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Evaluation of Soils and Their Cover Before and After a Natural Disaster in Madagascar

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Abstract:

In Madagascar, the statistics on the natural disaster allowed us to determine the study area and the type of natural disaster to be treated in our study. The choice of the Vatovavy Region for our project treatment of the theme ''Evaluation of soils and its coverings before and after natural disaster Madagascar'' is based on crucial considerations linked to its history of vulnerability to cyclones between 2006 and 2022. This region was particularly affected by these natural phenomena during this period, making it a suitable site for assessing the impact of natural disasters on soils and their covers. We aims to analyze the evolution of space observation of the Earth, focusing on technological advances of spatial remote sensing, spectral discrimination of satellite sensors, and the physical principles of remote sensing for agriculture. With a focus on Madagascar, it includes satellite identification relevant, the collection of spatial data, and the use of these data to characterize agricultural areas. The project highlights the benefits of remote sensing for agriculture, analyzes the evolution of coverage and land use, studies natural disasters, and maps land use between 2006 and 2022, in identifying the factors of change and prioritizing them according to their impact on land use.

Keywords:
soils, coverings, disaster

I. Introduction

Spatial remote sensing ('Remote Sensing') is a scientific discipline that integrates a broad range of skills and technologies used for observing, analyzing and interpreting terrestrial and atmospheric phenomena. Its main sources are measurements and images obtained using air and space platforms.

Current remote sensing systems, unlike those at the start of the development of these Technologies have undergone significant changes, particularly in the last decade, with an essential technology in monitoring multiple processes that affect Earth's surface and

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atmosphere. A significant impact, in particular, on our planet, such as climate change, deforestation, desertification, etc.

Our consists of assessing the condition of soils and vegetation before and after a natural disaster in Madagascar to understand the impact of the disaster on the environment (by measuring the changes in the physical and chemical properties of the soil, erosion, loss of biodiversity, etc.), to assess potential risks (by identifying areas at risk of landslides, floods, drought, etc.), plan the restoration of soils and vegetation (by defining the measures necessary to rehabilitate soils and vegetation after the disaster). (Dunham et al., 2011)

Our research is entitled "evaluation of soils and its covers before and after a disaster natural disasters in Madagascar", an application project which aims to understand the impact of natural disasters on the floors and their coverings. We aim to assess Madagascar in the face of natural disasters, to start the study, we start the assessment with a region most affected by natural disasters in 2 cases. The project includes two phases: a pre-disaster assessment phase and an assessment phase after disaster. (FAO, 2022)

Pre-disaster assessment phase: The pre-disaster assessment phase involves collecting data on soils and their covers in areas at risk of natural disasters. These data are collected using remote sensing, geophysics and pedology techniques. The data collected is used to create maps of soils and their covers. These cards are used to identify areas most vulnerable to natural disasters. (Catry et al., 2020)

Post-disaster assessment phase: The post-disaster assessment phase involves collecting data on soils and their covers in areas that have been affected by a natural disaster. These Data is collected using the same techniques used in the evaluation phase before disaster.

The data collected is used to compare the condition of soils and their covers before and after the disaster. This comparison allows us to understand the impact of the disaster on the soil and its cover. We expect research results to show that natural disasters can have a significant impact on soils and their coverings or not. Cyclones can cause soil erosion, degradation of plant covers and soil contamination. These results are important for management natural disaster risks in Madagascar. They will allow us to better understand the impacts of natural disasters on soils and their covers and to develop more risk management strategies effective. (Fidan et al., 2023)

II. Research Method

2.1 Study Sites

Over the period 2006-2022, the first 2 regions most affected by cyclones in Madagascar are:

1. Mananjary (Vatovavy Fitovinany region): 6 cyclones (Clovis, Jade, Fami, Hubert, Batsirai, Freddy)
2. Toamasina (Antsinanana region): 6 cyclones (Jaya, Ivan, Jokwe, Fami, Ava, Ana)

The districts of Mananjary and Toamasina are the most affected by cyclones in Madagascar. These two Districts are located on the east coast of the country, which is the region most exposed to cyclones. The region is also characterized by a flat relief, which makes it more vulnerable to flooding.

The vulnerability factors of these districts to cyclones are multiple. The district is located on the coast eastern Madagascar, which is the region most exposed to cyclones. The region is also characterized by a flat terrain, which makes it more vulnerable to flooding. Additionally, the district is made up of a population rural areas, which are often more vulnerable to natural disasters. (Ghosh et *al.*, 2022).

2.2 Plots Establishment

We deliberately chose the Vatovavy study area because of its particularity of being the region most frequently affected by cyclones during the period from 2006 to 2022. This distinctive climatic feature is of crucial interest to our research, as it provides a unique opportunity to analyze the impact of cyclones on the environment, local communities and infrastructure. By focusing on a region recurrently exposed to these phenomena extreme weather, our study aims to better understand the long-term consequences of cyclones and to formulate recommendations to strengthen the region's resilience to such climatic events. This strategic decision to choose Vatovavy as a study area is motivated by the need to contribute to a thorough understanding of the challenges posed by cyclones in this region, in order to guide initiatives future preparation and adaptation to climate change. (Dunham et *al.*, 2011)

2.3 Identifying Behaviors

From 2006 to 2022, Madagascar was hit by a variety of natural disasters, including cyclones, floods, droughts and forest fires. Cyclones are the most frequent natural disaster in Madagascar, and they are also the most destructive natural disaster. Cyclones can cause significant damage to infrastructure, crops and homes. They can also cause human losses.

Floods are another common natural disaster in Madagascar. Flooding can be caused by cyclones, torrential rains or flash floods. They can cause significant damage to infrastructure and homes, and can also lead to losses human. Droughts are a less frequent natural disaster in Madagascar, but they can have devastating consequences. Droughts can lead to food and water shortages, and they can also cause public health problems.

Forest fires are a relatively rare natural disaster in Madagascar, but they can cause significant damage to forests and wildlife. Forest fires can also cause public health problems due to air pollution. Among these natural disasters, we have noted that the cyclone is the most frequent. It often followed flooding. (Chikodzi & Nhamo, 2021)

2.4 Specimens Identification Method

The work focuses on the assessment of soils and their cover before and after a disaster natural in Madagascar. The main objectives of these projects are:

1. Understanding the evolution of space earth observation: Start by studying the evolution of space remote sensing technologies, from the first satellites to current systems. Understand how these advances have enabled better monitoring of the Earth.
2. Discrimination of spectral information: interpret spectral data from different satellite sensors. Understand how the Spectral variations are linked to the characteristics of soils and land covers.
3. Physical principles of spatial remote sensing of soil types for agriculture: the basic principles of remote sensing, such as the reflectance of land surfaces and the interaction of light with soils and plants. Understand how these principles are used to identify types of soil useful for agriculture.
4. Satellite observation and identification: Identify orbiting satellites that are relevant to your study. Note their characteristics, their passage frequencies over Madagascar and their capacity to collect useful data for assessment soils and land covers.

