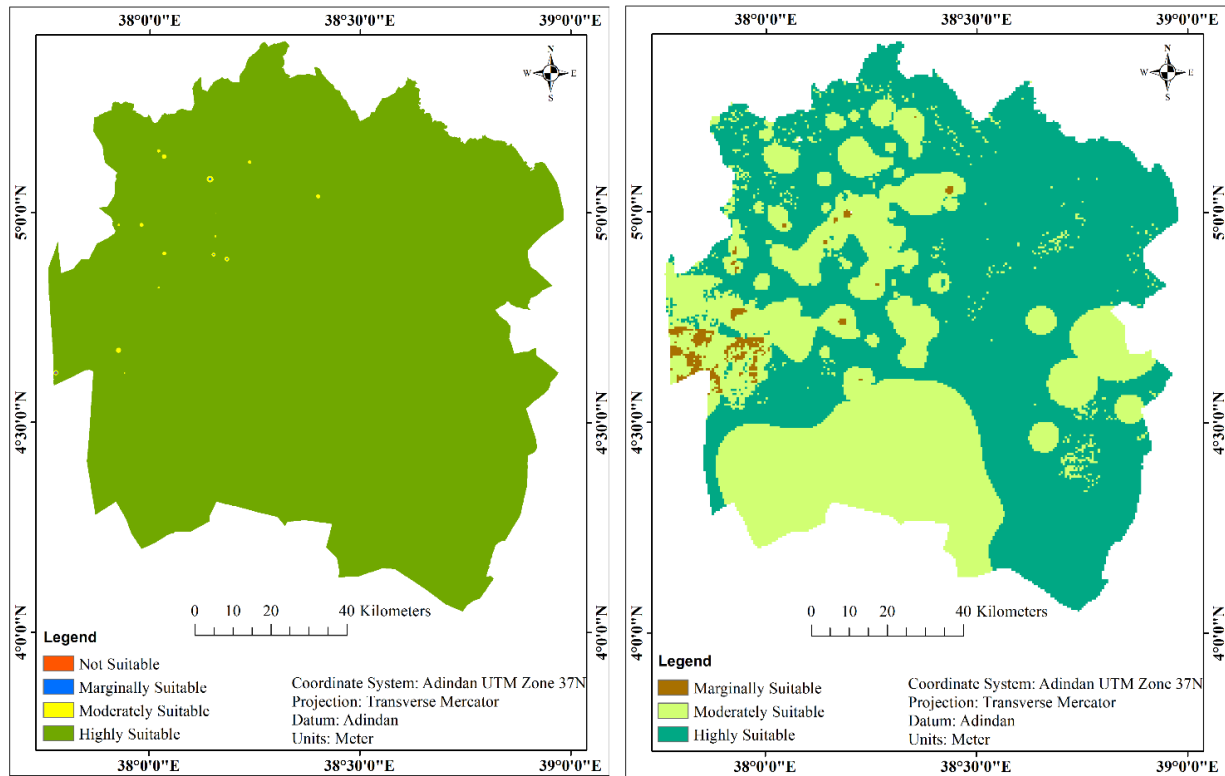


Figure 4. 22 (Left) Soil Total Nitrogen Suitability Map; (Right) Overall Soil Suitability Map

Overall Soil suitability analyzed using the five component factors/criteria and the result indicates that about 60.88% (8,400.83 km²) area of the rangeland soil is highly suitable for the rehabilitation of the rangeland (Table 10). Whereas, 38.16% (5,265.61 km²) area coverage of the soil in the study area is moderately suitable. Only 0.97% (133.89 km²) and 0.32 km² of the rangelands soil area coverage is marginally and not suitable for rehabilitation through grass reseeding respectively.

Table 4. 10: Area Coverage of Soil Suitability

Suitability Range	Value	Area (km ²)	Area (%)
Not Suitable	1	0.32	0.002
Marginally Suitable	2	133.89	0.97
Moderately Suitable	3	5265.61	38.16
Highly Suitable	4	8400.83	60.88
Total area		13800.65	100.00

4.5.2. Site Suitability Criteria

Table 4. 11: Area Coverage and Level of Suitability Criteria for Rangeland Rehabilitation

	Soil		LULC		Rainfall		Slope		Temperature	
	(km ²)	(%)	(km ²)	(%)	(km ²)	(%)	(km ²)	(%)	(km ²)	(%)
S1	8378.91	60.71	1646.97	11.93	8284.29	60.03	3972.67	28.79	2059.58	14.92
S2	5283.70	38.28	511.00	3.70	4734.11	34.30	7074.32	51.26	3925.35	28.44
S3	138.40	1.00	4652.07	33.71	782.60	5.67	1696.98	12.30	4963.82	35.97
N	-	-	6990.96	50.66	-	-	1057.09	7.66	2852.60	20.67

4.5.2.1 Soil

The result of soil suitability shows that 60.71% and 38.28% of the total area is highly and moderately suitable for rehabilitation respectively (Table 4.11 above). Consequently, the result indicates high suitability of all types of component factors except that the maximum suitable depth is identified in the moderate suitability class than in the high suitability. However, there is a highly suitable soil in general than the other suitability classes to make it an input for suitability analysis.

4.5.2.2 LULC

From the suitability result, it is observable that 11.93% and 3.70% of the total rangeland is highly suitable and moderately suitable respectively. Whereas, a significant area coverage (33.71%) of the LULC has little contribution to rehabilitation. More than half (50.66%) of the total area coverage of the rangeland is not suitable for rehabilitation. Since this study intended to rehabilitate the degraded grazing land damaged due to overgrazing, drought, and soil degradation, the LULC type that would be suitable for rehabilitation is mainly the bare soil and the sparsely vegetated part. As a result, the marginally suitable and the unsuitable part of the LULC classes including water, bush, forest, Settlement, and crop in the analysis account for the larger amount of area coverage. The highly suitable site is located in the central part of the study area extending to the south.

4.5.2.3 Rainfall

The suitability result of the rainfall for forage germination and growth is 60.03%, 34.3% and 5.67% highly suitable, moderately suitable, and marginally suitable respectively. About 94.33% of the total area of the rangeland gets from highly suitable to moderately suitable rainfall. There is no location in

the study area receiving unsuitable rainfall (minimum of 250mm - 300mm or maximum of 1000-1200 mm) for forage growth based on the suitability classification (Dengiz et al, 2016).

4.5.2.4 Slope

From the result, 28.79% of the total area with slope of 0-2% is highly suitable for reseeding. Whereas, more than half (51.26%) of the total area of the rangeland is moderately suitable for rehabilitation of the rangeland. From this result, it is clear that in terms of gradient, about 80.05% of the area is highly to moderately suitable for rehabilitation. The result shows that 12.30% and 7.66% (>12% slope) of the total area is marginally suitable and unsuitable respectively.

4.5.2.5 Temperature

The result indicates that areas located in the central part of the study area covering 14.92% with a temperature of 14.9 °C -18.4 °C have a highly suitable temperature. Whereas, 28.44% area coverage of the study area located in the south-central and north-central parts has a moderately suitable temperature. The study area located in the northern and southern parts next to the unsuitable areas with 35.97% of area coverage is marginally suitable and 20.67% of area coverage of the north and south tips of the study area with temperature of 20.8 °C -21.3 °C is unsuitable. Figures (4.23), (4.24) and (4.25) below show results of factors' of site suitability.

