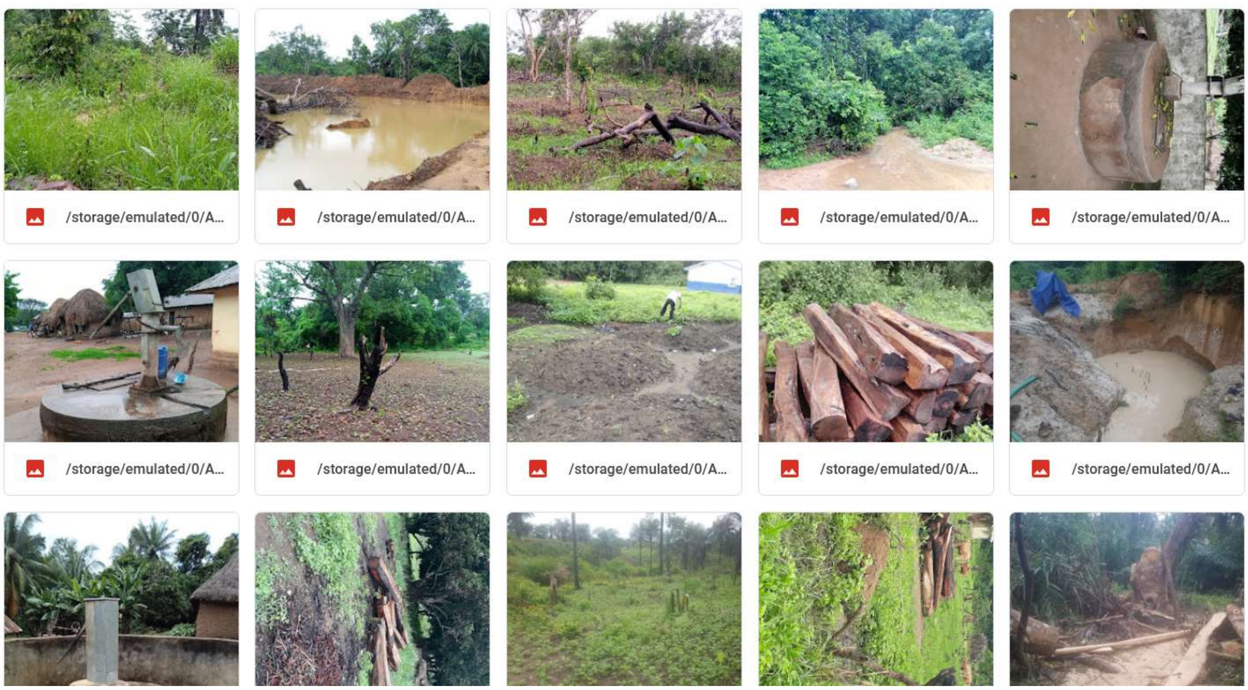
FINAL REPORT

Delineation and Mapping of Catchments and Sub-catchments in the Rokel and Western Area Basins that are in Critical Danger



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GEODATA SL
3 Frazer Street, Cole Farm, Off Wilkinson Road, Freetown

EXECUTIVE SUMMARY

Sierra Leone receives 80-120 inches of rainfall annually. Catchments collect the rainwater, which the country receives, and channel it down to stream and rivers from where it is used to supply houses and industries, power hydroelectric plants, and make irrigation for agriculture possible. However, rapid urbanization and growing anthropogenic activities in the catchment areas such as timber logging, agriculture and mining have led to reduction in the capacity of catchments to supply sufficient and clean water for livelihood and economic activities in many parts of the country, including the Seli-Rokel River and Western Area communities of Sierra Leone.

For this project, a combination of satellite, digital elevation model, and field survey datasets were used to produce land use land cover maps and sub basins in the Seli-Rokel River and Western Area. The sub basins that are in critical danger were also identified based on their deforestation levels and restoration potential.

Staff of the National Water Resource Management Agency were trained on geographic information system (GIS), Remote Sensing, drone technologies and field data collection procedures using Open Data Kit mobile application. Twenty sub basins were delineated for the Rokel River and 73 for the Western Area. In the Rokel River basin, 11 sub catchments were placed in a high-risk category because of high forest removal activities. Agriculture and mining were identified as the two practices that put these sub basins in critical danger.

In the Western Area, 12 sub catchments were placed in the highest-risk category. These sub catchments include the city of Freetown where densely populated urban communities, offices, and public areas have led to massive deforestation. Fifteen sub catchments were placed in a high-risk category including rural areas that are rapidly urbanising. The rest of the sub catchments were placed in a low-risk category mostly encompassing the forested hills overlooking the Freetown peninsula.

Results from this project will be useful to the Sierra Leone National Water Resource Management Agency in resource prioritisation and planning for catchment restorations in the country. To that end, it is recommended to collect detailed ground-truth data within sub catchments in the high-risk categories to allow further ranking for prioritization of best management practices (BMPs). The method used here could also be used to identify the critical sub basins in other parts of the country.

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1.0 INTRODUCTION

Sierra Leone is a country known to have abundant water resources. However, the demand on these resources is growing rapidly due to increasing pressures from hydroelectric power generation; water supply to urban, small and large towns; mining; industrialisation and irrigation activities. The destruction of critical watersheds and water catchment areas and changing climatic conditions have resulted to water scarcity leading to the drying up of many streams and resulting in the decline of the groundwater aquifers.

The above challenges have to a great extent been due to lack of an institutional body and sufficient data for efficient Water Resources Management (WRM). Meeting the above challenges requires sound policies and legal framework supported by robust institutions that are adequately resourced and equal to the task of managing the water resources. It is as a result of this that the Government of Sierra Leone in 2017 passed into law the National Water Resources Management Agency Act.

The National Water Resources Management Agency (NWRMA) is mandated to ensure the management and sustainability of the country's raw water resources among the competing users, and at the same time ensure the resources are protected, developed, conserved with a view to first catering for the basic human needs of the people.

In order for the NWRMA to achieve this, it must:

- Adopt natural river basin and aquifer boundaries as the basic units of management of water resources.
- Protect the water resources for sustainability of the resource and protection of aquatic systems and recognizing the polluter-pays principle;
- provide for existing customary uses of water and avoidance of significant harm to other water users;
- Promote the efficient and beneficial use of water resources in the public interest;
- Promote community participation and gender equity in the allocation of water resources;
- Promote conservation and recognizing the economic value of water resources;
- Reduce and preventing pollution and degradation of water resources; and
- Meet international obligations in protecting and managing of both national and transboundary water bodies (Section 2 (1) of the Act).

Thus, for effective protection of the country's raw water resources, catchments and watersheds should be appropriately mapped, delineated, and restored.

It is against this background that the NWRMA secured funding support from the United Nations Development Programme (UNDP) to map and delineate catchments and sub-catchments that are in critical danger in the Western Area and Rokel River basin. Output from this project will help the NWRMA to document critical catchment areas as well as determining possible interventions and strategies for their protection and management.

1.1 Scope and Objectives of the Assignment

The overall objective of the consultancy services was to produce a comprehensive document containing maps of all water catchments within the Western Area and Rokel River basin overlayed with the present land use and land cover data. These catchments can also be overlaid with analysed data acquired from human activities depicting catchments that are in critical danger for immediate action.

The specific aim was to achieve the following:

(i) A five (5) day training to technical staff with the basics of remote sensing and GIS, land use land cover mapping and drone technology.
(ii) Delineation of all water catchment in the Western Area and Rokel River basin using the best resolution of DEM available.
(iii) Conduct detail land use and land cover mapping in the Western Area and Rokel River basin.
(iv) Map all human activities and other water sources within each catchment area.
(v) Analyse, quantify and rank the risks associated with the on-going deforestation, human activities on each catchment.
(vi) Final report with maps identifying catchment that are in critical danger that needs immediate intervention. All deliverables should be in English.

2.0 TECHNICAL APPROACH AND METHODOLOGY

A combination of GIS, Remote Sensing and Open Data Kit (ODK) were employed to get the deliverables for this project. Although the above were used as core tools to fulfil this assignment, both data collection and mapping processes followed a participatory approach by consulting all relevant actors as well as national geographical services in Sierra Leone, particularly for obtaining existing secondary data, and accurate boundary definitions, right from the onset.

