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An Integrated GIS Method – The Influence of Human Activities on Shoreline Change in Western Indian Small Island States: A Two Centuries Analysis of Urban West Unguja - Zanzibar Shoreline

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ABSTRACT

Purpose: Urban areas have a high impact on shoreline changes that are more influenced by human activities rather than natural factors, together with hard structural mitigation and management, which are more practiced compared to other areas. This paper describes shoreline changes of small islands specifically; the shoreline of Urban West of Unguja Island in Zanzibar United Republic of Tanzania. This island has been changed for 174 years in different stages due to human activities including; reclamation of Darajani creek, port expansion at Malindi, Mtoni beach nourishment, sewer and stormwater channeling at Kilimani, construction of walls, groins, jetties, etc.

Methodology: The study uses an integrated method to analyze and detect changes using a sketch plan survey map of 1846 and 1892, a topographic map of 1907 and 1987, an aerial photo of 2004, Landsat images, and google images of 2019 and 2020. These maps were carefully georeferenced with latitude and longitudes, digitized using ArcGIS and demarcated along the study area supported with ground truth observation to analyze the coastal shoreline changes.

Findings: The results show that the area experiences more accretion rather than retreat, integrated analysis and projections of the overall accretion and retreat for 174 years is 1,527,693.85 m^2 (1.53 km^2) and -936,135.48 m^2 (-0.94 km) receptively. The average accretion of land from 1846 to 2020 is 8,779.85m^2/yr. (0.0088 km^2/yr.) and retreat is -5,380.09m^2/yr. (-0.0054 km^2/yr.). A major accretion was observed and detected during the early 1900s to late 1987 which were major land transformation while other minor development activities were between 2010 to 2020. Sea walls, groins, beach nourishment, mangroves, barrier islands, and islets are major management practices of the shoreline which show a positive impact.

Recommendations: The study finds it more appropriate to use multi datasets as an integrated method to analyze long-term coastal shoreline changes especially when there is limited data.

Keywords: *Human activities, shoreline changes, Accretion, Retreat, Urban management, Zanzibar*

1. INTRODUCTION

Coastal zones especially small islands are places where many people would like to visit, invest and enjoy, thus why human major projects have been developed, small island areas, and ecosystem services are among the major economic driving factors [1]–[3] for development. In many countries, cities are allocated along the coast [4] which are the most populated places in the world holding high population density [5]. Historically, coastal zones were most used before the invention and advancement of space and air transport development. Thus, navigation along ocean and rivers were the most transportation means [6] which influenced the development of mega projects that are witnessed nowadays in many countries; such as port & harbor development, towns [7] and entertainment like tourism development [8]. Due to these development projects, tremendous changes along the coast become vulnerable to flooding due to climate change impacts such as sea level rise [8], [9] including the emergence and submergence of coralline islands.

Although coral and limestone islands have natural protection along the shore, the continuous wave processes over a long time, sea-level rise, monsoon winds, and other human activities like tourism influence the dynamic process of either accretion or retreat/erosion [8], [11], [12]. On one side it could be considered social and economic development [3] however, on another side, there are many impacts on ecology and environment [5], [13], [14] due to the anthropogenic. The shoreline of Small Island States has been originally changing over time like any other coast however when there is over interaction with human activities causes excess use of resources to interfere with the shoreline systems and processes [13], [15].

The general results in Urban West of Unguja Zanzibar shoreline show more accretion rather than retreat, the situation has been associated with major reclamation, especially at Darajani, Mnazi Mmoja, and Malindi port extension, as well as beach nourishments at Mtoni due to the hotel and mariner development. Also, it has been revealed that five major types of mitigation and management measures that influence to reduce retreat are; mangroves, sea walls, groins, barrier islets, inlets, and beach nourishment, even though the hard structural measures like groins and sea walls are helpful. They also exacerbate retreat in adjacent sides which luck such management practices. The experience shows that once the decision of construction of walls, jetties, and groins in urban areas should be entirely distributed along the shoreline or a small part of urban forest mangroves buffer should be maintained as a control measure, otherwise the adjacent sides will suffocate from severe erosion or retreat. This paper analyzes how human activities influence the transformation of shorelines and to what extent the long-term shoreline changes of Islands and urban areas have been reshaping coastline processes and management. The paper also considers how Geographical Information System on digital spatial analysis is important to detect and visualize shoreline position and how could be possibly used for coastal urban development, decision making, and management. The paper also considers a field survey and observation that was made by the author from August 2019 to January 2020 at Urban West of Unguja Island, Zanzibar.

2. METHODS AND STUDY AREA

The area of the study is the Urban West Region of Unguja, in Zanzibar. Zanzibar is one of two countries that form the United Republic of Tanzania which is also among the Small Island Developing States of the Western Indian Ocean [16]. Zanzibar is located on the eastern coast 40 km away from the east coast of Tanzania Mainland, West of the Indian Ocean. There are two major islands (Unguja and Pemba) and more than 50 other smaller islands and islets [16]. The northern tip of Unguja island which is the mother island is located at 5.72^0 Latitudes South and 39.30^0 East; with the Southernmost point at 6.48^0 South and 39.51^0 East. The other Island of Pemba is located at 4.870^0 South and 39.680^0 East, and the Southernmost point is located at 5.47^0 [17] [18]. Unguja is the larger of the two islands (having 1,666 km^2) and is some 35 kilometers from Mainland Tanzania, while Pemba (988 km^2) is located to the northeast (figure 3), around 55 kilometers from the Mainland [16]. The main objective of this paper was the part of the main study which has four areas of analysis on the coastal beach erosion vulnerability of Zanzibar, using GIS and RS applications. The study also find the relationship between the rate and trend of extreme beach erosion, extreme changing wind patterns, and sea-level rise, where the specific objectives were; First, to analyze the rate and trends time series of coastal beach dynamic and shoreline changes between the 1880s to 2018, using GIS and RS application. The second was to determine the relationship between extremely coastal beach erosion and extreme changes in wind patterns and sea-level rise. The third was to determine the vulnerability of Zanzibar coastal zones in terms of population displacement, coastal squeeze and loss of associated ecosystem services, and the limit of land capacity. The fourth was to identify current best practices and possible motivating adaptation factors in building resilience and reducing the risk for coastal beach management. However, in this paper it discusses objective one and four in Urban West of Unguja Islands.

