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# Peri-urban Mangroves of Dar es Salaam-Tanzania are Highly Vulnerable to Anthropogenic Pressures

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**Abstract:** Increasing demand for socio-economic services and infrastructure developments, exert multiple pressures on coastal and marine resources, especially mangroves that occur on the outskirts of Dar es Salaam city. The study therefore assessed and mapped the anthropogenic threats and vulnerability of mangroves at Kunduchi and Mbweni. The threats were identified and validated through field observations before they were mapped in Google Earth (GE) images. Major threats were ranked on the basis of their persistence and proportional area of mangrove forest modified. The mangroves were also ranked on the basis of their proximity to the major threats. These threat and mangrove ranks were then spatially integrated using ArcGIS to develop mangrove vulnerability maps. Normalized Vegetation Index (NDVI), proxy indicator for mangrove vegetation health, was analysed from 2014 Landsat 8 image in QGIS. GE images of 2003-2014 were analysed in ArcGIS for mangrove area change detection. The major human threats at Kunduchi were the salt works and settlement, whereas at Mbweni were settlement and trampling. Analysis of the 2014 GE images indicated that Kunduchi and Mbweni had 157.3 and 42.1 ha of mangroves, respectively. About 40% and 31% of the mangroves at Kunduchi and Mbweni respectively, were vulnerable to anthropogenic pressures. There was a net gain of 12.0 ha at Kunduchi and 0.7 ha at Mbweni during the period of 2003-2014. Effective control measures are required to regulate human pressures and protect these mangroves. Promotion of incentive based conservation schemes like community-based payment for ecosystem services is one of the plausible options to explore.

**Key words:** Mangroves, Athropogenic pressure and Vulnerability

## 1. Introduction

Mangroves are highly productive forests comprised mainly of trees and shrubs adapted to survive in or adjacent to the intertidal zones. In regions where they exist, mangroves provide numerous important socio-ecological goods and services. They protect the coast from erosion and storms by attenuating waves and favouring sedimentation. Mangroves also act as shelter, breeding and feeding grounds for some marine and terrestrial species. In addition, mangroves form ecological interconnections with other adjacent habitats such

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as seagrass beds and coral reefs [39]. Moreover, mangroves sustain local community livelihoods through supported fishery and provision of wood products such as timber, poles, charcoal, firewood and local medicine [32].

Despite their socio-ecological relevance, mangroves continue to be one of the highly threatened ecosystems receiving pressure from both anthropogenic and natural processes. Reports show that, nearly all global mangrove losses that have occurred in the recent past decades are a result of anthropogenic pressures. In addition to overexploitation, conversion of mangrove forest into other land uses such as aquaculture, agriculture, coastal development have accelerated the rate of loss, which stands at 1-2% at global level [2, 6, 44] and 0.7% at Tanzania's national level [8]. These anthropogenic pressures are mainly necessitated by the rapid coastal population growth [39].

The coastal regions of mainland Tanzania encompass about 15% of the country's land area [41] and 22% of the country's population [43]. This population and the resultant anthropogenic activities exert pressures on natural and man-made environments [10, 18, 30, 49] upheld the idea that rapid population growth is the major cause of mangrove degradation in Tanzania, especially in urban centers such Dar es Salaam, Tanga and Zanzibar. Mangroves located on the outskirts of these regions are highly vulnerable to degradation by uncontrolled development processes [1,45] In particular, overexploitation and clearance of mangrove forest for settlement development and construction of salt evaporation ponds have contributed to severe mangrove losses [31]. Human trampling along the shoreline is also an important threat observed to cause local but significant physical damages to the mangroves [1]. Moreover, mangroves face the problem of pollution from the discharge of domestic wastes [15, 25]. Awareness raising and in the understanding of the socio-ecological values of mangroves and the need for their conservation have been emphasized [31, 34] and government and non-government actors have taken efforts to promote mangrove management all over the country.

One of the major problems facing the management of mangrove resources in Tanzania is the lack of reliable and up-to-date information on extent, health, cover changes and vulnerability to anthropogenic pressures to inform the management strategies and plans. For example, the national mangrove management plan for mainland Tanzania [31] is outdated and increasingly becoming strategically inefficient [23]. While threats to mangrove forests are known, their impacts and spatial distribution, especially at local scales have not been well mapped. Therefore, demand still exists to understand the current situation on the spatial distribution of the mangrove threats. As Tulloch et al. [38] argue, spatial representation of threatening processes is an important aspect in identifying where and how biodiversity may be at risk so as to rationally prioritize conservation strategies. I this article, we analyse and map the anthropogenic impacts on the peri-urban mangroves of Kunduchi and Mbweni in Dar es Salaam, Tanzania. We present the results of the causes and effects of anthropogenic pressures on mangroves, their spatial distribution as well the mangroves vulnerability through anthropogenic pressures. This would provide up to date information on mangrove status and vulnerability in re-designing of the existing mangrove management plans for the sustainability of the peri urban mangroves.

## 2. Materials and Methods

### 2.1 Study Site Description

Dar es Salaam is the major economic hub of Tanzania. It is also the most populous city in Tanzania growing at a rate of 5.6% per year and it harbours about 4.36 million people, equivalent to 10% of the country's population [43]. This high population has attracted ever-increasing demand for socio-economic services including infrastructure and property development and has exerted multiple pressures on its coastal and marine resources including mangrove forests.

In the 2000s, Dar es Salaam had 2,516 ha, which was approximately 2.3% of the country's mangroves [48]. Mangrove stands found in this region include those located in areas of Ras Dege, Mji Mwema, Mtoni Kijichi, Msimbazi, Kunduchi and Mbweni [31]. Mangrove forests in these areas are one of the key components of the Dar es Salaam seascape ([46]. Kunduchi and Mbweni lay on the northern outskirts of Dar es Salaam (Figure 1).

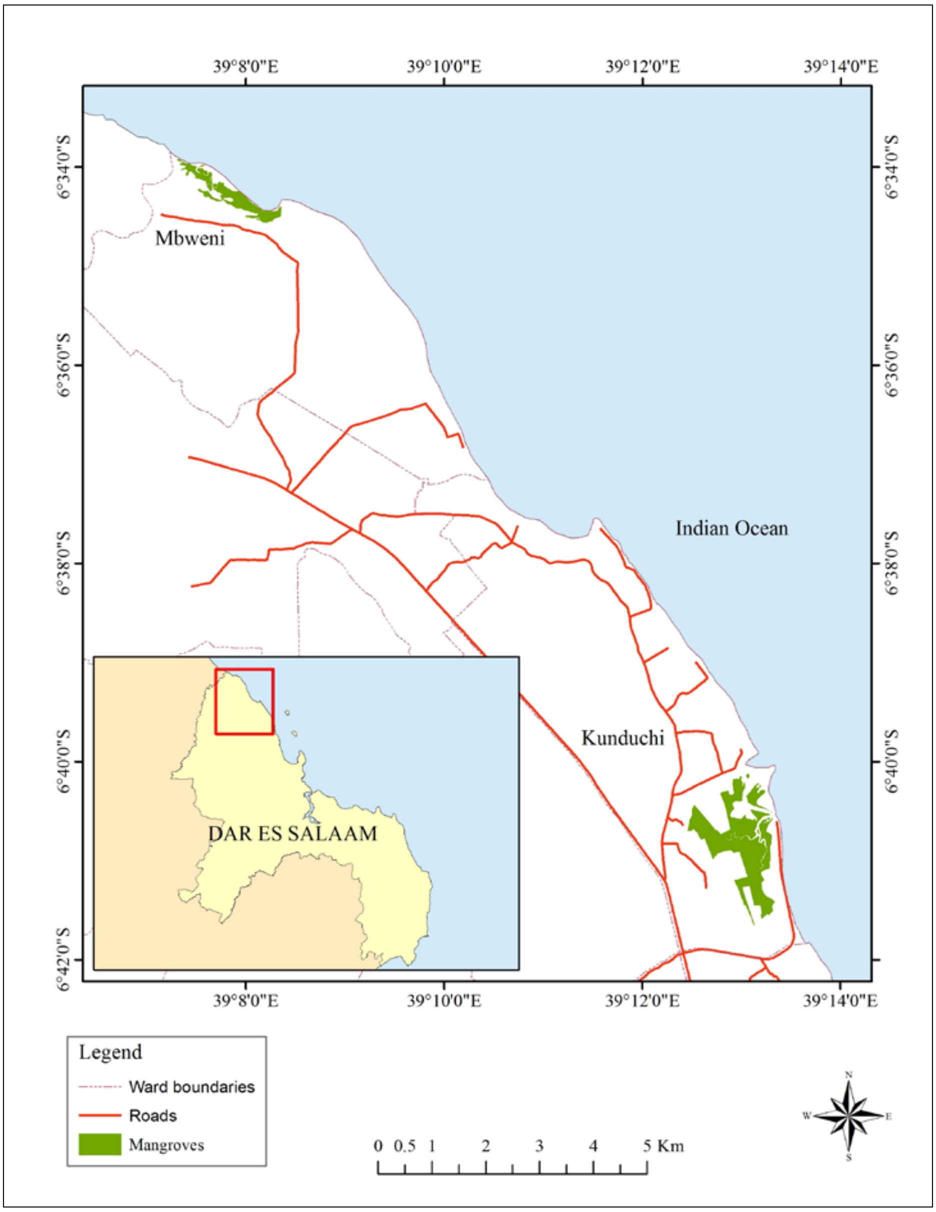


Figure 1. A map of Dar es Salaam (insert) indicating the location of the study sites. The forest patches Kunduchi and Mbweni where the study was conducted in March 2015 are presented using green colours. Source: NBS Database and Google Earth.

These areas experience high rates of settlements expansion and development of coastal infrastructure and properties than most of the other parts of Dar es Salaam [4].

## 2.2 Data Collection and Analysis

### 2.2.1 Anthropogenic Pressures on Mangroves

Key informant interviews, focus group discussions (FGD) and field observations were conducted with the aim of capturing information about the causes and effect of mangrove degradation. A checklist of questions was prepared to guide the discussions which consisted of a mix of community group leaders responsible for mangrove conservation, village leaders and community development officer, who were purposefully selected to represent stakeholder groups in mangrove use and conservation. A content analysis [12] was employed to summarize the information obtained through FGDs and key informant interviews.

### 2.2.2 Mapping of Mangroves and Threats

Spatial data for salt works, settlements, hotels, mangroves and corresponding areas affected through trampling were acquired through digitization of satellite imageries in GE. Other spatial information representing roads, sand flats, fish landing sites and non-mangrove vegetation were also acquired through the same method. All spatial data gathered through digitization in GE were then imported into ArcGIS for spatial analysis using GIS procedures.

### 2.2.3 Mangroves-Threats Proximity Analysis

Mangroves were ranked on the basis of their proximity to the identified major anthropogenic threats in order to determine their vulnerability. In addition, corresponding threats to mangroves were ranked in order of severity of their destructive impacts. The persistence and associated proportional area of mangrove cleared/modified were additional factors used to estimate and judge vulnerability according to MacDiarmid *et al*. [17]. Each factor was ranked into different vulnerability classes as indicated in Table 1.

Table 1: Rating of threat and mangrove vulnerability criteria. Adopted from MacDiarmid *et al*.[17].

| Factors | Vulnerability class |
|---|---|
| Relative area of mangrove lost or modified | >50% (High) |
| | 25-50% (Moderate) |
| | <25% (Low) |
| Persistence of a threat | Frequent (High) |
| | Regular (Moderate) |
| | Occasional (Low) |
| Proximity of mangrove forest to settlement and salt pans | <60 Meter (High) |
| | 60-120 Meter (Moderate) |
| | >120 Meter (Low) |
| Proximity of mangrove forest to trampling area | <6 Meter (High) |
| | 6-12 Meter (Moderate) |
| | >12 Meter (Low) |

Based on these classes, a semi-quantitative technique was applied to convert the mangrove vulnerabilities into measurable scores on a scale of 1-3 according to Maier [19] where low =1, moderate =2 and high =3. By adapting an approach developed by Kannan [14], the ArcGIS was used to aggregate these factors into maps portraying the vulnerability of the mangroves.

