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Recovery and protection of coastal ecosystems after tsunami event and potential for participatory forestry CDM – Examples from Sri Lanka

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ABSTRACT

By using an integrated approach, tsunami affected land, vegetation and inhabitants were assessed to evaluate the potential to restore and protect coastal land in the context of Kyoto Protocol's Clean Development Mechanism in Hambantota district in the south-eastern part of Sri Lanka. Firstly, assessments of the status of the tsunami affected area were carried out by collecting soil and well water samplings for carbon and salinity analysis. Secondly, identification of potential tree species for carbon sequestration and sustainable development was conducted to determine carbon stock and suitability to grow under the prevailing conditions. In addition, interviews to understand the local people's perception of forest plantations and land use were conducted. The results showed that the resilience process of salt intruded lands from the 2004 Asian tsunami has progressed rapidly with low salinity level in the soils 14 months after the event, while the well water showed evidence of salinity contamination. The carbon stock was highest in natural forests followed by coconut plantations. Land users could envision expanding their present plantations or establish new ones. The barriers were defined as lack of financial investment capital and limited land for extended plantations. If a Clean Development Mechanism project is to be established, the coconut tree was found to be the most appropriate tree species since it has high carbon content, had co-benefits and possesses a salt-tolerant characteristic. Finally, the tsunami event has triggered land users to perceive environmental benefits of protection from mangrove or other adequate vegetation such as coconut plantations as welcome and desired to decrease their vulnerability. The assessment of multi-functionality of forest plantations, such as small-scale community based Clean Development Mechanism, its generated income from carbon credits as well as the wish for environmental protection should be considered to increase the attractiveness of plantation projects in the coastal areas.

1. Introduction

Forests provide many benefits, such as conserving land and water resources, providing forest products, and preserving biodiversity. Forest ecosystems are capable of storing large quantities of carbon in solid wood and other organic matter. Contrary, forests may also function as a source and add carbon dioxide (CO_2) into the atmosphere through deforestation, forest fires or decomposition of wood products [1]. In the tropics, the release of green house gases (GHG) from land use and deforestation is the greatest source of emission responsible for up to 25 percent of all anthropogenic emissions [2,3]. Global net carbon flux resulting from land-use changes, predominantly deforestation in the tropics, during the 1990s have been estimated at 1.6 (0.5–2.7) GtC yr^{-1}, compared to fossil fuel and cement emissions of 6.4 ± 0.4 GtC yr^{-1} for the same decade [4].

The tropical climate of Sri Lanka is prone to forest growth. A closed-canopy natural forest cover, rich in diversity covered almost the whole island with a few exceptions a few hundred years ago [5]. The crown cover of natural forests has dwindled from 80% at the beginning of the 20th century to around 21% by 2006 [6,7] due to legal and illegal logging. The forests that have been cleared legally have been for agriculture purposes, settlements schemes and development programs. Forests have been cleared illegally for shifting cultivation, agriculture and settlement by encroachers and for other economical purposes [8]. The problem of deforestation has critically diminished water supplies, loss of biodiversity and caused heavy soil erosion and made the soils less productive [5]. As

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a result, there is now an increased vulnerability to extreme weather events, natural disasters or future impacts such as rising sea levels caused by human-induced climate change.

The 2004 Sumatra–Andaman earthquake on December 26 triggered a series of tsunamis that spread over the Indian Ocean, devastating seaside communities and killing thousands of lives [9,10]. Sri Lanka suffered hard from the tsunami and livelihoods, assets and infrastructure were severely affected. Over two-thirds of Sri Lanka's coastline were destroyed and claimed over 35,000 human lives [11]. The effects of the tsunami varied due to the complex interaction between wave energy, seabed topography and terrestrial topography, but in general the eastern, north-eastern and south-eastern coast of Sri Lanka were predominantly hard hit [9]. The agricultural sector was seriously damaged when seawater penetrated hundreds to thousands of meters into some rivers and lagoons, damaging and salinizated lands and forests as well as contaminated water bodies. Rubbish, clay and sediments deposited on land decreased the productivity of soils. Trees and vegetation standing near unprotected shoreline were significantly damaged compared to species that were covered by natural breaks such as sand dunes, coral reefs or mangrove [12]. The transportation of seeds of invasive alien species further inlands from coastal regions has also been a severe threat against natural ecosystems and biodiversity as they have spread in an unprecedented rate and dominate over native and natural species. The disastrous effects of the 26th December 2004 have provided incentive to work towards to more sustainable and diverse solutions that contribute to reducing vulnerability.