5. Remote sensing data collection: Obtain relevant spatial remote sensing data for Madagascar. This may include airborne or satellite multispectral images, aerial photographs,
6. geostatistical data, etc. Make sure you have access to historical data to compare before and after the natural disaster.
7. Identification and characterization of agricultural areas by remote sensing: Use remote sensing data to identify and characterize agricultural areas in Madagascar. You can use image classification techniques to differentiate between crop types and types of floors. (Mendelsohn et *al.*, 2012).
8. Benefits of Remote Sensing for Agriculture: Highlight the benefits of remote sensing for agriculture, such as crop expansion, crop forecasting and monitoring of damage caused by natural disasters.
9. Land cover and use: Analyze the evolution of land cover and use in Madagascar over time. Identify significant changes and the factors that caused them, such as economic development, population growth and climate variability. (Li et *al.*, 2023).
10. Natural disaster: Study the types of natural disasters that have affected Madagascar. Analyze how the remote sensing can contribute to the prevention, real-time monitoring and analysis of the effects of these disasters. Also identify disaster recovery activities.
11. Mapping of land use in 2006 to 2022: Use remote sensing data to map land cover in Madagascar between 2006 and 2022. Identify significant changes.
12. Determination of drivers of change: Analyze the factors that contributed to changes in land use, using the information on natural disasters.
13. Prioritization of change factors: Rank the drivers of change according to their relative importance in changing land use. Identify the most influential factors. We intend to address all cases from 2006 to 2022 as part of our project, but To begin this initiative, we selected two cases of natural disasters that occurred in an area particularly remarkable (Kabir et *al.*, 2016).

2.5 Data Analysis

The increasing frequency and intensity of cyclones pose significant threats to environmental stability and land degradation in vulnerable regions. This analysis utilizes remote sensing data, specifically the Normalized Difference Vegetation Index (NDVI) and the Normalized Difference Water Index (NDWI), alongside derived soil erosion factors, to assess the environmental impacts of Cyclones Fami and Batsirai. The spatial patterns of vegetation change, water inundation, and estimated soil loss provide critical insights into the ecological consequences of these extreme weather events.

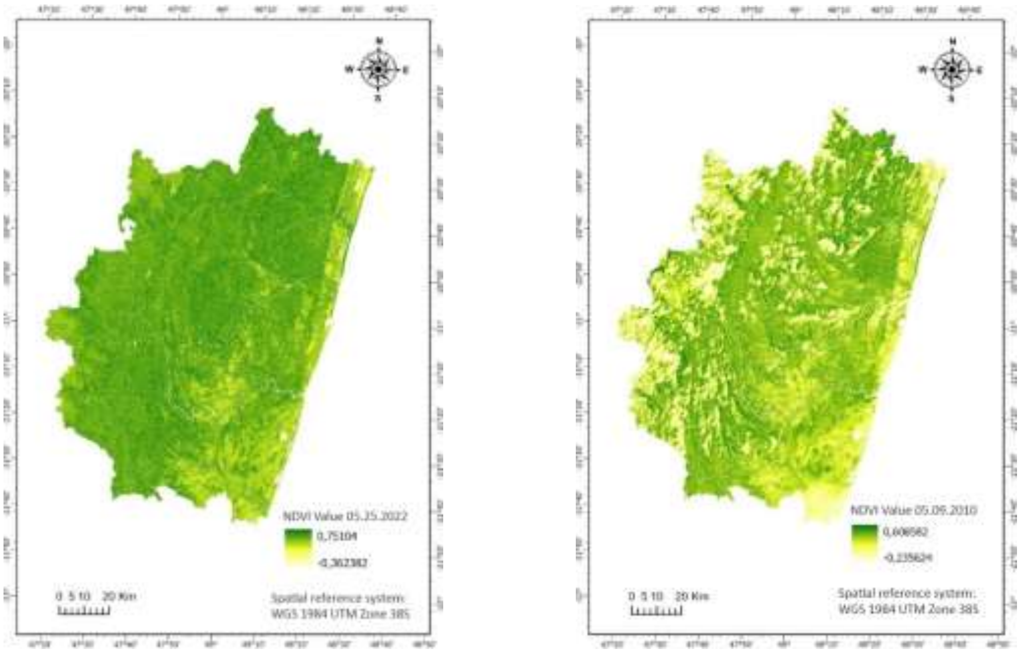

Figure 1. NDVI calculated from the image before and after the cyclone FAMI – Vegetation Index

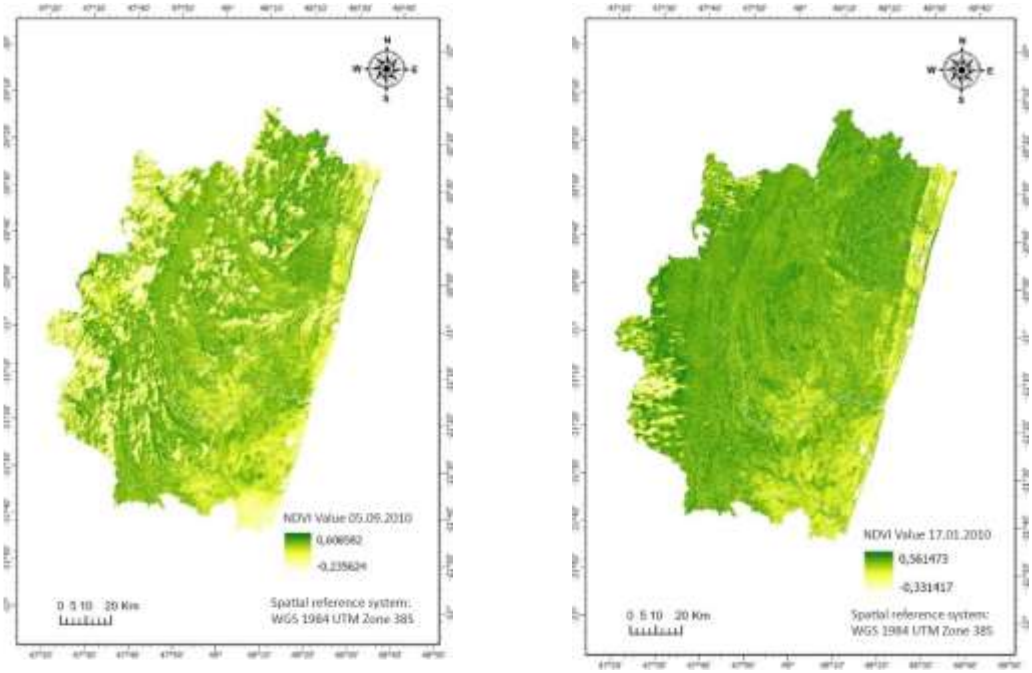

Figure 2. NDVI obtained from images before and after the cyclone BATSIRAI – Vegetation index

Note: The NDVI value is varied from -0.33 to 0.56 for the pre-cyclone image and from -0.23 to 0.60 for the image after the cyclone.

This NDVI analysis (Figure 1) following Cyclone Fami illustrates a clear and widespread impact on vegetation health. While the post-cyclone maximum NDVI slightly increased (0.56 to 0.60), the overall distribution suggests significant biomass loss, indicated by the consistently lower minimum NDVI and the visual reduction in green areas. This decline has implications for ecosystem services such as soil retention and carbon sequestration.

Understanding the spatial heterogeneity of this impact is crucial for targeted ecological restoration and for informing land-use planning in cyclone-prone regions.

