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RESEARCH ARTICLE

Optimising usage of salinized lands in the lower part of the river basin for the coastal community in Bentota, Sri Lanka

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Abstract: Land degradation in coastal areas due to seawater intrusion, and coastal salinity is one of the major critical problems affecting the sustainable development of Sri Lanka. Coastal salinity risk is increasing in the Bentota area while diminishing land productivity which results in poor food production and giving rise to several socio-economic issues for the community in the area. Bentota is below the agricultural production capacity level and no strategy has been implemented or introduced so far regarding the utilisation of degraded lands in the area. This study identified the optimised extent of salinized lands for paddy, coconut, vegetables, fruits, tea, rubber and cinnamon cultivations based on future coastal salinity effects, land use demand and the development trend of the area. Land use change, rainfall, temperature, topography, floods, soil, ground and surface water are the factors applied in evaluations of land use suitability as the prior requirement for land use optimisation. Future demands of land use were predicted applying population growth models, the theory of land carrying capacity and the ecological footprint. Strategies for optimising the productivity of salinized lands were identified using a stakeholder perception-based approach. The developed sustainable land use pattern will enhance the land productivity of highly (3.4 %), moderately (39.6 %) and slightly (57 %) salinized areas in Bentota. Identified land management strategies will facilitate the spatial planning of future land use of this area by providing guidance to the local authority in the process of allocating salinized lands for enhancing land productivity.

Keywords: Future demand analysis, land use pattern, linear programming model, population forecasting, optimising salinized lands, seawater intrusion

INTRODUCTION

Coastal ecosystems are among the most economically productive areas and densely populated regions in the world (Barbier, 2012). Coastal surface water bodies hydraulically linked to the ocean are subject to seawater intrusion at varying levels. Saltwater intrusion (SWI) into freshwater coastal rivers and aquifers has been and continues to be one of the most significant global challenges for coastal water resource managers, coastal city planners, industries and agriculture (Ferguson & Gleeson, 2012). There are many factors that can influence the dynamic equilibrium between freshwater and sea water and contribute to SWI in a coastal aquifer (Costa, 2008). These influences include both natural variations and anthropogenic activities. The natural factors include climate change and sea-level rise, groundwater extraction and recharge, aquifer hydraulic properties, tidal exchange, rainfall, prolonged drought and the effect of gravitational forces (Costa, 2008; Williams, 2010; Werner *et al*., 2013). Many activities of economic development such as agriculture, fisheries, industries, human settlement and transportation make significant impacts on the mechanics of SWI (Costa, 2008). Han *et al*. (2010) showed the vulnerability of Sri Lanka as an island to the effects of sea level rise in near future, which will be on average +12 cm per century. Taking precautionary steps for the now foreseen threats is highly important because Indian Ocean sea-level rise affects the

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lives of millions of people who inhabit coastal regions and islands (Han *et al.*, 2010).

Major economic and environmental consequences of SWI into freshwater aquifers and river basins include the degradation of natural ecosystems and the contamination of municipal, industrial, and agricultural water supplies (Barlow & Reichard, 2010). Saltwater flows towards the inlands along with the river through the process of infiltration and leaks into the soils and groundwater sources adjacent to the river making its salinity levels high. Soils in saltwater intrusion areas are characterised by high concentrations of soluble salts and low organic matter (Asma *et al*., 2009). Therefore, the lands adjacent to the river are vulnerable to saline deposition and fail to give optimum production, which will lead to land degradation at the end. Introducing engineering structural solutions for controlling SWI is uneconomical in the context of Sri Lanka and it needs in-depth analysis of the diverse environment settings (Costa, 2008).

Land degradation is one of the major critical problems affecting the future economic development of Sri Lanka (Ministry of Land, 2000). However, the coastal region encompasses 22 % of the country's total land extent, 32 % of the country's population, 65 % of the urbanised areas, four out of six cities (population >100,000) and two thirds of all industrial contributions of Sri Lanka (Ministry of Land, 2000). Natural land degradation is caused in coastal areas through SWI and most of the land use patterns have been changed with the impact of coastal salinity (Jayasiri & Dahanayake, 2012). The coastal salinity affected area of Sri Lanka has been estimated approximately as 0.112 million ha and electrical conductivity (EC) of the respective soil extraction has exceeded 4 dSm^{-1} in those areas (Ministry of Land, 2000).

Most of the effects of SWI are on the livelihood options of the coastal population in Sri Lanka. Therefore, strengthening the linkages between climate, hazards, community resilience and climate adaptation is essential to overcome the consequences of SWI. For that, climate change and its effects need to be observed, studied and predicted on a regional scale to take measures on the expectable consequences and planning the future development of that particular region. Land use optimisation models are tools to support the analysis of the causes and consequences of land use dynamics under the change of different environment conditions and therefore, scenario analysis with land use modelling can support land use planning and policy formulation (Veldkamp & Lambinb, 2001).

