National Water Resources Management Agency
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DELINEATION, MAPPING AND ASSESSMENT OF TAIA/PAMPANA RIVER BASIN

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Executive Summary

In Sierra Leone, the demand on water resources grows rapidly due to increasing pressures from hydroelectric power generation, water supply systems, mining, industrialization and irrigation activities. Despite the country's ability to have abundant water resources, Water Resources Management (WRM) has been a challenge over the years for the water sector. This can be seen from the destruction of critical basins and water catchment areas and the change in climatic conditions have also resulted in water scarcity, leading to the drying up of many streams as well as the decline of groundwater aquifers.

The National Water Resources Management Agency (NWRMA) was established by an act of parliament with the aim to protect, restore and manage all raw water sources in Sierra Leone. To achieve this, the NWRMA has developed a five (5) year Strategic Development Plan (NWRMA-SDP 2019 - 2023) indicating determinations to provide the road map for achieving the vision of the Agency to be one of the leading water resources management agencies in West Africa". With increasing competition for water across sectors and regions, the NWRMA faces severe and growing challenges in maintaining water quality, predicting models of future scenarios and meeting the rapidly growing demand for water resources amongst users. The river basin which is characterized by natural and physical processes has been recognized as the appropriate unit of analysis for addressing the challenges of water resources management. It is against this background that the Agency undertook the delineation and mapping of catchments project in the Taia River basin which faces severe threat from mining and other anthropogenic activities.

The delineation and mapping project was carried out in three phases at the upper, middle and lower sections of the Taia basin and in the months of August, September and October respectively. It involved desk study and intensive field work to identify main and alternative community water sources, predominant human activities, current and potential pollution sources and sanitation practices affecting catchments' health. Desk study involved the delineation of all sub-catchments within the basin using higher resolution digital elevation model in ArcGIS Pro. A simple and intuitive survey form was designed using ArcGIS Survey 123 for which focus group discussions and key informant interviews were incorporated into the survey which form the bases for quantitative and qualitative data collection. Stakeholder and community engagement were also conducted to acquire preliminary and concise information on how these catchment units could be sustainably managed to improve living condition.

Six districts including Koinadugu, Kenema, Bo, Tonkolili, Moyamba and Bonthe are found intersecting the basin across the upper, middle and lower sections. Tonkolili District covers the largest portion of the basin with 48.2% while Kenema and Koinadugu occupy smaller sections of the basin with 5.3% and 5.2% respectively. A total of 16 sub-catchments have been delineated in the Taia basin making up a total area of approximately 8,400 km2. These sub-catchments will be used as basic units for the management and protection of the Taia River basin. The Taia River basin accounts for approximately 11.6% of the country's land mass. Result from the mapping activity shows that the Taia basin has a total population of approximately 928,000.

Subsistence farming is the most predominant livelihood activity across the basin accounting for 65%. Small agricultural enterprises for which farmers embark mainly on gari and oil palm production is evidenced at the middle and lower sections of the basin. Pollution from farming activities within the basin can mostly be seen during the rainy season when erosion from debris caught in vegetation or harvested crops are transported to nearby stream/rivers. Next to farming, gold mining activities within the basin has emerged as another main source of livelihood accounting for 15%. Gold mining activities mainly take place at the upper and middle section of the basin. Intense mining and diversion of river course take place at and close to Lake Sunfon using heavy duty machines and other equipment (Annex 1). It was also discovered that the major sources of pollution to the Taia River basin originates from artisanal mining activities in and at the bank of the main river channel upstream. Of the mining activities, 80% is artisanal gold mining while 20% is a large/small scale industrial mining. Although large- and small-scale mining also take place at the basin, the former uses control measures for the treatment of effluent into the main river channel that do not have much impact to water bodies. Other human activities within the basin include the cutting down of trees for timber and charcoal which also have direct impact on the hydrology of the basin. Timber logging and charcoal production make up a total of 10% of all human activities mapped.

The most common primary sources of water for communities visited are dug wells and streams which account for 40% and 31% respectively. Many of the communities lack access to protected and improved water sources for drinking and domestic uses and for many of the primary sources mapped, water availability is only seasonal. Also, most of the communities who have dug wells and streams as primary sources have their alternative sources mainly from swamps, ponds, springs, or rivers being polluted. These alternative sources are also not protected and are located some distant away from the settlement.

Sanitation practices of most settlements visited across the basin indicates open defecation to be a common practice. Many of the communities visited lacked access to improved sanitation facilities and the practice of high open defecation might also impact the quality of nearby water sources. In addition, most toilets/latrines get collapsed during the rainy season or easily filled up which shows poor use of materials, siting and construction methods. In the management of solid wastes, almost all settlements do not have a community dustbin for the deposition of solid wastes and most have their wastes thrown at backyards and with only 2% that have their domestic wastes disposed along riverbanks.

The 2022 landcover map developed for the basin shows that forest cover still occupies the most with 72%. Next to forest cover is bare land which also occupies 18% of the general land cover in the basin. Since the percentage of bareland is greater than that of grassland or agricultural land, it is also evidenced that most of these bare soils are potential areas for development and or mining sites within the basin that will continue to increase pollution on water bodies if prompt management actions are not carried out.

Proposed interventions for the management and protection of the basin include the collaboration with other agencies and the security sector to stop the operations of all artisanal and illegal miners in and along the banks of the main river channel of the Taia River and its tributaries. The responsible agencies should also ensure all mining companies are registered and regulated as well as issuing discharge permits on mining wastes discharge as prescribed in the newly enacted pollution control regulation of the National Water Resources Management Agency. Conduct sensitization and awareness raising to communities regarding the negative impact of artisanal mining on their environment and the development of water quality monitoring programs across the basin. An integrated restoration plan for basin should also be developed using ecohydrology systemic solutions such as constructed wetlands to treat sediment load and remove heavy metals and seek funding for its implementation. The plan should also include strategies to manage the risk of runoffs from farms and encourage smart agricultural practices within the basin. Afforestation should also be done to restore the natural riparian vegetation and implement agroforestry intervention and enrichment through planting in degraded areas.

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1 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.

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 utilised funding from the Government of Sierra Leone to map and delineate catchments and sub-catchments that are in critical danger in the Taia/Pampana River basin. Output from this project will help the NWRMA, other government stakeholders as well as private and donor partners to document critical catchment areas, identify and implement possible interventions and strategies for the protection and management of these critical catchments.

1.1 Project Background

Catchments are important because they help to manage and distribute water resources, and they play a key role in the hydrologic cycle. Catchment boundaries are typically determined based on the topography of the land, as well as the underlying geology and soil type. Catchment delineation involves creating a visual representation of the boundaries of a catchment using geographic information systems (GIS). This process involves collecting data on factors such as elevation, slope, land cover, and soil type, and using this data to create a map of the catchment.

Potential water catchment sources in Taia River basin are depleting faster in our day-to-day life mainly because of increase in agricultural activities, mining and domestic demands. A water catchment, which is an area that drains surface water to a common outlet, is the basic unit of water resources management and is determined on the bases of topographical landscape of the area. Remote sensing and GIS technology have opened new paths in water management and the analysis of flow direction and flow networks from digital elevation models (DEMs) have led to several automated methods for watershed and stream delineation.

For effective implementation of integrated water resources management (IWRM) in a basin, acurate demarcation of river basin along catchment boundaries is an important input for any program connected with catchment management. The project has delineated all sub-catchments in the Taia River basin and mapped their respective land use/land cover, current human activities, pressure on water resources and water quality issues that were used to identify those catchments that are in critical danger.

1.2 Scope and Objectives of the Assignment

The overall objective of the assignment was to produce a comprehensive document containing maps of all water catchments within the Taia River basin overlayed with the present land use and land cover data, primary water sources as well as sanitation practices of most communities within the basin.

The specific aim was to achieve the following objectives:

1) To train technical staff of the Agency on the basics of remote sensing and GIS applications on water resources management.

2) To delineation all water catchments in the Taia River basin using the best resolution of DEM available.

3) To develop recent land cover map of the Taia River basin.

4) To identify community primary and alternative water sources in the basin

5) To map all human activities within the basin and identify major pollution sources.

6) To map sanitation practices and waste management system in rural communities

7) To produce final report with comprehensive analysis and maps showing critical catchment in danger for immediate intervention.

2 Technical Approach and Methodology

2.1 Study basin

The Taia River which is also known as Pampana or Jong is a river in Sierra Leone that flows from the North in Koinadugu Districts through Matru in Bonthe District and finally empties into the Atlantic Ocean. It is one of the major rivers in the country and is an important source of water for irrigation, domestic use, and hydroelectric power generation. The Taia River Basin is the region of land that drains into the Taia River and its tributaries. It is a large river basin covering much of Sierra Leone with a total area of approximately 8,400km^2, and it is home to a diverse array of plant and animal species.

The figure below shows Taia/Pampana basin with main river network.