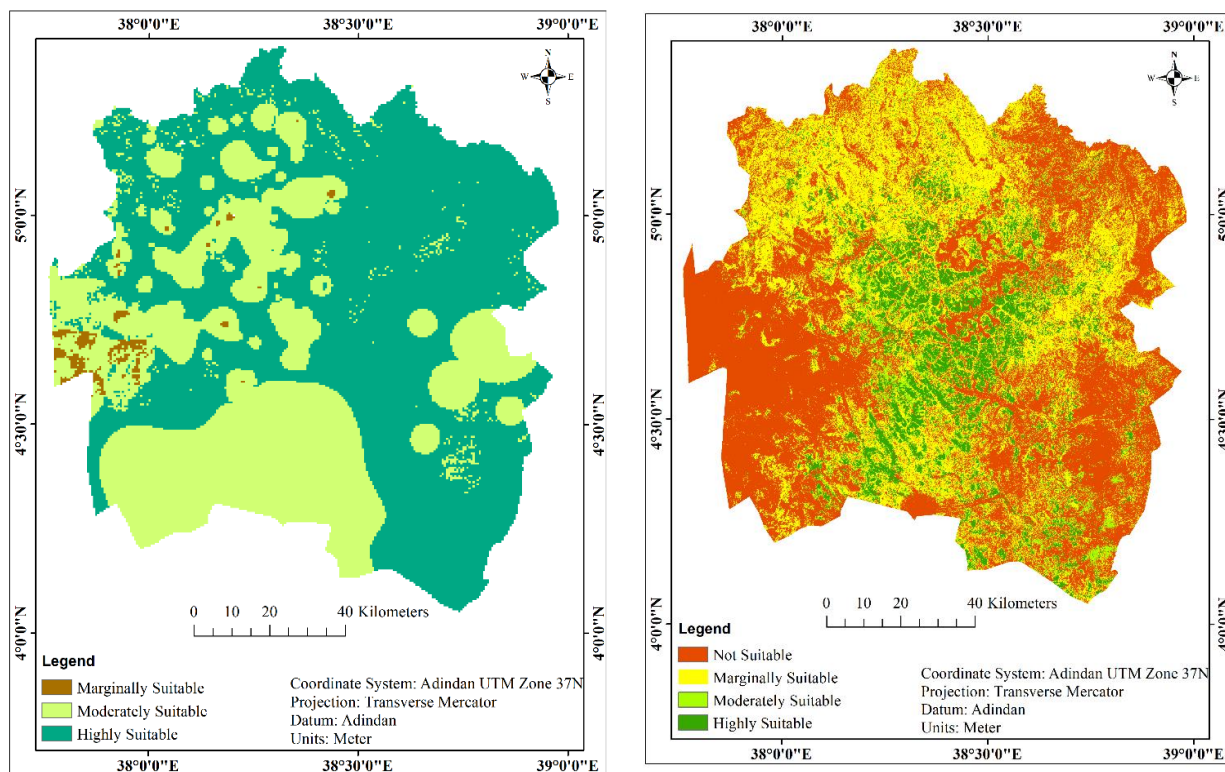


Figure 4. 23 (Left) Soil Suitability Map; (Right) LULC Suitability Map

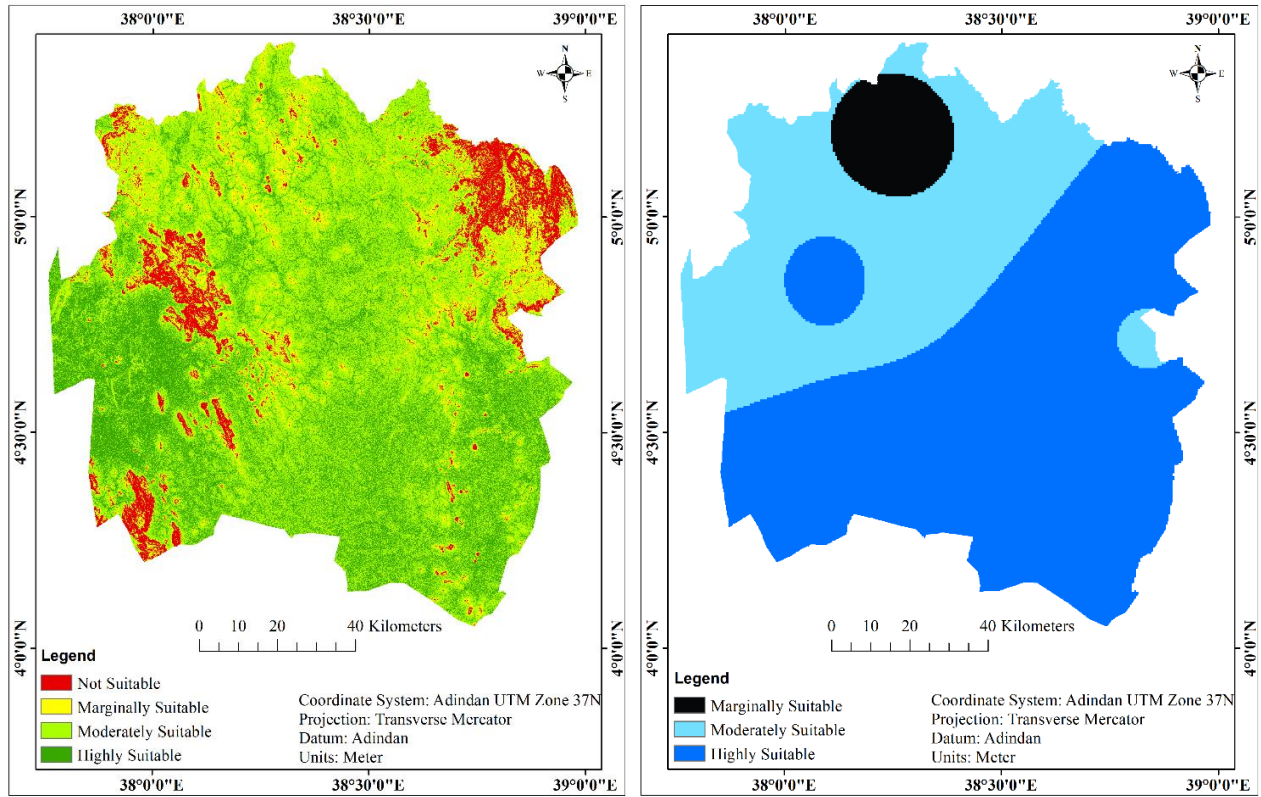


Figure 4. 24 (Left) Slope Suitability Map; (Right) Rainfall Suitability Map

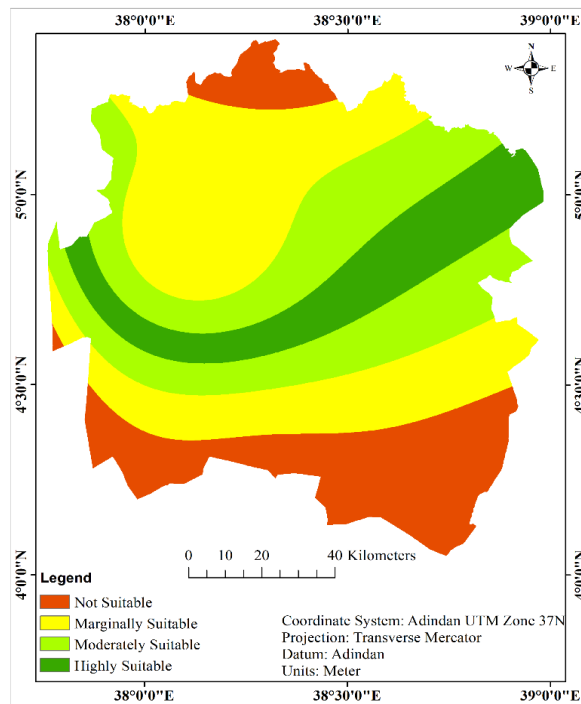


Figure 4. 25 Temperature Suitability Map

4.5.3. Overall Land Suitability Assessment for Rehabilitation

The weighted overlay analysis result of the site suitability indicates that an area of 1,480.62 km² (10.7%) has a minimum contribution for rangeland rehabilitation since it is marginally suitable (Table 4.12). An almost negligible amount of unsuitable area coverage resulted from the weighted overlay analysis of the factors. Whereas, the moderately suitable area accounts for 11,235.39 km² (81.4%) which is the majority of the study area and is suitable for grass reseeding purposes. The highly suitable site has an area coverage of 1,084.99 km² (7.9%) which is the best site that fulfills all the important requirements, and is identified for proper grass reseeding for rangeland rehabilitation (Figure 4.26).

Table 4. 12: Suitability Area Coverage of the Rangeland

Suitability Range	Value	Area (sq_km)	Area (%)
Not Suitable	1	0.0027	0.002
Marginally Suitable	2	1480.62	10.7
Moderately Suitable	3	11235.39	81.4
Highly Suitable	4	1084.99	7.9
Total area		13801	100

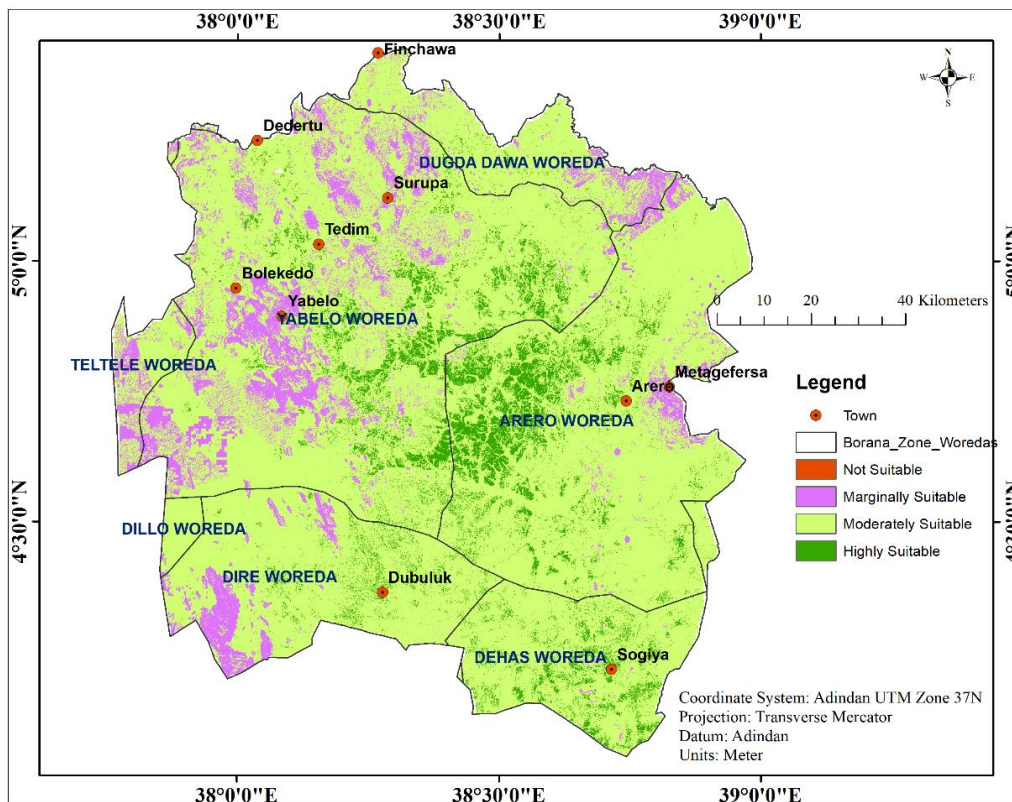


Figure 4. 26 Suitable Site for Grass Seeding/Reseeding in the Study Area

CHAPTER FIVE

5. DISCUSSION

5.1 Rangeland degradation

5.1.1. Vegetation Degradation

According to the result of the NDVI, the non-vegetated area shows an increase between 2002 and 2012. Whereas, it showed a decrease between 2012 and 2021. The sparsely vegetated area showed a continuous increase in 2012 and in 2021 from its state in 2002. On the contrary, moderately vegetated areas showed a continuous decrease in 2012 and in 2021 from the state it was in 2002. Similarly, densely vegetated area showed a significant decrease in 2012 and continued decreasing in 2021. From this result, sparse vegetation has been observed to increase while moderate and dense vegetation is decreasing continuously. This result is in alignment with a study conducted by Sisay et al, (2020) that forest cover was changing at an alarming rate with significant magnitude due to intensive grazing and browsing by the livestock, crop farming, woodcutting, and settlement. Besides, this study agrees with a study by Han et al., (2008) that when rangeland is degraded, the level of vegetation cover reduces and results a shift in vegetation condition from one state to another.

Mountainous parts of the study area, which was occupied by dense forest and vegetated areas in the eastern and western parts of the rangeland except a few areas changed to moderate and sparse vegetation conditions respectively in 2012. Similarly, sparse vegetation extending from north to south as well as moderate vegetation in the east, west, and north parts of the study area in 2002 changed to a non-vegetation condition in 2012. The decrease in vegetation condition is due to the use of trees for building a house in the settlement areas, charcoal for commercialization, firewood for cooking, house apparatuses, and the building of fences. This result is in alignment with a study conducted in one of the woredas in the Borana rangeland by Michael et al., (2015) that a decrease in vegetation condition was caused by the use of wood for fuel, fencing, and use as a construction input by the community. Moreover, the increase in settlements and urbanization can contribute to the decrease in vegetation conditions from dense to moderate and sparse vegetation conditions. Singh (2020), that urbanization and urban expansion as well as economic activities lead to deforestation, proves this idea and consequently increase sparsely vegetated areas.

An increase in the non-vegetated area in 2012 is also due to Agricultural expansion that contributed to the vegetated area being converted into a non-vegetated area. In their study, Sisay et al., (2020) stated that between 2006 and 2016, the forest cover in the Yabelo woreda of Borana rangeland has been

changing into cultivated land and invading bushland. They also added that firewood cutting, construction, and overgrazing deform the forest and vegetated areas and force them to be converted to non-vegetated areas. This study also showed that the degradation of the rangeland vegetation from time to time because human activities affect the ecosystem negatively in search of derived benefits from the rangeland resources. This is supported by a study conducted in Kenya by Waweru & Oleleboo (2013) indicated that human beings and wildlife both are using natural (land) resources and as a result compete negatively.

5.1.2. Livestock feed Degradation

The LULC classification accuracy assessment result shows an overall classification accuracy of 81.01% and Kappa Statistics of 0.77. Kappa values are ranging between 0 and 1 and are classified into three categories. Values greater than 0.80 denote strong agreement, those between 0.40 and 0.80 denote moderate agreement, and less than 0.4 denote poor agreement (Rahman, *et al.*, 2006). Accordingly, the kappa coefficient of the LULC result of this study is almost in strong agreement.

The result of this study indicates that the dominant land cover type in the study area is bush with 36.06% coverage. This result is in agreement with the study conducted by Sisay et al (2020) that the Borana rangeland is mainly dominated by bush that is the major degrading factor of the grazing land in the pastoral community. In addition, this result is also supported by studies that assessed the rangeland condition from 1973 up to 2010 and that one of the reasons for a decrease in grass cover was due to an increase in bush cover (Teshome, 2011; Jaleta et al., 2012; Sintayehu et al., 2006). The current result indicates that the encroachment of bush is still dominant that degrades the rangeland in terms of availability of pastureland. The expansion of bush was because of a ban on fire since the 1970s by government policy that prohibited pastoralists to use fire that was a traditional way for pastoralists to prevent it (Teshome, 2011). Michael et al., (2015) also stated that cutting trees for construction and overgrazing assisted in the deformation of palatable plants again enabling the emergence and expansion of bushes. In addition to the bush cover, bare land and agriculture are also degrading factors of the rangeland. The result of this study showed that agricultural and bare land covers are increased causing the rangeland to diminish. This is supported by Tilahun et al., (2017) that the rangeland communities in Borana especially in Yabelo woreda are increasingly involved in crop cultivation as an alternative means of livelihood, which significantly degrades the grazing area. The total area coverage of these three land cover types goes to 58.57%, which is a large area that is not providing feed for the livestock and encounters livestock production in the Borana rangelands (Yeneayehu et al., 2018). The result of

this study also showed that the bush cover mainly dominates the southwestern, southeastern, and northeastern parts of the rangeland. Whereas, areas extending from the center north to southern parts are dominated by bare lands and agricultural lands.

5.1.3. Soil quality (pH) Degradation

As the soil becomes more acidic, and more alkaline, its suitability to grow crops and grass will decrease. The result of the pH value extremely low to extreme high means its acidity and alkalinity are high indicating soil is degraded in terms of its chemical properties. The result of the soil pH level indicates that the study area has more neutral soil pH even though it is inclined to be more alkaline having a total area of 42.55%. This result aligns with a study conducted in Yabelo woreda that the majority of the area is more alkaline than acidic (Mohammed & Omar, 2021). Rangelands with bare land cover have lower soil pH and as there is continuous overgrazing, the soil quality (pH) will go higher (Getachew et al, 2007; Yong-Zhong et al, 2005). However, the majority of the area ranging from center to north covering an area of 7,496.31km² has no or very little effect of degradation. Whereas, 27.91% and 9.06% of the study area covering 5,102.46 km² has moderate and high degradation respectively. The highly degraded areas are located mainly in the southern parts of the study area as well as observed in the center and northern parts.

5.1.4. Soil Degradation due to Erosion and Deposition

Soil erosion and deposition is one of the degradation factors among the different types of land degradation factors that affect the productivity of land through the depletion of soil nutrients (Nigussie et al, 2015; Tegegne et al, 2017).

The result of rainfall erosivity (R-Factor) indicates that the highest value is observed in the north part of the study area where the higher altitude is observed and lower (239 – 285) values are located in the east part of the study area. Morgan (2005) stated that as altitude increases, the strength of rainfall intensity increases, and hence erosivity will be high. Moderate rainfall erosivity power is observed in the southwest part of the study area covering an area of 4,880.09km². Rainfall erosivity power increases in the northern part (higher R-Factor value of 433-499) of the study area and low erosivity is to the southeastern part. However, the erosion and deposition amount in the northern region is lower since the vegetation cover is better.