The need for land use planning (LUP) is frequently brought about by changing needs and pressures, involving competing uses for the same land or land degradation (Verburg *et al*., 2004). The process of land use planning and its implementation hinge on three elements as: the stakeholders involved in, the qualities of each component of land units being planned for and the consideration of available, viable land use options (Metternicht, 2017). An aspiration of land use planning is to coordinate current and future societal needs, while minimizing conflicts (Crossman & Bryan, 2009). Land evaluation is only part of the process of land use planning (Young, 1998) and its precise role varies in different circumstances (FAO, 1976). Land evaluation is a process for matching the characteristics of land resources using a scientifically standardised technique (Kamkar *et al.*, 2014). As a process, sustainable land use management (SLM) encompasses ecological, economical and socio-cultural dimensions of sustainable development (Bryan *et al*., 2015). SLM concerns on solutions that go far beyond the technological recommendations by counting on the social participation and policy dialogue aspects into consideration (Dumanski, 1994). The lately suggested 'multi-level stakeholder approach to sustainable land use management' encourages local-level participation and also consents the presence of other stakeholders in land use planning, which is negotiated via common agreement (Hurni,1997).

In this respect, finding a suitable mechanism for optimum utilisation of saltwater intruded lands in the coastal part is a current requirement in the context of Sri Lanka that needs to be studied in detail. As an agricultural country, there are many studies carried out on salinity intrusion on coastal aquifers and groundwater bodies (Ranjan *et al*., 2006: Jayasiri & Dahanayaka, 2012; Piyadasa & Wijesundara, 2014), but less on finding a solution for land use optimisation in coastal river basins. Consequently, productive land management is an essential practice nationwide and worldwide with the escalating population and food demand (FAO, 2007). Therefore, the present study has been designed to develop a land use optimisation model for enhancing land productivity of saline water affected areas in Sri Lanka by integrating all major environmental, physical and socio-economic factors.

METHODOLOGY

Study area

Bentota River basin is facing the natural phenomena of flooding in the rainy season and SWI in the dry season annually. At present more than 80 % of paddy lands in this area have been abandoned due to contrasting degrees of saltwater intrusion (Piyadasa & Wijesundara, 2012). Snowballing of marshy lands due to long-term abandonment of paddy lands has caused a dramatic change in land use patterns of the area. The Bentota river basin is below the agricultural production capacity level and there is no sustainable management system for rearranging the land use patterns in the area. Therefore, as the case study for this research, Bentota divisional secretariate division (DSD) situated in the left bank of Bentota river basin was selected to develop a land use optimisation model for enhancing its land productivity.

Data acquisition and processing

Land use data available for the years 1983, 1996, 2001 and 2008 were obtained from the Survey Department of Sri Lanka. Existing land use pattern of the area was digitized using latest satellite images taken in year 2013. Population, housing, employment and crop production details of the area were collected from the Resource Profile of the Bentota Divisional Secretariat Division (2014) and the Department of Census and Statistics (2012). Weather data on monthly mean temperature, total monthly rainfall and maximum daily rainfall for each month and total annual rainfall from year 1986 to 2015 that were recorded at three weather stations located in the Bentota River basin were obtained from the Meteorology Department of Sri Lanka.

Following systematic sampling method, 24 groundwater samples were collected from the wells that were closest to the mid points of the 2 km × 2 km grid used for the study by using Global Position System technology. Seventy-two soil samples were also collected from the same 24 sampling locations at three depths at each location at 20 cm, 40 cm and 60 cm by using a hand-held soil auger. Surface water samples were taken from the middle and ends of all the irrigation canals within the Bentota DSD. Sampling and monitoring period was from July 2016 to June 2017.

The *in-situ* parameters such as electrical conductivity (EC), pH and dissolved oxygen (DO) of each surface and groundwater samples were measured in the field immediately after sampling using portable glass electrode meter. Laboratory analyses for the surface and groundwater samples were tested for the presence of total dissolved solids (TDS) by applying the gravimetric method; for the presence of chloride (Cl^-) by applying the argenometric method; and for the presence of nitrate (NO_3^-) and sulfate (SO_4^{2-}) by applying the spectrophotometry method (Saxena, 1998; Clesceri *et al*., 1999). Sodium adsorption ratio (SAR) was determined after analysing the concentrations of Na, Mg and Ca by applying the flame photometer method (Clesceri *et al*., 1999). Soil colour, soil moisture content, pH, EC, chloride (Cl-) and nitrate (NO_3^-) were also determined for the soil samples. Soil moisture condition was determined by drying a soil sample into a constant weight and calculating the percentage of water in that sample. pH value and electrical conductivity in the soil suspension were measured using a glass electrode pH and EC meter at 1:2.5, soil: water ratio (Black, 1965). Water soluble chloride and nitrate concentrations in soil were determined using the argenometric method (Saxena, 1998).