#### 2.2.4 Determination of Mangrove Vegetation Health

In order to determine mangrove vegetation health, NDVI was analysed from the Landsat 8 sensor image accessed from the United States Geological Survey Global Visualization Viewer (USGS-GLOVIS) website (http://glovis.usgs.gov/). Atmospheric correction was done using a dark object subtraction (DOS 1) algorithm in a QGIS semi-automatic classification plugin (SCP) [5]. Then, a band calculator tool available in the SCP window was used to compute the NDVI values using the formula:

NDVI= (NIR-R/NIR+R)

Where: NIR and R represent band 5 and band 4 of the Landsat 8 image, respectively.

Mangrove areas on the NDVI image were manually delineated using the 2014 year mangrove boundaries digitized in GE. After delineation, the NDVI images for each study site were classified into three mangrove health classes; 0.00-0.35 (low health), 0.35-0.70 (moderate health) and >0.70 (high health), with 1, 2 and 3 ranks respectively.

#### 2.2.5 Spatial Correlation Between Mangrove Vulnerability and Health Maps

Five hundred 500 random points were automatically generated in ArcGIS. Then, mangrove vulnerability and health values from the corresponding raster layers were extracted to these points. After removing all no data cases, 493 and 478 points for Kunduchi and Mbweni, respectively, were used to explore the spatial correlation between mangrove vulnerability and health using a Geographically Weighted Regression (GWR) tool with an assumption that mangrove vulnerability and health are site-dependent and negatively correlated

#### 2.2.6 Mangrove Cover Change

The GE historical imagery tool was used to explore the imageries availability, coverage, and quality to capture a near decadal change in mangrove extent. The mangrove boundaries themes of 2003 and 2014 year were visually inspected and digitized following the maximum boundary of the mangrove extent. In order to quantify the mangrove cover change, the GE digitized mangrove boundaries themes of the two year period were overlaid in ArcGIS 10.2 according to Makota *et al*. [12]. The mangrove area gain and loss were then validated in the GE imageries.

# 3. Results

## 3.1 Anthropogenic Threats to Mangroves

Table 2: Summarizes the anthropogenic threats to mangroves and their impacts, whereas Plate 1 and 2 illustrate the degradation in selected parts of the mangres in the study sites.

| Site | Threats | Ways in which mangroves are impacted |
|---|---|---|
| Kunduchi | Settlement (Residential house and hotel construction) | Loss and modification of mangroves through clearance and land reclamation |
| | Solar salt extraction works | Loss/modification of mangroves through clearance and obstruction of water flow. |
| | Domestic waste dumping | Pollution |
| Mbweni | Settlement (Residential house and hotel construction) | Loss and modification of mangroves through clearance and land reclamation |
| | Trampling | Modification of mangrove vegetation structure through death of seedlings/tree pruning |
| | Domestic waste dumping | Mangrove pollution |

Although the main focus of the present study was on the anthropogenic cause of mangrove degradation, natural events also contributed to the observed mangrove losses as summarized in Table 3. Plate 3 illustrates mangroves affected by flash floods in selected parts of the mangroves in the study sites.

Table 3: Summary of natural threats to mangroves at Kunduchi and Mbweni

| Site | Threat | Ways in which mangroves are impacted |
|---|---|---|
| Kunduchi | Shoreline changes | Loss and modification of mangroves through erosion |
| Mbweni | Shoreline changes | Loss and modification of mangroves through erosion |
| | Terrestrial flash flood | Loss of mangroves due to prolonged inundation |

## 3.2 Spatial Distribution of Mangroves and Threats

Analysis of the 2014 GE imageries indicated that there were 157.3 ha of mangroves at Kunduchi. Mangroves were generally encroached, cleared and converted to salt pans and property development (hotels and human settlements) (Figure 3.2). Salt works coverage recorded 50.9 ha and up to 4.3 km of the salt works perimeter directly bordered by the mangrove forest. On the other hand, the length of settlements bordering mangroves was recorded to cover 3.2 km.

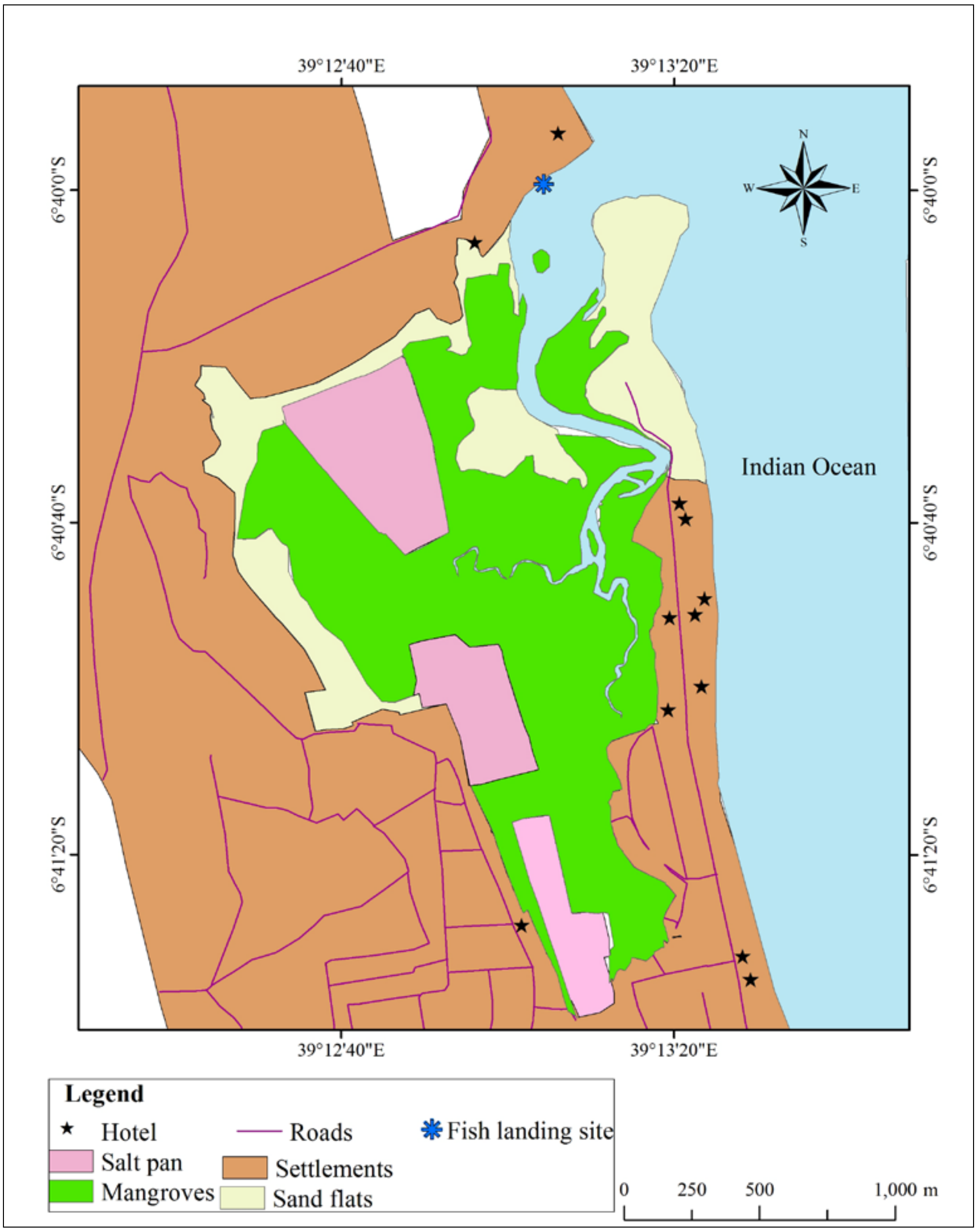


Figure 2. A map of Kunduchi site showing the extent of human encroachment in mangroves through settlement development (hotels and residential houses) and salt works construction.

At Mbweni site (Figure 3), results from GIS analysis of the 2014 mangrove coverage showed 42.1 ha. Unlike at Kunduchi, settlement encroachment in mangroves in this area was not intense as mangrove forest was at least 35 meters from the closest edge of settlement.

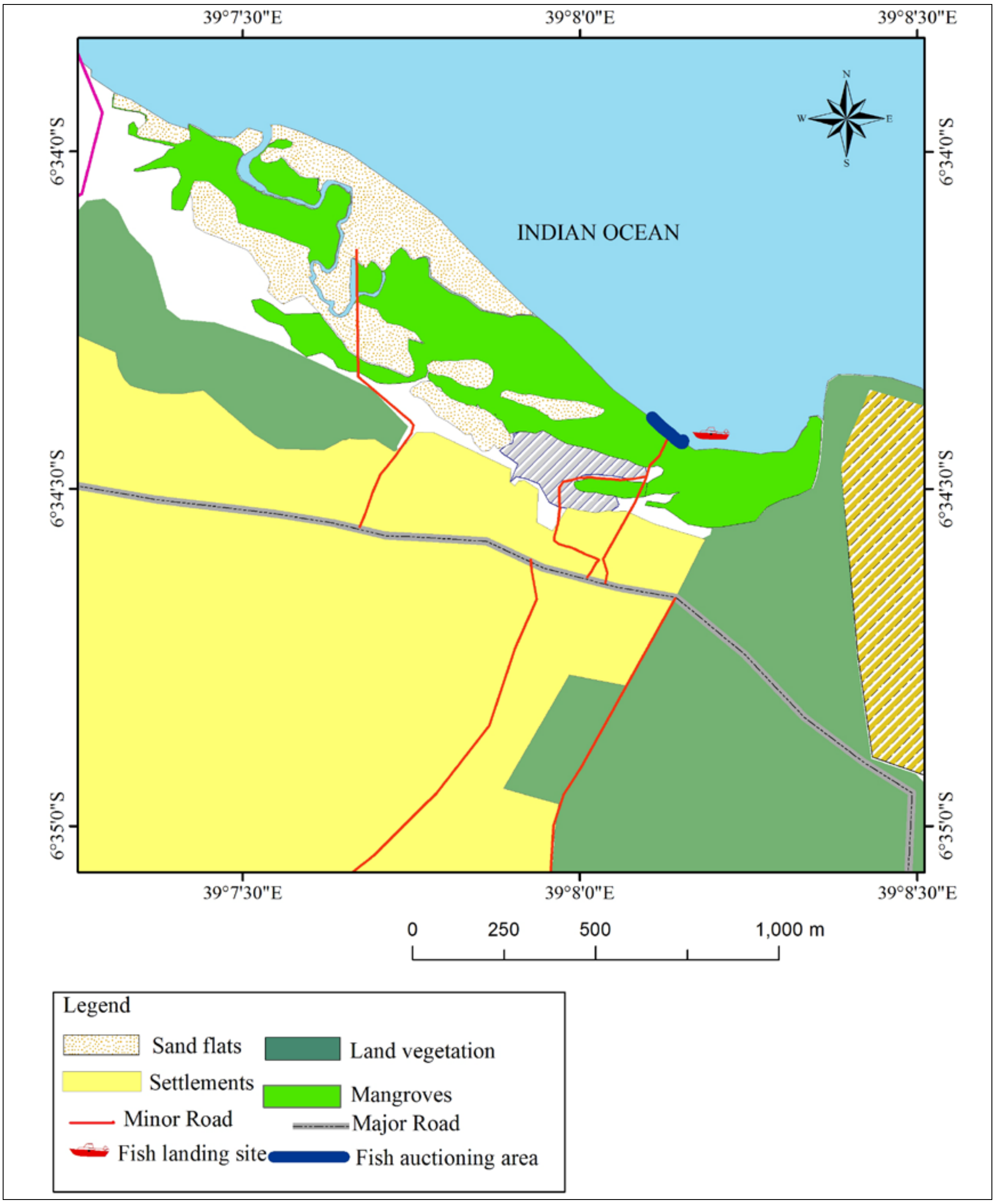


Figure 3. A map of Mbweni site showing the extent of human encroachment in mangroves through property development (settlements, roads, fish auctioning area and fish landing site).

