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Spatial-Temporal Patterns of Mangrove Forest Change in Zanzibar: A Case Study of Magharibi 'B' and Kati Districts in Unguja, Tanzania

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Abstract:
Climate change and variability have been affecting marine biodiversity, including the mangroves, which have numerous advantages for the ocean and human life. For instance, the mangrove habitats at Magharibi B and Kati Unguja have been highly impacted by both human and climate factors. As such, the communities living in these areas need a thorough understanding of the importance of this habitat for their coastal life. The study was conducted to determine the spatial-temporal patterns of mangrove forest changes in Zanzibar, where mangrove forests in three villages, namely Kisakasaka, Fuoni Kibondeni, and Kibele, were investigated. The change detection approach using satellite images from different years was employed for analysis, and interviews and questionnaires were used for ground truthing. The study involved 373 household heads who were obtained using purposive and simple random sampling methods. The primary data-gathering approaches were employed. The results revealed that in the year 2000, dramatic changes in mangroves started to be observed. From 1990 to 2020, forest changes were further observed using satellite photos. As for the respondents' responses, the findings show that 73% of respondents believe that mangrove forests are declining. Also, the study revealed that more than 62.5% of all respondents experienced extreme changes in mangroves between 2000 and 2010. In addition, people's perceptions revealed that the mangrove forest was very large before 2000. Apart from the observed forest decline, the study showed that the main causes leading to changes in mangroves were overpopulation, lack of alternate sources of income, poor management, and widespread clearing of mangroves for charcoal, firewood, and construction materials. The study concludes that the community's reliance on the forest is in jeopardy and that the mangrove forest's transformation has had a significant impact on the community's livelihood. Hence, the study recommends revitalizing the forest, regeneration and rehabilitation, and establishing adequate structures. Also, mangrove preservation projects and departments should conduct extensive community mobilization on effective ways to have alternative socio-economic livelihoods as an adaptation mechanism towards relying on mangrove forests.

Keywords: *Spatial-temporal patterns, mangrove forest*

1. Introduction

Mangrove ecosystems are among the most significant coastal habitats based on their unique ecological functions, socio-economic values, and beliefs in indigenous communities and nations (FAO, 2005). Mangrove ecosystems are well recognized for their ability to provide all types of ecosystem services, from provisioning to supporting services (Atkinson *et al.,* 2016; Afonso *et al.,* 2021; Nyangoko *et al.,* 2021). They provide services like building materials, timber, fuel wood, charcoal, coastal protection, spiritual values, and nursery grounds for fish, erosion control, and prevention of salt-water intrusion and, most importantly, they play an important role in regulating climate as they store a large amount of carbon compared to other terrestrial forests (Atkinson *et al.,* 2016; Afonso *et al.,* 2021; Nyangoko *et al.,* 2021). Mangrove services are commonly dominant in Asia and Africa, where more than 60% of all mangroves are found (Giri *et al.,* 2011). A substantial amount of deforestation and degradation has affected mangroves, which occupied 20,100,000 hectares of the world's coastline in 2002, according to Giri et al.; 2015. These forests are more prone to natural and human-induced threats, including sea level rise, salt-water intrusion and sedimentation. Mangrove clearance is considered another threat due to the massive demand on humans to secure livelihoods, such as the establishment of aquaculture along mangrove areas, expansion of agricultural land toward coastal zones, and overharvesting (Islam *et al.,* 2014).

In African countries, mangroves have been subjected to massive stresses and threats for the past decades, with great losses of over 20-30% (Armah *et al.,* 2009). Mangrove ecosystems are also faced with several threats, which are mostly caused by anthropogenic forces like deforestation, urbanization, urban infrastructural development, quarrying, salt and sand extraction, pollution from industries, agro-industrial chemicals, petroleum and gas exploitation, and growth

(Feka & Ajonina, 2011). Nigeria has the largest mangrove forest in Africa, providing good breeding and nursery grounds for many important fish and shellfish species (Armah *et al.,* 2009).

In Eastern Africa, the main causes of mangrove degradation are mainly associated with population increase, poor governance, economic pressure in the rural and urban centres and unequal distribution of resources (Ajonina *et al.,* 2018). Countries like Kenya have benefited a lot from the services provided by mangrove ecosystems, such as energy sources, medical purposes, and support for coastal communities to sustain their daily lives (Mirera, 2007). Although mangroves support the livelihood of the community, these forests are facing threats due to population pressure, pollution from oil spills, increasing industrial pollution, woodchip production, aquaculture, housing, and firewood, among others (Mirera, 2007).