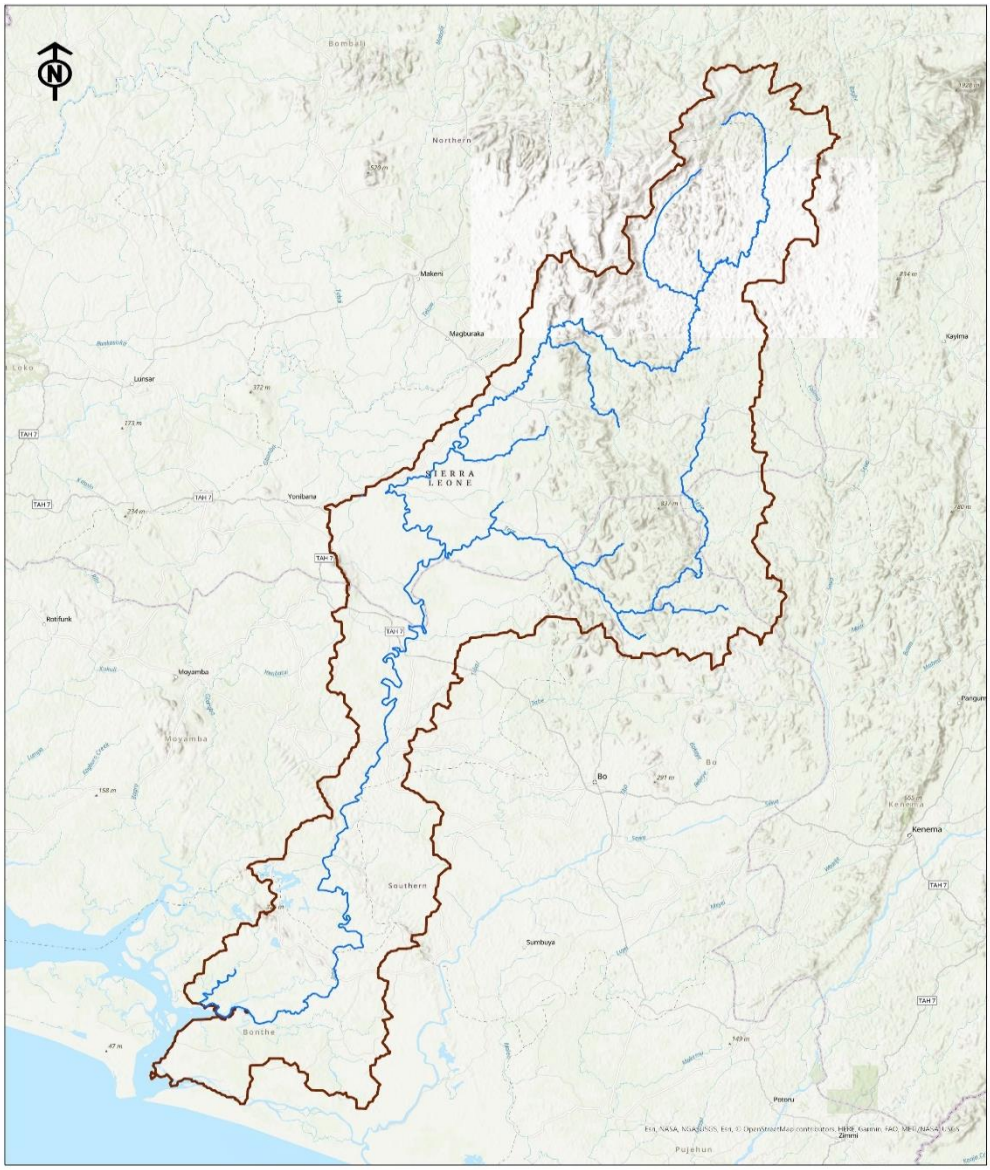


Figure 2.1:

Taia/Pampana River basin showing river network.

The Taia River Basin is also an important source of livelihoods for the people who live in the region, as many rely on the river and its resources for their daily needs. The Basin is vulnerable to a number of natural and man-made hazards including floods, landslides and extreme mining activities along the riverbanks which can have serious consequences for the people and ecosystems in the region. With a total population of approximately 928,000, farming and mining have been the predominant livelihood activities and occur along the riverbanks and its tributary streams.

The Taia River is fed by several tributaries including the Kamakwie, Magbeni, and Kamadugu Yagala and the Hugy Rivers. The Taia River basin is also characterized by a humid tropical climate with high levels of precipitation throughout the year. The main land use in the catchment is mining and agriculture, with crops such as rice, cassava, and sugarcane being grown in the area. Small scale and uncontrolled artisanal mining activities within the basin have led to the deterioration and extreme pollution of the main river network. The Taia River Basin is also home to a number of protected areas, including the Outamba-Kilimi National Park and the Gola Forest National Park.

2.2 Delineation of the Taia River Basin

Delineation of all sub-catchments in the Taia River basin was done using a high-resolution digital elevation model (DEM) covering the entire basin. The DEM has 16-bit signed integer data in a simple binary raster and encompasses land areas on earth at a spatial resolution of 12.5 m. In addition, catchment boundary datasets covering the basin was also obtained from the HydroSHEDS website. HydroSHEDS provides consistent and comprehensive hydrographic information for regional and global-scale applications. These data layers are now available to support watershed analyses, hydrological modeling, and freshwater conservation planning in many parts of the world. Using the boundary files from HydroSHEDS in combination with a 12.5 m DEM data downloaded from https://search.asf.alaska.edu/#/, a stream network and sub-catchments were generated using ArcGIS Pro.

A new project using ArcGIS pro was created for the Taia Basin and 12.5m DEM added. The hydrology tools available in ArcToolbox was run in the sequence as shown below:

- Fill
- Flow Direction
- Flow Accumulation
- Con
- Stream Link
- Stream Order
- Stream To Feature
- New Feature Class
- Watershed
- Raster to Polygon

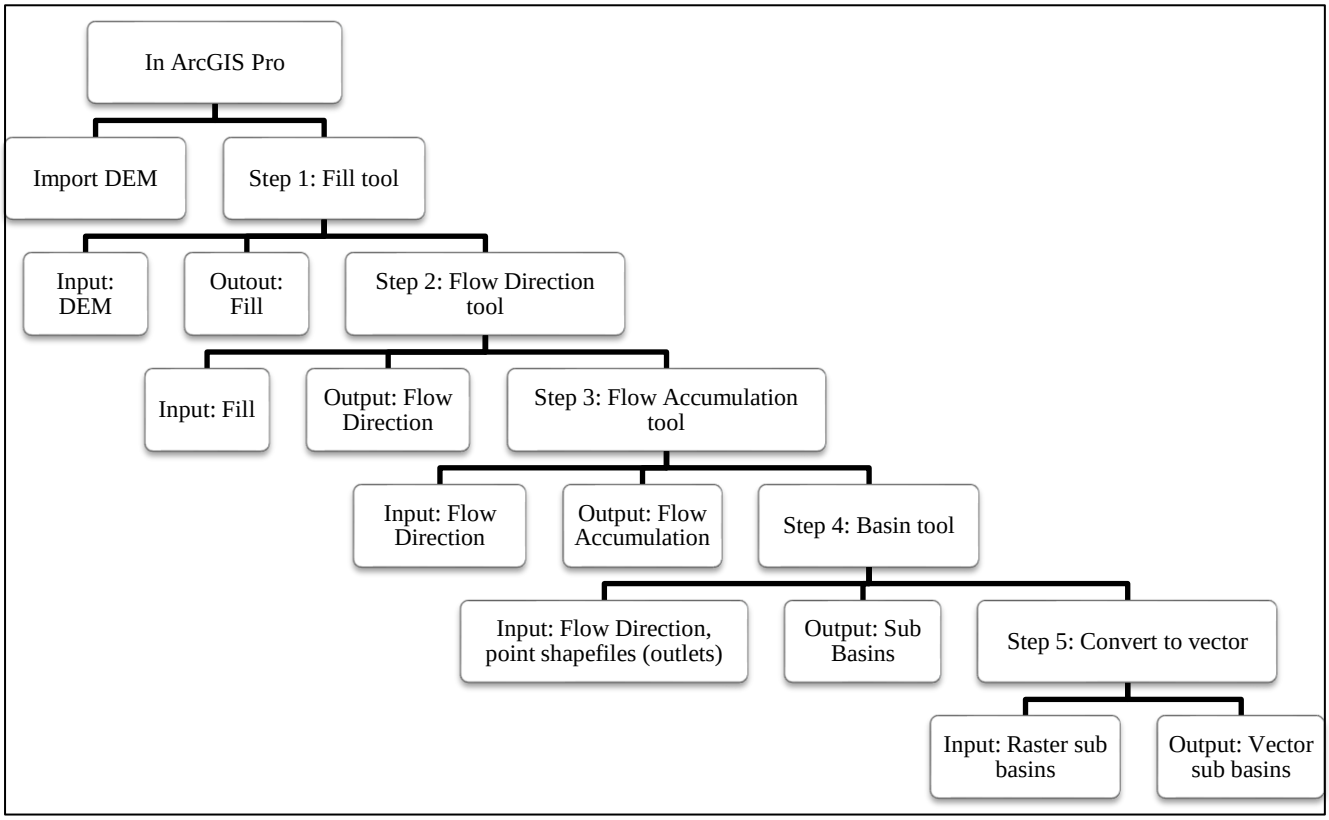


Figure 2.2: Sub basin delineation steps in ArcGIS Pro

2.3 Setting up Data Collection Systems

Secondary data regarding the general governance and administrative structures as well as social, economic and environmental information within the basin were examined. Water resources management, supply and sanitation plans with result framework from public sector institutions, development agencies and NGOs for all the districts within the basin were also reviewed. Primary data was collected from key informants at each settlement using both quantitative and qualitative methods. For each settlement, focus group discussions (FGD) and key informant interviews (KII) on the predominant land use type, primary and secondary water sources, sanitation practices as well as general socio-economic and environmental conditions within the basin were conducted. Detailed approach to the study and method of data collection is described below:

2.3.1 Literature Review of the Study Area

General socio-economic activities and environmental conditions of all the districts intersecting the basin was assessed. Also, a detailed review to identify and georeference all communities and administrative boundaries of the Taia River basin was done for which geo-spatial data and coordinates for each settlement was obtained through digitisation. Preliminary data on the extent of water resources management, water supply and sanitation development plans within the basin were also assessed. Zoning and the selection of all communities as target areas to be used by data collectors/ enumerators was done using ArcGIS Pro and Avanza app.

Major and minor road networks linking the communities/villages were also georeferenced and digitised using districts scanned maps with updated and high-resolution satellite imagery. Thus, maps for the basin including settlements, minor and major road networks were reproduced during the literature review and inception stage.

2.3.2 Overview of the baseline data collected.

The sampling procedure and the selection of target areas were designed in a way that sample data on human activities, water sources and sanitation practices were representative of the project's objectives covering the basin. The data selection and questionnaire type including both qualitative and quantitative were designed in order to capture the information required to successfully achieve the objectives of the project. The data collected was divided into three sections including human activities, water sources and sanitation practices. It is also worth noting that all key stakeholders and village heads were the targeted informants during the mapping and assessment.