Being one of the two project-based flexible mechanisms within the Kyoto Protocol, Clean Development Mechanism (CDM) is designed to make it easier and cheaper for Annex 1 countries (in essence an industrial country according to the nomenclature of the United Nations Framework Convention on Climate Change) to meet their GHG reduction targets that were agreed under the Protocol. The CDM must also contribute to sustainable development in developing countries (i.e. non-Annex 1 countries) [13]. The basic idea of the CDM is that industrialized countries – either the state or privately financed companies invest in projects in developing countries that contribute to the reduction of GHG emissions. Through these projects a contribution will be made to global climate protection but the respective sector in the developing country will also be modernized. The investing country can then credit the emissions' reduction achieved through its investment in the developing country towards its own emissions commitment. The afforestation and reforestation (A/R) projects within CDM have been loaded with methodological problems concerning leakage, baseline, permanence and monitoring, which is evident on the present (October 2008) statistic with only one project that has got registered. Recently more methodologies have been approved by the CDM Executive Board and there are now 14 methodologies available for A/R projects [14]. Also yet to be seen is a registered project based on bundling where several small but similar projects are registered as one to lower transaction costs [15].

Field work was carried out in the tsunami affected coastal area of Hambantota district in southern Sri Lanka (Fig. 1). A large variety of land-use systems, good knowledge and availability of relevant information about the area from earlier studies [e.g. [12,16]] and established contacts with citizens and organizations made this area the most appropriate for sampling of data. Hambantota district is a lowland region in the south-eastern part of the island and is situated about 240 km south-east of the capital of Colombo. The area has a shoreline of 130 km and a land area of 2609 km^2. The coastal district of Hambantota is a major production area for agriculture and fish industry. The livelihoods in the district are diverse with the main economic activities in the area comprising of fishing, agriculture, trade and services. According to Department of Census and Statistics of Sri Lanka the population in the district was 526,414 in 2001. The population density is 210 inhabitants per km^2 ranging from 100–150 in the eastern part to 400–600 in the western part [17]. Despite diverse agriculture and fish industry, Hambantota ranks as the third poorest district in the country and poorest coastal district, recording 32% of its people as poor. The district is located in what climatologically is best described as a tropical dry climate. For Hambantota town (around 16 m above sea level) the annual mean temperature is 27.1 °C and the annual mean precipitation is 1075 mm [18]. The study area is exposed to two monsoon periods. The south-west monsoon is from May to September and the north-east monsoon from December to February. Most rain is falling during the north-east monsoon.

The purpose of this study is to analyze the recovery of coastal ecosystems caused by the Sumatra–Andaman earthquake and the subsequent tsunami and the potential to recover these areas by participatory A/R CDM and decrease the vulnerability for future similar events. The following scientific questions were put forward.

- What is the present status of soils, land and vegetation as well as the process of resilience of tsunami affected areas and its significance for coastal ecosystem?
- What tree species have the best potential to sequester carbon and thereby be most feasible for an A/R CDM-project?
- What parameters are important for the local people in terms of local sustainable development and how could A/R CDM-projects be established to meet this demand?

2. Data collection and methodologies adapted

The methodologies used for this integrated assessment include estimation of the salinity developments of different land-use systems and wells used for drinking, impact on tree vegetation and standing biomass of selected species and a questionnaire survey to gather related information from the local people.

2.1. Soil sample collection

Soil samples were collected from forests- and land-use systems mentioned in Table 1. These are widely spread in the study area and are the most relevant in terms of possible implementation of A/R CDM related activities.

The samples were collected from 15 transects around the district (Fig. 2). Local people support and physical observations were obtained to identify the inundated land-use types and the extent for the laying of transects. When selecting transects, consideration into factors such as topography, gradient or soil characteristics just came secondary to land use and inundation. Transects were laid beginning from seashore towards inland reference points where tsunami water did not reach. In each transect, sampling points were selected at 50–100 m intervals, depending on the extent of the affected area. From each sampling point, three soil samples were collected at three depths increments (0–10, 10–30 and 30–50 cm). In addition, soil was collected from reference points situated further inland on non-tsunami affected soil (one per transect). The reference sample at each transect would function as an important comparison with the other samples to see the salinity difference between affected land and land not affected by the tsunami.

In home gardens, composite samples were collected from 10 to 15 sampling points within a small area, since the home garden area was limited in size which subsequently led to that the transects only covered a small portion. Electric conductivity (EC) analyses of the soil samples were carried out in laboratory experiments. The procedure mentioned in FAO [19] was followed when measuring EC

