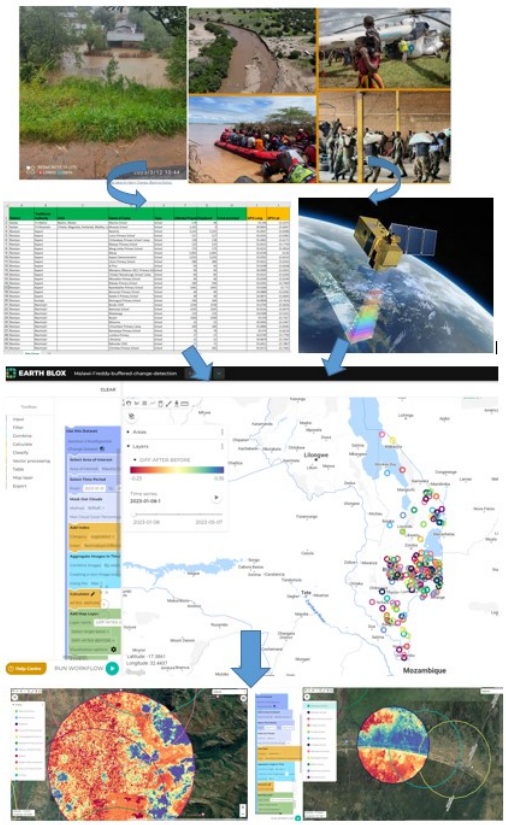
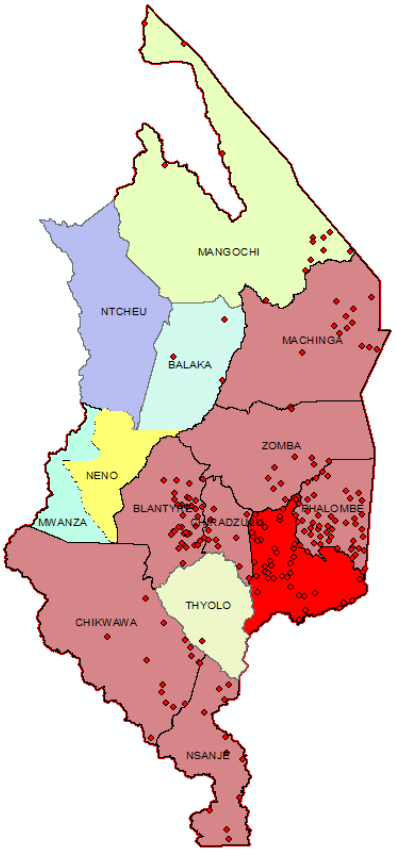
POST CYCLONE FREDDY DISASTER MAPPING – MALAWI





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ABSTRACT

Cyclone Freddy, a natural disaster of significant magnitude, struck the Southern Region of Malawi with devastating consequences in March 2023. This report focuses on mapping and assessment of the cyclone's impact using geospatial analysis. The exercise is a voluntary initiative conducted by the Scotland Malawi Partnership in collaboration with Professor Iain Woodhouse of the University of Edinburgh. The objective is to contribute to a comprehensive understanding of the locations and extent of damage caused by the cyclone. The mapping exercise employed the following datasets; (i) ground-based x-y locations, provided by Malawi's Department of Disaster and Management Affairs (DoDMA), and (ii) Remote Sensing data acquired from Sentinel-2 Multispectral Instrument 2023 imagery. The exercise was conducted using the following GIS software; (i) Earth Blox, (ii) Google Earth Pro platforms, (iii) ArcMap, and (iv) QGIS. The Normalised Difference Vegetation Index (NDVI) was employed to detect and analyse changes in vegetation cover and the hydrological features, impacted by the cyclone. The assumption being that surface damage would reduce surface vegetation cover and so vegetation loss becomes a proxy for impact. Areas that crossed a threshold of NDVI change were categorised as "impacted" so that an estimate of total impacted area for each area of interest could be determined.

Results show that the highly affected districts include; Mulanje, Machinga, and Zomba, especially areas surrounding the Nansato, Nankuyu, Kandimana, Khama and Kathebwe schools. Their change in NDVI value ranged from -0.5, -0.4, -0.3, -0.3 to -0.2, respectively (where more negative equates to greater impact). The less affected include areas around Bondo (0.3), Mtondoko (0.3), Msinje (0.2) and Mapazi (0.3) schools in Blantyre and Mangochi districts. While this work contributes to the better understanding of the impact of Cyclone Freddy in Malawi, the maps generated help in highlighting the affected areas and the vulnerable spots. Potentially, this aids the Government of Malawi (DoDMA) in allocation and mobilisation of prioritised relief efforts and resource. The study's methodology can serve as a model for mapping the aftermath of other natural disasters.

ACKNOWLEDGEMENTS

My profound gratitude should go to the Scotland Malawi Partnership (SMP) for entrusting Professor Iain Woodhouse and I with this technical work that entailed integration of ground-based datasets with GIS and Remote Sensing state of the art. Special thanks to Prof., Woodhouse again for his generosity in providing the Earth Blox platform user licence, which was indispensable to the geospatial analysis, and his invaluable his knowledge and experience that has shaped the entire work.

I am grateful to the Department of Disaster Management Affairs (DoDMA)-Malawi, in particular to Messrs; Charles Kalemba and Sam Gama who authorised and provided shared the ground datasets used, respectively.

I quote one of the recent Linked Earth Blox blogs by Prof., Woodhouse, '...*It is true that the final customer of Earth Observations does not need to know about satellite technology*…'. In the same vein, it is our hope that this write-up has been presented in a very simplified manner that any reader can understand and appreciate the impact of Cyclone Freddy in Malawi.

Furthermore, it is the anticipation of the SMP that this report can be used as a stepping-stone for the Government of Malawi to appreciate the extent of damage that the Cyclone Freddy caused and support the process of making informed decision for not only post-disaster response and recovery efforts, but for also for the disaster risk preparation and management.

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1.0 INTRODUCTION

Reliable and up-to-date information about on-site disaster situation and local context is key to not only to efficient humanitarian assistance delivered to displaced persons, but also pivotal to the accounting of the damage of affected areas (Hu et al., 2017; Popa et al., 2019). It is further indispensable to the derivation of mitigation interventions and risk management (*ibid*). In this respect, Dr Henry Kadzuwa (under the Scotland Malawi Partnership) and Professor Iain Woodhouse of the University of Edinburgh offered to map some key areas highly affected by the Cyclone Freddy disaster in Malawi. This follows the worst damage caused by the torrential rains that claimed more half a million lives and displaced many others between 11-13 March 2023 (Department of Disaster Management Affairs, 2023). The cyclone affected Malawi's Southern Region most, particularly, Blantyre and Zomba cities and urban, in addition, to the following; Chikwawa, Chiradzulu, Mulanje, Machinga, Mwanza, Neno, Nsanje, Phalombe and Thyolo districts.

Figure 1. Tropical Cyclone Freddy Extent and Emergency Response Plan. *Source:* https://www.scotland-malawipartnership.org/news/tropical-cyclone-freddy-2

Pre- and post-disaster mapping helps identifying impacted areas, especially the most hit (Hu et al., 2017). In this case, the post-Cyclone Freddy disaster exercise was aimed at assisting the Malawi Government through the response team (under the Department of Disaster Management Affairs-DoDMA) to also plan and prioritise their post-disaster relief efforts and management. This can enable the government to prioritise allocation of relief resources such as food, water, shelter, and medical supplies to the areas highly affected.

This post-disaster mapping exercise was particularly intended to assess the level of damage caused by the cyclone in terms of the extent that was expressed through vegetation damage. The exercise also aids in appreciating the disaster by rendering Earth Observations of the affected locations (Lekkas et al., 2021). It is the expectation of the SMP and Prof., Woodhouse that this work further supports the Government of Malawi to make informed decisions on mitigation of vegetation damage and infrastructure planning that will contribute to building more resilience among communities, in the near future.

Figure 2. A Road Infrastructural Damage Caused by the Tropical Cyclone Freddy

Source: https://www.scotland-malawipartnership.org/news/tropical-cyclone-freddy-2

While physical monitoring visits to appreciate disaster's situation provide key insights (i.e., Fig., 2), studies have however, noted that such efforts require integration mapping data to analyse the patterns of the affected areas, identify the factors and understand the risks of natural hazards and help mitigate disasters (Lang et al., 2017; Popa et al., 2019). In the same vein, by employing such datasets and mapping products, the DoDMA can identify hotspots and proactively prepare for their rehabilitation.

