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CASE REPORT

Cost–benefit analysis of mangrove ecosystems in flood risk reduction: a case study of the Tana Delta, Kenya

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Abstract Mangrove ecosystems are valuable and productive coastal ecosystems that provide several ecosystem services. Nevertheless, trivialization of the value of mangrove ecosystems has led to their decline at an annual global rate of 1–2%. Degradation undermines the resilience of these ecosystems and threatens the continuous supply of goods and services that they provide. Diverse mangroves that contribute to the well-being of coastal communities characterize Kenya's coastal region. Despite their importance, 0.7% of the mangroves are destroyed annually. In this study, the value of mangroves with regard to coastal flood risk reduction was estimated via a case study of the Tana Delta, Kenya. The valuation was calculated using the total economic value framework where both direct and indirect use values that influence flood risk are calculated using flood-avoided damage approach and local market prices. For comparative purposes, all the estimates presented in this paper were standardized to the 2015 US$/ha equivalent value using the United States Consumer Price Index for all urban consumers. The net value of mangroves for flood reduction was estimated to be between US$238/ha/yr and US$311/ha/yr. The skewed distribution was largely attributed to a variation in flood frequency and mangrove forest density.

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Introduction

Mangrove ecosystems are one of the most valuable and productive coastal ecosystems and provide a wide range of ecosystem services. These services are of value to local, national, and international communities and include provisioning (fuel wood, timber, poles, posts, charcoal, and non-wood products—such as food, thatch, fodder, medicine, and fisheries), regulating (carbon sequestration, shoreline protection, and erosion control), supporting (by providing a habitat conducive to biodiversity), and cultural (recreation, esthetic, and tourism) (Barbier et al. 2011; FAO 2007; Kirui et al. 2013). Despite these invaluable services, mangroves are one of the most threatened ecosystems in the world and are declining globally at an annual a rate of 1–2% (FAO 2007). Mangroves along the Kenyan coastal region are estimated to have declined at a rate of 0.7% per year between 1985 and 2010. The decline was accelerated by the overharvesting of mangrove wood products, conversion to other land uses, and legislative inadequacies (Kirui et al. 2013).

The degradation of ecosystems undermines their resilience and threatens the continuous supply of ecosystem services. It is estimated that mangrove deforestation generates 0.02–0.12 Pg carbon per year in emissions and constitutes approximately 10% of the total emissions from global deforestation (Donato et al. 2011). A degraded ecosystem continuously increases a community's vulnerability and exposure to hazards because the ecosystem's capacity to meet people's needs decreases (Colls et al. 2009; Gandage and Ranadive 2009; Munang et al. 2013). Mangrove forest cover decline severely disrupts the subsistence of coastal communities. Mangrove deforestation also threatens the flora and fauna that depend on mangroves for survival, especially fragile coral reefs (Gupta and Nair 2012).

A lack of knowledge of the economic value of the invaluable services provided by mangroves has promoted their overexploitation (UNEP 2011). Inadequate information regarding the true value of mangroves has led to the preservation of these ecosystems being neglected in public decision-making and the formulation of environmental policies (Brander et al. 2012; Kareiva et al. 2011). Insufficient economic valuation of ecosystem services is also a major impediment to ecosystem-based disaster risk reduction (Eco-DRR) (Barbier et al. 2011; Renaud et al. 2013). Many users are aware of provisioning services. The value of regulating services is either trivialized or unknown and is rarely considered in the decision-making process (DEFRA 2007). Das and Vincent (2009) also noted that the role of mangroves in protecting coastal communities against hazards continues to be undervalued. This finding highlights the need to shed more light on regulation services, such as flood control. Given that mangroves in Kenya are declining at an annual rate of 0.7% (Kirui et al. 2013), it is likely that the local users, legislators, and policy-makers are unaware of and/or underestimate the actual value of the mangroves.

Several studies have examined the role of mangroves in storm protection and flood control. Alongi (2008) and Lacambra et al. (2013) discovered that a healthy and well-managed mangrove ecosystem acts as a buffer against flood hazards and reduces the exposure of people and productive assets to floods. Studies conducted after the 2004 tsunami indicated that in areas with a healthy mangrove belt, only 7% of villages were affected, and the damage to these villages was minimal. Meanwhile, areas with degraded mangroves experienced between 80 and 100% damage (Dahdouh-Guebas 2006). Costanza et al. (2008) estimated that the value of mangroves for hurricane protection ranges from US$158/ha/yr to US$736,327/ha/yr. The skewed distribution value was based on the skewed distribution of hurricane damage. In Thailand, the net value of mangroves for storm protection ranges from US$13,544/ha to US$16,346/ha (Barbier 2007). However, due to data unavailability, most studies employ replacement methods, which tend to undermine the reliability of the estimates (Barbier 2007).

Although the valuation of coastal ecosystems has received much attention, an analysis by Barbier et al. (2011) exemplified that there are relatively few reliable estimates. Most of the studies have focused on Asia. In Thailand, the raw materials and food provided by mangroves were valued at between US$731/ha/yr and US$884/ha/yr (Barbier 2007). Brander et al. (2012) estimated the average and median value of mangroves in Southeast Asia to be US$4783/ha/yr and US$273/ha/yr, respectively. Only two studies have attempted to value mangrove forests in Kenya; however, despite the studies being conducted in the same region (Gazi), their findings are inconsistent. These two studies estimated the value of mangroves for shoreline protection at US$100/ha/yr (UNEP 2011) and US$1753/ha/yr (Kairo et al. 2009).

Our study aimed at contributing to the limited literature on Kenyan mangroves by conducting a case study of the Tana Delta. Most studies have focused on regulating services (shoreline protection and flood control) provided by mangroves (Alongi 2008; Costanza et al. 2008; Kairo et al. 2009; Lacambra et al. 2013; Mazda et al. 1997) without sufficiently examining how provisioning and cultural services influence the vulnerability of coastal communities. If sustainably managed, the provisioning services provided by mangroves can help reduce the vulnerability of coastal communities (Renaud et al. 2013) and aid in the disaster response and recovery phases by providing reconstruction materials (Gupta and Nair 2012; Munji et al. 2014; Renaud et al. 2013). Barbier (2007) estimated the value of raw materials and food products provided by mangroves in Thailand at a range between US$731 ha/yr and US$884 ha/yr. Additionally, the value of the role of mangrove forests as a breeding ground for fish was US$1070/ha to US$1491/ha. Our study took an integrated approach to comprehensively understand the role of provisioning and cultural ecosystem services of mangroves in augmenting the coping capacity of coastal communities. Our research aimed to holistically estimate the economic value of mangrove ecosystems in a flood disaster cycle by conducting a case study of the 2013 flood incident in the lower Tana Delta. The objectives of this study were threefold: (1) to assess the 2013 flood damage and loss in the lower Tana Delta; (2) to determine the role of the mangrove ecosystem in flood risk reduction; and (3) to estimate the economic value of mangrove ecosystem services. This study used a single flood (2013) event to estimate the amount of flood damage avoided as a result of mangrove presence.