## 3.3 Proximity to Threats

At Kunduchi, mangroves were highly vulnerable to salt works that had the highest impact score of 5, 2 for the proportional area of mangroves affected and 3 for their persistence. Settlements also recorded the total impact score of 4, 1 representing the proportional area of mangroves affected and 3 for persistence of the threat. Figure 4 and 5 respectively indicate the mangroves vulnerability based on proximity to salt pans and settlements at Kunduchi.

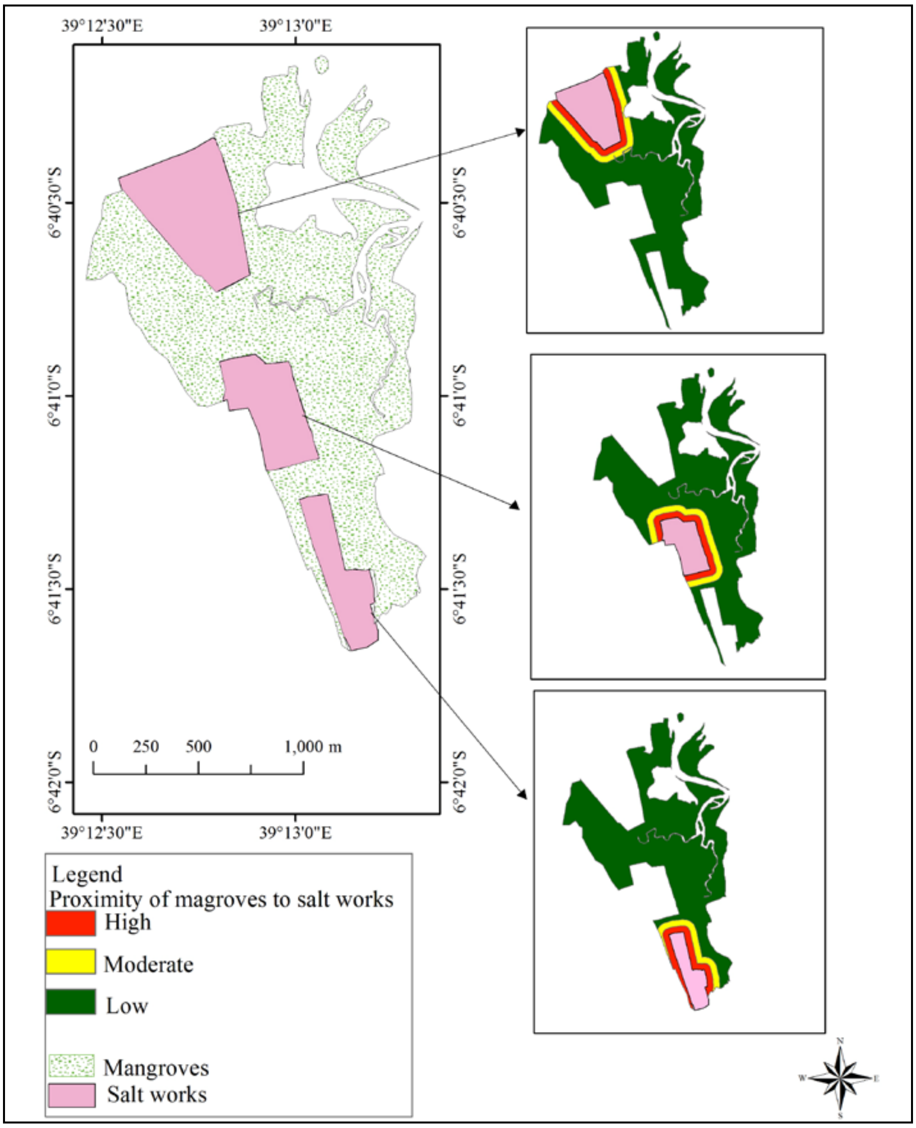


Figure 4. Mangroves vulnerability based on proximity to salt pans at Kunduchi site. Red colour = mangroves in 60 meters of salt works; Yellow colour = mangroves in 60-120 meters from the salt works and Green colour = mangrove beyond 120 meters from the salt works.

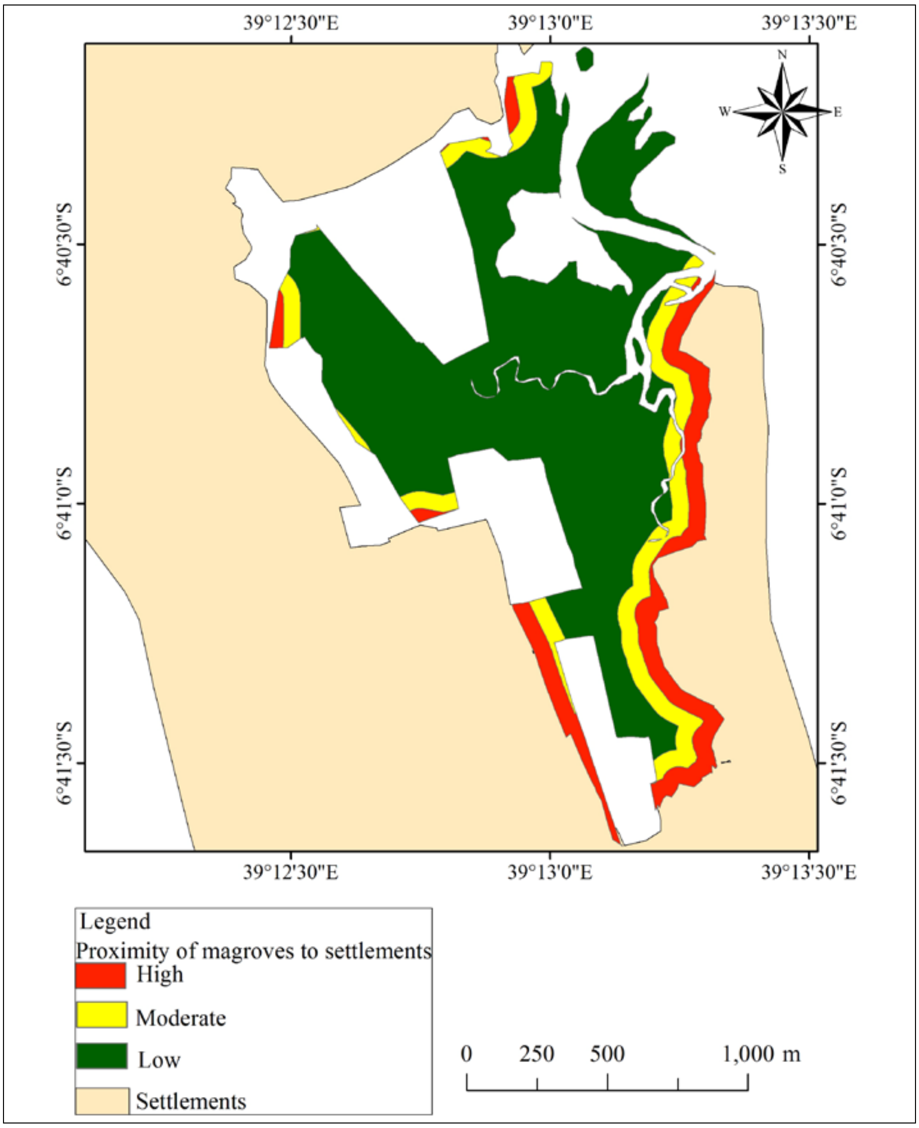


Figure 5. Mangroves vulnerability based on proximity to settlements at Kunduchi site. Red colour = mangroves in 60 meters from the settlements; Yellow colour = mangroves in 60-120 meters from the settlements and Green colour =mangroves beyond 120 meters from the settlements.

An overall analysis of GIS overlay data representing mangroves-threats proximity, proportional area of mangroves affected and persistence of the salt works and settlements indicated that 49.7%, 24.9% and 25.4% of the mangrove forest area of Kunduchi site had low, moderate and high vulnerability (Figure 3.6), respectively. Most of the least vulnerable mangroves were located on the eastern side of the creek. A narrow belt of moderate vulnerable mangroves on the eastern side surrounded the least vulnerable mangroves spread on the west side between the salt works. The highly vulnerable mangroves were on the outer edges of mangrove forest closer to salt pans and settlement boundaries.

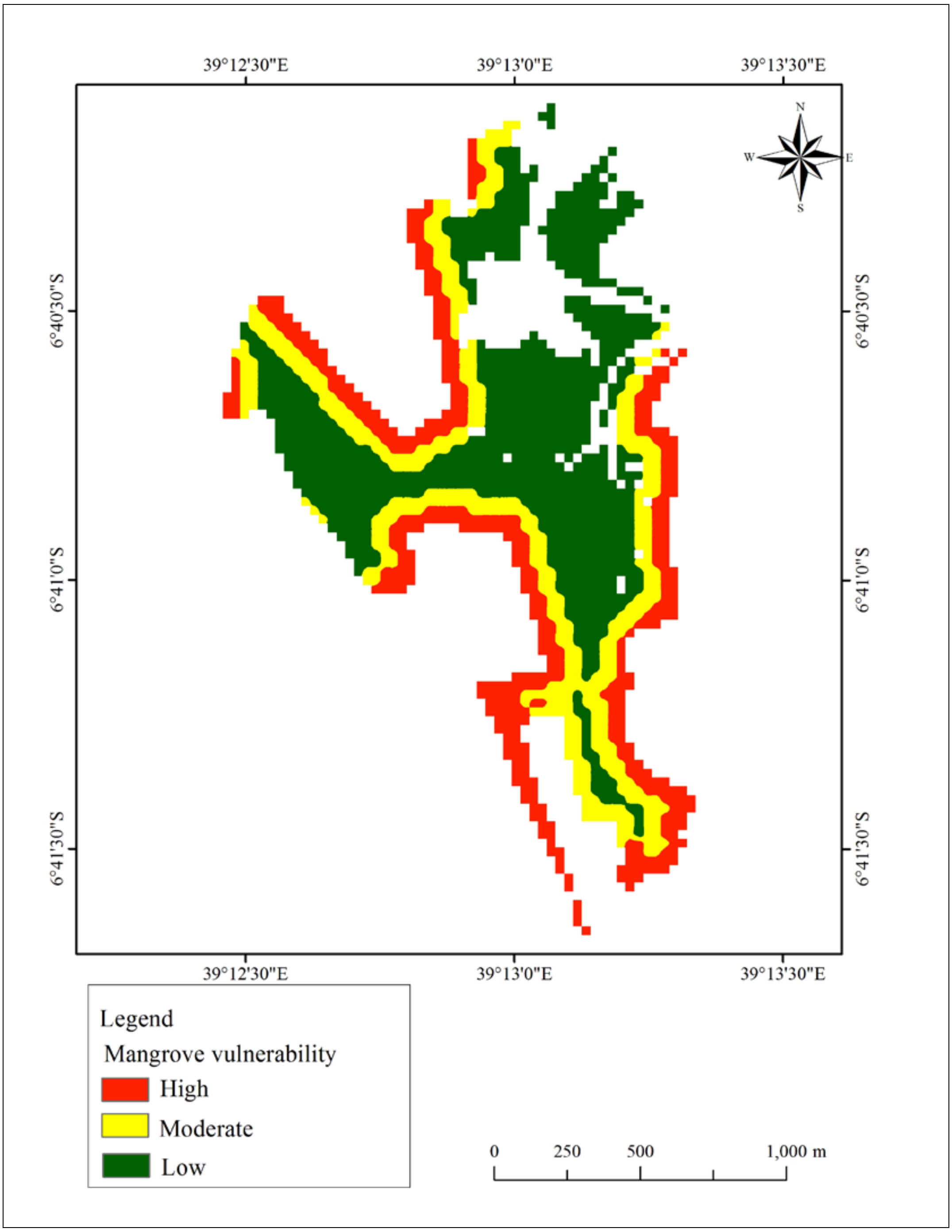


Figure 6. Overall vulnerability of mangroves to salt works and settlements at Kunduchi.

