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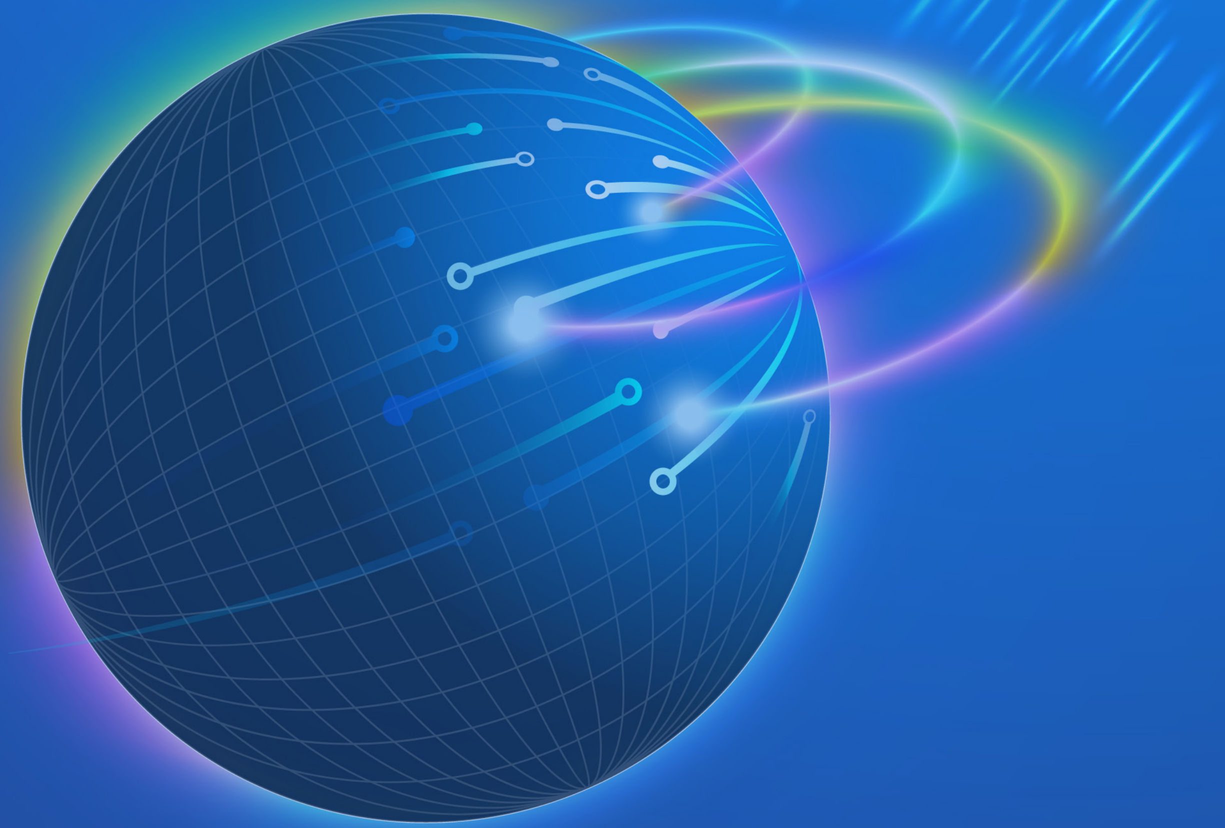

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Geospatial Technique and Forest Management of Coastal Areas in Bagamoyo Tanzania

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ABSTRACT

This article assesses the occurrence of forest crimes mostly in Bagamoyo coastal region using qualitative and quantitative approaches. The probability sampling along with non-probability sampling, was applied when selecting the participants who were used in the study, the collection of data was done through a community information system (participatory GIS), documents investigation, GPS survey, remote viewing as well as observation. Arc GIs software was used to create hotspot maps, forest crime patterns and visual representing of data. The outcomes revealed that areas which are highly vulnerable to the crime increase overtime from 2010 to 2022, it is due to the various factors like the family status of people along the study area, economic status, education, poor infrastructure around the area, low living standard and more, availability of forest markets and more.

INTRODUCTION

Over 30 percent of the world's earth's surface is covered by forests, which are termed the earth's air sacs. Forests provide oxygen gas in the atmosphere, which saves humans' and all other species' lives (WWF, 2011).

The 75 % of the biosphere of the earth's total key productivity is contributed by the forest as well as 80 % of the forestry residues (plant biomass) of the earth (Keenan *et al.*, 2015). The distribution of forests is that around half of the resources of the world's forests are hosted in South America and Asia (Pan *et al.*, 2013). The world's Food and Agriculture Organization (FAO) data in the year 2013 shows that the forests of the world were unevenly dispersed, but Southern America and Asia hold the most of the forests of the world; Also there is a notable global forest share in the North, South, and Central regions of America (FAO, 2013, 2015). Moreover, African forested area is 17% of the world's forest areas (Keenan *et al.*, 2015). The mainland part of Tanzania dwells forests with high biodiversity. The country has totality of over 10,000 species of plants, where only hundreds of the species are nationally managed by using Geospatial techniques. There is the identification of Over 305 species of plants as the threatened species in the IUCN List Red, also about 276 plant species are categorized as at-risk species (endangered) (IUCN, 2013). The protection and management of the major forests is done by using cartographic (geospatial) systems. Across the western, central, and south zones of Tanzania, there is forest kinds which are deciduous Miombo woodlands but in the northern regions there is Acacia-Commiphora woodlands, coastal forests together with along the Indian Ocean coast there is the mangrove forests, the eastern zone is covered with woodland mosaics and the closed-canopy forests are growing across the Eastern Arc old mountains , they also found along the Albertine Rift, moreover in the west zone along the Lake Tanganyika, as well as across the central and north regions of the country on the juvenile volcanic mountains (Burgess *et al.,* 2004). The most spacious Woodlands that are always deteriorated, it leads to the grass and shrubs undergrowth. The activities done by human beings, such as agriculture, expose Woodlands to frequent grass fires. there is areas that are mostly forested around the Bagamoyo district in the Fukayosi ward and Makurunge ward contrary to the other less forested wards found in Bagamoyo, there are legally conserved reserve areas of forest which are Kikoka forest in the mainland and Mangrove forest to the coastline, they are under the management of TFS since 2010/2011 when it was established. The Reserve Forest of Kikoka that found across the Fukayosi ward and Makurunge ward covers about of 1654.8 hectare according to G.N. number 399 of 1958 and map Jb No. 415. Kikoka forest is the representative forest of all coastal Forests of Tanzania, coastal forests are important in the world for supporting endemic plants, birds, and other vertebrates with high potential for investigation, schooling, and recreation.