In the following section, both the characteristics of the study area and the methods used for flood damage assessment and mangrove ecosystem service valuation are described. The results are then summarized, and a cost–benefit analysis conducted to determine the net value of the mangroves. In the "Discussion" section, the findings are compared with those of previous studies. This section also identifies how valuation is likely to influence comprehensive land use policies.

Materials and methods

Study area

This research was conducted in the lower Tana River Delta located at 02°30′S 40°20′E in Tana River County in Kenya

(Fig. 1). The mouth of the Tana River, the Tana River Delta, has a catchment area of approximately 100,000 km^2 (UNESCO 2010) and has been designated a Ramsar Site since 2012. The delta covers an area of 163,600 hectares (ha) and provides rich ecological diversity as well as subsistence for the coastal communities. It comprises a variety of freshwater, floodplain, estuarine, and coastal habitats with extensive and diverse mangroves. The delta supports such economic activities as mangrove harvesting, cattle grazing, crop farming, and fishing (Kenya Wildlife Service 2014). According to the 2009 census, the Tana Delta sub-county had an estimated population of 85,823. The majority of these residents practice agriculture by farming and livestock rearing (Kenya National Bureau of Statistics 2009).

The Tana River is notorious for flooding, especially in the lower Tana Delta region. Although dams constructed in upstream areas for hydropower generation largely regulate the discharge, heavy precipitation causes flooding in the coastal region due to excessive drainage. In addition, glacial melt from Mount Kenya (the source of the Tana River) greatly contributes to river flow and triggers floods in lowland areas. Floods usually occur during the rainy seasons in April–May and November–December, but the timing, extent, and duration of floods greatly vary from year to year (UNESCO 2010). Although the Tana River County is vulnerable to floods, it is also prone to drought because it is situated in a semi-arid region. Annual rainfall varies between 400 and 750 mm with a mean annual temperature around 30 to 33 °C. Although the area is rich in natural resources, it has been marginalized and the majority of its residents live in poverty (Commission on Revenue Allocation 2015).

The study site was subdivided into three clusters, designated A, B, and C (Fig. 2), to determine the role of the mangrove forest in flood risk management. Classification of the study area was mainly based on mangrove density and administrative boundaries. Mangrove abundance varied greatly across the selected clusters (Fig. 2). Cluster A consisted of villages (Kau and Kilelegwani) unprotected by mangrove forest. Cluster B included the Kilunguni and Kibauni villages with narrow mangrove belts. Cluster C encompassed the Kipini village situated behind a wide mangrove forest. The three clusters are under Kipini administrative location, governed by the area chief. A village elder represents each village. The data acquired from the area chief indicated that the villages in cluster A have a total of 89 households with a population of 584. Clusters B and C had 76 and 99 households with populations of 443 and 464, respectively. An analysis of variance indicated that the household income, education level, and building structures were not significantly different across the three clusters. More details about household occupation, education, household size, and house structure are provided in "Occupation".

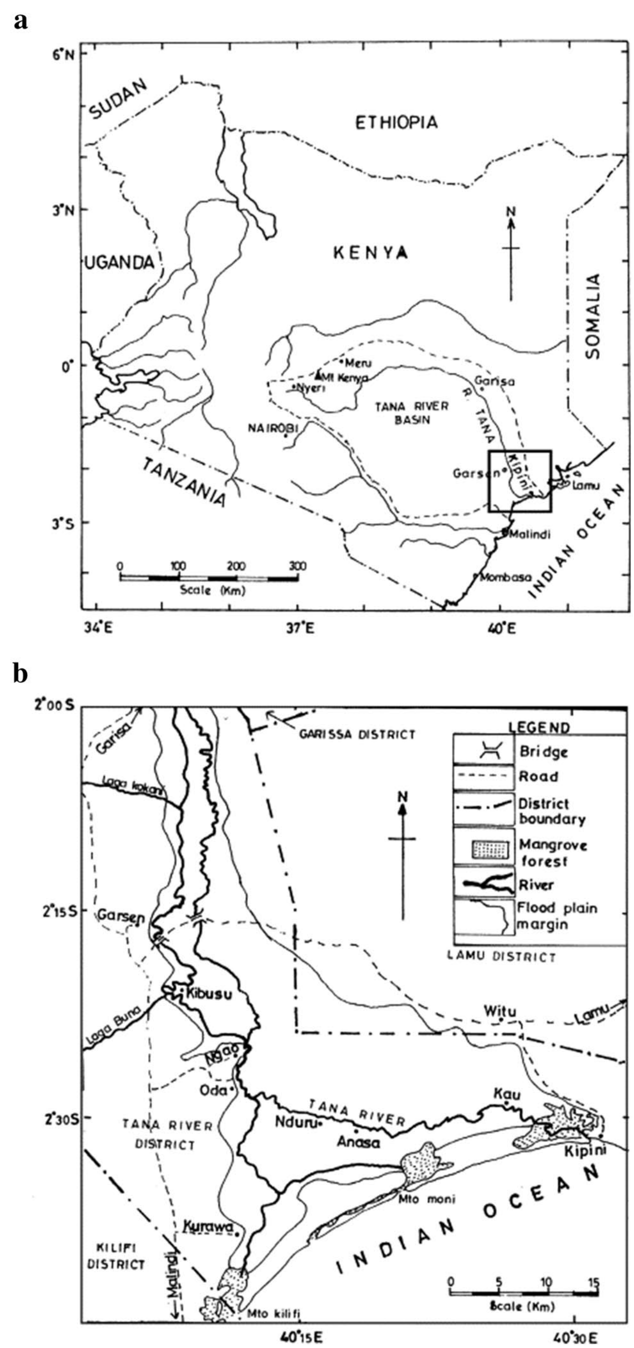

Fig. 1 **a** Tana River Basin in Kenya. **b** Tana River Delta with mangrove forest distribution. Source: (Kitheka et al. 2005)

The geophysical location and condition are similar across the clusters. According to the 30-m resolution digital elevation map obtained from the United States Geological Survey, the river trend (slope) was calculated as $y = -0.001x + 17.12$ (cluster A), $y = -0.001x + 14.33$ (cluster B), and $y = -0.001x + 13.56$ (cluster C), where