The Urban West of Unguja Town also known as Zanzibar Town/City is the region that has three districts with more than 700,791 population until 2019 [19] based on the 2018 population projection, with a density of more than 2600/km^2 [16]. The general characteristics of the coast are intertidal fringing coral-rich limestone of Pleistocene age [11], the shoreline of Urban West of Zanzibar City is a fringing reef, cliff coral, beaches and sandbanks, stream deltas, mangroves with mudflat and wetland. It has a warm and humid tropical climate with an average rainfall exceeding 1500mm/year and an average temperature of above 26 ^{0}C, which is also influenced by Northern and Southern Monsoonal winds [11], [20].

The dataset used for spatial analysis is from the Guillain sketch plan survey map of 1846, Baumann sketch plan survey map of 1892 (1: 10,000 Scale), Map of Zanzibar PWD No./44 M-8 of 1907 (1: 63,360 Scale), Hydrological Map of Zanzibar Map No. 3344 of United Nation of July 1987(1: 125,000 Scale), Aerial photographies field 2004 - 2005 from the Department of Survey and Urban Planning under Smole II project, Landsat image data from SIO, NOAA, US Navy NGA, GEBO, CNES/Airbus 2020 google image 2019 copyright dataset (table 1). All sketch maps, topographic maps, and images were carefully georeferenced with hours, minutes, and seconds (latitude and longitudes) using ArcGIS software whereby spatial analysis was made through demarcating along the study area. The study also involves ground truth observation carried out between August 2019 and January 2020 where photos, GPS coordinates, and video were collected to support the analysis.

Table 1: Type of data set and their sources

Dataset	Year	Scale	Author/Publisher/Organization
Map Plan	1846		Guillain 1846
Map Plan	1892	1:10,000	Baumann 1892
Topographic Map	1907	1: 63,360	Zanzibar PWD No./44 M-8 of 1907
Topographic Map	1987	1: 125,000	United Nation No. 3344 of 1987

Aerial Photograph	2004		Department of Survey, Zanzibar 2004-2005
Landsat Image	12/27/2010	2000ft	Google Map 2020 datasat
Landsat Image	02/24/2016	2000ft	Google Map 2020 datasat
Landsat Image	07/27/2017	2000ft	Google Map 2020 datasat
Landsat Image	10/11/2018	2000ft	Google Map 2020 datasat
Landsat Image	07/24/2019	2000ft	Google Map 2020 datasat
Landsat Image	02/26/2020	2000ft	Google Map 2020 datasat

The Shoreline spatial analysis was carried out about 15km and 5km stretch of Urban Wes of Zanzibar City from Kilimani to Mtoni area, using a mixed and integrated method using map and images for long term changes detection which is also used by [21]–[23]. This was suitable to detect and analyze long time series of shoreline change when there is a limitation of data such as images of more than 100 years. It was used to analyze the shoreline position from 1846 to 2020 based on the distance of the shoreline stretch and area differences compared one dataset time shoreline position to another after being merged in both accreted or retreated. That means the dataset was carefully scanned, georeferenced, alienated, digitized, plotted, and merged, and then area measurement and geometry calculation were carried out to each spatial difference accreted or retread/eroded/reclaimed between two shoreline positions of executive years. Then, shoreline position was used to categorize the dynamism of changes of the area as such comparative for qualitative method has been used by [24], [25], as well as quantitative methods from dataset shoreline position differential in geometry calculation both length and area in meter square/kilometer square of each shoreline.

3. RESULTS AND DISCUSSION

After carefully spatial analysis of mixed data, the results were categorized based on the availability of information collected, there was a dataset that only covers part of the Urban West shoreline only 5 km, and a dataset that covers a 15 km shoreline. Also, results from analyses were performed based on the potential of the areas, length, and area of shorelines accretion and retreat as well.

3.1. Maisara, Malindi to Funguni shoreline changes between 1846 to 2020

This is an important area in Zanzibar where the capital city (Zanzibar City) is located. Results show that there are tremendous changes in the Malindi area due to the extension of the port and reclamation of Darajani creek and Mnazi Mmoja areas. Malindi port during 1846 observed having huge sand deposits at the shore (figure 3, the year 1846) in a place known as '*Funguni'* in Swahili which means the bank of sand deposit. Funguni developed north to the southwest along the shoreline, however at the inlet which is Darajani creek also known as '*Pwani ndogo'* looked wide and extended to the southwest up to about 0.46 km square inland as seen in figure 1.

In this year (1846) it could be seen a small Islet called Kisiwani within the inlets whereby the time was called '*Pwani Mbovu'* (rotten sea) which is nowadays is known as the Mnazi Mmoja area (figure 5 the year 1846). In figure 5 year 1892, the top north of Malindi area is observed there is development of '*ras'* due to improvement of deposit and port extension and the expansion of the

Stone Town city along the bank of the creek. This noticable especially at Mbuyuni, Darajani, Kisiwandui, Mkunazini, Mchambawima, Kokoni and Mnazi Mmoja, these areas especially Mbuyuni and Kokoni were the areas with huge mangroves at this time. The analysis showing that the Kisiwani Islet at Mnazi Mmoja is already joined with Eastern part land of Mnazi Mmoja and Kikwajuni which form shoreline to change by creating new land area. Due to the slowly reclamation and extension of the city, even though there was a slightly erosion and over floor of seawater, changes also is observed at top north of Malindi inside creek where there is high erosion forming an elbow shoreline shape. This is probably due to the amount of water coming inside the creek bouncing along the bank of western part of the creek, from these changes also slowly result shoreline length reduction.