Mangrove Forest Reserve found along the shoreline of the Indian Ocean in Bagamoyo covered 5636ha according to G.N. number 324 of 1928 in various areas but concentrate in Mankurunge ward streets including Mkunga, Shanga, Kijitokamba, Dago la ukindu, kwa mwarabu, Batini, Chamamba and along the river mouth of Ruvu and Wami river that cross the areas of Sadani National Park and the Ranch of Zanzibar found in Bagamoyo. Therefore, the management of forest appears as either durable or unstable in some areas, the majority of mangrove specie decreases, at the same time in Bagamoyo, the forests are seriously affected by harvesting, mostly people exploit

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forest resources illegally while few harvest the forests legally following the procedure of business for products from the forest, for both domestic and commercial purposes as the source of fuel (fuelwood), it is locally utilized though the forest products are highly needed in Zanzibar. The forests are continuously deteriorated for the generation the Income, tourism activities that lead to clearing forests to build hotels, opening beach areas, unlawful charcoal burning, clearing for agriculture and harvesting of salt (Francis *et al.*, 2011). There have been evidenced various forms of forest crimes, including illicit lumbering, transportation, logging, as well as the gathering of products from the forest illegally (UNDOC, 2015, 2008). Among of the listed crimes experienced in some countries as the statistical data exemplify Japan 14 percent, Hungary, Denmark, and Chile49 percent. In the countries of Africa, the forest crimes are associated with not only economic status but also social, political state, and human activities, where the suspected individuals of forest crime evidenced that they were struggling for the life betterment to be obtained from the forest's products (FAO, 2003, 2008). In spite of the challenge of crimes in the forests, number of forest crimes avoiding measures and the managerial measures has been initiated to control the forest crimes in the forests. Geospatial techniques (GPS, CCTV, Mobile phones, and other web maps techniques) is the established forest crime controller that offers data and complete information for monitoring and management of crimes in the forest. The information accessed and acquired by using cartographic techniques is used to create and to provide the clear means of controlling protecting forests from crimes.

MATERIALS AND METHODS

The Area of Study

This research was done across the two wards of Makurunge and Fukayosi, that are located in Bagamoyo district, which is among of 8 (eight) district councils of Tanzanian political region called Coastal region (Pwani Region). It is 75 kilometers from Dar-es-Salaam city to Bagamoyo District (UNH, 2009). Bagamoyo is neighboring the Tanga Region northwards, the West side Bagamoyo is bordered by Morogoro Region, also the Indian Ocean to the East, as well as Districts of Kinondoni and Kibaha to the South side (Bagamoyo District profile, 2009).

According to DP, 2006; 2009, The Bagamoyo District is located between 370 and 390 Longitude and between 60 and 70 Latitude. The area of the district is about 9,842 km2, where water area including Ocean and river covers 855 km2, the remaining 8,987 km2 is the area of dry lands (Bagamoyo District, 2009). There are two parliamentary provinces that are Chalinze constituent and Bagamoyo constituent (Bagamoyo District profile, 2006).

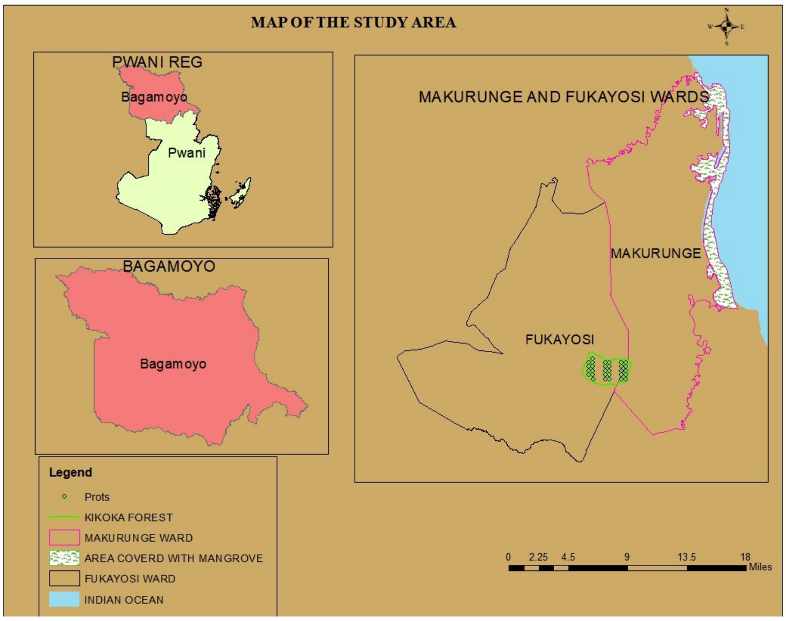

Figure 1: Location of Fukayosi and Makurunge wards

Research Design and Sampling

The study used both qualitative n and quantitative design to assess the distribution and factors influencing Forest crime using Geospatial techniques. Moreover, this design gives a clear awareness of the processes, interactions, as well as mechanisms through which the forest crimes are interacted with Geospatial technique .The researcher utilized a quantitative approach to gather quantitative data around the forest crime areas using GPS and other GIS software (QGIS and ArcGIS) both spatial and spatial attributes were collected. Using quantitative approach, an attempt was made to understand the evidence of forest crime cases in Bagamoyo; Purposive sampling was applied in selecting Bagamoyo district as it has forest cover that experiencing a lot of forest crimes. Therefore, the ideal target population for this research was the forest staffs and officers. So far, WEO and the Street chairman in the study area included .The probability sampling was used to obtain Quantitative data where 70s of officers from the department of forest was sampled. The

Probability sampling technique was conducted through listing the officers' names from the principal forester's office Tanzania forest Service (TFS). On the isolated small pieces of paper, the names were written and kept in the bag. So, around 94.6% which is 71 names of the target population were taken from the bag to make a sample, furthermore, the WEO and street chairman were purposively selected by the researcher as the respondents who endowed with a lot of forest crime information about in their power positions.