In Tanzania, mangrove ecosystem change has been caused by climatic stressors like pest infestation, desiccation due to rising sea surface temperature, and increased sedimentation. Also, non-climatic stressors, which include poor management of mangrove harvest for firewood, charcoal-making, building poles, boat-making, and illegal commercial logging, have impoverished the mangrove ecosystem (FAO, 2005; Mwita *et al.,* 2014).

In Zanzibar, the mangrove ecosystem has been largely supporting the livelihood of communities directly and indirectly, but it has been facing human threats, including exploitation of its products since the eighteenth century when mangrove wood was a precious resource that the Sultan of Zanzibar harvested (Mchenga & Ali, 2015). Due to that, the forests have been subjected to enormous pressures and threats within the last few decades (Khatib, 2010; Islam & Abdalla, 2014; Mchenga & Ali, 2017). Overexploitation of mangrove resources has been reported in many areas of Zanzibar Island. This has been attributed to various factors such as salt production, fuel wood supply, the use of mangroves as construction and building poles, and urban development. However, anthropogenic factors are not the only causes of mangrove change, as there are natural processes that are linked to mangrove change and reduction in Zanzibar, like coastal erosion due to sea level rise and temperature change. Therefore, this paper intends to observe the spatial and temporal changes of mangrove forests.

2. Materials and Methods

2.1. Study Area

The study was conducted in West B and central districts, and the study areas are Kisakasaka and Fuoni Kibondeni, located in West 'B' District, whereas Kibele is in Central District (Figure 1). These areas were purposively selected based on their high rates of mangrove forest deforestation. The geographical coordinates of the study sites are as follows: 6° 14' 13" S and 39° 17' 43" E for Kisakasaka, 6° 13' 0" S and 39° 16' 59" E for Fuoni Kibondeni, and 6°13 S and 39°19 E for Kibele, respectively. Moreover, all the selected areas are mangrove forests of Menai Bay's intertidal zone. Also, these areas are characterized by the interconnected features of mangroves, which create the home of a wide range of natives and visiting biotic and abiotic organisms. These organisms maintain mangroves' ecological functions in the areas. However, since the early 90s, due to the tremendous disappearance of mangroves in the area (Mchenga & Ali, 2014), the ecological functioning of mangroves in these areas has declined significantly.

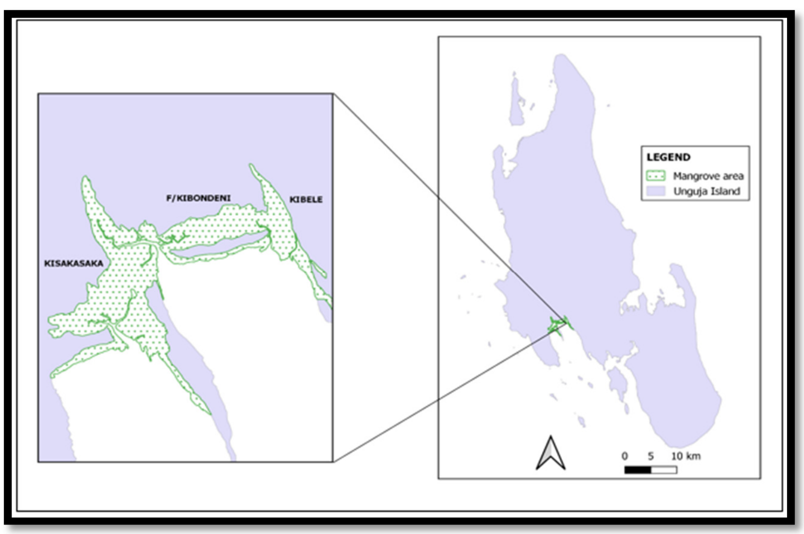

Figure 1: The Location of the Study Areas
Source: Modified GIS Layer of Unguja

2.2. Sampling Approach and Data Collection Methods

The population distribution over the study area is 3246, 1843, and 1755 households for Kibele, Kisakasaka, and Fuoni Kibondeni, respectively (Census, 2022). Studies, including those conducted by Nchimbi and Lyimo (2019), have noted that most communities surrounding the mangrove forest rely heavily on mangrove extraction to sustain their livelihoods.