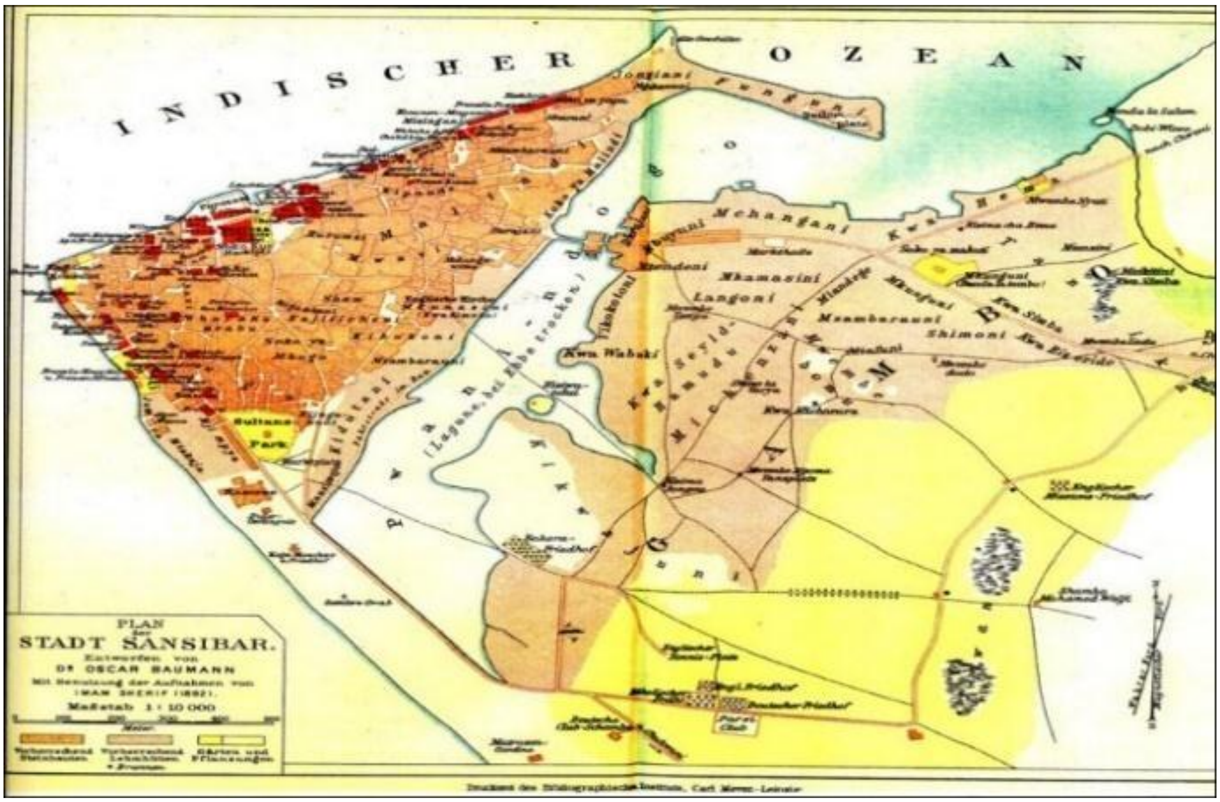

Figure 1: Unguja Urban West plan of 1892 with its creek

Figure 2: Unguja Urban West map image of 2020

Figures 1 and 2 are showing how the transformation of an area from sea to land. The creek has been reclaimed from 1892 to 2020. Between 1907 to 1987, there is a major change, a tremendous and major reclamation was done during this time. In figure 1, 2, and table 2, figures 3, 4, and 5 are showing clearly the entire creek from Mnazi Mmoja, Darajani to Funguni. At this time, it was reclaimed and transformed into other human development projects like; cities and other huge construction took place during this time. About 0.46 km square of the creek where it was called a rotten sea and '*Pwani ndogo'* (figure 1 and 2) was reclaimed totally except for a small portion which is now called Bwawani wetland. At the northwest of the area there is an extension seaward side up to several meters for Malindi port expansion (figure 5 for the year 2004 - 2020), figure 3 and 4 are an example of changes before reclamation in 1920 and after 2020 respectively. However, at this time there was much sea wall development for protection along the entire shoreline of Zanzibar Stone Town to manage the shoreline and properties from wave destruction.

Figure 3:Darajani Creek 1920 with shopping facilities.

Source: ZNA A23(73)

Figure 4: Former Darajani Creek, now Darajani with shopping facilities in 2020

Figure 3 and 4 show clearly how and to what extent the shoreline has been shifting which also reduce its length from 1846 to 2020; Mpigaduri mangroves northeast of Malindi has been acting as a defensive mechanism for every reclamation that was made within nearly 2 centuries (174 years) from 1846 to 2020.

Shallow and calm water on the western side of Unguja island together with barrier coral Islets far north of Malindi port has been protecting the Island from direct strong waves and longshore bouncing. The strong waves and longshore bouncing are mostly caused by not only monsoon winds but from ferry boats across and landing. However, apart from this natural protection, the removal of Mpigaduri mangroves will highly affect the entire shore unless there will be other feasible adaptation measures. This development of mega projects although is said to be an advantage for land accretion, the analysis shows there were challenges along the shoreline, especially at the Funguni passage. In this area, there is cumulative erosion and inland water floor which extend several meters to Mpigaduri up to Mtoni shoreline that has also influence the development of mangroves (figure 5). Although the increasing of mangroves is an advantage, it was also seeming like an attempt of increasing level of water at Malindi port in such a way that seafloor forced to change its direction to the southwest where there was a high and long impacts on this shoreline. Two jetties are evidence (figure 5 the year 2004 – 2020) which were constructed offshore of Malindi and Funguni site to trap the sediments and protect the port from sediment accumulation to avoid the high cost of maintenance of dragging at later days. The sediments are also caused by rivers from the upland of the western side which also enhance mangroves' development.