At Mbweni, the impacts of both settlements and human trampling in mangroves recorded 4 total scores, 1 being for the proportional area of mangroves affected and 3 for their persistence. Figure 7 and 8 portray the mangrove proximity to human settlement and trampling pressures, respectively.

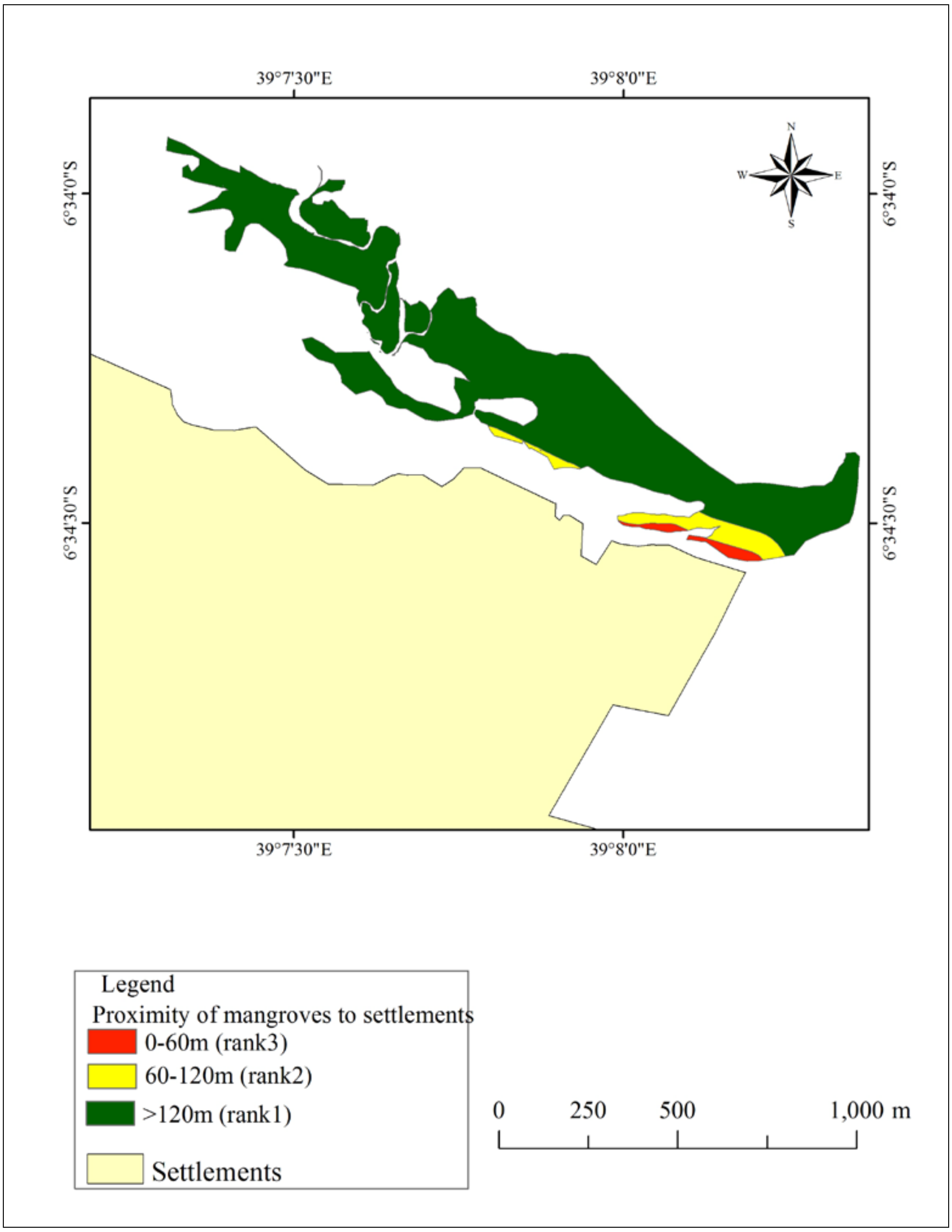


Figure 7. Ranking of mangroves based on proximity to settlements at Mbweni. Red colour = mangroves in 60 meters from the settlement; Yellow colour = mangroves in 60-120 meters from the settlement and Green colour =mangrove beyond 120 meters from the settlement.

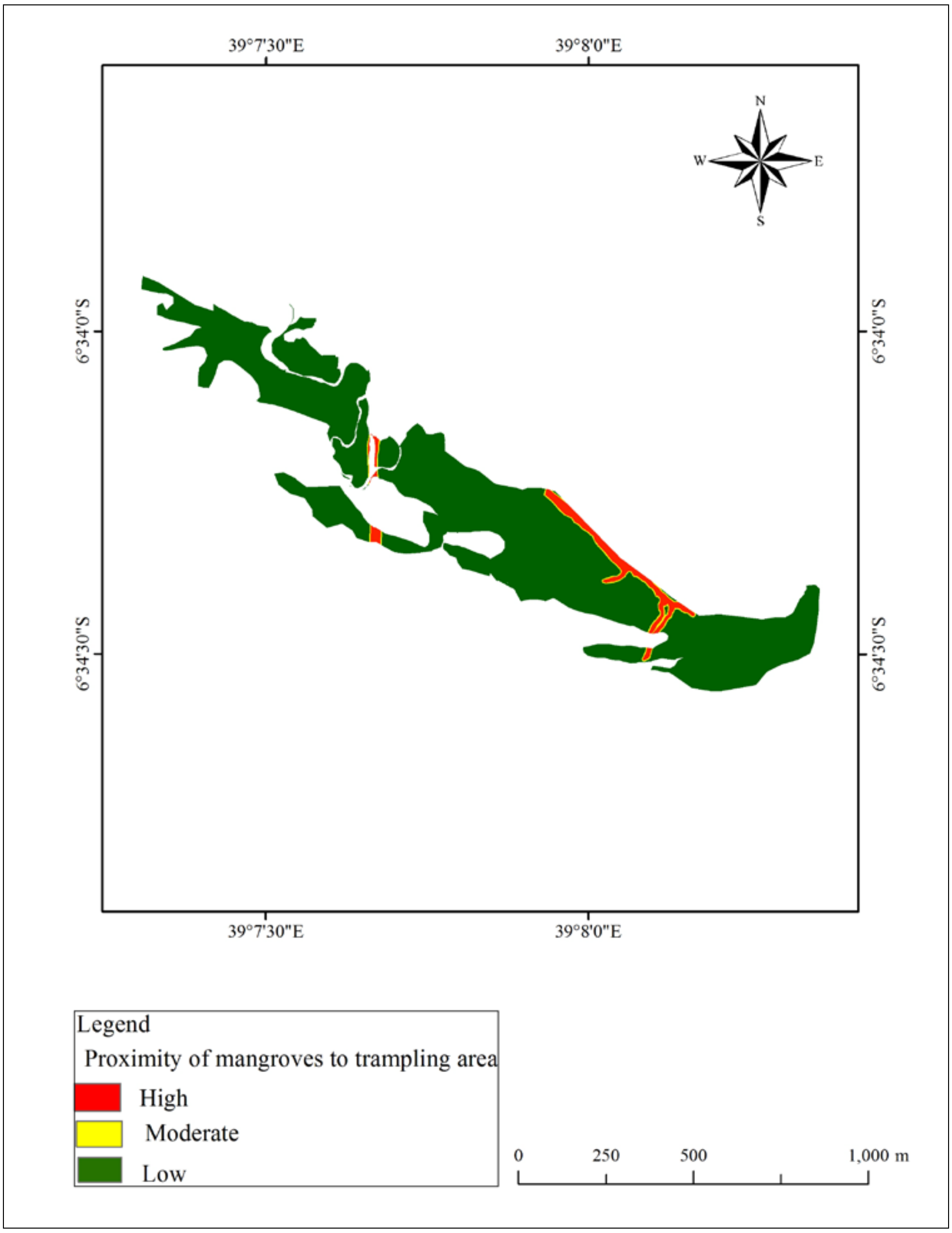


Figure 8. Ranking of mangroves based on the proximity to human trampling area at Mbweni. Red colour = mangroves in 6 meters from trampling area; Yellow colour = mangroves in 6-12 meters from trampling area and Green colour = mangrove beyond 12 meters.

An overall analysis of GIS overlay data representing mangroves-threats proximity, proportional area of mangroves affected and persistence indicated that 87.7%, 8.3% and 4.0% of the mangrove forest area of Mbweni site had low, moderate and high vulnerability (Figure 9), respectively. Like those at Kunduchi, the low vulnerable mangrove in this area dominated at the middle of the mangrove forest circumvented by a region of moderate vulnerable mangroves. The high vulnerable mangroves mostly occupied the outer edge of the forest, particularly at the mangrove-shoreline interface.

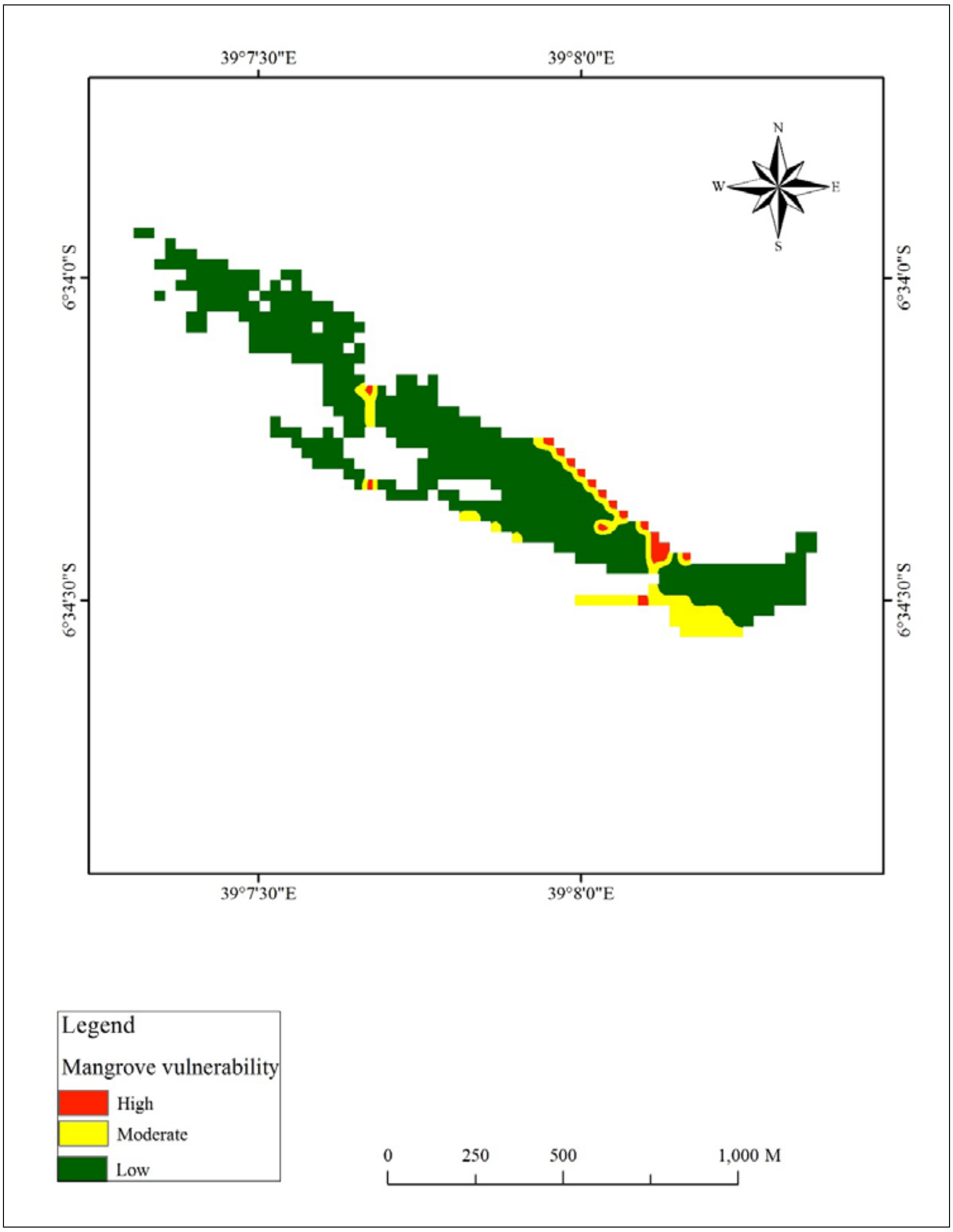


Figure 9. Overall vulnerability of mangroves to settlement and trampling pressures at Mbweni.