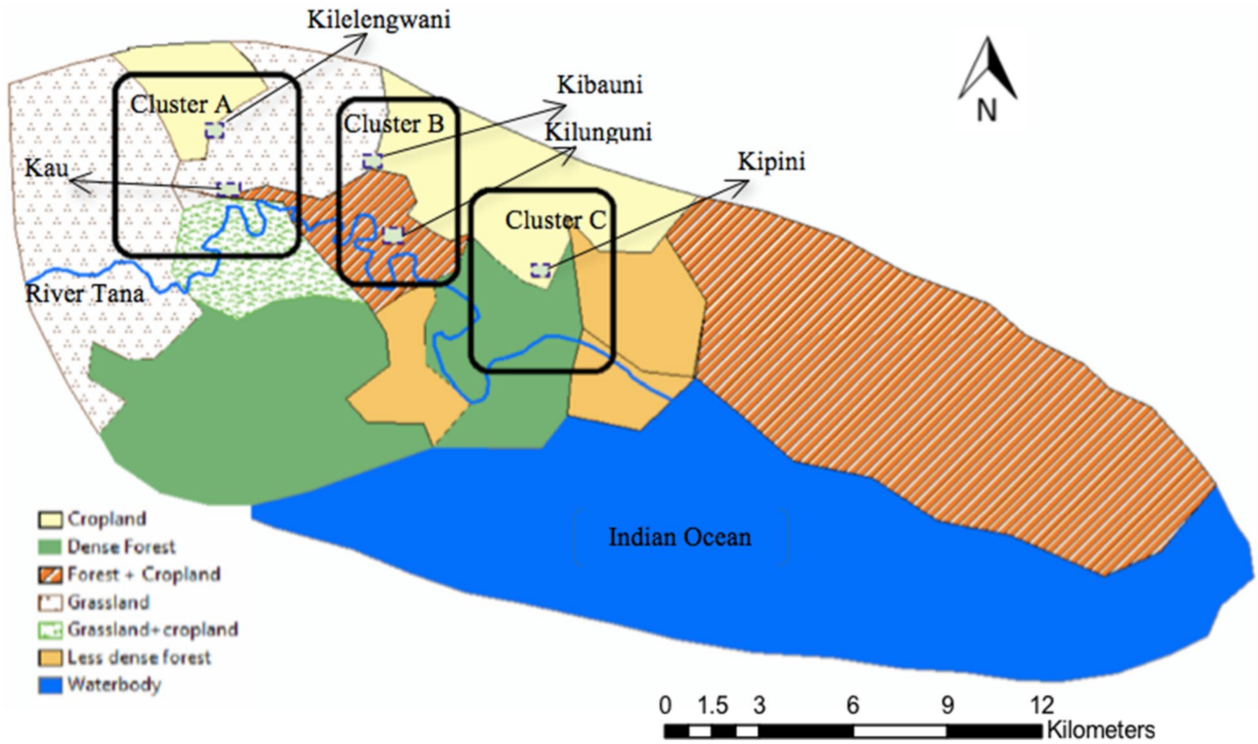

Fig. 2 Land use map of the study area (Dense Forest represents dense mangrove forest)

y represents the altitude, and *x* is the distance from the upstream to the downstream of cluster boundary intercept. Given that the gradients (−0.001) along the river were similar, the water velocity and flood impact were assumed to be analogous across the clusters.

The topographic relief in the field site is relatively flat and homogenous. Given that this is a delta, the average elevation is low and insignificantly different across the clusters. The elevation was approximated as 3.44, 3.35, and 3.11 m above sea level in clusters A, B, and C, respectively (AfriGIS 2017).

Methods

This study applied both quantitative and qualitative research methods to analyze the role of mangrove ecosystems in flood risk management. The valuation of mangrove ecosystem services was conducted based on the total economic value framework (TEV). TEV categorizes ecosystem services into use and non-use values. The use values are further subdivided into direct use, indirect use, and optional value. Non-use value has three components: altruism, bequest, and existence values (DEFRA 2007). This study only accounted for direct and indirect use values (which were thought to influence flood risk) using avoided damage and market price approaches (Table 3). For comparison purposes, all the estimates of the previous studies were standardized to 2015 US$ equivalent values using the United States Consumer Price Index for all urban consumers (CPI-U) (Bureau of Labor Statistics 2016).

A cost–benefit analysis was conducted to estimate the cost that the community would likely incur as a function of mangrove forest degradation. The analysis accounted for the total benefits and costs.

$$\text{Net benefits} = \text{Total benefits (TB)} - \text{Total cost (TC) (Bann 1998).} \quad (1)$$

Here TB = (Avoided flood damage + Socio-economic benefits) and TC = (Maintenance cost + Opportunity cost).

The cost benefit analysis was calculated to determine the net flood benefits/loss that the coastal communities acquire for conserving the mangrove forest. This can also be translated as the probable community's loss in case of total deforestation. The total benefits included goods and services that the coastal community acquires from mangroves. In our analysis, we focused only on the goods and services that are assumed to influence flood risk/vulnerability, more details of which are provided in "Socio-economic benefits". The total cost was defined as the cost incurred in the daily management and conservation of mangroves and the forgone benefits for mangrove conservation.

First, the research estimated the avoided damage by comparing the 2013 flood impacts in areas protected by dense (cluster C) and narrow belt (cluster B) of mangroves with that of unprotected areas (cluster A). Second, the ecosystem services, such as firewood, timber, fish, honey, and medicinal values, provided by mangroves were valued using TEV in clusters B and C. Third, the annual-avoided damages and ecosystem services were estimated and aggregated for the entire study population, to represent the total benefits. Fourth, the annual cost of maintaining mangrove forests was calculated. The opportunity cost was determined as alternative land uses, which was estimated and valued. The net benefits were obtained by calculating the difference between aggregated total benefits and total costs. The annual net benefits per hectare were estimated. Detailed description of these methodological steps is provided below.

Avoided damage

The avoided damage approach (Bann 1998) was used to understand the avoided damages and losses during the 2013 flood incident.

$$\mathrm{AD_a} = \frac{\sum\left(H_0 + C_0 + L_0 + B_0\right) - \sum\left(H_m + C_m + L_m + B_m\right)}{f}, \tag{2}$$

where AD_a refers to annual-avoided damage; H stands for damage in house structures; C refers to crop damage and loss; L means livestock loss and damage; and B stands for loss in the business sector. $_0$ represents areas unprotected by mangroves (cluster A), $_m$ areas shielded by mangroves, which were classified into areas shielded by narrow mangroves belts (cluster B), and for areas shielded by dense mangrove forest (cluster C). Flood frequency is denoted by f.