Data Collection

The study applied the primary source and secondary source of data. The Primary sources of data included inclusive mapping, field observation and in-depth interview. The remote sensing and scanning of raster data and digitization forest management journals, reports, and magazine were the secondary sources of data , obtained from Tanzania Forest Agency office (TFS) coastal zone. The participatory mapping technique, gave the participants an opportunity to contribute their experiences, information, and knowledge concerned with location and the intensity of forest crime in the area of study; this process resulted into the production of maps of distribution of the forest Crimes. participatory mapping was used to execute a base map in form of the high-resolution Google earth images was used to map locations of different levels of forest crime using a systematic procedure. Firstly, the identification of ten (10) participants engaged in participatory mapping was made. Eight (8) of the identified participants were forest staffs and other officers 2 WEO. All of these have more than 6 years of experiences about forest crime occurrence along their areas. Next, the chosen participants were involved in the process of mapping that was done through analyzing the past and the present forest crime occurrence. it was fulfilled through indicating the places of the mapped area and approximating the magnitude of the forest crimes on the study area and labeled the places with different colored gravels guided by the prepared questions. Third step, the labeled area that is regarded as the forest crime area were calculated to analyses hotspot to get distance and relationship between one point to another

The images with high resolution showing the area encompassed by a single image cell on ground were for participatory mapping. With a scale of 1:3600. Features such as the roads, Indian Ocean, Schools and churches were used to orient participants during the participatory mapping process. the obtained Data was visualizing using the ArcGIS 10.7 software's

Figure 2: Participatory Mapping with research participants

This study utilized Global Positioning System (GPS) surveying and systematic field observations to validate data obtained through interviews and participatory mapping exercises. GPS surveying proved instrumental in accurately verifying the spatial locations of reported forest crime incidents and key land use features, such as religious institutions, commercial areas, educational facilities, and other relevant sites. To further enhance data reliability, a transect walk was conducted, serving to complement both the GPS data and the observational findings. This approach enabled direct, on-the-ground verification of forest crime locations and associated land use activities, thereby strengthening the validity of the spatial data collected from community mapping and key informant interviews.

Data Analysis

Hotspot analysis was employed in this study to identify areas prone to forest crimes by mapping the spatial and socio-economic factors associated with the occurrence of these crimes. The primary objective was to generate maps illustrating the locations and distribution of forest crime incidents, including illegal lumbering, Charcoal production, unauthorized timber harvesting, agricultural encroachment, and illegal grazing activities.

Key underlying drivers of forest crime—namely economic pressures, educational attainment levels, and the availability of supportive markets—were identified and spatially referenced using GPS coordinates. Point data were collected with a handheld GPS device offering an accuracy range of 0–5 meters. These geospatial data points were subsequently overlaid onto high-resolution Google Earth imagery to cross-validate the accuracy of locations reported by participants. This integrated analysis provided deeper insights into the spatial distribution of forest crime and contributed to an enhanced understanding of participants' awareness regarding the geographic patterns of such offenses.

The hotspot analysis aimed to highlight the density of forest crime incidents and pinpoint areas with frequent occurrences of these illegal activities. Using Arc Map software, the hotspot mapping was carried out following a series of specific steps. First, a 200-meter fishnet grid (polygon grid) was created to cover the area of analysis, using the "Create Fishnet" tool in the Data Management Tools (Sampling). The grid cells served as the spatial units for the analysis. Next, the point data layer representing individual crime incident locations was joined to the polygon grid cells based on spatial proximity, using the "Join" function. This allowed each grid cell to be linked with the corresponding forest crime points. To calculate crime hotspots, the "Hotspot Analysis" tool in the Geographical Statistics toolbox was applied, using the Z-score method. This tool identifies clusters of statistically significant forest crime incidents .The results of the hotspot analysis were visualized, with areas of high crime density represented by a high Z-score and small P-values, indicating significant hotspots. Conversely, areas with low negative Z-scores and small P-values were classified as cold spots, representing areas of lower crime activity. The intensity of clustering was measured by the magnitude of the Z-score: higher positive Z-scores indicate stronger clustering, while Z-scores near zero suggest random distribution of incidents. For a significance level of 0.05 (95% confidence), Z-scores below -1.96 were classified as statistically insignificant, while those above 1.96 were considered statistically significant. Finally, additional steps were taken in Arc Map to refine the analysis and ensure the accuracy of the results, leading to the identification of key forest crime hotspots within the study area. Statistically important, for the comparison of a specific confidence values level range. For instance, if 0.05 level of significance (95 percent level of confidence), the "z" score is below -1.96. Statistically it is insignificantly classified also, when the z score is between 1.96 and above is said as factually significant. To finish this study, the other steps were performed in the Arc map Computer program.