This NDVI visualization (Figure 2) before and after Cyclone Batsirai reveals a substantial and geographically extensive decline in vegetation health. The post-cyclone imagery indicates a significant loss of photosynthetic biomass, signifying widespread damage to terrestrial ecosystems. This degradation has critical implications for soil stability, hydrological regimes, and carbon sequestration capacity. Understanding the spatial correlation between cyclone intensity and NDVI reduction is crucial for targeted environmental restoration efforts and for building resilience against future extreme weather events, which are increasingly pertinent in the context of climate change.

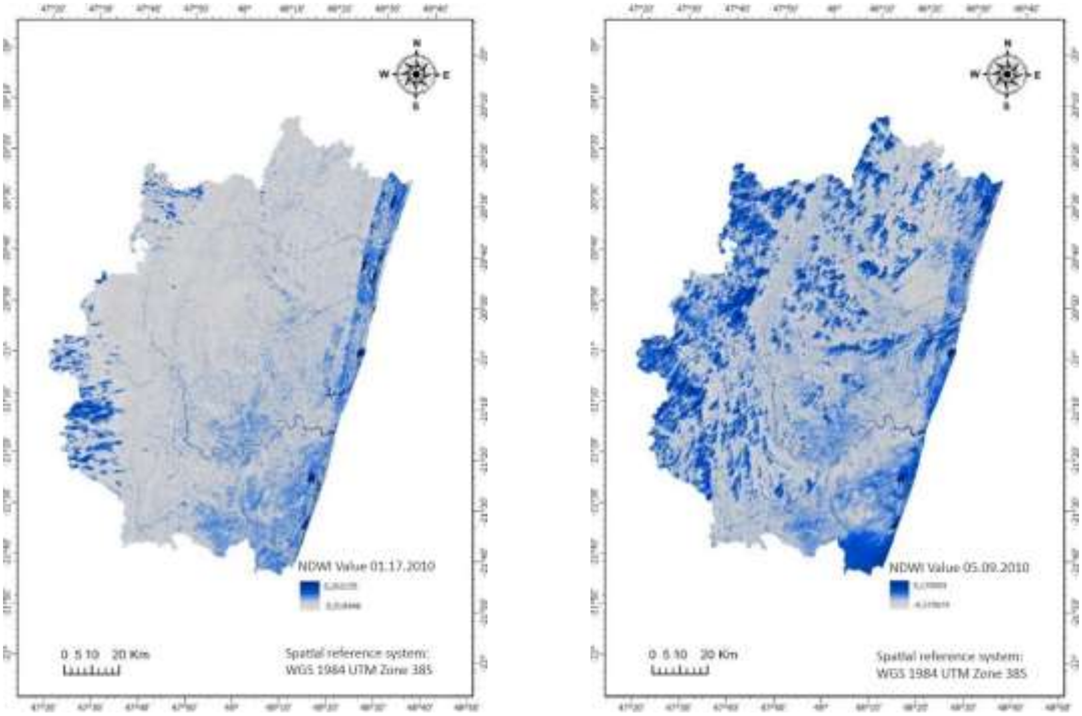

Figure 3. NDWI classified image before and after cyclone FAMI

This classified image (Figure 3) of the Normalized Difference Water Index (NDWI) before and after Cyclone Fami reveals significant alterations in surface water distribution. Post-cyclone, there is a discernible expansion of areas classified as water, likely due to heavy rainfall and potential flooding. Conversely, some previously water-rich areas may show a decrease, possibly due to altered drainage patterns or inundation of vegetation. Analyzing these changes is crucial for assessing flood extent, impacts on water resources, and potential risks to infrastructure and ecosystems in the cyclone's aftermath.