2.3.3 Development of Web-based Survey Questionnaire

Survey123 for ArcGIS is a simple and intuitive formcentric field data gathering solution that makes creating, sharing, and analysing surveys possible in three simple steps: ask questions, get answers, and make better decisions. For the purpose of this project, the three sections in a single "smart" form were created using ArcGIS Survey 123 platform. One section on predominant human activities, another for primary and alternative water sources and third for community sanitation practices. All questions in the form were administered to community heads and key stakeholders and the data was automatically analysed once uploaded.

Survey123 has been selected to design the web-based mapping questionnaire since it is part of the ArcGIS platform. When Survey123 publishes a survey to ArcGIS, behind the scenes, a form item and a hosted feature service are created in ArcGIS Online or Portal for ArcGIS and

secured with the same security model of the project. Collected survey data are then stored as points in the hosted feature service. This hosted feature service works and behaves like any other hosted feature service and can work with the entire ArcGIS platform from which interactive web-maps and dashboards can be derived in a real time. To securely use this online survey questionnaire, the android app (Survey123) was downloaded from Google Play store for which the barcode of the survey was scanned and uploaded into the enumerator's mobile phones and or tablet. After the survey is completed, the link can be blocked from all users to prevent future data uploaded.

2.3.4 Conduct Meetings and Validation of the Survey Questionnaires

The assessment and mapping of the Taia River basin was fully implemented by the Agency's staff through the Hydrological Services Department in consultation with other key staff from the Planning, Legal and Admin Departments. Thus, technical meetings comprising members from these departments was conducted at the Agency's Conference room. The set of questions to be included in the smart form which was designed using Survey 123 to obtain data related to the mapping and assessment were also validated during the technical meetings.

2.3.5 Resources Mobilisation and Training

The National Water Resources Management Agency is a government institution that is equipped with the expertise needed to conduct the mapping and assessment. Through the GIS Unit of the Hydrological Services Department, capacity building and training has been conducted to other few technical staff on the application of remote sensing and GIS for watershed management and the use of the web-based survey questionnaire (ArcGIS Survey123) for the creation of survey and analysis of data. Both resource mobilization and training were conducted to ensure that the necessary resources are available and that individuals have the necessary skills and knowledge to effectively carry out their roles and responsibilities.

A three (3) day refresher training to few technical staff of the Agency on the basics of remote sensing and GIS, development of land use land cover maps and the use of drone to plan flight missions for georeferenced aerial photographs was conducted. In the remote sensing and GIS training, the Staff were taught to understand the basic of vector and raster GIS data types, sources and attributes, coordinate reference systems, production of professional maps, spatial analysis and GIS applications. They were also thought on how to download open-source satellite imagery (Landsat) for the development of land cover using both supervised and un-supervised classification systems.

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.

The Agency also undertook all administrative activities with respect to obtaining training materials and provided logistics to staff as well as breakfast and lunch during the training. Six set of power banks were also procured that were used to charge smart phones/tablets during field data collection in remote areas.

2.4 Field Data Collection

A total of six data collectors/enumerators, one supervisor and two drivers have been involved in field data collection in the entire basin. The data collection process was divided into three phases including the upper, middle and lower sections of the basin and each phase lasted for a period of nine days. As there are over 1,000 settlements in the basin, focus group discussions (FGD) have been held in almost all the settlements and few key informant interviews (KII) conducted. In addition to FGD and KII, GPS coordinate points as well as drone survey was used in order to have accurate georeferenced location with high resolution aerial imagery within the project area. Table 2.1 below shows the timeline for which data was collected at upper, middle and lower sections.

Table 2.1: Phases of data collection in the Tai River Basin.

Phases	Description of Work	Proposed start dates
Phase One (Upper)	Data collection, analysis and reporting on the assessment and mapping of the UPPER Taia Catchment	August 2022
Phase Two (Middle)	Data collection, analysis and reporting on the assessment and mapping of the MIDDLE Taia Catchment	September 2022
Phase Three (Lower)	Data collection, analysis and reporting on the assessment and mapping of the LOWER Taia Catchment	October 2022

2.4.1 Data Collection at the Upper, Middle and Lower Sections

Data collection at the entire basin was carried out in three phases during the months of August, September and October respectively. The digitisation tool in ArcGIS Pro was used to divide the basin into the three phases and the total approximate area at the upper, middle and lower are 2,500km^2, 3,200km^2 and 2,600km^2 respectively as shown in the figure below.

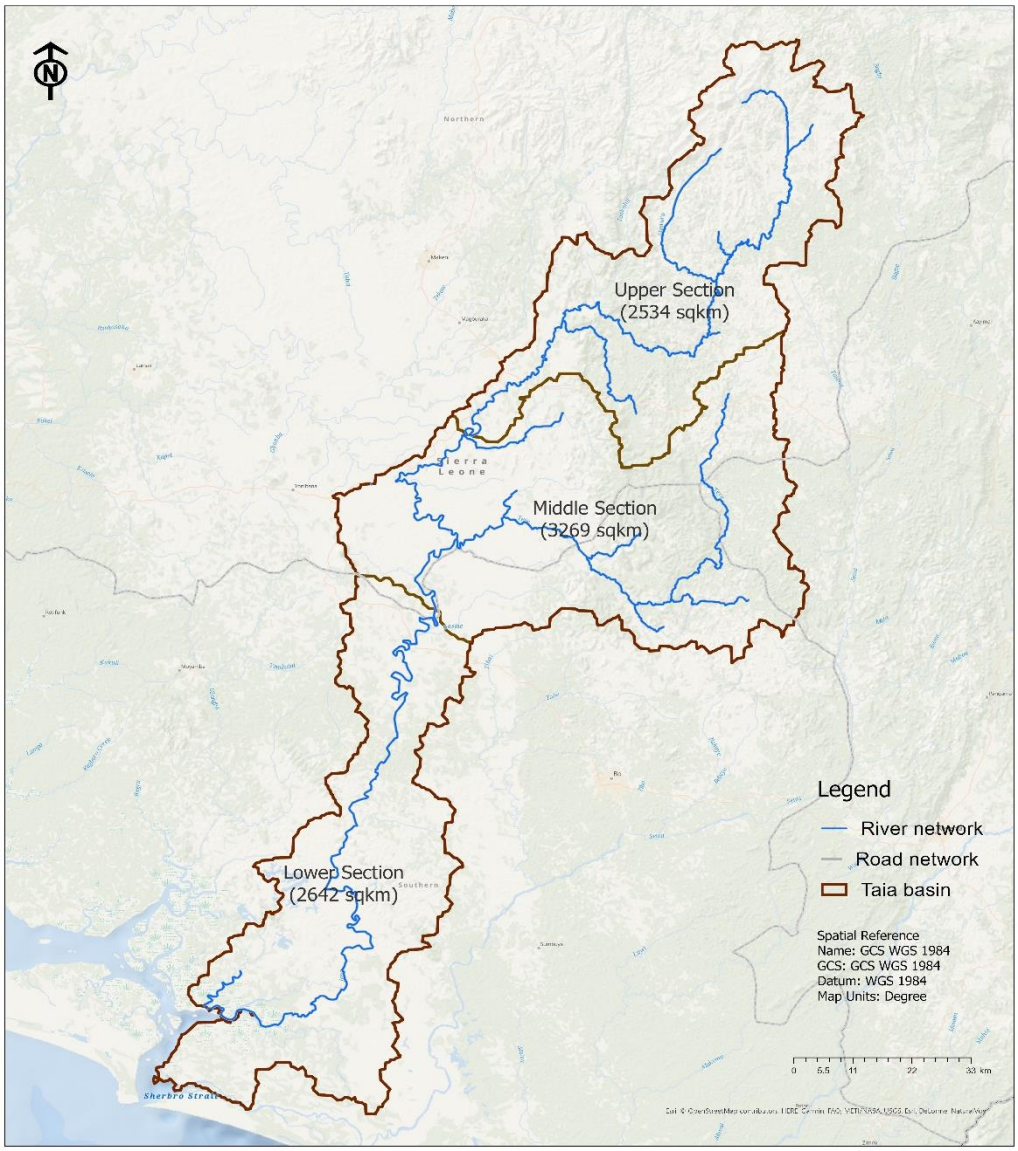


Figure 2.3:

Upper, middle and lower sections of the Taia River basin

During data collection, each set of team converged at a suitable town or community and each staff was provided with a motor bike to ease movement to data collection points located in remote or hard to reach areas. For ease of navigation and to accurately locate settlements within the basin, sub-zones were created within the basin and each data collector utilized fully the Avenza app that was installed during the training.

Each settlement within the basin was visited and a FGD conducted through community engagement. During the FGD, questions on the predominant landuse/human activities, primary and alternative water sources as well as sanitation practices were administered to the group and responses recorded in the smart form. In the mapping of landuse/human activities and water sources, GPS module has been integrated into the smart form which was used to record the specific coordinates of all human activities and water sources at each community.
In addition, drone was used to plan a real time flight mission to obtain a georeferenced high resolution satellite imagery for most mining activities.

Figure 2.4: Focus group discussion at communities

Figure 2.5: Ground and drone mapping of human activities.

In over 400 settlements, a total of 1,120 data collection points on human activities, water sources and sanitation practices were recorded across the basin as shown in the figure below.