## 3.4 Mangrove Vegetation Health

Analysis of NDVI for Kunduchi indicated 47.9%, 23.9% and 28.2% of the mangrove forest had high, moderate and low health, respectively (Figure 10). At Mbweni NDVI analysis indicated 51.7%, 34.3% and 14.0% of the mangroves had high, moderate and low health (Figure 11), respectively. In both sites, healthy mangroves dominated the central portions of the forests.

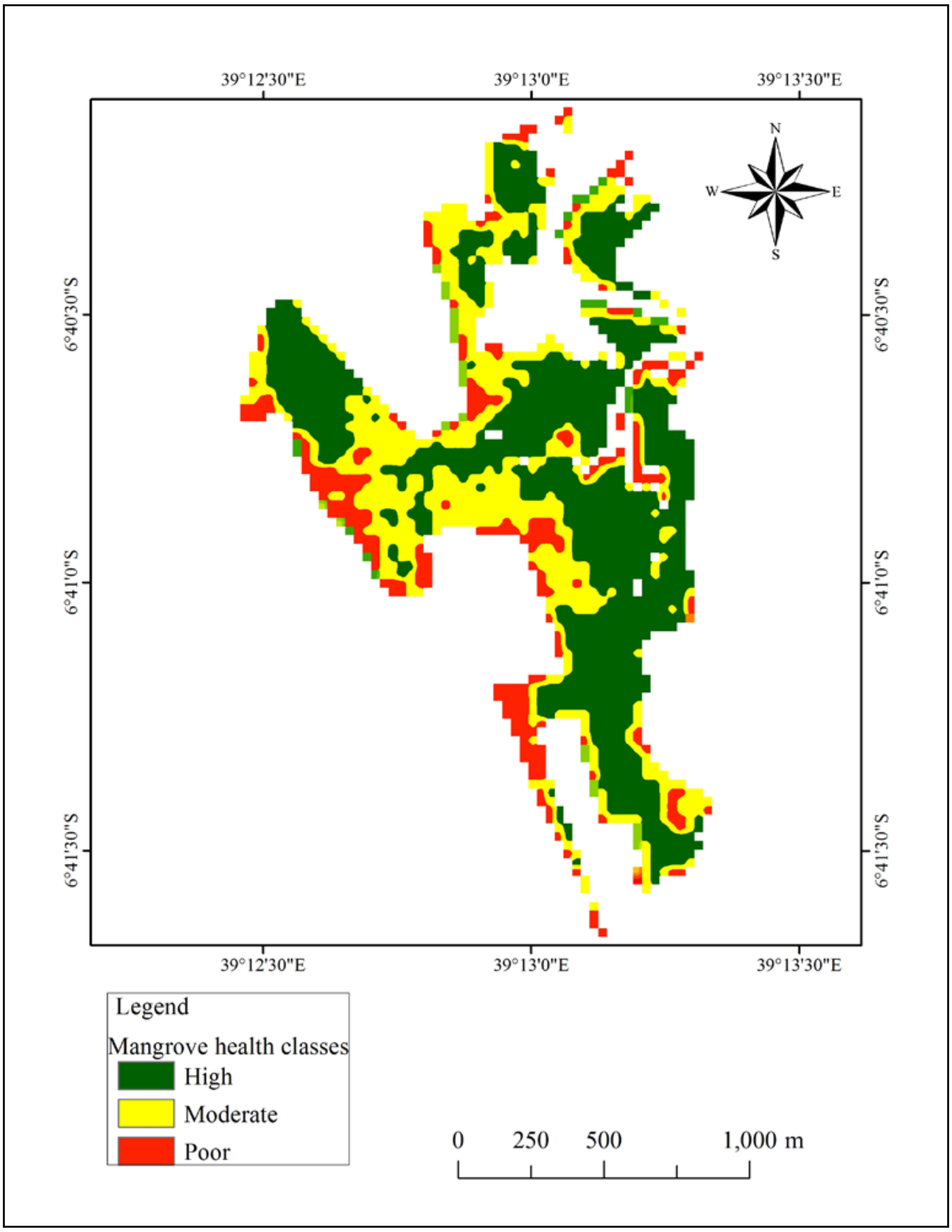


Figure 10. Distribution of mangrove vegetation health at Kunduchi determined by analysis of NDVI.

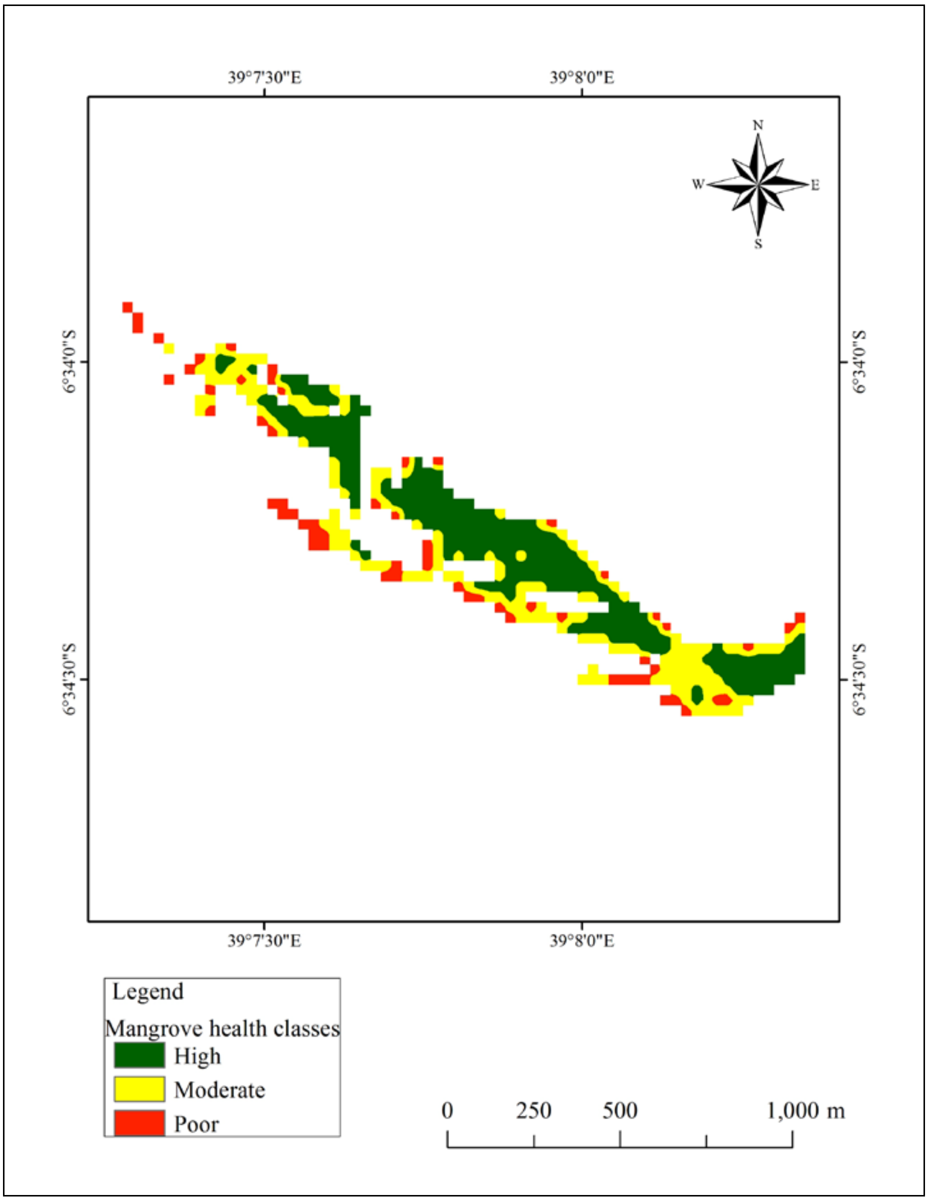


Figure 11. Distribution of mangrove vegetation health at Mbweni determined by analysis of NDVI.

## 3.5 Spatial Correlation between Mangrove Vulnerability and Health Status

At Kunduchi, analysis of GWR showed low spatial correlation between mangrove health and vulnerability based on proximity to the salt works and settlements (Adjusted $R^2$ = 0.40), translating into only into 40% vulnerability. The correlation was non-stationary as the regression coefficients varied between -1.6 and 0.8 (Figure 12). Negative correlation dominated the central part of the study site while the positive correlations were located in the northern, western and eastern parts of the forest.

For Mbweni, the mangrove vegetation health also showed low spatial correlation with vulnerability based on proximity to settlements and human trampling (Adjusted $R^2$ = 0.31), translating to only 31% vulnerability. Correlation in this area was also not stationary as the regression coefficients varied from -4.3 to +0.2 (Figure 13). Positive correlations dominated the southern parts of the study area, whereas a small region of negative correlation was portrayed near the north-eastern parts of the forest.