Based on the population size of the three villages and using the Slovin formula (1960), a total of 373 households were selected as the sample size. A systematic sampling procedure was used for the household representatives from each village. This process guarantees that sampled participants from the total number of households are selected according to a random starting point and a fixed (periodic interval). The reason behind selecting this method was to help avoid repetition of the respondents, reduce bias, and be very conducive to covering a wide area.
The study sample size was obtained using Slovin's (1960) formula.

$$\boldsymbol{n} = \frac{\boldsymbol{N}}{\mathbf{1} + \mathbf{N}(\boldsymbol{e}^{\mathbf{2}})}$$

Where:
n = sample size,
N = population size for households in the sampled three villages, and
e = the level of precision ($p \leq 0.05$).
n = 5672 / [1 + 5672(0.05^2)]
n = 5672 / 15.18
n=373

Cochran's (1977) proportional formula was utilized to determine the proportion of households in each village based on a sample size of 373 out of 5672 households. As a result, the number of homes in each village was determined as indicated below:

$$\boldsymbol{nh} = \frac{\boldsymbol{Nh}}{\boldsymbol{N}}\boldsymbol{n}$$

Where:
Nh = proportional households' sample from each village,
N = the total number of households from each village,
n = total number of households from all three villages.
Therefore, the calculated size in each village is shown hereunder:

$$Kisakasaka = \frac{1843}{5672}x373 = 122$$
$$Fuoni\ Kibondeni = \frac{1755}{5672}x373 = 115$$
$$Kibele\ = \frac{2074}{5672}x373 = 136$$

The primary data were collected through household surveys, interviews, and Satellite images. The satellite images were used to examine the changes in mangrove forest coverage at Kisakasaka, Fuoni Kibondeni and Kibele villages for the past thirty years, from 1990 to 2020, by the interval of five years. i.e. 1990, 1995, 2000, 2005, 2010, 2015 and 2020. These were downloaded from the USGS (U.S Geological Survey) Earth Explorer, where the percentage of cloud cover was 30%. The five-year interval was chosen since it provided a broader picture of the changes in time series that occurred in the area during the period of 30 years. This procedure is consistent with the procedure used by Mohamed et al. (2023) and Saunders et al. (2010).

2.3. Data Analysis, Processing and Presentation

The data gathered from quantitative data were coded using Statistical Package for Social Sciences (SPSS) software, and descriptive statistical analysis was performed. The data were then tabulated to reduce explanatory and descriptive statements. In addition, Microsoft Excel Office 2019 was used to draw graphs and charts for more illustrations.

The satellite data from the Landsat thematic mapper (30m spatial resolution) covers the period from 1990 to 2020, and seven images were acquired from USGS. Due to atmospheric effects and sensor error, extra pre-processing of the data was done before performing actual processing and analysis (satellite images). The change was detected using remote sensing and geographic information systems under a supervised classification approach. The selection of satellite images was very important to provide the capabilities and meet the requirements of this research (Table 1).

Satellite Image	Data and Date of Requisition	Resolution
Landsat 8	LC08_L2SP_166064_20200222_20200822_02_T1	30m
Landsat 8	LC08_L2SP_166064_20150616_20200909_02_T1	30m
Landsat 7	LE07_L1TP_166064_20100423_20200911_02_T1	30m
Landsat 7	LE07_L1TP_166064_20050423_20200911_02_T1	30m
Landsat 7	LE07_L1TP_166064_20000513_20200918_02_T1	30m
Landsat 5	LT05_L1TP_166064_19950929_20200912_02_T1	30m
Landsat 4	LT04_L1TP_166064_19900211_20200916_02_T1	30m

Table 1: Characteristics of Satellite Images Used in This Research
Source: Glovis Landsat Portal USGS Earth Explorer Platform

In order to provide sufficient analysis, image processing involves band ratio image creation, noise reduction, geometric and radiometric corrections, and image enhancement. To produce a band ratio image, the spectral values were spread from one band to another band in a satellite image. This ratio helps enhance certain features or characteristics in the image. For example, the ratio of near-infrared (NIR) to red bands can highlight vegetation health and density. Band ratio images are important in satellite image analysis because they can provide valuable information about specific land cover types, such as vegetation, water bodies, or urban areas. They help in identifying and mapping different features more effectively, aiding in tasks like land cover classification, change detection, and environmental monitoring.

