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Mangrove cover change detection in the Rufiji Delta in Tanzania

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Abstract

The Rufiji Delta is a critical ecosystem that comprises 50% of mangrove cover in mainland Tanzania, providing a plethora of ecosystem services that support diverse livelihood options. However, the rate of mangrove loss, especially due to rapid expansion of rice farming in the delta, is alarming. Landsat imagery from 1991, 2000, 2009 and 2015 was used to estimate total current mangrove area in the delta. There has been loss of mangroves from 51,941 ha estimated in 1991 to 45,519 ha in 2015, which is an annual loss rate of 0.52%. Clearance for rice farming expanded from 5,344 ha in 1991 to 12,642 ha in 2015. The average mangrove annual loss and gain from 1991 to 2015 were estimated to be 378 ha and 109 ha respectively. The consequences of this loss are not well appreciated. The present analysis serves as an updated baseline to inform the urgent need for coordination of multiple stakeholders to address the complex drivers of mangrove loss to secure the future of mangroves and ecosystem services in the delta.

Keywords: Rufiji Delta; mangrove forest change; Landsat; deforestation; rice farming

Introduction

Mangrove forests in mainland Tanzania are categorized as State Forest Reserves by the Forest Act of 2002 (URT, 2002). They occur along almost the entire coastline in continuous and fragmented stands (Mangora *et al.,* 2016). Recent estimates by the National Forest Resources Monitoring and Assessment (NAFORMA) indicate that mangroves cover approximately 158,100 ha, which is about 0.3% of the total forest area in the country (MNRT, 2015). Although this represents a small proportion at the country level, mangroves form a critical interface between terrestrial, estuarine, and near-shore marine ecosystems. Where they occur, mangroves are important economic and ecological resources for communities, providing useful products such as firewood, charcoal, poles and traditional medicines, and support for fisheries (Masalu, 2003; Wang *et al.,* 2003; Mangora *et al.,* 2016). For instance, about 80% of all wild shrimp catches in the country are associated with mangrove forests in the Rufiji Delta (Masalu, 2003).

Despite the critical value of mangroves, they are still exposed to degradation and deforestation due to weak law enforcement, poor management and land use prioritization, poverty and extreme dependence on natural capital (Mangora, 2011). Globally, mangroves have been reported to rapidly degrade at rates exceeding loss in many other tropical forests (Polidoro *et al.,* 2010; Giri *et al.,* 2011; Jones *et al.,* 2015). They are being lost at the rate of about 1% per year (FAO, 2007); in some areas, the rate may be as high as 8% per year (Miththapala, 2008). It is estimated that 20% to 35% of the world's mangrove area has been lost since 1980 (Giri *et al.,* 2011). The rates of loss are highest in developing countries where mangroves are cleared for coastal development, aquaculture, timber and fuel production (Polidoro *et al.,* 2010). Mangroves in Tanzania are not the exception; they are being rapidly degraded and deforested through over-exploitation for poles and timber, and the conversion of forests to other uses like agriculture, aquaculture and salt making, the impact of which is not well appreciated (Mangora *et al.,* 2016). As an attempt to address these management challenges, the government has invested in developing a National Mangrove Management Plan during 1989 – 1991 (Semesi, 1992). This Plan emphasized the need

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to have close coordination among the various users of the mangrove ecosystem. The Management Plan was however not effectively implemented due to weak institutional frameworks and inadequate financial and technical resources, and has remained without revision over the years, making it obsolete (Mangora, 2011).

Assessment of the status of mangrove forest cover is thus important for proper decision making on management of mangroves, including prioritization of management activities. Yet, studies on the forest cover and land use changes on mangroves in Tanzania are limited. Nindi *et al.* (2014) reported on mangrove cover change and land use only for the northern Rufiji Delta. Brown *et al.* (2016) used three ALOS PALSAR images to investigate the spatial-temporal patterns of backscatter mechanisms in mangrove forests using target decompositions, not actually dealing with land use and land cover changes in the delta. Mwansasu (2016) reported that although the potential of over-exploitation exists, there is no significant difference between the rate of mangrove loss and gain in the delta. This is contrary to observations by other similar studies carried out in the delta, which reported significant loss of mangroves (Wang *et al.* 2003; Peter, 2013). In this study remote sensing data combined with field surveys were used to assess mangrove forest cover and land use change in the entire Rufiji Delta from 1991 to 2015. The data forms a useful updated baseline for subsequent management planning, enforcement and monitoring.