In this regard, the exercise was executed in the following steps:

- Preliminary meeting with NWRMA representatives for a review of the ToR, negotiations and final agreement of the ToR.
- Review of secondary data obtain from stakeholders, national geographic agencies, and other relevant national and international agencies
- Preparation and submission of an inception report
- Field data collection in the Rokel River and Western Area catchment areas
- Data analyses and preliminary processing of maps
- Drafting and submission of an interim / provisional report

- Incorporation of comments and finalization of work
- Delivery of final version of the products

More specifically, the following technical approach was adopted to accomplish the deliverables:

2.1 Training of Technical Staff on the basics of Remote Sensing, GIS, land use land cover mapping and drone technology.

A five (5) day training to technical staff of the NRWMA and other relevant government agencies in Sierra Leone on the basics of remote sensing, GIS, land use land cover mapping and drone technology was conducted from 14/6/2021 to 21/6/2021.

Of the five days, one day was used to train Staff on basics of remote sensing and GIS, one day was used for land cover land use mapping, and one day for drone technology. Training on land cover land use mapping and drone technology included one day of practical session for each.

The Staff were thought to understand the basic of vector and raster GIS data types, sources and attributes, vector topology error and rules, coordinate reference systems, map production, spatial analysis and GIS applications. They were also thought to understand the basic of remote sensing, remote sensed data acquisition and remote sensing applications. How to download satellite from an opensource website was demonstrated.

The land cover land use training both involved training and hands-on exercise focusing on the use of satellite image for land cover classification.

The drone technology training was aimed at preparing the Staff of the Agency for their first drone flight, stay safe, get airborne and learn basic and advanced quadcopter flying techniques. The training was designed for the Staff to be familiar with quadcopter controls and transmitters, flight preparations (checklist, choosing a place to fly, safety precautions), getting your drone off the ground, flight controls, and safely landing your drone. Following the classroom session was a hands-on exercise.

2.2 Delineation of all water catchments in the Western Area and Rokel River basin using the best resolution of DEM available.

Delineation of all water catchments in the Western Area and Rokel Basin was done using combination of catchment boundary dataset covering both Western Area and River Rokel and a high resolution DEM. The catchment boundaries dataset was obtained from the HydroSHED site (ref). Using the boundary files in combination with a 12.5 m digital elevation model (DEM) data which was obtained from (https://search.asf.alaska.edu/#/), a stream network and sub-catchments were generated using a suitable geospatial software (ArcGIS 10.5).

2.3 Conduction of detail land use and land cover mapping in the Western Area and Rokel River basin.

To do the land cover land use mapping, supervised classification on a Sentinel-2 image was used. A combination of ground truth and Google Earth imagery was used to identify land cover classes including forest, vegetation, bare land, built up area, road and river network. In ArcGIS, training data and signature files was created for the various land cover classes and then maximum likelihood algorithm used to produce the land cover classes.

2.4 Mapping of all human activities and other water sources within each catchment area.

To map all human activities (land uses) and other water sources such as boreholes, spring water or waterfall in each catchment, field data were collected using an electronic questionnaire and Open Data Kit (ODK) which was mounted on android tablets. Field Data Collectors visited selected communities within each catchment and conducted a focus group interview to help identify the activities taking place within their assigned catchments. With the assistance of a community lead, activities identified were located and their attribute information recorded in the android tablets. Chiefdom administrative boundary and dataset of communities were overlaid on the catchment boundaries to ease geolocation of communities.

2.5 Analysis, quantification and ranking the risks associated with the on-going deforestation, human activities on each catchment.

The risk assessment had two main components, risk characterization and risk ranking. Risk characterization involved defining the land use practices that lead to deforestation in the catchments. The following steps were taken to identify such land use practices.

Literature review: Relevant literature were reviewed which enabled the identification of land use practices leading to deforestation within the catchments. Literature resources used included peer reviewed journal articles, reports, and websites.

Site visit: The trained technical staff from both NWRMA and other relevant Agencies/departments visited sites within the catchments to recorded activities that may lead to deforestation.

Satellite imagery: Sentinel-2 images with 10-m spatial resolution were used to calculate vegetation indices in the two catchments. The Sentinel-2 Multi-Spectral Instrument (MSI) provides open access images available to users. The Level-2A products are ready-to-use surface reflectance images available for download at the Copernicus Open Access Hub. This study utilized the 10-m red and near infrared bands to calculate the normalized difference vegetation index (NDVI).

Six cloud-free Sentinel-2 images acquired between April 2019 and April 2021 were fused to give one image covering the Rokel and Western Area catchments. The assumption was that no major land cover change took place within the timeframe that these images were acquired. The fused image was used to calculate the NDVI across the landscapes of the two catchments.

The NDVI is an indicator of the relative density and health of vegetation. It is the most widely used vegetation index with range of values -1.0≤NDVI≤1.0. Low NDVI values were indicated as non-vegetated land cover such as water, built areas, bare rocks, sand, and bare land (NDVI = -1.0-0.2). Values ranging from 0.2-0.5 indicated sparse vegetation such as shrubs, grassland, and crops. High NDVI values (NDVI = 0.5 to 0.9) corresponded to densely forested areas. The polygon generation tool in ArcGIS 10.5 was used to digitize and estimate the areas covered by each land cover type.

To rank the activities, the land cover types were distributed into the sub-catchments of the two catchment areas. In the Seli-Rokel Basin, there was a total of 20 sub basins while the Western Area had 73 sub basins. The sub basins were ranked into high risk and low risk based on the types of land cover and land use practices that fall within each sub basin. The activities that were predominant in high-risk sub basins were ranked according to their forest removal potential. We also included, as ranking criteria, the potential impacts, vegetation restoration potential, and recommended best management practices (BMPs).

2.6 Final report with maps identifying catchment that are in critical danger

This report with maps showing catchments that are in critical danger was produced based on results from objective (v) above.

2.7 Work Plan

Table 2.1 shows details of how the project was executed, including timelines. In total, the project took a period of 7 weeks.

Table 2.1 Work plan for training and catchment delineation. Table shows main and sub activities, and the respective activity timelines for this project.

MAIN ACTIVITY	SUB ACTIVITY	wk 1	wk 2	wk 3	wk 4	wk 5	wk 6	wk 7
	Drone service							
	Subscription for drone software use							
GIS, REMOTE SENSING AND DRONE TECHNOLOGY	Vehicle hire to and from training site							
	Hall rental							
	Printing of GIS course materials							

	Printing of RS course materials							
	Printing of drone materials							
	Training on remote sensing and GIS							
	Practicals							
DELINEATION OF CATCHMENT AND SUB-CATCHMENTS	Purchase and subscription to internet service							
	Acquisition of higher resolution DEM							
	Stream and catchment delineation							
	Catchment map production							
LAND COVER LAND USE MAPPING	Acquisition of Sentinel-2 satellite imagery							
	Field visit to identify land cover classes							
	Creation of training classes and signature files							
	Do supervised classification							
	Do accuracy assessment							
	Produce land use map							
HUMAN ACTIVITY AND WATER RESOURCE MAPPING	Coding of field questionnaire and deployment on android tablets							
	Transportation for Field Data Collectors to and from the field							
	Data download and cleaning							
	Data analysis and reporting							
	Map production							
RISK ANALYSIS, QUANTIFICATION AND RANKING	Risk analysis							
	Risk quantification							
	Risk Ranking							
ASSESSING CATCHMENTS IN CRITICAL DANGER	Was produced based on risk ranking and qualification							
REVIEW AND SUBMISSION OF FINAL REPORT AND MAPS								

2.8 Work Force

The work force for this project comprised both human and material resources. The human resource consisted of the Team Leader / Project Manager, GIS Specialists and Remote Sensing Specialist, a Water Resource Specialist, and Field Data Collectors. The team was assisted by Staff of NWRMA in the project planning and field data collection.

The material resources we used were tools and equipment ranging from Internet based computers and Open Data Kit (ODK) mobile app to GIS software packages (ArcGIS and Google Earth), secondary data from water resource and GIS websites. We also used satellite imagery as references to check the accuracy of our work and to do land sue land cover mapping.

3.0 RESULTS

The following are results based on the deliverables requested for this work.

3.1 Training of Technical Staff on the Basics of Remote Sensing and GIS, Land Use Land Cover Mapping and Drone Technology.