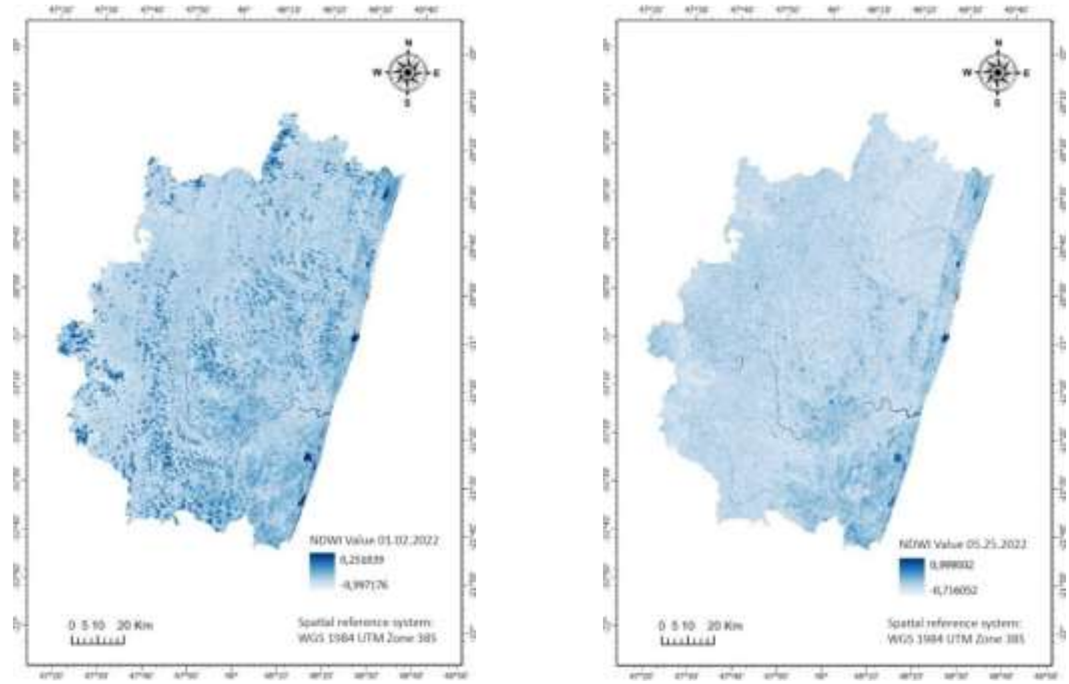

Figure 4. NDWI obtained from images before and after the cyclone BATSIRAI

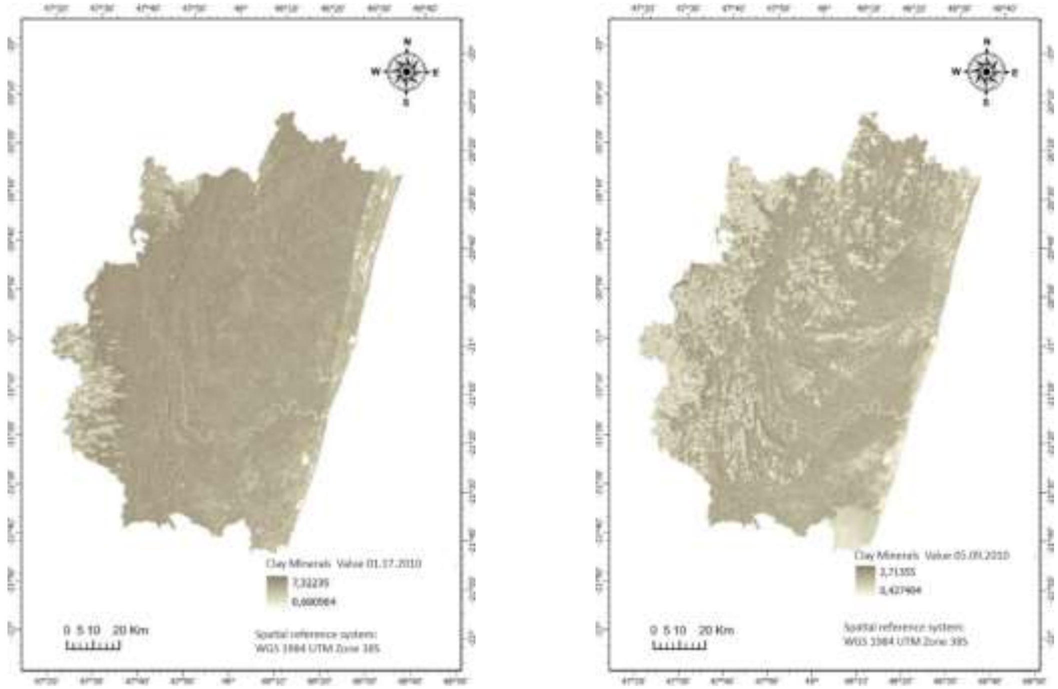

Figure 5. Clay content of obtained from the image before and after cyclone FAMI

This NDWI analysis (Figure 4) following Cyclone Batsirai illustrates the spatial changes in surface water. Comparing pre- and post-cyclone imagery reveals areas of likely inundation due to increased water presence, potentially impacting low-lying regions and infrastructure. Conversely, decreases in NDWI in other areas might indicate altered drainage or saturation of previously drier land. Quantifying these changes is vital for assessing the hydrological impact of the cyclone, informing flood risk management, and understanding potential long-term effects on water resources and dependent ecosystems.

This image (Figure 5) depicting clay content before and after Cyclone Fami suggests potential alterations in soil composition. Post-cyclone, there might be areas exhibiting increased clay content due to erosion and deposition of finer sediments from upstream or coastal regions. Conversely, other areas could show a relative decrease if coarser materials were deposited or if clay particles were washed away. Analyzing the spatial distribution of these changes is important for understanding the cyclone's impact on soil structure, agricultural potential, and overall land stability in the affected areas.

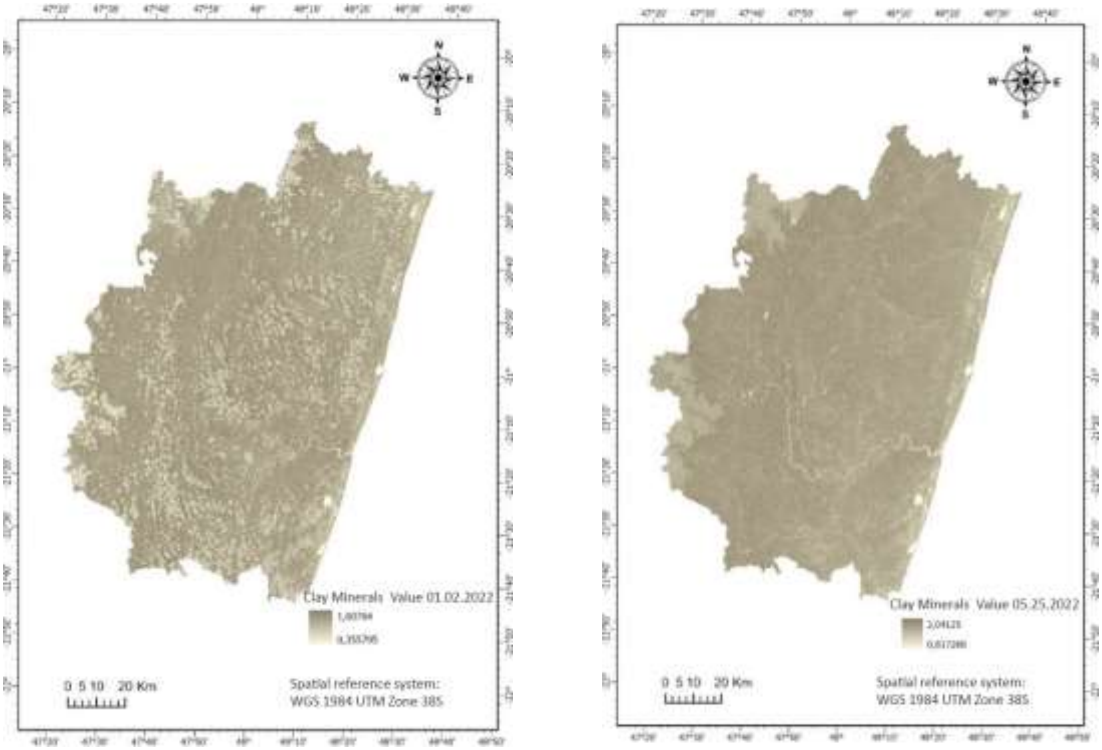

Figure 6. Clay content obtained from the image before and after the cyclone BATSIRAI

This depiction (Figure 6) of clay content before and after Cyclone Batsirai suggests a spatial redistribution of fine soil particles. Areas exhibiting increased clay content post-cyclone likely experienced deposition of finer sediments due to flooding and surface runoff. Conversely, regions showing decreased clay content might have undergone erosion, with lighter particles being washed away. Understanding these shifts in soil texture is crucial for assessing the long-term impacts on soil fertility, water infiltration rates, and the overall resilience of agricultural lands and natural ecosystems to future extreme weather events.

The equation below was adopted for the calculation of the LS factor, in accordance with the proposal of Moore and Burch:

$$Ls = \frac{(Flowaccumulation \times Cellsize)^{0,4}}{22.13} \times \frac{(sinslope)^{1,3}}{0,0896}$$

Value of the degree of slope in sin

This Figure 7 presents the derived LS factor, a key topographic variable in soil erosion assessments, for regions impacted by Cyclones Fami and Batsirai. Calculated using the Moore and Burch method incorporating slope gradient, the LS factor quantifies the combined effect of slope length and steepness on potential soil loss. Spatial analysis of these values aids in identifying areas most susceptible to erosion following cyclone-induced landscape modifications. (Al Rammahi & Khassaf, 2018)