2.0 METHODOLOGY

2.1 Study Site

The study was conducted in the Southern Region of Malawi, particularly in the following districts that were affected by the Cyclone Freddy in March 2023; Balaka, Blantyre, Chikwawa, Chiradzulu, Machinga, Mulanje, Mwanza, Neno, Nsanje, Phalombe, Thyolo and Zomba districts (Department of Disaster Management Affairs, 2023).

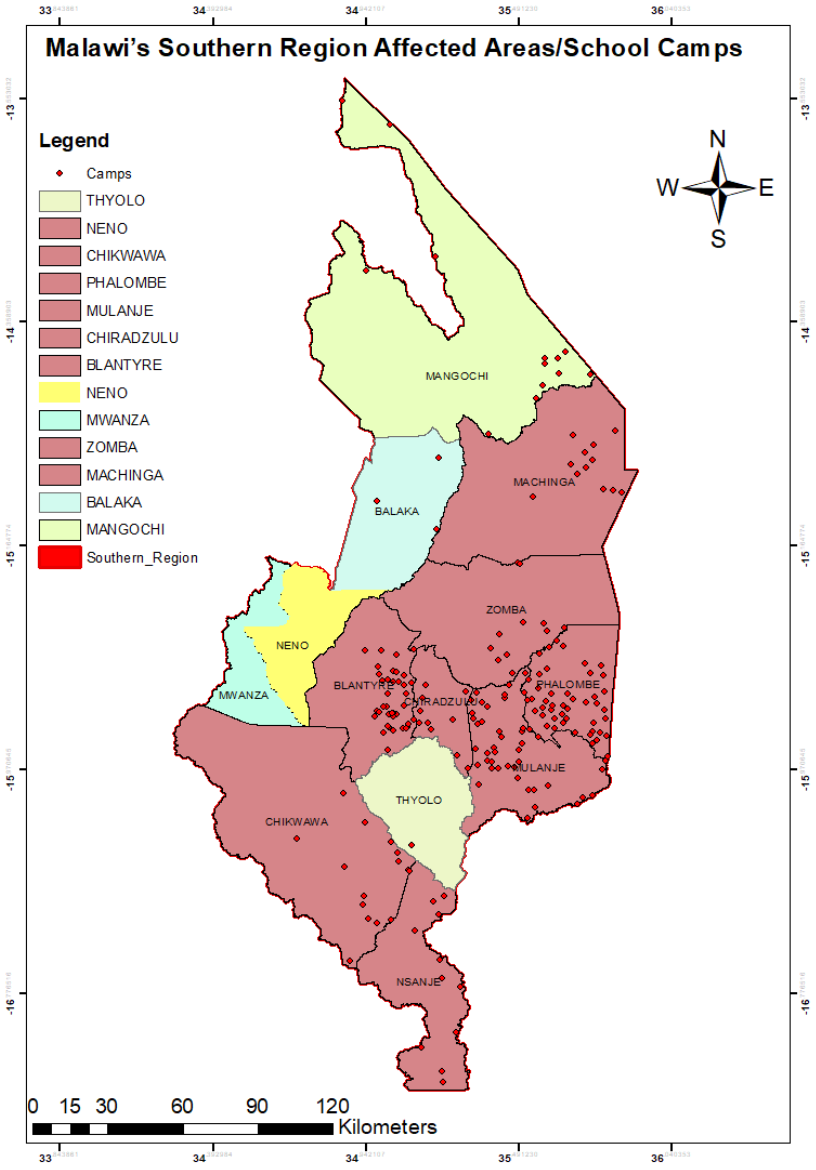


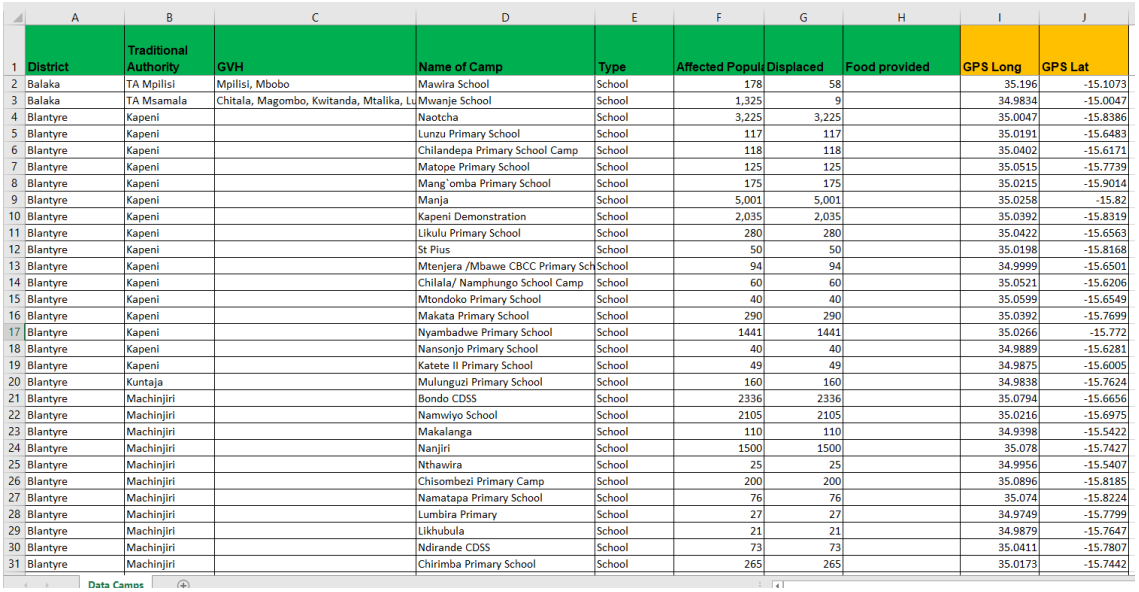
Figure 3. Malawi's Southern Region Affected Areas/School Camps

2.2 Ground-based Data Acquisition

The SMP received raw ground-point data (Microsoft Excel format) from the DoDMA (Directorate of Resilience and Recovery) which covered the Southern Malawi. These contained the following;

(i) 209 points (*x-y* coordinates) of school camps (used as safe havens), their jurisdiction and population attributes, and

(ii) Hard-to-reach areas where stakeholders were unable to get *x-y* coordinates.



	A	B	C	D	E	F	G	H	I	J
1	District	Traditional Authority	GVH	Name of Camp	Type	Affected Popul	Displaced	Food provided	GPS Long	GPS Lat
2	Balaka	TA Mpilisi	Mpilisi, Mbobo	Mawira School	School	178	58		35.196	-15.1073
3	Balaka	TA Msamala	Chitala, Magombo, Kwitanda, Mtalika, Lu	Mwanje School	School	1,325	9		34.9834	-15.0047
4	Blantyre	Kapeni		Naotcha	School	3,225	3,225		35.0047	-15.8386
5	Blantyre	Kapeni		Lunzu Primary School	School	117	117		35.0191	-15.6483
6	Blantyre	Kapeni		Chilandepa Primary School Camp	School	118	118		35.0402	-15.6171
7	Blantyre	Kapeni		Matope Primary School	School	125	125		35.0515	-15.7739
8	Blantyre	Kapeni		Mang`omba Primary School	School	175	175		35.0215	-15.9014
9	Blantyre	Kapeni		Manja	School	5,001	5,001		35.0258	-15.82
10	Blantyre	Kapeni		Kapeni Demonstration	School	2,035	2,035		35.0392	-15.8319
11	Blantyre	Kapeni		Likulu Primary School	School	280	280		35.0422	-15.6563
12	Blantyre	Kapeni		St Pius	School	50	50		35.0198	-15.8168
13	Blantyre	Kapeni		Mtenjera /Mbawe CBCC Primary Sch	School	94	94		34.9999	-15.6501
14	Blantyre	Kapeni		Chilala/ Namphungo School Camp	School	60	60		35.0521	-15.6206
15	Blantyre	Kapeni		Mtondoko Primary School	School	40	40		35.0599	-15.6549
16	Blantyre	Kapeni		Makata Primary School	School	290	290		35.0392	-15.7699
17	Blantyre	Kapeni		Nyambadwe Primary School	School	1441	1441		35.0266	-15.772
18	Blantyre	Kapeni		Nansonjo Primary School	School	40	40		34.9889	-15.6281
19	Blantyre	Kapeni		Katete II Primary School	School	49	49		34.9875	-15.6005
20	Blantyre	Kuntaja		Mulunguzi Primary School	School	160	160		34.9838	-15.7624
21	Blantyre	Machinjiri		Bondo CDSS	School	2336	2336		35.0794	-15.6656
22	Blantyre	Machinjiri		Namwiyo School	School	2105	2105		35.0216	-15.6975
23	Blantyre	Machinjiri		Makalanga	School	110	110		34.9398	-15.5422
24	Blantyre	Machinjiri		Nanjiri	School	1500	1500		35.078	-15.7427
25	Blantyre	Machinjiri		Nthawira	School	25	25		34.9956	-15.5407
26	Blantyre	Machinjiri		Chisombezi Primary Camp	School	200	200		35.0896	-15.8185
27	Blantyre	Machinjiri		Namatapa Primary School	School	76	76		35.074	-15.8224
28	Blantyre	Machinjiri		Lumbira Primary	School	27	27		34.9749	-15.7799
29	Blantyre	Machinjiri		Likhubula	School	21	21		34.9879	-15.7647
30	Blantyre	Machinjiri		Ndirande CDSS	School	73	73		35.0411	-15.7807
31	Blantyre	Machinjiri		Chirimba Primary School	School	265	265		35.0173	-15.7442