Even though the Landsat 8 and 7 images were downloaded at a level 2 processing, which corrected the image in terms of both geometry and radiometry, including corrections for atmospheric effects, some images needed further pre-processing to make sure the images were in good quality for analysis. It is important to note that the images at the particular processing level (Level 2 for Landsat, for example) are currently offered as "ready products," which means that users do not need to perform any pre-processing in order to access these datasets directly from earth data engines like the USGS Earth Explorer platform.

For the image analysis over the study areas, polygons of the forest area were created, and they were then used to define the areas of mangrove forests in the pre-processed Landsat images. Using the shape files of these polygons, the images were clipped to extract the defined mangrove-covered areas with their boundaries before the image classification was undertaken using ArcGIS 10.4 (Arc map version 10.4).

Also, the supervised classification approach, Maximum likelihood classification, was performed to classify the satellite image. This classifier was used because it helps to determine the most likely class for each pixel in an image based on statistical analysis. By considering the probability distribution of each class, it can accurately classify pixels and identify different land cover types in satellite images, which is useful for various applications like land use planning and environmental monitoring. It is also used since it works by comparing the statistical characteristics of different classes to determine the most likely class for each pixel in an image. It calculates the probability of a pixel belonging to each class based on its spectral values and the probability distribution of each class. The class with the highest probability was assigned to the pixel. This process is repeated for all pixels in the image, resulting in a classified image where each pixel is assigned to a specific class. It is a powerful technique that helps in accurately mapping and analyzing different land cover types in satellite images. It tells us how likely it is for a pixel with certain spectral values to belong to a specific class. The probability distribution is usually represented by a mathematical function, such as a Gaussian distribution, that describes the likelihood of different spectral values occurring within a class. This helps in accurately classifying the pixels in an image and identifying different land cover types.

Field observation was done to obtain true data on the study area. In this approach, all clusters were portrayed through the instructional class. In preparing the process, a researcher identifies the features of the class by detecting sample areas through ground truth collected from the Google Earth engine. This has been characterized as the method for utilizing tests of known personality (for example, pixels previously assigned to instructive classes) and characterizing pixels of obscure personality (for example, to appoint unclassified pixels to one of the few instructive classes) (Weiss & Walsh, 2009). In this study, the images were classified into four classes which are mangrove, bare land, water body and other vegetation.

3. Results and Discussion

The period from 1990 to 2020 was used to measure the degree to which the mangrove forest changed for this study. The information in this section was gathered using satellite imagery to identify changes in the mangrove forest's location and timing. The results from the satellite image were verified from the field by asking neighbourhood members about the changes in mangrove trends during the previous 30 years (1990 to 2020).

The findings of the study based on satellite images revealed that during 1990, the forest area contained 418ha, of which mangroves comprised 362ha (87%). Furthermore, 4ha (1%) were covered by other plants, 31ha (7%) by bare land, and 21ha (5%) by water bodies (Figure 2A). Specifically, in 1995, mangroves covered 353ha (84%), other vegetation covered 4ha (1%), bare ground comprised 30ha (7%), and water bodies covered 34ha (8%) (Figure 2B).

In addition, the results from image analysis in 2000 showed that there were 332ha of mangroves (78%), 5 ha of other plants (1%), 62ha of barren land(15%), and 27 ha (6%) of water bodies (Figure 2C). In 2005, there were 329ha (79%) of mangroves, 3ha (1%) of other vegetation, 64 ha (15%) of barren land, and 23 ha (5%) of water bodies (Figure 2D).

The study also discovered that the area of forest covered by mangroves declined by 10ha between 2010 and 2015. The results discovered that in 2010, mangroves had total coverage of 317ha (75%); however, in 2015, mangroves only covered 307ha (73%), showing a 10ha (31%) decline in mangrove coverage. The survey also discovered that the area covered by other plants remained steady between 2010 and 2015, whereas bare land expanded by 8ha in 2015. As indicated in figures 2E and 2F, the area covered by mangroves declined while that containing bare land increased throughout this time period.

Moreover, the observation indicated that, in 2020, the forest had 302ha (71%), other vegetation covered 4ha (1%), bare land was 92ha (22%), and water bodies constituted 27ha (6%) as shown in figure 2G. Figures 2F and 2G show that the number of mangroves in the forest area further decreased from 362ha to 302ha, meaning that 5ha of mangroves were lost between 2015 and 2020. The continuous cutting of mangroves resulted in the increase of the size of the bare land from 84ha to 92ha.