Study area

The Rufiji Delta is located about 200 km south of Dar es Salaam between latitudes 8˚ 20′ 00″, 7˚35′ 00″S and longitudes 39˚10′ 00″, 39˚20′ 00″E (Fig. 1). The delta is created by the Rufiji River, the largest river basin in Tanzania, which drains about 20% of the country, with a mean annual flow of some 800 $m^3 s^{-1}$ (Duvail and Hamerlynck, 2007). The Rufiji has a strong seasonal flow pattern, with a main flood peak around April. The delta has the largest continuous mangrove forest, covering about 50% of the total area of mangroves in Tanzania (Wang et *al.,* 2003; URT, 2009). For local management purposes, the delta has been divided in three major blocks: northern; central; and southern blocks (Semesi, 1989). The northern block contains about 46% of the total mangrove coverage, and is characterized by more freshwater input, is more accessible, and therefore more frequently utilized for local and commercial interests than the other blocks (Brown *et al.,* 2016). Information about the central and southern blocks are limited compared to the northern block because of accessibility difficulties, and therefore attract limited research interests. Eight mangrove species have been reported to occur and are well represented in the delta, namely *Avicennia marina*, *Sonneratia alba*, *Ceriops tagal*, *Lumnitzera racemosa*, *Bruguiera gymnorrhiza*, *Rhizophora mucronata*, *Xylocarpus granatum* and *Heritiera littoralis* (Wagner and Sallema-Mtui, 2016). The two missing species, *Xylocarpus molluccensis* and *Pemphis acidula* are characteristically rare in the region, potentially due to their limited geomorphological niche.

The Rufiji mangrove forest was the first to be declared a forest reserve in Tanzania in 1898 during the German colonial period (Sunseri, 2007). One of the unique features of this forest reserve is that there are legally established village settlements within it (Mwansasu, 2016), who rely on mangroves and the associated marine environment for a range of resources and ecosystem services to enhance their livelihoods (Semesi 1991; Masalu*,* 2003; Wang *et al.,* 2003). Recent estimates indicate that over 49,000 people live in and around the delta, directly engaged in rice farming, mangrove cutting for poles and timber, and fishing activities for both food and income security (Peter, 2013). Mangroves are cleared for rice farming and timber to feed other parts of Tanzania including the islands of Zanzibar. Areas dominated by *H. littoralis* are more favored for rice farming while *C. tagal*, *R. mucronata* and *B. gymnorrhiza* are heavily cut for poles, *X. granatum*, and more recently *S. alba*, are logged for timber. Other species are not considered suitable for timber. Accordingly, mangrove cover in the delta has declined over time. An inventory carried out in 1989 combining aerial photographs and ground truthing, showed that the Rufiji Delta had about 53,255 ha of mangroves (Semesi, 1992). In the year 2000, Wang *et al.* (2003) used Landsat images and estimated the total area covered by mangroves in the Rufiji Delta to be 48,030 ha. Nindi *et al.* (2014) reported a loss in the northern block of 2,865 ha of mangrove forest from 25,312 ha reported in 1989 to 22,447 ha in 2010. The structural and floristic degradation may have taken place in the delta as well, but no detailed information is available, probably due to detection complexity by remote sensing. Unpublished inventory data indicate that there is a species change towards the dominance of *C. tagal* and *A. marina* in many areas of the delta. Mshale *et al.* (2017) reported a complex governance landscape in the delta, characterized by lack of mechanisms to coordinate a diversity of resource users and conflicting conservation actors' interests that further threaten the integrity of this unique coupled human-nature system.