The result of the soil erodibility factor (K-Factor) in this study ranges between 0.09 – 0.17 and is considered a low erodibility of soils of the study area to runoff. Moreover, the majority of textural

characteristics of the soils in the study area are Sandy clay loam, sandy loam, and clay loam types (Table 3.8), clay and clay compound soils, as well as, sandy soils are less detachable and less transportable. This result is in agreement with the USDA RUSLE development team (2001) standard that states soil types with high clay content and fine texture ranging between 0.05 – 0.15 k-values as well as high organic carbon content are less susceptible to soil erosion. Besides, the high organic content of the soil in the study area which helps the soil particles to stitch together and resist detachment to erosion. The USDA RUSLE development team also confirmed that organic carbon has the power to aggregate and bind soil particles and the nature of clay soil has the power to resist detachment. Land cover has a major role in soil erosion in terms of protecting the soil from detachment and transportation. From the result, the lower values of cover-factor indicate the soil types under forested area cover are less susceptible to erosion. Whereas, the higher values assigned to bare soil types indicate these cover types are more prone to soil erosion than the rest of the cover types. The result showed that forest cover type, shrublands, and bushland have less vulnerability to soil erosion as compared to other land cover types. Croplands and grasslands, farmlands, and bare soil have medium to highest vulnerability to erosion. Whereas, the central parts of the study area covered with more bare soil are more susceptible to erosion. Most of the study area is considered moderately vulnerable to erosion.

With respect to topographic condition, areas located in the west, Northeast, and South-West parts of the rangeland can be categorized as slightly-to-moderately steep having higher LS-Factor values (101.26 – 586.82), and are highly prone to erosion. Mitasova et al., (1996) stated that areas with higher slope angle and with higher slope lengths are prone to erosion. Consequently, areas from the bottom of the mountains to some parts in the central North and center south with medium values of slope angle and slope length (LS-Factor) are moderate to strongly inclined and are also prone to erosion. Whereas, the majority of the center part and west part are categorized as level to gently inclined (LS-Factor value of 0 – 4.60) and are less prone to erosion and deposition. About 80.05% of the slope of the study area has a 0 – 6 gradient in percent.

The overall result of erosion and deposition indicates that high erosion and deposition observed in the highlands and seasonal riverbanks where high runoff and sediment deposition is a phenomenon. Besides, the higher slope of the terrain as well as the length of this slope near mountains and riverbanks together with the higher intensity of rainfall increases the erosion and deposition rate. This is in agreement with a report (Balasubramanian, 2017) that soil erosion will increase as the topographic

factor (LS-Factor) increases creating speedy runoff as well as, a higher accumulation of water. Cultivated agricultural lands and barren soil areas are the susceptible areas that show more significant erosion and deposition potential than the other land cover types. Streams are mainly flowing from the northwest (Higher topography) to the southeast (Lower topography) and heighten the power of seasonal rivers and increasing erosion and deposition along them. This idea is supported by Mitasova (2014) stated as, streams reinforced by surface runoff due to higher flow accumulation have a higher rate of erosion.

5.1.5. Overall Rangeland Degradation

The overall degradation was identified by categorizing the degradation level into four levels and can be said to be moderately degraded. Based on the results of component factors of degradation, LULC has higher degradation value (47.81%) whereas, soil pH and erosion and deposition have 9.06% and 11.28% respectively. The highly degraded areas have area coverage of 6.33% out of the total land. This result is lower as compared to the above component degradation factors results indicated. This is because the weighted overlay analysis computes common areas of the component factors since some degraded areas in one factor will not match with the other and Vis versa. The result (46.98%) of the weighted overlay analysis indicates that most of the areas in the southwest, southeast, and center north are moderately degraded since these areas are covered with bushes, farm and bare soils. This result agrees with a study conducted by Sisay et al, (2020) that bush encroachment and agriculture land increased between 1986 and 2016 whereas, forestland decreased in Yabelo woreda. Bush cover, bare soils, and riverbanks are the major deteriorating indicators of rangeland in terms of the availability of livestock feed. These areas are endangered to be converted to a high level of degradation very soon unless necessary mitigation measures are taken. The highly degraded area is mainly located in the southern part of the study area and scattered to the north in the form of small patches. In addition, areas near riverbanks are highly degraded because of the high slope that exposes the land for erosion as well as the associated bush cover. The area where it is very little or no degradation is mainly located in the Northern and Northeastern parts of the study area which is good for livestock productivity in terms of availability of enough feed species (mixed grassland and forest). Moreover, the North is mainly characterized by neutral soil type as observed from soil quality (acidity and alkalinity) result. Soil erosion and deposition condition also in the north is not significant or very little as compared to other parts of the rangeland.

The major rangeland degradation indicator in the study area is the bush encroachment that is expanding from time to time as discussed in the LULC part of this study. Next to the bush are the increase of bare soil due to overgrazing as well as the agricultural expansion that is declining the rangeland productivity (Yeneayehu et al, 2018). Whereas, the soil is the major land productivity material where crops and vegetation are growing on. However, the degradation of soil in terms of its increased alkalinity is the source of rangeland degradation that in turn degrades the rangeland productivity. Soil erosion also washes away, deposits soil nutrients useful for plant growth in the lower areas, and turns the upslope land tough and unproductive.

5.2 Rehabilitation Site Suitability

The overall suitability of the area for rehabilitation was categorized based on the suitability classes as high (S1), moderate (S2), marginal (S3), and not suitable (N) (Dengiz et al., 2016; Amiri, 2009).

5.2.1. Soil Suitability

Accordingly, Soil suitability was analysed using soil depth, texture, pH, organic matter and total Nitrogen since these soil characteristics are essential for growing grass (Stichler, 2002; Hamere & Teshome, 2018). These soil components were analysed individually and their respective suitability is presented in (Table 4.13) in the results section. A combined result of these soil characteristics showed that majority the (60.88%) of the soil in the study area is highly suitable for rehabilitation. This class according to Dengiz et al., (2016) has suitable soil texture, organic carbon, soil pH, total nitrogen, and soil depth. This result of soil suitability was taken as input for the suitable site selection for rangeland rehabilitation in the study area. Accordingly, Soils in the areas where no/very little degradation are located in the South-East, North, Northeast, and North-West part of the study area are highly suitable. Whereas, areas in the south, the north, center, and western part have moderately suitable soil types.

5.2.2. LULC Suitability

The suitability of LULC of the study area is analysed from the perspective of its condition to grow palatable grass. Bush cover is not suitable for rehabilitation through replanting since it is difficult to prepare the land for seeding. A total area of LULC covering 36.06% is encroached by bush which limits the suitable site identification for rehabilitation. The agricultural area also is not suitable as it is occupied by crops and farmlands prepared for crop growing. The highly suitable area to rehabilitate would be the bare land that is highly degraded. Approximately, 15% of the total area is highly to moderately suitable for grass reseeding respectively.

5.2.3. Rainfall suitability

The result of rainfall suitability indicates that 60.03% and 34.3% of the study area receives highly suitable and moderately suitable rainfall. The rainfall amount of the study area ranges (from 443mm – 917mm) and is suitable. No area is receiving an unsuitable rainfall amount except for the difference in its magnitude of suitability. Consequently, the southern part of the study area and southwest to northeast direction as well as some area in the center is highly suitable for rehabilitation since it receives 450 mm – 650 mm rainfall is an appropriate rainfall amount (Dengiz, et al. 2016). The majority of the west and northwest of the study area receives moderate (350-450 and 650-850) millimeter rainfall. Whereas, some area in the northern tip has higher rainfall amount which has little suitability (796mm – 917mm).

5.2.4. Slope Suitability

Rangeland topography in the northern and eastern directions that range from moderately inclined to strongly inclined (Ramirez et al, 2020) is marginally suitable. Whereas, the center, South, southeastern, and the western part of the rangeland where the topography ranges from nearly level to gently inclined is moderate to highly suitable for rehabilitation. This area has 28.79% and 51.26% (80.05% total) of the area with highly suitable and moderately suitable slopes respectively. These areas are useful for rehabilitation as the highly suitable area is represented by a 0 – 2 percent gradient while the moderately suitable area is a 2 – 6 percent gradient (Dengiz et al., 2016). Areas in the Center west, northeast, and southwest parts of the rangeland that are mountainously ranging from moderate to very steep slopes are not suitable for rehabilitation.

5.2.5. Temperature Suitability

The result of temperature in the study area shows that the central part covering an area of 14.92% is highly suitable. This area is extended from the west part to the northeastern part of the study area. Whereas, the adequately suitable temperature of 28.44% of the total rangeland is located next to the highly suitable area in north and south directions. An area with little contribution to rehabilitation is covering the majority area (35.97%) in the south and north directions. Areas in the north and south tips of the study area are not suitable in terms of temperature for rehabilitation.

5.2.6. Overall Land Suitability

The dark green area in the suitability map (Figure 4.22) is the highly suitable area used to sow grass seed after the land is prepared for seeding. The highly suitable site covering an area of 7.9% is mainly located in the central and southern parts of the study area where more bare soil LULC class, fertile soil, a suitable amount of rainfall, flat to gentle slope, and appropriate temperature are available. From the result, it is visible that a large size of the rangeland (81.4%) is moderately suitable and this area could

be useful for rehabilitating the area next to the highly suitable area depending on the magnitude of preparing the land for rehabilitation. Areas in the north and northwestern parts with an area coverage of 10.7% are covered with palatable vegetation and are less suitable. The bush cover that occupies 36.06% of the total area minimized the suitable area cover of the rangeland, as the bush is difficult to grow plants under it. This result is in alignment with Berhanu and Suryabhagavan (2015) that the bush has a negative effect in terms of suitability due to its nature to reduce palatable feed and movement to graze and browse for cattle and sheep.

Various rehabilitation methods like removing bush through cutting, managing overgrazing through differed grazing, grass reseeding and using prescribed fire are recommended to manage and rehabilitate the rangeland in Borana Zone (Yeneayehu et al., 2018; Bedasa et al., 2014). Majority of suitable sites located in western part of Arero woreda, around Sogiya town of Dahas woreda, and eastern parts of Yabelo woreda can be rehabilitated using the reseeding method. Suitable sites selected in this study can be used to plant improved seeds of highly productive, fast growing, palatable and deep rooted Rhodes grass in order to restore the degraded area in the rangeland. Rhodes grass is an improved perennial grass which can be grown on-farm and used by agro-pastoralists (Yenesew et al., 2015). According to Yenesew et al., (2015) this grass species was tested and had better productivity and nutritive value when compared with other six species of grasses in their study in Amhara Regional state. Rhodes grass is a recurrent, fast growing, palatable and deep rooted grass that can sustain longer time without being degraded. According to this study, the identified highly and moderately degraded areas in borana rangeland can be rehabilitated using an improved Rhodes grass seed. A study conducted by Bedasa et al., (2014), highly degraded areas that were selected at Jegesa site of Dugda-Dawa woreda, one of the woredas in borana zone were planted with Rhodes seed purchased from Elfora (at Hawassa) and found highly productive and acceptable by pastoralists.

CHAPTER SIX

6. CONCLUSION AND RECOMMENDATIONS

6.1 Conclusion

Rangeland is Land on which the native plant mainly grasses, grass-like plants, forbs, or shrubs are used for current and future grazing and browsing in the customary environment for the production of livestock and wildlife (Allen et al., 2010). The Borana rangeland is degraded and unable to accommodate the requirements of the livestock in providing feed due to different degradation factors. Because of this, pastoralists in the area are unable to get necessary products and services for their livelihood, as the livestock is not productive due to a lack of feed. This condition will exacerbate unless a study to the identification of the type and level of rangeland degradation and take measures to recover it. This study was therefore, initiated to analyse the Borana rangeland degradation condition using factors affecting the degradation and to identify suitable rehabilitation sites through remote sensing and GIS techniques.

Accordingly, NDVI was analysed to identify the degradation and magnitude of change of the rangeland in general and the vegetation in particular. It also addressed the assessment of soil erosion and deposition threats, and soil chemical properties (pH) degradation to know the overall degradation. Finally, the study addressed the assessment of grass reseeding site selection to rehabilitate the rangeland and conducted using appropriate datasets.

Specific data were collected from global websites, local institutions, and from the field that is appropriate and applicable for the analysis works. Accordingly, satellite images of Landsat 7 ETM+ and Landsat 8 OLI images of the three periods (2002, 2012, and 2021) as well as elevation data were collected. Soil data was collected from the Ethiopian Agricultural Research Institute and WLRC of Addis Ababa University. Climate (temperature and rainfall) data were collected from the National Meteorological Institute of Ethiopia. Field data using GPS technology was collected from the study area to be used for training and accuracy assessment.

NDVI-based vegetation analysis and supervised classification methods and techniques were applied to identify the vegetation degradation and map the LULC of the area respectively. The USPED model was applied to investigate the potential threats of erosion and deposition. Soil erodibility, rainfall erosivity, cover condition, and topographic factors were used as indicators to analyse the erosion and deposition potential of the study area using weighted overlay analysis in the ArcGIS environment. The

overall composite degradation map was generated by mapping the level of Soil pH degradation and by conducting a weighted overlay analysis in combination with erosion and deposition as well as vegetation degradation factors. Finally, a suitable site for grass seeding was analysed using LULC, slope, rainfall, temperature, soil depth, soil texture, soil pH, OC, and total Nitrogen factors of suitability. All the results were interpreted based on the actual quantitative outputs of the analysis and discussed. Accordingly, the degradation of the rangeland indicates that 27.70% of the total study area is not degraded or has a very low level of degradation. Whereas, 18.97% of the total rangeland located next to the low degraded areas is marginally degraded. Rangelands with area coverage of 46.98% and 6.33% are degraded moderately and highly respectively. The findings show that majority of the area is categorized in the moderately degraded range. This implies that after some time shortly, the majority of the rangeland will be degraded highly unless proper measures are taken.