Technical staff from both NWRMA and other line Agencies can now clearly identify vector and raster datasets and their sources. There is now a better understanding of GIS concept and vector data attributes. Topology errors such as undershoot, overshoot and sliver can now be easily identified, and rules set to avoid them in data digitisation. The Staff can now clearly explain the difference between geographic coordinate systems such as WGS84 and projected coordinate reference systems such as the UTM. The staff can now map production, spatial analysis and GIS applications.

At the end of the session, staff learned how to access and download Landsat imagery and display it in a GIS environment, do band combinations, analyse spectral signatures of land cover types and conduct both supervised and unsupervised classifications. Total period for the training included time for Staff to complete the hands-on exercise and ask questions.

By the end of the training session, the trainees were familiar with quadcopter controls (throttle, yaw, pitch and roll) and transmitters. They also had an excellent understanding of flight preparations (checklist, choosing a place to fly and safety precautions), getting a drone off the ground, flight controls, and safely landing a drone. Also in the training, a software app (DJI go 4 app) was introduced for flight. Following the classroom session was a practical session where the trainees had hands-on experience with flying the DJI Mavic 2 Pro drone. Figure 3.1 shows the trainees gathered around the drone awaiting flight.

Figure 3.1 Drone technology training. A group photo taken on Friday 18/6/21.

3.2 Delineation of all water catchments in the Western Area and Rokel River basin using the best resolution of DEM available.

The Rokel and Western Area Catchment boundaries have been delineated and all administrative boundary dataset extracted. Next in the process was the delineation of sub-catchments. Open-source Digital Elevation Model (DEM) data were retrieved from NASA's Earth-data website. The DEM has 16-bit signed integer data in a simple binary raster. The DEM encompasses land areas on Earth at a spatial resolution of 12.5 m. The DEM files were downloaded and imported into ArcMap 10.5 to develop sub basins.

Figure 3.2 presents the steps followed in delineating the sub basins. Figure 3.3 shows the delineated sub basin of Rokel and Western Area respectively.