Materials and methods

Landsat images

Free (https://www.usgs.gov/) Landsat TM 4, 7 and 8 (path 166, row 65 and 66) images for 1991, 2000, 2009 and 2015 with 30 m spatial resolution was acquired and used to analyze and quantify the mangrove forest change from 1991 to 2015.

Figure 1. Map of the Rufiji Delta in Tanzania showing the study site.

Image processing for cover change detection

The IMPACT toolbox version 2.1.12 was used for image pre-classification. Unzipped Landsat images were saved in the IMPACT raw data file while the study site shape file was saved in the vector data. The shape file was geo-referenced to WGS-84 UTM zone 37S, which is the geographic location of the Rufiji Delta.

Pixel based classification was performed for all the images to partition digital images into multiple segments based on spectral, geometrical or computed properties (texture), together with user-defined parameters describing the size, shape and similarity compared to adjacent segments. Due to clear spectral distinctness of the classes in the Rufiji Delta, supervised classification and segmentation of images were used to classify land cover classes. The layers were coded using the Impact Tool legend. The ground truthing data and the analyst's expert knowledge were used to obtain land cover classes for each year. The land cover map for the year 2015 was processed first and a copy of it was edited as per interpretation from the image from 2009 to derive a new land cover layer for that year. The same process was repeated to generate land cover maps for the years 2000 and 1991 retrospectively. Gain and loss statistics were computed with ArcGIS, and new layers showing the status of the mangroves for the years 1991, 2000, 2009 and 2015 were obtained. Changes of other land uses into mangroves were considered as a gain of mangroves, while conversion of mangroves into other land uses was considered as a loss of mangroves.

Field data collection for validation

A field mission was organized in November 2016 to collect ground truth data to validate classified images. A Garmin GPS (Garmin inReach Explorer+, made by Garmin, USA) was used to collect 20 coordinate points in the delta for each of the 5 classified land covers (mangroves, agriculture, bare lands, non-mangroves, and water). In this study, the bare land includes salt pans and mud flats, while non-mangroves are dominated by coconut trees and *Barringtonia racemosa.* In total, 100 coordinate points were collected randomly in the delta. The coordinate points were taken from the most representative land cover class. Photos were taken and consultations with Tanzania Forest Service (TFS) Agency field officers and local farmers were conducted to broaden our understanding of the land cover changes in the delta to help in the accuracy assessment.

Classification and accuracy assessment

As recommended by Smits *et al.* (2010), a confusion matrix was used to assess and compare accuracy of the classification results. Fifty coordinate points, 10 points for each classified land use class, collected directly from the study site were used to estimate user accuracy, producer accuracy, overall accuracy,