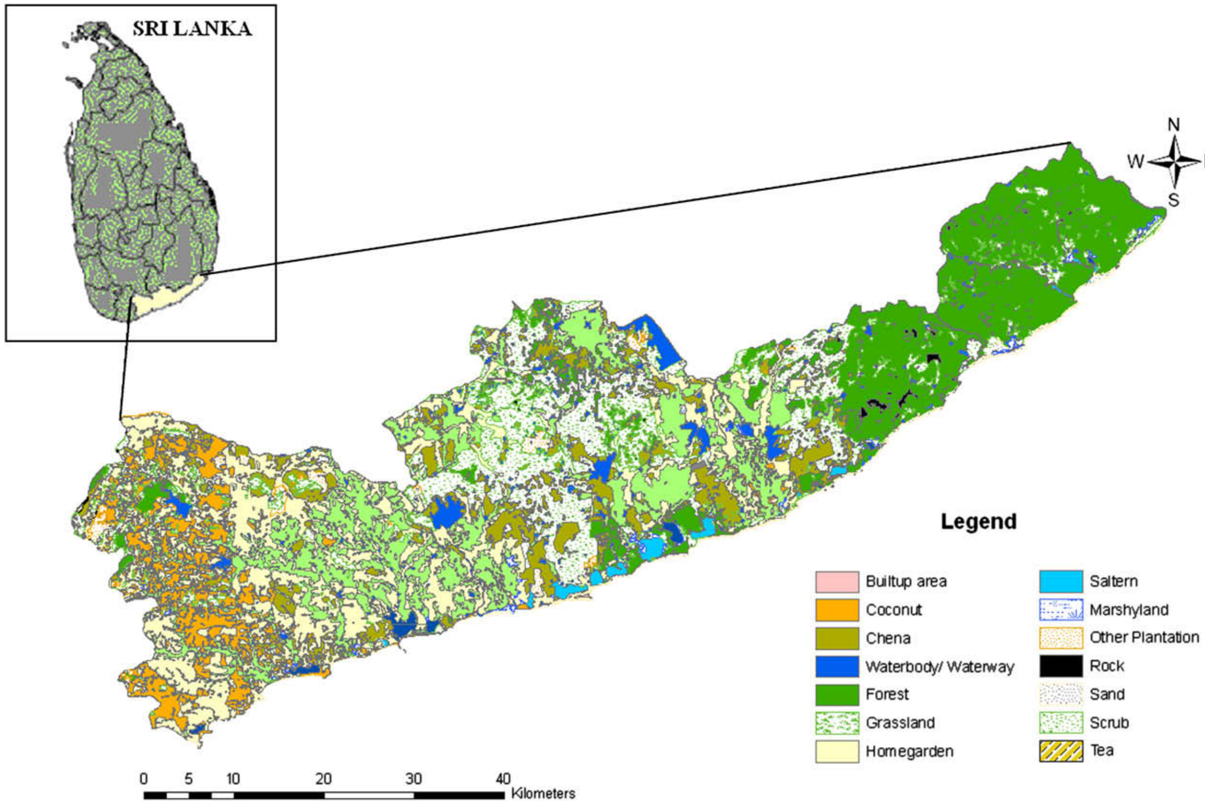

Fig. 1. Map showing the extent and land-use systems of Hambantota district.

of the soil. EC-meter measurements provide accurate information on soil salinity. The reading corresponds to the amount of electrolytes in solution. Therefore, the higher the value, more salt is accumulated in the soil.

2.2. Well water collection

Tsunami waves brought seawater to inland areas where it pooled for several days, before migrating back towards the coast with groundwater flow. Water samples from wells throughout the district were therefore monitored and collected to see whether the salinity levels in freshwater supplies still were prominent. These results could be used as guidelines together with the soil samples for a deep vertical transect analysis of the salt status in the ground. In every well one composite sample was taken by stirring the water. This procedure was conducted in order to avoid only surface water in the samples. According to the land-owners, the wells were inundated with 0.3–0.9 m (1–3 feet) of seawater at the tsunami event. When choosing the position of the wells consideration was taken to distance from seashore and soil property. The wells were situated within 200 m from seashore in sandy soil conditions. Most of them were used for drinking and washing purposes prior and post the tsunami. Salinity in well water had not been a problem in the district prior the tsunami. Only during severe droughts (which was not the case at the time of the study) higher conductivity can be expected.

Table 1
Land-use types assessed for soil samples showing the most common species.

Land-use type	Species
Natural forests	e.g. *Manilkara hexandra*, *Elaeocarpus serratus* spp.
Mangrove forests	e.g. *Sonneratia accida* spp.
Casuarina plantations	*Casuarina equisetifolia*
Coconut plantations	*Cocos nucifera*
Rural-and urban-home gardens	e.g. *Cocos nucifera*, *Azadirachta indica*
Rice fields	*Oryza*

2.3. Biomass and carbon sink potential

In order to find appropriate trees for a potential A/R CDM-project in this coastal environment, i.e. salt-tolerant tree species that are relatively fast growing, several perennial forest types were selected as sampling sites. The biomass and carbon measurements of trees were performed in the following land-use systems: *Casuarina equisetifolia* plantations, natural forests, coconut plantations, home gardens and mangrove forests.

For stock measurements in the forests and plantations, the quadrate method was used [20]. Girth measurements were taken at breast height (132 cm) from all tree species (>10 cm girth) in the quadrates (25 × 25 m).

Most of the land-use systems in the district, such as rural- and urban-home gardens, are relatively small-scale in size. Their extent is usually not bigger than 0.5 ha and the generally accepted method by using quadrates could not be assessed. Instead, girth measurements of 10–15 trees of various species[1] were compiled from each of these land-use types to get an idea of tree density and carbon sequestration potential of each individual tree. The estimated area of the sampling, relatively small in size (<15 × 15 m) was then recalculated and interpolated into the 25 × 25 m quadrate size.