Apart from human influences, some other factors have also influenced the shoreline changes, there are natural processes as discussed by [10]. Even though there is no direct report of climate change impacts such as sea-level rise until the 1980s due to the limited availability of data sources in Zanzibar that could be also a reason for shoreline changes. Some studies [26] showing falling of relative sea-level until 2000, it might be also a bit of good luck for the city to reduce severe impact from flooding of the shore. However, in recent years between 2000 to 2012 [1] shows there is a sign of rising in sea level that could be also possible related to shoreline changes [10], [27]. Thus why in some areas like Kilimani (will be explained later) have been facing such challenges which are associated to climate change impacts.

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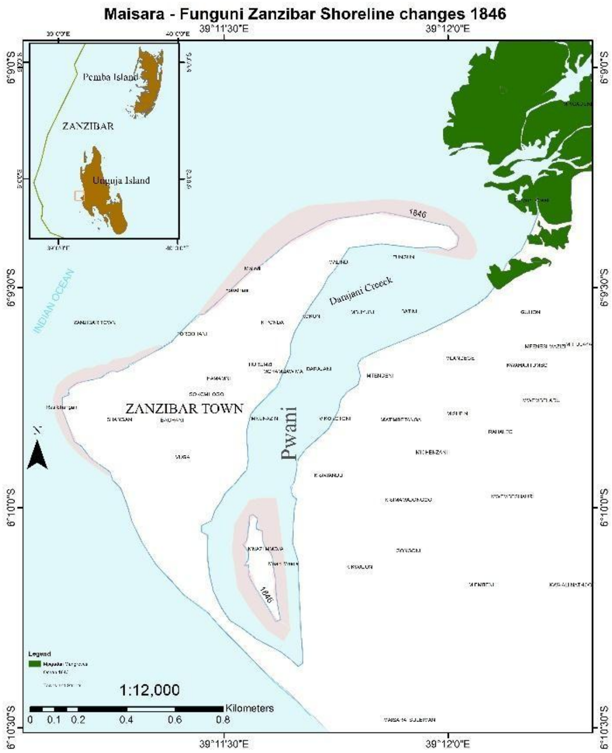