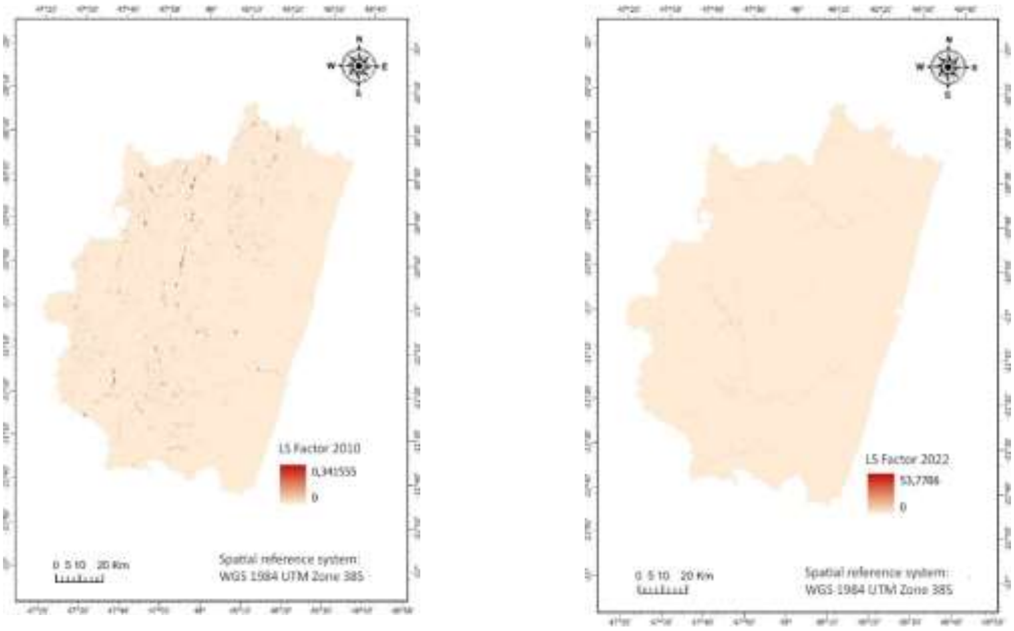

Figure 7. Value of the length of the slope and slope factor FAMI and BATSIRAI

This figure (Figure 7) presents the derived LS factor, a crucial component in soil erosion models, for the areas affected by Cyclones Fami and Batsirai. The calculation, based on the Moore and Burch proposal incorporating the sine of the slope degree, yields spatially explicit values representing the combined influence of slope length and steepness on erosion potential. [1] Comparative analysis of the LS factor before and after the cyclones would reveal areas rendered more susceptible to soil loss due to altered topography and land cover changes induced by these extreme weather events, informing targeted soil conservation strategies. (Ansari & Tayfur, 2023)

a. Hedging management factor (C)

Understanding soil erosion dynamics following extreme weather is crucial for environmental management. This analysis focuses on the Cover Management factor (C), derived from NDVI data before and after Cyclone Fami. The spatial distribution of the C factor reveals areas with altered vegetation cover, directly impacting soil erosion susceptibility and informing targeted mitigation strategies.

This map (Figure 8) depicts the derived Cover Management factor (C), a crucial variable in soil erosion models, based on the NDVI before and after Cyclone Fami. The spatial variation in the C factor reflects the changes in vegetation cover and its protective capacity against soil erosion induced by the cyclone. Areas exhibiting a higher C factor post-cyclone likely experienced significant vegetation loss, rendering the soil more vulnerable. This spatial information is vital for identifying regions requiring targeted soil conservation and land management interventions to mitigate erosion risks.

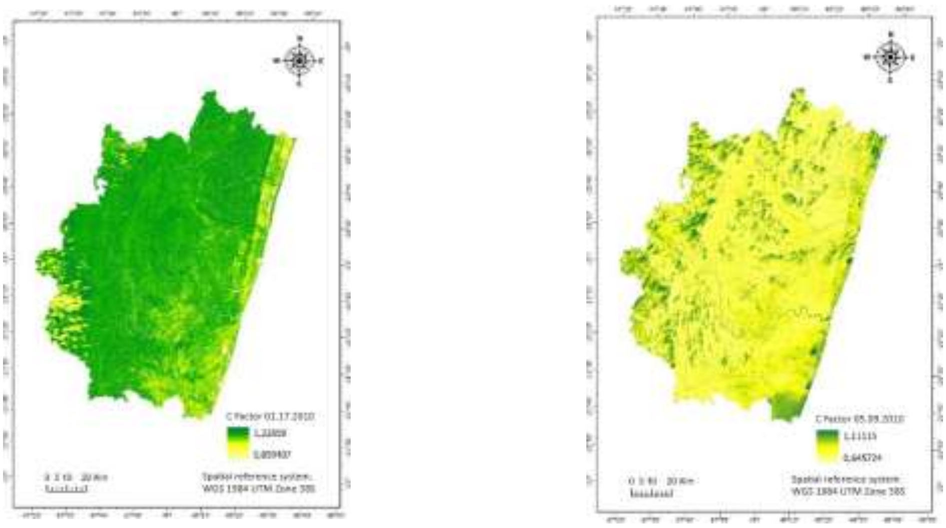

Figure 8. Factor C map obtained from NDVI of the image before and after cyclone FAMI

The Cover Management factor (C), derived from post-Cyclone Batsirai NDVI, spatially illustrates altered ground cover and its erosion protection capacity. Higher C values indicate significant vegetation disturbance, increasing soil erosion susceptibility. Understanding this spatial variability is crucial for targeted land management strategies aimed at mitigating soil loss and promoting ecosystem recovery.

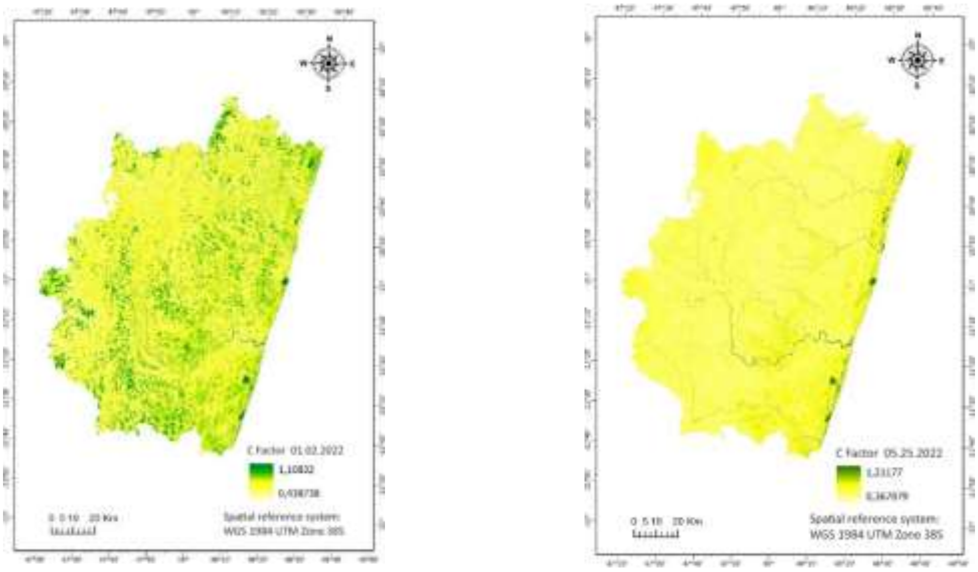

Figure 9. C Factor map calculated from the front image cyclone BATSIRAI and after Cyclone

This map displays the Cover Management factor (C) derived from NDVI data following Cyclone Batsirai. The spatial patterns illustrate the altered ground cover and its capacity to protect the soil surface from erosive forces. Regions with higher C values post-cyclone likely experienced significant vegetation disturbance or removal, leading to increased soil erosion susceptibility. Understanding this spatial variability is crucial for implementing targeted land management strategies aimed at mitigating soil loss and promoting ecosystem recovery in the cyclone-affected areas.

b. Conservation Practice Factor (P)

These maps illustrate the estimated spatial distribution of soil loss following Cyclones Fami and Batsirai. By integrating factors such as topography, vegetation cover (derived from NDVI), and potentially conservation practices (P-factor), this analysis identifies regions most vulnerable to post-cyclone erosion. The depicted soil loss patterns are crucial for prioritizing targeted interventions and informing sustainable land management strategies to enhance landscape resilience.