With respect to suitability for rehabilitation of the degraded rangeland in terms of grass seeding or reseeding, a negligible amount (0.002%) of area show unsuitability while 10.7% is marginally suitable. A total of 81.4%, which is the majority of the study area, is moderately suitable for grass reseeding while 7.9% of the total area is highly suitable for rehabilitation. In general, the highest area coverage is accounted for moderately suitable land for rehabilitation. The moderately suitable area of the rangeland is also important for rehabilitation if it is sowed with natural fertilizer for grass seeding and tilling the land to some extent. The highly suitable land can help pastoralists grow the necessary feed in the form of hay that could be used during drought seasons to withstand drought-induced cattle starvation and death.

6.2 Recommendations

The following points of recommendation are forwarded based on the findings of this study:

- Different experts in different countries have already used the USPED model to estimate the threat of soil loss in terms of erosion and deposition in an area. However, the results obtained from this study need validation through further investigation by using high-resolution DEM as well as field verification of the result.
- Measures to prevent the expansion, and finally the removal of bush that is highly spreading need to be taken through a detailed feasibility study to initiate rehabilitation projects with the involvement of the community to restore the degraded rangeland.
- Proper planning of the land use in the form of pasture land, agriculture, and forest in the rangeland is required as well as to demarcate the pasture land from other land use types in

proportion to the livestock population minimize overgrazing as well as, discourage the expansion of agriculture.

- In Ethiopia, more recent soil sample data covering the whole country, especially in the rangelands are deficient. Higher precision of the level of physical and chemical properties of soil in the study area can be achieved and shall be conducted by taking recent soil samples at a larger scale in the rangeland. Besides, it is important to do a detailed study and identify which soil parameter is highly important for grass production in the rangelands.
- The fast expansion of the bush encroachment in the study area shall be monitored and action can be taken through the application of remote sensing technologies and frequent mapping of the land use land cover of the rangeland.
- Even if the highly degraded areas are smaller as compared to moderately degraded areas based on the findings, there is a high risk of turning the majority of the rangeland into a highly degraded condition unless degradation protection such as Rhodes grass reseeding and other restoration measures are considered sooner.

REFERENCES

- Abduselam A. Mohamed (2019). Pastoralism and Development Policy in Ethiopia: A Review Study. Budapest International Research and Critics Institute-Journal (BIRCI-Journal) Volume 2, No 4, November 2019, Page 01-11
- A. A. Mustafal, Man Singh R. N Sahoo, Nayan Ahmed, Manoj Khanna, A. Sarangi1 and A. K. Mishra (2011), Land Suitability Analysis for Different Crops: A Multi Criteria Decision Making Approach using Remote Sensing and GIS. Researcher, 2011; 3(12)
- A.O Fatunbi and S. Dube (2008). The Influence of Physical Landscape and Soil Properties on the Threshold of Rangeland Degradation. Grassroots: Newsletter of the Grassland Society of Southern Africa. Vol 8, No.1
- Abera Tilahun, Beyene Teklu and Dana Hoag (2017). Challenges and contributions of crop production in agro-pastoral systems of Borana Plateau, Ethiopia, Hawasa University
- Abhinav Mehta, Shital Shukla and Shrey Rakholia, (2021), Vegetation Change Analysis using Normalized Difference Vegetation Index and Land Surface Temperature in Greater Gir Landscape.
- A.Pistocchi, G.Cassani and O.Zani (2002), Use of the USPED model for mapping soil erosion and managing best land conservation practices. International Congress on Environmental Modelling and Software. 191 (conference)
- Aadugna Tolera and Aster Abebe (2021). Livestock production in pastoral and agro-pastoral production systems of southern Ethiopia. College of Agriculture, Hawassa University, Hawassa, Ethiopia
- African Development Fund (2000), The Federal Democratic Republic of Ethiopia Southeast Rangeland Development Project Completion Report. Agricultural and Rural Development Department North, East and South Regions
- Alelgn Ewunetu, Belay Simane, Ermias Teferi and Benjamin F. Zaitchik 4 (2021), Mapping and Quantifying Comprehensive Land Degradation Status Using Spatial Multicriteria valuation Technique in the Headwaters Area of Upper Blue Nile River. Sustainability, MDPI
- Amaha Kassahun, Asheber Tegegne and Dejene Aberra (2012), Impacts of rangeland degradation on soil physical, chemical and seed bank properties along a gradient in three rangeland vegetation types in Somali region, Eastern Ethiopia; Ethiopian Journal of Agricultural Sciences 22:84-101 (2012)

- Amiri, F., (2009a). A model for classification of range suitability for sheep grazing in semiarid regions of Iran. *Journal of Livestock Research for Rural Development* 21, 68-84.
- Anna Hofmann Oliveira, Gustavo Klinke Neto, Sueli Yoshinaga Pereira (2022), Estimation of erosion and deposition by Unit Stream Power Erosion and Deposition in a sub-basin on the Mogi Guaçu River's margins, municipality of Mogi Guaçu, SP, Brazil.
- Arrebei, N., Sabir, M., Naimi, M., Chikhaoui, M. and Raclot, D. (2020) Assessment of Soil Erosion with RUSLE 3D and USPED in the Nekor Watershed (Northern Morocco). *Open Journal of Soil Science*, 10, 631-642. <https://doi.org/10.4236/ojss.2020.1012031>
- Bedasa E. Tebeje, Bikila N. Gilo, Samuel T. Kawo and Jaldessa D. Liban (2014). Effect of reseeded of Rhodes Grass on the Restoration of Degraded Rangeland of Borana, Southern Ethiopia *Direct Research Journal of Agriculture and Food Science (DRJAFS) Vol.2 (7)*, pp. 102-106
- Berhanu Keno Terfa & K.V. Suryabhadgavan (2015), Rangeland Suitability Evaluation for Livestock Production using Remote Sensing and GIS Techniques in Dire District, Southern Ethiopia; *Global Journal of Science Frontier Research: Environment & Earth Science Volume 15 Issue 1 Version 1.0*
- B.P. Ganasri, H. Ramesh (2015), Assessment of soil erosion by RUSLE model using remote sensing and GIS - A case study of Nethravathi Basin. *Geoscience Frontiers*
- Brabant P., 2010. A land degradation assessment and mapping method. A standard guideline proposal. Les dossiers thématiques du CSFD. N°8. November 2010. CSFD/Agropolis International, Montpellier, France. 52 pp
- B. Terefe, M. Limenih, A. Gureb, A. Angassa (2011), Impact of *Acacia drepanolobium* (An Invasive Woody Species) on Gum-Resin Resources and Local Livelihood in Borana, Southern Ethiopia. *Tropical and Subtropical Agroecosystems*, 14 (2011): 1063-1074
- Carol Kerven, (2006), Review of the literature on Pastoral Economics and Marketing: Central Asian, China, Mongolia and Siberia. Report prepared for the World Initiative for Sustainable Pastoralism, IUCN EARO. Odessa Centre Ltd., UK
- Cees De Haan, Etienne Dubern, Bernard Garancher, and Catalina Quintero (2014), Pastoralism Development in the Sahel: A Road to Stability. Global Center on Conflict, Security and Development. World Bank

- Central Statistical Agency (CSA) (2015/16), Agricultural Sample Survey 2015/16 [2008 E.C.], Volume II Report On Livestock And Livestock Characteristics. Statistical Bulletin 583
- Central Statistics Agency (2019), Population Size by Sex, Area and Density by Region, Zone and Wereda.
- Chuan Liao, Patrick E. Clark, Stephen D. DeGloria (2018), Bush encroachment dynamics and rangeland management implications in southern Ethiopia. *Ecology and Evolution*. 2018; 8:11694–11703.
- Coppock D. Layne (1994), the borana plateau of southern Ethiopia: Synthesis of pastoral research, development and change, 1980-91. IICA (International Livestock center for Africa), Addis Ababa, Ethiopia. 393 pp.
- Daniel Hillel (1998), Environmental soil physics. Elsevier ACADEMIC PRESS 1998 (Book)
- Danielle A. Way, Shannon L. Ladeau W , Heather R. Mccarthy Z, James S. Clarks, Ram Oreng, Adrien C. Finzi and Robert B. Jackson (2009), Greater seed production in elevated CO₂ is not accompanied by reduced seed quality in *Pinus taeda* L. *Global Change Biology* 16, 1046–1056
- David L. Spittlehouse¹ and Robert J. Stathers² (1990), Seedling Microclimate. Ministry of Forests Report Number 65 ISSN 0702-9861.
- Dawit Akeberegna and Mebrate Getabalew (2015). Grazing Land and Rangeland Rehabilitation and Improvement Method. *World Applied Sciences Journal* 33 (12): 1834-1841
- Deepak Gautam (2020), Rangeland Management. Institute of Forestry, Tribhuvan University, Nepal
- Dessalegn G. Desso (2009). Remote sensing and GIS based suitability analysis for livestock production in Yabelo district, southern Ethiopia, Addis Ababa University
- Dika Godana G (2016), The Role of Indigenous Knowledge in Rangeland Management in Yabello Zone, Southern Oromia, Ethiopia. *Arts and Social Sciences Journal*; 7:172
- Dr. Mekbebe Tesema, Addisu Asefa and Yila Delelegn (2022), National Biodiversity Threat Assessment: Ranking Major Threats Impacting Ethiopia's Biodiversity
- E. Raymond Hunt, Jr., James H. Everitt, Jerry C. Ritchie, M. Susan Moran, D. Terrance Booth, Gerald L. Anderson, Patrick E. Clark, and Mark S. Seyfried (2003). Applications and Research Using Remote Sensing for Rangeland Management; *Photogrammetric Engineering & Remote Sensing* Vol. 69, No. 6, June 2003, pp. 675–693
- Espach C; Lubbe LG; Ganzin N. (2009), Determining grazing capacity in Namibia with the aid of remote sensing. *African Journal of Range & Forage Science*, 26(3):133-138.

- Faramarzi1, Z. Heidarizadi1, A. Mohamadi1, and M. Heydari (2018), Detection of Vegetation Changes in Relation to Normalized Difference Vegetation Index (NDVI) in Semi-Arid Rangeland in Western Iran; *J. Agr. Sci. Tech.* (2018) Vol. 20: 51-60
- Fazel Amiri, Abdul Rashid B. Mohamed Shariff and Taybeh Tabatabaie (2012). Monitoring Land Suitability for Mixed Livestock Grazing Using Geographic Information System (GIS)
- Fikadu Lemmessa (2009). Rangeland suitability analysis for livestock production using GIS and Remote Sensing: The case of Yabelo woreda, Southern Ethiopia. Addis Ababa University
- Food and Agriculture Organization of the United Nations (1976). A framework for Land Evaluation. Soil Resources Development and Conservation Service, *FAO Soils Bulletin* No. 32; ILRI Publication No. 22
- Food and Agriculture Organization of the United Nations Rome (2018), Terms and Definitions FRA 2020. Forest Resources Assessment Working Paper 188
- Gemedo Dalle, Brigitte L. Maass and Johannes Isselstein (2006), Encroachment of woody plants and its impact on pastoral livestock production in the Borana lowlands, southern Oromia, Ethiopia; *African Journal of Ecology*, 44, 237–246
- G. Oba D. G. Kotile (2001), Assessments of Landscape Level Degradation in Southern Ethiopia: Pastoralists Vs Ecologists. A Paper Prepared For the International Conference on Policy and Institutional Options for the Management of Rangelands in Dry Areas May 7 - 11, Hammamet, Tunisia
- Getachew Haile, Mohammed Assen and Abule Ebro (2007), Effects of rangeland management systems on soil characteristics of Yabello rangelands, Southern Ethiopia. *Ethiopian Society of Soil Science*
- G. Telkar1* and Neha S. Pote (2018), Soil Erosion: Types and Their Mechanism. *Biomolecule Reports- An International eNewsletter* BR/05/18/14
- Hamere Yohannes & Teshome Soromessa (2018). Land suitability assessment for major crops by using GIS-based multi-criteria approach in Andit Tid watershed, Ethiopia, *Cogent Food & Agriculture*, 4:1
- Helena Mitasova, Jaroslav Hofierka, Maros Zlocha & Louis R. Iverson (1996), Modelling topographic potential for erosion and deposition using GIS, *International Journal of Geographical Information Systems*, 10:5, 629-641