Data Camps

Figure 4. School Camps Attribute Microsoft Excel Data Excerpt

2.2.1 Data Pre-processing

The dataset was cleaned i.e., removal of double entries, correction of typos/incomplete digits (for the lat. long). The next step involved converting the x-y coordinates from Microsoft Excel to the csv. format, thus, for software interoperability. This was followed by further conversion of the dataset to ESRI format and then to the Geodetic Coordinate System of Latitude and Longitude, using QGIS Desktop software (3.16.9). To match with the universal referencing system that suits Malawi, the datasets were re-projected to the EPSG:32736-WGS 84/UTM Zone 36S as a processing pre-requisite (Kadzuwa and Missanjo, 2023).

The next phase involved generation of a shapefile (vector container) for all the grounds-locational data points. Buffer zones of 4km radii, which are basically, circular polygons originating from the central point/centroid of each camp to the perimeter/edge were created around each of the 209 school camps as Areas of Interest (AOIs), Figure 5.

2.3 Ground Data Caveats and Geospatial Assumptions

The SMP requested point data (x-y) coordinates of the areas affected by the cyclone, instead, though quite understandable, DoDMA provided school camps locational attributes used as safe havens. This was because the severity of the cyclone's damage rendered most of the impacted areas inaccessible during data collection. In the face of this challenge, a key decision was made to optimally utilise the available datasets to help mapping the disaster. Hence, the datasets were subjected to systematic random sampling assay. Precisely, they were tested to establish the proximity (horizontal distance) of the school camps and the areas affected by the cyclone in Google Earth platform. The results revealed that least ≥80% of the damaged areas fell within 4km radius of the school camps.

Therefore, the mapping exercise was premised on the following key geospatial assumptions;

(i) the affected areas mapped are within the 4km radius of the safe camps,
(ii) there is 80% probability of including affected areas within the 4km buffers, and alternatively, 20% chances of missing out some affected areas that may not fall within the 4km radius of the school camps, and
(iii) that some camps overlap (close by each and share horizontal space within the 4km radii), Figures 3 and 5.

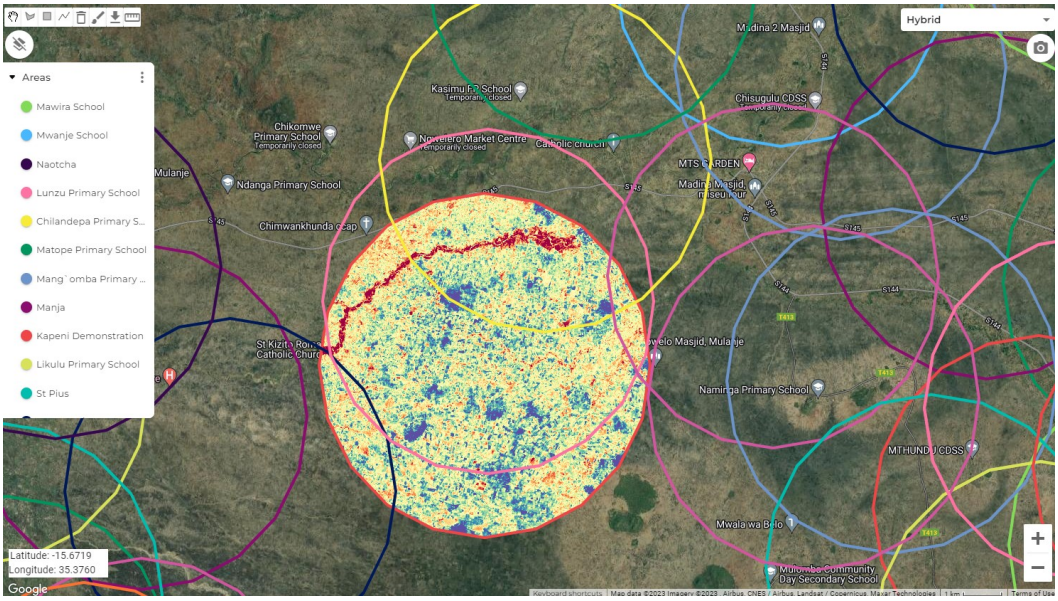


Figure 5. Overlapping 4km radii safe camps of Nankuyu, Kamwendo, Chilera, Muhiyo and Mgode in Mulanje district displayed on Earth Blox and Google Earth Hybrid Platform.

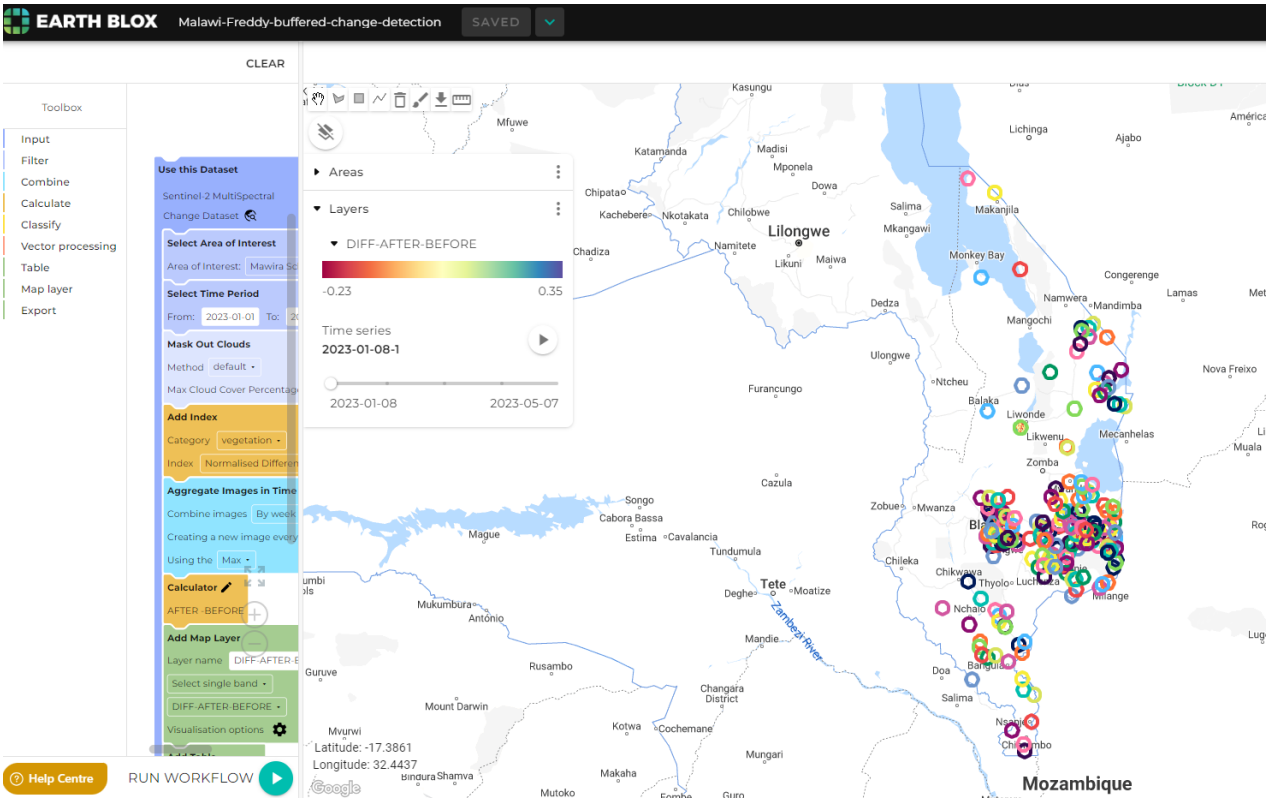


Figure 6. Distribution of 4km Radii Buffered Disaster AOIs (School Camps) in Malawi's Southern Region.