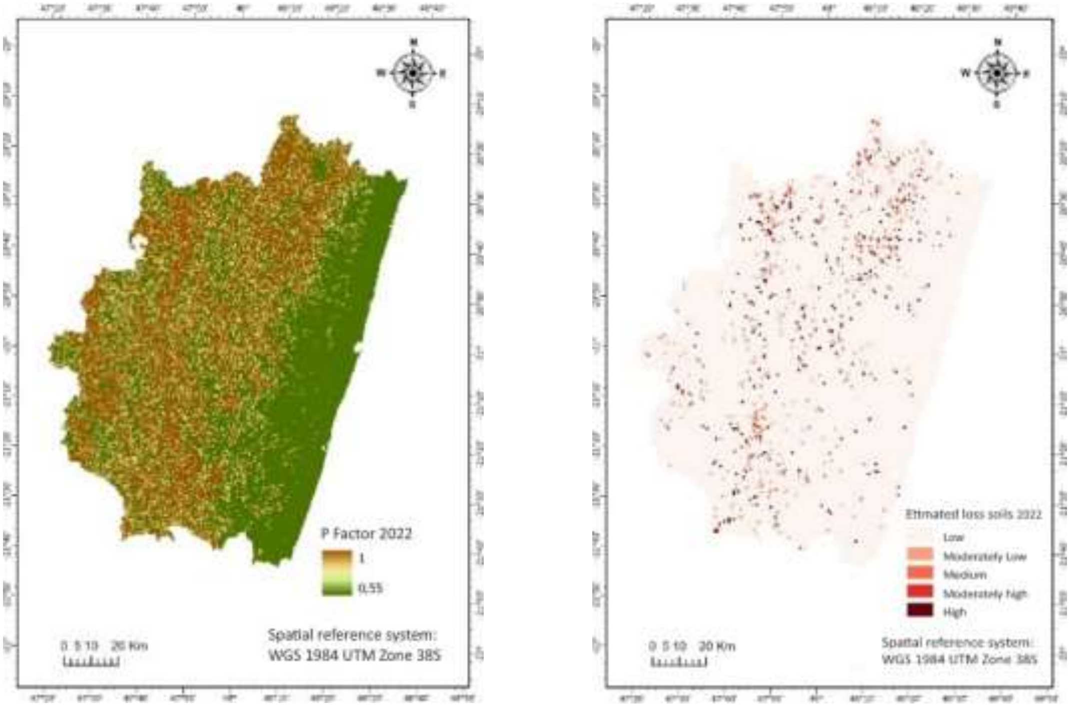

Figure 10. Map Showing Estimated Loss soils after cyclone FAMI and BATSIRAI

This map illustrates the estimated soil loss after Cyclones Fami and Batsirai, integrating factors such as slope, vegetation cover, and potentially conservation practices. The spatial distribution of soil loss indicates areas most vulnerable to erosion following these extreme weather events. Regions exhibiting high estimated soil loss warrant immediate attention for soil conservation measures to prevent further land degradation, protect water resources, and safeguard agricultural productivity in the affected landscapes. This analysis is crucial for prioritizing intervention efforts and informing sustainable land management strategies.

III. Result and Discussion

The ecological and infrastructural consequences of cyclones necessitate quantitative spatial-temporal analysis. Figures 11, 12, and 13 illustrate the evolution of vegetation cover, hydrography, and damaged surfaces (in km²) in the Vatovavy Region following Cyclones Fami and Batsirai. Comparative assessment of these changes provides critical insights into environmental vulnerability and recovery trajectories.

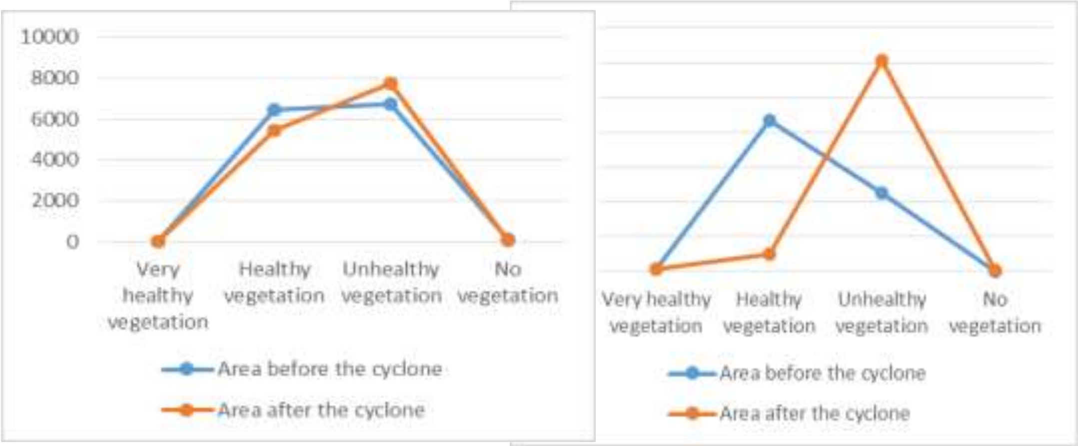

Figure 11. Evolution of the vegetation cover of Vatovavy Region after the passage of Cyclone FAMI and BATSIRAI (in Km^2)

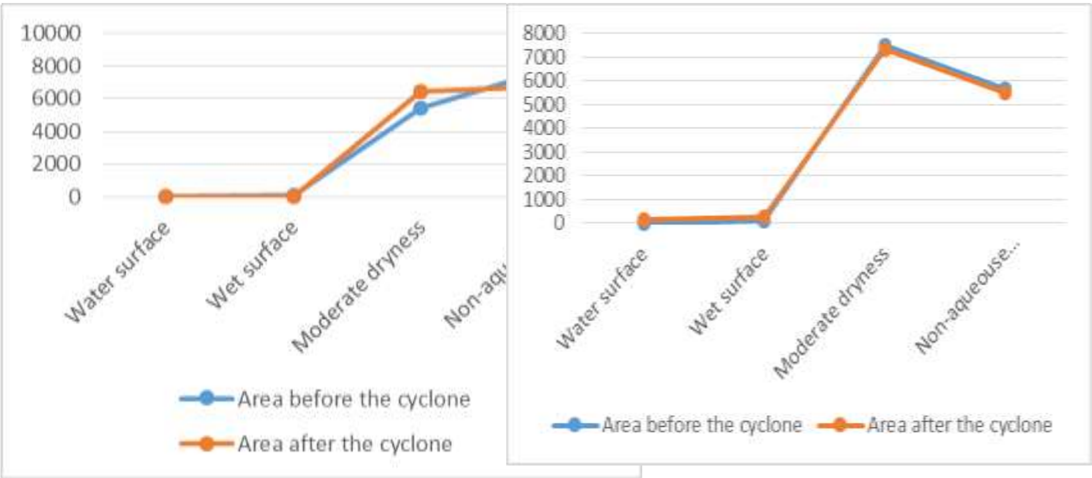

Figure 12. Evolution of hydrography after the passage of cyclone FAMI and BATSIRAI (in Km^2)