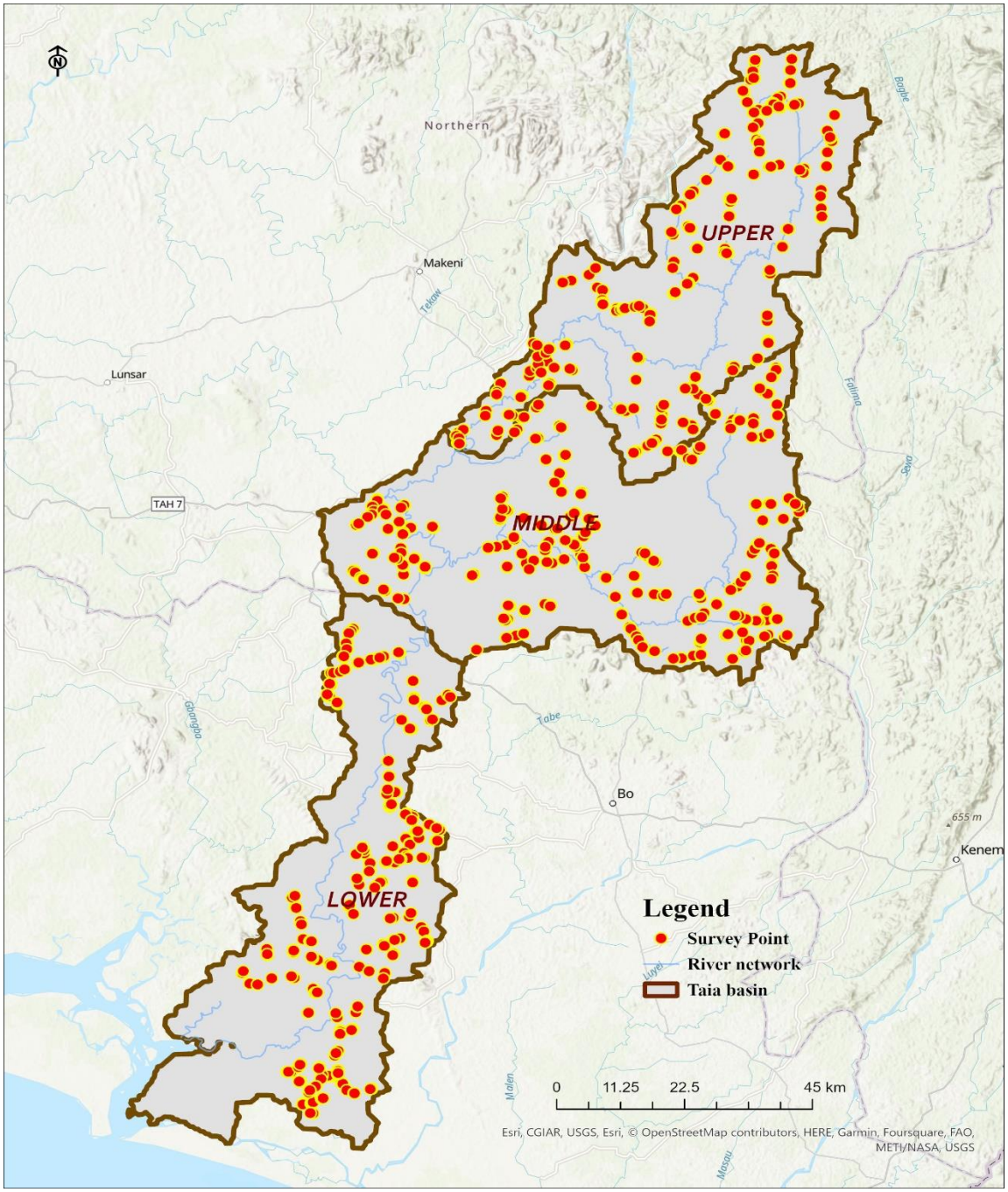


Figure 2.6: Survey data points across the Taia Basin

At the end of the data collection exercise, all the saved geodatabase files from Survey 123 platform were downloaded and analysed using remote sensing, GIS applications and Microsoft Excel.

2.5 Land Cover Development

The development of a land cover map using Landsat 8 images involved several steps, including image acquisition, pre-processing, classification, and validation. The first step in the process is image acquisition. Landsat 8 dataset were downloaded from the United States Geological Survey (USGS) website available at https://earthexplorer.usgs.gov/ for the entire study region. In the "search criteria" of the Explorer platform, four coordinates defining the bounding box of the Taia Basin was identified. Data sets for Landsat Collection 2 Level 3 Science Product that contains Landsat 8-9 OLI/TIRS C2 L2 was downloaded for the selected area as shown in the figure below.

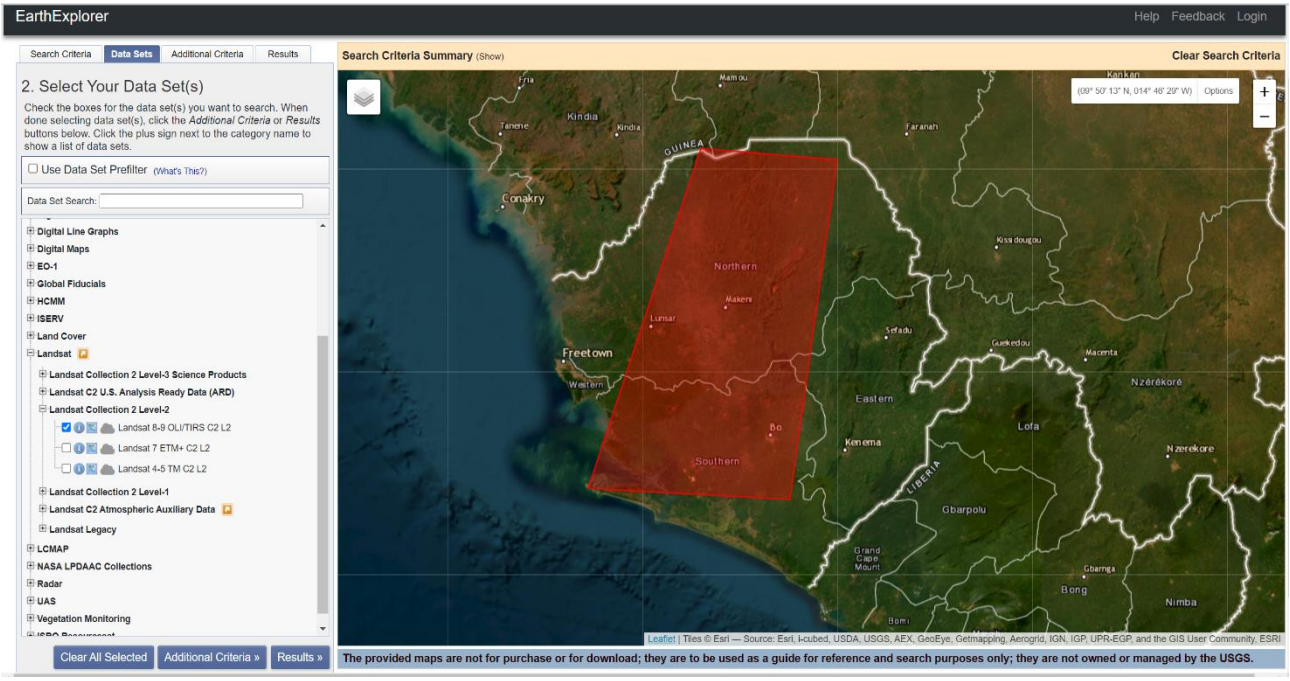


Figure 2.7: Earth Explorer used to download Landsat 8 images.

With a nominal spatial resolution of 30 m, different scenes and images containing 66% or less cloud cover for 2022 were obtained and used to generate temporal composite images for the study region using ArcGIS Pro. Un-supervised classification system was done using the normalized difference vegetation index (NDVI).

2.5.1 The Normalized Differenced Vegetation Index (NDVI)

Regarding the multispectral vegetation indices, one of the first well-known indices was Ratio Vegetation Index (RVI). This index enhances the contrast among vegetation and soil.

The best known and most widely used vegetation index is the Normalized Difference Vegetation Index (NDVI) (Dimosthenis et.al, 2020)[1], which is the evolution of RVI and is calculated by the visible and near infrared light reflected from the vegetation. It is based on absorption in Red due to chlorophyll and reflectance in near infrared red (NIR) and is an indicator of the relative density and health of vegetation. It has a value range from -1.0 to 1.0. Low NDVI values indicate non-vegetated land cover such as water, built areas, bare rocks 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.
NDVI is calculated as:

RVI = NIR/ R ……. eq. 1)
NDVI = (NIR – R)/ (NIR + R) ……eq. 2)

where R is the reflectance in the red band and NIR is the reflectance in the near infrared band. In Landsat 8, bands 4 and 3 represent the NIR and Red bands respectively. Thus, raster calculator in ArcGIS pro was used to calculate NDVI values as:
(Band 4 – Band 3)/ (Band 4 + Band 3).

In this project, NDVI values have been used to conduct unsupervised land cover classification in the Taia River basin for 2022. To estimate the percentage change in bare land and forest areas, four (4) land cover classes have been derived for each year and include Water body; Bare land; Grass land and Forest. The polygon generation tool in ArcGIS Pro (raster to polygon) was used to estimate the areas and percentage covered by each land cover type. In addition, several high spatial resolution satellite images available in ArcGIS Pro Living Atlas as well as base maps were also viewed and utilized for the purposes of calibration and validation of the various land cover product.

[1] Dimosthenis C. Tsouros, Anna Triantafyllou, Stamatia Bibi, Panagiotis G. Sarigannidis (2020). Data acquisition and analysis methods in UAV based applications for Precision Agriculture. Dept. of Informatics & Telecommunications Engineering University of Western Macedonia Kozani, Greece.

3 Data Analysis and Result

This section describes the key deliverables set as objectives that includes training of staff, delineation of sub-catchments, development of land cover maps, identify and maps human activities, water sources, pollution and sanitation practices of most communities within the Taia River basin. The result and analysis of these deliverables are presented in the following sections.

3.1 Training of Staff on Remote Sensing and GIS

12 technical staff from NWRMA can now clearly develop smart survey forms using ArcGIS Survey123, calculate geometry and display suitable symbology from both vector and raster datasets. There is now a better understanding and application of ArcGIS to water resources management through the acquisition of field data and analysis using ArcGIS geoprocessing tools. 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 develop professional maps and perform data management and spatial analysis tools on GIS applications for water resources management.