2.4 Earth Observations Data

2.4.1 Sentinel-2 Imagery Acquisition

The exercise used the following GIS software; (i) Earth Blox, and (ii) Google Earth Pro platforms, (iii) ArcMap, and (iv) QGIS software in acquisition, interpretation, integration, processing and analysing the geospatial data. The optical median seasonal composite Sentinel-2 Multispectral Instrument (MSI) 2023 imagery were acquired in May 2023 over Malawi's Southern Region, encompassing the areas affected by the Cyclone Freddy. This was done using the Earth Blox. The datasets covered the rainy season, thus within a preferred period of 01-01-2023 to 16-05-2023 when the Cyclone Freddy was experienced in Malawi. While the Cyclone Freddy peak period was 11-13 March in Malawi, selection of the January 01 to May 26 epoch served to aid the understanding of the subtle vegetation changes, thus for accurate image interpretation and analysis.

Despite the Sentinel-2 satellite imagery datasets being unrestricted (free and open), their preference was largely due to the following;

(i) the capability of the mission's imaging sensors' red-edge (RE) of the Near-InfraRed (NIR) window that is used to detect vegetation at moderate spectral resolution of 10-20m (Li et al., 2021). Such a scale provides fine details of observations, and

(ii) the assessment of the vegetation damage/change that uses the Normalised Difference Vegetation Index (NDVI) technique (Cunliffe et al., 2020; Pettorelli et al., 2005). This is rendered possible by being provided the Near-Infrared (NIR) Red-Edge spectral region of the Sentinel-2 MSI imagery *(ibid*). The NIR is located in the sharp change of canopy reflectance range between 680nm and 750nm where a slope occurs, providing an advantage to mapping vegetation (*ibid*).

2.4.2 Normalized Difference Vegetation Index

The term Normalized Difference Vegetation Index (NDVI) simply refers to a graphical indicator most widely characterised in plant studies, and it is correlated with green leaf cover, and consequently biomass set by the plant physiology i.e., when canopy cover is correlated with biomass. It is simply calculated as follows (Roy et al., 2016);

$$NDVI = \frac{(NIR - Red)}{(NIR + Red)}$$

Where;

(i) NDVI = Normalised Difference Vegetation Index,
(ii) NIR = Near-Infrared band of the Electromagnetic Spectrum (EMS), and
(iii) Red = the optical (visible) red band of the EMS.

NDVI interpretation is based on the simple principle that healthy vegetation (chlorophyll) reflects more Near-InfraRed (NIR) and green light compared to other wavelengths. In contrast, it absorbs more red and blue light (Roy et al., 2016; Vrieling et al., 2018).The general trend is that NDVI values range from -1.0 to 1.0, and the negative values indicate clouds and water, while the positive ones near zero indicate bare soil (*ibid*). Therefore, in this mapping exercise, the higher positive range of values for NDVI, i.e., 0.1 to 0.5 denote the transition from bare land/dead or sparse vegetation to dense green vegetation (≥0.6). In this case, the higher positive values would signify the areas where the cyclone/floods affected less while the low ones denote those were highly affected.

The NDVI numerical difference was computed by getting the change (after subtracting the before disaster scene covering 01-01-2023 to 10-03-2023 from the post-disaster scenes covering 17-03-2023 to 16-05-2023), thus (After-before). This was divided into 12 weeks to encompass the variability of the changes observed.

2.5 Sentinel-2 Imagery Processing

The key Sentinel-2 Imagery processing tasks involved the following

i. selection of AOIs – the school camps,
ii. selection of time periods 01-01-2023 to16-05-2023, divided into weeks,
iii. masking out of clouds- done to reduce the radiometric distortion of land surfaces of the AOIs and also to remove dark pixels due to the effect of cloud shadows. The maximum cloud cover was 40%.
iv. selection of theme category and appropriate technique i.e., vegetation and NDVI
v. calculation of AOI scenes difference (Post cyclone minus Before cyclone) and generation of results.

3.0 RESULTS AND DISCUSSION

This section derives the findings of the mapping exercise concerning vegetation damage (expressed as change in NDVI) and change in area/hectares.

3.1. Extent of Vegetation Damage using NDVI Change

As stated earlier, the extent of vegetation damage was assessed using the change in the NDVI technique, which was categorises as low or high, for the purpose of this exercise.

3.1.2 Low NDVI change value (High vegetation/cyclone impact)

Appendix 1 displays a Table of NDVI values calculated at within the 4km radii of each school camps affected by the Cyclone Freddy.

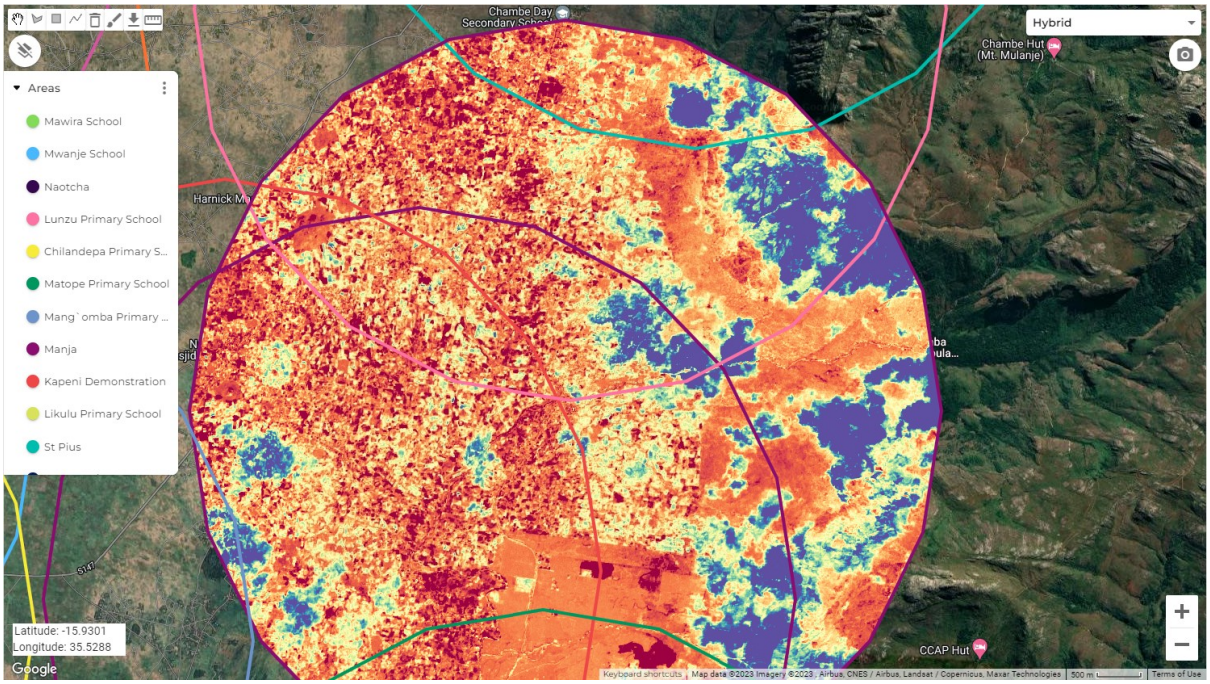


Figure 7. Nansato Area in Mulanje registered the highest negative NDVI change value (-0.5) measured at the scale = -1 to 1. The reddish to magenta areas denote high vegetation damage (highly affected areas) and cyan/blue to green indicate healthy vegetation (less affected areas)

While the values of the NDVI ranged from -.05 to 0.3, for each of the week occurring from 1st January-16th May 2023, the average was 0.006. Hence, the assessment of these areas show that the 5 highly affected areas are within the 4km zone of Nansato, Nankuyu,

Kandimana, Khama and Kathebwe schools, thus with NDVI values of -0.5, -0.4, -0.3, -0.3 and -0.2, respectively. The means that vegetation of these areas was highly damaged and alternative that these were heavily impacted by the cyclone.