To estimate the 2013 flood damages and losses, ninety questionnaires [30 per cluster (Table 1)] were self-administered from November 2014 to January 2015. The data were collected in units of Kenya shillings (KSh). The flood damage estimation was based on the cost of reconstruction ("Avoided damage"), which is not time specific and varies from one household to another. As a result, to convert the values to US$, we used an average exchange rate (KSh 91 = US$ 1) from the year of flood occurrence (2013) to the final year of data collection (2015) Central Bank of Kenya (2015).

The flood damage and loss assessment was conducted using the modified United Nations Economic Commission for Latin America and the Caribbean (UN-ECLAC) framework, and the damage avoided was compared among the clusters. The UN-ECLAC methodology has been successfully applied in South America and the Caribbean since 1972. This methodology has been customized, simplified, and further developed by the World Bank. It is now widely applied in Asia and Africa as well.

Table 1 Villages and number of households in the studied clusters

Cluster	Village	Total HH*	Surveyed HH*
A	Kau	47	15
	Kilelegwani	42	15
B	Kibauni	43	15
	Kilunguni	33	15
C	Kipini	99	30

*HH: household

This tool can be used to estimate the impacts of a disaster on assets (damage) and economic flows (losses and additional losses) and accounts for socio-economic and environmental effects (UN-ECLAC 2014). Given that our study site and study population were relatively small and considering the very limited data available on the 2013 flood and river characteristics, this methodology was preferred. The household surveys made it possible to capture the social impacts of a flood disaster that are not easily detected by flood damage simulation models. Additionally, the lack of a gaging station in the lower Tana Delta hindered the simulation of the flood damages.

The modified UN-ECLAC framework recommends that disaster damage and loss assessment be conducted sector-wise (UN-ECLAC 2014). The flood impact varies from household to household, and the sectors affected depend mainly on the economic activities of the affected community. Therefore, the flood impacts on the following practiced economic sectors were considered in the household survey: housing, agriculture, fishing, and small-scale businesses. Different variables and parameters were used to estimate the flood damage and loss in each sector (Table 2). The damage assessment was based on the cost of repairing or rebuilding the affected assets. The loss assessment (reduction in output from the productive sectors) was largely based on the resale values and lost investments. The highest and lowest prices were used to calculate the average price assumed to be the actual cost of repair, reconstruction, or resale to avoid over- or under-estimating the flood damage. Focus group discussions were conducted with experts in various sectors to determine these prices. This study further modified the UN-ECLAC to include short- and long-term positive impacts, referred to as gains, which resulted from the 2013 flood.

The results of the sectoral assessments were aggregated to determine the total disaster damage and loss in each cluster. The aggregated damages and losses were compared in relation to cluster A to determine the avoided damages in both clusters B and C. The annual-avoided damage was estimated based on flood frequency. Questionnaires were administered to local residents to determine the minimum and maximum return periods of the flood.

Table 2 Variables and parameters used in flood damage, loss, and gain assessment

Sector	Variables	Parameters (values are based on the local market price)		
		Damage	Loss	Gain
Housing	Size of houses and extent of damage	Cost of repairing or rebuilding houses	–	–
Crop cultivation	Types of crops affected Acreage affected Land productivity	Value of missed harvest	Initial costs of preparing land, planting, and seeds	
Livestock	No. of domestic animals killed	Price of domestic animals	–	–
Fishing	Extent of damage to fishing equipment No. of increased/decreased daily fish catch	Cost of repairing or rebuilding fishing equipment	Value of decreased fish catch	Value of increased fish catch
Business	Extent of damage and losses incurred	Cost of repairing damaged structures	Losses incurred	Increased reported sales
Total flood damage and loss	(Damage + loss) – gains			

Socio-economic benefits

The socio-economic benefits derived from mangroves were valued for clusters B and C. Provisioning and cultural services providing some tangible benefits were assumed to supplement the income of the community. The supposition is that without mangroves, these freely acquired goods and services would have been bought from the local market. We argue that communities with higher income are better able to cope with floods. The freely acquired tangible goods and services were estimated using the local market price approach based on the use value (TEEB 2010) (Table 3). This approach was chosen because the focus of the study was on current mangrove ecosystem services that have direct or indirect influences on flood risk. However, the national standardized market price for most of these ecosystem benefits greatly differs from the local market prices. In addition, local market prices fluctuated throughout the year, which made it challenging to choose one fixed price. The economic valuation of these services involved the calculation of the average of the lowest and highest local market prices in determining the actual measure of each ecosystem service to overcome these challenges and increase the accuracy of the study results. Focus group discussions were conducted with residents of clusters B and C to determine the lowest and highest prices of each ecosystem service considered in the economic valuation. As there are no mangroves in the vicinity of cluster A, it was assumed that residents in this cluster did not directly acquire ecosystem services from the mangrove forest.

The value of direct provisioning services (firewood, timber, thatch, fodder and medicinal value) was estimated by capturing the harvested quantities and their respective prices, as illustrated by the equation below. This equation has been adapted from Kairo et al. (2009).

$$\text{Annual value of the direct provisioning services} = \sum Q_{\mathrm{a}} P_{\mathrm{a}}, \tag{3}$$

where Q_{a} is the quantity of a particular direct ecosystem service collected annually, and P_{a} is the annual average price of the ecosystem service.

Table 3 Valuation techniques used in this study

Service type	Goods/services	Value type	Valuation method	Approach
Provisioning	Firewood, timber, and thatch	Direct	Local market price	Harvested thatch, timber, firewood
	Herbal medicine	Direct	Local market price	Cost of treating prevented/cured disease in the hospital
	Aquaculture	Indirect	Local market price	Value of annual fish catch
	Apiculture	Indirect	Local market price	Harvested honey
	Fodder	Indirect	Local market price	Estimated daily value of fodder and no. of days grazed in interior region of mangroves
Regulating	Flood control	Indirect	Avoided damage	Areas with vs. without mangroves
Cultural	Ecotourism	Indirect	Local market price	Income generated from tourism

The Tana Delta sub-county fisheries department provided data concerning the marine and freshwater fish catches of 2014. As annual data were unavailable for the Kipini division, we used the biannual data instead (April–September 2014). A focus group discussion was held with fishermen to determine whether there was a significant difference in the quantity of fish caught per month throughout the year, in order to estimate the annual amount. Half of the freshwater fish catch was attributed to cluster B and half to A, whereas the marine fish catch was attributed to cluster C, since cluster B is adjacent to the river and cluster C is adjacent to the ocean. We used the standardized local fish price of US$0.65/kg obtained from the Tana Delta sub-county fisheries department (2014). It is generally accepted that mangroves act as a breeding ground for fish. However, it is still unclear how much they contribute economically to onshore and offshore fisheries. Most studies report a variable level of contribution ranging from 25 to 70% (UNEP 2011). The economic value of mangroves to the fishing sector in the lower Tana Delta as a breeding ground for fish was estimated as the average (47.5%) of the lowest (25%) and highest (70%) amounts reported.