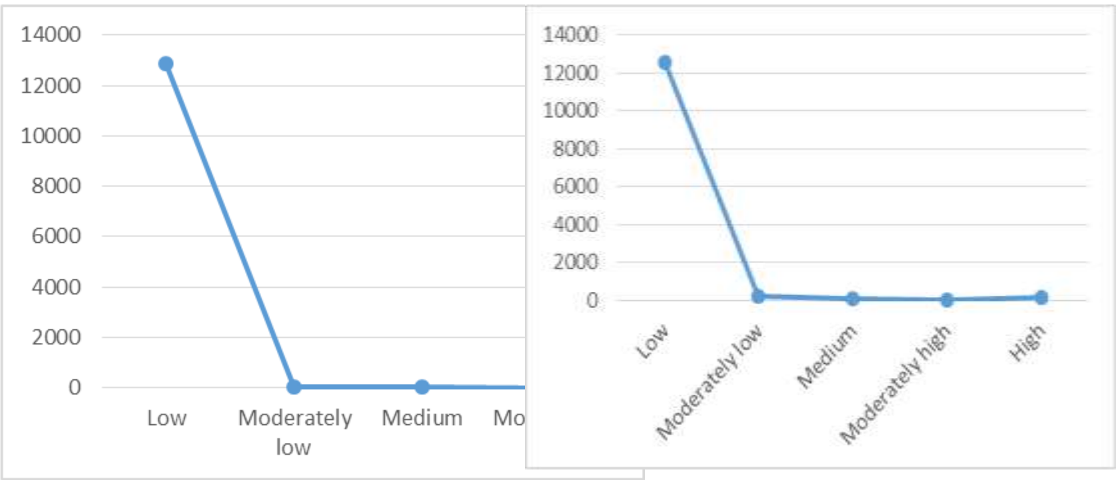

Figure 13. Damaged surface after the paage of cyclone FAMI and BATSIRAI (in Km^2)

Following the passage of the cyclone, we observed a reduction in healthy vegetation, the surface occupied increasing from 643,459.82 ha to 5458.75 ha. This remarkable reduction can be explained by various factors. First of all, the heavy rains and strong winds associated with the cyclone which ravaged the plants. At the same time, unhealthy vegetation has experienced significant growth in its surface area, only increasing by 1.08% after the cyclone, from 671,929.96 ha to 776,113.08 ha. This phenomenon can be attributed to damage caused by the cyclone to unhealthy plants, making them more vulnerable to diseases and infestations, as well as increased competition with healthy vegetation for access to light, water and nutrients. By elsewhere, very healthy vegetation has almost completely disappeared due to the direct impact of violent winds and intense rains. Finally, the surface area without vegetation decreased considerably from 130.55 ha to 66.75 ha, mainly due to the growth of unhealthy vegetation on areas that were initially naked. The vegetation changes observed after the cyclone have significant positive impacts on the agricultural soil. Reducing healthy vegetation and increasing unhealthy vegetation can assess the soil fertility. (Nash et *al.*, 2015)

On the hydrographic level, The significant reduction in the water surface and the surface wet, due to increased infiltration, increased runoff and increased evaporation, has contributed to a notable increase in surface area which shows moderate dryness. This increase indicates a increased water content in the soil, creating favorable conditions for crop growth. Furthermore, the reduction in non-aqueous surface area is an additional positive sign, suggesting that water resources are recovering, which could have beneficial long-term implications for agriculture local. So while the cyclone brought challenges and destruction, it also left behind regeneration and renewal opportunities for the region's agricultural sector. (Rakotobe et *al.*, 2016)

Changes in geological indices before and after the cyclone reveal variations significant. Before the cyclone, the clay ratios were in a range from 0.68 to 7.32, indicating diversity in the composition of agricultural soils. However, after the cyclone, these ratios experienced a notable decline, falling between 0.42 and 2.71. These variations underline a substantial modification of soil texture, suggesting direct impacts of the cyclone on the composition of agricultural soil. Several factors can explain these changes. First, the cyclone's strong winds and intense rains could lead to soil erosion, leading to the loss of clay particles. In addition, the consecutive water intake cyclonic precipitation may have influenced the redistribution of soil constituents. These Changes in clay ratios can have significant consequences on fertility and structure agricultural soil. The potential impacts of these changes on agricultural soils are multiple. A decrease clay ratios can affect water retention, nutrient retention capacity, and therefore, crop productivity. Agricultural soils with high clay ratios are generally considered to be favorable to plant growth. Thus, the modification of these ratios after the cyclone could present challenges for farmers, requiring adjustments in agricultural practices to maintain productivity lands affected by the cyclonic phenomenon. (Parida et *al.*, 2018).

The annual estimation of soil loss after cyclone FAMI is an important tool for identify the most affected areas and implement soil conservation measures. The estimate annual loss of soil after the passage of cyclone FAMI in Madagascar is illustrated in the table and the image above, divided into five color categories. The most severely affected areas, marked in red, indicate soil loss exceeding 35 tonnes per hectare per year, these areas are characterized by a mountainous terrain and fragile soils. This degradation results from the combined effects of heavy rains from the cyclone, uprooting trees and plants and thereby exposing the soil to erosion. In addition to the harmful consequences on agriculture, water quality is also affected, and the risk of landslides and other natural disasters are increased in these vulnerable regions. (Podest, 2019).

Following the events linked to the cyclone, there are significant variations in coverage plant. On the one hand, there has been a significant increase in the area occupied by very healthy vegetation and unhealthy. However, in return, the area occupied by healthy vegetation has decreased. At the same time, the zone without vegetation has almost completely disappeared, with a reduction of 99% of its initial surface. The factors likely to explain these changes are multiple. First of all, the cyclone exerted strong winds and intense rains, causing significant damage to vegetation, particularly trees and crops. In addition, the intense rains may have caused soil erosion, contributing to the degradation of the quality of the vegetation. Additionally, climate change may also have played a role in these transformations, particularly with regard to the increase in the area occupied by vegetation unhealthy. Thus, these combined factors have had notable repercussions on the plant landscape, with both positive and negative consequences. (Singh & Chudasama, 2017).

In addition, Cyclone Batsirai had a significant impact on the hydrography of the area. There disappearance of water surface and decrease in wet surface indicate a decrease in available water. The increase in moderate drought confirms this observation. The slight reduction in surface area watery can be explained by the infiltration of water into the soil.