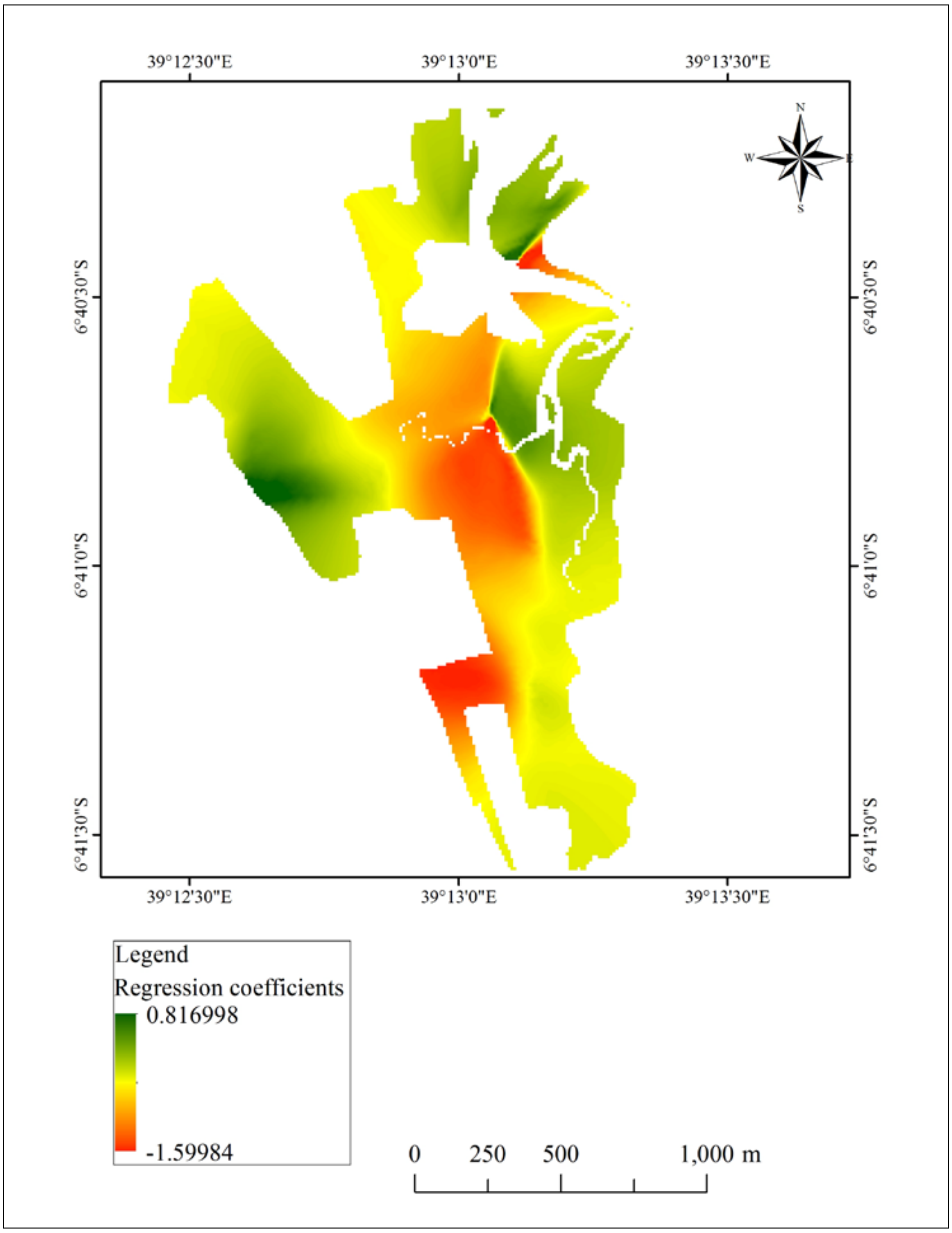


Figure 12. A GWR coefficient raster surface portraying the spatial correlation between vulnerability and NDVI-derived mangrove health at Kunduchi.

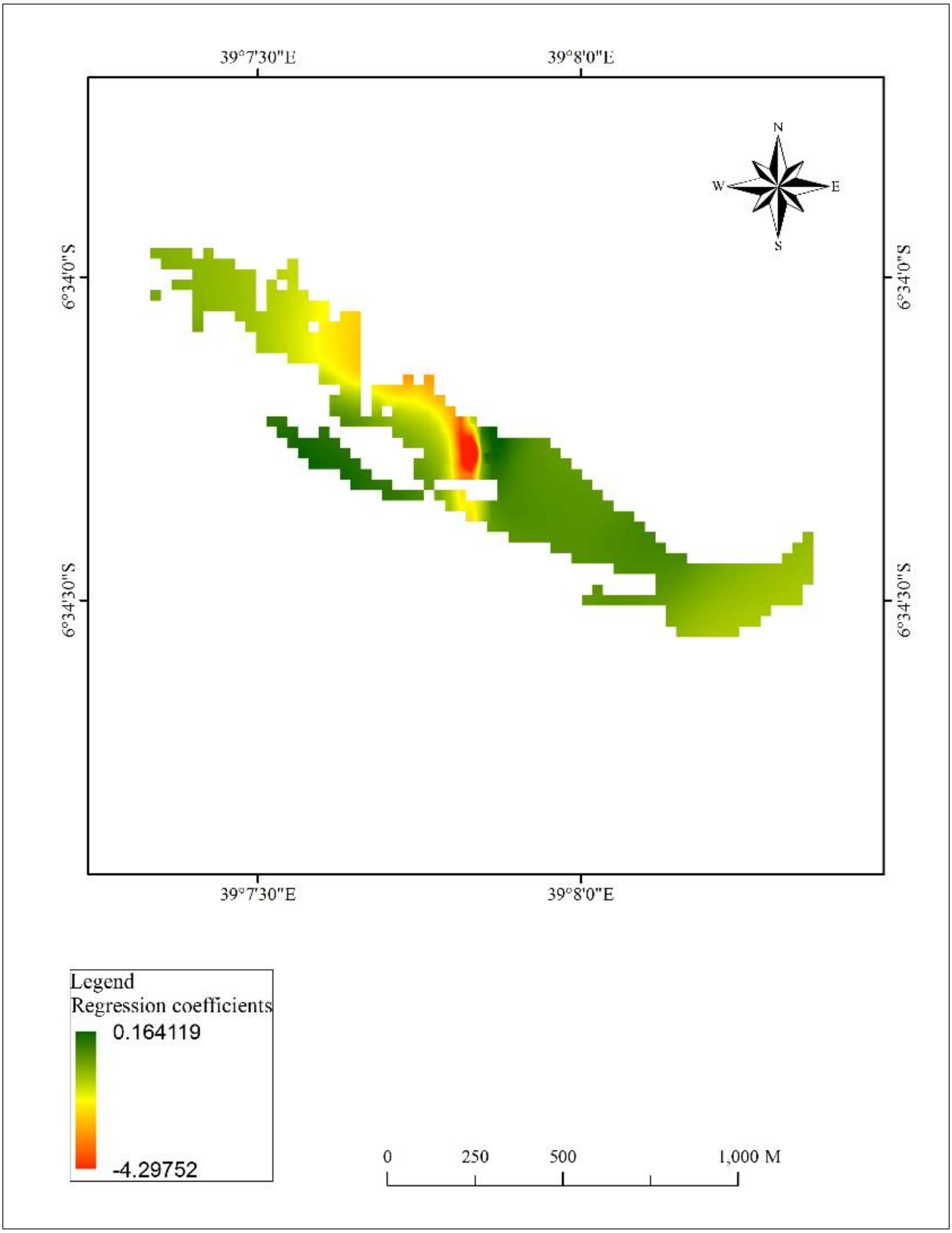


Figure 13. A GWR coefficient raster surface portraying the spatial correlation between vulnerability and NDVI-derived mangrove health at Mbweni.

## 3.6 Mangrove Cover Change

At Kunduchi, analysis of the 2003- 2014 GE satellite images for mangrove cover change (Figure 14) indicated loss (L) and gain (G) of 16.4 ha and 4.4 ha, respectively. Field observation and analysis of NDVI on the gained patches indicated low vegetation health. GE- based validation of loss (L) for some selected patches of the mangrove forest at Kunduchi is presented in Plate 4 as reflected in Figure 14.

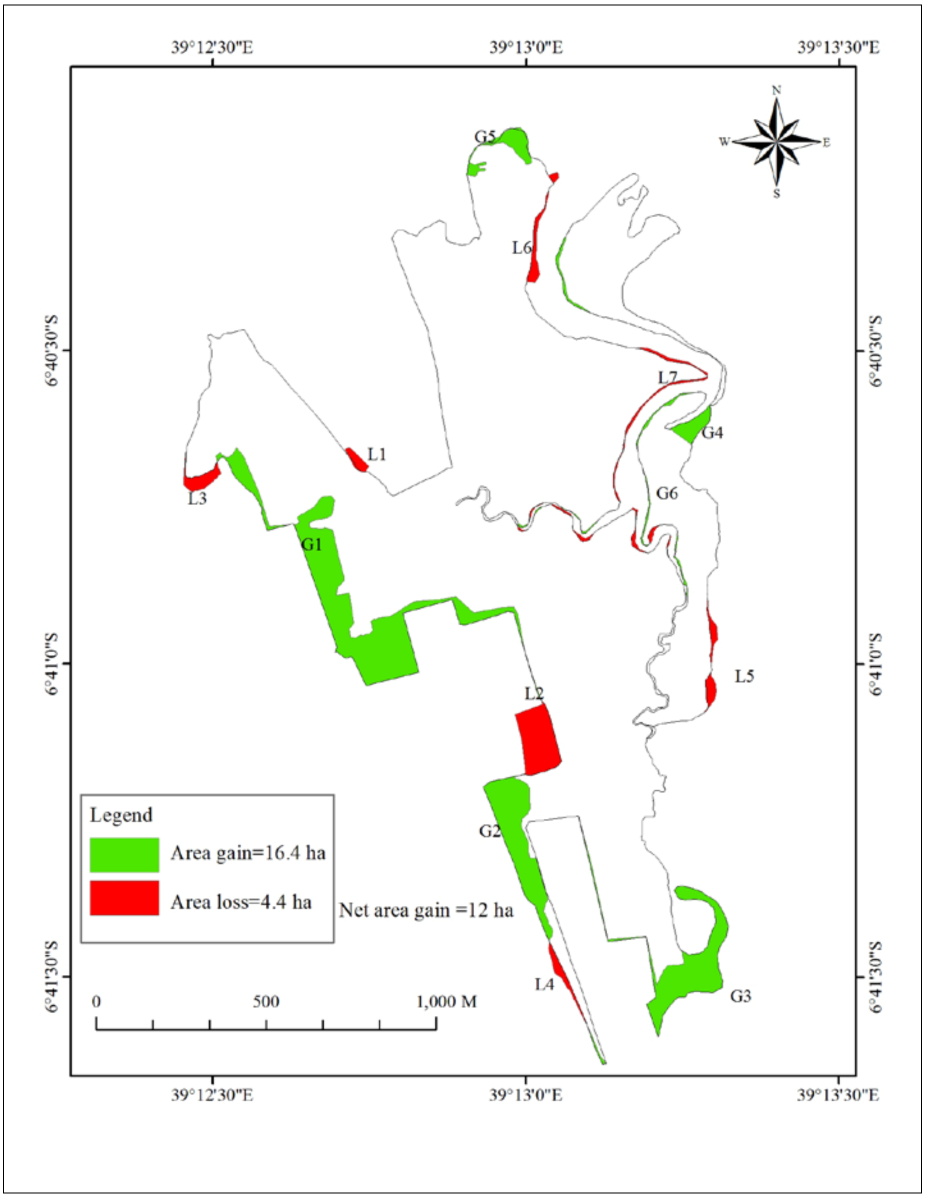


Figure 14. A map of Kunduchi site showing loss (L) and gain (G) of mangrove cover between 2003 and 2014.