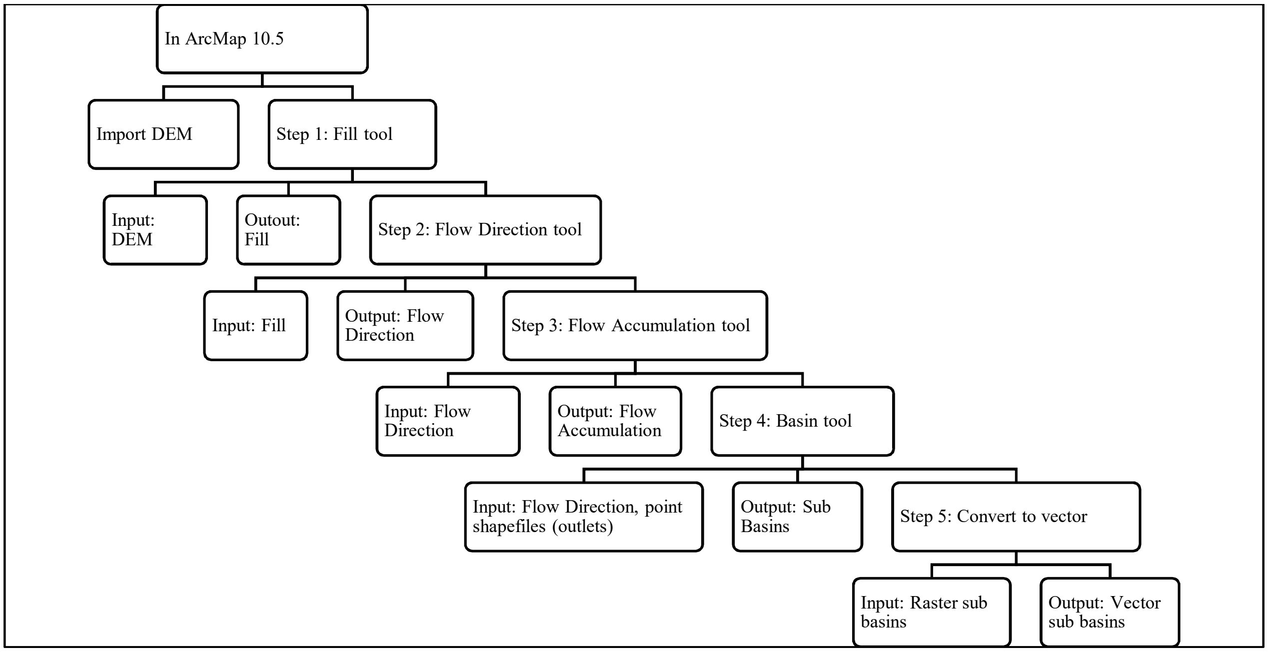


Figure 3.2 Sub basin delineation steps

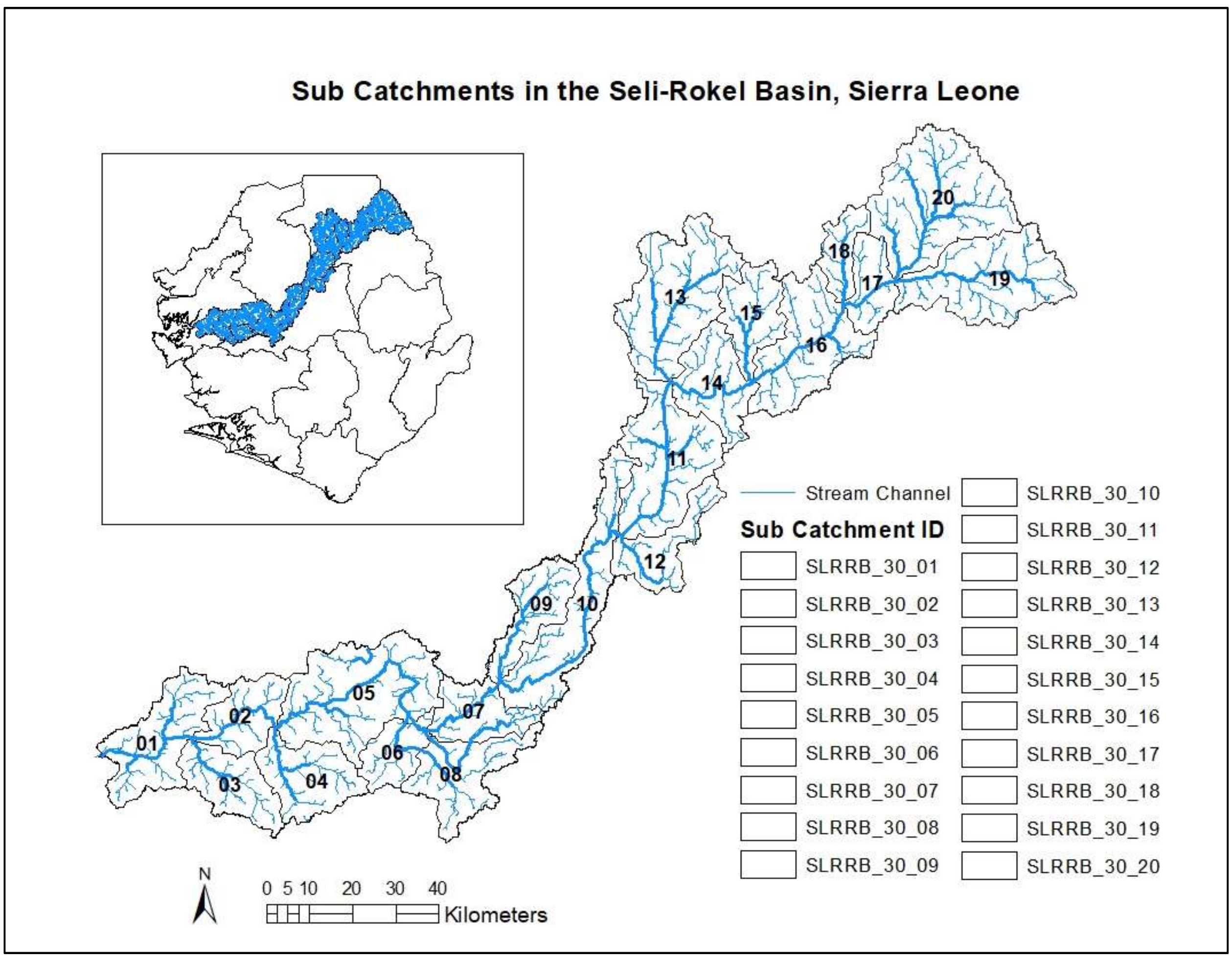
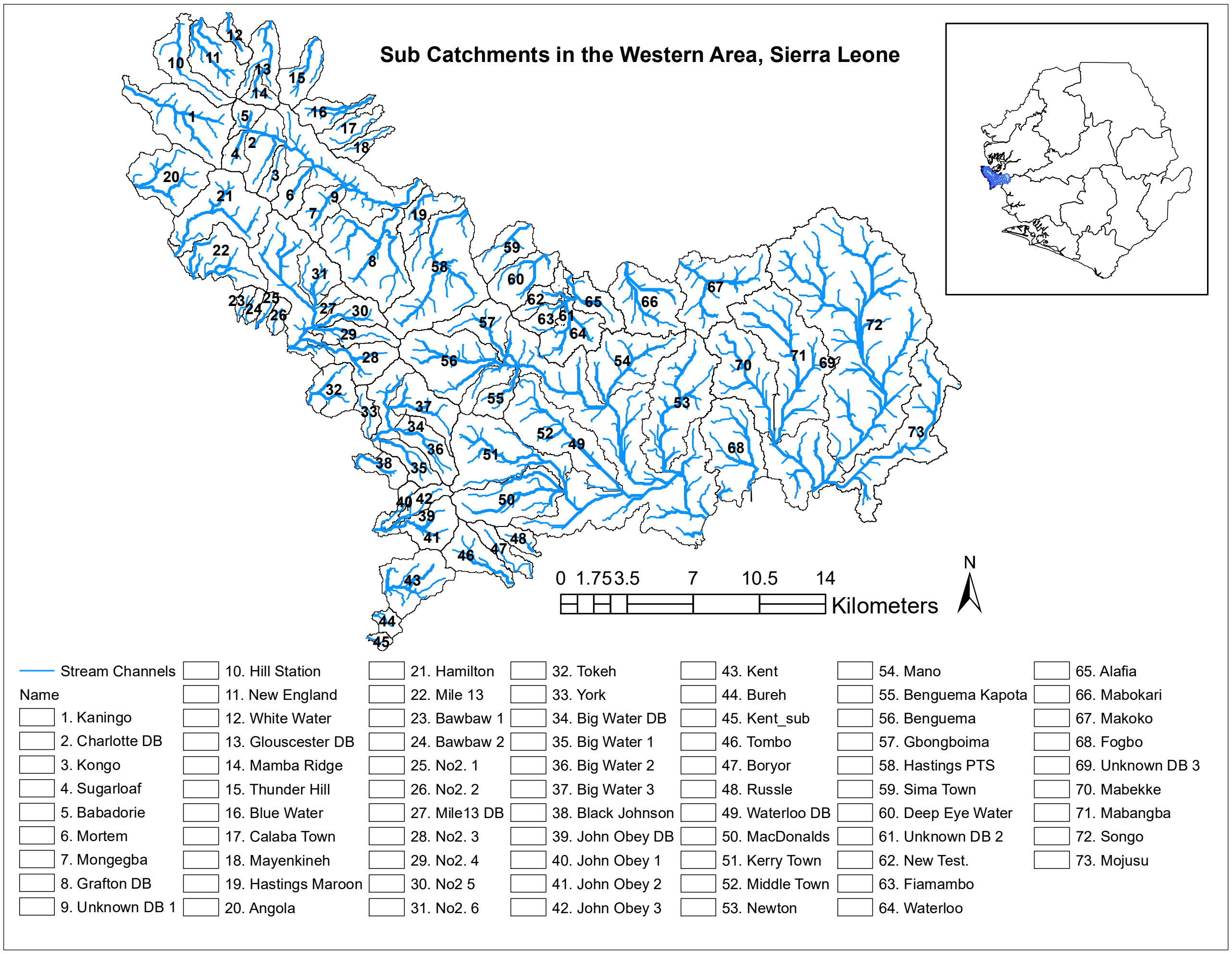


Figure 3.3 (a) Delineated sub catchments in the Seli-Rokel catchments.



Figures 3.3 (b) Delineated sub catchments in the Western Area catchments.

3.3 Land use and land cover mapping in the Western Area and Rokel River basin.

A 10-meter resolution sentinel-2 image was downloaded from www.usgs.gov and used to produce the land cover maps for the Western Area and the Rokel River basins. Figure 3.4 shows the land use land cover maps for Western Area and the Rokel River basins, which has five classes: water, bare land, vegetation, built area and forest. Most of the Rokel River and Western Area basin area is covered with vegetation and bare land. The vegetation areas include woodland, scrubland, savanna and mangrove plantations, which are low and not strong enough to hold running waters. The built up areas which are experiencing population growth, are causing high demand for food and water, thereby craving for more agricultural lands, a possible reason high agricultural practices and related deforestation in the basins. Forest areas are less, causing more exposure to surface water and promoting the drying up of water in streams and arable lands due to increasing evaporation.

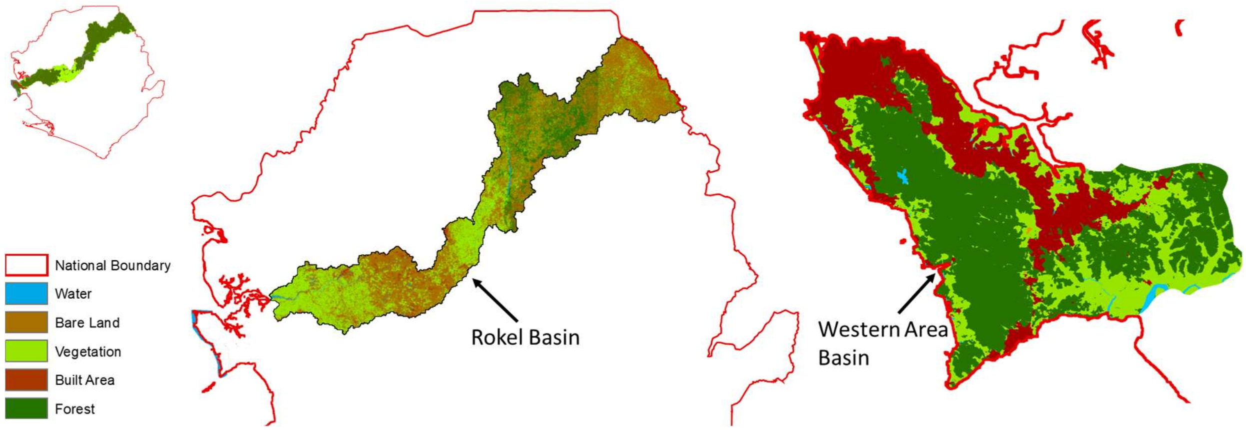


Figure 3.4 Land use land cover mapping. Panel shows land use land cover map of Rokel River and Western Area basins in Sierra Leone.

3.4 Map all human activities and other water sources within each catchment area.

Figure 3.5 shows four maps indicating the predominant land use practices recorded during the site visits. Agriculture was the highest land use practice recorded in the two catchment areas. In the Seli-Rokel basin, the agricultural practices recorded were upland rice farming, vegetable gardening, industrial scale sugar cane production, and grazing. In the Western Area, the agricultural practices were vegetable gardening, some upland rice farming, and a large-scale oil farm production. Mining was recorded as a major economic activity in the Seli-Rokel basin. The key mining activities are iron ore, gold, and small-scale sand mining. The key mining activities in the Western Area catchments are stone extraction from geological outcrops, quarrying, sand mining.

Services include a wide range of activities that provide goods and services in the urban towns of the Western Area. These include but not limited to transportation, marketplaces, mechanic workshops, industrial activities, and construction. Most of these activities may not have a direct impact on forests; however, they encourage urbanization, which in turn impact forests.

In addition to these activities, direct deforestation was recorded in the two catchment areas. The main deforestation activities are timber logging in the upper catchment of the Seli-Rokel Basin, charcoal/fuel-wood production, and land clearing for private use.