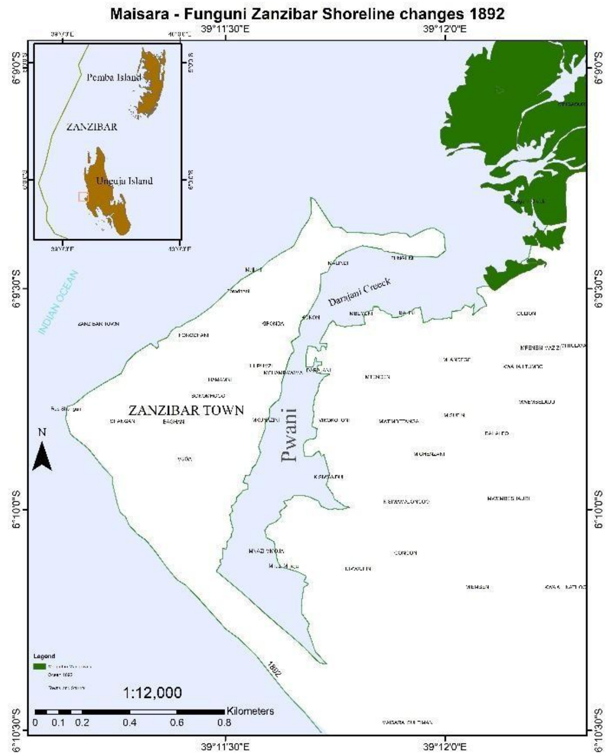

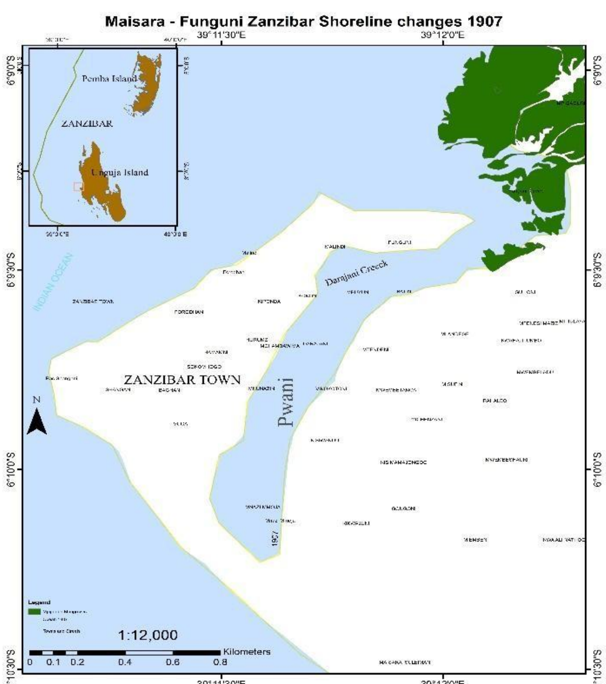

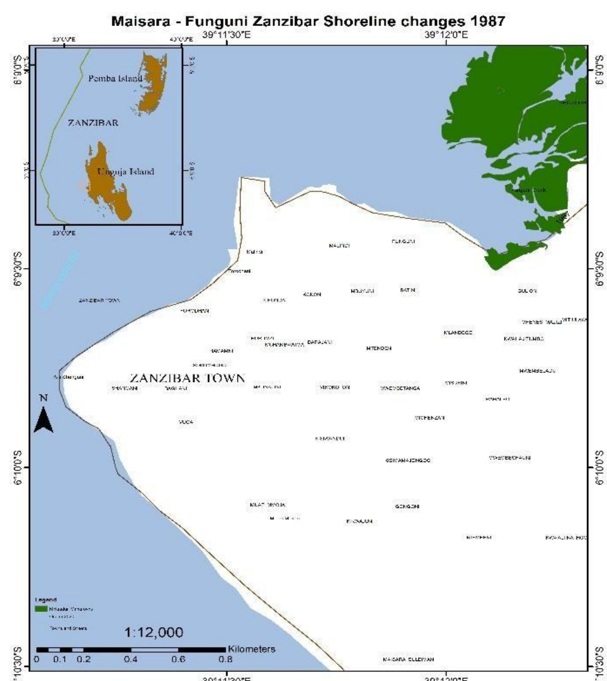

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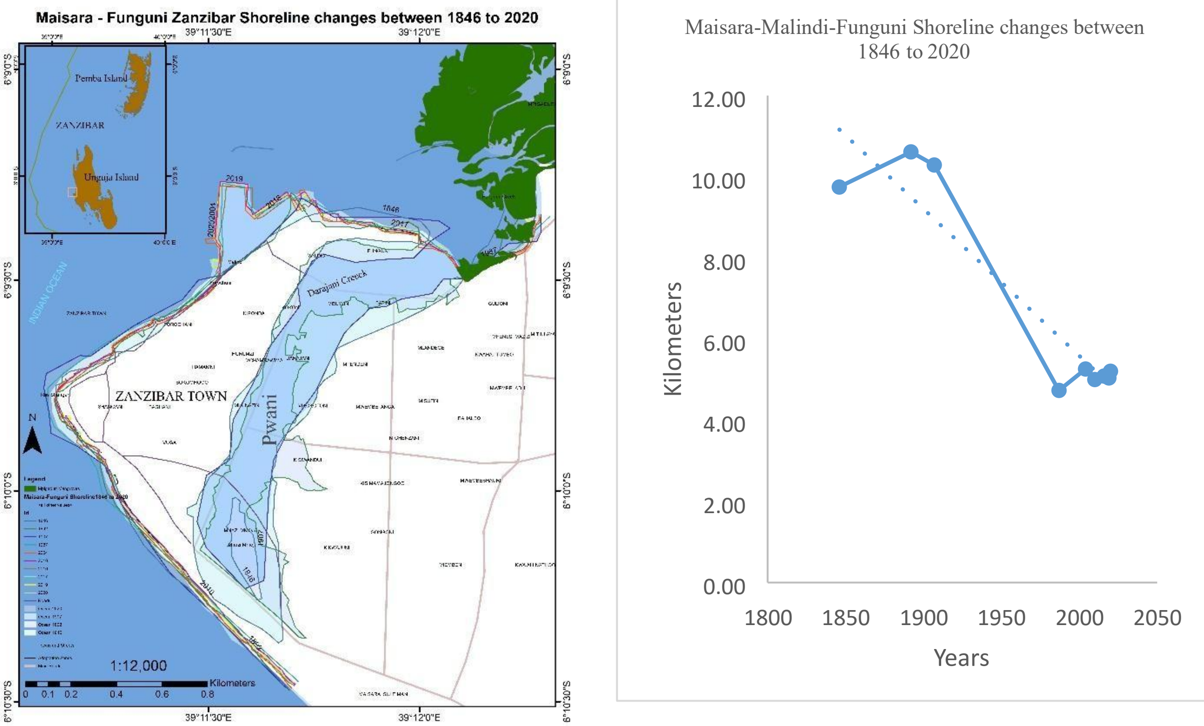

Figure 4: Maisara - Funguni Zanzibar shoreline changes

3.2. Shoreline changes Kilimani to Mtoni between 1846 to 2020

The findings show that when the shoreline is longer than the previous one is an indication of having either too much retreat or huge accretion. The trend of the shoreline length in figure 6 shows that in the early 1900s (1846, 1892, and 1907) shoreline was longer while in the late 1980s has been reduced onward, however, the tendency of stretched again is shown from the late 1980s to 2020. This is correlated with accretion and retreat results obtained as shown in figure 8 which will be explained later.

The figure shows four hotspot area changes, two have a higher accretion rate and two with a high rate of retreat of the shoreline. In the Malindi hotspot which includes Darajani and Mnazi Mmoja (Zanzibar Town area), there is accretion from 1846 to 2020, as described earlier in this study, we can see the shoreline is longer and extended onshore several meters (figure 7). The second hotspot that shows changes of accretion is the Mtoni area, this location has been accreted for the last decade in different years; 2004, 2010, 2016, 2017, 2019 to 2020. Kilimani and Migaduri are the other three and four hotspots respectively their shoreline is enlarged and extended landward, for the Mpigaduri hotspot which also involves Funguni and Kinazini; these areas according to spatial analysis are alternatives to reduce wave movement to maintain a balance of Malindi and Darajani reclamation caused by port and city development which is adjacent to it. Likewise, Kilimani hotspot shoreline changes (figure 7 the year 1907 – 2020 and from the years 2010, 2016, 2017, 2019, and 2020) show different stages of shoreline changes that have been caused by many factors. These factors are the development of sewer channels that interrupted coastal processes and causing seawater landward (inundate) and develop an inlet which did not exist before 2010 as shown in a map. Although the area had a sandbank ridge in adjacent side of shoreline north westward there are walls thus why when seawater bounce is deflected and forced southeastward which found its way in loose white sand beach deposits which are easy to erode loose sandbank.

Because the area is on the opposite side where coastal processes are likely to be little interrupted from Malindi Darajani reclamation, relative wave movement from ferry boat from and to Dar es salaam and climate change impact could also be a causal factors. Other activities like sewer and stormwater drainage construction and channeling were very likely the cause of erosion (retreat) where seawater found its way easily to weep out loose materials of sandbank. Beside the sewer channel before 2004, Kilimani area before 2010 had several human activities practiced including paddy cultivation, sports. Sadly from 2010, the area changed totally when seawater invade the area and approached to settlement zones during high tide. From then onward, there was no more agricultural activities nor sports which also lead to a reduction of a crosswalk along the shore. This changed the ecological system and new form of an inlet, mangroves, salt marsh, and tidal flat dominated the area. In figure 7, someone can see how Kilimani changed from 1907 to 2020, and from 2004 to 2020.