Management costs

According to the data obtained from the Kenya Forest Service, approximately US$12,000 was allocated to Tana River County for natural forest management and conservation in 2015. Natural forests cover approximately 3700 ha of Tana River County (UNESCO 2010). Although a budget breakdown was unavailable, interviews with experts revealed that much attention was paid to the management of mangroves in the lower Tana Delta, especially after it was designated as a Ramsar Site. Thus, we assumed that this budget was largely used for the management of mangroves at this study site (cluster B: 90.2449 ha, cluster C: 133.142 ha). This value translates to US$54/ha/yr.

Although we included the management cost in the analysis, conservation costs should not be perceived as an expenditure but rather as an investment. Investing in conservation is likely to increase the benefits rendered by the said ecosystem. Conservation costs should be concisely incorporated in the cost–benefit analysis.

Opportunity cost

In this study, opportunity cost is defined as the foregone benefits of alternative land uses in favor of mangrove ecosystem maintenance. Although shrimp aquaculture has led to the widespread degradation and conversion of mangrove forests in Southeast Asia (Brander et al. 2012), this practice is uncommon in this study area. As crop cultivation is the main economic activity (practiced by 76% of the respondents), farming was considered as an alternative land use. Salt-adapted rice plantations were also assumed to be an alternative land use because rice farming is the most common agricultural practice in both clusters B and C. In order to estimate the opportunity cost, the land productivity was calculated on the basis of both a good and a poor harvest.

Results

Occupation

Table 4 summarizes the socio-demographic features of the respondents in clusters A, B, and C. Among the respondents, 82% were 20–49 years old. The education level did not differ significantly among the three clusters and was low, with 22% of the respondents having no formal education.

The surveyed households had on average 5.6, 5.1, and 4.1 people in clusters A, B, and C, respectively. The total average household size (5.0) correlates with the estimated 2015 average household size (5.1) in Tana River County, but it is slightly higher than the 2015 national average (4.4) (Esri 2015).

Crop cultivation (practiced by 76% of the respondents) was the most practiced economic activity across the three clusters. Twenty-three percent of the respondents were operating small-scale businesses, of which nearly half were stationed in cluster C, specifically in Kipini town, a shopping center at the lower Tana Delta. Fishing was the third practiced activity in the area. Residents in clusters A and B mainly fish in Tana River, whereas those in cluster C largely fish in the Indian Ocean. Some households had more than one occupation.

Ninety-seven percent of the houses were made from mud, and the rest were made either of bricks or wood (Table 4). No licensed building contractor operates in the area. The building codes and other building construction standards are not strictly adhered to.

Flood damage, loss, and gain assessment

This section outlines economic estimates of the damages and losses triggered by the 2013 flood that affected lower Tana Data.

Physical and monetary impact in Cluster A

All the respondents in cluster A reported that the 2013 floods affected them. One person was killed, and two were injured. Seventy-three percent of houses were affected, and sixty per cent of them were completely destroyed. The total value of house damages was estimated to be US$14,863.

Table 4 Socio-demographic features of the respondents

	Number of respondents			
	Cluster A	Cluster B	Cluster C	A + B + C
Gender				
Male	15 (50%)	13 (43%)	14 (47%)	42 (47%)
Female	15 (50%)	17 (57%)	16 (53%)	48 (53%)
Age				
<20	1 (3%)	2 (6%)	2 (6%)	5 (6%)
20–29	11 (38%)	11 (38%)	11 (38%)	33 (37%)
30–39	7 (23%)	10 (33%)	9 (30%)	26 (29%)
40–49	4 (13%)	4 (13%)	6 (20%)	14 (16%)
50–59	2 (6%)	3 (10%)	2 (6%)	7 (8%)
>59	5 (17%)	0 (0%)	0 (0%)	5 (6%)
Education level				
None	9 (30%)	6 (20%)	7 (23%)	22 (24%)
Primary	15 (50%)	17 (57%)	15 (50%)	47 (52%)
Secondary	4 (13%)	6 (6%)	6 (20%)	16 (18%)
Post-secondary	2 (7%)	1 (3%)	2 (7%)	5 (6%)
Occupation	No. of household practicing			
Crop cultivation	26 (87%)	23 (77%)	19 (63%)	68 (76%)
Livestock-keeping	4 (13%)	7 (23%)	4 (13%)	15 (17%)
Fishing	4 (13%)	4 (13%)	9 (30%)	17 (19%)
Business	6 (20%)	5 (17%)	10 (33%)	21 (23%)
Civil servants	0 (0%)	0 (0%)	2 (7%)	2 (2%)
Students	0 (0%)	1 (3%)	1 (3%)	2 (2%)
Household size (HH)				
Average no. of people per HH (standard deviation)	5.6 (1.6)	5.1 (1.8)	4.3 (1.7)	5.0 (1.8)
Range per HH	Min 3, max 8	Min 1, max 8	Min 1, max 7	Min 1, max 8
House structure				
Bricks	1 (3%)	0 (0%)	1 (3%)	2 (2%)
Mud	29 (97%)	30 (100%)	28 (94%)	87 (97%)
Wooden	0 (0%)	0 (0%)	1 (3%)	1 (1%)

All the respondents in this cluster were practicing farming. The flood affected approximately 1.5 ha farmland per household. Ranked by magnitude, the most affected crops were bananas, rice, coconut, maize, and mangoes. The total value of crop damages and losses were estimated to be US$67,086.

A pre-disaster livestock ownership per household was estimated as 2.1, 13.6, and 19.0, for cattle goats and poultry, respectively. During the 2013 flood, 13 cattle, 40 goats, and 406 poultry died. The daily catch in the fishing sector decreased by 21. No fishing equipment was physically damaged. The loss in the fishing sector was estimated to be worth US$451.

Twenty percent of the respondents operated small-scale businesses. Eighty-three percent of these businesses were affected by the 2013 flood disaster. The total business losses and damages were approximated to be US$1648.

Overall, cluster A registered a total damage and loss cost of US$92,514.

