ARDHI UNIVERSITY

SCHOOL OF EARTH SCIENCE, REAL ESTATES, BUSINESS STUDIES

AND INFORMATICS

DEPARTMENT OF GEOSPATIAL SCIENCES AND TECHNOLOGY.

# Analyzing The Extent and Effect of Wildfire on Mount Kilimanjaro.

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REG No: 25535/T.2020

DISSERTATION

BSC IN GEOGRAPHIC INFORMATION SYSTEM AND REMOTE SENSING

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ANALYZING THE EXTENT AND EFFECT OF WILDFIRE ON MOUNT KILIMANJARO.

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A Dissertation Submitted to the Department of Geospatial Sciences and Technology in Partially Fulfilment of the Requirements for the Award of Science in Geographic Information Systems

(BSc. GIS & RS) of Ardhi University

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The undersigned certify that he has proof read and hereby recommend for acceptance of a Dissertation Report entitled "**Analyzing the extent and effect of wildfire on Mount Kilimanjaro**" for University Examination.

Supervisor: Dr Zakaria Ngereja.

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Yolanda Kitama Elias

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# CHAPTER ONE

# INTRODUCTION

## **1.1** Background of the study

Mount Kilimanjaro is a dormant volcano in Tanzania. It has the three peaks Kibo, Mawenzi and Shira. It is the highest Mount Kilimanjaro in Africa. Standing mountain above the sea level with an elevation of 5895m (19,341 ft) above the sea level and about 4900m (16,100ft) above its plateau level it is the highest volcano in Africa and the Eastern Hemisphere. Mount Kilimanjaro contains of the animals where the large animals are rare to be found in Mount Kilimanjaro and are more frequently in the forest and lower parts of the mountain such animals are elephants, cape buffaloes, bush backs, chameleons, dick-dicks, mongooses etc.

Mount Kilimanjaro is covered with about 1000 square kilometers (250,000 acres) where by in other areas cultivation is taking place of different crops like maize, beans, sunflowers most of the land is covered with vegetation’s different vegetation’s the natural and artificial vegetation’s planted by the people who are living around there of which chagga tribal is occupying that land in large percent. From the present records the vegetation’s of Mount Kilimanjaro is varying over time this is due to variation of the change of climatic condition. (Das , Zhang, & Ren, 2022)

Mount Kilimanjaro is a volcanic Mountain its volcanic interior is poorly known because there has been any significant eruption of volcano, eruptive activity at Shira commenced in 2.5 million years ago due to deeply erosion between 4900 and 5200m high, caldera was formed. Mawenzi and kibo began erupting about 1 million years ago. (Courtey, Kinyanjui, Shoemaker, & Marchant, 2020)

Wild fire is the largest fire that is not easy to be controlled, Mount Kilimanjaro has experienced these consequences of forest fire, due to studies done by different researchers provides that active fire on 11 October 2020 which was obtained from MODIS optical sensor and masked the burn area the results indicate that 398.89 ha is in higher severity condition within the burn area of 7011.30 ha.

## **1.2** Statement Of the problem

The increasing occurrence of wildfires on Mount Kilimanjaro poses significant threats to its ecosystem. In order to develop effective management strategies, it is crucial to analyze the extent of the affected areas, understand the impact of wildfires on soil erosion, and quantify the vegetation loss resulting from these outbreaks.

## **1.3** Research objectives

### **1.3.1** Main Objective

To analyze the extend and the effect of wildfire on Mount Kilimanjaro

### **1.3.2** Specific Objectives

Specifically, study aims to

i. To determine the extent of affected areas by wildfire on Mount Kilimanjaro.
ii. To analyse the effect of wildfires on mountain to soil erosion.
iii. To quantify vegetation loss due to outbreak of wildfire on Mount Kilimanjaro.

### **1.3.3** Research Questions

i. What is the extent of area affected by wildfire on Mount Kilimanjaro from 2018-2022?
ii. What is the effect of wildfires on mountain to soil erosion?
iii. What is the vegetation loss on Mount Kilimanjaro caused by wildfire?

## **1.4** Organization of report

This report has got six chapters, chapter one is an introductory, gives overview of the report, background and significance of the study. Chapter two provide literature review about how other scientists addressed mountainous wildfire, and challenges facing data selection due cloud cover. Chapter three describes methodology used to generate results, including forest fire extent, Vulnerability to soil erosion, and Vegetation Loss. Chapter four shows results generated, while chapter five discusses the results, and last chapter six provide valuable recommendations to provide solution to findings observed from this study.

## **1.5** Study area

Mount Kilimanjaro, located in northeastern Tanzania, is Africa's highest mountain, reaching a towering height of 5,895 meters (19,341 feet). This stratovolcano consists of three volcanic cones and showcases a diverse range of ecosystems, including rainforests, moorlands, alpine deserts, and snow-capped peaks. It supports a rich variety of plant and animal species, some of which are endemic and endangered. Mount Kilimanjaro holds cultural and religious significance, attracting tourists from around the world. However, the vulnerability of its fragile ecosystem to wildfires poses a significant threat, making it crucial to understand the extent and effects of wildfires on the mountain for effective conservation and management.