The location and topography of Nansato (surrounded by rivers and upland streams) at the foot of Mulanje Mountain) at high risk to floods (Figure 7). The topographic analysis shows that Nansato, just like Nankuyu and most of the affected areas in Mulanje lie at the foot of the 3,000m or 10,000ft high Mulanje Mountain, and worse still the areas serve as a streams and rivers' confluence. The upland rivers and streams include; Nansato, Likhubula and Thuchila, among others. The geographical location attributes of the affected areas render such areas more prone to floods. This is exacerbated by the fact that most of the trees and vegetative cover of the upland mountain has been unscrupulously removed by illegal wood harvesting i.e., curio makers and timber extractors.

This scenario applies to most of the remaining affected areas in Mulanje i.e., Nongwe, Chiwambo, Kambenje. While this also applies to some areas in Phalombe located at the foot of Michesi/Mulanje Mountain i.e., Phaloni, Mpata and Namilango, it is the wetland condition of the area (Lake Chilwa basin) that also exacerbates the floods (Chiotha et al., 2017). The Lake Chilwa basin faces environmental challenges that include deforestation, soil erosion and floods (*ibid*).

For Machinga district, the topographic analysis shows that Nankuyu, Naphuthu and Nayuchi is a stretch of low land (basin) that does not only lie in between Lake Chiuta and Lake in Chilwa, but it is also a gentle flat wetland that is prone to floods (Chiotha et al., 2017). Hence, the affected areas are quite prone to floods prone/disaster risk and should be prioritised for disaster management.

3.1.3 High NDVI value (High vegetation/Cyclone Impact

Some of the least affected areas include those that are within the radius of; St Joseph Primary School and Liwesa in Mangochi district, with almost no change in NDVI (zero

value). Those around Bondo Community Day Secondary School, Mtondoko, Mapazi and Likulu Primary Schools, all in Blantyre with 0.3, 0.3, 0.3, 0.3 NDVI values, respectively.

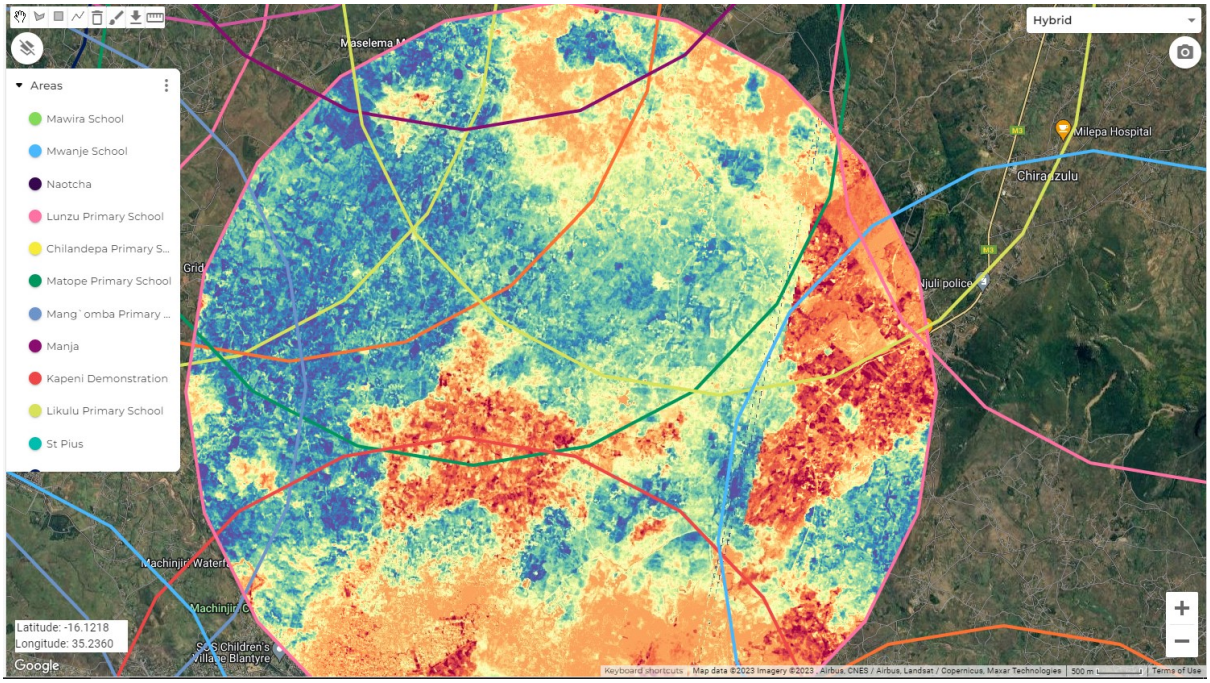


Figure 8. Mapazi Area in Chiradzulu registered the on the highest NDVI values (0.3) measured at the scale = -1 to 1. The reddish to magenta areas denote high vegetation damage (highly affected areas) and cyan/blue to green indicate healthy vegetation (less affected areas).

The relatively low impact of the areas in Blantyre and Chiradzulu can be attributed to the fact that they are located in the highlands (Shire Highlands) where drainage takes place at a higher speed compared to the low-lying areas such as Nsanje and Chikwawa districts.

On the other hand, the due to the low terrain of the Nsanje and Chikwawa, which is also regarded as the Lower Shire River Valley/area, it is common to experience seasonal floods (Ministry of Natural Resources, Energy and Mining, 2017; Mwase et al., 2007). Any increase in precipitation from the upper land, i.e., Lake Malawi, the Shire Highlands that include (Blantyre inclusive) and the surrounding districts are most like to cause floods in the Lower Shire (Nieman et al., 2021). In addition, the bare lands of the Middle and Upper Shire also exacerbate this flooding conditions. Most of the areas that were affected in

Blantyre are those that are landslides/erosion due to deforestation e.g., While the protected areas (forests) in Malawi act as natural protectors of landslides, soil erosion, most of these have not been spared from illegal harvesting there rendering increasing the risk of flood more during heavy down pour or torrential rains.