Physical and monetary impact in Cluster B

The 2013 flood affected seventy-seven per cent of the respondents. During the flood, two people were injured and no death was reported. Thirty percent of the houses were partially damaged and recorded a total damage of US$126 (Table 5).

All the respondents were engaging in farming. The flood affected 0.8 ha/household of farmland. The most affected crops were rice, bananas, coconut, maize, and mangoes

Table 5 Total estimated flood damage, loss, and gain in 2015 (US$)

Sectors	Cluster A			Cluster B			Cluster C			Total Impact Cost
	Damage	Loss	Gain	Damage	Loss	Gain	Damage	Loss	Gain	
Housing	14,863	–	–	126	–	–	66	–	–	15,055
Crops	62,729	4357	–	30,221	2363	–	4344	319	–	104,333
Livestock	8466	–	–	5025	–	–	1380	–	–	14,871
Fishing	–	451	–	–	–	60	–	–	5	386
Business	1648	–	–	440	–	–	220	–	–	2308
Total	92,514	38,115	6324	136,953						
Avoided damage										
Total	–			54,399 (Cluster A–Cluster B)			86,190 (Cluster A–Cluster C)			140,589
2.5 year return period	–			21,760			34,476			56,2366

arranged in the order of the flood effect. The total value of crop damages and losses were estimated to be US$32,584.

The ownership of livestock in pre-flood disaster phase per household was estimated as 2.7, 16.3, and 17.7 for cattle, goats, and poultry, respectively. 10 cattle, 27 goats, and 7 poultry died due to the flood.

The overall daily catch in the fishing sector increased by 6 kg. The loss and gain assessment reveals that clusters B experienced a total flood gain of US$60.

Seventeen percent of the respondents owned small-scale businesses of which sixty per cent of them of were affected by the flood and reported a total damage of US$440.

Cluster B, in total, reported a total value of flood damage and loss amounting to US$38,115.

Physical and monetary impact in Cluster C

Thirty percent of the respondents in Cluster C were affected by the 2013 flood incident. No deaths or injuries associated with the flood were recorded. Thirteen percent of the houses were partially damaged and registered a total damage amounting to US$66 (Table 5).

Seventy-seven percent of the respondents practiced farming. Approximately 0.1 ha/household of farmland were partially affected by the 2013 flood incident. Ranked by magnitude, the most affected crops were rice, bananas, coconut, maize, and mangoes. Cluster C registered US$4663 in crop damages and losses.

The pre-disaster livestock ownership per household was estimated at 2.3 for cattle, 11.9 for goats, and 21.0 for poultry. The 2013 flood led to the deaths of 3 cattle, 4 goats, and 9 poultry.

The overall daily fish catch increased at a rate of 4 kg/day. During the flood session, the fishing sector recorded gains worth US$5.

Thirty-three percent of the respondents operated small-scale businesses. Although cluster C had the most businesses, it had the lowest proportion of business affected (20%) and the lowest total damage (US$220).

The total value of damages and losses in cluster C were estimated to be US$6324.

Cluster-based comparative analysis of flood damage

Overall, cluster A recorded the highest flood damages and losses, being 2.4 and 14.6 times those of clusters B and C, respectively (Table 5). Assuming that the flood impact was similar across the three clusters, US$54,399 and US$86,190 of damage was avoided in clusters B and C, respectively (other factors will be examined in the section on regulating services). According to the respondents, the flooding frequency is once every 2–3 years. The study determined that floods in the lower Tana Delta are caused by both heavy precipitation and a sudden release of stored water in the dams constructed upstream for hydropower production. The annual-avoided damage was estimated on the basis of the average flood return period of 2.5 years (Table 5).

Valuation of mangrove ecosystem services

Respondents in clusters B and C perceived mangroves as beneficial or somewhat beneficial to their daily lives. Aquaculture, water cycle support, and firewood source are the three mangrove ecosystem services most appreciated by residents of clusters B and C.

Provisioning services

Residents of clusters B and C enjoy an array of provisioning services including both wood and non-wood products. There is no electricity in clusters B and C. Firewood is the main source of fuel. Sometimes people harvest firewood from mangroves forest, which is estimated to value at US$51.60/ha/yr and US$25.80/ha/yr in clusters B and C, respectively (Table 6).

Timber is mainly used for the construction of houses and boats. Harvesting of timber for commercial purposes is prohibited in the area and regularly monitored by the local residents. The local people also utilize thatch for building roofs, beds, baskets, and seats.

The residents also obtain herbal medicine from *Xylocarpus granatum* mangrove species. This herbal medicine is used to treat pneumonia and typhoid and to deter mosquitoes, which ultimately helps prevent malaria.

Given that some communities are semi-nomadic pastoralists, they move their livestock into mangrove forests in search of fodder. Grazing occurs in the exterior regions of the forest because dangerous animals such as elephants, buffalo, and crocodiles are found in the interior regions. Fodder recorded the highest value within the classification of provisioning services at US$229.70/ha/yr and US$125.40/ha/yr in clusters B and C, respectively. Cluster B had a higher cattle ownership ratio and, thus, recorded a higher fodder value.

Fishing in cluster B is conducted on a small scale and usually for household consumption. However, fishing in cluster C is practiced on a large scale for commercial purposes. According to data provided by the Tana Delta sub-county fisheries department, the annual marine and freshwater fish catches were estimated to be 31,778 and 1222 kg and worth approximately US$20,959 and US$805, respectively. Using 47.5% as the contribution value, the annual value of mangroves as breeding grounds for marine life (cluster C) was estimated to be US$74.90/ha/yr. As cluster B was approximated to have 50% share of the freshwater fish catch, the mangroves in this cluster were estimated as providing US$2.10/ha/yr to the fishery sector.

Regulating services

Regulating services provided by mangroves include carbon sequestration, climate regulation, flood control, prevention of soil erosion, and reducing the acidity of ocean water. Our study only focused on valuation of the flood control function, as one of the key regulating services given the high vulnerability of this region to floods. During the time of data collection, there were no flood mitigation and/or preparedness measures rolled out in the area. The local people perceive mangrove forests as critical resources in flood risk reduction. 80% of the respondents in both clusters B and C stressed that mangroves greatly reduce flood risk. The rest of the respondents stated it they somehow reduce the flood risk. Economically, flood control is one the most valuable

Table 6 Economic value (US$) of mangrove ecosystem services

Classification of ecosystem services	Ecosystem services (ES)	Sample value (30 HH)		Population value (B: 89 HH) (C: 99 HH)		Annual value/ha	
		Cluster B	Cluster C	Cluster B	Cluster C	Cluster B	Cluster C
Provisioning	Firewood	1565.90	1038.50	4645.60	3426.90	51.60	25.80
	Timber	1147.30	395.60	3403.50	1305.50	37.80	9.80
	Herbal medicine	596.70	529.70	1770.20	1747.90	19.70	13.10
	Thatch	362.60	544.00	1075.80	1795.10	12.00	13.50
	Fishing	–	–	191.40	9955.60	2.10	74.90
	Fodder	6967.00	5053.80	20,668.90	16,677.70	229.70	125.40
	Honey	8.80	13.20	26.10	43.50	0.30	0.30
Regulating	Flood control	21,759.60	34,476.00	64,553.50	113,770.80	717.30	855.40
Cultural	Ecotourism	–	1022.00	–	3372.50	–	25.40
Total		32,407.90	43,072.80	96,335.00	152,095.50	1070.50	1143.60

services, approximated at a value of US$717.30/ha/yr in cluster B and US$855.40/ha/yr in cluster C.