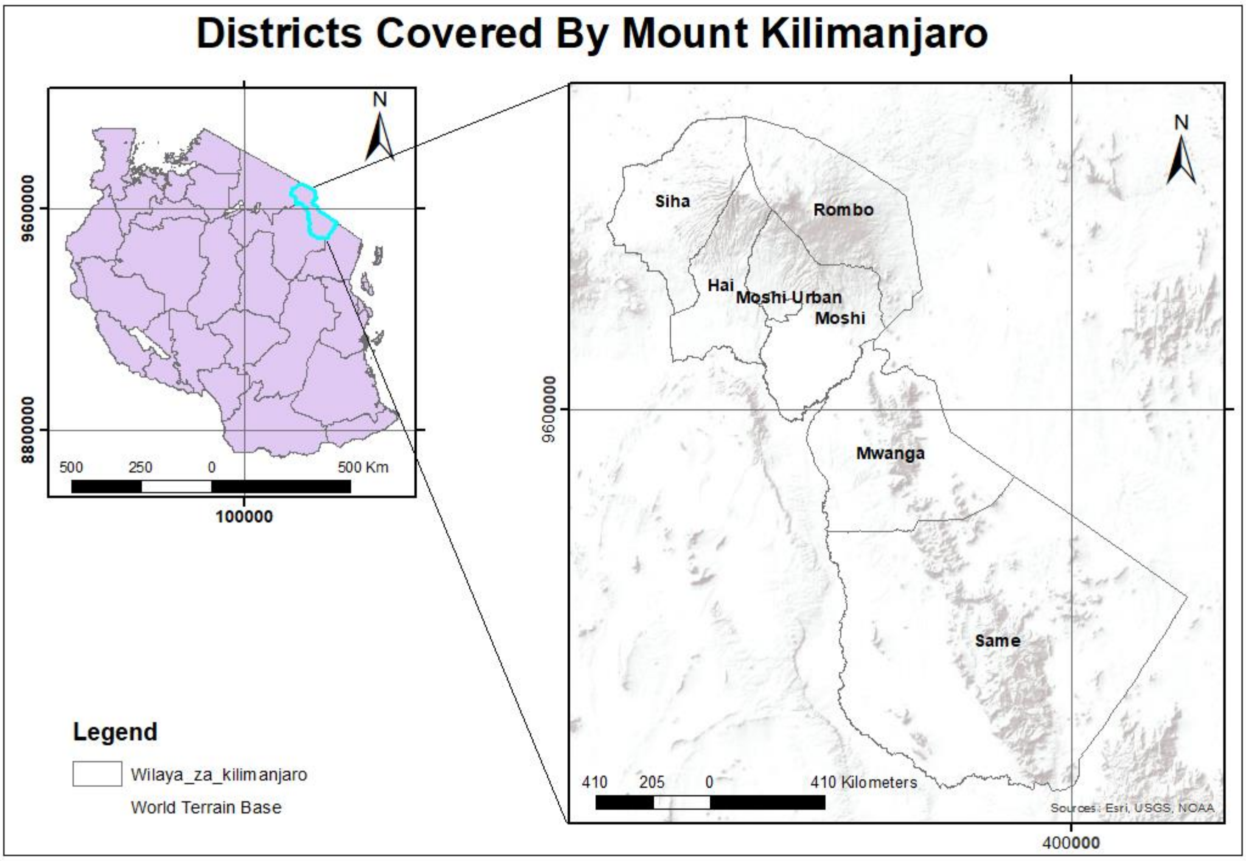


**Figure 1.1 study Area**

**1.6** Significance and contribution of the study

This study on the impacts of wildfires on Mount Kilimanjaro's ecosystem aims to contribute valuable insights and knowledge. The analysis of the extent of affected areas will enhance our understanding of the spatial distribution and severity of wildfires, providing essential information for assessing ecological consequences and guiding future management efforts. The findings will also aid in developing effective conservation and management strategies by prioritizing efforts and implementing appropriate restoration measures based on the magnitude of vegetation loss. Additionally, the assessment of soil erosion processes will identify vulnerable areas and help prevent further degradation, preserving soil fertility, ecosystem stability, and minimizing downstream impacts. Quantifying vegetation loss resulting from wildfires will evaluate ecosystem resilience, monitor post-fire recovery, and inform restoration and conservation strategies. Moreover, the study's outcomes can influence policy decisions on wildfire management and conservation efforts, assisting government agencies, environmental organizations, and local communities in developing proactive measures and allocating resources. The utilization of remote sensing data and advanced methodologies contributes to scientific knowledge in wildfire ecology, allowing for further studies and refining global wildfire monitoring and assessment techniques.

## **1.7** Limitations

The utilization of SAR data and remote sensing techniques for wildfire analysis in mountainous regions presents specific challenges and limitations. This section focuses on the key issues to be addressed when utilizing SAR data in these areas. Steep slopes and complex topography in mountainous regions result in shadowing effects, layover, and foreshortening in SAR imagery, hindering the accurate identification and mapping of fire-affected areas. Moreover, the dense vegetation cover in mountain ecosystems introduces significant backscatter and speckle noise in SAR data, making it challenging to differentiate fire-induced changes from natural variations. Additionally, SAR data struggles to capture small-scale fire dynamics and subtle changes in vegetation structure and composition, limiting the ability to analyze wildfire impacts accurately. The interpretation of SAR imagery in mountainous regions requires careful consideration of terrain effects and the accuracy of terrain correction algorithms, which significantly impact the reliability and precision of the analysis

# CHAPTER TWO

# LITERATURE REVIEW

## 2.1 Wildfire Occurrence and Impact on Mount Kilimanjaro

According to (Africanews, 2022) fire started on October 2021 near the Karanga camp, which is a popular among the thousands of hikers who attempt the climb of the mountain every year. Also reported that blaze destroyed 33 square kilometers on Africa's tallest and most famous mountain.

## 2.2 Wildfire Extent Mapping.

(Liu, Wang, & Zhang) and (Garcia, Martinez, & Rodriguez) focuses on the automatic detection and delineation of fire-affected areas in mountainous regions using Sentinel-1 SAR images. The authors employ a thresholding approach combined with object-based image analysis to classify fire-affected areas based on SAR backscatter intensity and texture features. The study evaluates the accuracy of the detection results by comparing them with ground truth data or other reference sources. It demonstrates the potential of Sentinel-1 SAR data and thresholding techniques for mapping fire-affected areas in mountainous terrains.