In addition to acquiring knowledge on the basics of GIS, remote sensing has also been taught using ArcGIS software and open-source satellite imagery. The staff have acquired knowledge on how to access and download Landsat imagery from the United States Geological Survey (USGS) website and display them in a GIS environment, do band combinations, analyse spectral signatures of land cover types and conduct both supervised and unsupervised classifications. As the training is not a one-off period, staff will be given exercises and tasks during normal working periods to acquire data, perform analysis and produce professional maps when required.

Moreover, staff have also been trained on the use of drone to acquire high resolution georeferenced images. 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, image capturing software apps (DJI go 4 app and Pix4D Capture) as well as post-processing software (Pix4D Mapper) were introduced for flight mission planning and image processing respectively. Following the classroom session was a practical session and a real time scenario in the field where the trainees had hands-on experience with flying the DJI Mavic 2 Pro drone.

3.2 Delineated Catchments of the Taia Basin

Boundaries for the Taia River basin and all sub-catchments have been delineated using high resolution (12.5m) open-source DEM data from NASA's Earth-data website. The DEM has 16-bit signed integer data in a simple binary raster and was imported into ArcGIS Pro to develop the basin and its sub-catchments as shown in the figure below.

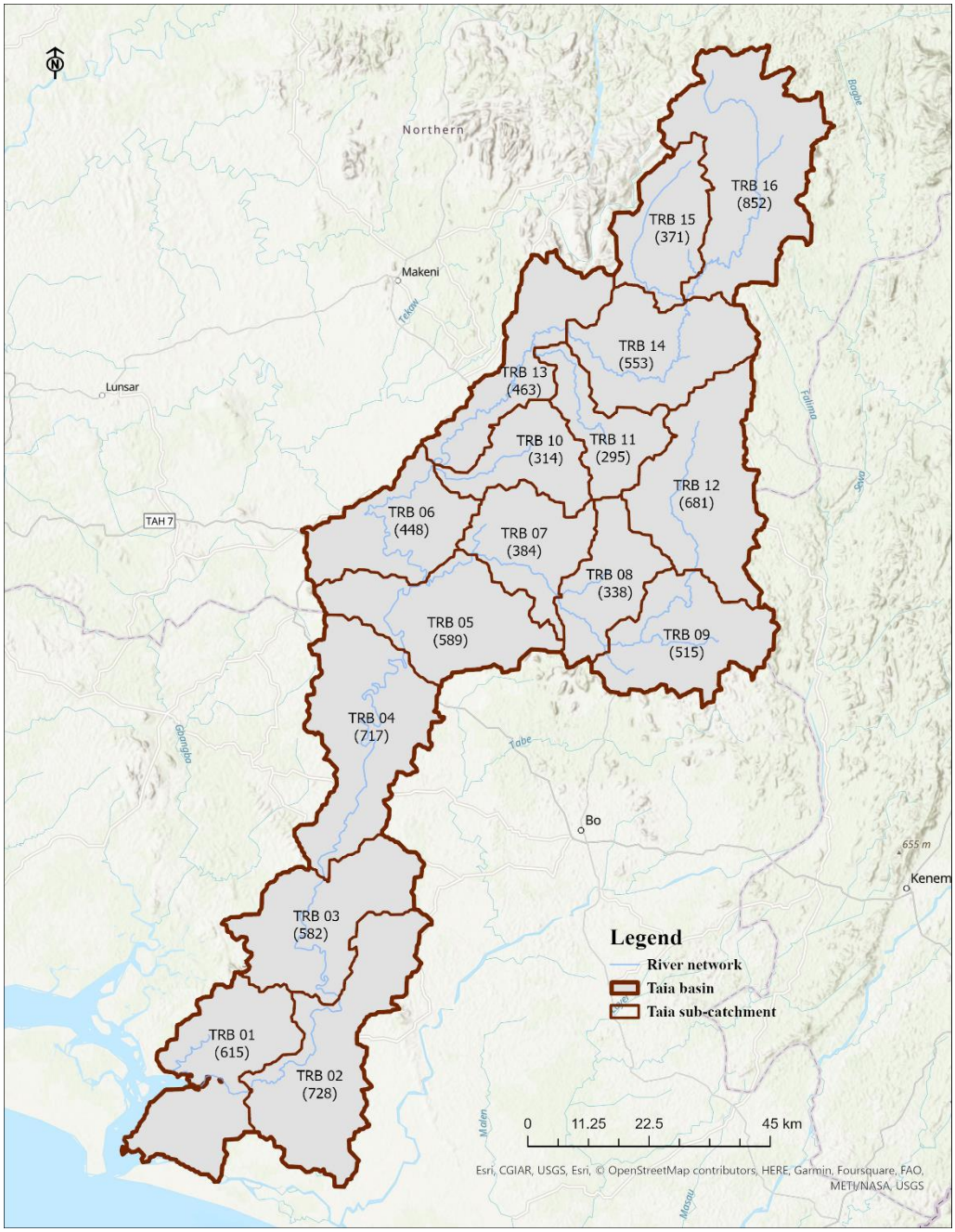


Figure 3.1:

Delineated sub-catchments of the Taia River basin with areas in km^2.

3.3 Human Activities, Water Sources and Sanitation Practices

After acquiring data and completion of all surveys on human activities, water sources and sanitation, data analysis and processing immediately commenced. For quantitative data analysis, ArcGIS Pro, python programming and Microsoft excel were used. Python is a high-level programming language used by data scientists to analyse and visualise big dataset and has been widely used by researchers. Thus, python 3.0 was used with Jupyter notebook as interpreter. For quantitative data analysis, NVivo 10.0 was used. NVIVO is a handy application which can be used for analysing qualitative data. This application can be utilized for importing as well as analysing documents, images, PDFs, audio, video as well as webpages. One can also use coding for bringing different themes and topics like people and places into single category so that identifying patterns in data is easy.

3.3.1 Administrative and Population Distribution

Field data collection for the delineation, mapping, and assessment of Taia/Pampana River Basin started at Lake Sonfon in Diang Chiefdon, Koinadugu district. Lake Sonfon, which is also the source of the Taia River, is located at the upper section of the basin. The Taia River basin spans across six (6) Districts and thirty (30) chiefdoms with Koinadugu Districts at the source and Bonthe District at its outlet where it finally empties into the Atlantic Ocean. The figure below shows the percentage of districts covered in the Taia River basin.

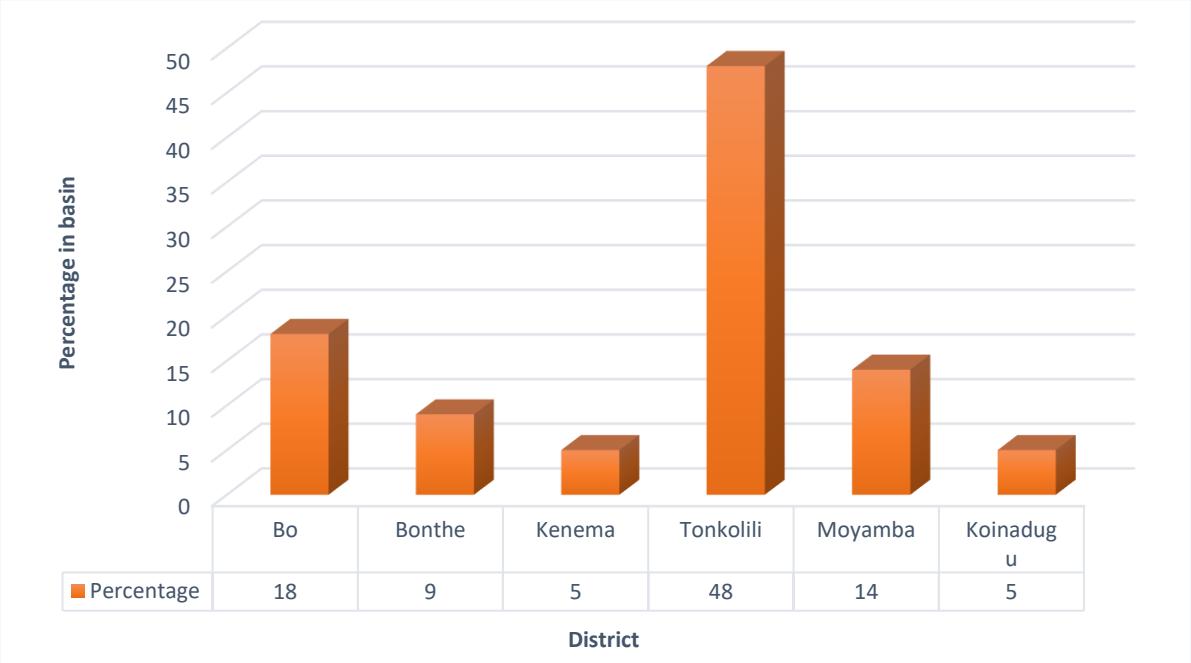


Figure 3.2: Percentage of districts covered in the basin.

Over 1,000 settlements were mapped across the basin and for which 95% of all settlements have population greater than 200 people. Of all the settlements mapped, 27% have population greater than 1,000, 31% have a population between 500 – 1000, 27% have population between 250 – 500 while 5% have population less than 100. Since most of the settlements visited have population greater than 200, this shows that data on human activities, water sources and sanitation practices were fully representatives of the communities living in the Taia River. The figure below shows the population range of settlements visited across the Taia Basin.