In addition, the significant changes observed in the clay ratios of agricultural soils before and after the passage of the cyclone indicate substantial alterations in the composition of the soil. Before the cyclone, clay ratios were between 0.30 and 1.6, while after the cyclone these values increased to be between 0.8 and 2.04. This variation suggests a substantial increase in the amount of clay present in the ground following the cyclonic event. The causes of these changes can be multiple, including increased erosion due to heavy rains and strong winds associated with the cyclone. These Extreme weather conditions may have resulted in the transport and deposition of fine elements such as clay, thus modifying the composition of the soil. Additionally, flooding caused by the cyclone may have influenced the redistribution of soil particles, impacting the clay ratios observed. The consequences of these Changes in clay ratios on agricultural soils are significant. An increase in the content of Clay can affect soil structure, drainage and its ability to retain water. This could have impacts on soil fertility, influencing crop growth and potentially requiring adjustments in agricultural practices. Additionally, categorizing clay ratio values as high during spectral analysis highlights the importance of carefully monitoring these changes to understand andmitigate potential impacts on local agriculture. (Dadhich et *al.*, 2019)

The annual estimate of soil loss is also important in the evaluation of soil after the cyclone. Analysis reveals that the Weak predominates, encompassing the majority of the impacted surface with 96.58%, or 1,257 828.48 hectares, meaning low soil loss. On the other hand, the categories Moderately low, Medium. Moderately strong and Strong accumulate only 3.47% of the total surface area, representing a significant loss of soil less extensive but still significant over 44546.30 hectares. Cyclone BATSIRAI had an impact substantial, affecting more than 1.3 million hectares in this region. The consequences of this loss of soil are diverse, ranging from soil erosion and reduced land fertility to a tangible threat to agricultural production and food security of local populations. In addition, soil loss increases the risk of flooding and landslides, highlighting the widespread implications of this situation on the environment and the daily life of the inhabitants. (Youssef & Hegab, 2019).

The analysis of cyclone impacts has been an essential component of our work. THE benefits, such as water supply and soil renewal, were outweighed by the disadvantages, including erosion, flooding, salinization and nutrient loss. This detailed analysis highlighted the importance of a balanced approach, recognizing that although cyclones can have aspects beneficial, their negative consequences can lead to significant impacts on the quality and health of floors.

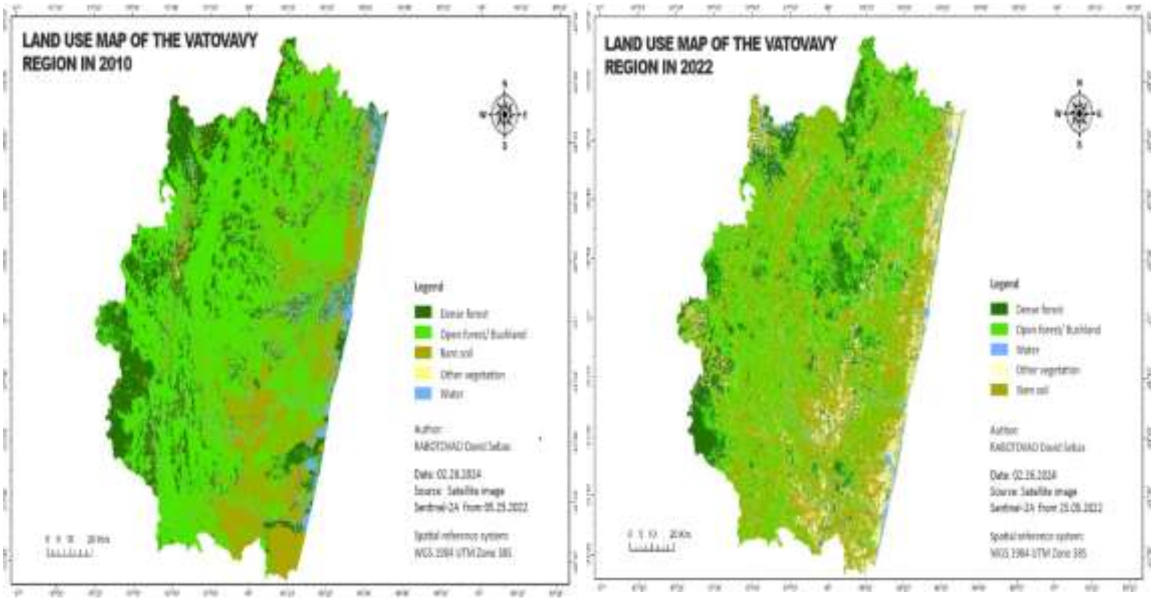

Figure 14. Land use MAP of Vatovavy Region in 2010 and 2022

This land use map of the Vatovavy Region, comparing 2010 and 2022, reveals significant land cover changes over this period. Analyzing these transformations, particularly in relation to natural vegetation, agricultural expansion, and built-up areas, is crucial for understanding long-term environmental trends and informing sustainable land management policies in this cyclone-prone region.

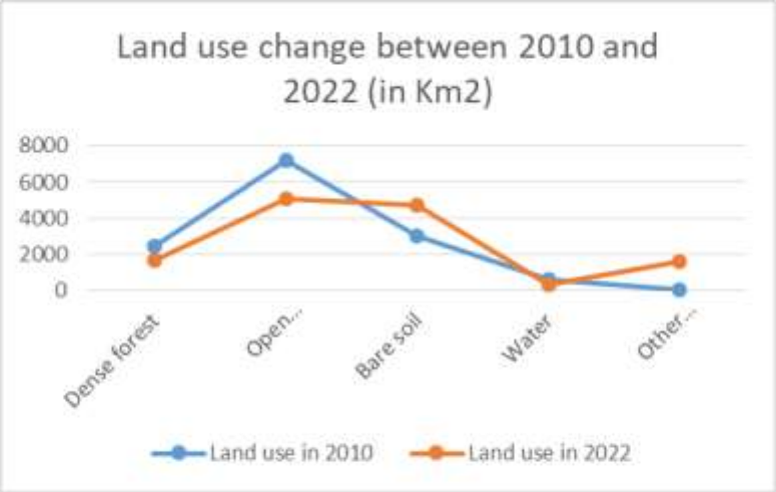

Figure 15. Land use map of the Vatovavy Region in 2010 and 2022

This comparative land use map of the Vatovavy Region for 2010 and 2022 reveals notable diachronic shifts in land cover. Quantifying these changes across categories like forest, agriculture, and settlements provides critical data for assessing long-term environmental change, understanding anthropogenic pressures, and informing sustainable land-use planning strategies, particularly in a region prone to cyclone impacts.

The integrated ecological assessment from 2010 to 2022 revealed significant trends in the plant cover, hydrological balance, mineral structure of soils and soil losses. These changes were particularly marked after the passage of cyclone Batsirai in 2022. Forecasts for The future has been outlined with these trends in mind, highlighting the need for monitoring reinforced environmental and adaptive measures to deal with extreme climatic phenomena. As the future dawns, it becomes imperative to further explore the possibilities of technological innovation to overcome the identified challenges, both in terms of satellite image quality and processing capabilities. International collaboration, interdisciplinary research and policy implementation integrated environmental measures will be key elements to strengthen the capacity to respond to changes environmental and natural disasters. (Mouquet et *al.*, 2020).

IV. Conclusion

The integrated ecological assessment of the Vatovavy Region following Cyclones Fami and Batsirai reveals significant and interconnected environmental changes. A notable reduction in healthy vegetation cover was observed, coupled with an increase in unhealthy vegetation, impacting soil fertility dynamics. Hydrological analysis indicated a decrease in surface water and wet areas, suggesting altered water retention and runoff patterns. Furthermore, changes in clay content signify substantial modifications to soil texture, potentially affecting agricultural productivity.

The spatial modeling of soil loss identified highly vulnerable areas requiring targeted conservation efforts. Land-use analysis between 2010 and 2022 highlights long-term environmental transformations, potentially exacerbated by cyclone impacts. These results underscore the profound and cascading ecological consequences of extreme weather events, necessitating integrated environmental management and adaptation strategies for this cyclone-prone region.

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