Cultural services

Some respondents appreciated the mangrove ecosystem as a source of recreation, esthetic value, and tourism. People in cluster B do not benefit directly from ecotourism and cited the poor road network as a major detriment to tourism. However, one-third of the households in cluster C benefited directly from ecotourism. Most people benefit as tour guides, and boat passengers also require accommodation and catering services. The value of tourism was estimated at US$25.40/ha/yr in cluster C. The value of tourism is almost equivalent to the value of firewood harvested by residents of cluster C. Some respondents noted that they earned much more from the tourism sector in previous years, but recent conflict and terrorism threats have negatively affected the tourism industry (Nation 2014).

Cost–benefit analysis

The quantified mangrove ecosystem services (with the exception of fishing) only represent the sample size of this study. The total value of ecosystem services for the entire population in clusters B and C was calculated assuming that the sample is truly representative of the entire population (Table 6). The total value of benefits is estimated to range from US$1071/ha/yr to US$1144/ha/yr depending on the density of the mangroves.

The opportunity cost was defined as the benefits forgone to maintain a mangrove forest. The price (salt-adapted) production output for the adjacent land was estimated to be US$774/ha/yr. The maintenance cost was estimated to be US$ 59/ha/yr. The total cost was thus US$833/ha/yr. The net benefit of mangrove forest is estimated at US$238/ha/yr and US$311/ha/yr in clusters B and C, respectively, (Fig. 3).

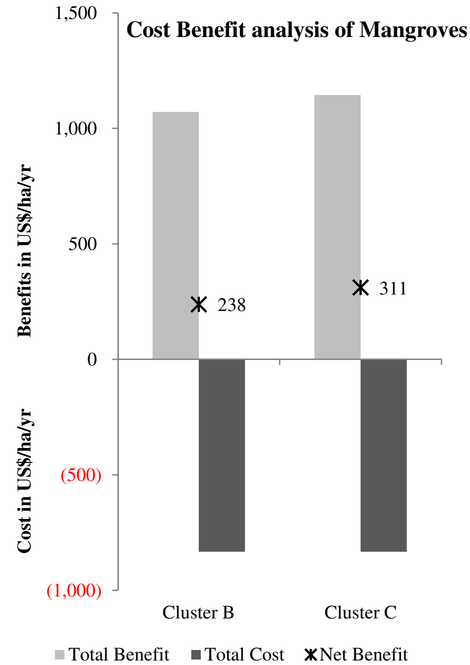

Fig. 3 Cost Benefit analysis of mangroves

Discussion

The flood impact experienced by villages unprotected by mangroves was 2.4 times greater than that of villages partially protected by mangroves and 14.7 times greater than that of villages completely protected by mangroves. Mangroves also saved human lives, as deaths were only experienced in villages unprotected by mangroves. Das and Vincent (2009) reported that during a cyclone disaster, villages with wider mangrove belts reported fewer deaths compared with those with narrow belts or no mangroves.

The net value for mangroves in flood risk reduction was estimated to range between US$238/ha/yr and US$311/ha/yr, depending on the density of the mangroves. Our results differ from other mangrove valuation studies undertaken in Kenya. The value of mangroves in Gazi, Kenya, for tsunami protection was approximated to be US$100/ha/yr (UNEP 2011). The difference is largely attributed to the approaches employed. UNEP (2011) attributed the occurrence of tsunamis with the eruption of the Karthala volcano in Comoros and calculated the avoided tsunami damage using a method similar to that used in this study. Their analysis assumed that mangroves offer 5% protection annually to the accumulated coastal assets. In their analyses, they projected the potential impacts of tsunamis by assuming 700 houses, each worth US$2,418, would be affected. Our estimation is based on empirical evidence of the 2013 flood that affected the residents of Tana Delta. Unlike our study (Table 5), UNEP (2011) avoided damage assessments only focused on the housing sector. In addition, the return period of tsunamis is their study is unclear.

On the other hand, Kairo et al. (2009) estimated the value of replanted mangroves for coastal protection in Gazi to be of US$1753/ha/yr. The authors employed replacement costs by estimating the cost of building a protective sea wall along the Gazi coastline. Their analyses did not capture the maintenance cost of the wall and the opportunity cost likely to be incurred by the local people because of the limited access to ecosystem services offered and/or supplemented by the mangroves. Although the replacement cost method was employed due to data unavailability, according to (Barbier 2007), it has a tendency of undermining the reliability of the estimates, as it uses costs as a measure of economic benefit.

Kairo et al. (2009) estimated the value of poles (US$4728/ha) and firewood (US$245/ha) by calculating the profits obtained if all the forests were cleared and their products sold at the local market. Our study focused on the sustainable management of mangroves and only accounted for the permitted harvest of wood products. Furthermore, Kairo et al. (2009) assumed that mangroves contribute 100% to onshore and offshore fishing. Where most studies report a variable level of contribution from 25 to 70% (UNEP 2011), our study adopted an average value of 47.5%.

Meta-analysis performed by Brander et al. (2012) estimated the average and median values of mangroves in Southeast Asia at US$4784/ha/yr and 273/ha/yr, respectively. Their median value is within the range of our estimate.

Barbier (2007) approximated the value of mangroves for storm protection in Thailand at between US$13,544/ha and 16,346/ha. The differences can be associated with varying biotic characteristics of mangroves, different frequency and magnitude of coastal hazards, and vulnerability levels of coastal communities. The higher the risk, the higher the protection value of mangroves. The GDP per capita also influences the value of a certain ecosystem service. De Groot et al. (2012) argue that the value of coastal ecosystems is higher in countries with a higher gross domestic product (GDP) per capita.