## 2.3 Wildfire Effects on Soil Erosion

(Brown, Davis, & Smith) provides a synthesis of multiple studies to assess the impacts of wildfires on soil erosion and sediment yield in mountain catchments. The researchers compile data from various field measurements, such as sediment samplers, erosion plots, and hydrological monitoring stations, to quantify post-fire soil erosion rates and sediment transport. They examine the relationships between fire severity, vegetation cover, hydrological responses, and soil erosion processes to gain insights into the environmental consequences of wildfires. The study highlights the importance of considering spatial and temporal variations in erosion rates and sediment yield and discusses the implications for land management, erosion control, and post-fire rehabilitation strategies. (Martinez, Garcia, & Rodriguez, Assessing Post-Wildfire Soil Erosion and Sedimentation in Mountainous Environments) focuses on assessing post-wildfire soil erosion and sedimentation in mountainous environments using remote sensing techniques. The researchers employ a combination of satellite imagery, such as Landsat or Sentinel-2, and topographic data to estimate soil erosion rates and identify areas prone to erosion and sediment transport following wildfires. They utilize established models or indices, such as the Revised Universal Soil Loss Equation (RUSLE) or the Soil Erosion and Deposition Index (SEDI), to quantify soil erosion potential and estimate sediment yields. The study explores the environmental consequences of increased soil erosion and sedimentation, emphasizing the impacts on water resources, downstream ecosystems, and land productivity.

## 2.4 Vegetation Loss Assessment

(Chen, Wang, & Li, Mapping Fire-Induced Vegetation Loss in Mountainous Areas Using Sentinel-1 SAR Data and Object-Based Image Analysis) focuses on mapping fire-induced vegetation loss in mountainous areas using Sentinel-1 SAR data and object-based image analysis (OBIA). The authors apply OBIA techniques to segment SAR images into meaningful objects and then utilize a rule-based classification algorithm to identify fire-affected areas and quantify vegetation loss. By combining the spatial information provided by OBIA with the SAR data, they are able to accurately map the extent of vegetation loss caused by the wildfires. The study evaluates the accuracy of the classification results by comparing them with ground truth data or other reference sources. This research highlights the effectiveness of Sentinel-1 SAR data and OBIA techniques for detailed mapping and quantification of fire-induced vegetation loss in mountainous regions, providing valuable information for post-fire management and ecological restoration efforts. (Garcia, Martinez, & Rodriguez) focuses on monitoring post-fire vegetation recovery in mountainous landscapes using Sentinel-1 SAR imagery and land cover classification. The authors utilize a change detection algorithm to analyse SAR data acquired before and after wildfires. They employ supervised classification techniques to classify land cover types, including vegetation, and quantify the vegetation loss caused by the fires. The study investigates the temporal dynamics of vegetation recovery over time by comparing post-fire classifications with pre-fire classifications. By examining the recovery process, this research contributes to our understanding of vegetation dynamics following wildfires in mountainous regions. The study highlights the potential of Sentinel-1 SAR data for long-term monitoring of vegetation recovery and ecosystem resilience. Also, (Smith, Johnson, & Brown) focuses on assessing vegetation loss following wildfires in mountainous regions using Sentinel-1 SAR data and land cover classification. The authors apply a supervised classification algorithm to classify pre-fire and post-fire SAR images and quantify the changes in land cover, particularly vegetation cover, in the fire-affected areas. By comparing the classified images, they are able to assess the extent of vegetation loss caused by the wildfires. The study also evaluates the accuracy of the classification results by comparing them with ground truth data or other reference datasets. This research provides insights into the potential of Sentinel-1 SAR data and land cover classification techniques for effectively assessing vegetation loss in mountainous regions affected by wildfires.

## 2.5 Limitations and Challenges

The utilization of SAR data and remote sensing techniques for wildfire analysis in mountainous regions presents certain challenges and limitations. First, the presence of steep slopes and complex topography in mountainous areas can lead to shadowing effects, layover, and foreshortening in SAR imagery, which may hinder accurate identification and mapping of fire-affected areas. Second, the dense vegetation cover in mountain ecosystems can introduce significant backscatter and speckle noise, making it challenging to distinguish between fire-induced changes and natural variations in the SAR data. Additionally, SAR data may struggle to capture small-scale fire dynamics and subtle changes in vegetation structure and composition. Moreover, the interpretation of SAR imagery in mountainous regions requires careful consideration of terrain effects and the accuracy of terrain correction algorithms. Finally, the temporal availability of SAR data may be limited due to cloud cover and acquisition constraints, which can affect the timeliness and frequency of wildfire monitoring in mountainous areas. Despite these challenges, advancements in SAR processing techniques, integration with other data sources, and the development of specialized algorithms offer promising avenues to overcome these limitations and improve the accuracy and effectiveness of wildfire analysis in mountainous regions.