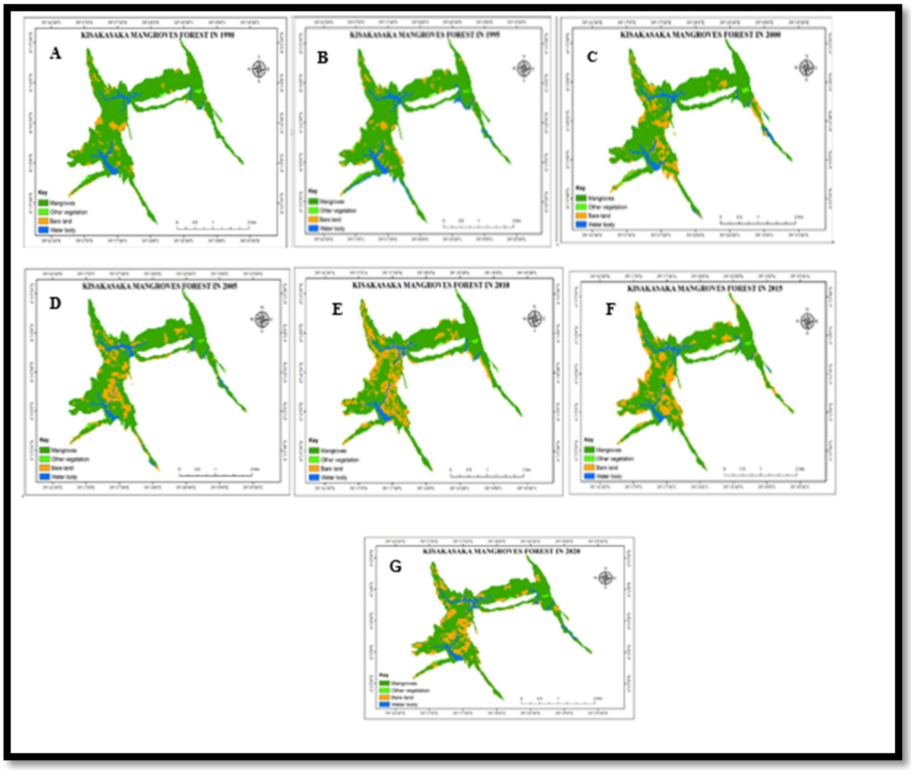

Figure 2: Supervised Classification That Shows the Status Mangroves 1990-2020

On the other side, the results suggest that the number of mangroves decreased significantly between 1990 and 2020, indicating the increase in bare land extent. This indicates that the rate of mangrove cutting is increasing. Table 2 summarizes the loss and gain in mangrove and bareland areas between 1990 and 2020.

Year	1990	1995	2000	2005	2010	2015	2020	Total
MANGROVES	362	353	332	329	317	307	302	2302
	9	0	0	0	0	0	0	9
		-6	0	0	0	0	0	-6
			-21	0	0	0	0	-21
				-3	0	0	0	-3
					-13	0	0	-13
						-10	0	-10
							-5	-5
Total								-49
Year	**1990**	**1995**	**2000**	**2005**	**2010**	**2015**	**2020**	**Total**
BARE LAND	31	30	62	64	77	84	92	440
	1	0	0	0	0	0	0	1
		-1	0	0	0	0	0	-1
			32	0	0	0	0	32
				2	0	0	0	2
					13	0	0	13
						7	0	7
							8	8
Total								60
Key								
(orange)	**Initial State**							
(blue)	**Gain**							
(green)	**Loss**							

Table 2: Summary of the Image's Classification with Gain and Loss of Mangroves and Bare Land from 1990-2020
Source: Field Data through Arcgis Software 10.4

These findings are further illustrated in the chart, which shows mangrove forest gain and loss among the variables in figure 3.