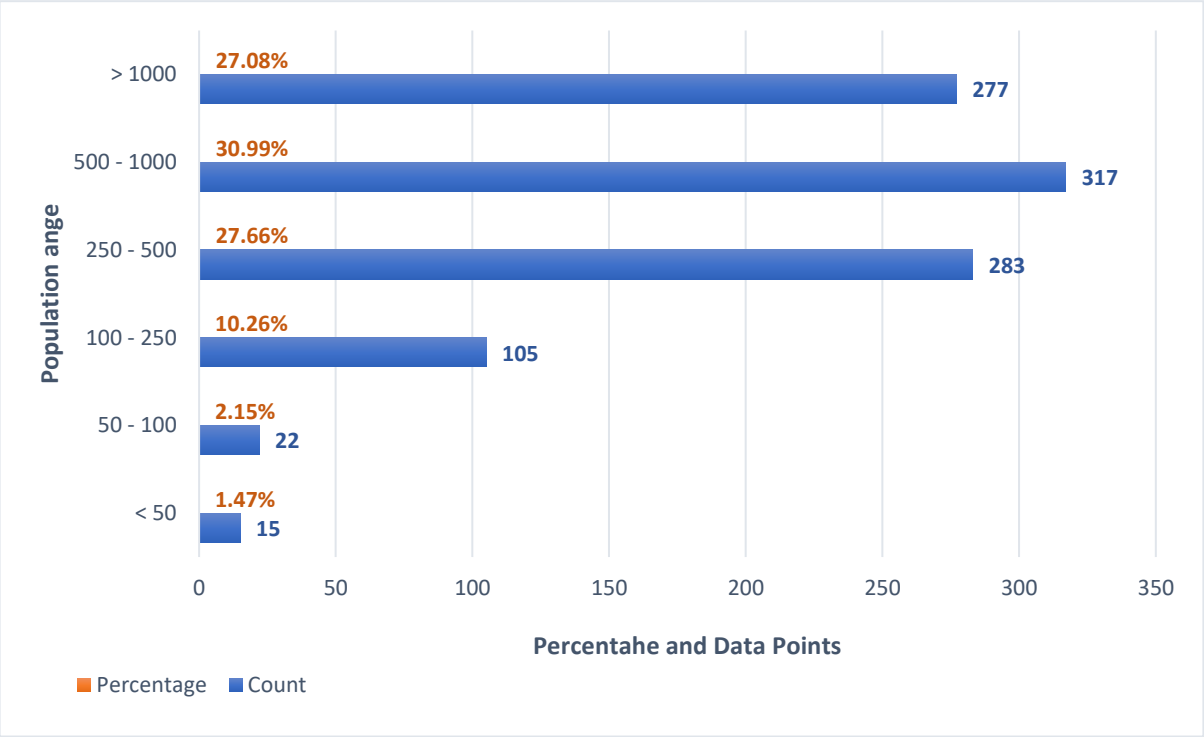


Figure 3.3: Population profile of settlements visited.

3.3.2 Human activities

Several human activities were mapped along the entire Taia River basin and analysis from the data collected shows farming as the most common human activity practised by communities in the upper, middle and lower sections of the basin (65%). Second to farming is mining, which accounts for about 15% of human activities mapped. The remaining 20% includes activities on fishing, timber logging, coal burning, trading and other small agricultural enterprises including palm oil and gari production as shown in the figure below.

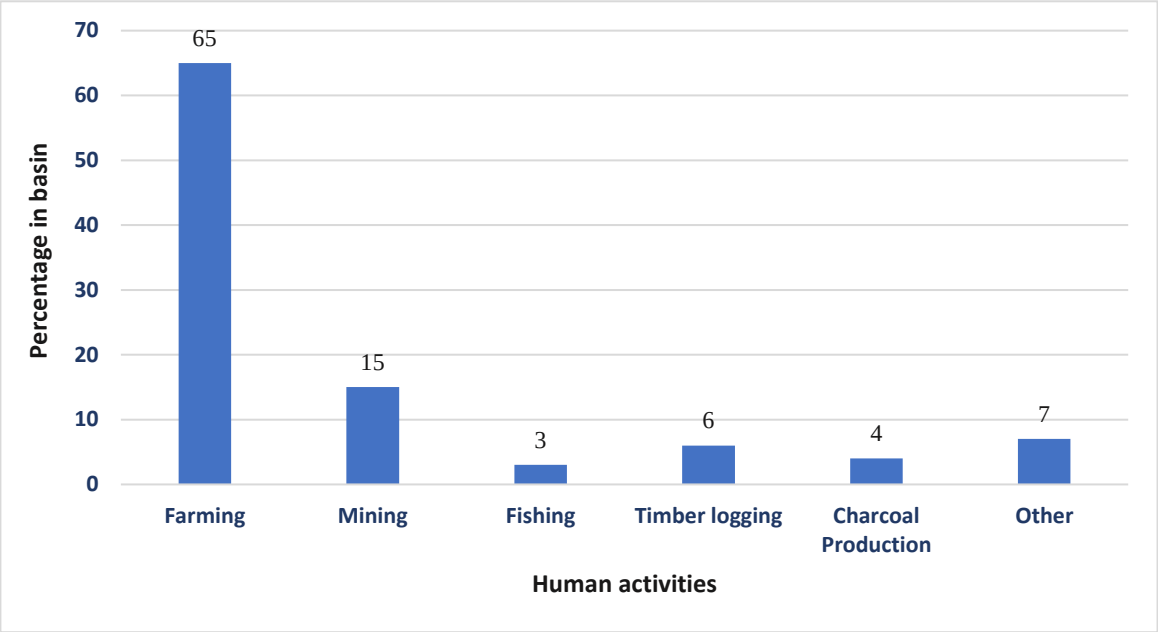


Figure 3.4: Percentage of human activities across the Taia Basin

The type of mining activities is performantly gold mining that takes place along the riverbanks and has been the major source of pollution in the basin. In addition to acquiring general information on mining activities, data on the scale of mining was also collected and analysis from the report shows that 55% of all mining activities mapped are artisanal, 31% small scale and 14% large scale as shown in the figure below.

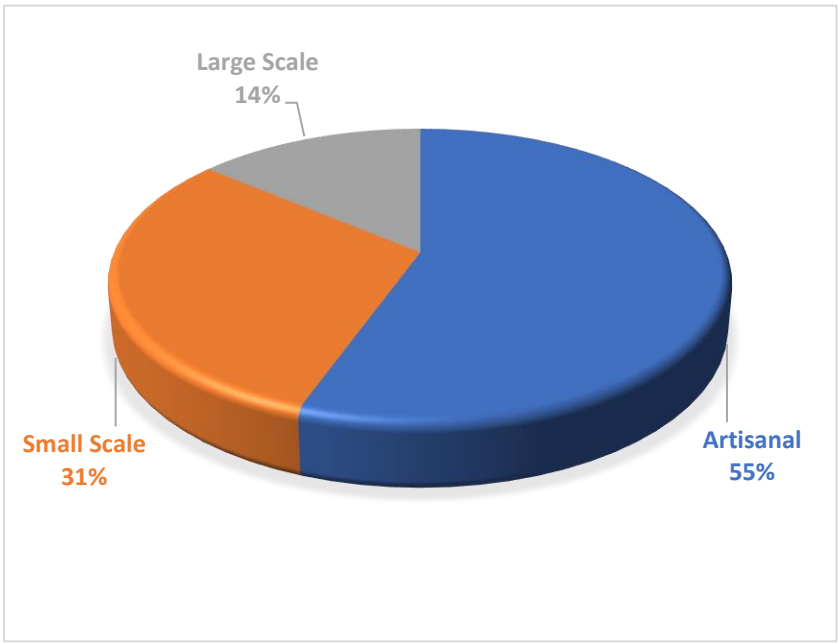


Figure 3.5:

Scale of mining activities across the basin

The map below also shows distribution of human activities across the Upper, Middle and Lower Taia basin.

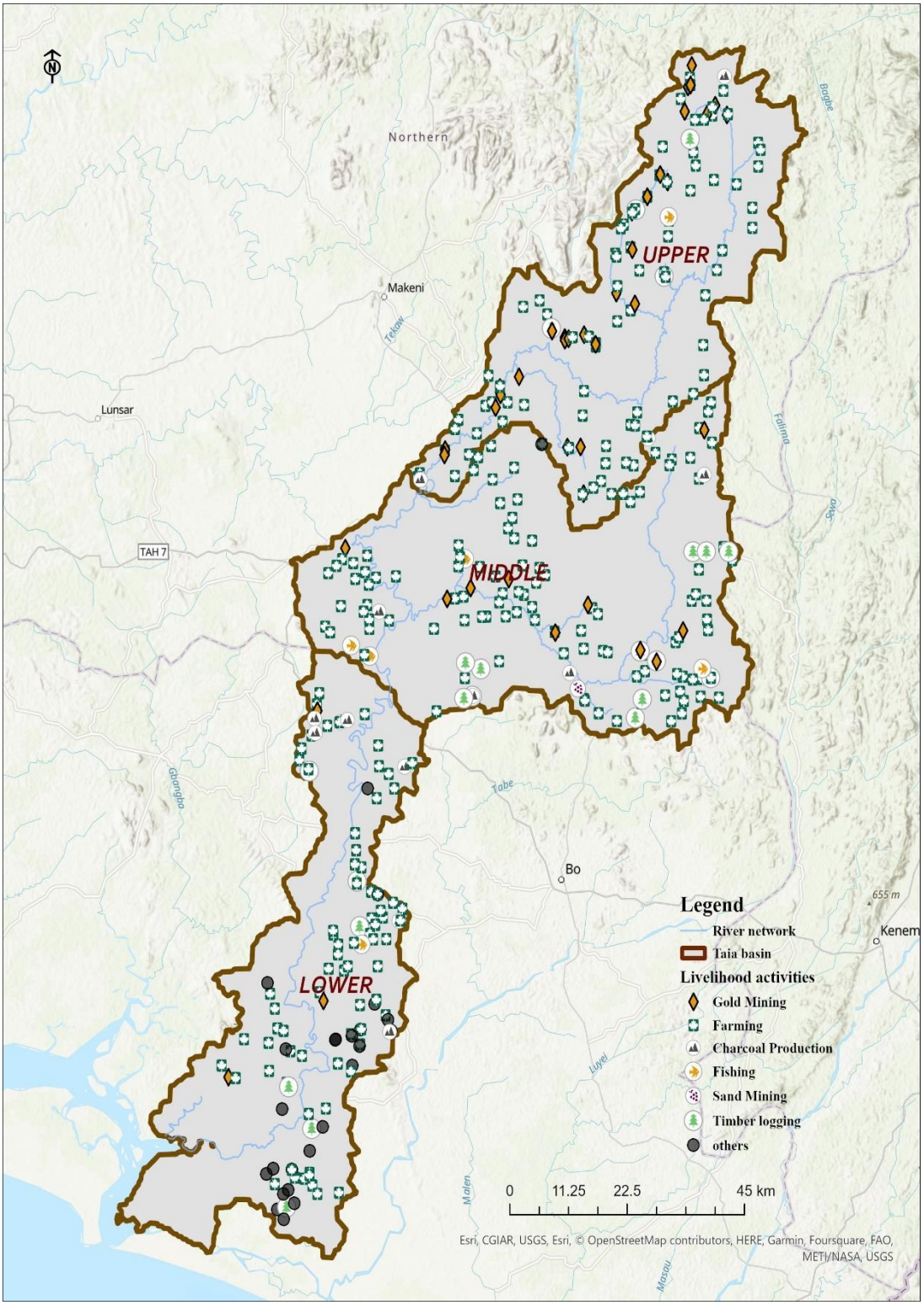


Figure 3.6:

Human activities mapped across the Taia River Basin

3.4 Primary water sources of communities within the basin

Primary water sources of all settlements visited as well as alternative water sources were mapped during the survey. It was discovered that dug wells and streams are the most common primary sources of water for communities along the upper, middle and lower sections of the Taia River basin with 40 and 31% respectively. Other primary water sources used by communities include borehole with elevated tank, spring, swamps, ponds, and gravity scheme with standposts.

In most settlements visited, alternative waters sources vary from swamps, ponds, rivers and streams. Where dug wells and streams are used as primary sources which normally get dried during the months of March to May, alternative water sources used are mostly streams and swamps respectively. Figure 3.7 below shows counts and percentage distribution of primary water sources across the basin.

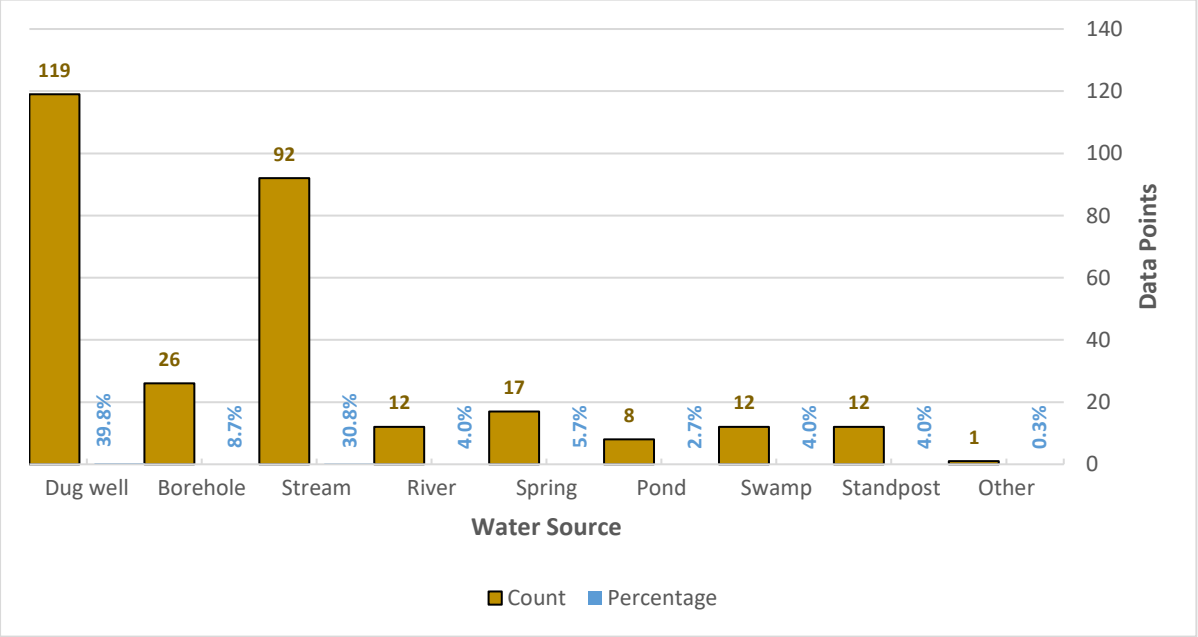


Figure 3.7: Primary water sources of communities across the Taia River basin

3.5 Sanitation practices of communities within the basin

Sanitation practices of communities is another category considered in the mapping of the Taia River basin as they may influence the quality of both surface and groundwater sources. The two main practices considered in the sanitation components include open defecation and method of waste disposal.

3.5.1 Open Defecation

Community-led total sanitation (CLTS) is a widely used approach to reduce open defecation in rural areas of low-income countries. Following CLTS programs, communities are designated as open defecation free (ODF) when household-level toilet coverage reaches the threshold specified by national guidelines (e.g., 80%)[2]. However, because sanitation conditions are rarely monitored after communities are declared ODF, the ability of CLTS to generate lasting reductions in open defecation is poorly understood.

This study examined total number of functional toilet coverage and the total number of houses in the communities of the Taia River basin. The extent of open defecation for each community was determined using a comparative ratio of houses to functional sanitation facilities (Latrines/Toilets). The level of open defecation free (ODF) practiced by communities have been divided into three categories as High, medium and low which is determined using the formula below:

$$ODF\ level\ =\ x/N \qquad \text{..... eq. 3.1}$$

Where x = number of functional toilet/latrines in a community

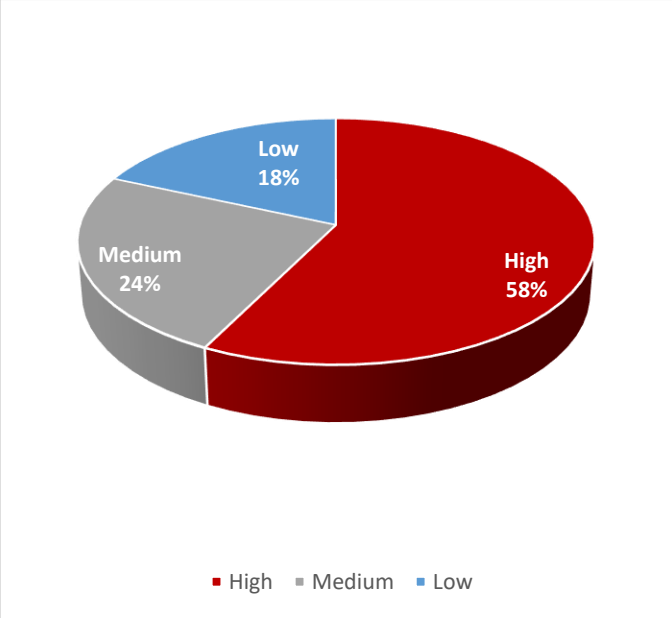
N = Total number of houses in the community

$$If\ \frac{x}{N} \leq 0.1\ =\ High\ ODF\ level$$

$$If\ 0.1 < \frac{x}{N} \leq 0.4\ =\ Medium\ ODF\ level$$

$$If\ \frac{x}{N} > 0.4\ =\ Low\ ODF\ level$$

[2] Delaire C, Kisiangani J, Stuart K, Antwi-Agyei P, Khush R, Peletz R (2022) Can open-defecation free (ODF) communities be sustained? A cross-sectional study in rural Ghana. PLoS ONE 17(1): e0261674. https://doi.org/10.1371/journal.pone.0261674



From the analysis, 58% of all the communities visited practiced high open defecation (OD) while 24% practice medium OD. Only 18% practice low OD as shown in the figure 3.8.

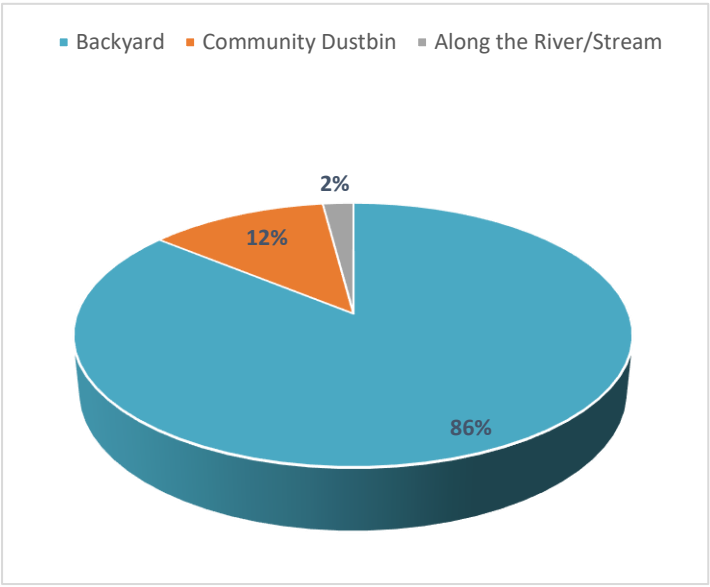
Figure 3.8:

Level of open defecation across the basin

3.5.2 Waste Disposal

Pollution of water sources for the Taia River basin originates from haphazard disposal of solid wastes, discharge of untreated or inadequately treated mining effluent to water sources, lack of standard sanitary facilities and poor hygienic practices. Contaminated water used for human consumption can lead to serious health problems such as cholera, typhoid, skin diseases, etc.

The method of waste disposal mostly includes solid waste management in rural communities and proximity to nearby water sources.



Waste disposal in rural communities is mostly done in either backyard, community dustbin or at the banks of river/stream which were captured in the mapping process. This result shows 86% of the communities visited dispose their waste at their backyards, while 12% and 2% percent have their wastes disposed at community dustbins and along Rivers/Streams respectively.

Figure 3.9: Methods of solid waste disposal across the basin

3.6 Land Cover Map of the Taia Basin

In order to identify further influences and pressures on the ecosystem and quality of the Taia River, land cover map for the basin was developed using derived NDVI values from Landsat 8 images. Places of mining activities were also digitised into the land cover dataset in ArcGIS pro in order to obtain the area/percentage of land mass occupied by each land use/land cover. The resulting landuse/landcover map is shown in figure 3.10 below.