[1] In natural forests mainly two species dominated; Palu (*Manilkara hexandra*) and Neralu (*Cassine glauca*). In mangrove forests *Rhizophora apiculata*, *Rhizophora mucronata*, *Heritiera fomes*, *Xylocarpus moluccensis*, *Sonneratia apetala* and *Excoecaria agallocha* prevailed. Approximately 15 tree species were assessed in home gardens, mainly fruit trees.

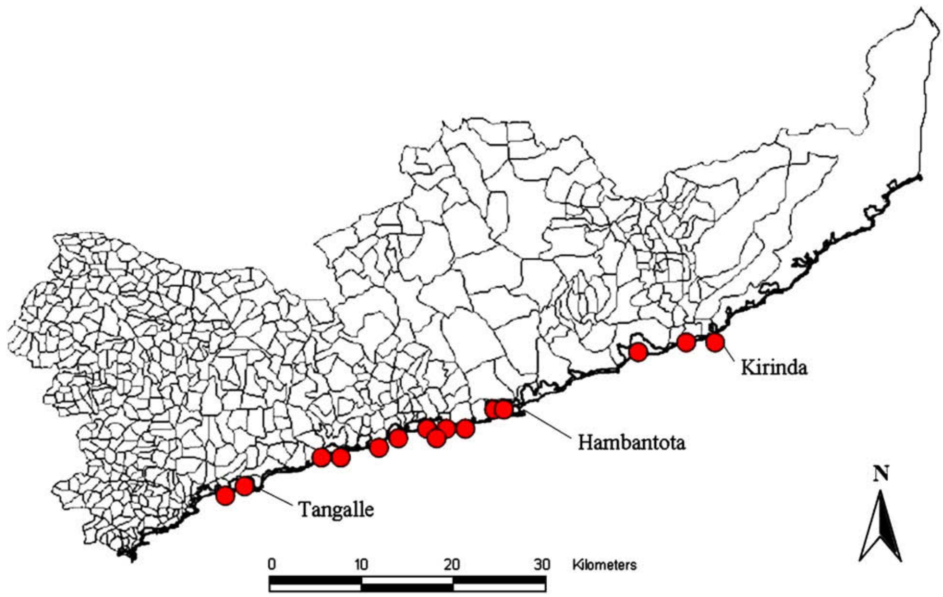

Fig. 2. Locations of different transects used to collect soil samples in the Hambantota district (modified from Ref. [16]).

The criterion for selecting appropriate sites for tree sampling in the district was firstly that they were situated in tsunami inundated areas. The second criterion was that the trees should be large in size since the objective was to find the potential carbon sequestration of the mature trees for a given species.

When the measurements were carried out, the aim was to calculate the amount of carbon in tons per hectare in the different forest types where the data was collected. The girth values were used to calculate the basal area (BA) of each tree using pre-defined formulas [21].

$$BA = \frac{GBH^2}{4\pi}$$

The basal areas were used to calculate the volume of the trees. To retrieve this information the basal area had to be multiplied with the area in question. The trees measured in home gardens were recalculated in the same manner.

Standing woody biomass volume can be calculated from a general formula where in the actual estimate of biomass was determined from the basal area for tropical forest areas. A linear regression coefficient was computed [22], considering basal area as an independent variable and the biomass as a dependent variable. This resulted in general formulas as follows:

$$\text{Volume of above ground biomass}(m^3/ha) = 50.66 + 6.52BA$$

$$\text{Weight of carbon per hectare in above ground biomass} \\ (tC/ha) = (50.66 + 6.52BA)\left(\frac{0.85}{2}\right)$$

The numerator (0.85) gives the dry matter weight of biomass and accounting for a moisture content of air dry wood at 15% [23]. The denominator arises from that half of the dry matter in biomass consists of carbon. Note that the formula is general for Indian forest and holds limitations since crown size and height are not considered.

2.4. Participatory information

In order to get the land users' views about plantation establishments, questionnaire interviews were conducted. Households around different land-use systems were selected to get a broad range of land users. Given that some land-use types (mangrove, *C. equisetifolia* and natural forests) are owned by the Government, no surveys were performed in these areas. The information was collected from land users in or outside small villages along the coastline in the district.

The questionnaire was pre-tested on land users in the study area and it was concluded that some of the questions had to be erased, modified or added. The final questionnaire contained *structured* and *open-ended* questions, a combination that according to Bernard [24] and Berg [25] is preferable. For instance, the interview began with structured questions and once the quantifiable data was covered, a more open discussion with the interviewee ended the visit. A method of pre-defined set of questions was chosen since the respondents would then answer the same questions and secondly, it would be simple to compile the data when the answers would be fairly standardized.

The first part contained questions of background information of the respondents. The other topics dealt with land use, effects of tsunami, questions related to cultivation and people's expectations of the future. A total of 24 interviews were conducted with help of an interpreter.