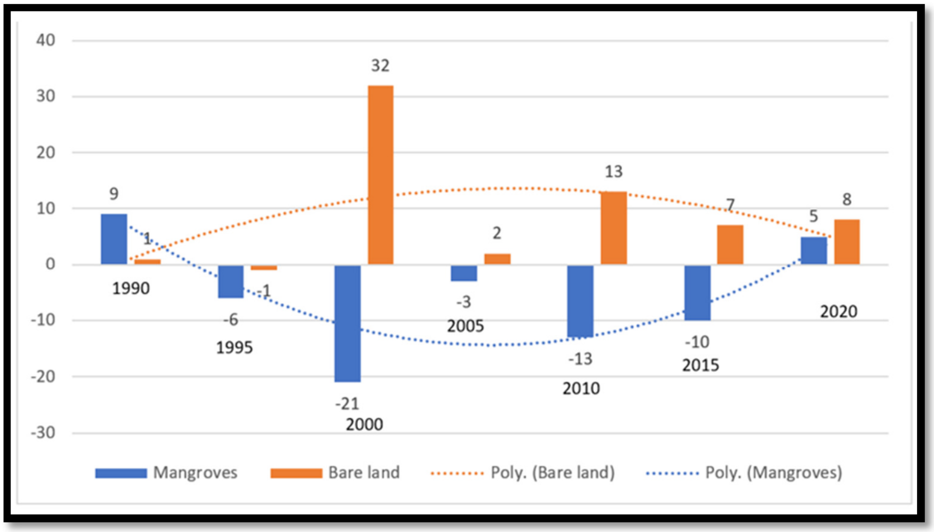

Figure 3: Gain and Loss of Mangroves and Bare Land from 1990-2020
Source: Field Data Analyzed Through Arcgis Software 10.4

The analysis from the satellite image revealed that between 1990 and 2020, in 2000, there was much cutting of mangrove forest, and this period was the end of the community-based natural resource management project that was established by the government to conserve the forest for it is indeed evident that after the completion of the projects people continue cutting down the forest for their daily income, which in return caused increasing of bare land area.

3.1. Community Perceptions of the Trend of Mangrove Changes

More information was gathered from the community regarding the degree of mangrove changes based on their observations between 1990 and 2020, apart from the spatial and temporal change from satellite images. According to the findings, 236 (63.3%) of the 373 respondents reported that the changes in the mangrove forest were very high, 2.7% said that the changes were low or very low, and 5.6% said that they were moderate. In general, a majority of the participants (60%) felt that mangroves have undergone significant changes. The primary source of these changes is the rise in mangrove demand that began a few years ago (Figure 3).

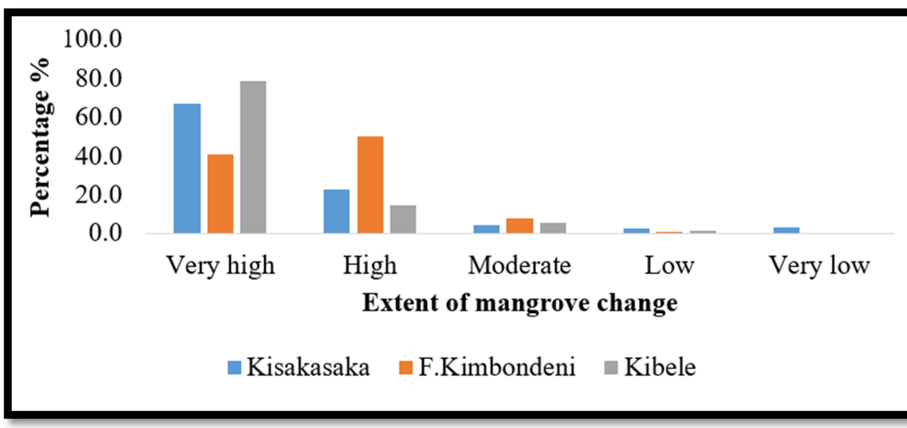

Figure 4: The Extent of Mangrove Changes
Source: Field Survey, 2023

The study also revealed that respondents interviewed in all three villages concur that there is a high decline in the number of mangroves due to overdependence on mangrove resources. A 50-years-old interviewee from Kisakasaka added:

> *"The mangroves have decreased a lot. They have been cut down for ages and ages, and until now, they are still being cut down. In this period, more and more mangroves are being cut down. It is an undeniable fact that the mangroves have decreased to a large extent."*

This means that the community members are aware of the situation facing mangrove forests. They know that they are declining at a very high rate and that a very large area has been cleared over the past few years. The same results obtained from Haji (2013) found that the mangrove forest in the Bwejuu area is in bad condition with all signs of diminishing.