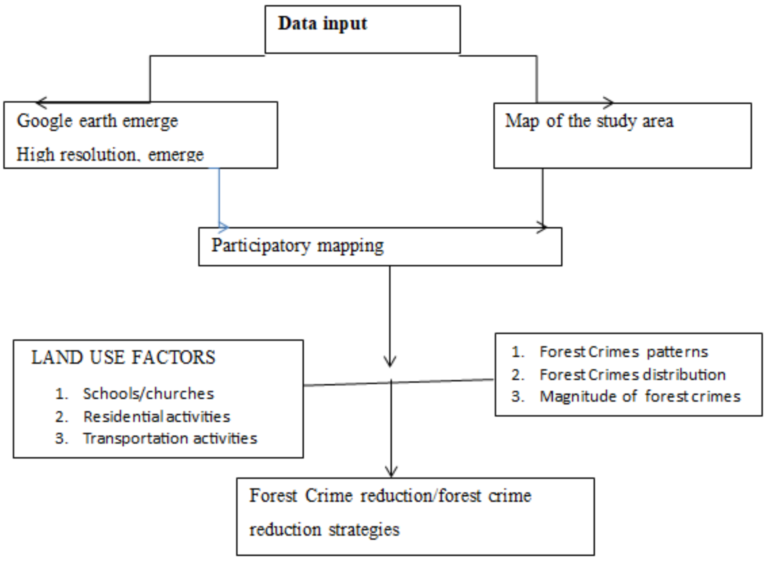

Figure 3: The forest management analytical Model

The overlaid GPS point data, with the sub wards shape file, then filled into an excel work sheet file and served as a comma-delaminate text file (CSV) configuration, uploaded into the Arc GIS and overlaid with sub-wards shape file to verify the response obtained from participatory mapping.

RESULTS AND DISCUSSION

The Mangrove Forests Distribution in the Area of Study

The observation of Mangrove Forests was carried out across several streets within the study area, including Mkunga Street, Shanga Street, Mto Ruvu Street, Dango Lakindu Street, Kijito Kamba Street, Batini Street, Kwamwarabu Street, and Bandari ya Kati Street. A variety of human activities were reported within these forested areas, including illegal gathering of forest resources, charcoal burning, land clearing, and encroachment for

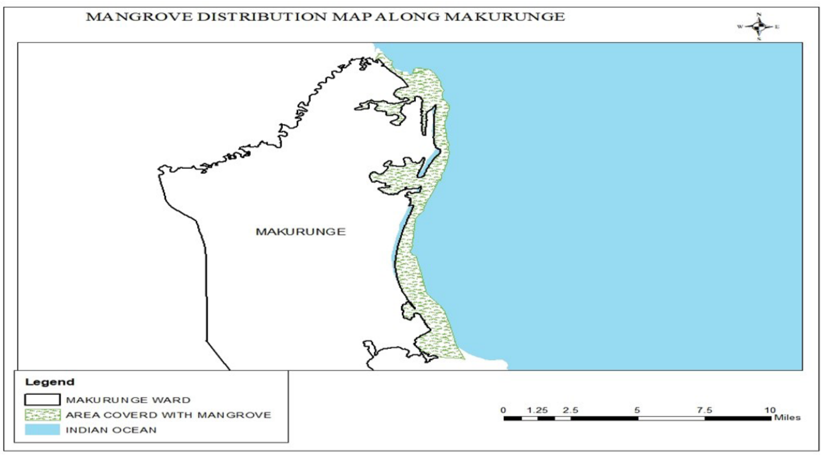

Figure 4: The Mangrove Forest distribution of along the Makurunge ward coastline

settlement, agriculture, tourism, and livestock grazing. Additionally, unlawful fishing activities have been noted, contributing to the degradation of these vital ecosystems. These activities are largely driven by the proximity of the surrounding communities, as highlighted by respondents from the Makurunge ward, who identified the close relationship between the local population and the mangrove forests. The mangrove forests in the Makurunge ward, located along the Indian Ocean coastline, are particularly vulnerable to these human pressures. The map below illustrates the distribution of these mangrove forests, highlighting their importance as both ecological and economic resources for local communities.

The Distribution of Kikoka (Terrestrial) Forest along the Area of Study

The Kikoka Forest Reserve spans two wards within the Bagamoyo District, namely Makurunge and Fukayosi, encompassing several villages and neighborhoods, including Relini, Vihagata, Mwana Senga, and Usigwa, as shown in the map extract below. In the map, the boundaries of Kikoka Forest are demarcated by green-colored lines, which outline the forested area. The total area covered by the Kikoka Forest Reserve is approximately 1,654 hectares, as recorded in field data collected in 2023. The surrounding areas of Kikoka Forest are heavily influenced by human activities, particularly those associated with illegal forest use. Reported activities include charcoal burning, timber harvesting, land encroachment for settlement and agricultural purposes, as well as illegal lumbering. These activities are largely driven by the proximity of the local communities, with respondents from both Fukayosi and Makurunge wards confirming the close interactions between forest areas and human settlements.

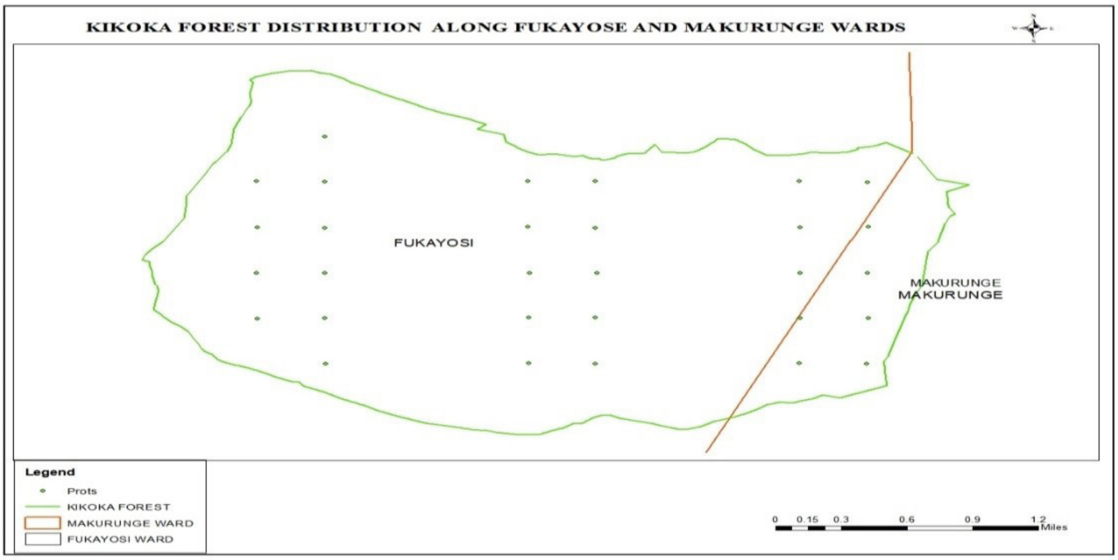

Figure 5: The distribution of Kikoka Forest around the Fukayosi and Makurunge wards