CHAPTER THREE

METHODOLOGY

3.1 Flow chart

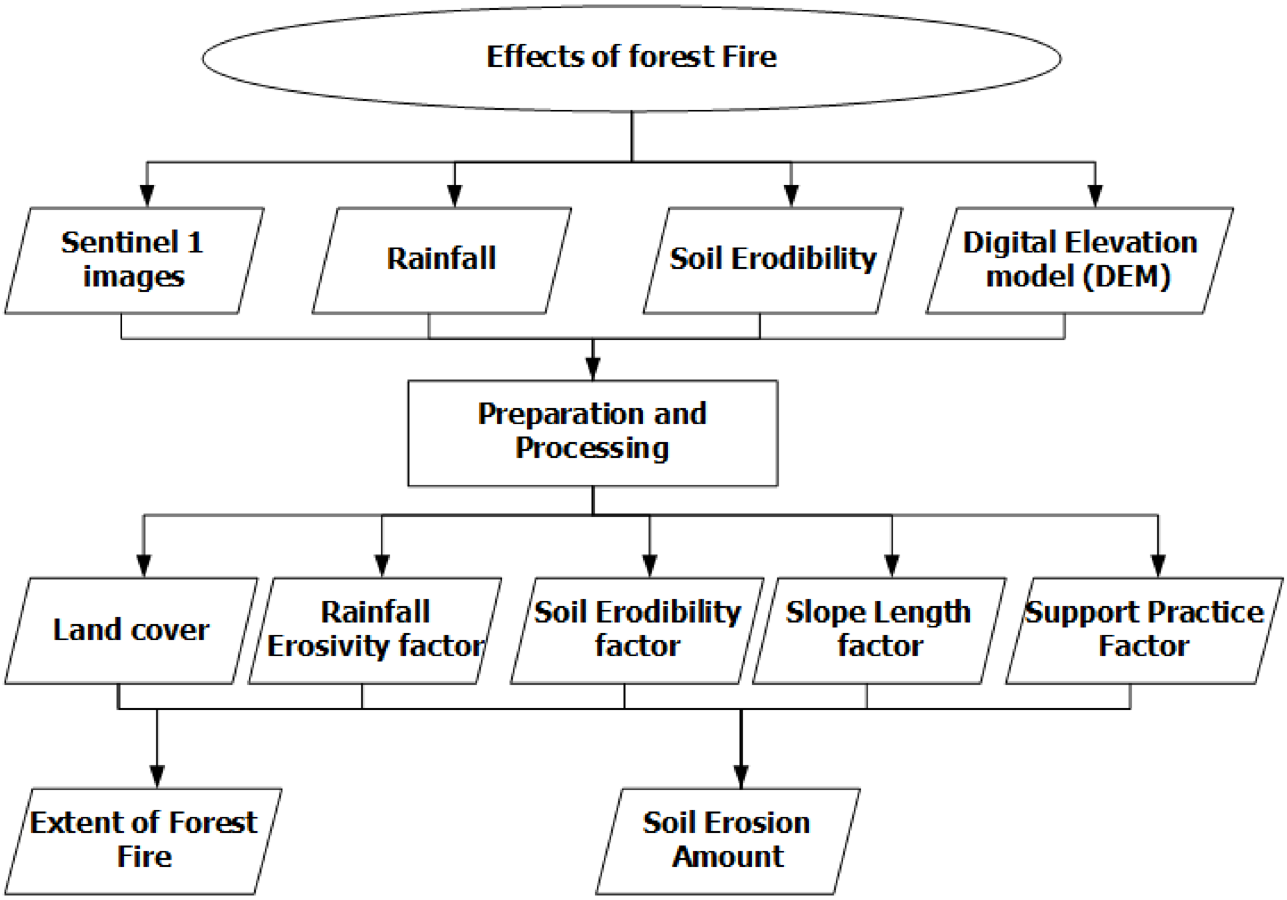


Figure 3.1 Flow Chart

3.2 Data Collection

Table3.1 Data Collection

| Data | Date | Source |
|---|---|---|
| Sentinel 1 Images | | European Space Agency (ESA) |
| Annual Rainfall | 2022 & 2021 | Terraclimate |
| Soil Erodibility | | Digital soil map of the world (DSMW) |
| Digital Elevation Model | | United State Geological Survey (USGS) |

### 3.3 Preprocessing and Processing techniques

In the analysis of Sentinel-1 SAR data for wildfire assessment, a series of preprocessing steps was conducted using the SNAP (Sentinel Application Platform) software. The initial step involved applying the orbit file correction to accurately geolocate the SAR images by compensating for orbital errors. Next, thermal noise removal techniques were applied to reduce noise artifacts caused by thermal variations. Radiometric calibration was performed to convert the SAR data from digital numbers to radiance or backscatter coefficients, enabling quantitative analysis. To enhance the visual quality and reduce speckle noise, a speckle subduction technique was employed. Geometric correction, specifically terrain correction, was carried out to compensate for topographic effects and ensure accurate georeferencing in mountainous regions. Finally, the SAR image band values were converted from a linear scale to the logarithmic decibel (dB) scale to improve dynamic range and visibility of features. These preprocessing steps are crucial for accurate and reliable analysis of Sentinel-1 SAR data in wildfire assessment tasks, ensuring the quality and usability of the data for subsequent analysis and mapping efforts.

#### 3.31 Land cover/Cfactor

Obtained using sample points from around Karanga Camp to observe any changes in landcover classes within 2022 and 2021 years, and these were the observation from back scatter values extracted from vertical – vertical polarization SAR image. Then followed thresholding to get land cover classes basing on previous observed points.

Table3.2 Land cover/Cfactor

| Land cover | Raster Value | 2022 | 2021 | Cfactor |
|---|---|---|---|---|
| Bare land | Minimum | 72 | 71 | 0.3 |
| | Maximum | 255 | 255 | |
| | Mean | 189 | 200 | |
| Dry vegetation | Minimum | 56 | 33 | 0.2 |
| | Maximum | 237 | 240 | |
| | Mean | 134 | 137 | |
| Green vegetation | Minimum | 71 | 79 | 0.1 |
| | Maximum | 255 | 255 | |
| | Mean | 176 | 149 | |

### 3.32 Rainfall Erosivity

Rainfall Erosivity obtained using a power function established by Yu and Rosewell to establish a relationship to estimate the R-factor (MJ*mm/(ha*hr.)) based on the mean annual precipitation(mm) in southern Australia in 1996.

$$R\text{-factor}=0.0438P^{1.61}$$, where P is Precipitation value.