From the analysis, it was discovered that mining areas occupy about 0.34% of the basin and it is mostly practised in the middle and banks of the river. Breland which could be due to agricultural shifting cultivation and mining covers about 18% of the basin and the largest cover can be seen from forest with 72%. While grassland and agricultural areas make up a total of approximately 8%, water bodies and urban areas cover 1.3% and 0.35% respectively.

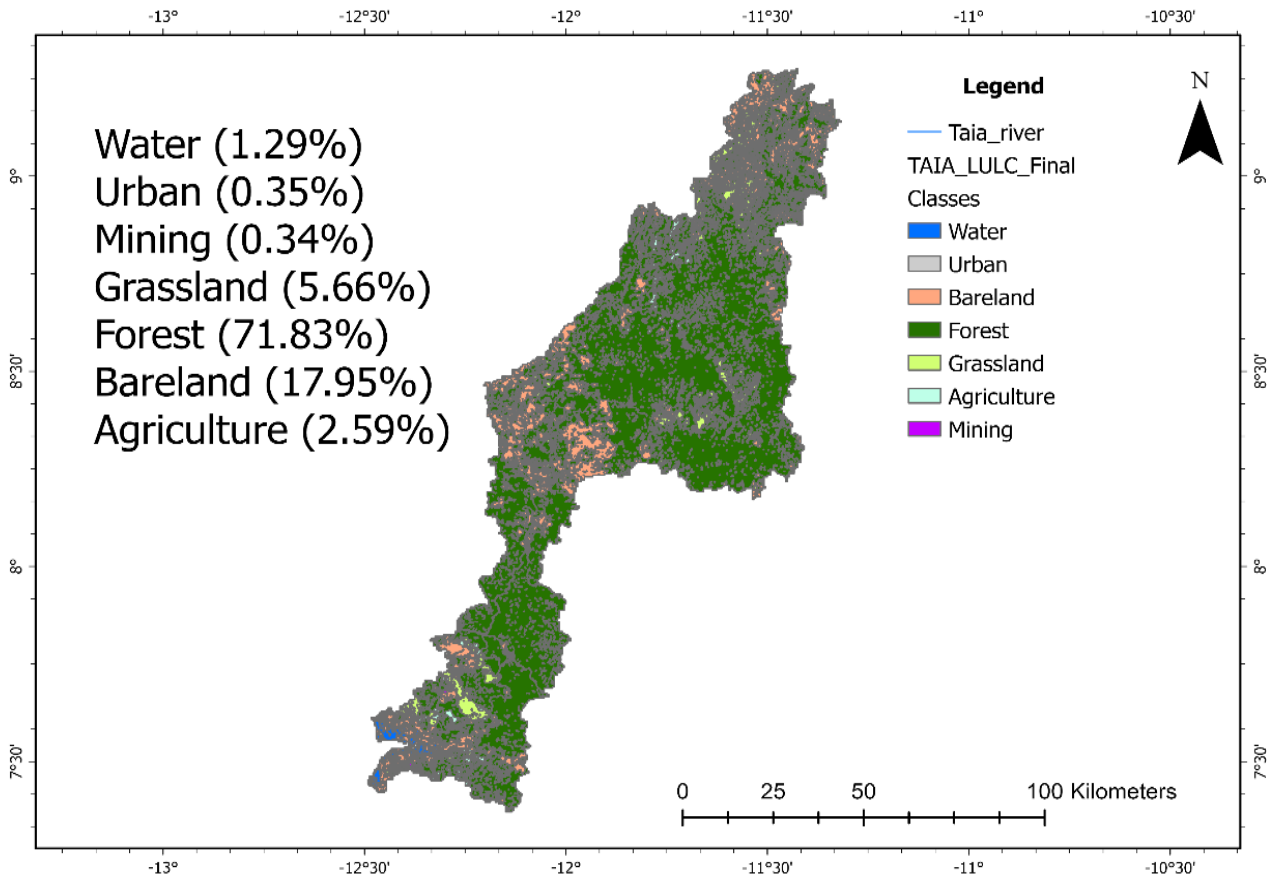


Figure 3.10: 2022 Land cover map of the Taia basin

4 Conclusion and Discussion

The first, second and third phases of the delineation, mapping and assessment of Taia/Pampana River Basin were conducted successfully in the months of August, September and October 2022 respectively. A technical team from the agency mapped and collected survey data from 400 settlements located in six districts including Koinadugu, Tonkolili, Bo, Kenema, Moyamba and Bonthe.

4.1 Human activities

The team collected data on human activities which are the predominant sources of livelihood for all communities. Analysis from the data shows that farming is the most predominant livelihood activities across the basin accounting for 65%. Farming activities are mostly subsistence in the major part of the basin. Small agricultural enterprises for which farmers embark mainly on gari and oil palm production is evidenced at the middle and lower sections of the basin. From the survey, it was also discovered that most farming activities are located close to water sources and depend on rain fed with little or no herbicides/insecticides that might pollute the water sources. Thus, pollution from farming activities within the basin can mostly be seen during the rainy season when erosion from debris caught in vegetation or harvested crops are transported to nearby stream/rivers.

Next to farming, gold mining activities within the basin has emerged as another main source of livelihood accounting for 15%. Gold mining activities mainly take place at the upper and middle section of the basin. It was also evidenced that intense mining and diversion of river course take place at and close to Lake Sunfon using heavy duty machines and other equipment as shown in Annex 1. It was also discovered that the major sources of pollution to the Taia River basin originates from artisanal mining activities in and at the bank of the main river channel upstream. Although large and small scale mining also take place at the basin, the former uses control measures for the treatment of effluent into the main river channel that do not have much impact to water bodies. Other human activities within the basin include the cutting down of trees for timber and charcoal which also have direct impact on the hydrology of the basin. Timber logging and charcoal production make up a total of 10% of all human activities mapped.

4.2 Water sources

The most common primary sources of water for communities visited are dug wells and streams which account for 40% and 31% respectively. Many of the communities lack access to

protected and improved water sources for drinking and domestic uses and for many of the primary sources mapped, water availability is only seasonal. Also, most of the communities who have dug wells and streams as primary sources have their alternative sources mainly from swamps, ponds, springs, or rivers. These alternative sources are also not protected and are located some distant away from the settlement.

4.3 Sanitation Practices

Information collected on sanitation practices of most settlements visited across the basin indicates open defecation to be a common practice. It was also discovered that many of the communities visited lacked access to improved sanitation facilities and the practice of high open defecation might also impact the quality of nearby water sources. It was also reported from focus group discussion that most toilets/latrines get collapsed during the rainy season or easily filled up which shows poor use of materials, siting and construction methods.

In the management of solid wastes, almost all settlements do not have a community dustbin for the deposition of solid wastes and most have their wastes thrown at backyards and with only 2% that have their domestic wastes disposed along riverbanks.

4.4 Delineation of Sub-catchments.

Since everyone lives and works in a river catchment, every activity done in either backyard, playground, farmland or business places then has the potential to affect waterways or drainage flowing down the river or stream of that catchment. Thus, the management of a river basin begins with the management of the basic unit which is known as catchment. As a result of this, a system of sub-catchments have been delineated using the best free available digital elevation model (12.5m) for the Taia River basin. A total of sixteen (16) sub-catchments have been delineated with area ranging from 300km^2 to 850km^2. These catchment management units can be used for the general management of the Taia River basin.

4.5 Landcover Map

Although forests and grass land have been converted into agricultural land and bareland respectively, the 2022 landcover map developed for the basin shows that forest cover still occupies the most with 72%. Next to forest cover is bare land which also occupies 18% of the general land cover in the basin. Since the percentage of bareland is greater than that of grassland or agricultural land, it is also evidenced that most of these bare soils are potential areas for development and or mining sites within the basin that will continue to increase pollution on water bodies if prompt management actions are not carried out.

5 Recommendation

Results from the assessment show that the Taia River basin has high levels of sediments from mining activities causing an increase in the turbidity of the river which mainly affects the use downstream, aquatic organisms and subsequently increase the cost of any potential water supply infrastructure. As a result, immediate and robust actions are needed as interventions for the management of the Taia River basin and its ecosystem. Below are the recommendations proposed from the study.

- Ensure all mining companies are registered and regulated as well as issuing discharge permits on mining wastes discharge as prescribed in the newly enacted pollution control regulation of the National Water Resources Management Agency.

- Collaborate with other agencies and the security sector to stop the operations of all illegal and artisanal miners in and along the banks of the main river channel of the Taia River and its tributaries.

- Establish routine water quality monitoring stations at most confluence points of the basin and also conduct monthly or quarterly monitoring at point source pollution.

- Develop an integrated restoration plan using ecohydrology systemic solutions such as constructed wetlands to treat sediment load and remove heavy metals for the Taia/Pampana River basin and seek funding for its implementation.
- Set up the Taia/Pampana River Basin management committee and sub catchment Committees.
- Work with CBOs, NGOs and INGOs in the WASH sector for the provision and maintenance of WASH facilities. Also provide training and proper sensitization on good sanitation practices through community led total sanitation (CLTS) programs in the riverine communities.
- Conduct sensitization and awareness raising to communities regarding the negative impact of artisanal mining on their environment.
- Develop a strategy to manage the risk of runoffs from farms and encourage smart agricultural practices within the basin.
- Afforestation to restore the natural riparian vegetation and implement agroforestry intervention and enrichment through planting in degraded areas.
- Review abstraction permits for the dry months (Feb, Mar, and Apr) and regulate water use judiciously.
- Implement solid waste management interventions for riverine communities.

Annex 1: Mining activities upstream of basin

Section of Lake Sunfon

Mining at side of lake

River diversion from main course

Mining along the riverbanks

Small scale artisanal mining

Mining in river tributary

Ing A.B Kamara
GIS Officer

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