Statistical and spatial analysis methods

Method for exploring land use and land cover change

Arc GIS 10.5 software was used to show the spatial and temporal distribution of land use pattern of the area. Mixed land use diversity of the area was examined by calculating the 'entropy' value for land use pattern of the area during the years 1983, 1996, 2001, 2008 and 2013. Entropy value was calculated by applying a formula (equation 1) developed by Cervero and Kockelman (1997) to assess the similarity and diversity of land use types of the area as categorised into built-up areas, home garden, paddy, rubber, coconut, cinnamon, tea, other cultivation, land underutilisation, scrub, forest, marshes, grasslands, mangroves, barren land, reservoir, sand, and rock area.

$$H = -1\left[\frac{\sum (P_j) * \ln(P_j)}{\ln(K)}\right] \qquad ...(01)$$

where H is the entropy value and K is the number of different types of land use in the area. P_j indicates the proportion of total land area in the j^{th} land use type and ln is the natural logarithm using e (approximately 2.718) as its basis. Entropy values range between 0 and 1, with 1 representing equal proportion of each land use type and 0 representing the presence of a single dominant land use.

Method for exploring topography and climatological influence

Weather forecasting is a scientific appraisal of the weather conditions in an area during a specified time (Aziz *et al*., 2013). Box and Jenkins (1970) show that time series analysis has two most common patterns as trends and seasonality. Time series analysis of weather data on monthly mean temperature, total monthly rainfall and maximum daily rainfall values from year 1986 to 2015 allows the development of mathematical equations, which explain the data in such a way that prediction or monitoring can be done. Hence, Mann-Kendall trend test was used to describe a trend of the time series, and to see whether there is a decreasing or increasing trend. Mann-Kendall trend test is also the most widely used method since it is less sensitive to outliers and is the most robust as well as suitable for detecting trends in rainfall (Keredin *et al*., 2013). In the case of seasonal Mann-Kendall test, the seasonality of the series has been taken into account. For this test, all Kendall's tau for each season was first calculated and then an average Kendall's tau was calculated. To calculate the p value of these tests, a software called XLSTAT, which uses a normal approximation to the distribution of the average Kendall tau was used. Inverse distance weighted interpolation (IDW) method in Arc GIS 10.5 (Tomczak, 1998) was used to estimate cell values by averaging the values of forecasted rainfall of all weather stations in the neighbourhood of each processing cell. A digital elevation model (DEM) was used to compile a slope map of the area. The spatial distribution of total monthly rainfall during two major seasons and the slope of the area were considered to identify the climatic suitability for different land use types.

Method for soil analysis

Model builder is an application in the Arc-GIS software to create, edit and manage models (Amiri & Mohamed, 2012). Model builder tool with IDW technique, reclassifying and weighted overlaying methods were applied to develop spatial distribution of soil salinity by integrating all soil parameters focused on their susceptibilities to soil salinity risks and considering related soil salinity classes (FAO, 1988; Baruah & Barthaur, 1997). The multi-criteria evaluation (MCE) approach was used in weighted overlay analysis. Using a pairwise comparison matrix (PWCM) in analytic hierarchy process (AHP), the weight values for each soil parameter was calculated by comparing two parameters with each other for their relative importance in evaluating the soil salinity susceptibility by consulting professionals from environment planning related fields. Five professionals from the fields of Agriculture, Land use Planning, Geography, Hydrology and Coastal Resources participated in this survey. The scale formulated by Saaty (1980) was utilised in the application of PWCM. This scale has values from 9 to 1/9. A ranking of (1, 3, 5, 7, 9) shows that in comparison with the column factor, the row factor is more significant. Furthermore, a ranking of (1/3, 1/5, 1/7, 1/9) shows that the row factor is less significant than the column factor. Responded values were applied to AHP calc version 22.5 software programme developed by Geopel (2012) to run the process of application of AHP. Priority vector (Pj) was calculated as percentage value for each soil parameter in evaluating the soil salinity susceptibility. Once the layers of soil parameters and their weights were obtained, a weighted overlay analysis was applied multiplying the salinity class value of every soil parameter by its particular weight to produce a map of soil salinity levels (equation 2).

$$\text{Soil salinity} = (0.32 \times \text{soil EC}) + (0.30 \times \text{soil pH}) + (0.28 \times \text{soil chloride}) + (0.05 \times \text{soil moisture}) + (0.05 \times \text{soil nitrate}) \quad ...(2)$$

In the output raster, two classes were obtained from the model, ranging from 1 to 2, where the moderate raster class 2 represents the areas with moderate soil salinity levels, while the lower raster class 1 represents areas with slightly soil salinity levels.