- Helena Mitasova and Lubos Mitas (1999), Multiscale Soil Erosion Simulations for Land use Management. University of Illinois at Urbana-Champaign; North Carolina State University; <https://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.69.5171&rep=rep1&type=pdf>
- Helena Mitasova, Anna Petrasova, Vaclav Petras, Steve Warren, Matt Hohmann, Niels G Svendsen, Tom Ruzycki (2014), Soil erosion and deposition modeling, GIS-based tutorial. <https://ncsu-geoforall-lab.github.io/erosion-modeling-tutorial/>
- Helena Mitasova, Barton M., Ullah I., Hoierka J., and Harmon R.S. (2014) GIS-Based Soil Erosion Modeling. In: John F. Shroder (ed.) Treatise on Geomorphology, Volume 3, pp. 228-258. San Diego: Academic Press. Elsevier Inc. All rights reserved.
- Hijaba Ykhanbai, Rishu Garg, Aman Singh, Stephen Moiko, Cherie Enawgaw Beyene, Dilys Roe, Fred Nelson, Tom Blomley, and Fiona Flintan (2014), Conservation and “Land Grabbing” in Rangelands: Part of the Problem or Part of the solution?
- Hillary Mugiyo, Vimbayi G. P. Chimonyo¹, Mbulisi Sibanda, Richard Kunz, Luxon Nhamo, Cecelia R. Masemola, Caroline Dalin, Albert T. Modi, Tafadzwa Mabhaudhi (2021). Multi-criteria suitability analysis for neglected and underutilized crop species in South Africa
- Hurni H. (1985), erosion-productivity-conservation systems in Ethiopia. Soil Conservation Research Project; University of Berne, Switzerland in association with United Nations University Addis Ababa Ethiopia. Presented for IV International Conference on Soil Conservation
- Hurni H, Solomon Abate, Amare Bantider, Berhanu Debele, Ludi E, Portner B, Birru Yitaferu, Gete Zeleke (2010), Land degradation and sustainable land management in the Highlands of Ethiopia.
- IGAD Center for Pastoral Areas & Livestock Development (ICPALD) (2013). The Contribution of Livestock to the Ethiopian Economy. Policy Brief Izzy Birch (2018). Economic growth in the lowlands of Ethiopia
- Daniel Jaleta, Mulugeta Limenih & Bekele Lemma (2011). Extent of Bush Encroachment and Its Impacts on Selected Soil Properties in Borana Rangeland, Ethiopia. Proceeding International Conference on Ecosystem Conservation And Sustainable Development 293-307; (ECOCASD 2011) 10-12 February 2011, Ambo University, Ethiopia

- James R. Anderson, Ernest E. Hardy, John T. Roach, and Richard E. Witmer (1976), A Land Use and Land Cover Classification System for Use with Remote Sensor Data. United States Geological Survey, Washington
- Jannes Stolte, Mehreteab Tesfai, Lillian Øygarden, Sigrun Kværnø (NIBIO) Jacob Keizer, Frank Verheijen, Panos Panagos, Cristiano Ballabio, Udi Hessel (2016), Soil threats in Europe: status, methods, drivers and effects on ecosystem services. A review report, deliverable 2.1 of the RECARE project
- Jens Oldeland, Wouter Dorigo, Dirk Wesuls and Norbert Jürgens (2010), Mapping Bush Encroaching Species by Seasonal Differences in Hyperspectral Imagery. *Remote Sens.* 2010, 2, 1416-1438
- Jinlan Wang, Wen Li, Wenxia Cao and Shilin Wang (2021), Effects of different intensities of long term grazing on plant diversity, biomass and carbon stock in alpine shrub land on the Qinghai-Tibetan Plateau. Creative commons
- Jinxun Liu, Shuguang Liu, Larry L. Tieszen, and Mingshi Chen (2007), Estimating Soil Erosion Using the USPED Model and Consecutive Remotely Sensed Land Cover Observations. Conference Paper
- John E. Mitchell, Editor (2010), Criteria and Indicators of Sustainable Rangeland Management. University of Wyoming Extension Publication No. SM-56. 227 p.
- J. G. Han, Y. J. Zhang, E. C. J. Wang, W. M. Bai, Y. R. Wang, G. D. Han and L. H. Li (2008), Rangeland degradation and restoration management in China. *The Rangeland Journal*, 2008, 30, 233–239
- Lang, M.; Mahyou, H.; Tychon, B. (2021), Estimation of Rangeland Production in the Arid Oriental Region (Morocco). Combining Remote Sensing Vegetation and Rainfall Indices: Challenges and Lessons Learned. *Remote Sens.*, 13, 2093.
- Lin Bai, Cuizhen Wang, Shuying Zang, Yuhong Zhang, Qiannan Hao and Yuexiang Wu (2016), Remote Sensing of Soil Alkalinity and Salinity in the Wuyu'er-Shuangyang River Basin, Northeast China. *Remote Sens.* 2016, 8, 163
- L. Onyango, J. Mango, S. Desta, S. Tezera, Z. Kurui, B. Wamubeyi, A. Mohammed, A. Fatuma Edited by: C. Perez, W. Förch, L. Cramer (2012), CGIAR Research Program on Climate change, Agriculture and Food Security (CAAFS) Village Baseline Study: Site Analysis Report for Yabello – Borana, Ethiopia (ET0106)

- Louisa J M Jansen and Antonio Di Gregorio (2014), Land Cover Classification System (LCCS): Classification Concepts and User Manual (FAO)
- Lydia M. Chabala, Augustine Mulolwa and Obed Lungu (2014), Mapping the Spatial Variability of Soil Acidity in Zambia. *Agronomy* 2014, 4, 452-461
- Malabo Montpellier Panel (2020). Meat, Milk and More: Policy innovations to shepherd inclusive and sustainable livestock systems in Africa. Ethiopia case study Dakar, Senegal: International Food Policy Research Institute.
- Masoud Masoudi, Parviz Jokar, and Biswajeet Pradhan (2018), A new approach for land degradation and desertification assessment using geospatial techniques. *Natural Hazards and Earth System Sciences*, 18, 1133–1140, 2018
- Meera Gandhi.G, S.Parthiban, Nagaraj Thummalu Christy (2015), Vegetation change detection using remote sensing and GIS – A case study of Vellore District. *Procedia Compute Science* 57 1199 – 1210, Published by Elsevier B.V.
- Mengesha Asefa, Min Cao, Yun He, Ewketu Mekonnen, Xiaoyang Song, Jie Yang (2020), Ethiopian vegetation types, climate and topography; *Plant diversity* 42(2020) 302-311
- Mganga K. Zowe (2009). Impact of Grass Reseeding Technology on Rehabilitation of the degraded Rangelands: A Case Study of Kibwei District, Kenya. University of Nairobi
- Michael Elias, Oliver Hensel, Uwe Richter, Christian Hülsebusch, Brigitte Kaufmann and Oliver Wasonga (2015). Land Conversion Dynamics in the Borana Rangelands of Southern Ethiopia: An Integrated Assessment Using Remote Sensing Techniques and Field Survey Data. *Journal Of Environments* 2, 1-31
- Michael Elias Mgalula (2016). Assessing trends in land use change in the Borana rangeland Ethiopia as one cause of greenhouse gas emissions and carbon sequestration variations; German Institute for Tropical and Subtropical Agriculture, Germany
- Mohammed Abaoli, Omer Kara (2021), Soil Quality Status under Dryland Vegetation of Yabello District, Southern Ethiopia. *International Journal of Agricultural and Bio systems Engineering*, Vol: 15, No: 6
- Mohammed Mussa, Hakim Hashim and Mukeram Teha (2016), Rangeland Degradation: Extent, Impacts, and Alternative Restoration Techniques in the Rangelands of Ethiopia. *Tropical and Subtropical Agroecosystems*, 19: 305 – 318

- Mohammed Yimer (2015). Pastoral Development Pathways in Ethiopia: The Policy Environment and Critical Constraints, Arba Minch University
- Morales, F., Jr.; de Vries, W.T. (2021), Establishment of Land Use Suitability Mapping Criteria Using Analytic Hierarchy Process (AHP) with Practitioners and Beneficiaries. *Land*, 10, 235. <https://doi.org/10.3390/land10030235>
- Morgan RPC. (1995) Soil Erosion and Conservation (second edition). Longman Group: Har-low.
- Morgan RPC. (2005) Soil erosion and conservation. Third edition. *National Soil Resources Institute, Cranfield University*. Blackwell Publishing Company
- Mostafa A. Abdellatif, Ahmed A. El Baroudy, Muhammad Arshad, Esawy K. Mahmoud, AhmedM. Saleh, Farahat S. Moghanm , Kamal H. Shaltout, Ebrahim M. Eid, and Mohamed S.Shokr (2021), A GIS-Based Approach for the Quantitative Assessment of Soil Quality and Sustainable Agriculture. *Sustainability*, 13, 13438
- M. Sreelekha and Dr. S. Narayana Reddy (2019), Accuracy Assessment of Supervised and Unsupervised Classification using NOAA Data in Andhra Pradesh Region. *International Journal of Engineering Research & Technology (IJERT)*; Vol. 8 Issue 12
- Mussa, Mohammed; Hashim, Hakim; Teha, Mukeram (2016). Rangeland degradation: extent, impacts, and alternative restoration techniques in the rangelands of Ethiopia; *Tropical and Subtropical Agroecosystems*, vol. 19, 3, pp. 305-318
- Nahom gudeta fajji (2015). A remote sensing and GIS scheme for rangeland quality assessment and management in the North West province, South Africa
- Neitsch s.l., Arnold j.g., kiniry j.r., Williams j.r. (2000), Erosion Soil and Water Assessment Tool Theoretical Documentation Texas Agricultural Eksperiment Station. pp. 625.
- Niguse Bekele and Gizachew Kebede (2014), Rangeland Degradation and Restoration in Semi- arid Areas of Southern Ethiopia: - The Case of Borana Rangeland. *International Journal of Environmental Sciences Vol. 3 No. 2. 2014. Pp. 94-103*
- Nigussie Haregeweyn, Atsushi Tsunekawa, Jan Nyssen, Jean Poesen, Mitsuru Tsubo, Derege Tsegaye Meshesha, Brigitta Schu'tt, Enyew Adgo, Firew Tegege (2015), Soil erosion and conservation in Ethiopia: A review.
- Nigus T.Tsegaye (2021). Land Use and Land Cover Change Analysis Using GIS and Remote Sensing in The Case of Kersa District, Jimma Zone, Oromia Region, Ethiopia. Research Center of the CHU of Québec-Laval University

- Orhan Dengiz, Mustafa Sağlam, İnci Demirağ Turan (2016), Determination of Land Suitability Site for Some Forage Legumes Using Multi-Criteria Assessment and Geostatistical Approach. *International Scientific Researches Journal*; Vol. 72 | No. 3 | Mar 2016
- Pellant, M., P. Shaver, D.A. Pyke, and J.E. Herrick. (2005), Interpreting indicators of rangeland health, version 4. Technical Reference 1734-6. U.S. Department of the Interior, Bureau of Land Management, National Science and Technology Center, Denver, CO. V05. 122 pp.
- Peter Omondi Bolo, Rolf Sommer, Job Kihara, Michael Kinyua, Sylvia Nyawira, An Notenbaert (2019), Rangeland Degradation: Causes, Consequences, Monitoring Techniques and remedies. CIAT Publication No. 478, Regional Office for Africa, Kenya
- Prakash T.N. (2003), Land Suitability Analysis for Agricultural Crops: Fuzzy Multicriteria Decision Making Approach. Thesis
- Prof. A. Balasubramanian (2017), Soil Erosion – Causes and Effects. Technical report
- P.J.J.Desmet and G.Govers (1995), GIS-based simulation of erosion and deposition patterns in an agricultural landscape: a comparison of model results with soil map information. Volume 25, Issues 1–4, June 1995, Pages 389-401; Elsevier Publishing
- P. M. Saco, G. R. Willgoose, G. R. Hancock. Eco-geomorphology and vegetation patterns in arid and semi-arid regions. *Hydrology and Earth System Sciences Discussions*, European Geosciences Union, 2006, 3 (4), pp.2559-2593.
- Rahman, M.M, Csaolovics, E., Koch, B., and Kohl, M. (2006). Interpretation of Tropical Vegetation Using Landsat ETM+ Imagery
- Rajendra B. Zolekar, Vijay S. Bhagat (2018), Multi-Criteria Land Suitability Analysis for Plantation in Upper Mula and Pravara Basin: Remote Sensing and GIS Approach. *Journal of Geographical Studies*, 2(1), 12-20, 2018
- Rami Zurayk, Faraj el Awar, cristine Sayegh, Shady Hamadeh and Abdel Ghni Chehab (2001), AGIS Based methodology for soil degradation evaluation. Faculty of agricultural and food sciences American university of Beirut.
- Rattan Lal (2015), Restoring Soil Quality to Mitigate Soil Degradation. *Sustainability* 2015, 7, 5875-5895
- Ronald C. Estoque (2011), GIS-based Multi-Criteria Decision Analysis. Division of Spatial Information Science
- R. Lasage, A. Seifu, M. Hoogland, A. de Vries (2010), Report on general characteristics of the