Table 1: The Distribution of Kikoka Forest table

Boundary	Name of forest	The Distribution	Predominant species
Fukayosi	-Koka forest	-Around reline strip area	-Riverine and miombo species
		Around manga strip area	
		Around usigwa strip area	
Maku Runge	-Kikoka forest	-Around kifunde strip area	-Riverine and miombo species
		Around the Gezaulole Street area	

Table 2: The tabulation of Distribution Forest in Makurunge ward and Fukayosi ward

Boundary (ward)	Forest Type	Distribution of Forest	Predominant species
Makurunge	-Miombo tree species and riverine forest vegetation	-Kifunde Geza ulole	- miombo and Riverine species
	-Mangrove forest	-Makurunge streets Viagata Relini Usage Mwanasenga	
Fukayosi	-Miombo tree species and riverine forest vegetation	-	-Mangrove Riverine and miombo species
	-Mangrove forest		-

Mapping of the Illegal Ports in the Research Area

The survey of unlawful ports in this study aimed to identify specific coastal locations requiring monitoring and regulatory control due to their association with illegal forest product transport. The exercise was conducted in collaboration with local stakeholders, specifically the Beach Management Units (BMUs) and the Village Natural Resource Management Committees (VNRCs) from Fukayosi and Makurunge wards, who served as primary informants and participants in the mapping process Participatory mapping (community mapping) was employed as the principal data collection method. Participants were provided with geo-referenced Google Earth imagery, which served as the base map for marking known illicit port locations. The imagery had been symmetrically processed and projected into the Arc 1960 Zone 37S coordinate reference system to align with the national mapping standard and ensure consistency with other geospatial datasets. Each participant was individually interviewed and asked to identify any known illegal ports after reviewing the reference map. Orientation landmarks such as rivers, coastal lines, roads, and settlement features were used to assist participants in spatially locating the ports. The participatory mapping approach ensured that local knowledge was accurately captured and spatially represented, enhancing the reliability of the dataset. Areas of Mkunga, Batini, and Chamamba were listed; it challenged the forest management since they transported the forest products including poles and fuel wood with the support of the listed illegal seaports to other areas like Zanzibar. By using the Global Positioning Systems, the researcher recorded the coordinates of the illegal ports area with as shown on the map extract underneath.

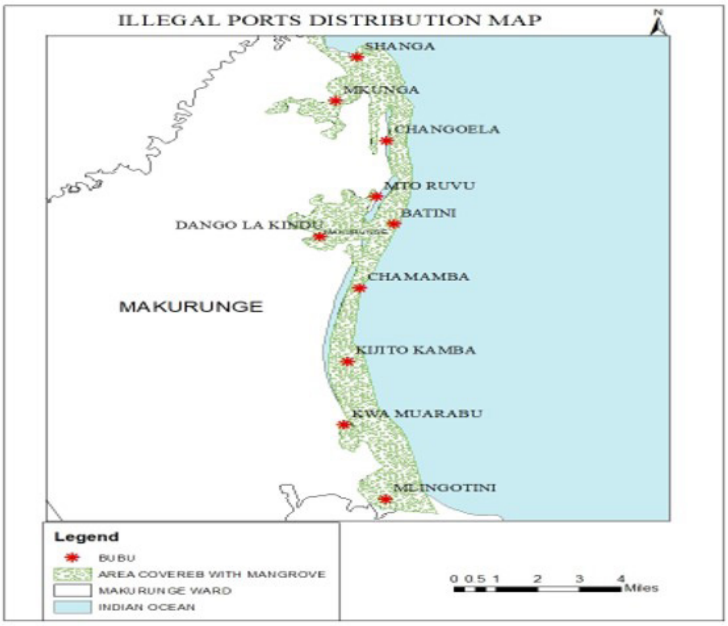

Figure 6: The distribution of illicit boatyards along the Makurunge coastline

The Location-Based Trend of the Forest Crimes Across the Research Area

As condemned in different literatures such as the 2002 forest act no .14 describes the forest offences including the human economic activities performed within a reserve area of forest without a legal license (authorization) from an authorized body. The human activities conducted are cutting of Tree, burning of Charcoal, harvesting of Timber, Agriculture, Settlement, Mining, Fishing, animal keeping and unpermitted Entering within a forest reserve area. Thus, this study part confers about the forest offences geographical trend in the Fukayose ward and Makurunge ward for ten years from the year 2003 to the year 2023. There have been the negative and positive presentation of forest changes from the official patrol reports and documents and several relevancies were verified by the participants from the area of the field. Participants used various referring records including their everyday documentation, reports and journals of district council that contained various information and public stories about of forest crimes along Fukayosi ward and Makurunge ward in Bagamoyo district and the Coastal region (PWANI)at large, this provided a critical room for the understanding of forest crimes along Fukayosi and Makurunge wards.