Method for assessing groundwater and surface water quality

Consequently, a water quality index (WQI) for groundwater (GW) and surface water (SW) was developed assessing the quality of water suitable for drinking purposes and irrigation purposes. WQI is defined as a rating and reflects the composite influence of different water quality parameters (Alhadithi, 2012). WQI is one of the most effective tools to communicate information on the quality of water to the concerned citizens and policymakers. WQI can be calculated applying the following equation:

$$Wi = wi / \sum n\ wi \quad ...(3)$$

where Wi is the relative weight and wi is the weight of each parameter which was assigned based on their perceived effects (1 to 5 being most significant) on primary health and their relative importance in the overall quality of water for drinking purpose and irrigation water purpose as indicated in Table 1. The highest weight of 5 was assigned to parameters which have the major effects on water quality and their importance in quality (SO_4^{2-}, NO_3^- and TDS) and a minimum of 2 was assigned to parameters which are considered as not harmful (Ca^{2+}, Mg^{2+}). n is the number of parameters and i is the i^{th} sample location.

$$Qi = (Ci / Si) \times 100 \qquad ...(4)$$

while, the quality rating for pH or DO was calculated on the basis of equation (3)

$$Qi = (Ci - Vi / Si - Vi) \times 100 \qquad ...(5)$$

where, Qi = the quality rating, Ci = value of the water quality parameter obtained from the laboratory analysis, Si = value of the water quality parameter obtained from recommended WHO standards (Table 1) and Vi = the ideal value which is considered as 7.0 for pH and 14.6 for DO. For computing WQI, the sub-indices (SIi) were first calculated for each parameter, and then used to compute the WQI as in the following equations:

$$SIi = Wi\, Qi \qquad ...(6)$$

$$WQI = \sum n\, SIi \qquad ...(7)$$

Table 1: WHO Standards

Parameter	Drinking		Irrigation	
	Si	wi	Si	wi
pH	8.5	3	8.5	3
EC µs/cm	250	3	1000	3
DO mg/L	6	3	6	3
TDS mg/L	500	5	1000	5
Cl^- mg/L	250	4	1000	4
Nitrate (NO_3^-) mg/L	50	5	100	5
Sulfate (SO_4^{2-}) mg/L	200	5	500	5
Calcium(Ca^{2+}) mg/L	75	2	200	2
Magnesium(Mg^{2+}) mg/L	30	2	100	2
Sodium (Na^+) mg/L	100	3	200	3

Source: WHO, 2011

Si: value of the water quality parameter obtained from recommended WHO standards.

wi: weight of each parameter which was assigned based on their perceived effects (1 to 5 being most significant) on primary health and their relative importance in the overall quality of water for drinking purpose and irrigation water purpose

The computed WQI values for groundwater (GWQI) were classified as <50 = Excellent, 50 – 100 = Good, 100–200 = Poor, 200–300 = Very poor, > 300 = Unsuitable (Alhadithi, 2012). The computed WQI values for surface water (SWQI) were classified as < 200 = Excellent, 200–500 = Good, 500–1250 = Poor, 1250–2000 = Very poor, > 2000 = Unsuitable (Ravikumar *et al*., 2013). Spatial variation of each parameter of surface and groundwater samples and WQI values were analysed applying the IDW method. WQI values calculated for surface water samples based on their suitability for irrigation was mapped out considering the river and irrigation canal network of the area. The significant linear relationship between the considered parameters of surface water, groundwater and soil were identified applying correlation analysis in SPSS software.

Method for simulating flood inundation

Flood simulation model was developed using ArcGIS Model builder, Python scripting and mathematical algorithms. Model builder is applied as a visual programming language for building workflows (Amiri & Mohamed, 2012). Python was introduced to the ArcGIS community at version 9.0. Since then, it has been accepted as the scripting language of choice for geo-processing users and continues to grow (Al-Mashreki *et al*., 2011). The ArcGIS model builder was used to identify flood-prone areas considering 10 m × 10 m pixel size layers of contours (DEM), soil, land use, hydrology and forecasted maximum daily rainfall values (IDW). The curve number for the watershed area was obtained related to the soil conditions of the watershed by different land use types. Runoff model was used to identify flood depth of the area. The accuracy of the simulated flood levels of the entire inundation area was tested using Classification Accuracy Assessment (Cleve *et al*., 2008). This method uses Kappa coefficient to test the consistency of the actual values and simulated values.