3. Results

3.1. Soil salinity

The threshold value for EC was set at 4 mS/cm (milli-Siemens per centimetre) according to the saline/non-saline boundary in United States Department of Agriculture (USDA) soil salinity standard analysis [26]. The results revealed that out of 150 sample points taken on tsunami affected land only eight samples had values over 4 mS/cm. All saline samples were found in mangrove forests and rice fields. A majority of the remaining samples showed values well below the saline threshold value and could not be distinguished from the reference samples. More than half of all sample points were situated in areas containing sandy soils. Land-use systems in these areas were e.g. *C. equisetifolia*, coconut, rural- and urban-home gardens. The conductivity values turned out to be the lowest in these areas, probably due to fast leaching of the salt as a result of monsoonal rains since the inundation of ocean water.

Samples collected in coconut plantations and rice fields where the soil had a silty-clayish structure, showed higher salinity levels than samples that were collected in sandy areas. However, these values were still below the threshold value but higher than the reference values. The higher values recorded in areas with silty-clayish soils can be a result of smaller porous volume in these soils and hence slower leaching. Overall, the mean values from the different soil depths at 100 m and 200 m from seashore (Figs. 3 and 4) confirm that land-use systems in general had mean conductivity values between 0.1 and 2.0 mS/cm.

Another important finding was that mangrove forests showed higher conductivity levels than other land-use types. Soil was collected in two mangrove transects in which five out of 24 sample points had values above 4 mS/cm. This observed correlation can be a result of extended accumulation of ocean water due to topographical features such as pockets at these transects points. Moreover, mangrove forests proximity to the ocean and lagoons and hence exchange of tidal water, might explain the higher conductivity values.

3.2. Well water salinity

Since most of the soil sampling sites showed no considerate result of salt contamination the question arises if the salt has been leached further down into freshwater aquifers. Therefore several samples of well water were collected within the study area. The samples were taken within 200 m from seashore in predominantly sandy soil conditions throughout the district to get a representative variation.

FAO [19] points out that clean water has a conductivity value less than 0.5 mS/cm, but water up to 2.0 mS/cm is acceptable. Hence, Fig. 5 shows that all but one of the wells still was contaminated with salt. People living around the wells were aware of the situation but most of them used their water for drinking purposes despite the high salt concentration. Since a substantial part of the soil was sandy, this might result in that contaminated water could go through the porous sand layers into the groundwater table below. People had pumped out saline water of the wells which was successful in some cases. However, overpumping can lead to upconing of the saltwater interface and rising salinity which have been observed in earlier tsunami related studies [27]. A problem might also be that people dumped the contaminated water nearby. The water will then go down through the soil and into the groundwater system again and the situation will not improve. Previous research findings on the issue [27,28] have reported that the natural recovery process will reduce conductivity over time. Moreover, monsoonal rains seem to have a beneficial effect on the recovery, but the amplitude of recovery will vary from one well to another.

3.3. Biomass and carbon sink potential

In Table 2 it can be concluded that natural forests have more standing biomass and carbon content than the other forest types. This is mostly a result of the thicker stems that were observed at the trees in the natural forests. However, since these trees are climax species they are having a great stability and relatively slow growth compared to other vegetation types [29]. Therefore it is also hard to get an estimate about the age of the trees in the natural vegetation. The coconut plantations showed a high volume of carbon compared to the other plantations, home gardens as well as the mangrove. Comparing the carbon stock of different coconut plantations, namely 12- and 20-year-old trees, it was found that the 20-year-old plantation contained the highest carbon stock, also as a result of thicker stems. The mangrove plantations (*Sonneratia accida* spp.) had the lowest volume of standing biomass. This can be explained by low girth values and a low spatial density of trees. Additionally, the carbon stocks in home gardens were lower than in natural forests and coconut plantations. Home gardens were having a rich diversity with many smaller fruit trees mixed with larger trees such as the ubiquitous coconut.

It should be mentioned that standing biomass does not say anything about the carbon sequestration potential over time. Therefore the results show only a snap-shot picture of existing carbon. Also, due to the small number of available plots on coastal land for measuring natural forests in the district, these results should be seen more as an indication than a quantifiable result that natural forests have the largest pool of biomass. There are, however, other studies [23,30] showing the same result, i.e. that natural forests have more standing biomass compared to other forest types. Furthermore, age of trees has not been taken into consideration (except for coconut trees) since there was no proper way to readily monitor this parameter.

3.4. Participatory evaluation

Most of the respondents felt frightened of living near the seashore since they found it possible that a tsunami will strike

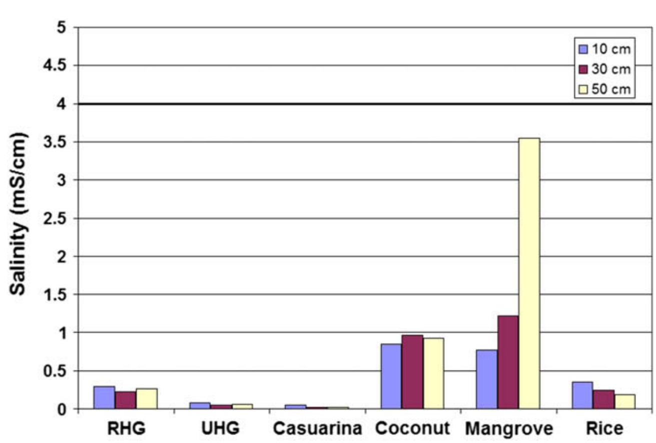

Fig. 3. The mean salinity levels of soils at 100 m from seashore in different land-use systems of rural- (RHG) and urban-home garden (UHG), *Casuarina*, coconut, mangrove and rice. The thick line at 4 mS/cm is representing the saline/non-saline boundary according to USDA soil salinity standard analysis [25].