1.1. Area of land accretion and retreat of Urban West Unguja - Zanzibar Shoreline of Western Indian Ocean between 1846 to 2020.

Accretion here also meant deposits or land reclamation through natural and human influences through projects development or any other activities along the shoreline, the same way applies vise vasa to retreat. As noticed earlier, one of the characteristics of the shoreline is that when the stretch is long, it means either there is high erosional or deposition (retreat or accretion). It has been revealed in this study that over 174 years, the shoreline has been changed in different stages. Over these years, the geographical areas of Urban West sites experience more accretion rather than retreat, geographical, spatial analysis, and projections of the overall accretion and retreat. What figure 8 and 9 shows for 174 years, is 1527693.85 m^2 (1.53 km^2) and -936135.48 m^2 (-0.94 km) receptively. The average accretion of land from 1846 to 2020 is 8779.85m^2/yr (0.0088 km^2/yr.) and retreat is -5380.09m^2/yr (-0.0054 km^2/yr.) as shown in figure 8. A major accretion is observed during the early 1900s to late 1987 in which there was a major land transformation as shown in figure 9, as well as between 2010 to 2020. However, the land retreat is higher from 1987 to 2004. The process of accretion and retreat took place in a repetitive form from year to year, observed areas of high accretion up to 2020 are Malindi, Mtoni, Darajani, Mnazi Mmoja, and Funguni. Areas of the high retreat are some parts of Kilimani, Mpigaduri, Mtoni and parts of Maisara shoreline. The accretion in urban cities is likely associated with the development and technological advancement in many cities especially in developed countries [28] compared to the previous situation of a higher rate of erosion as postulated in Bird [29]. However still developing countries, SIDS, and rural coastlines facing a higher rate of recession. Nevertheless, this western side of urban Unguja is the main port where frequent ferry bort and large ships across near-shore and landing, the frequent boat navigation from and to Dar es salaam has exact pressure of waves toward the shoreline.

Kilimani - Mtoni Zanzibar Urban West Shoreline changes between 1846 to 2020

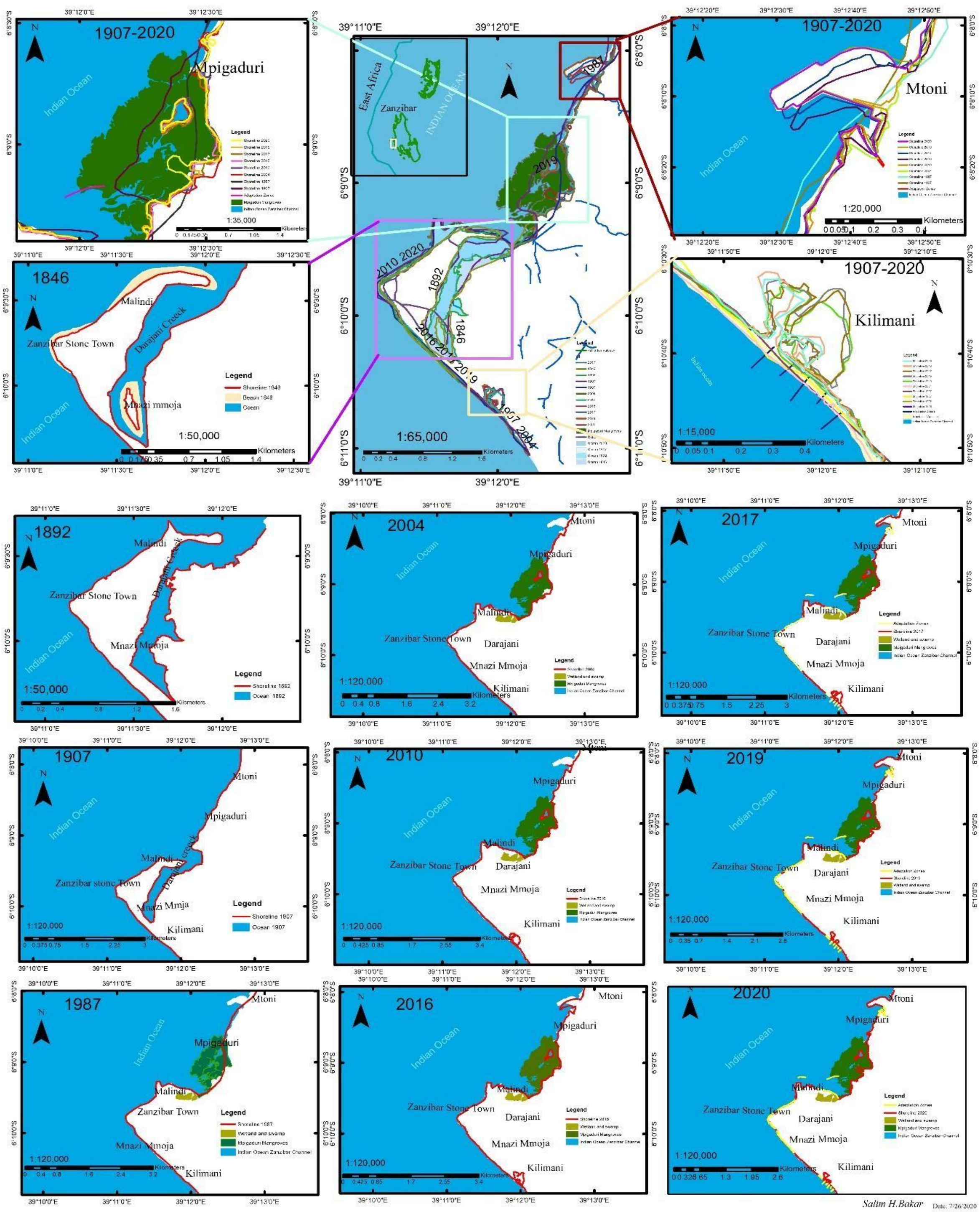

Figure 5: Kilimani - Mtoni Zanzibar Urban West shoreline Zanzibar between 1846 to 2020