Table 3: The tabulation of the location -based trend of Forest offences in the Fukayosi ward and the Makurunge ward

Year	The Kikoka forest reserve	Mangrove forest	Total
2003-2005	129	63	192
2006-2008	102	78	180
2009-2011	99	84	183

2012-2014	70	99	169
2015-2017	44	139	183
2018-2020	29	144	173
2021-2023	11	151	162
SUM	486	758	1,242

As presented in the table above, data derived from various official documents indicate a clear trend in the decline of forest-related crimes within the Makurunge and Fukayosi wards, particularly in the Kikoka Forest Reserve. The analysis reveals a positive trajectory in forest crime reduction between the years 2003 and 2023. Specifically, between 2003 and 2005, a total of 129 forest offence cases were recorded. This number declined to 102 cases between 2006 and 2008, followed by a further reduction to 99 cases from 2009 to 2011. The downward trend continued with 70 cases recorded between 2012 and 2014, and subsequently, only 44 cases were reported during the 2015–2017 period. Between 2018 and 2020, the number of forest crime incidents further decreased to 29, and most notably, only 11 offences were recorded between 2021 and 2023.This consistent decline over the past two decades signifies a substantial improvement in forest governance and protection efforts within the Kikoka Forest Reserve. The findings suggest that the area has been gradually recovering and experiencing increased forest cover, which can be attributed to the implementation of strategic forest management interventions. These include the establishment of effective monitoring plans, enforcement of forest conservation laws, and active involvement of the Tanzania Forest Service Agency (TFS). A notable milestone was the enforcement operation conducted by TFS in 2015, which included significant banishments and restrictions within the forest reserve. The sustained decline in forest crimes demonstrates the positive outcomes of these interventions and underscores the critical role of institutional enforcement in achieving long-term forest conservation goals. above, from the year 2003, the Mangrove Forest along the Indian Ocean coast across the area of Makurunge ward witnessed the negative variations as per trend, indicates that between the year 2003 and 2005 the forest offences experienced were 63, then between 2006 to 2008 the area witnessed about 78 forest offence cases. Also, from 2009 to 2011 the forest crime increased too up to 84 incidents; also from 2012-2014 forest incidents witnessed 99. Between the year 2015 and 2017 the number of cases of the forest crimes affecting the forests of mangrove species raised to 139. furthermore, between the year 2018 to 2020 the crime cases increased to 144. Finally, from the year 2021 to 2023 the mangrove forest crimes increased contrary to the other years to 151 cases. For The Mangrove forests, the crimes increase contrary to the previous two decades and this may be because of the presence of illicit boat yards, this influences unpermitted exploitation and transportation of the products from the forest and extension of tourism activities including building of new hotels and settlement adjacent to the mangrove forest boundary. The activity that needs both intensive and extensive track purposively to undermine and solve issues of forest crimes increments.

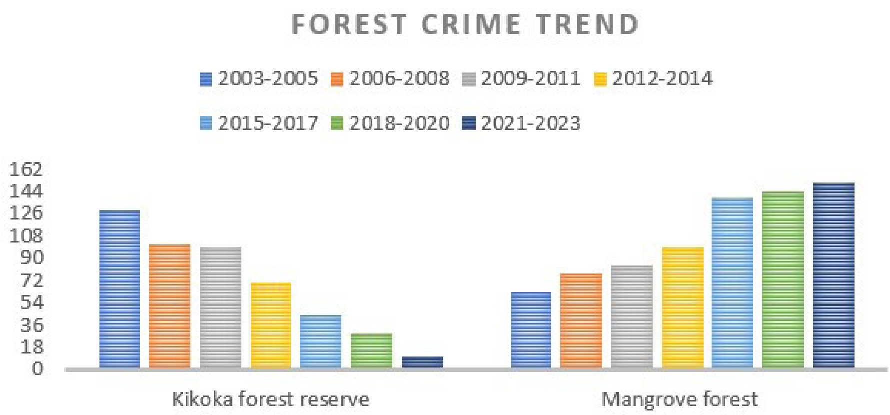

Figure 7: The forest crimes geographical trend along the Fukayosi ward and the Makurunge ward

Satellite imagery used in this study was obtained from the United States Geological Survey (USGS) Earth Explorer platform. A temporal scope of ten years, beginning from 2003, was considered for the analysis. Two datasets were utilized: a 2003 Landsat Thematic Mapper (TM) image and a 2023 high-resolution thematic map. Both images provided a spatial resolution of 30 meters by 30 meters, which is appropriate for detecting land cover changes over time. The 2003 Landsat image was selected to assess forest cover in the Makurunge and Fukayosi wards, while the 2023 imagery was employed to analyze recent forest cover dynamics in the same locations. In addition to standard-resolution data, higher spatial resolution imagery (i.e., finer than 30 meters) was also utilized to enhance the accuracy of forest cover analysis. Satellite imagery was critical for evaluating changes in forest ecosystems and has been widely applied in similar studies involving more complex landscapes than those of the Makurunge and Fukayosi wards (Basommi *et al.*, 2015; Acheampong *et al.*, 2018). To support the image classification and accuracy assessment, approximately 108 Geo-referenced checkpoints were collected using a Global Positioning System (GPS) receiver. These ground control points were used as training sites during supervised image classification. Additionally, a topographical map sheet from 2008 was incorporated to supplement the forest cover assessment, particularly in supporting the spatial analysis and management of forest resources in Bagamoyo District, with specific attention to the Makurunge and Fukayosi wards.

Table 4: Collected geographical data for forest cover changes detection

S/N	Type of Data	The Path	The Date of Acquisition
1.	Landsat 7 ETM+	166/064 & 166/065	2003
2	Landsat 8-9 OLI/TIRS	166/064	2013
3	Landsat 8-9 OLI/TIRS	166/064	2023