Method for evaluating land use suitability based on coastal salinity susceptibility

Model builder in GIS was applied to assess land suitability, which is commonly applied in land use suitability evaluation (Liu *et al*., 2006; Al-Mashreki *et al*., 2011; Amiri & Mohamed, 2012). The developed layers of spatial distribution of soil salinity, groundwater quality and surface water quality were integrated using weighted overlay techniques to determine land use suitability based on coastal salinity susceptibilities. The multi-criteria evaluation (MCE) approach was used in weighted overlay analysis. The weight values for the layers of soil salinity, groundwater quality and surface water quality were calculated by comparing two factors with each other for their relative importance in evaluating the coastal salinity susceptibility of the study area by consulting five related professionals and applying the afore-explained AHP method. Finally the remaining factors such as current land use pattern and slope of the area, spatial distribution of forecasted total monthly rainfall and new agro-ecological regions, highly and moderately salinized surface waterways and simulated flood inundation areas were overlaid to appraise and group specific areas based on coastal salinity effect and their suitability for different land uses.

In this study, the level of coastal salinity was evaluated under two scenarios. The first scenario assumes that the prevailing coastal salinity impacts and SWI conditions in the area will be continued up to year 2025. The maximum value of each parameter with respect to each ground and surface water sampling location during the one-year period was considered to calculate the maximum WQI of each sampling location, since the maximum values define the reachable highest conditions in the present context of the area. The spatial distribution of coastal salinity was demarcated by overlaying the spatial distributions of soil salinity, GWQI and SWQI conditions. All the layers were with a spatial resolution of 30 m.

Method for exploring the perception of future development trend and land use management

The toolkit for the indicators of Resilience in Socio-ecological Production Landscapes and Seascapes (SEPLS) (UNU-IAS, 2014) was followed in the community perception workshops with the participation of multiple strata community and government sector stakeholders. The SEPLS toolkit claims having the prospective to be one of the most effective tools for "not only measuring, but also raising awareness of the concept of resilience in the field of sustainable development" (UNU-IAS, 2014). Following the toolkit of SEPLS methodology, the historical transformation, present context and future trends associated with the development of the area, issues regarding land use management and prospective strategies were identified in the resilient assessment community workshops. This was done by capturing the diverse details with reference to the 20 indicators under five major performance criteria as: landscape diversity and ecosystem protection, biodiversity (including agricultural biodiversity), knowledge and innovation, governance and social equity, and livelihoods and wellbeing. Accordingly, several stakeholder consultation workshops and focused group discussions were conducted covering Pahalagamhaya (65 participants) and Gonagalapura (40 participants) Agrarian Services Divisions (ASD) in Bentota DSD. Participants were farmers who have matured experience in farming and officers from relevant institutions.

Method for land use demand prediction

The land demands for different uses by year 2025 were predicted using statistical data and applying the theory of land carrying capacity and the principle of ecological footprint. Geometric growth model and exponential growth model were applied to calculate population growth rate and to predict the population of the area by year 2025 assuming that the same growth rate will be sustained. The land demand for paddy, coconut, vegetables and fruits were predicted based on the theory of land carrying capacity. For paddy, it started with predicting the population size and the consumption of rice as a strategic commodity in this area considering 2025 as target year. The rice productivity per hectare was estimated by modelling the historical rice production trend using statistical data. The same procedure was applied to find the land extent that should be cultivated to meet the demand by the population in year 2025 for coconut, vegetables and fruits.

Based on trend analysis of the ecological footprint for rubber, tea and cinnamon, linear regression models were calculated with years as the dependent variable and footprint as the independent variable. Land demand for housing construction was estimated using housing deficit of the area based on future population growth. Currently, available forest and water area are supposed to be conserved, and the extent of land that should be allocated for marshy lands and grasslands were identified considering the conservation of flood inundation area and animal habitat locations.

Method for developing land use optimisation model

Linear programming model (LPM) was applied as a technique for optimisation of linear objective function, subject to linear equality and linear inequality constraints. In using optimisation approach, objectives are represented using objective functions and the decisions to be made are represented using decision variables. Objective functions are the measures of performances expressed as functions of the decision variables. Constraints are any restrictions on the values the decision variables can take. In the case of land use allocation, restrictions are the amount of land available or the amount of land required. There were logical constraints or simply non-negative constraints, which restrict the ranges of the decision variables and the relationships among them.