2022 Rainfall erosivity

Table3.3 2022 Rainfall erosivity

| Precipitation | Rfactor |
|---|---|
| 83.2 | 54 |
| 85.1 | 56 |
| 89.9 | 61 |

2021 Rainfall erosivity

Table3.4 2021 Rainfall Erosivity

| Precipitation | Rfactor |
|---|---|
| 113.3 | 89 |
| 118.5 | 96 |
| 123.7 | 102 |

### 3.33 Soil Erodibility

Soil erodibility factor, K-factor obtained from,

$$k\text{-factor} = f_{csand} * f_{fci\text{-}sil} * f_{organic} * f_{hisand}$$

where;

$f_{csand}$ – factor that the lower the K indicator in soils with high coarse sand content and higher for soils with little sand.

$$=0.2+0.3*e[-0.256*ms*(1-m_{sil}/100)]$$

$f_{fci\text{-}sil}$ – gives low soil erodibility factors for soils with high clay-to-silt ratios.

$$= (m_{sil} / (m_c + m_{sil}))^{0.3}$$

$f_{organic}$ – reduces K values in soils with high organic carbon content.

$$=(1-(0.25*organic)/ (organic + e[3.27-2.95*organic]))$$

$f_{hisand}$ – Lowers K values for soils with extremely high sand content.

$$=(1-(0.7*(1-m_s/100))/((1-m_s/100) + e[-5.51+229*(1-m_s/100)))$$

### 3.34 Slope Length

LS = Power(flowacc*[cellres]/22.1,0.4) *Power(sin(slopedegr*0.01745)/0.09,1.4) *1.4

Where;

Flowacc – flow accumulation,

Cellres – resolution of Digital Elevation Model

Slopedegr – slope in degree unit

LS – slope length

### 3.35 Support Practice

According to cultivation methods and slope (shin,1999). P values range from 0 to 1, where by 0 represents a very good manmade resistance erosion facility.

Table3.5 Support practice/Pfactor

| Slope(degree) | Support Practice(P-factor) |
|---|---|
| 0-13 | 0.55 |
| 13-29 | 0.6 |
| 29-74 | 0.8 |

### 3.36 Soil Erosion Amount

Obtained using The Universal soil Loss equation (USLE) which introduced by Belt Walt Wischmeier and Dwight Smith in 1965 and a revised in 1978.

$$A = R * K * LS * C * P$$

Where; A – Soil loss in tons per acre per year

R – rainfall erosivity factor

K – soil erodibility factor

LS – slope length (gradient factor)

C – crop/vegetation and management factor

P – support practice factor.

CHAPTER FOUR

RESULTS AND ANALYSIS

## 4.1 Overview

This chapter include results obtained after doing analysis which are land cover which shows extent of forest fire especially on green vegetation class which provided significant changes between 2021 and 2022 vertical-vertical polarization SAR back scatters. Also includes Vulnerability to erosion for year 2021 and 2022.