To facilitate effective visualization and analysis, a band combination process was carried out by integrating multiple Landsat satellite images into a single dataset. For each year analyzed, seven spectral bands from the respective Landsat datasets were combined using ArcGIS Desktop version 10.5. This step was essential for enhancing the interpretability of land cover features across the study period. Additionally, a mosaic operation was performed to merge individual raster datasets into a seamless image. This was necessary particularly for the 2003 imagery, which comprised scenes from different paths and rows. These were mosaicked to form a single continuous raster dataset that fully covered the study area. This data preparation ensured spatial continuity and completeness of the area under investigation. Subsequent to the mosaic process, image processing and projection were conducted. The datasets were clipped according to the defined boundaries of the study area to isolate relevant spatial information and minimize processing time for subsequent analysis shape file (Fukayosi and Makurunge wards). Likewise, image projection was performed to give images the actual reference system (projected coordinate system). The images used were projected into Arc1960 UTM Zone 37S. Lastly, Land Use/Land Cover Classification was done as a classification providing information on land cover and the types of human activity involved in the use of land. The classification helped on the assessment of impacts to the environment, as well as the latent alternative land uses. The sets of information were added to the Arc Map windows for the classification. So, with the use of Maximum Likelihood Classification, the seven classes of LULC were classified they are; Forest, Wetland, Water, Agriculture, Area with Buildings, Rangeland, and the open ground. shape file (Fukayosi and Makurunge wards). Likewise, image projection was performed to give images the actual reference system (projected coordinate system). The images used were projected into Arc1960 UTM Zone 37S Lastly, Land Use/Land Cover Classification was done as a classification providing information on land cover and the types of human activity involved in the use of land. The classification helped on the assessment of impacts to the environment, as well as the latent alternative land uses. The sets of information were added to the Arc Map windows for the classification. So, with the use of Maximum Likelihood Classification, the seven classes of LULC were classified they are; Forest, Wetland, Water, Agriculture, Area with Buildings, Rangeland, and the open ground Shape file (Fukayosi and Makurunge wards). Likewise, image projection was performed to give images the actual reference system (projected coordinate system). The images used were projected into Arc1960 UTM Zone 37S. Lastly, Land Use/Land Cover Classification was done as a classification providing information on land cover and the types of human activity involved in the use of land. The classification helped on the assessment of impacts to the environment, as well as the latent alternative land uses. The sets of information were added to the Arc Map windows for the classification. So, with the use of Maximum Likelihood Classification, the seven classes of LULC were classified they are; Forest, Wetland, Water, Agriculture, Area with Buildings, Rangeland, and the open ground.

Table 5: The Seven classes of LULC

N	LULC	illustration
1	Water	The waterlogged Areas throughout the year, may be not included among the temporary water areas (sporadic water or ephemeral water areas).
2.	Forest	The classification (clustering) of long (15 m or higher) and thick vegetation, naturally characterized with the thick - closed canopy.
3	Wetland	The Areas with any kind of vegetation and covered with water all over the year; the seasonally flooded area that includes grasslands, shrubs, and bare ground.
4	Agriculture	The artificial or Humans planted crops, grasses, and cereals that are not tree-like height.
5	Built Area	The Human-constructed infrastructures including vital roads and rail ways, also the large correspondent water-resistant structures such as the office buildings and household buildings (residential housing).

6	Bare Ground	The exposed surface Areas where either rock or soil is not covered with vegetation throughout the year; more over the large sand areas with no plants.
7	Rangeland	The homogeneous grass - covered open areas with less or no longer (plants) vegetation; wild cereals and grasses, a mix of small clusters of plants or single plants dispersed; scrub-filled clearings in the forests that are not taller than trees.

Using Land Use/Land Cover (LULC) prediction techniques, the MOLUSCE plugin was employed to project potential LULC changes for the year 2033. The analysis was conducted using version 3.0 of the QGIS MOLUSCE 22 plugin, applying the Artificial Neural Network (ANN) model—specifically the Multilayer Perceptron (MLP) approach. The resulting predictive map and associated outputs are presented as follows:

Table 6: Seven LULC (Ha) matrix table

N	C.name	2003	2013	2023	2033	Total
1	water	740.5	516.1	586.6	612.5	4911.3
3	Forest	27542.9	32953.7	23708	22988.7	214386.4
4	Wetland	808.5	380.7	305.31	345.6	3580.14
5	Agriculture	2350.4	4192.3	7464.1	8824	45661.66
6	Built areas	20.5	684.2	1288.4	1516.1	7018.39
7	Bare ground	10.8	58.25	33.2	7.1	218.05
8	Rangeland	57760	49847.45	55247.33	54438.84	434586.92
	Total	89233.6	88632.7	88632.94	88732.84	710362.86

The matrix table above shows the land use, From the year 2003 to 2023 at Makurunge and Fukayosi wards found in Bagamoyo district. The table displays that the forest changes with time from 2003 to 2023 due to different factors. The study identified seven major Land Use and Land Cover (LULC) classes in the Bagamoyo District, namely: water bodies, forest areas, wetlands, agricultural land, built-up areas, rangelands, and bare ground. Forecasts based on temporal geospatial analysis predict both partial and complete changes in land use across these categories from 2023 to 2033, particularly within the Fukayosi and Makurunge forest zones. In 2003, water bodies covered approximately 740.5 hectares. This coverage decreased to 516.1 hectares by 2013, before increasing again to 586.6 hectares in 2023. Projections suggest that by 2033, water bodies will expand further to approximately 612.5 hectares. Forest cover in the study area was estimated at 27,542.9 hectares in 2003. This increased to 32,953.7 hectares in 2013, indicating improved conservation efforts during that period. However, by 2023, forest cover had declined significantly to 23,708 hectares. The study predicts a continued decline to 22,988.7 hectares by 2033, potentially due to increasing human pressures and land use changes. Nevertheless, enforcement of forest protection laws in Fukayosi and Makurunge wards appears to have contributed to some level of forest preservation. Agricultural land use has shown a notable increase over the study period. In 2003, agricultural land occupied approximately 2,350.4 hectares. This expanded to 4,192.3 hectares in 2013 and further to 7,464.1 hectares by 2023. Projections estimate that agricultural land will extend to 8,824 hectares by 2033. This expansion is largely attributed to population growth and the consequent rise in demand for food and related agricultural resources. However, this trend is considered a negative factor in relation to forest conservation, as it contributes to the continued reduction of forest cover. Built-up areas have also experienced significant growth. In 2003, built environments covered only 20.5 hectares. This increased to 684.2 hectares in 2013 and further to 1,288.4 hectares in 2023. By 2033, it is projected that built-up areas will cover 1,516.1 hectares. This expansion correlates with the rising population, which drives the demand for both permanent and temporary human settlements. Bare ground—land without significant vegetation or use—was approximately 11 hectares in 2003, increased to 58.3 hectares in 2013, and then declined to 33.2 hectares in 2023. Forecasts suggest this will further reduce to 7.1 hectares by 2033. This reduction is likely due to the increased establishment of forest cover, rangeland, and water bodies, all of which reduce the extent of unused land. Rangeland, defined as land used for grazing and natural vegetation cover, is expected to increase considerably. By 2033, it is projected that rangeland will cover approximately 54,438.84 hectares, partly due to the emergence of new vegetation, albeit predominantly juvenile. Overall, the study concludes that changes in LULC patterns—driven by population growth, increasing food demand, settlement expansion, and forest product utilization—pose significant challenges to sustainable forest and land resource management in Bagamoyo District, particularly in the Fukayosi and Makurunge wards. These trends underscore the importance of integrated land use planning, enforcement of environmental regulations, and the promotion of sustainable livelihood alternatives.