Method for validating the simulation models

In this study, developed models on WQI, soil salinity, coastal salinity and flood simulation were validated in ground level situation. For this, a structured questionnaire survey was carried out by interviewing 48 community people including one famer and one community peopleperson from each 24 sampling location in the area. They were selected by searching the farmers and the community who live neighbouring each sampling location. Other than this, these developed models were presented at two community workshops conducted in Pahalagamhaya and Gonagalapura ASD in order to validate these spatial distributions in the ground level situations based on community perception and experiences. Land use optimisation models were developed to identify suitable lands from each salinized area for cultivating paddy, coconut, local vegetables and fruits in order to meet the deficit demand of each land use by the population in Bentota DSD during year 2025. Finally, the possibility and constraints regarding the utilisation of the above identified land extent for cultivating paddy, coconut, local vegetables and fruits were identified through two stakeholder discussions. Paddy Lands Acts No 1 of 1958 and No 30 of 1958 and the legal procedure mentioned in the Agrarian Development Act, No. 46 of 2000 were studied to identify the possibilities for conversion of abandoned paddy lands for other cultivation.

RESULTS AND DISCUSSION

Analysis of land suitability factors

Bentota DSD had 2524 ha of cultivated paddy lands during 1983, but this has been reduced to 245 ha by 2013 due to salt stress conditions on paddy in the area. However, 1385 ha of paddy lands were abandoned without utilising for any purposes while 894 ha have been converted to other uses such as marshes, scrubs and grasslands by the year 2013. The level of mixed land use diversity of the area during the last three decades is similar. Tea and cinnamon can be identified as the emerging crops since tea cultivation has been increased by 4 % annually and cinnamon by 2 % annually. Rubber and coconut lands in the area have shown a reduction of annual rates of 4 % and 1 %, respectively (Figure 1).

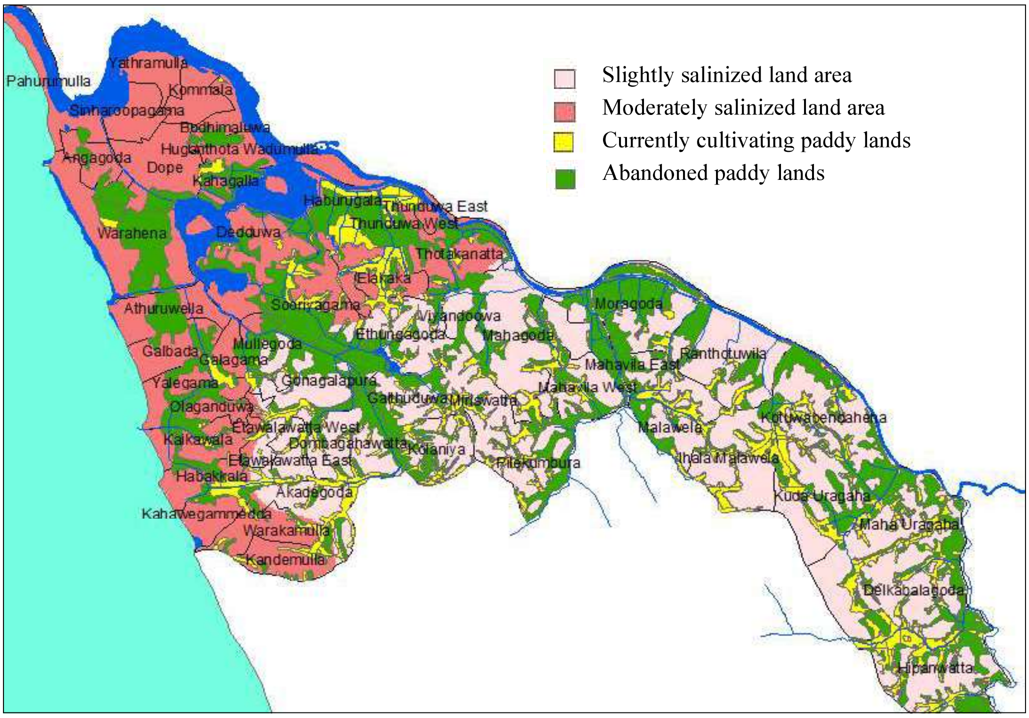

Figure 1: Spatial distribution of coastal salinity and land use in Bentota DSD: scenario one

According to time series analysis of climatic data, monthly mean temperature and maximum daily rainfall show a general increasing trend, whereas total monthly rainfall and total annual rainfall show a general decreasing trend in Bentota area. Relatively high rainfall situations will be expected during May and October while low rainfall situations will be expected during January and February. Flood situations will occur, once in every five years. During Yala season (March to August), the area will receive comparatively more rainfall with average monthly rainfall around 331 mm by year 2025. During Maha season (September to February), the area will receive an average monthly rainfall of 300 mm by the year 2025. As per Ritung *et al.* (2007) flood hazard classification, medium level of flood inundation was recorded in Thunduwa area while slight level of flood inundations were recorded in surrounding areas of the Dedduwa lake where the flood level was between 40 cm and 60 cm during May and September when flood situation occurred in those areas.