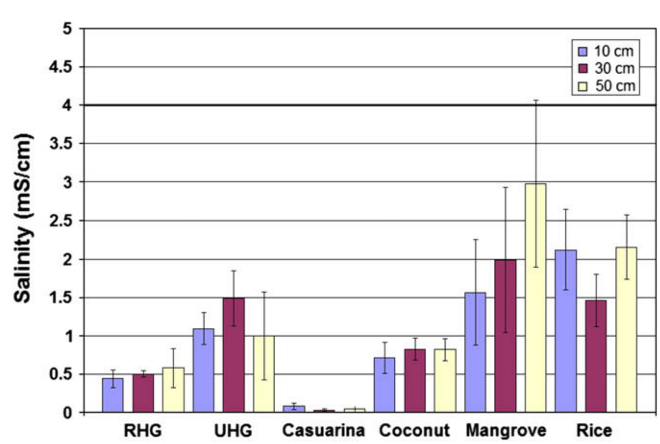

Fig. 4. The mean salinity levels of soils at 200 m from seashore in different land-use systems of rural- (RHG) and urban-home gardens (UHG), *Casuarina*, coconut, mangrove and cashew. The standard deviation is shown as error bars ($n = 45$). The thick line at 4 mS/cm is representing the saline/non-saline boundary according to USDA soil salinity standard analysis [25].

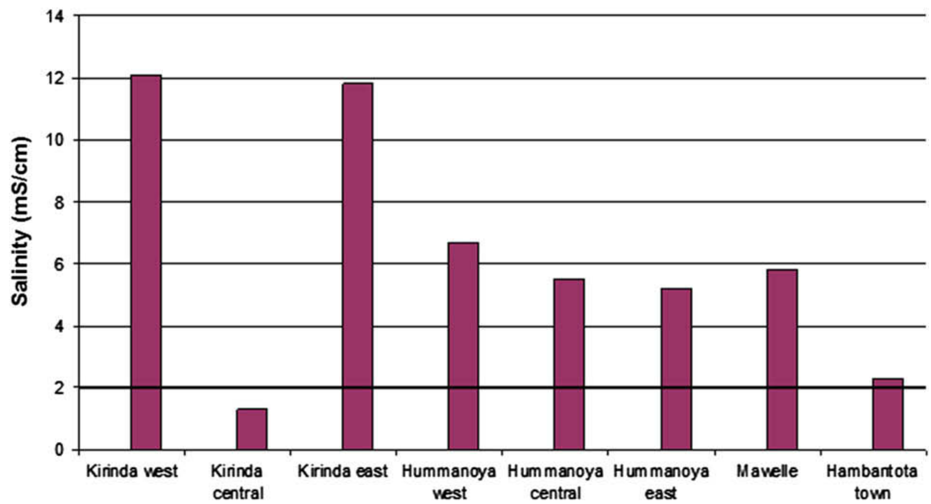

Fig. 5. Salinity from wells in tsunami affected areas of Hambantota district within 200 m distance range from the seashore. The thick line at 2 mS/cm is representing the maximum accepted value for clean water according to FAO [18].

again. A problem is that most of the respondents could not afford moving out to a safer place and abandon their land and properties where a substantial part of their income is coming from. The tsunami had caused the market prices of house- and land-property to fluctuate depending on where in the district and how far from seashore it was situated. For example people living within 100 m from seashore had seen the market price on their land decrease rapidly, whereas property value further inland had increased due to higher demand. Regarding land tenure, a small number of those interviewed could imagine giving up their land if they received some compensation, such as money or food. It was hard to find out in specific figures how much compensation they would acquire, but at least it had to cover their cost for the land.

The majority of the respondents found it possible to change crops from fruit trees and cultivate coconuts instead. A few respondents were satisfied with their current situation and could not imagine planting anything else. In some cases the land user wanted to expand his cultivated area but was unable to do so due to lack of investment capital and land availability. The advantages with the trees at present were several. Many pointed out that they are shading the ground and protects from the harsh tropical sun. It was also indicated that coconut trees are a good income in terms of fruit, drinks and timber. People mentioned that trees growing in tsunami affected areas now produce smaller fruits and even smaller yields, especially on coconut trees. For some other species, early flowering and deformed fruiting were also observed.