The findings on people's perceptions of current mangrove coverage show that 72.9% of 373 respondents believe that mangroves are currently decreasing, 21.7% believe they are fluctuating, 4.3% believe they have seen no changes, and only a few (1.1%) believe the size of the mangrove forest is increasing. In general, these findings imply that mangrove forests are declining, as 72.9% of respondents indicated. Furthermore, the study's findings show that 279 (74.8%) respondents thought the mangrove forests were in poor condition, while only one (1) respondent (0.3%) said that they were in good shape. However, 93 (24.9%) indicated that they were lightly damaged. According to the findings, participants from all villages, as indicated in table 3, believed that the quantity of mangroves is declining and that they are now in poor condition.

	Kisakasaka		**Fuoni Kibondeni**		**Kibele**	
	Frequency	%	Frequency	%	Frequency	%
Mangrove Status						
Decreasing	92	75.4	88	76.5	92	67.6
Fluctuating	22	18.0	24	20.9	35	25.7
The same	6	4.9	3	2.6	7	5.1
Increasing	2	1.6	-	-	2	1.5
Total	122	100.0	115	100.0		
Mangrove Forest Condition						
Damaged	90	73.8	79	68.7	110	80.9
Lightly damaged	31	25.4	36	31.3	26	19.1
Good	1	.8	-	-	-	-
Total	122	100.0	115	100.0	136	100.0

Table 3: Status and Condition of the Mangrove Forest
Source: Field Survey, 2023

During the interview session, one of the interviewees from Kisakasaka was quoted saying:

"...In the past, the mangrove forest was very huge, and the villagers depended on the forest for various activities of life, but every day, as the uses and demand increase, the forests have been shrinking more and more..."

The findings of the current status of mangrove forests based on the residential period show that many respondents (72.9%) indicated that the mangrove forests are decreasing, but 21.7% indicated that the forests are fluctuating. Moreover, 4.2% said that it has not changed, while very few indicated that it is increasing (Figure 5).

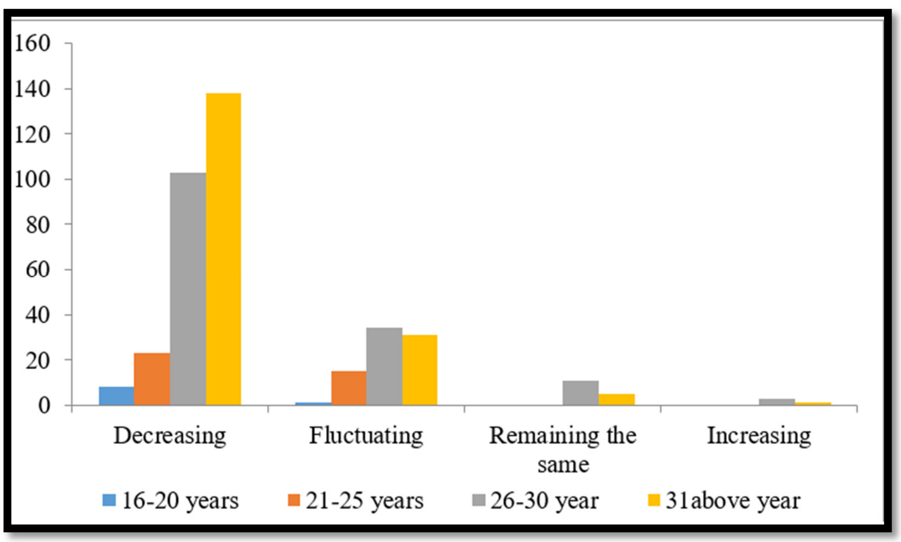

Figure 5: The Current Status of Mangrove by Residence
Sources: Field Survey, 2023

The study results are supported by Saunders and Mohammed (2008), who found that the forest was in poor or very poor condition, and its usefulness as a source of livelihood has vastly diminished over the past years. The same was reported by Lessons, Pezzuti and Orchard (n.d.), who found that in Brazil, Zanzibar and Vietnam, the state of mangroves has generally declined. It was further reported that in Dukuh, Indonesia, there was a large area of mangrove forest, but the forest has been declining rapidly (Science, n.d.). Haji (2013) revealed that the mangrove forest in Bwejuu village was not in good condition because of the lack of employment, which forced the local community to engage in mangrove cutting as an alternative way of getting employment.