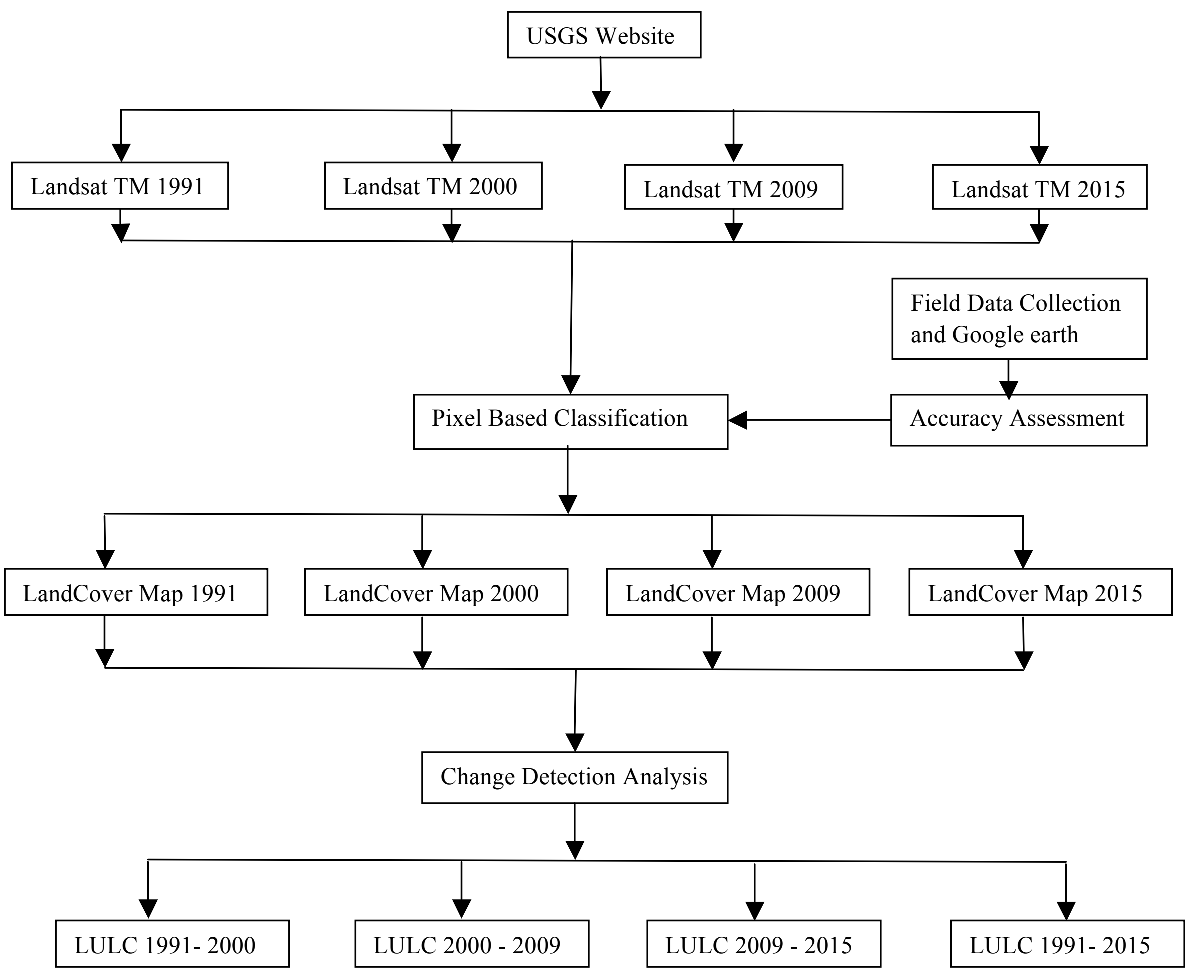

Figure 2. Flow chart showing procedures used for land use/ land cover classification.

and Kappa coefficient. A new shape file was created from fifty reference points. Reference points were aligned with pixels of classification to ensure classes in both references and classified images had similar codes. The reference points were then combined with classified images and displayed in a confusion matrix. The displayed data were then computed to obtain percentage user, producer and overall accuracies, and the Kappa coefficient.

Results

Landsat image classification showed an overall accuracy of 90%, user accuracy of 92%, and producer accuracy of about 88% for the mangrove cover in the year 2015, while the Kappa coefficient was calculated to be 86%. More cumulative loss than gain of mangrove cover was detected, from a total area of 51,941 ha estimated in 1991 to 45,519 ha in 2015 (Tables 1, 2 and Figs. 3a, b). It was estimated that 9,089 ha of mangroves were lost between 1991 and 2015 compared to 2,632 ha gained in the same period, translating to a net loss of 6,456 ha (12.4%) of mangroves in the period of 24 years (Table 2). Rice farming remains the main driver of mangrove loss in the delta, where conversion of mangrove areas for rice farming expanded from 5,344 ha in 1991 to 12,642 ha in 2015. Bare lands have constantly decreased from 19,993 ha in 1991 to 17,170 ha in 2015. Expansion and shrinking dynamics were evident for the river channels (water body) and non-mangrove areas over the analysis period.

Annual loss was estimated to be between 489 ha and 532 ha, whilst the gain was between 176 ha and 302 ha (Table 2). The average annual loss and gain were calculated at 378 ha and 109 ha respectively. Therefore, the average net annual mangrove change was calculated at -269 ha, translating into an annual rate of mangrove loss of 0.52%.