- Borana zone, Ethiopia; IVM Institute for Environmental Studies; Report R-10/03
- R. W. Saaty (1987), The Analytic Hierarchy Process-What It Is and How It Is Used. *Mathl Modelling*, Vol. 9, No. 3-5, pp. 161-176, 1987, Printed in Great Britain. Pergamon Journals Ltd
- Russell G. Congalton (1991), A Review of Assessing the Accuracy of Classifications of Remotely Sensed Data. *REMOTE SENS. ENVIRON.* 37:35-46; Department of Forestry and Resource Management, University of California, Berkeley
- Salomón Ramírez, Carolina Espejo, Mauricio Ramírez, Alexander Páez and Dustin Gómez (2020), Method for vertical accuracy assessment of digital elevation models derived from remote sensing data. *SSNe* 2244-8853 ISSN 1012-1617
- Seedling Microclimate (2021), GIS-Based Multi-Criteria Analysis of the Suitability of Western Siberian Forest steppe Lands.
- Shapiro, B.I., Gebru, G., Desta, S., Negassa, A., Nigussie, K., Aboset G. and Mechale. H. (2017), Ethiopia livestock sector analysis. ILRI Project Report. Nairobi, Kenya: International Livestock Research Institute (ILRI).
- Perminder Singh, Ovais Javeed (2020). NDVI Based Assessment of Land Cover Changes Using Remote Sensing and GIS-(A case study of Srinagar district, Kashmir). *Sustainability, Agri, Food and Environmental Research*, (ISSN: 0719-3726), 8(X),
- Sintayehu Mesele, Heluf Gebrekidan, Lemma Gizachew, D. Layne Coppock (2006), Changes in Land Cover and Soil Conditions for the Yabelo District of the Borana Plateau, 1973-2003, pastoral risk management project
- Sisay Taye Gifawesen, Debela Hunde Feyssa and Gudina Legesse Feyissa (2020), Analysis of forest cover change in Yabello Forest, Borana Zone, Ethiopia. *International Journal of Biodiversity and Conservation*. Vol. 12(4), pp. 350-362, October-December 2020
- Solomon Desta (2006). Pastoralism and development in Ethiopia; *Ethiopian Economic Association*, Vol. 9 No. 3
- Solomon Desta, S. Tezera, G. Gebru, P. Kristjanson (2011), Summary of Baseline Household Survey Results: Borana, Ethiopia CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS); Copenhagen, Denmark. Available online at: <http://ccafs.cgiar.org/resources/baseline-surveys>

- Stefan Hajkovicz (2007), A comparison of multiple criteria analysis and unaided approaches to environmental decision making. *Environmental science & policy* 10 (2007) 177–184
- Steven D. Warren, Thomas S. Ruzycki, Robert Vaughan, Peter E. Nissen (2019), Validation of the Unit Stream Power Erosion and Deposition (USPED) model at Yakima Training Center, Washington. *Northwest Science*, Vol. 92, No. 5
- Steven D. Warren and Thomas S. Ruzycki (2022), Validation of the USPED Erosion and Deposition Model at Schofield Barracks, O‘ahu, Hawai‘i. *Pacific Science* (2022), vol. 76, no. 1:43–51 doi:10.2984/76.1.4
- Charles Stichler (2002), *Grass Growth and Development*. Soil & Crop Sciences Communications. The Texas A&M University
- Su Yong-Zhong, Li Yu-Lin, Cui Jian-Yuan, Zhao Wen-Zhi (2005), Influences of continuous grazing and livestock exclusion on soil properties in a degraded sandy grassland, Inner Mongolia, northern China. *Catena* 59 (2005) 267 – 278. Elsevier
- Tegegne Molla and Biniam Sisheber (2017), Estimating soil erosion risk and evaluating erosion control measures for soil conservation planning at Koga watershed in the highlands of Ethiopia. *Solid Earth*, 8, 13–25, 2017
- Terrance Booth, Paul T. Tueller (2003), *Rangeland Monitoring Using Remote Sensing*. *Arid Land Research and Management*, 17: 455–467, Taylor & Francis group
- Teshome Abate Beza (2011), *Land Cover Dynamics in Savanna Ecosystem of Borana Ethiopia*. Thesis; Master of Science in Geospatial Technologies
- Teshome Abate and Ayana Angassa (2016). *Conversion of savanna rangelands to bush dominated landscape in Borana, Southern Ethiopia*, Hawasa University
- Thanh Tuan Nguyen, Ann Verdoodt, Van Y Tran, Nele Delbecque, Thuy Chi Tran, Eric Van Ranst (2015), Design of a GIS and multi-criteria based land evaluation procedure for sustainable land-use planning at the regional level. *Agriculture, ecosystems and environment* 200 (2015) 1-11
- Thenkabail, P. S., Gamage, M. S. D. N. and Smakhtin, V. U (2004), *The Use of Remote Sensing Data for Drought Assessment and Monitoring in Southwest Asia* (Vol. 85). IWMI
- Thomas M. Lillesand, Emeritus, Ralph W. Kiefer, Emeritus, Jonathan W. Chipman (2015), *remote sensing and image interpretation*. 7th edition, ISBN 978-1-118-34328-9
- Tsegaye Birkneh (2007), *Assessment of Land Degradation Using GIS Based Model and Remote*

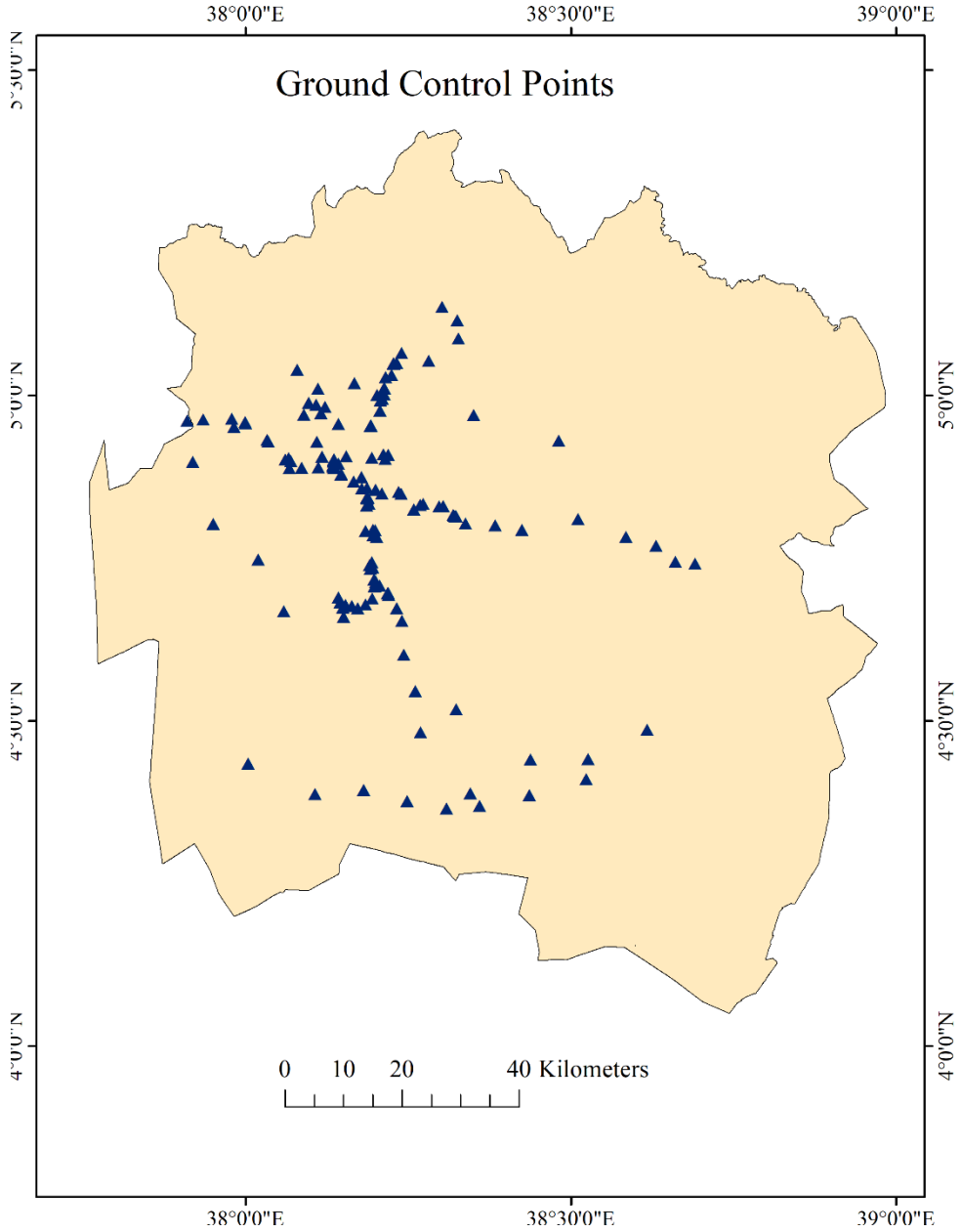
- Sensing in Bishan Guracha-Adilo Sub catchments, Southern Ethiopia. A Thesis Submitted to the School of Graduate Studies of Addis Ababa University
- United States Department of Agriculture (USDA) Natural Resources Conservation Service (1998), Soil quality Information Sheet. Soil Quality Indicators: pH; <http://soils.usda.gov>
- USDA RUSLE Development Team (2001), Revised Universal Soil Loss Equation Version 2, (RUSLE2) HANDBOOK
- Valerie Graw, Carsten Oldenburg, and Olena Dubovyk (2016), Bush Encroachment Mapping for Africa: Multi-scale analysis with remote sensing and GIS; ZEF-Discussion Papers on development Policy No. 218
- V.G. Allen, C. Batello, E.J. Berretta, J. Hodgson, M. Kothmann, X. Li, J. McIvor, J. Milne, C. Morris, A. Peeters and M. Sanderson (2010). An international terminology for grazing lands and grazing animals, Blackwell Publishing Ltd. Grass and Forage Science, 66, 2–29
- V. Kiranmai, N. Aparna, B. Jyothi Sree, D. Pavan Kalyan, K. Suresh (2020), Land Use/Land Cover Classification Using Normalized Difference Vegetation Index (NDVI) And PCA. Journal of Engineering, Computing and Architecture; Volume 10, Issue 6
- V.K. Kalichkin, A.I. Pavlova & O.M. Logachova (2021), GIS-Based Multicriteria Analysis of the Suitability Of Western Siberian Forest-Steppe Lands, Annals of GIS, 27:2, 225-237
- F. K. Waweru and W. L. Olelebo (2013), Human-Wildlife Conflicts: The Case of Livestock Grazing Inside Tsavo West National Park, Kenya. *Humanities and Social Sciences* Vol.3, No.19
- Wischmeier, Walter.H, and Smith, Dwight.D. (1978), Predicting Rainfall Erosion Losses. A guide to Conservation Planning. US Department of Agriculture, agriculture handbook no. 537.
- Yahya Farhan and Samer Nawaiseh (2015), Spatial Assessment of Soil Erosion Risk Using RUSLE and GIS Techniques. *Environ Earth Science* (2015) 74:4649–4669; Springer Verlag Berlin Heidelberg
- Yared Mesfin Tessema , Justyna Jasińska, Lemma Tiki Yadeta, Marcin Switoniak , Radosław Puchałka, and Eyob Gebrehiwot Gebregeorgis (2020), Soil Loss Estimation for Conservation Planning in the Welmel Watershed of the Genale Dawa Basin, Ethiopia. *Agronomy* 2020, 10, 777
- Yeneayehu Fenetahun, Xinwen Xu, Yongdong Wang (2018). Assessment of Range Land Degradation, Major Causes, Impacts, and Alternative Rehabilitation Techniques in Yabello Rangelands Southern Ethiopia.