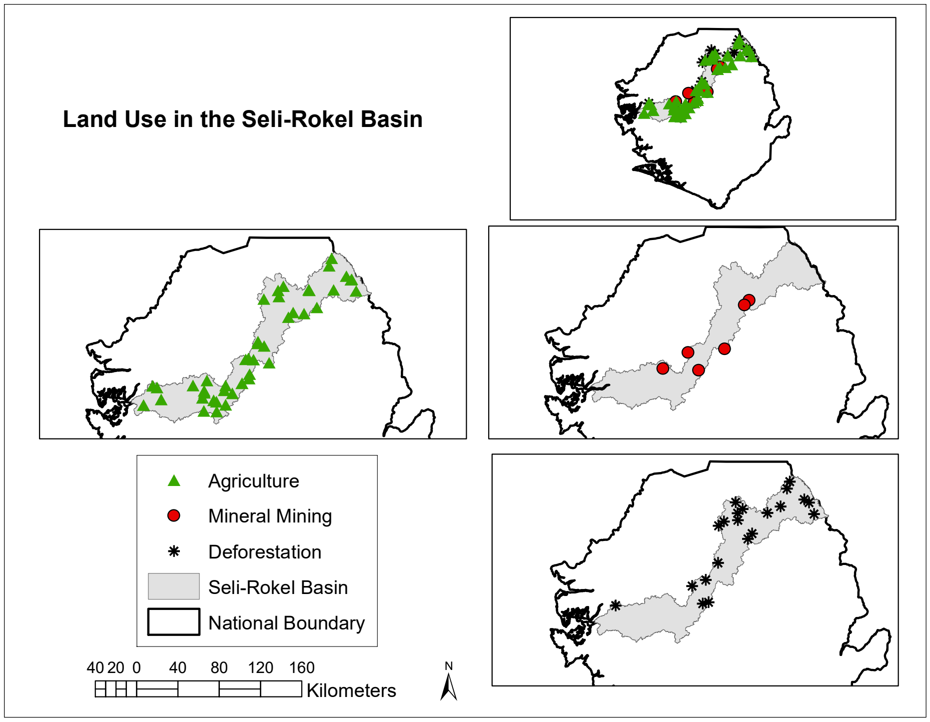


Figure 3.5 (a) Maps showing land use practices in the Seli-Rokel Basin

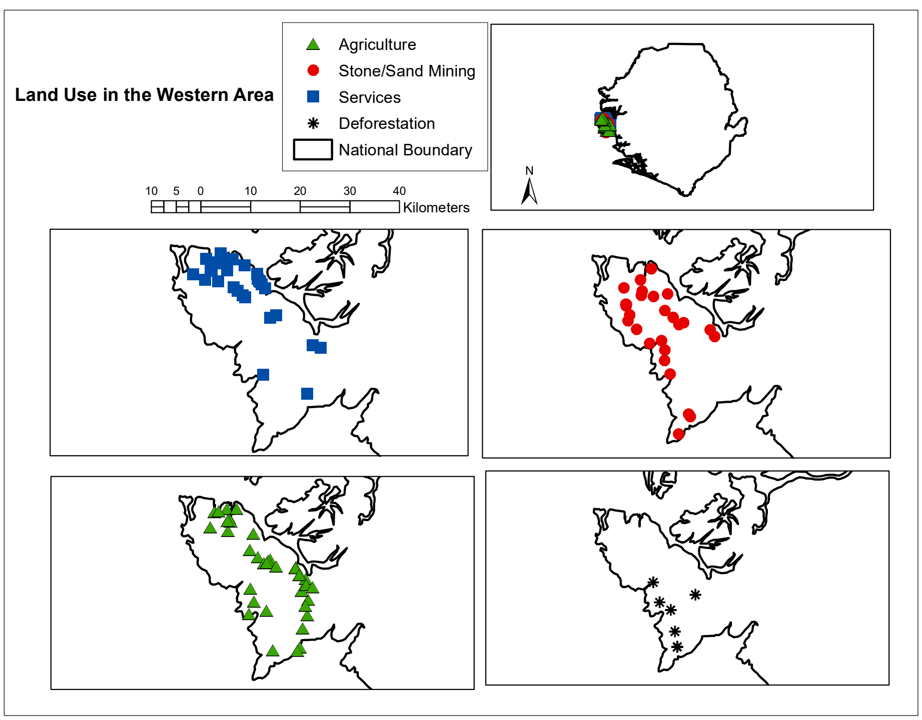


Figure 3.5 (b) Maps showing land use practices in the Western Area catchment

Table 3.1 shows the predominant land use practices recorded during the site visits. A total of 182 sites were visited that lie in the Seli-Rokel Basin. Table 3.1 also shows the land use practices in the Western Area. A total of 131 sites were visited to record the land cover types and land use practices.

Table 3.1 Communities (Districts and Chiefdoms) visited and their corresponding land use practices.

District	Chiefdom	Agriculture	Logging	Mining	Fishing	Protected	Urban
Bombali	Bombali Shebora	■		■			
Bombali	Makari Gbanti	■		■			
Bombali	Paki Masabong	■	■				
Bombali	Safroko Limba	■	■		■		
Koinadugu	Kassunko	■	■				
Koinadugu	Diang	■	■	■	■		
Koinadugu	Neini	■					
Koinadugu	Wara Wara Yagala	■	■		■		
Koinadugu	Wara Wara Bafodia		■				
Koinadugu	Sengbe	■	■		■		
Koinadugu	Mongo	■	■		■		
Koinadugu	Sulima	■	■				
Port Loko	Maforki	■		■			
Port Loko	Koya	■					
Port Loko	Masimera	■					
Port Loko	Marampa	■		■			
Port Loko	Buya Romende			■			
Tonkolili	Kholifa Mabang	■			■		
Tonkolili	Yoni	■					
Tonkolili	Malal Mara	■		■	■		
Tonkolili	Kholifa Rowalla	■			■		
Tonkolili	Kalansogia	■	■	■	■		
Tonkolili	Kafe Simira	■			■		
Western Area Rural	Koya Rural	■	■	■			
Western Area Rural	Mountain Rural	■	■	■			
Western Area Rural	Waterloo Rural	■	■	■		■	
Western Area Rural	York Rural	■	■	■	■	■	■
Western Area Urban	East I						■
Western Area Urban	East II	■					■
Western Area Urban	East III	■		■			■
Western Area Urban	West I						■
Western Area Urban	West II	■					■
Western Area Urban	West III	■		■			■

Agriculture: Agriculture is the most predominant activity in the Seli-Rokel basin; it was recorded in 51% of the sites visited. Agricultural practices include vegetable gardening in the north catchment area, upland and swamp rice farming throughout the basin, and the ADDAX sugarcane plantation. Agriculture is also predominant in the Western Area. Agricultural practice was recorded in 34.4% of the sites visited. The mountain villages in the Western Area are key sources of vegetables supplied to Freetown are. Other types of crops are grown in the area but not on a large scale.

Clearing of vegetation for agricultural purpose destroys the habitats of the biodiversity that depend on it. It may also lead to sediment transport, which increases the turbidity of the river thereby causing adverse impacts on aquatic life. The agricultural runoff may have excess nutrients which may cause eutrophication and adversely impact exposed animals and humans.

Timber Logging: Timber logging was the second most predominant activity recorded during the site visits in the Seli-Rokel basin. Together with charcoal production (5.32%), logging accounted for 26.6% of all the activities observed. Logging is minimal in the Western Area, compared to the Seli-Rokel basin. The activity was recorded in only 5.3% of the sites visited.

Logging also clears the forests and leads to habitat loss and sediment transport. Cutting down of forest trees is known as deforestation and it has several consequences. One such consequence is the loss of animal and plant species due to their loss of habitat; 70% of land animals and plant species use forests as their habitats. This includes both known and unknown species that are of ecological and medicinal importance to humans. These trees also provide the canopy that regulates local temperature. Deforestation results in a more drastic temperature variation from day to night and this may adversely impact local populations. Forest clearing also has a direct correlation with greenhouse gas emission into the atmosphere. This is because healthy forests serve as carbon sinks, which lead to cooling down of the Earth's surface. Forest clearance may adversely impact soil-water balance, which may subsequently have an adverse impact on food security in the country.