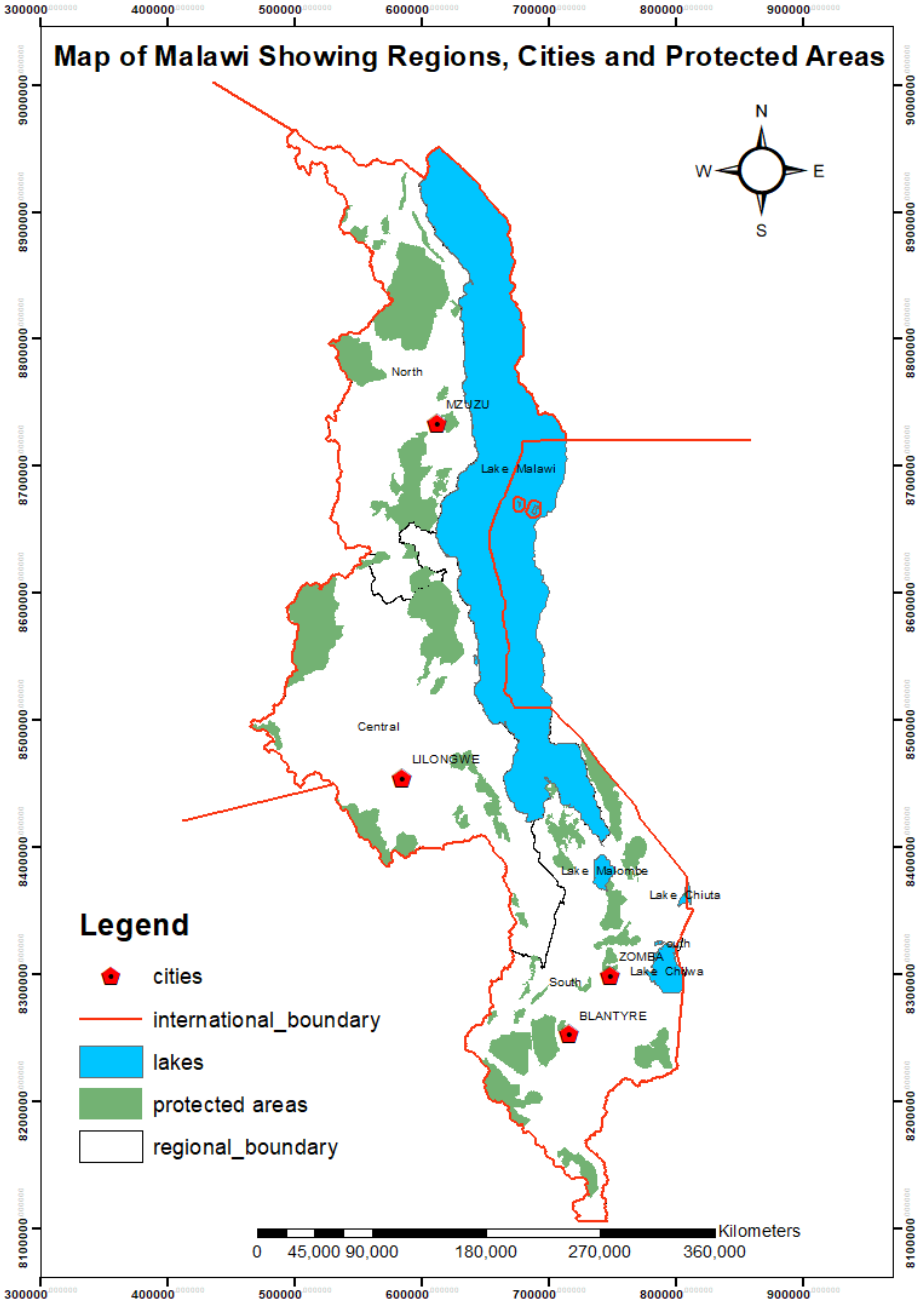


Figure 9. Map of Malawi Showing Regions, Cities and Protected Areas.

3.2 Extent/Area of change in Hectares

To quantify the relative impact across the areas of interest (the camps with a 4km buffer) the difference in NDVI from before and after the storm were calculated and differenced. Since NDVI can range from –1 to +1, the maximum difference between two NDVI values is +/- 2. In practice, for the given data, the differences were much smaller. An NDVI difference of 0 meant no change. Negative values meant that the pixel had experienced a reduced NDVI. Since surface damage would likely also reduce the surface vegetation, it was interpreted that minus values are a proxy for storm damage. To account for non-impactful change, or seasonal variation (since the differences were calculated from Jan-Feb and April-May), a threshold of –0.2 was set as the criteria to define impact. The total area could then be calculated for each area of interest (Appendix 2). The most affected areas include; Nansato, Nankuyu, Dzanjo, Khama and Kathebwe schools. The change of area trend displayed by these sites could equally be explained by the same topographic attributes discussed under NDVI change in Section 3.1.

4.0 CONCLUSION

This study focused on mapping and assessment of the Cyclone Freddy's impact in Malawi's Southern Region. It employed ground-based x-y locations and Sentinel-2 MSI imagery acquired over the Southern Malawi in May 2023. The exercise used Earth Blox, and Google Earth Pro online platforms, and the Arc Map, and QGIS software. The objective was to contribute to a comprehensive understanding of disaster by; (i) identifying the locations, and (ii) extent of vegetation cover damage caused by the cyclone. The study employed the Normalised Difference Vegetation Index (NDVI) technique to examine the two parameters. Results indicate severe vegetation damage in, Mulanje, Machinga and Zomba, especially areas surrounding the Nansato, Nankuyu, Kandimana, Khama and Kathebwe schools. Their NDVI values ranged from -0.5, -0.4, -0.3, -0.3 to -0.2, respectively. In contrast, Bondo (0.3), Mtondoko (0.3), Msinje (0.2) and Mapazi (0.3) schools in Blantyre and Mangochi districts were the less affected areas.

The outcomes contribute to the better understanding of the impact of Cyclone Freddy in Malawi in a multifaceted manner. By comparing pre- and post-cyclone imagery using the NDVI technique, the study identified worst hit areas, including those that are more vulnerable to flooding, landslides, and infrastructural damage. It has further estimated the hectarage of vegetation damage. The maps generated showcase the affected areas and highlight the vulnerable spots. Potentially, this aids the DoDMA in allocating and mobilising prioritised relief efforts and resource. The study's methodology can serve as a model for mapping the aftermath of other natural disasters, out of which timely and effective response strategies can be facilitated, thus in case of an impending disaster. To crown it all, this work is envisaged to support the Government of Malawi through the DoDMA appreciate the extent of damage and make informed decision for post-disaster response and recovery efforts

The lessons learned from this endeavour can serve as a blueprint for similar disaster response and recovery initiatives around the world, emphasizing the pivotal role of geospatial analysis in safeguarding communities against the impact of natural disasters.

5.0 MITIGATION INTERVENTIONS AND WAY FORWARD

5.1 Interventions

This mapping exercise suggests the following environmental interventions for the vegetation damaged assessed;

i. Afforestation/Re-afforestation- especially for the fragile areas such as Mulanje Mountain, Soche Hill, Chigumula Forest, for example, collaborative afforestation of Mulanje Mountain and other forests,
ii. Urban forestry,
iii. Forest landscape restoration,
iv. Riverine/bank planting, and
v. Relocation to safe places.

Redressing of the various landscapes using the interventions mentioned above can take advantage of the following forestry and climate change programmes that are on-going in Malawi;

a. Forest Land Scape Restoration Programme,
b. Malawi Youth Forest Restoration Programme,
c. Modern Cooking for Healthy Forests Project,
d. Establishment of Forest Plantations in Selected Reserves under the Malawi Watershed Services Improvement Project, and
e. Malawi Carbon Initiative Programme.

5.2 Way Forward

5.2.1 Targeted Resource Allocation

The mapping exercise has provided for the identification of high-impact zones, i.e., especially areas surrounding; Nansato, Nankuyu, Kandimana, Khama and Kathebwe schools, in Mulanje, Machinga and Zomba, just to mention, but a few. It therefore recommends the Government of Malawi to allocate relief resources to these areas as they are needed most. This will ensure efficient resource distribution i.e., provides that aid reaches these target areas and communities as they require more attention.

5.2.2 Data-Informed Decision-Making

This post-disaster geospatial mapping has provided decision-makers evidence-based information on the extent and nature of vegetation damage. This information shall live to guide strategic planning and response efforts that can facilitate timely decision-making to address immediate and long-term challenges using land use/land cover based solutions. For example, collaborative afforestation of Mulanje Mountain and other forests, urban forestry, relocation to safe place.

5.2.3 Vulnerability Assessment

The maps generated from the analysis have highlighted vulnerable districts/areas and populations. This allows for a proactive approach to disaster risk reduction and management. It is envisaged that by understanding the geospatial distribution of these affected areas, the DoDMA can implement mitigation strategies, infrastructure improvements, and land-use policies that enhance resilience to future cyclones and disasters.

5.3.4 Efficient Response Coordination

Accurate disaster mapping enables better coordination among various agencies (Government, Non-Governmental, Civil Societies, and any other stakeholders involved in disaster response. By providing a common operational picture, as this case with this exercise, it is envisaged that such mapping will facilitate collaboration while reducing duplication of efforts, leading to a more streamlined and effective response to the Cyclone Feddy.

5.2.5 Long-Term Planning and Reconstruction

The mapped data serves as a valuable resource for post-disaster reconstruction and recovery planning. It informs the development of comprehensive recovery strategies that address both immediate needs and long-term sustainability, ensuring that communities can rebuild with resilience.

5.2.6 Monitoring and Evaluation

Over time, the disaster affected area’s maps can be used to monitor changes in the affected areas, track progress in recovery efforts, and assess the effectiveness of implemented interventions. The DoDma data-driven approach to monitoring and

evaluation informs adaptive strategies and continuous improvement in disaster management practices.

5.3 Suggested Areas of Improvement

5.3.1 Community Engagement and Participation

This study recommends engagement of local communities and stakeholders, valuing their insights and input in order to be quite robust. This participatory approach empowers communities to contribute to the post-disaster data collection and analysis to some extent) which will, fostering a sense of ownership and agency in disaster recovery efforts.