## 4.2 Forest fire extent

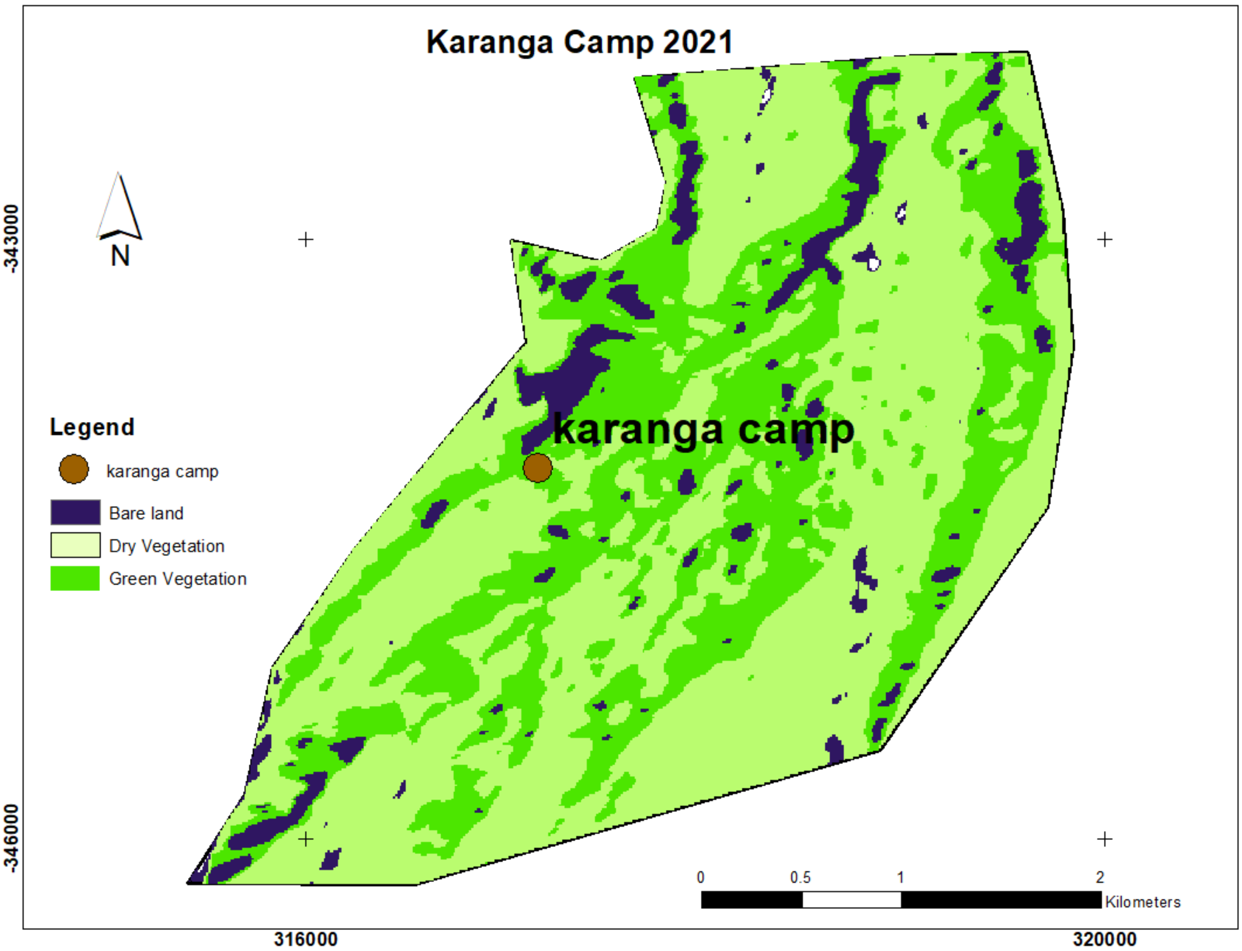


Figure 4.1 2021 Land cover

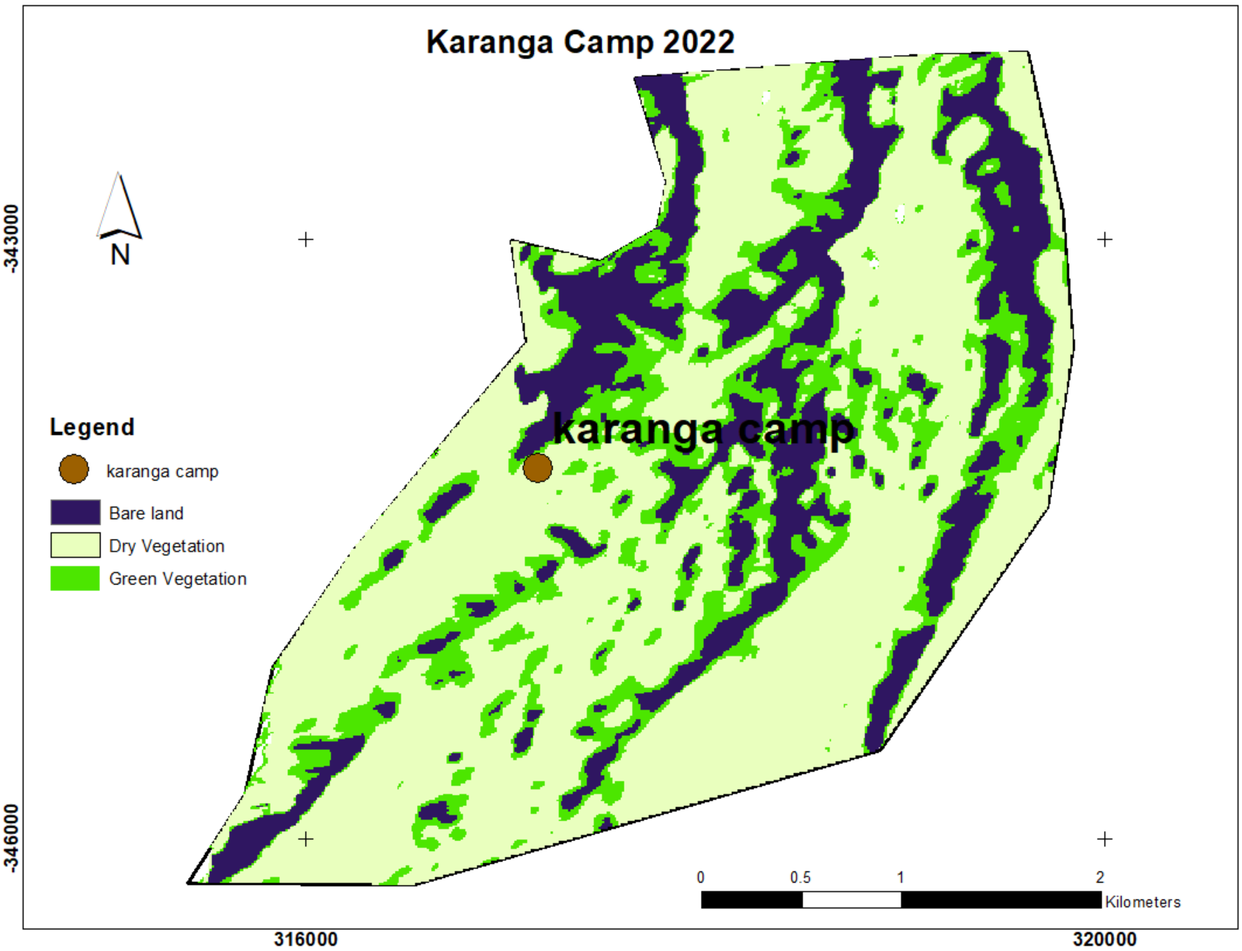


Figure 4.2 2022 Land cover

4.3 Vegetation Loss due to wild fire

Table4.1 Vegetation Loss

| Year | Land cover class | Hectares | Hectares |
|---|---|---|---|
| 2021 | Bare land | 79.21 | |
| | Dry Vegetation | 654.28 | |
| | Green Vegetation | 375.58 | |
| | | | |
| 2022 | Green Vegetation | 208.76 | 166.82 |
| | Dry Vegetation | 674.72 | |
| | Bare soil/Ashes | 223.52 | |