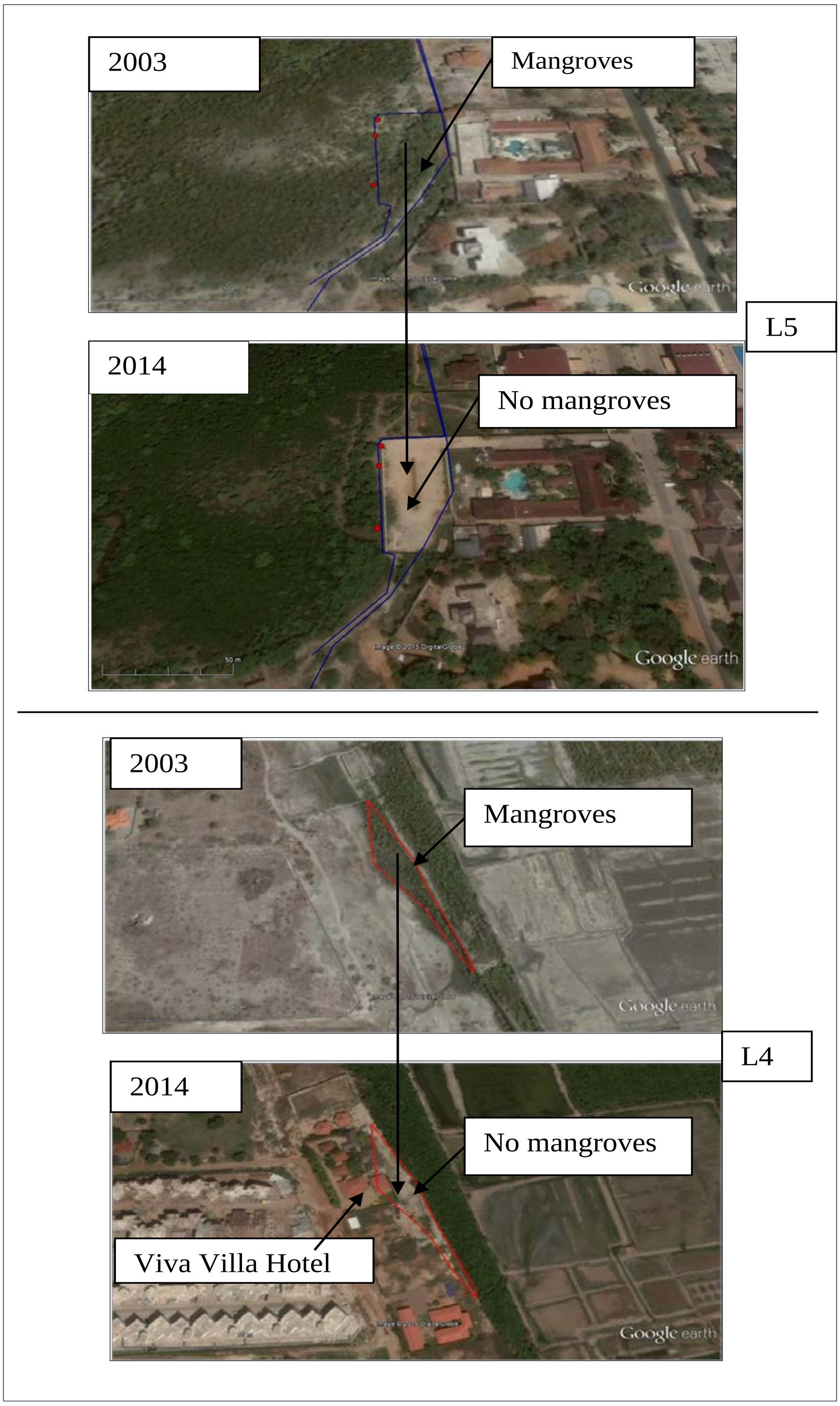


Plate 4. Google Earth images validating loss of mangroves at Kunduchi due to hotel construction. The top (L5) and bottom (L4) section indicate the lost mangrove area as reflected in corresponding label L5 and L4 in Figure 14.

For Mbweni, GE image analysis for mangrove cover change (Figure 15) indicated 1.9 ha loss and 2.6 ha gain during the period 2003-2014. Similar to Kunduchi, field observation and analysis of NDVI on the gained patches showed low vegetation health. Plate 5 and 6 provide GE based validation of mangrove loss (L1) in some selected patches of the mangrove forest at Mbweni as reflected in Figure 15.

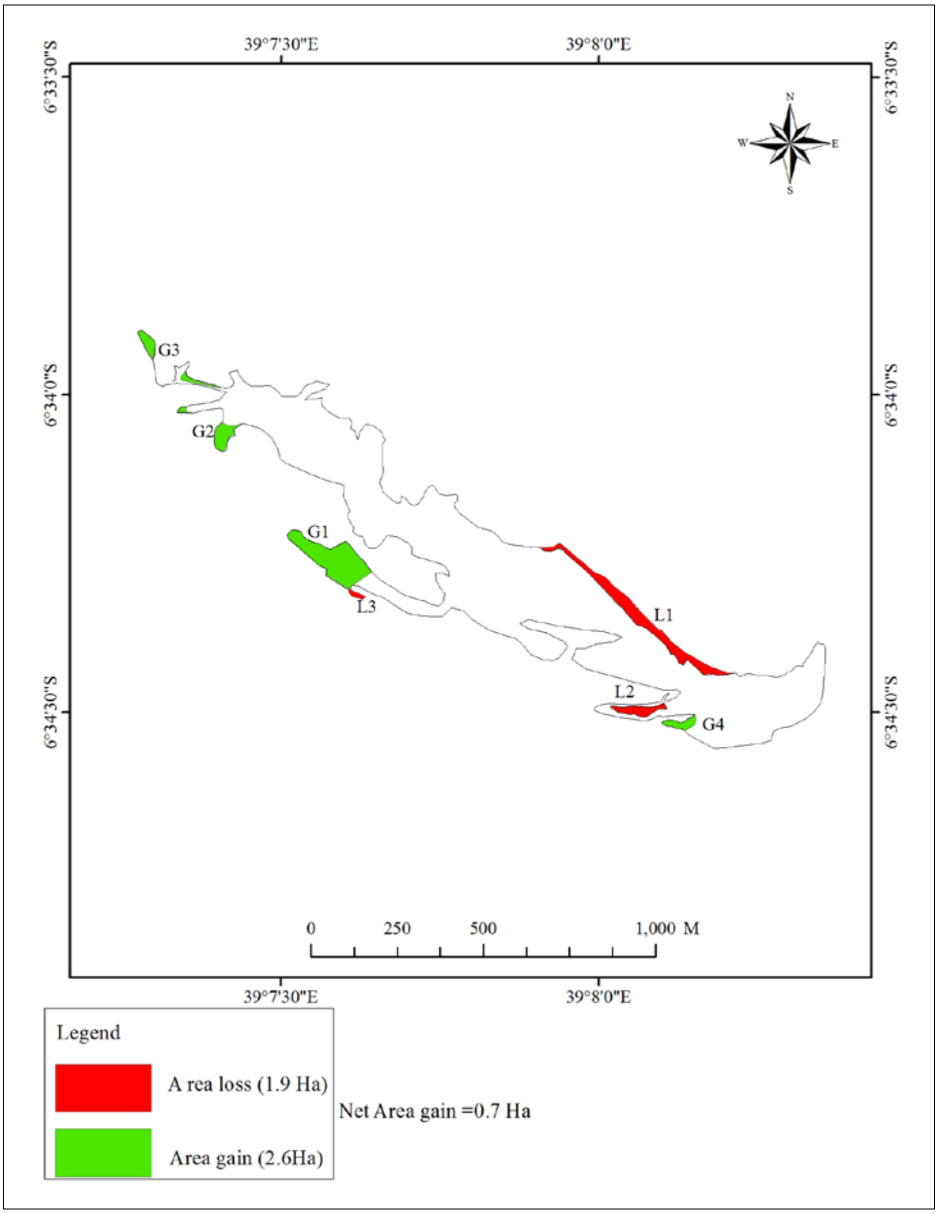


Figure 15. A map of Mbweni site showing loss (L) and gain (G) of mangrove cover between 2003 and 2014.

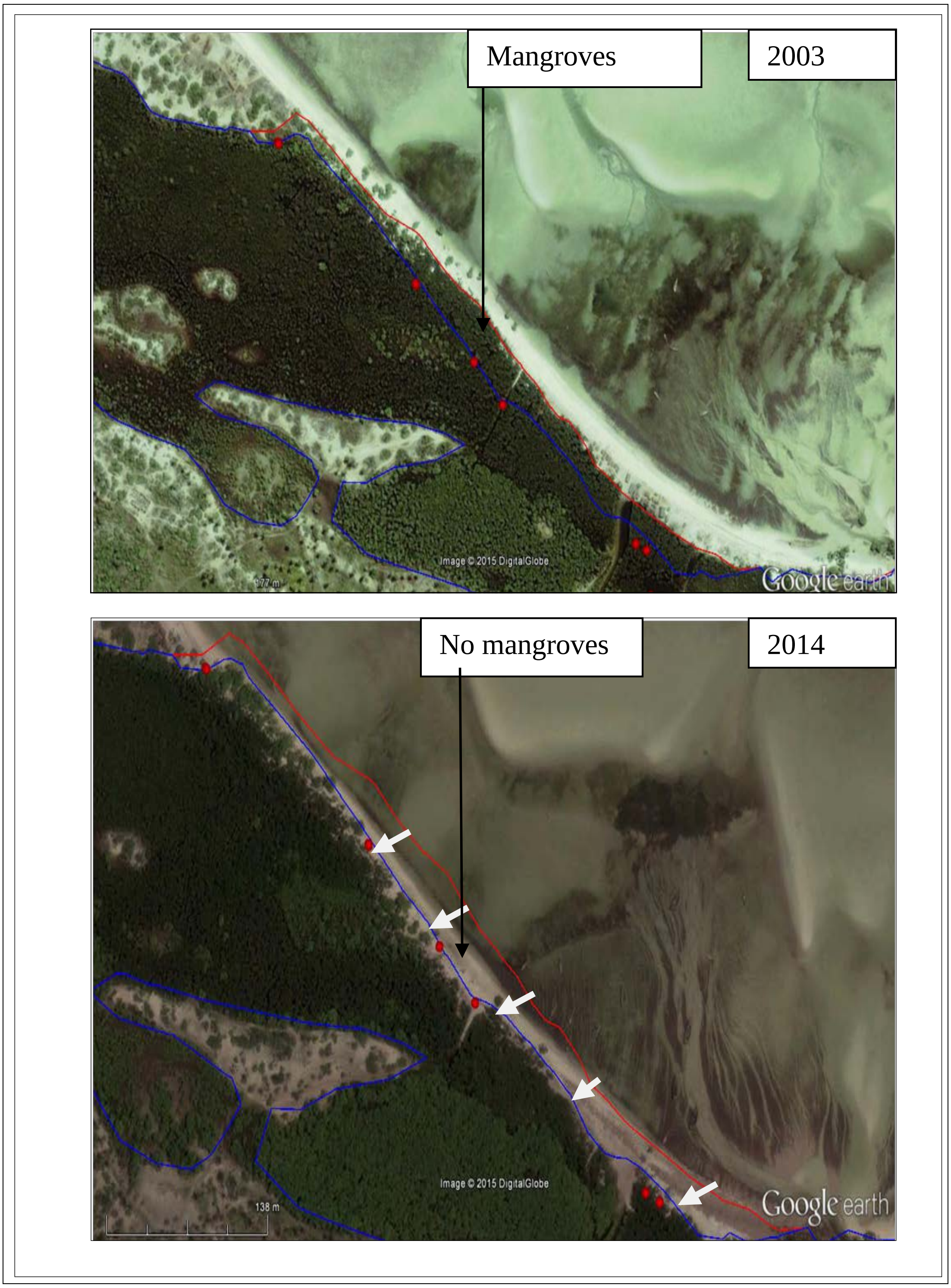


Plate 5: Google Earth images validating loss of mangroves at Mbweni due to erosion and trampling. The red and blue lines are respectively the 2003 and 2014 mangrove boundaries. The red dots are GPS ground points taken in March, 2015.