5.3.2 Use of Artificial Intelligence to Model Disaster Potential.

This report suggest that the DoDMA should employ an oriented approach in further identification of disaster vulnerable areas, i.e., by computing Flash-Flood Potential Index FFPI) for the mountains areas such as Mulanje, Blantyre, and floods Flood Potential Index (FPI) for the relatively flat or wetland areas such as Machinga, Some parts of Zomba, Phalombe, and Chikwawa and Nsanje. These have proven quite effective in mountainous and low altitude areas (Popa et al., 2019).

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APPENDIX1.MEAN NDVI CHANGE PER AOI (DESCENDING ORDER)

AREA OF INTEREST AREAS OF INTEREST (AOI)	DIFFERENCE (AFTER-BEFORE (mean)
Nansato school	-0.52401
Nankuyu school	-0.36649
Kandimana school	-0.26803
Khama school	-0.24968
Kathebwe	-0.21799
Nafisi school	-0.21472
Dzanjo Primary School	-0.18593
CHIKONJE	-0.17523
Makuwa School	-0.16868
Kholonje Primary School	-0.1507
Milala	-0.13268
Malambwe Primary School	-0.13057
Kankomba	-0.11911
Tharu primary school	-0.09946
NYAMITHUTHU	-0.09772
Nanyowa Primary School	-0.09492
NYACHILENDA	-0.09453
Mpambezu Primary School	-0.09349
Nkhulambe EPA/Chigwirizano CBO	-0.09298
Nkhulambe Full primary school	-0.09298
MANKHOKWE	-0.09286
Thambe Primary School	-0.09216
Komzere	-0.08912
M'BWAZI	-0.08301
Phaloni Primary School	-0.08158
Mwananjovu School	-0.08132
THANGADZI	-0.07689
Chiuta school	-0.07672
MGUDA SCHOOL	-0.07494
MPEPE SCHOOL	-0.07449
Chikowa primary	-0.06899
Makhawani primary school	-0.06889
Migowi Primary School	-0.06842
Ndakwera	-0.06612
Nguludi girls primary	-0.0645

Gomani Primary	-0.06289
Mfera primary Camp	-0.05957
Jombo primary school	-0.05767
Thendo	-0.05711
NSANJE CATHOLIC PRIMARY SCHOOL	-0.05461
Naminjiiwa Primary School	-0.05422
Mpama camp	-0.05028
Montfort primary	-0.04879
Namikango	-0.04805
Misangu primary30	-0.04796
Chidalale Primary School	-0.0472
Chingazi Primary	-0.04593
Nambiti Primary School	-0.0449
Monjo	-0.04481
Chitawotowo Primary School	-0.04461
Bona	-0.04453
Mbembembe School	-0.04315
Nzedi Primary	-0.04265
Chapomoka primary school	-0.03875
John Primary School	-0.03821
Chimesya school camp.	-0.03783
Makalanga	-0.03775
Thundu school	-0.0377
Mitondo School	-0.03761
Nogwe Primary School	-0.0348
Nyangu Primary school	-0.03462
MASENJERE	-0.03445
Linguni	-0.03208
Mambala Primary School	-0.03126
Likulezi	-0.02885
Nthawira	-0.02801
Chilala school	-0.02785
Mchenga School	-0.02752
Nambiro Primary School	-0.02602
Mwangothaya	-0.02368
Maera school	-0.02358
Mchenga Primary school	-0.0235
Katete II Primary School	-0.02184
Mbulumbuzi	-0.02091
Likangala	-0.02061
Namasoko Primary School	-0.02057
Makuwa Primary school	-0.01847

Nalingula	-0.01823
Mwanazanga School	-0.0181
Longwe Primary School	-0.0174
Chilayeni School	-0.01656
Makulo	-0.01632
Mtendele	-0.01621
NAMILEMBE	-0.01578
Kambenje Primary School	-0.01566
Khwalala	-0.01449
Rimera school	-0.0142
Chisani school	-0.01232
Mgodi School	-0.01132
Masuku primary	-0.0113
Nangalamu school	-0.01126
Sagawa School	-0.01049
Pambachulu School	-0.01037
Jeke primary school	-0.00967
Chifide LEA School	-0.0095
Mpasa Primary School	-0.00724
Namikate Primary School	-0.00607
Litchenza Primary school	-0.00548
Mpale	-0.00503
Nanthupi School	-0.00471
Nansonjo Primary School	-0.00374
Mchacha Primary school camp	-0.00354
Chinjika School	-0.00307
Nangalole school	-0.00104
Chayanika school	-0.00073
Nsanga school	0.001196
Maula school	0.001239
Chikuli	0.001913
MWANAMBWERE PRIMARY SCHOOL	0.002985
St. Ignatious primary	0.003215
Mawira School	0.003841
Lisawo Primary	0.003984
Chikonde	0.006071
	-0.05841
Chisamba LEA School	0.006872
Lihaka School	0.007402
Phalombe Primary School	0.009988
Phalombe TTC	0.009988
Chimbiri School	0.01011

Malilima	0.013381
Thawale 1 School	0.014378
Chisese school	0.015545
Muhiyo School	0.016711
Namatuni School	0.017232
Namasimu school	0.019817
Nachituluka School	0.020266
Nyengeni/Waruma School	0.020386
Thuchila Primary school	0.020442
Nakawale 2 primary	0.020538
Mbuyemwana Primary School	0.021871
Namansimba school	0.021993
Nampeya school	0.022184
Thundu	0.026028
Malundu School	0.026939
Mtenjera /Mbawe CBCC Primary School	0.027669
Namphungo Primary School	0.027684
Nakamba School	0.031385
Namatapa Primary School	0.03248
Sukayakwe School	0.032888
Mpingwe Primary School	0.035684
Magomero primary	0.036922
Kamwendo Catholic School	0.038676
Chikhwaza School	0.039138
Chilera LEA School	0.039875
Chisawani School	0.040491
Chitekesa School	0.040611
Lumbira Primary	0.040642
Ufa	0.046417
Chiwambo School	0.048081
Ming'ambo School	0.051071
Ndungunya primary school	0.051347
Namalombe Primary	0.051415
Milepe Primary School	0.051544
Chisombezi Primary Camp	0.05598
Taibu School	0.056229
sakalawe	0.058134
Bangwe Catholic Secondary School	0.05834
Naminga	0.058861
Nankuyu School	0.060395
Likhubula	0.063784
Mulunguzi Primary School	0.064207

Mwanga Primary School	0.064411
Nanjiri	0.065806
Matope Primary School	0.076803
Chimwaza School	0.07806
Makata Primary School	0.084656
Chitsime Primary School	0.084871
Namatete	0.086397
Mwanje School	0.087435
Nkanda	0.087528
Samson	0.093127
Tcheleni Primary School	0.093577
Nyambadwe Primary School	0.094643
Chilandepa Primary School Camp	0.096969
Ndirande CDSS	0.102159
Chirimba Primary School	0.103009
Lunzu Primary School	0.103877
Chanda School	0.104377
Chithumbwi	0.11372
Mulanje Government	0.114461
O.M school	0.11929
Mpala School	0.121155
St Pius	0.125473
Naotcha	0.126903
Manja	0.127841
Chilala/ Namphungo School Camp	0.129475
Kapeni Demonstration	0.130666
Chitedze School	0.132966
Namwiyo School	0.146466
Laundare School	0.146867
Mloza Lea	0.152806
Nansato School	0.152935
Mudi Primary School & Kachere CBCC	0.165588
Mang`omba Primary School	0.167557
Malimba Primary School	0.171693
Chumani Primary School	0.176105
Msinje primary school (18)	0.178588
Likole School	0.187428
Mpata	0.211737
Mitawa School	0.212763
Chilele Primary School	0.256513
Likulu Primary School	0.2576

Mapazi Primary School	0.297171
Mtondoko Primary School	0.302792
Bondo CDSS	0.333211
Liwesa (302)	-
St Joseph primary	-

APPENDIX 2. MEAN AREA (HECTARAGE) CHANGE PER AOI (DESCENDING ORDER)