Mining: Mining activities were recorded in 5.3% of the sites visited in the Seli-Rokel Basin. The predominant mining activities are iron ore and gold mining. There is also a small-scale sand mining. Stone (including quarrying) and sand mining are two major mining activities in the Western Area. This is in response to the boom in urbanization in the area.

Although mining is not as widespread as agriculture, large-scale mining clears large areas of forests and produces large amounts of sediments that end up in the river and contiguous waters. In addition, small-scale mining of gold, sand, and stones are popular fund-raising activities among residents in these areas. These introduce sediments into the river and render the water turbid.

Fishing: Fishing was the third most predominant activity recorded in the communities visited (13.8%). Fishing was introduced as an alternative livelihood following the impoundment of the Bumbuna dam. However, most of the fishers are farmers; fishing is a secondary land use practice. Fishing is a predominant livelihood activity among inhabitants along the coast of the Atlantic

Ocean. Two fishing communities were visited during the survey. Since fishing has no direct significant impact on forest cover, it was not considered in the risk ranking.

3.5 Analysis, quantification and ranking of the risks associated with the on-going deforestation, human activities on each catchment and identification of catchments in critical danger

3.5.1 The Seli-Rokel Basin

Figure 3.6 shows the NDVI results in the Seli-Rokel Basin. The maximum NDVI value was 0.70 and the minimum value was -1.0. NDVI values ranging from -1.0 to 0.2 were indicated as built up areas, rocks, bare land, water, and other non-green vegetated areas; values ranging from 0.2 to 0.5 were indicated as shrubs, grass, and crops; and values greater than 0.5 were indicated as forest.

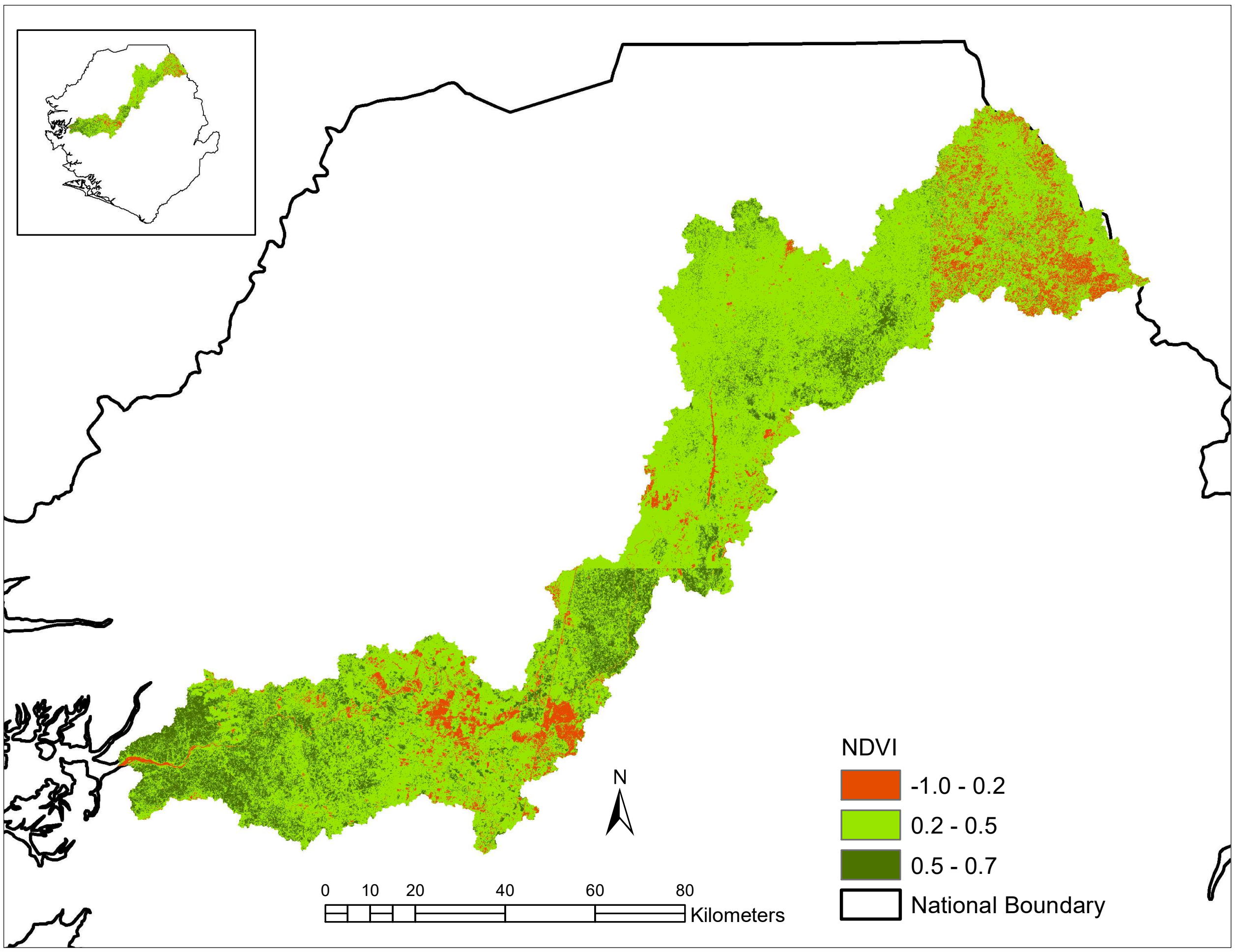


Figure 3.6 NDVI results of the Seli-Rokel catchment area.

Figure 3.7 shows the risk ranking based on the NDVI results and land use practices in the Seli-Rokel Basin. The percent forest, sparse vegetation and non-vegetation are shown in Table 3.2.

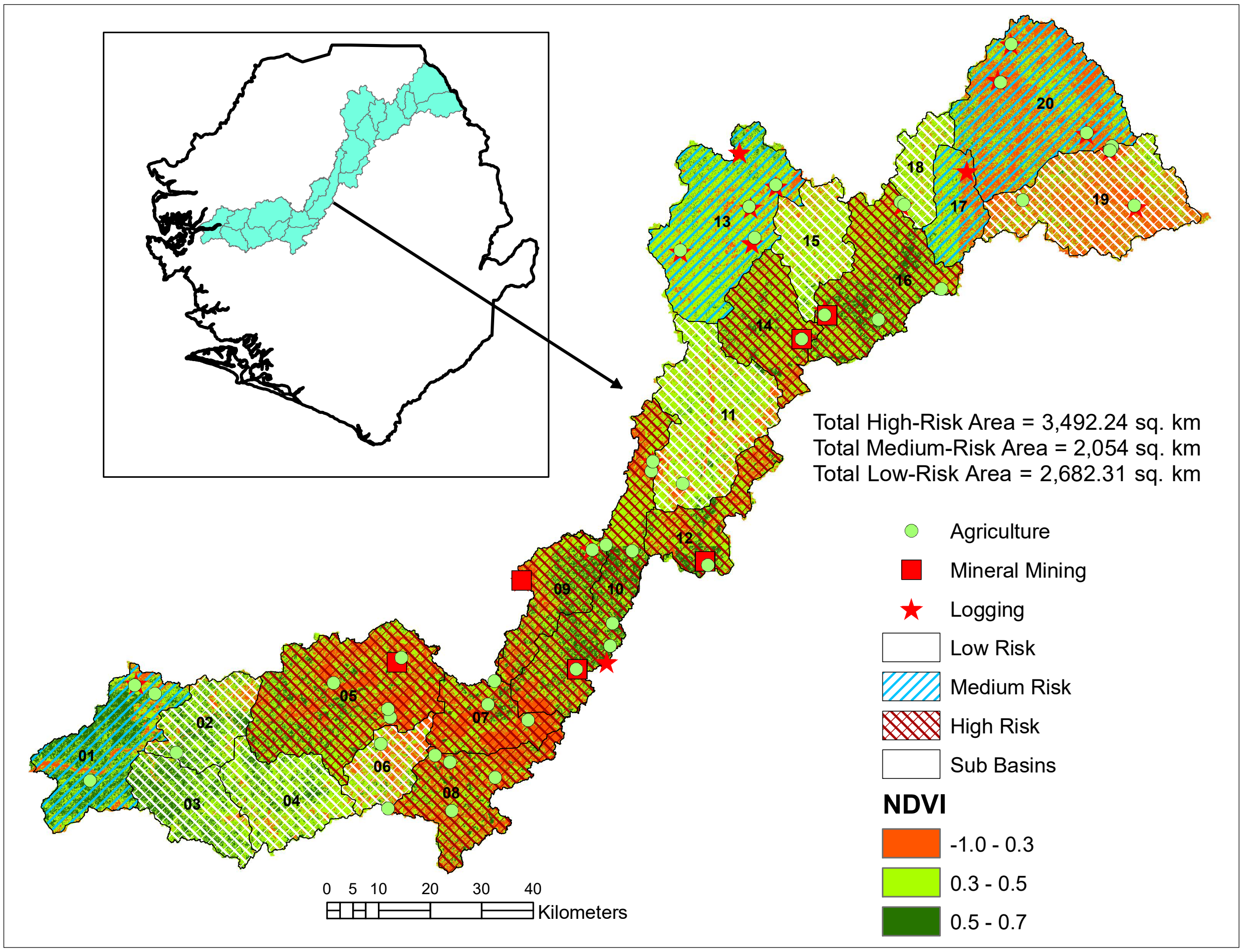


Figure 3.7 Risk ranking in the Seli-Rokel catchment area.