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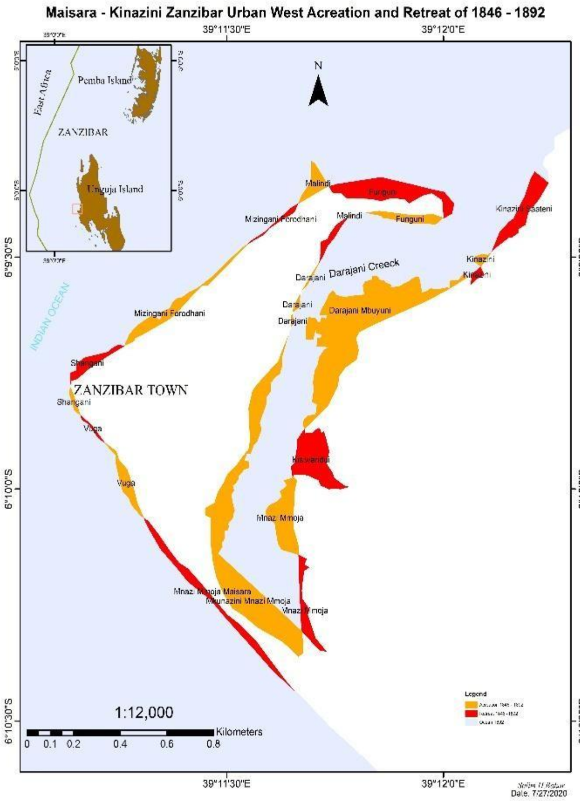