4.4 Soil Erosion

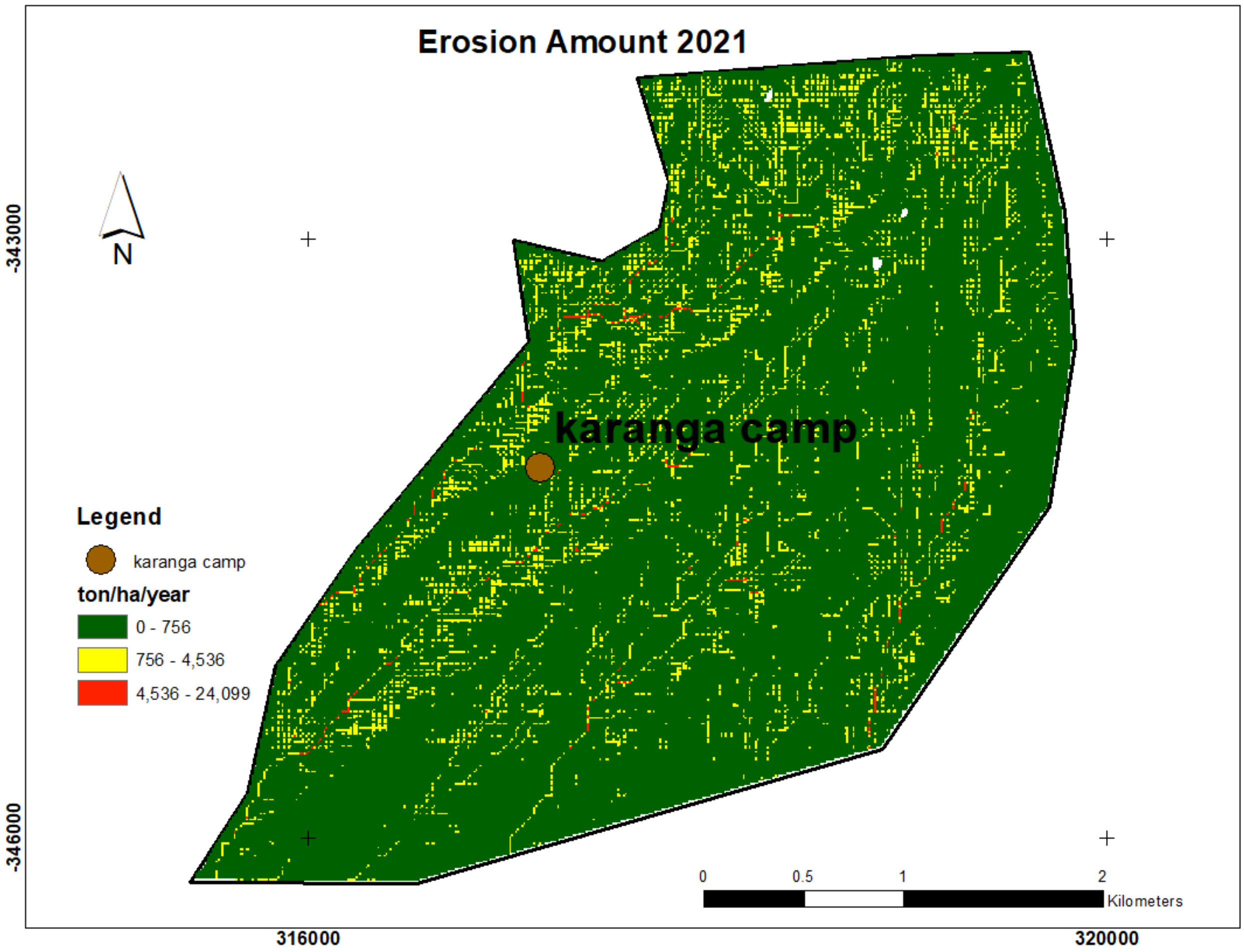


Figure 4.3 2021 erosion vulnerability

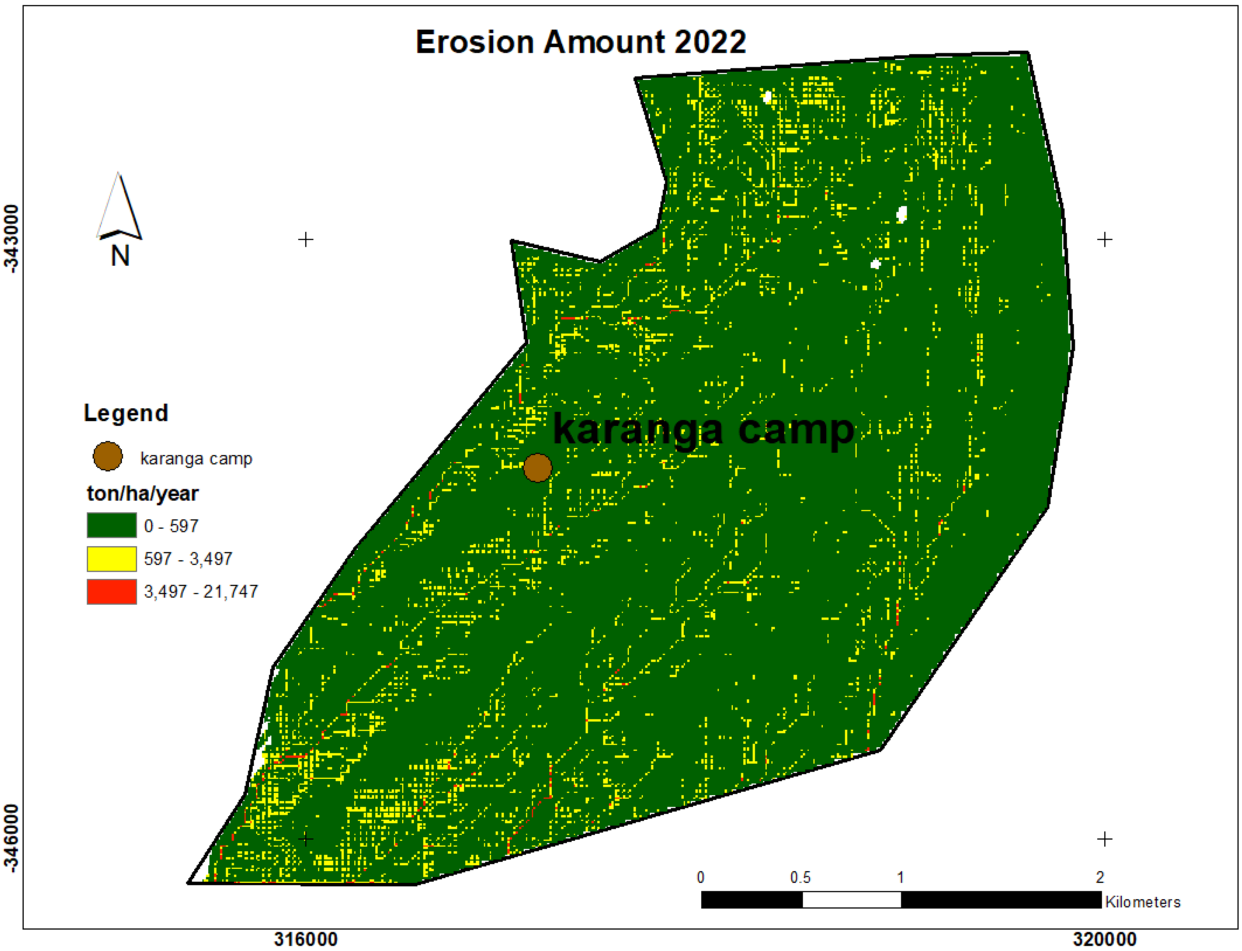


Figure 4.4 2022 erosion vulnerability

# CHAPTER FIVE

# DISCUSSION AND CONCLUSION

## 5.1 Amount of soil Erosion.

Mountain Erosion Dynamics: The data highlights the dynamic and complex nature of soil erosion in mountainous regions. The observed variations across different years indicate that multiple factors influence erosion processes in these unique environments. Precipitation patterns, slope steepness, vegetation cover, and geological characteristics specific to mountains all play significant roles in shaping erosion dynamics. The interplay of these factors creates diverse erosion patterns and rates in mountainous regions.

Erosion Vulnerability: The higher erosion levels observed 2021 than 2022, reveal the vulnerability of mountainous regions to erosion processes. Rainfall events, which are common in mountain environments, contribute to increased erosion rates, especially for this study where 2021 experienced highest annual mean rainfall up to 102mm and lowest 89mm, while in 2022 lower annual mean rainfall was 83mm and highest was 90mm. These findings emphasize the need for tailored erosion management strategies in mountainous areas to address the specific challenges posed by their natural characteristics.

Conservation Measures: The findings underscore the importance of implementing erosion control measures specifically designed for mountainous regions. Effective strategies may involve targeted vegetation management.

Environmental Consequences: High erosion levels in mountainous regions carry significant environmental consequences. Soil loss resulting from erosion can lead to reduced soil fertility, diminished water holding capacity, and heightened landslide risks. Furthermore, sediment runoff stemming from erosion can adversely affect downstream water quality, disrupt aquatic habitats, and compromise overall ecosystem health. Implementing erosion control measures in mountain areas is crucial to safeguard these sensitive ecosystems and their associated benefits.