One important outcome of the participatory evaluation was the respondents' feeling of vulnerability that the tsunami event caused. The importance of protection in terms of viable vegetation was seen as important to protect inland land-use systems. The result shows that people in the area perceived the tsunami event as a triggering factor for the need of other land-use practices. Here the establishment of an A/R CDM could play a role both in terms of income bringing activities as well as an important environmental service.

Table 2
Mean values of basal area, standing biomass and carbon stock of the different forest types.

	Natural Forest	Coconut	*Casuarina*	Home gardens	Mangrove
BA (m^2/ha)	75.6	62.4	36.3	31.2	26.4
Standing biomass (m^3/ha)	702.4	457.5	285.2	253.8	222.5
Carbon stock (tC/ha)	294.8	194.4	121.5	107.9	94.6

4. CDM potential

If establishing an A/R CDM-project in Hambantota district it will be important to find a suitable tree that can adapt to the predominantly sandy coastal soil and the relatively hot and dry climate. Considering results from this study and future threats from rising sea levels and storm surges an appropriate tree should also be salt-tolerant enough to cope with saline ground conditions. Therefore using a fast growing tree with a short rotation period and good growth rate as well as other multiple uses would be preferable.

4.1. Coconut

Compiling the different aspects assessed, coconut plantation would be the most suitable plantation option. The coconut palm was the most beloved tree among the respondents since it provides multi-purpose uses for e.g. food and timber. It is salt-tolerant, especially to salt spray [31], though not as tolerant as *Casuarinas* or mangrove forests. Trees in the beachfront were mostly damaged in the tsunami since it intercepted a lot of the wave force, but further inland the destruction was very light and one of the least affected tree species. The coconut is moderately fast-growing and the biomass and carbon sink potential analysis showed that coconut had the highest standing biomass after natural forest. Being the "tree of life" the coconut is suggested as the best tree alternative for CDM establishment in the district.

4.2. Home gardens

Home gardens are perhaps the best developed agroforestry system in Sri Lanka. Home gardens are widespread in the district and vary in species composition and tree density. The probably most interesting suggestion based on the findings in this study would be to bond home gardens in the terms of "bundling". The small-scale A/R projects under the CDM allow bundling of individual small plots established by low-income individuals or communities with maximum annual sequestration of 16 kilotonnes CO_2 [32]. Every family would have the opportunity to cultivate their own individual plot which means that more people possibly could be involved in the A/R CDM-project. The bundling mechanism connecting home gardens could result in rich diversity of trees, multi-purpose uses as well as sustainable development. A majority of the households in the district owns a home garden and it is the most spread land-use system in Sri Lanka.

4.3. *Mangrove*

An interesting option would be to regenerate coastal land by planting mangrove. These species are the most salt-tolerant of the selected trees in this study and has the greatest possibility to improve environmental and coastal protection. The biodiversity it supports could exclude pests that would affect monocultures of other tree species. On the other hand, the carbon sequestration potential is the least and it would be costly and time consuming to afforest or re-afforest mangrove habitats. Since a large part of the coastline in the district consists of sandy beaches there are few potential places where new plantations could be established. However, the environmental benefits could be substantial when sensitive cultivated areas further inland are protected. Mangrove ecosystems are important habitats in developing countries, playing a key role in human sustainability and livelihoods. The increase of biodiversity in form of fauna, flora and improved livelihoods as a result of increased fishing are just a few examples of environmental advantages if establishing mangrove forests [33].

Earlier studies [33,34] confirm that mangroves played a vital role in protecting and reducing the effects of the tsunami. Mangroves also act as a natural filter by preventing phosphates and nitrates from reaching the ocean and salt entering the land. Furthermore, these forests support the livelihood around coastal areas by providing fishing. In recent years much of the mangroves have been clearcut for coastal development. Many of the hardest hit tourist facilities from the Asian tsunami in regions around the Indian Ocean were originally mangrove forest reserves. People in the region have very well realised the negative impacts that they exposed by destroying mangrove ecosystems and are willing to participate in community based replanting programmes. They mentioned that if mangrove plantations are established several natural commercial products such as drinks and jam could be obtained if suitable mangrove species are used.

4.4. Casuarina

Another alternative is to establish *C. equisetifolia* plantations. This fast-growing tree is also a multi-purpose tree. Timber, fuelwood and medicine purposes are the most common uses. However this species is logged and owned by the forest department and does not gain the local people in the same extent as other species such as the coconut. Therefore it is not certain whether *Casuarina* plantations can bring sustainable development on a local level comparable to the coconut. On the other hand, the *Casuarina* is not sequestering carbon as good as the coconut and has poor coppicing ability. It is also reported to be highly invasive [35]. The *Casuarina* plantations investigated in this study outside Hambantota town were established during 1986–1997 under a forestry development project funded by the Norwegian Agency for Development Cooperation (NORAD). It has recently [36] been found that this *Casuarina* shelterbelt is not able to act as a windbreak for adjacent agricultural fields or to produce timber with economic value for the area. However, the plantations have improved the aesthetic and micro-climatic benefits for the local dwellers and provide nearby citizens with fuelwood.