Discussion

The present analysis indicates that there have been greater mangrove losses in the Rufiji Delta in comparison with other mangrove areas in Eastern Africa between the 1980s and present. Nevertheless, the annual mangrove loss estimated in this study corresponds with the findings of Nindi *et al.* (2014), although that study concentrated on the northern block only. Similarity of these findings, regardless of differences in sizes of study sites, could be due to the fact that the major mangrove losses occur in the northern block where there is active rice farming and cutting for poles and timber (Fig. 4). Elsewhere, more annual mangrove gains than losses have been reported, for example in the Zambezi Delta (Shapiro *et al.*, 2015). Slight annual mangrove losses have also been reported in the Mahajamba Bays in Madagascar (Jones *et al.*, 2015), Mida Creek (Alemayehu *et al.*, 2014), and Tudor and Mwache creeks in Kenya (Bosire *et al.*, 2014). The greater mangrove losses observed in the Rufiji Delta might be due to the nature of the delta where, contrary to other parts of Eastern Africa, people have

Table 1. Land cover sizes (ha) for the classification years.

Land cover type\Year	1991	2000	2009	2015
Mangroves	51,941	49,687	46,862	45,519
Agriculture	5,344	8,395	11,172	12,642
Bare land	19,993	18,602	17,930	17,170
Other forest	3,921	2,522	3,548	4,268
Water	13,317	15,310	15,002	14,916

Table 2. Land cover changes for the 4 epochs of the classification years (annual loss/gain).

Change rate/epochs	1991-2000	2000-2009	2009-2015	1991-2015
Loss (ha)	4,468 (496)	4,409 (489)	3,192 (532)	9,089 (378)
Gain (ha)	2,324 (258)	1,584 (176)	1,814 (302)	2,632 (109)
No change (ha)	74,439	73,595	74,697	69,745
Water	13,284	14,926	14,812	13,049