Table 3.4 risk Ranking of sub basins in the Seli-Rokel catchment

Risk category	Sub basins	Land uses	No vegetation	Vegetation	Forest
High	6, 7, 8, 9, 10, 12, 14, 16	Agriculture, Mineral mining and logging	4.1%	85.6%	10.3%
Medium	1, 13, 17, 20	Logging	3.1%	91.4%	5.5%
Low	2, 3, 4, 6, 11, 15, 18, 19	Logging	3.7%	90.0%	6.3%

Non-vegetated areas cover the least of the total land in the Seli Rokel basin. Sparse vegetation (shrubs, grass, and crops) covers the largest land area while forests cover the second largest area.

Fallow farms, shrubs, grassland, and crops cover 86% the high risk area while forests cover 10% of the area. Bare land and built areas cover 4% of the total high risk area. The high risk sub basins are mostly in the agriculture and mining dominated areas (Sub basins 6, 7, 8, 9, 10, 12, 14, and 16). These two activities give the high risk categorization because they are the biggest stressors to vegetation in the basin.

The area includes the large scale agriculture company, ADDAX Bioenergy. Additionally, fallow periods in shifting cultivation are shrinking due reduced arable land to allow settlements and large scale agriculture in the area. The area also includes major iron ore mines which have been ongoing for several decades.

The rest of the other sub basins were considered low risk areas. Forests cover 10% of this area while other types of vegetation cover 84% and non-vegetated areas, 6%. Land use practices such as logging, farming, and mining happen on a small scale in these areas. The predominant type of farming is labor intensive shifting cultivation while mining is mainly small scale gold mining. The key stressor to waters of the area is sediment transport during the growing season. Table 3.5 presents recommended BMPs for each risk category.

Table 3.5. Impacts, restoration potential, and recommended BMPs

Risk category	Impact on river	Restoration potential	Recommended BMPs
High risk areas	Nutrient and sediment transport, pesticides, river water for irrigation	The land in agricultural lands may not be reforested. It will be continuously used to grow crops and sustainably support human needs such as food and energy. Moreover, fallow periods are shorter because of shrinking arable land owing to urbanization, mining, and industrialization. Mining areas can be reforested after project closure.	Riparian buffers along the Seli-Rokel River and its tributaries, contour farming, crop rotation, no-till farming, land reclamation and reforestation of old mines, conservation easement projects (landowners may be paid a negotiated amount to have them avoid using their land and, thus, prevent vegetation clearance).
Low risk areas	Sediment transport	Cost-share incentives for small-scale miners and farmers.	Reforestation of abandoned farms and mines through cost-share program. Conservation easement

3.5.2 Western Area

Figure 3.8 shows the NDVI results in the Western Area catchment. The maximum NDVI value was 0.70 and the minimum value was -0.2. NDVI values ranging from -0.2 to 0.2 were indicated as built up areas, rocks, bare land, water, and other non-green vegetated areas; values ranging from 0.2 to 0.5 were indicated as shrubs, grass, and crops; and values greater than 0.5 were indicated as forest.

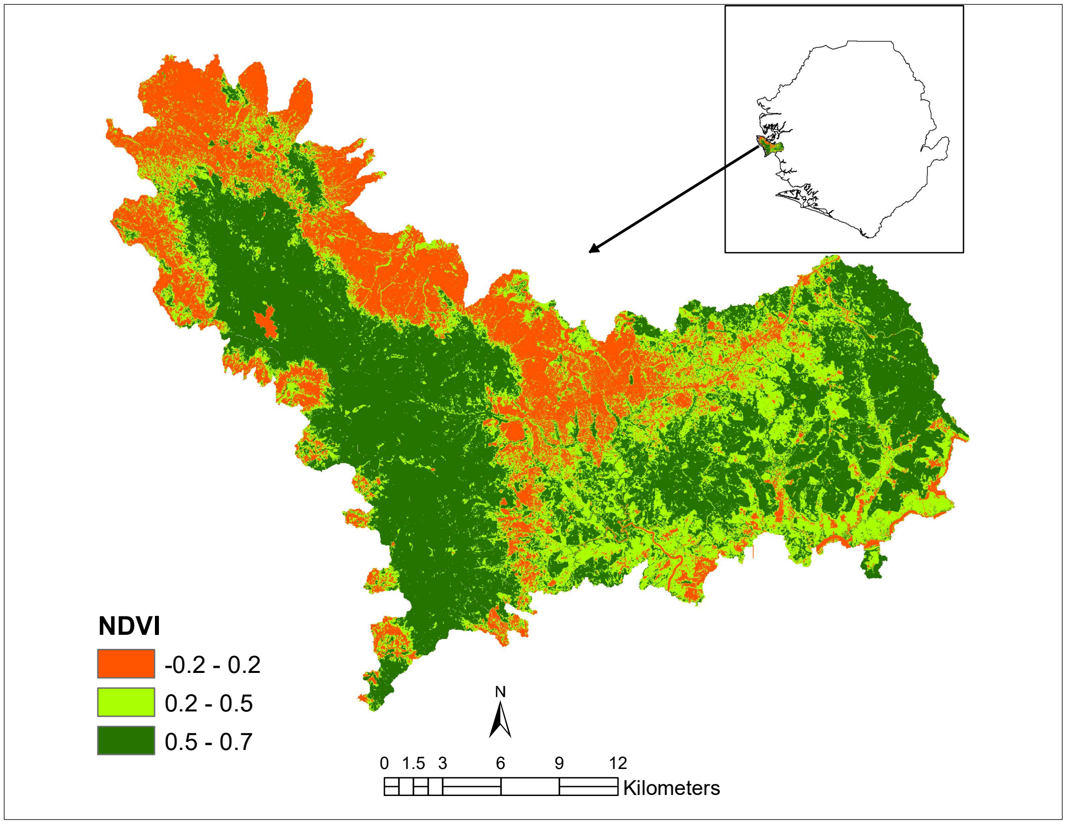


Figure 3.8 NDVI results in the Western Area catchment areas.

Figure 3.9 presents a map of western area showing the sub basins, land use practices, land cover types, and the ranked risks. Explanation of the ranked risks is given in Table 3.6.