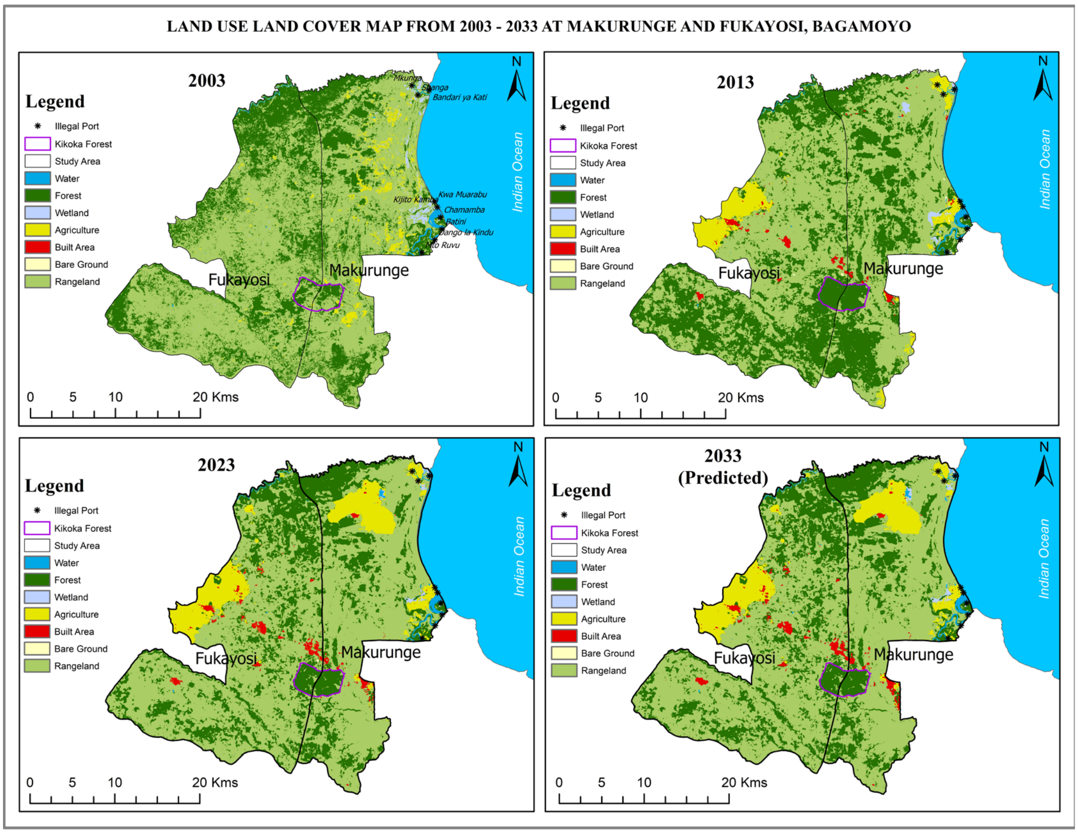

Figure 8: Land use land cover from 2003-2033 at Makurunge and Fukayose

The availability of wetland and drained areas in the study region is projected to be significantly influenced by the presence of the Ruvu River, which primarily sources its water from the Indian Ocean and serves as a major hydrological contributor. Additionally, the existence of unauthorized ports along the Indian Ocean coastline facilitates the illegal transportation of forest products. This activity is expected to intensify over time, and projections indicate that by the year 2033, the volume of forest products transported through these illicit channels will surpass that of previous years. As a consequence, the mangrove forest is increasingly transitioning into a high-risk degradation zone, as indicated by its classification within the "RED" (critical) category. Conversely, Kikoka Forest is forecasted to exhibit a positive vegetative trend, with projections indicating an increase in forest density. This improvement is attributed to effective protection measures implemented under various legal frameworks and environmental regulations.

CONCLUSION

The findings of this study confirm that forested areas within the study region are adversely affected by forest-related criminal activities. The study aimed to explore strategies for mitigating these crimes through the application of geospatial techniques. Using spatial analysis, crime-prone forest zones were delineated, and hotspot areas were successfully identified. The study further established that socioeconomic factors significantly influence individuals' involvement in forest crimes, often as a means of economic survival. Key contributing factors include employment status, educational attainment, and income level. Among these, the unemployment rate emerged as the most influential determinant in the decision to engage in forest-related criminal behavior. Moreover, the study demonstrated the critical role of cartographic techniques in supporting forest crime prevention and management. These techniques proved effective in spatially visualizing areas of high criminal activity, thereby enabling enforcement agencies to take targeted and evidence-based interventions. The results underscore the necessity for enforcement bodies to adopt proactive measures informed by the spatial distribution of criminal activities and their underlying drivers. Finally, the study recommends incorporating community stakeholders into policy formulation processes. Given their localized knowledge and lived experiences regarding forest crime incidents and affected locations, community members can provide valuable insights that enhance the relevance and efficacy of forest crime mitigation strategies.

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