- Yeneayehu Fenetahun, Xu-Xinwen, WangYong-dong (2019). Rehabilitating benefits and its sustainability of a degraded semi-arid Rangeland in Borana Zone Southern Ethiopia; MOJ Ecology & Environmental Sciences Volume 4 Issue 4 (4):153–158.
- Yeneayehu Fenetahun, Tihunie Fentahun (2020), Socio-economic profile of arid and semi-arid agro pastoral region of Borana rangeland Southern, Ethiopia. MOJ Ecology & Environmental Sciences Volume 5 Issue 3 – 2020
- Yenesew Abebe, Molla Tafere, Shiferaw Dagne, Mekonen Tolla, Yihenew G.Selassie, Agraw Amane And Dessalegn Molla (2015), Best fit practice manual for Rhodes grass (*Chloris Gayana*) production
- Yoram Wind and Thomas L.Saaty (1980), Marketing applications of analytical hierarchy process. Management science vol.26, No. 7 1980
- Zemenu Mintesnot (2009), Bush Encroachment Mapping Using Supervised Classification and Spectral Mixture Analysis in Borana Rangelands: A Case Study in Yabello Zone, Addis Ababa, July 2009

APPENDICES

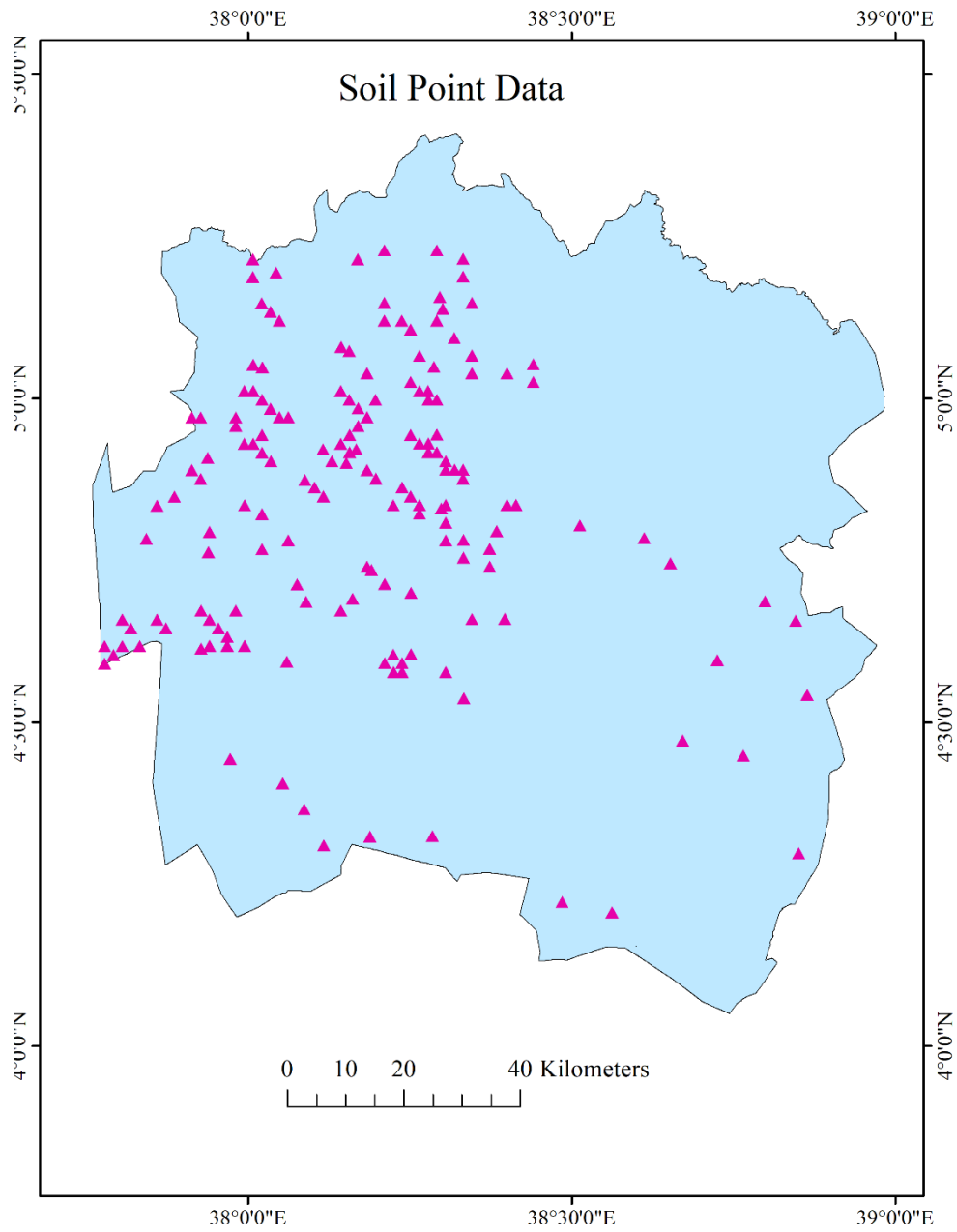
APPENDIX 1

Coordinates collected from Field

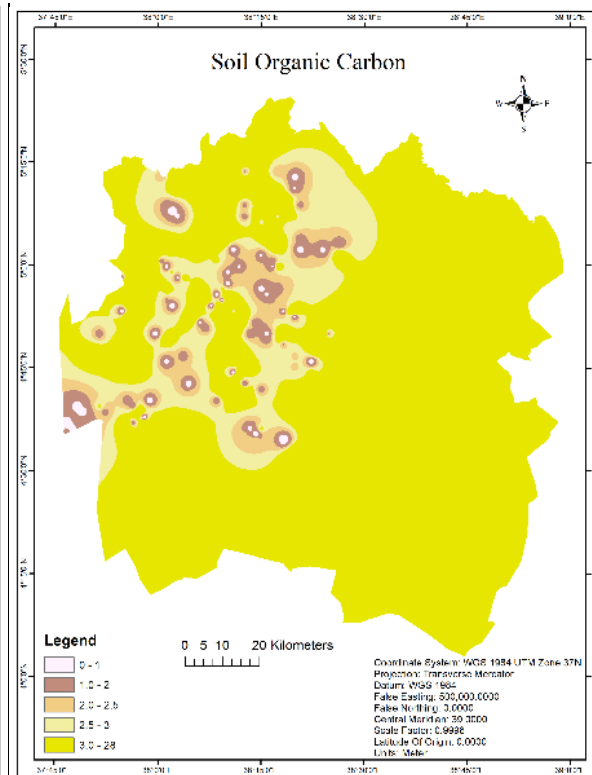
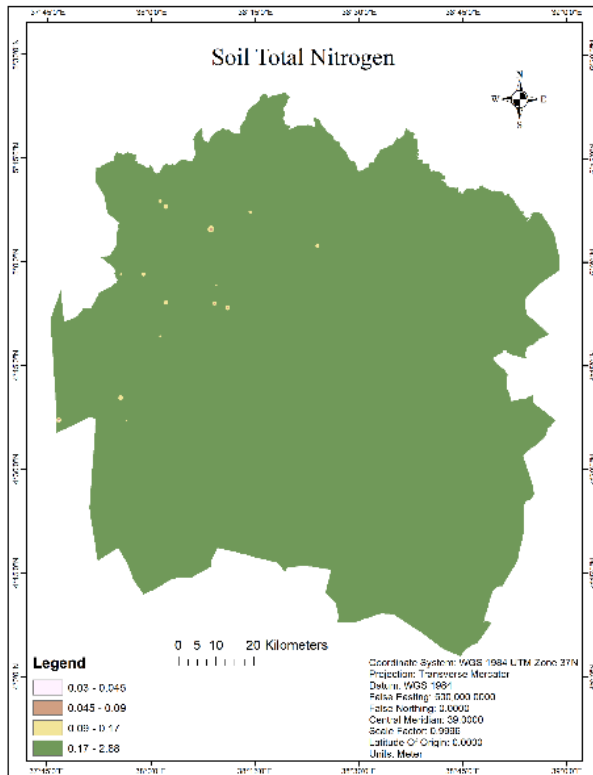
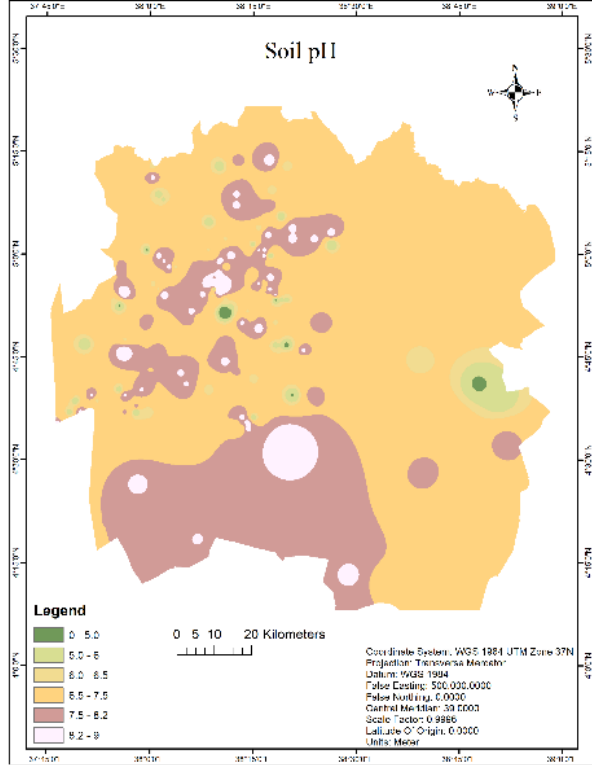
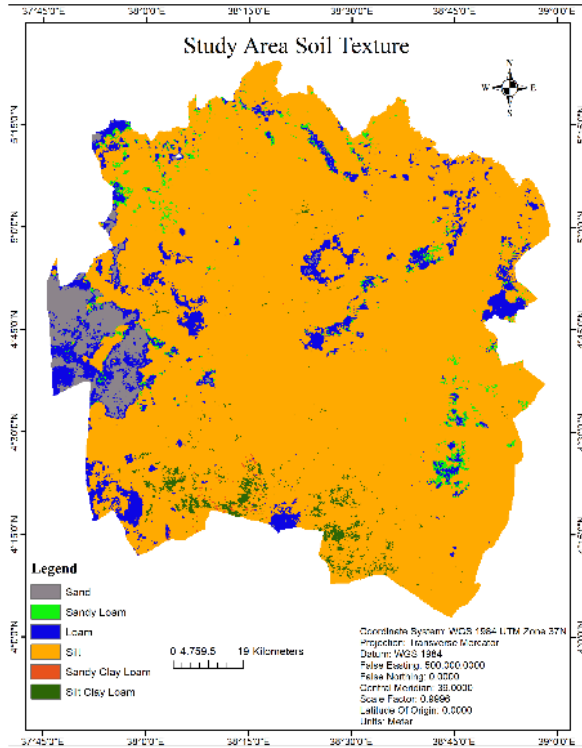


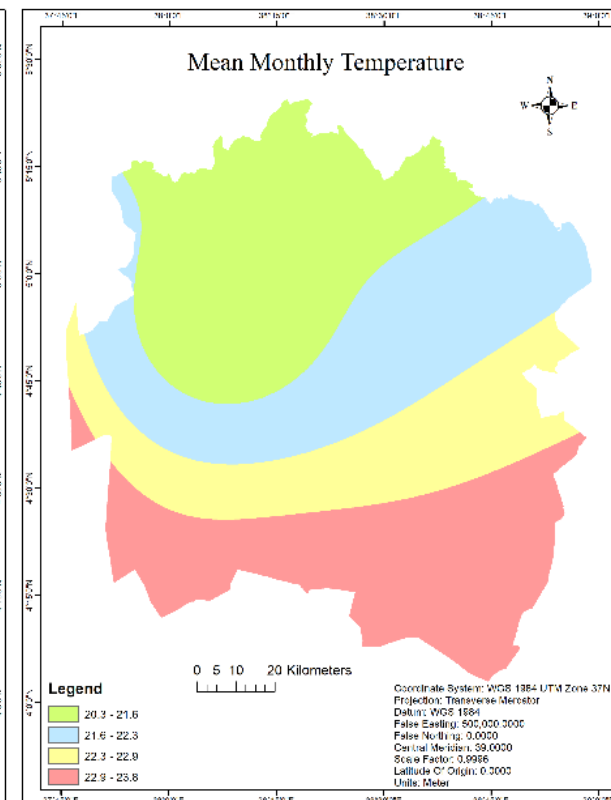
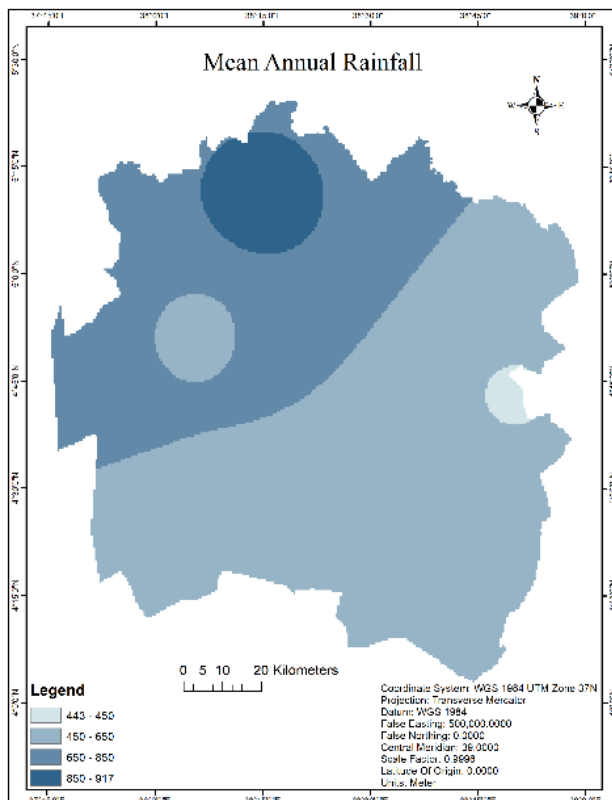
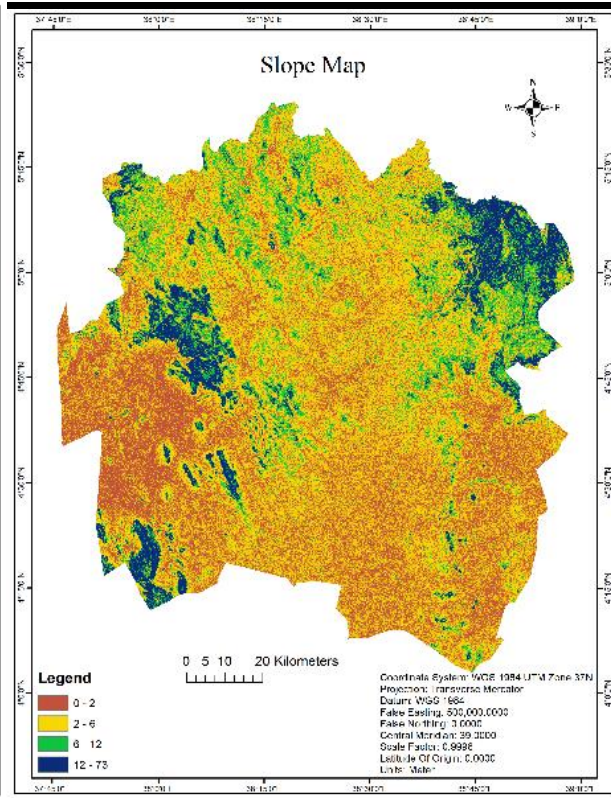
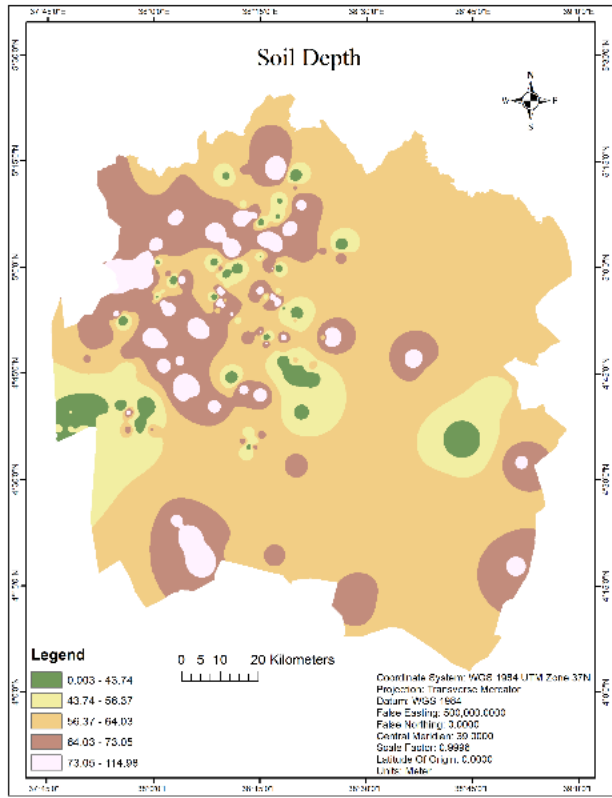
Study area GCP Distribution