# CHAPTER SIX

# RECOMMENDATION

The utilization of SAR data and remote sensing techniques for wildfire analysis in mountainous regions presents specific challenges related to topographic effects, vegetation cover, resolution constraints, and terrain effects. These challenges can hinder the accurate identification and mapping of fire-affected areas and limit the ability to analyse wildfire impacts accurately. However, the findings of this study provide valuable insights into the intricate dynamics of soil erosion in mountainous regions.

The analysis of soil erosion dynamics emphasizes the need for targeted conservation efforts to mitigate erosion risks, protect natural resources, and maintain the ecological integrity of mountain ecosystems. It is crucial to prioritize conservation measures in areas prone to erosion, considering the unique topographic and vegetation characteristics of mountainous regions. Implementing erosion control measures, such as reforestation, terracing, and improved land management practices, can help reduce soil erosion and enhance the resilience of mountain ecosystems.

Furthermore, the integration of SAR data with other data sources, such as optical imagery and LiDAR data, can provide a more comprehensive understanding of wildfire impacts and soil erosion processes in mountainous areas. This integrated approach enables a holistic assessment of vegetation dynamics, terrain characteristics, and erosion patterns, facilitating more accurate analysis and informed decision-making for conservation and management efforts.

In light of these findings, it is recommended that policymakers, government agencies, environmental organizations, and local communities collaborate to develop proactive measures and allocate resources for wildfire management, erosion control, and conservation strategies in mountainous regions. Additionally, further research and technological advancements in SAR processing techniques, algorithm development, and global wildfire monitoring can contribute to the refinement of wildfire analysis methods and enhance our understanding of the complex interactions between wildfires, soil erosion, and mountain ecosystems.

By addressing these challenges, implementing targeted conservation measures, and fostering interdisciplinary collaborations, we can safeguard the fragile ecosystems of mountainous regions, mitigate erosion risks, and ensure the long-term sustainability of these vital natural resources

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