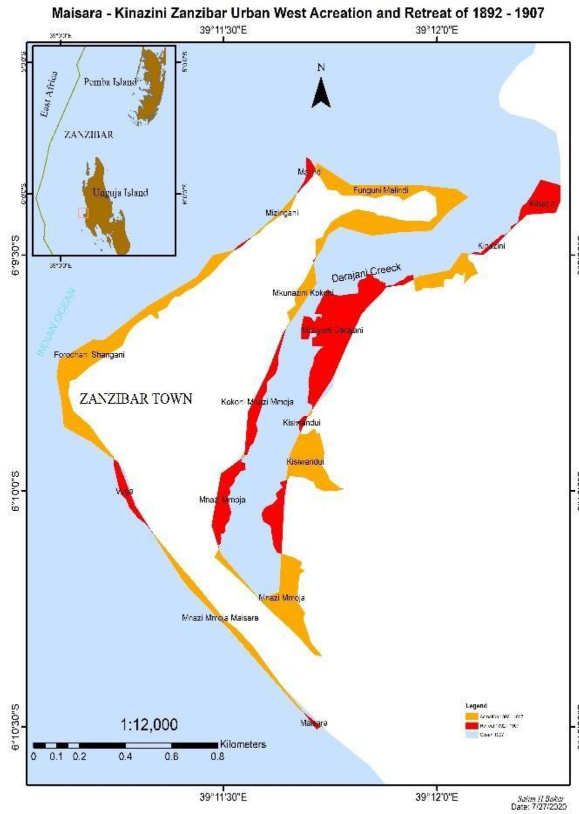

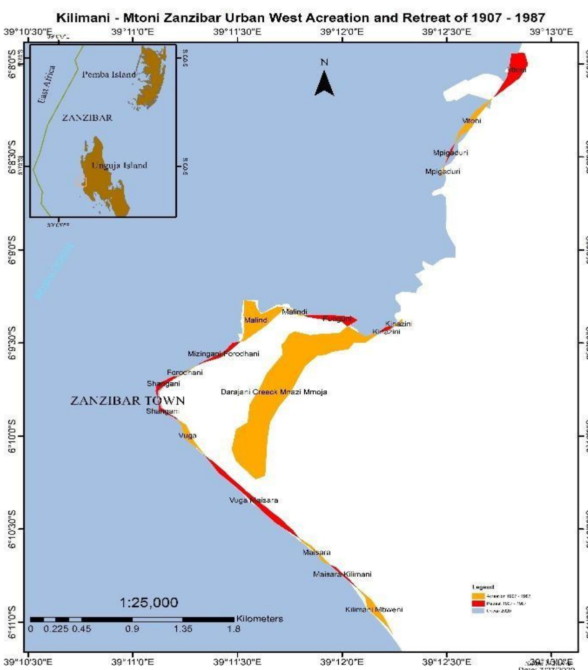

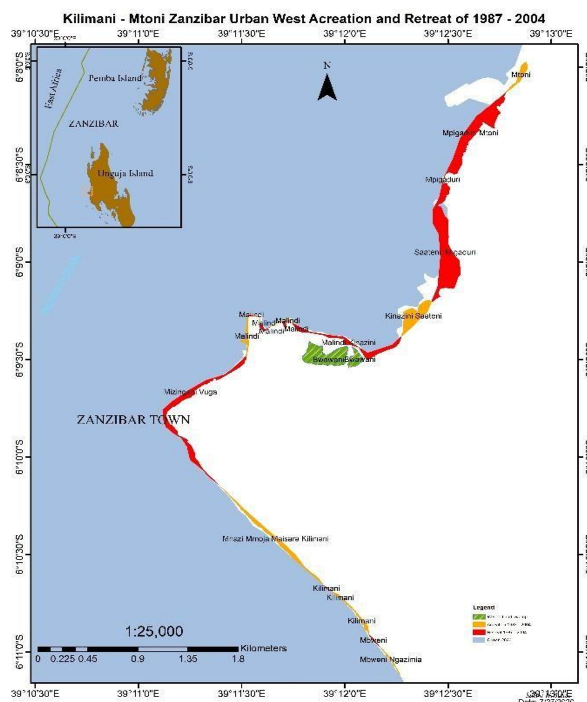

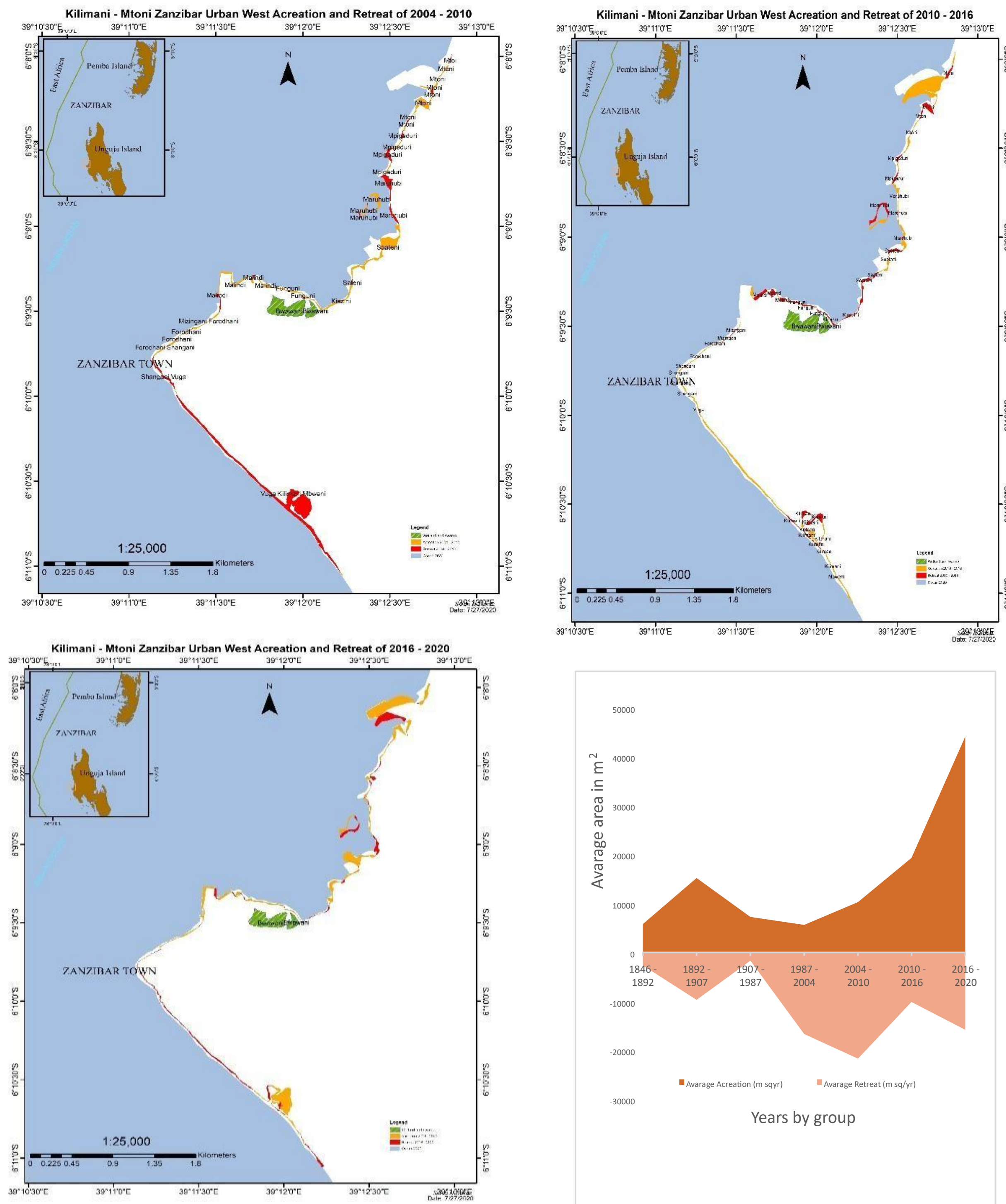

Figure 6: Accretion and retreat of the shoreline of Urban West of changes between 1846 to 2020

Figure 7: Kilimani inlet development, picture of 2020 4. CONCLUSION

There is a high impact of shoreline changes of Urban West of Unguja is more influenced by human activities rather than natural factors, especially the reclamation of Darajani creek, Malind port expansion, and other sewage channel development. Also, there are hard structural protection and management of properties which are more practiced compared to other areas. Hard structural management always reduces sand deposits where seawater finds weaker and loose areas to retreat and inundate forming an inlet or canal landward (figure 8). When inlets are formed, mangroves and other coastal vegetation grows faster in a short period. However, it protects the properties from destruction since the seawater follow the inlet. A natural setting like small islands and islets acts as a barrier and should be considered in coastal urban development and Island states as management and protection measures. The extension of the city in shallow, long swash intermittent seafloor, closed shoreline coral and barrier reefs are likely to have low impacts if the reclamation will only consider natural setting and not exceed coralline strip seaward side in consideration of mangrove site. Alternatively, the open and remote shorelines like small Islands and Islets are more likely to have high impacts when there is too much interruption from the human.

5. RECOMMENDATIONS

Maintaining the available mangroves in urban areas is most important to slow the wave movement and balance especially when there is a major land transformation on the shoreline. When it comes to shoreline management through hard structural and engineering development at least a small portion of mangroves could be mitigated at these urban areas from the retreat and sever erosion as well as maintaining ecological and aesthetic value. In urban areas where there is a higher ferry exchange engineering structures like walls, they are worth to protect the shore from wave impacts. Any construction in this area should consider the rise of sea level not only from climate change impacts but also from human-induced activities, ocean currents, hydrodynamics, and morphology which are influenced by the monsoon of the area. The Urban West of Unguja especially Stone town and nearby zones is very complicated. To protect the area from coastal retreat due to the nature of this place, the best option is to construct a sea wall from Malindi to Kilimani to cover the entire area. The study revealed that using GIS integrated methods for small island shoreline change analysis is highly recommended when there is limited data for long-term study.

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