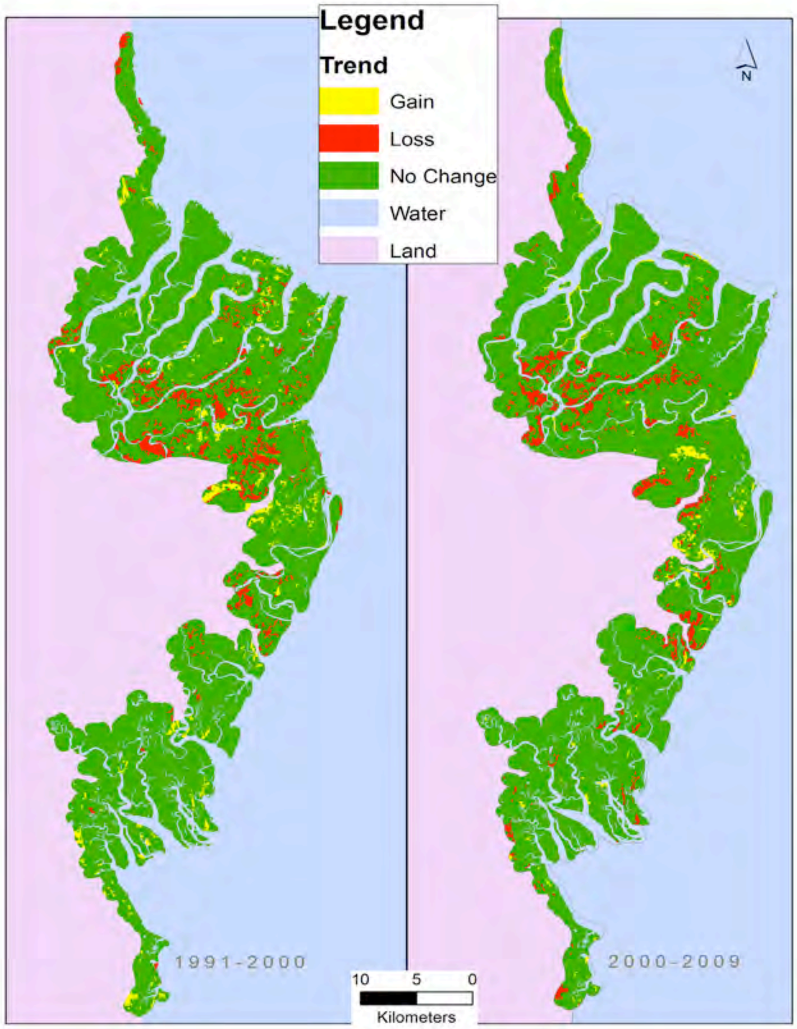

Figure 3a. Mangrove cover change detection (gain, loss and no change) in the Rufiji Delta for the classification periods between 1991-2000 and 2000-2009.

permanent settlements in the delta with sole dependence on mangrove resources for livelihoods, such as rice farming and cutting of mangroves for poles and timber (Mshale *et al.,* 2017). Although the Mangrove Management Plan developed in 1991 clearly categorized mangrove forests into four management zones: Zone I - forests for total protection; Zone II - forests for production; Zone III - degraded areas to be closed to allow recovery; Zone IV - areas to be set aside for different developments (Semesi 1992), there has been weak enforcement of the plan, allowing mangroves to become a tacit common pool resource (Mangora, 2011; Mangora *et al.,* 2016).

Areas surrounding the Rufiji river mouth in the northern block and the northern part of the central block are the areas severely under pressure from rice farming. These areas were initially dominated by *H. littoralis*, and through traditional knowledge, farmers understand these areas have low water salinity and high soil nutrients. Farming activities were also noted to expand to other areas dominated by *C. tagal* in the northern part of the northern block. The farmed areas are also easily accessible by local boats and therefore promote rice farming activities. Peter (2013) linked expansion of rice farming in the delta with rapid human population increase. Statistics show that human population in and around the delta has increased from 38,148 people in 2000 to 49,902 people in 2012. Mwansasu (2016) noted that the rapid expansion of rice farming in the northern block was contributed by the shift of the dominant fresh water-flow in the 1970s. The shift increased population in the northern block, with consequent increase in food demand and therefore increased rice farming activities. Due to poor agronomic knowledge, the farming approach in the delta is of a shifting nature where farms are cultivated in a rotation of 3-5 years before farmers move on to open new farm fields by clearing mangrove forests; and the vicious cycle continues (Fig. 5).