Due to a lack of data, the impact of floods on tourism, health, water resources, roads, and communication networks was not considered. This would have ultimately increased the value of avoided damage. The TEV approach adopted in this study represents the sum of all goods and services obtained from mangrove forests. The prevailing value of ecotourism in the Tana Delta was estimated at US$25/ha/yr. Nonetheless, investment in the neglected tourism industry would increase the value of mangroves. Cooper et al. (2009) estimated that mangroves in Belize contribute between US$66 and US$86 million to the tourism industry. Therefore, the value of mangroves is not static and is likely to change with changes in economic conditions, even without changes in the mangrove forest cover. As the community accumulates more assets, mangroves will protect a higher value of assets. The valuation was based on the local market values, where economic affluence is likely to increase these prices. De Groot et al. (2012) noted that population has a positive effect on the value of wetlands. Given that 40% of Kenyans are under 15 years of age, Kenya's population is projected to increase from the current 44 million (World Bank 2016) to 82 million (with the current fertility rate) or to 65 million (with a fertility of 2.1) by 2040 (National Coordinating Agency for Population and Development 2010). Population increases in the coastal regions will lead to more people benefiting from coastal ecosystems. However, population increases are also likely to exert more pressure on coastal ecosystems.

This case study reveals that mangrove ecosystem-based flood risk reduction is a cost-effective strategy that provides net benefits ranging from US$238/ha/yr to US$311/ha/yr. The results further support the work of Renaud et al. (2013), who recognized the need for economic valuation of ecosystem services for hazard mitigation through evidence-based valuation methodologies. Our results also address one of the obstacles highlighted by the United Nations International Strategy for Disaster Reduction (UNISDR) in its 2011 Global Assessment report, namely, the enormous challenge of economic undervaluation of ecosystem services for ecosystem-based DRR (UNISDR 2011). These results provide societies with the empirical evidence needed to take advantage of this cost-effective strategy.

The flood damage and loss assessment method applied in this study advances the UN-ECLAC disaster damage and loss framework, as it also incorporates flood gains. This modified UN-ECLAC can be used to critically examine another aspect of flood disaster, in which not only are flood risks mitigated/reduced but the benefits resulting from flood disasters are also capitalized upon. Furthermore, using average prices in flood damage and loss assessment and mangrove service economic valuation reduces the tendency to incorrectly estimate flood impacts and the value of mangrove services.

This study analyzed the array of goods and services mangroves provide and that contribute to the livelihoods of coastal communities. Although direct provisioning services contribute to the immediate livelihood of a local community, their overexploitation can render a community vulnerable in the long term. Trade-off analysis of direct provisioning services vis-à-vis disaster risk reduction is a prerequisite for sustainable mangrove management. There is a need to mainstream ecosystem management into disaster risk reduction practices and policies. For Eco-DRR to be fully operational and effective, current challenges to sustainable ecosystem management, such as poor land use planning, need to be addressed. Estella et al. (2013) argue that mainstreaming land use planning and DRR can disentangle conflicting priorities between long-term DRR and ecosystem management and short-term livelihood needs.

Although flood control is by far the most economically valuable service, only a few residents appreciated this role. It is possible that this service is undervalued, underappreciated, and/or misunderstood by local residents. A concerted effort to raise awareness is necessary for the local population to fully understand and, ideally, appreciate the vital role of mangroves, especially in flood risk reduction. However, even though avoided flood damage was attributed to the presence of mangroves, some uncertainty remains. Ecosystems such as dunes and other types of vegetation in the area might have played a crucial role in reducing flood impact. Future studies need to examine the role of other coastal ecosystems in flood risk reduction in the Tana Delta.

This study quantified the net benefit of reducing flood impact by a mangrove ecosystem in the Tana Delta, Kenya. Similar scientific research should be performed to determine performance and function before and after a flood event. This includes the resilience and/or adaptability of mangroves against extreme events. We acknowledge that the relationship between mangrove degradation and flood impacts is nonlinear and that projection of the impacts of mangrove loss on flood risk involves a certain degree of uncertainty. Nhuan et al. (2014) found the total contributions from natural factors (including natural vegetation) to be directly proportional to the total vulnerability.

Our case study illustrates the strong nexus between mangrove ecosystems and flood risk reduction. The Sendai Framework for DRR (SFDRR 2015) affirmed that disasters and environments are necessarily interdependent. Well-maintained mangrove ecosystems can substitute for hard infrastructure to protect against coastal floods; this strategy is also economically effective. This study demonstrates that it is possible for coastal communities to live in harmony with the mangrove ecosystem if they fully appreciate its true value.

Without knowledge of the economic value of mangroves, alternative land use with known economic value is likely to be perceived as more desirable (Brander et al. 2012). The main purpose of the valuation of ecosystem services is to provide insights for decision-making and land use planning. Nonetheless, mangrove ecosystem services should not be perceived as tangible goods that can be traded in the local market. The valuation should be an illustration of how much a coastal community is likely to lose upon the degradation of mangroves.

Conclusion

This study found that mangroves provide many goods and services that contribute to the subsistence of coastal communities and aid in flood risk reduction. The mangrove ecosystem in the Tana Delta is estimated to provide an annual net benefit ranging from US$238/ha/yr to US$311/ha/yr for flood risk reduction. Degradation of mangrove ecosystems is not beneficial to coastal communities and derails sustainable development. The economic valuation of ecosystem services provides support for ecosystem-based DRR studies, bridging ecosystem management, and DRR. The results of this case study draw attention to the need for further advancement of risk and vulnerability assessment methodologies that currently fail to recognize the crucial role of the environment, including ecosystems, in their assessments. This case study also recognizes the need to coordinate disaster management with land use planning and ecosystem management. Therefore, we recommend integrated coastal zone management that incorporates coastal land use planning, sustainable ecosystem management, and development planning into coastal flood management.

Limitations

Assessment of the damage, loss, and gain from the 2013 flood was conducted one year after the disaster. The total disaster impact would have most likely been higher if this assessment were conducted a few weeks after the disaster, as most of the immediate damage and loss would have been captured. However, this assessment captured the long-term impacts of a flood disaster that would have been missed if the assessment were conducted immediately after the disaster.

The study assumed that the soil types and the characteristics of the riverbed are similar across the three clusters, which should be examined by the future studies. This case study also did not consider damage and loss from secondary disasters, such as the outbreak of water-borne disease (cholera or typhoid) resulting from or compounded by the flood, because of limited data and the difficulty of distinguishing the effects of disasters from those of other causes. Future research should explore the assessment of these secondary impacts as well as cultural ecosystem services from the mangroves, such as spiritual enrichment, recreation, and esthetic value.

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