5. Discussion

By using an integrated assessment approach and multiple methods, the results show that there is a need for land-use management in this area based on three needs. These three demands are interlinked and land-use management in this area would benefit by using a multifunctional system approach when assessing the alternatives.

Firstly, this area is vulnerable to salt water inundation even under non-tsunami events [37]. The soil affected by the tsunami in 2004 showed a recovered status 14 months later in terms of salt content. But the majority of the investigated well waters on the other hand were unsuitable for human consumption according to FAO [19]. The freshwater situation needs to be solved for people living in the area. In terms of land-use management the impact of more or changed vegetation on the groundwater quality needs to be considered and more research needs to be conducted on this interlinked system [27].

Secondly, land users in the area are in need of improved livelihoods and hence increased income from the resources they have, which is the land. Tree plantation through A/R CDM-projects could in this perspective have a role to play since the land users would earn money on the carbon that their proposed tree plantation would sequester. With investment coming from an Annex 1 country, the barrier of investment cost, as expressed by interviewees, would be eliminated for the land users. Due to the size of these land patches there is a need for bundling together, according to United Nations Framework Convention on Climate Change (UNFCCC) guidelines. These types of A/R projects are still to be established and approved, but could for small-scale land users offer an income generating activity.

Thirdly, due to these areas vulnerable position along a storm frequent coast, the use of proper land-use management for protection has increased, not the least after the 2004 tsunami. Re-establishing the mangrove forest is one possibility which showed low carbon potential in this assessment. However, by assessing below-ground biomass in the carbon calculation, the mangrove plantation prospect might increase in attractiveness. Establishing plantations by using salt-tolerant and storm resistant species, which coconut showed in this study, are also a possibility. Coconut showed high carbon content as well as co-benefits for land users, which suggests that coconut is the most suitable specie to use for carbon sequestration, environmental protection and income. These parameters, generating income and protection, are seen as important factors for local sustainable development for the people in the area.

This study could readily be repeated to other coastal regions in the country, raising the A/R CDM potential substantially, if these community based projects could successfully be implemented. However, a triggering effect such as the devastating impact such as the 2004 tsunami can be the needed incentive for coastal populations to be willing to change their land use.

For policy implementation the following two criteria could be suggested given from the results in this study

- For local, regional or national authorities, it is important to consider a people-centred participatory approach in coastal management planning. Valuable participation of land users and community members is crucial since they often have the expert knowledge and are the direct users of the resources; hence their action has direct effect in both positive and negative ways. It is also important to evaluate the short- and long-term impact of different schemes of environmental policies and projects in general. Being part of the whole process by contributing in a constructive way by rehabilitating and modernizing land users own communities in a transparent way is a sound approach for improved livelihoods. This approach has been acknowledged in e.g. Hambantota Integrated Coastal Zone Management Project (HICZMP), funded by NORAD. [16,38].
- If implementing land-use policies that can improve livelihoods and bring sustainable development to land users in

Hambantota district, other policies than A/R CDM currently discussed within the UNFCCC such as Reducing Emissions from Deforestation in Developing Countries (REDD) could be considered. REDD offers the chance to put a monetary value on standing forests, and could give developing countries a way to contribute more substantially to the goals of global emissions reduction, while at the same time protecting their forest resources and investing in forest-related sustainable development for their forest-dependent communities. This policy proposal could be an incentive to ensure that natural forests are protected while at the same time increases the commercial value and co-benefits stemming from forest plantations.

6. Conclusion

The 2004 tsunami resulting from the Sumatra–Andaman earthquake caused severe destruction in land and vegetation in coastal areas in Hambantota district. By applying several approaches 14 months after the disaster it was found that the resilience process on soils and vegetation has been substantial. Salinity levels in the soils were found to be low throughout the district. Only some rice fields and a few mangrove sites showed moderate values of salinity. To evaluate the status of the soils deeper in the ground, well water samples were collected as part of deeper vertical transect's analysis. A majority of these samples showed that moderate to high salinity values are still prominent in the groundwater. In order to improve the soil status and to bring additional income for the local people A/R CDM could be implemented. Plantations of the coconut tree are suggested as the most suitable trees. This is due to its multi-purposes, importance for the livelihood and high carbon sequestration potential. It is also tolerant for the dry climate, wind, salt and possibility to grow adjacent to the coast on sandy soils. In terms of the most tolerant vegetation mangrove would be the far best option. The drawbacks are the low carbon potential. As a part of the participatory evaluation land-owners in the district can imagine raising plantations that can work as a CDM-project. If a potential CDM plantation project is well received by the locals it can sequester carbon and makes it easier for developed countries to meet their GHG emission reduction target under the Kyoto Protocol. CDM plantations in this area could have multiple benefits: protection from higher sea level in the future, improved livelihoods, economical benefits for people and income from carbon credits within the CDM. The prospects of establishing plantations such as A/R CDM are seen as much more welcome in the wake of a disaster such as the tsunami due to its environmental benefits in terms of protection.

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