Moreover, the study indicated that mangrove forests started experiencing extreme changes and problems from 1990 to 2020. The period was divided into three phases, namely 1990 – 2000, 2000 - 2010 and 2010 - 2020. The findings show that out of 373 respondents, 33.8% said the changes took place between 1990 and 2000, 62.5% said they started experiencing the changes between 2000 and 2010, and 3.8% said the changes took place between 2010 and 2020. This implies that more than 62.5% of all participants responded that mangroves experienced extreme changes during the period between 2000-2010. These changes are attributed to rapid population growth as people were attracted by good social services offered in the area. The population growth caused an increase in the demand for resources from mangroves. Very few participants mentioned that they had started experiencing the changes during the period between 2010-2020.

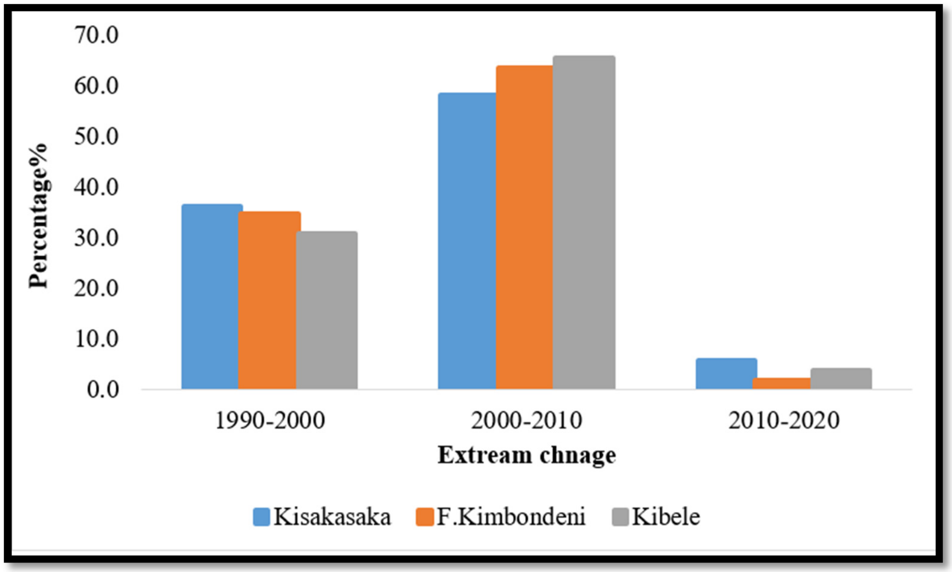

Figure 6: Period of Extreme Changes
Sources: Field Survey, 2023

During an interview session, a 60-year-old informant who has lived in Kisakasaka village for all his life described the changes as follows:

> *"We use mangroves to support our daily lives, and in the past, there were only a few people in our villages surrounding these forests. Despite having a small number, mangroves were used more by people outside the area. In the 1990s, the decline of mangroves was not very great, but from the year 2000, that's when the changes started to be big, and until now, the situation has not changed. This is due to the increase in the consumption outside and inside the villages."*

The results of this study are consistent with Saunders and Mohammed (2008) who found that mangrove deforestation in Zanzibar has increased dramatically. They further reported that the overall condition of the forest has deteriorated for the past 5–6 years. Similarly, Sarker (2012) indicated that in 2000, the community believed that the overall condition of the forest had deteriorated. Moreover, Mohamed, Adam and Jackson (2023) observed that Chwaka and Minai bays are experiencing a rapid decrease in mangrove coverage despite being under the conservation area. They add that the deterioration was extreme in the 2000s.

4. Conclusion and Recommendations

The study findings reveal that the amount of the mangrove forest has been declining dramatically in all three locations, particularly after 2000. Other portions of the forest are now bare due to the continuous cutting of the mangrove area, which led to the change in its coverage. Between 1990 and 2020, the total area of bare land rose by 68ha (34%). Kisakasaka, among the three analyzed locations, is experiencing a more severe reduction in mangroves than the other two. This appears to imply that major regeneration is taking place in the other two locations, notably Kibele and Fuoni Kibondeni. According to the results, mangrove regeneration should be done in all barren places. This should be done in all locations that were once covered by mangroves but are now barren. Given that local communities are the primary victims of the shift, the government they are responsible for addressing this. Regeneration will contribute to improving or returning the forest to its natural state; also, since the community is over-relying on mangrove forests for their livelihoods, it is better for the people to find other alternative sources of income so that the mangroves are used sustainably**.**

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