Area of Interest	DIFF-THRESHOLD (sum)	Area (ha) within AOI
Nansato school	4174	5881.115825
Nankuyu school	3172	5888.68457
Dzanjo Primary School	2814	5857.081782
Khama school	2632	5894.164325
Kathebwe	2326	5876.168059
Kholonje Primary School	2247	5869.702648
Malambwe Primary School	2051	5871.986179
CHIKONJE	1976	5846.564891
Kandimana school	1934	5883.859165
Makuwa School	1708	5864.648846
Milala	1545	5890.908482
Makhawani primary school	1534	5855.809457
Nafisi school	1527	5906.231564
Nkhulambe EPA/Chigwirizano CBO	1478	5865.365135
Nkhulambe Full primary school	1478	5865.365135
Phaloni Primary School	1457	5869.696434
Tharu primary school	1451	5859.961034
Thambe Primary School	1369	5875.240254
Kankomba	1332	5871.042341
Nanyowa Primary School	1294	5846.385037
NYAMITHUTHU	1180	5842.734279
Malilima	1049	5860.806869
Bona	1035	5865.528104
THANGADZI	1015	5828.715399
Mpambezu Primary School	954	5870.641544
Thundu school	935	5850.19695
Mwananjovu School	927	5848.92364
Namatapa Primary School	904	11706.15261
NYACHILENDA	882	5820.846265
MANKHOKWE	879	5823.045266
Migowi Primary School	824	5861.277832
MGUDA SCHOOL	789	5853.14481
M'BWAZI	787	5863.232214
Chikowa primary	711	5868.672126
Nzedi Primary	702	5867.871036

NSANJE CATHOLIC PRIMARY SCHOOL	695	5826.284504
Nambiti Primary School	669	5848.336304
Chidalale Primary School	662	5865.23785
Nogwe Primary School	655	5866.573059
Area 1	621	349772.4773
Chiuta school	612	5893.457586
Komzere	593	5827.561368
Mambala Primary School	582	5852.901875
Monjo	579	5850.483524
Mpama camp	569	5847.40449
Chingazi Primary	566	5854.196023
Naminjiiwa Primary School	553	5860.260189
Gomani Primary	538	5852.225345
Mfera primary Camp	533	5850.703492
Pambachulu School	501	5859.205466
Mpale	496	5864.110983
Mbembembe School	495	5861.20216
Misangu primary30	484	5868.027227
Namikango	481	5860.769307
Ndakwera	472	5841.226312
Mloza Lea	453	5849.568749
Mpala School	422	5840.515899
Likangala	419	5877.607628
Chitedze School	418	5864.864192
Jombo primary school	413	5847.794467
Lisawo Primary	407	5866.211088
Mitondo School	407	5845.518931
Nalingula	407	5848.845182
Rimera school	405	5891.169879
Nakamba School	402	5870.603802
Linguni	401	5853.944409
Phalombe Primary School	400	5865.056372
Phalombe TTC	400	5865.056372
Kambenje Primary School	397	5859.374109
Chimwaza School	389	5874.092566
Mpingwe Primary School	388	5850.166501
Mwanazanga School	388	5859.731592
Nambiro Primary School	387	5856.928986
Nguludi girls primary	384	5857.021248
Chitawotowo Primary School	377	5860.261844
Mitawa School	376	5844.503738
Malundu School	373	5878.036819

Chinjika School	372	5867.778671
Chiwambo School	369	5846.282616
Chitekesa School	365	5867.826747
Mpasa Primary School	361	5860.18395
Ndungunya primary school	341	5863.854406
MASENJERE	326	5847.415148
Mwanga Primary School	325	5868.084658
Nyangu Primary school	318	5867.537225
Mchenga School	315	5864.344219
Chilayeni School	308	5864.304381
Mwangothaya	298	5858.286435
Chilera LEA School	292	5855.071156
Montfort primary	281	5858.206444
Nachituluka School	281	5862.341215
Chikonde	279	5847.847687
Jeke primary school	278	5838.114142
Namasoko Primary School	273	5862.854415
Mtendele	271	5863.614642
Chifide LEA School	258	5857.171032
Chimbiri School	258	5866.298575
Milepe Primary School	257	5862.393634
Kamwendo Catholic School	254	5862.695723
Muhiyo School	252	5867.23517
Mbulumbuzi	251	5870.377659
Chisombezi Primary Camp	247	5853.684487
Lihaka School	241	5867.576223
Mgodi School	237	5849.536087
Longwe Primary School	236	5859.933549
Ming'ambo School	232	5856.4692
Nankuyu School	221	5874.756013
Chisamba LEA School	216	5848.793067
Mpata	210	5865.567986
Chimesya school camp.	209	5886.321755
Khwalala	205	5867.884686
Nkanda	201	5854.158271
Chisani school	200	5881.645445
Likulezi	200	5884.177902
Nangalole school	199	5886.228793
Nanjiri	198	5861.5605
Tcheleni Primary School	188	5859.065614
Matope Primary School	187	5852.070732
Thuchila Primary school	185	5861.835626
Sagawa School	184	5861.044151

Chilala school	179	5886.075211
Bangwe Catholic Secondary School	174	5864.994152
Makuwa Primary school	171	5886.051408
Masuku primary	169	5893.485047
Naminga	169	5863.056871
Mchacha Primary school camp	166	5845.603537
Makulo	158	5870.212407
Chikhwaza School	148	5848.721133
Maula school	141	5860.107157
Mchenga Primary school	137	5842.792527
Chapomoka primary school	136	5845.705964
Chithumbwi	134	5863.384518
Chisawani School	133	5858.012544
Mawira School	129	5878.11544
John Primary School	124	5860.448503
St. Ignatious primary	121	5915.127341
Thendo	100	5838.801308
Thawale 1 School	99	5850.29023
Chikuli	96	5878.791097
sakalawe	95	5863.925753
Litchenza Primary school	92	5847.011551
Nakawale 2 primary	84	5887.290995
Malimba Primary School	82	5855.30776
MPEPE SCHOOL	82	5839.781914
Namphungo Primary School	82	5853.071334
Ufa	81	5863.868665
Namalombe Primary	79	5893.755557
Nangalamu school	78	5891.534608
Maera school	77	5861.092055
Nanthupi School	77	5872.145048
Magomero primary	70	5892.8788
Chayanika school	69	5899.927412
Katete II Primary School	68	5861.710887
Chisese school	63	5891.114719
O.M school	63	5899.647369
Namatuni School	59	5847.593057
Ndirande CDSS	58	5854.749512
Mapazi Primary School	57	5862.813557
Mulanje Government	54	5859.871851
Nyengeni/Waruma School	51	5847.541624
Namasimu school	47	5891.657126
Nthawira	47	5870.080396

Sukayakwe School	47	5846.790648
Thundu	44	5877.550228
Mwanje School	42	5883.75755
Namansimba school	42	5890.342238
Nansonjo Primary School	42	5858.070413
Nsanga school	42	5910.277267
Chumani Primary School	39	5861.590852
Makalanga	39	5856.626855
Makata Primary School	38	5852.182813
Samson	38	5862.959229
Mudi Primary School & Kachere CBCC	35	5853.195219
Lunzu Primary School	34	5861.335556
Chitsime Primary School	33	5862.763382
Mbuyemwana Primary School	33	5846.325354
Mtenjera /Mbawe CBCC Primary School	33	5863.198863
NAMILEMBE	30	5843.755291
Chanda School	27	5877.289
Nyambadwe Primary School	25	5863.605751
Nansato School	24	5870.199048
Taibu School	23	5859.424557
Chilala/ Namphungo School Camp	22	5873.59945
Mtondoko Primary School	21	5854.448224
Namikate Primary School	19	5871.533832
Chirimba Primary School	18	5859.603776
Likulu Primary School	18	5853.452166
Namwiyo School	18	5856.129162
Chilandepa Primary School Camp	17	5858.375263
Laundare School	17	5861.607306
Kapeni Demonstration	14	5851.392071
Manja	14	5848.85744
Nampeya school	13	5873.834212
St Pius	13	5864.254135
Bondo CDSS	12	5869.467951
Namatete	9	5858.632591
Naotcha	8	5852.159467
Chilele Primary School	5	5858.694721
Likole School	5	5844.772395
MWANAMBWERE PRIMARY SCHOOL	4	5819.927231

Mang`omba Primary School	1	5856.119379
Likhubula	0	5862.855069
Liwesa (302)	0	5918.564189
Lumbira Primary	0	5862.425181
Msinje primary school (18)	0	5924.574954
Mulunguzi Primary School	0	5859.091705
St Joseph primary	0	5905.742329