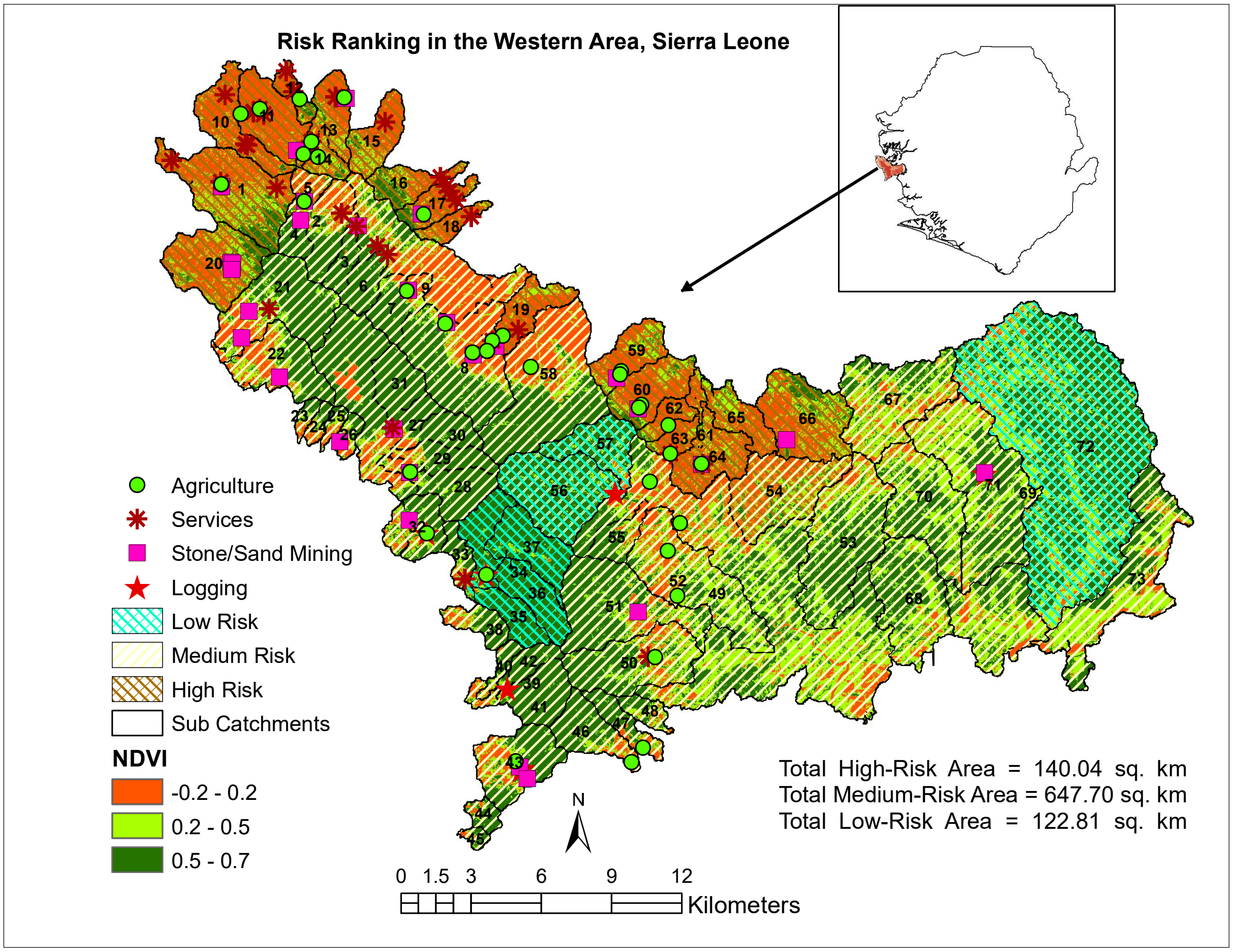


Figure 3.9. Risk ranking in the Western Area catchment

Table 3.6 risk Ranking of sub basins in the Western Area catchment

Risk category	Sub basins	Land uses	Not vegetated	Sparse vegetation	Forest	Type of settlements
High	1, 5, 10, 11, 12, 13, 15, 16, 17, 18, 19, 20, 54, 59, 60, 61, 62, 63, 64, 65, 66	Services, mining, agriculture	53.7%	33.9%	12.4%	Urban
Medium	2, 3, 4, 7, 8, 9, 21, 22, 23, 24, 25, 26, 27, 32, 33, 38, 39, 40, 43, 44, 45, 46, 47, 48, 49, 50, 51, 52, 53, 58, 67, 68, 69, 70, 71, 73	Mining, agriculture	36.9	47.5	15.6	Rural
Low	34, 35, 36, 37, 56, 57, 72	Agriculture	16.3%	56.8%	26.9%	Rural

Forests cover the least of the total land in the Western Area catchment (19.1%). Sparse vegetation (shrubs, grass, and crops) covers the highest land area (48.6%) while non-vegetated areas, which are mostly built up and bare land areas (Figure 3.9) cover the second largest area (32.3%).

The highest risk sub basins are those in the northwest of the Western Area catchment (Sub basins 1, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 59, 60, 61, 62, 63, 64, 65, 66). The primary land use practices in these basins are services, mining (mainly sand mining in the beaches), and small scale vegetable gardening. This area includes the city of Freetown with densely populated urban communities, offices, and public areas. These urban settlements cover about 54% of the area. There is hardly any Forest left in this area especially in the northern end. The few forests (12%) are in the southern hills. Grasses cover about 34% of the area.

Sub basins 2, 3, 4, 7, 8, 9, 21, 22, 23, 24, 25, 26, 27, 32, 33, 38, 39, 40, 43, 44, 45, 46, 47, 48, 49, 50, 51, 52, 53, 58, 67, 68, 69, 70, 71, 73 were characterized as medium risk areas. These areas are mostly rural settlements that are rapidly urbanizing. The cleared areas (37%,), which are mostly built up areas and bare land (Figure 3.9) are not as large as the highest risk sub basins. Sparse vegetation covers 48% whilst forests cover 16% of the land in this area.

The rest of the other sub basins were considered low risk areas. Forests cover 27% of this area while other types of vegetation cover 57% and non-vegetated areas, 16%. Table 3.7 presents recommended BMPs for each risk category.

Table 3.5 Recommended BMPS for the risk categories

Risk category	**Impact on water bodies**	**Restoration potential**	**Recommended BMPs**
Highest risk	Sediment, solid waste, and wastewater end in the Atlantic Ocean. Flooding and landslide during the peak rainy season. Sand mining may impact the shoreline of the Atlantic Ocean.	The land may not be reforested because it is a high-density residential area. The city is growing southeast towards the hilly areas containing the remaining forests.	The most ideal BMP is low impact development (LID). This may include reforestation in the south hills, vegetated filter strips along roadways, pervious open land areas, sediment traps, bioretention cells (rain gardens), vegetated recreational parks, and stormwater control.
High risk	Removal of riparian vegetation along the coast may lead to increased transport of sediment and solid waste material into the Atlantic Ocean. Potential removal of remaining vegetation along the coastline due to urbanization.	The rapid urbanization makes it difficult for reforestation.	Similar LID options as in the highest risk category; conservation easement projects; reforestation of mangrove trees along the coast.
Urban services, fishing, sand mining	Vegetation in the south may prevent flash floods to downstream communities. Wetlands in the north may remove	Same issue ass priority 1. However, there is more vegetation in this sub region.	The communities may not afford to fund and implement urban BMPs. Additionally, the communities may not afford to prevent continued

	contaminants in surface runoff before water enters the ocean.		removal of vegetation for other land use practices. However, cost will be relatively cheaper through promotion of conservation practices.
Low risk	Protected area	This area includes protected forests.	Maintain the protected status of the forests and reforest cleared areas especially in downhill communities.

4.0 CONCLUSIONS

This report contains deliverables of a consultancy conducted by GeoData SL Consultancy Firm for NWRMA with funding from the United Nations Development Programme (UNDP).

Technical Staff of NWRMA and other Institutions such as the Bumbuna Watershed Management Authority (BWMA), Guma Valley Water Company, Environmental Protection Agency and the National Protected Area Authority (NPAA), were trained on GIS, Remote Sensing, Drone technologies and field data collection procedures using Open Data Kit mobile application. It is believed that the training activity brought in additional value to the participants and their respective Institutions.

Twenty sub catchments were delineated for the Seli-Rokel River basin and 73 were delineated for the Western Area basin. The sub catchments in the Seli-Rokel basin were grouped into two risk categories: high risk and low risk. High risk sub catchments had dwindling forests and predominantly mining and agricultural activities. Low risk areas had less stress from the land use practices.

In the western area the sub catchments were grouped into three risk categories: highest risk, high risk and low risk. The highest risk categories were characterized by major urban activities largely cleared vegetation. The high-risk areas were rural areas that are rapidly urbanizing. The low-risk areas included the protected forests in the peninsula mountain. Further ranking of sub catchments in the high-risk areas will require additional data to detail the magnitude of land use practices and their impacts on water resources.

Findings from this project will be handy in helping NRWMA in the prioritisation of resources in planning for restoration of the catchments to ensure sustainable and safe supply of water to the Rokel River and the Western Area communities.