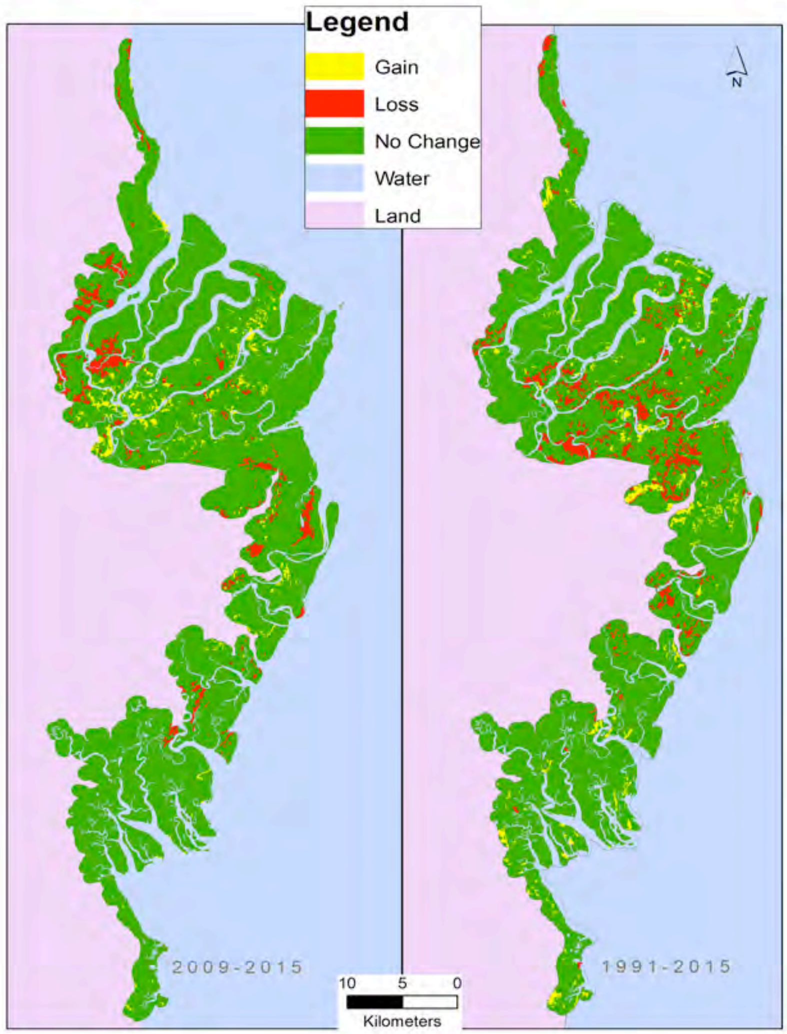

Figure 3b. Mangrove cover change detection (gain, loss and no change) in the Rufiji Delta for the classification periods between 2009-2015 and overall from 1991-2015.

There were greater mangroves gains between 2009 and 2015 than in other years. This is probably due to conservation projects initiated in the delta in late 1990s. Some of the projects were implemented by WWF-Tanzania, TFS Agency and the Rufiji District Authority and aimed at restoring deforested areas in the delta. Like any other large river delta, the Rufiji River Delta is also dynamic, with changing flow paths, shoreline position and development of new lands, which can result in changes to mangrove cover, notably directional changes or shifts along geomorphological patterns (Woodroffe, 1992; Beilfuss *et al.,* 2001). Newly formed islands and mud flats are colonized by *A. marina* and *S. alba*, representing some of the mangrove gain recorded in this study.

Non-mangroves, especially coconut trees, do not perform so well in the delta. The under-performance of coconut trees discourages farmers from planting more trees, therefore areas covered by non-mangroves remain relatively unchanged over the years. Decrease of bare land was mainly contributed by the collapse of salt making processes in the delta. Salt making collapsed in the delta because of the loss of a market for locally made salt from traditional salt pans that is not iodized. Some abandoned salt making areas have been observed to be colonized by mangroves, especially *A. marina* (Fig. 6). However the regenerated *A. marina* appears to be stunted, probably due to high soil salinity in these areas.

Conclusion

The present data analysis serves as an updated baseline on the mangrove cover and land use in the Rufiji Delta, where management planning should be a conservation priority. This retrospective analysis of mangrove cover change demonstrates that freely available Landsat images are an important source of data for land use/cover change studies, especially in developing countries where resources to purchase high resolution imagery data are limited. The loss of 12.4% of

Figure 4. Illegal mangrove pole cutting in the Rufiji Delta. Poles are cut for construction purposes by local communities and for business in the near towns.
Figure 5. Re-opened rice farm in the mangrove forest in the Delta. The area was left as fallow for about 3-5 years before being cleared again. The photo was taken in January 2016.
Figure 6. Mud flat in the Rufiji Delta. Some mud flat areas are colonized by stunted *Avicennia marina.* The photo was taken in 2018.

mangroves in the period of 24 years is alarming and the consequences are not well appreciated. This calls for more strategic collaboration between stakeholders to address the main drivers of mangrove loss in the delta. To address the challenge of mangrove loss, especially conversion of mangroves into rice farming, TFS should take the initiative of establishing multi-stakeholder platforms to regularly discuss opportunities and threats to the delta, and agree on the best way that they can work together to address the challenges for longer term benefits. There is also a need to establish a special management arrangement for the Rufiji Delta, which integrates various actors and communities. This management arrangement should facilitate agreement between TFS and communities where roles and responsibilities of communities in the delta are well clarified and managed. This will reduce the long-term ongoing friction between TFS and communities, which promotes illegal mangrove practices in the delta. Further research, especially on mangrove cover projection and analysis of species composition change for management planning, is relevant.

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