There was a relatively high moisture content (21–52 %) in the soils of inland part of the area, and the low moisture availability in coastal part of the area will limit crop yield and saturate the salinity level. The distribution pattern of soil EC was changed with the depth of soil layer varying from 0.14 – 5.43 dSm^{-1} whereas 0 – 20 cm layer reported relatively high EC values than other layers. Soil pH varied from 5.5 – 9.2 according to the depth of soil layer. Chloride percentage in soils of this area varied from 0.006 – 0.230 % and inland area consisted of 0.051 – 0.120 % of chloride, which indicate average salinized conditions. High EC values, high alkaline conditions and high chloride concentrations in soils were recorded in proximity to the shoreline and the Bentota estuary. Concentration of nitrate in soil varied from 4 – 100 mg/kg and relatively moderate concentrations between 51 – 75 mg/kg were recorded proximity to the shoreline and the Bentota estuary. Respective salinity classes with reference to each soil parameter were given weightage values from 1 to 4 based on their susceptibilities to soil salinity risks where 1 represents the lowest susceptibility to soil salinity and 4 represents the highest susceptibility to soil salinity. According to PWCM, soil EC (32 %), pH (30 %) and chloride (28 %) are more or less equally important for identifying soil salinity susceptibility and that is six times higher than the importance of soil moisture (5 %) and soil nitrate (5 %). In soil, 64.4 % of total land extent of Bentota DSD has been slightly salinized while 35.6 % of total land extent has been moderately salinized.

Consequently, groundwater pH, EC, TDS and Cl^- varied in the ranges of 5.2 – 9.3, 21 – 1310 µS/cm, 1000 – 2760 mg/L and 21 – 204 mg/L, respectively. The highest values were recorded from the wells with proximity to the shoreline and the Bentota estuary. Groundwater pressure, temperature and DO varied in the ranges of 753 – 757 ppm, 26.4 – 30.9 °C and 7.49 – 8.2 mg/L, respectively. The variation of groundwater nitrate concentration was different from the other parameters. The calcium (Ca^{2+}), magnesium (Mg^{2+}) and sodium (Na^+) concentrations of groundwater ranged from 0 – 31.95 mg/L, 1.3 – 102.12 mg/L and 3.77 – 85.66 mg/L, respectively, being high in shoreline areas and low in Ethungoda, Mullegoda and Mahawila areas. The groundwater SAR and SO_4^{2-} ranged from 0.18 – 6.68 mg/L and 11 – 473 mg/L, respectively in the Bentota DSD being high in Warahena area and low in Ranthotuwila area.

The impact of salinity has been increased and indicated high groundwater depths and high parameter values in sampling wells during the months of August and September in 2016 and January, February and March in 2017 due to the absence of rainfall throughout these months. The impact of salinity has been decreased and indicated low groundwater depths and low parameter values in sampling wells during October and November in 2016 and May and June in 2017 due to high rainfall intensity in the area during these months. GWQI was calculated to assess the quality of water, which is suitable for drinking purposes. The GWQI values of wells located near to shoreline, river and irrigation canals have shown high GWQI values indicating the groundwater quality as poor and very poor. The wells located in inland part of the area indicated low GWQI values and the quality of water in two wells being excellent.

All considered surface water parameters in the canals that originated from the river near the estuary were very high and over the permissible limit of WHO (2011) standards and indicated very highly saline conditions during the months of August and September in 2016 and January, February and March in 2017. SWQI values were obtained to assess the overall quality of surface water for irrigation purposes. Accordingly, SWQI fluctuated from 368.05 – 2637.08 being good to unsuitable conditions, respectively for irrigation purposes. High SWQI values that indicate very poor and unsuitable conditions were found near the estuary of Bentota River, Dedduwa Lake and coastal belt. Only two canals located in inland part of the area indicated low SWQI values and good quality of water. This study has not found areas which have surface water in excellent conditions for irrigation purposes and also shows that groundwater parameter values have increased near the river and the streams that originated from the river near the estuary.