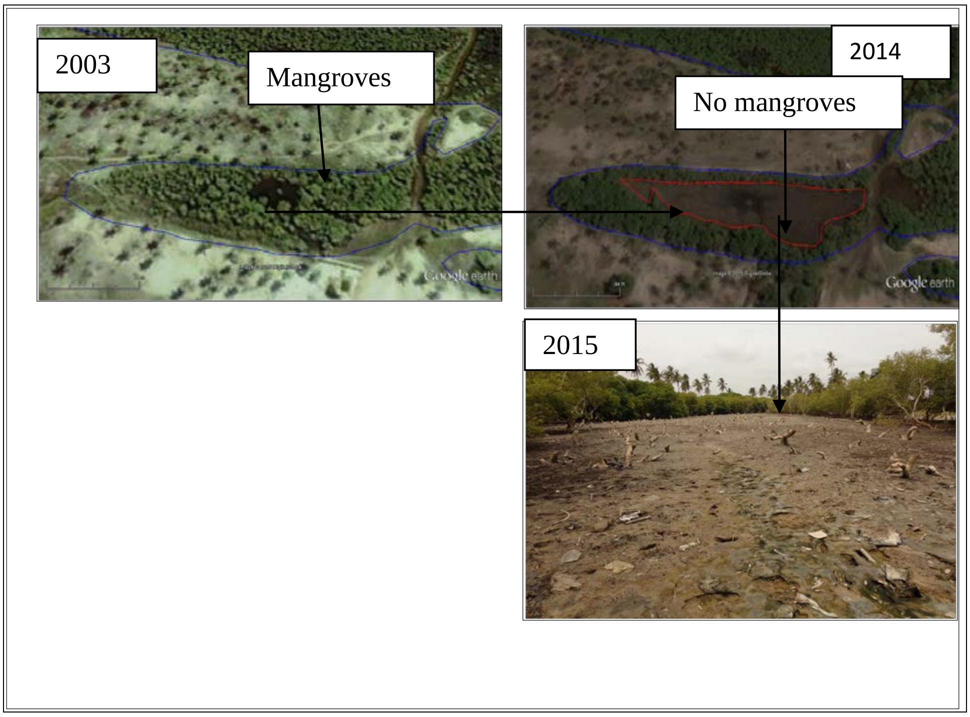


Plate 6: Google Earth images validating loss of mangroves at Mbweni due to flash floods. The inserted photo indicates the actual situation as witnessed during field observation. Restoration of the mangroves by local communities in the die-back area failed as seedlings did not survive. Photo credit by M. J. Mabula.

# 4. Discussion

## 4.1 Causes and Effects of Anthropogenic Pressures on Mangroves

Despite the conservation efforts by the CBOs, government and non-government actors, mangroves in these are still vulnerable to degradation as a result of anthropogenic activities. Major human threats are associated with coastal property development for both residential and commercial investments propelled by the fast expanding tourism industry in these coastal areas. Efforts made by TFS to install sign posts for the public awareness on the conservation status of mangroves have not spared the mangrove forests from human encroachment (Table 2; Plate 1 and 2). This implies that, mangroves have not been practically managed despite their legal protection by the instruments such as the Environmental Management Act, 2004 (subsection 57 (1)) and the Tanzania coastal tourism development guidelines, 2003. As Mangora [22] reported, the continued degradation of mangroves through anthropogenic pressures can be viewed as a result of institutional failure, caused by the absence of a central authority to coordinate the conflicting interests concerning licenses for land titles. Private investors have therefore taken this failure as a window of opportunity to violate regulations in favour of short term profits, but at the expense of the long term society's interests in mangrove resources [22].

### 4.2 Spatial Distribution of Mangrove Forests and Associated Anthropogenic Threats

The present study indicates the spatial distribution of major anthropogenic threats to the mangrove forests at Kunduchi (Figure.2) and Mbweni (Figure 3). At Kunduchi, total area for salt works recorded in the present study is relatively small compared to that reported by Mainoya *et al.* [20] and Semesi [31]. The present study has spatially revealed the significant extent of human encroachment into the mangrove forest for property development, particularly in the south-eastern part of the forest where tourist hotels are concentrated.

Unlike Kunduchi, human encroachment at Mbweni is low (Figure 3; Figure 7). Attempts to construct houses and hotels in and around the mangrove forest in this site were made in the past, but it was reported to have been stopped by the government.. Another possible explanation for this low mangrove proximity to settlements might be due to the small population size and the number of households which translate into low pressure on land resources as compared to Kunduchi site.

Infrastructure development, such as roads, fish landing site and fish market also play some role in mangrove degradation. For example, the fish market and landing site at Mbweni are located along the mangrove - ocean interface such that fishmongers, fishermen, and other people accessing these areas trample through the mangrove forest leading to mangrove degradation. Akwilapo [1] reported significant destruction of mangrove seedlings and saplings caused by dragging of fishing vessels under the mangrove canopy at Mbweni. With the increase in human population in this area, proper land planning is undoubtedly becoming an important and urgent way to reduce mangrove destruction caused by human pressures, particularly trampling.

### 4.3 Mangroves-Threats Proximity and Vegetation Health

The present study has spatially revealed and correlated the vulnerability and health status of the mangroves at Kunduchi and Mbweni. As the mangrove vulnerability maps portray, the proportional areas of highly vulnerable mangroves at Kunduchi and Mbweni is by 25.4% and 4.0%, respectively. This model based vulnerability could be an implied consequence of the societal failure to abide the existing rules [40, 42] which restrict human activities within 60 metres of the coastline. Results from analysis of NDVI at Kunduchi (Figure 10) and Mbweni (Figure 11) indicated 28.2% and 14.0% of the mangroves had low health, respectively suggesting increased vulnerability irrespective of mangrove proximity to the threats. Nevertheless, analysis of GWR (Figure 12 and 13) indicated a non- stationary spatial correlation of mangrove vulnerability and health; with negative values in some patches and positive in other locations. This could be caused by several reasons.

At Kunduchi for instance, negative correlations dominated the central part of the study area because of low proximity to the threats but high vegetation health. The highly vulnerable mangrove region in the eastern edge of the forest (Figure 6) unexpectedly showed high vegetation health (Figure 10). This observation may be attributed to the fact that, although the mangroves closer to settlements are susceptible to clear cuttings, those which survive might not necessarily lose their vegetative health status unless there is further degradation. However, the observed dumping of domestic wastes and landfills in the mangrove forest should be of much concern. Although such human activities may not translate into observable loss of mangrove vegetation health, their effects might be on other important ecological processes such as nitrogen fixation which affect the mangrove ecosystem processes and function [15].

In the western part of Kunduchi mangrove forest, where there was a positive positive spatial correlation with unhealthy mangroves, had low vulnerability. Despite the cessation of the salt works at this patch, mangrove recovery has been difficult. Shunula and Allan [35] argued, salt works tend to alter the local hydrology and produce hypersaline soil and consequently impair mangrove regeneration and growth. Most of the mangroves in this patch were once severely impacted by the salt works [20]. A similar phenomenon also existed at Mbweni, particularly in those mangrove patches formerly occupied by salt works.

Generally, the GWR analysis revealed 40% and 31% of the spatial correlation of mangrove vulnerability and health at Kunduchi (Figure 12) and Mbweni (Figure 13), respectively. This low spatial correlation implies that, other factors contributing to mangrove vulnerability were missed in the models developed. Ellison [7] and Omo-Irabor *et al*. [29] reported that, environmental factors such as resilience of adjacent ecosystems, relative humidity, temperature, sea level rise and precipitation as well as anthropogenic (population pressures, user conflicts and poverty) contribute to mangrove vulnerability. Some of these factors could have modified the observed mangrove vulnerability, albeit they were not dealt with the present study. Therefore, the challenge for future research in mangrove vulnerability assessment is to find ways of integrating these factors in a single model for the better spatial representation of mangrove vulnerability. In addition, this study has applied NDVI proxy indicator for mangrove health status, which has its limitations [37]. The NDVI derived from single date satellite imagery might not be an ideal indicator of the long term health status of the mangroves in these sites. Mangrove health derived from multi temporal NDVI data supplemented with other *in situ* measurements such as tree density, basal area, and ground and above ground biomass could have modified the observed pattern of mangrove health. Another possible cause of the observed low spatial correlation might be due to data classification system adapted in the present study. The data for both mangrove vulnerability and health were classified into only three categories (low, moderate and high) on a scale of 1-3 discrete numbers. As Mennis [24] noted, data classifications cause loss of relevant variations of the values in input data and thus affecting the GWR outputs. Therefore, the interpretation of the results from these models needs high attention due to the violation of mangrove vulnerability-health negative correlation in certain locations of the forest in all study sites.

## 4.4 Mangrove Cover Change

Mangroves in the study sites have been altered by increased human activities. At Kunduchi areas which were once occupied by mangroves were lost to give way to expansion of salt works hotels (Figure 14 label L1-2) and residential house construction (Figure 14 label L4-5). The observed loss of mangroves particularly in the forest margins, suggests a high vulnerability to anthropogenic pressures than those in the interior of the forests (Figure 6).

Although the main focus of the present study was on anthropogenic drivers, mangrove losses in the Kunduchi mangroves were observed to be contributed by coastal erosion. The mangrove trees, particularly those located along the western side of the river bank were lost as a result of continued erosion (Figure 14 label L6-7). The losses of mangroves along the river banks were also once reported by Makota *et al*. [21]. Previous investigations ([27, 28] on the nature and cause of coastal erosion in this area indicated aggravation of the problems by anthropogenic activities involving sand mining and removal of protective mangroves. Although there have been efforts to abate the erosion problems through construction of groynes and seawalls around the river mouth [33], this protection effort has probably not been effective to retard the tidal and wind generated waves [28] along the river bank, leading to the observed mangrove loss.

Analysis of the GE imageries also revealed an increase in mangrove areas in some forest patches due to natural regeneration (Figure 14 label G1) and artificial restoration (Figure 14 label G5). However, most of the recovered patches showed poor health status (Figure 10) probably due to difficulties in recoveries.

Local knowledge and field observation at Mbweni site validated that, high human trampling impacts (Figure 8) in synergy with increased erosion processes have contributed to mangrove loss especially in those areas fronting the Indian Ocean (Plate 5). Flash flood associated with heavy rainfall that occurred in the recent past [13] caused the death of mangroves at Mbweni (Plate 6). However, human activities involving unplanned settlement construction were reported to obstruct natural waterways leading to water accumulation in certain patches of the mangrove forest. At the time of the field observation, the die-back area was predominantly occupied with stumps, the trunks being cut by local people as firewood. Efforts by the CBO members to replant *Avicennia marina*, the mangrove species to the area failed, probably due to changes in soil characteristics and hydrology [9]. This suggests a thorough consideration of ecological restoration principles [26] before actual planting of seedlings.

## 5. Conclusion

The results from the present study have revealed several anthropogenic pressures that need urgent mitigation measures. Mangroves continue to face degradation as a result of salt works, urban expansion, pollution and unsustainable fishing practices. The local CBOs, which were active in mangrove conservation during the KICAMP, have now weakened and lost cohesion. In order to re-strengthen the CBOs, further facilitation and empowerment should be given to community members for them to value mangrove conservation through CBOs for livelihood enhancements. This can be done through promotion of emerging incentive - based strategies and schemes like payment for ecosystem services.

The results from the mapping of threats and mangroves based on free and high resolution GE images have provided a significant contribution in up-dating our understanding about the spatial distribution of threats and mangrove resource for informed decision making and planning. Researches and managers, especially in developing countries like Tanzania, may take advantage of this open sourced spatial data for continuous monitoring of mangrove resources.

The present study has also spatially revealed the mangrove vulnerability (based on proximity to major anthropogenic threats), health and cover change, thus providing answers to the principal question inquiring about the extent of mangroves vulnerability in the study sites. These findings provide explanations for the current mangrove status as well as the extent of human impacts on these fragile mangrove forests. However, the present study has focused on a few but important mangrove threats in the study sites, leaving many unaddressed. In addition, the spatial information generated by the present study should not be viewed as a panacea for all problems inherent in mangrove conservation in the study area. Tulloch et al. [38] once argue that, threat maps are just assistant tools towards proper decision making. Effective resource protection largely depends on conservation commitment and determination of the consequences of all possible human actions affecting the resources.

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