APPENDIX 2
Study Area Soil, Degradation, and Suitability Maps

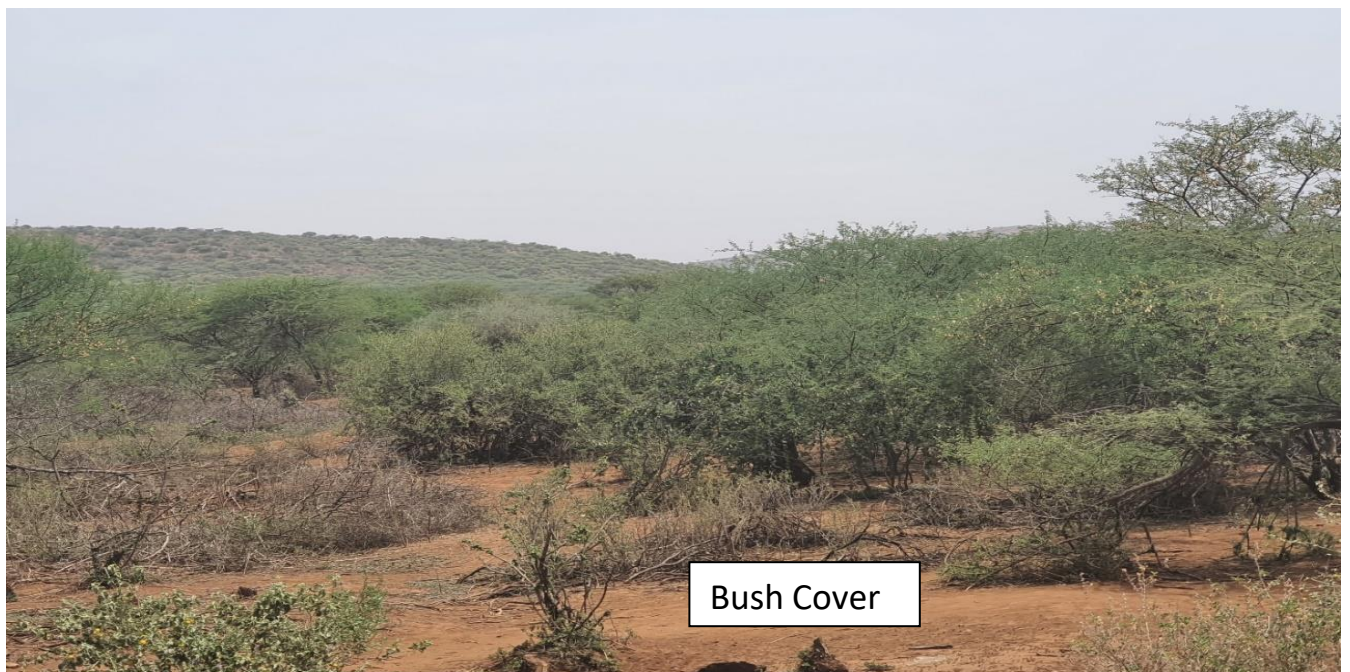
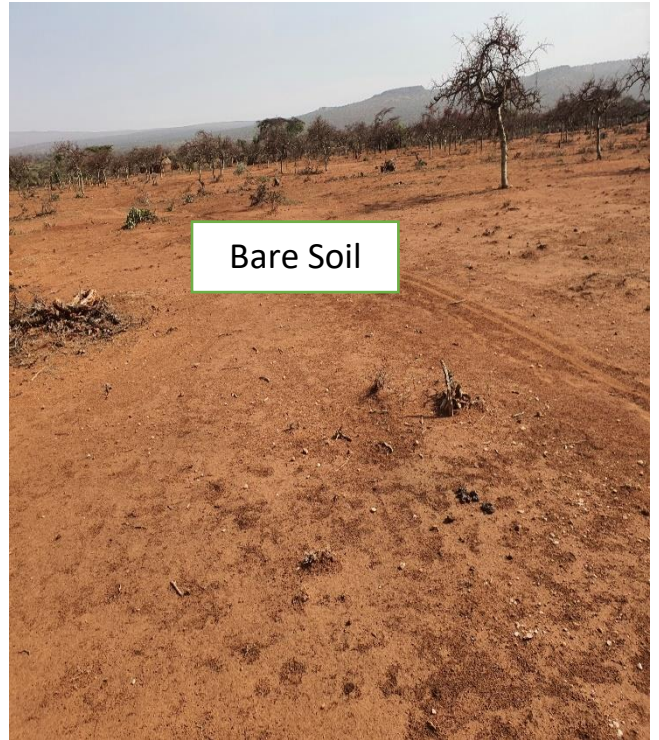
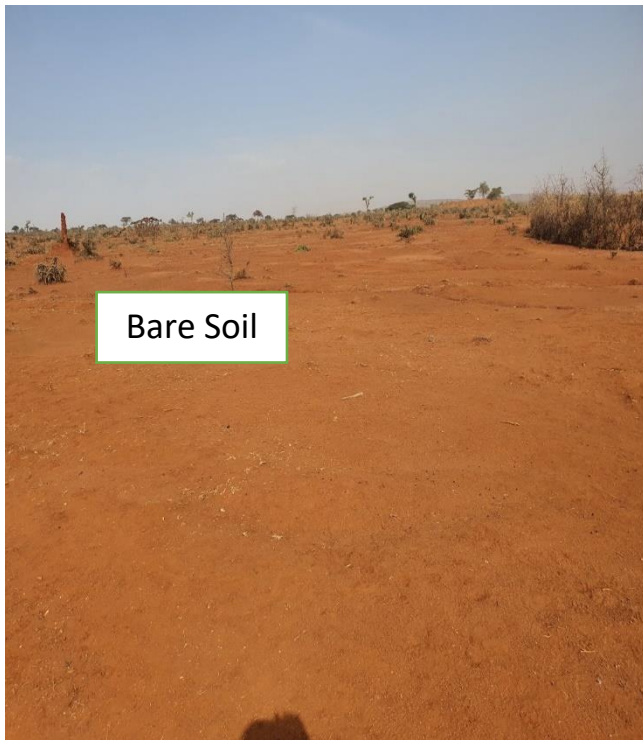


Study area Soil data





**APPENDIX 3:
Field Photographs**





Farm Land



Shrub Land

APPENDIX 4

Analytical Hierarchy Process (AHP) for Rangeland degradation

1. Pairwise Comparison of the Criteria					
Criteria	Bush	Settlement	Farm	Crop	Bare
Bush	1	5	2	3	2
Settlement	0.2	1	0.5	2	0.25
Farm	0.5	2	1	2	2
Crop	0.333	0.5	0.5	1	0.333
Bare	0.5	4	0.5	3	1
Sum	2.533	12.5	4.5	11	5.583

2. Normalization of pairwise comparison and weighting						
Criteria	Bush	Settlement	Farm	Crop	Bare	Weight
Bush	0.40	0.4	0.44	0.27	0.36	0.37
Settlement	0.08	0.08	0.11	0.18	0.05	0.10
Farm	0.20	0.16	0.22	0.18	0.36	0.22
Crop	0.13	0.04	0.11	0.09	0.06	0.09
Bare	0.20	0.32	0.11	0.27	0.18	0.22

3. Weighted sum computation						
Criteria	Bush	Settlement	Farm	Crop	Bare	Weighted sum
Bush	0.15	0.04	0.10	0.02	0.08	0.39
Settlement	0.03	0.008	0.03	0.02	0.01	0.09
Farm	0.07	0.02	0.05	0.02	0.08	0.23
Crop	0.05	0.004	0.03	0.008	0.01	0.10
Bare	0.07	0.03	0.03	0.02	0.04	0.20

4. Consistency Ratio(CR)		
Weighted sum	Weights	Weighted sum/Weights
0.39	0.37	1.04
0.09	0.10	0.88
0.23	0.22	1.04
0.10	0.09	1.14
0.20	0.22	0.89
	Lambda max	1

Lambda max=Average of (Weighted sum/Weight)

Calculating Consistency Index(CI)	
$CI=(\text{Lambda max}-n)/n-1$	n is the number of criteria

Final Consistency Ratio (CR)	
CR=CI/RI	0.023

APPENDIX 5

Analytical Hierarchy Process (AHP) for Site Suitability Analysis

Pairwise comparison of the criteria

Criteria	Slope	LULC	Rainfall	Temperature	Soil suitability
Slope	1	0.33	2	4	0.33
LULC	3	1	3	5	1
Temp	0.25	0.2	0.33	1	0.2
Rainfall	0.5	0.33	1	3	0.33
Soil Suitability	2	1	3	5	1
Sum	6.75	2.86	9.33	18	2.86

Normalization of the pairwise comparison values

Criteria	Slope	LULC	Rainfall	Temperature	Soil Suitability	Weight
Slope	0.15	0.12	0.21	0.22	0.12	0.16
LULC	0.44	0.35	0.32	0.28	0.35	0.35
Temp	0.04	0.07	0.04	0.06	0.07	0.05
Rainfall	0.07	0.12	0.11	0.17	0.12	0.12
Soil Suitability	0.30	0.35	0.32	0.28	0.35	0.32

Consistency value and Weighted sum computation

Criteria	Slope	LULC	Rainfall	Temperature	Soil suitability	Weighted sum
Slope	0.02	0.04	0.02	0.01	0.04	0.14
LULC	0.07	0.12	0.04	0.01	0.11	0.36
Rainfall	0.01	0.04	0.01	0.01	0.04	0.11
Temp	0.01	0.02	0.00	0.00	0.02	0.06
Soil Suitability	0.05	0.12	0.04	0.01	0.11	0.33

Consistency rasion

Weighted Sum	Weight	Weighted Sum/Weight
0.14	0.16	0.85
0.36	0.35	1.03
0.11	0.12	0.95
0.06	0.05	1.12
0.33	0.32	1.05
Lambda Max =1; <u>CR=0.022</u>		

APPENDIX 6

Maps of Erosion and Deposition Computation