Table 2: The relationships between groundwater (GW) parameters and salt water (SW) parameters

Parameter relationships	Correlation coefficient (r)	Parameter relationships	Correlation coefficient (r)
SW EC and GW EC	0.679	SW Ca and GW pH	0.703
SW EC and GW pH	0.631	SW Ca and GW Cl	0.867
SW pH and GW EC	0.753	SW Ca and GW Mg	0.836
SW pH and GW pH	0.677	SW Ca and GW SAR	0.819
SW TDS and GW EC	0.669	SW Mg and GW EC	0.693
SW TDS and GW pH	0.614	SW Mg and GW pH	0.646
SW Cl and GW EC	0.876	SW Mg and GW CL	0.839
SW Cl and GW pH	0.822	SW Mg and GW Mg	0.798
SW Cl and GW Cl	0.886	SW Mg and GW Na	0.806
SW Cl and GW Ca	0.802	SW Na and GW EC	0.715
SW Cl and GW Mg	0.838	SW Na and GW pH	0.663
SW Cl and GW Na	0.737	SW Na and GW CL	0.859
SW SAR and GW EC	0.651	SW Na and GW Mg	0.805
SW SO_4 and GW EC	0.827	SW Na and GW Na	0.820
SW Ca and GW EC	0.734		

Table 3: The relationships among groundwater (GW), salt water (SW) and soil parameters

Parameter relationships	Correlation coefficient (r)	Parameter relationships	Correlation coefficient (r)
GW EC and soil pH	0.804	GM Mg and soil EC	0.772
GW EC and soil EC	0.671	GM Mg and soil Cl	0.717
GW EC and soil Cl	0.628	GM Na and soil pH	0.688
GW EC and soil moisture	-0.523	GM Na and soil EC	0.723
GW pH and soil pH	0.758	SW Cl and soil pH	0.846
GW pH and soil EC	0.759	SW Cl and soil EC	0.666
GW pH and soil Cl	0.596	SW Cl and soil Cl	0.598
GW TDS and soil EC	0.610	SW Ca and soil moisture	-0.582
GW Cl and soil pH	0.570	SW Mg and soil moisture	-0.528
GW Cl and soil EC	0.721	SW Na and soil moisture	-0.555
GW Cl and soil Cl	0.537	SW pH and soil pH	0.699
GW SO_4 and soil pH	0.691	SW pH and soil EC	0.500
GW SO_4 and soil EC	0.691	SW pH and soil moisture	-0.543
GW NO_3 and soil NO_3	0.673	SW SAR and soil pH	0.558
GW SAR and soil pH	0.676	SW SAR and soil Cl	0.551
GW SAR and soil EC	0.630	SW SAR and soil EC	0.488
GW SAR and soil NO_3	-0.518	Soil pH and soil EC	0.575
GW Ca and soil pH	0.734	Soil Cl and soil EC	0.725
GW Ca and soil EC	0.891	Soil Cl and soil NO_3	0.662
GW Ca and soil Cl	0.559	Soil pH and soil moisture	-0.596
GM Mg and soil pH	0.716		

In the present study in Bentota DSD, GW resources have been recharged from SW sources and thus GW salinity was increased with the SW saline conditions by showing positive moderate linear relationships (r > 0.6) in between SWEC and GWEC, SWEC and GWpH, SWpH and GWEC and SWpH and GWpH (Table 2). Soil pH, EC and chloride were correlated with most of the GW and SW parameters showing positive moderate linear relationships (r > 0.6) as shown in Table 3, indicating that there was an effect of saltwater intrusion on soil properties due to the irrigation canals of the area and thereby changes of quality of groundwater. In this area, surface water salinity is closely linked to the distribution of salinity in GW and soil. Therefore, there is an effect of subsurface movement of salt water into the GW and soil conditions in the area as well as landward encroachment of saltwater. This coastal salinity effect has been the cause for the increasing percentage of abandoned lands in the area.

Evaluation of land use suitability based on coastal salinity susceptibility

Contamination of surface water due to SWI moves salt water into GW in the area affecting it the same way as landward encroachment of saltwater. The canals, which indicate poor, very poor and unsuitable quality of surface water, were considered by assigning a 100 m buffer zone around each canal where a high level of susceptibility to salinity risks prevails. The spatial distribution of soil salinity was weighted as 40 % while the spatial distributions of GWQI and SWQI were weighted as 35 % and 25 %, respectively. Once three layers of coastal salinity factors and their weights were obtained, a weighted overlay analysis was applied multiplying the obtained soil salinity class values and water quality level values by its particular weight to produce a map of coastal salinity levels (equation 8). In the output raster, two classes were obtained from the model, ranging from 1 to 2, where the moderate raster class 2 represents the areas with moderate coastal salinity levels (43 %), while the lower raster class 1 represents areas with slight coastal salinity levels (57 %) (Figure 1).

$$\text{Coastal salinity} = (0.40 \times \text{soil salinity}) + (0.35 \times \text{ground water quality}) + (0.25 \times \text{surface water quality}) \quad ...(8)$$

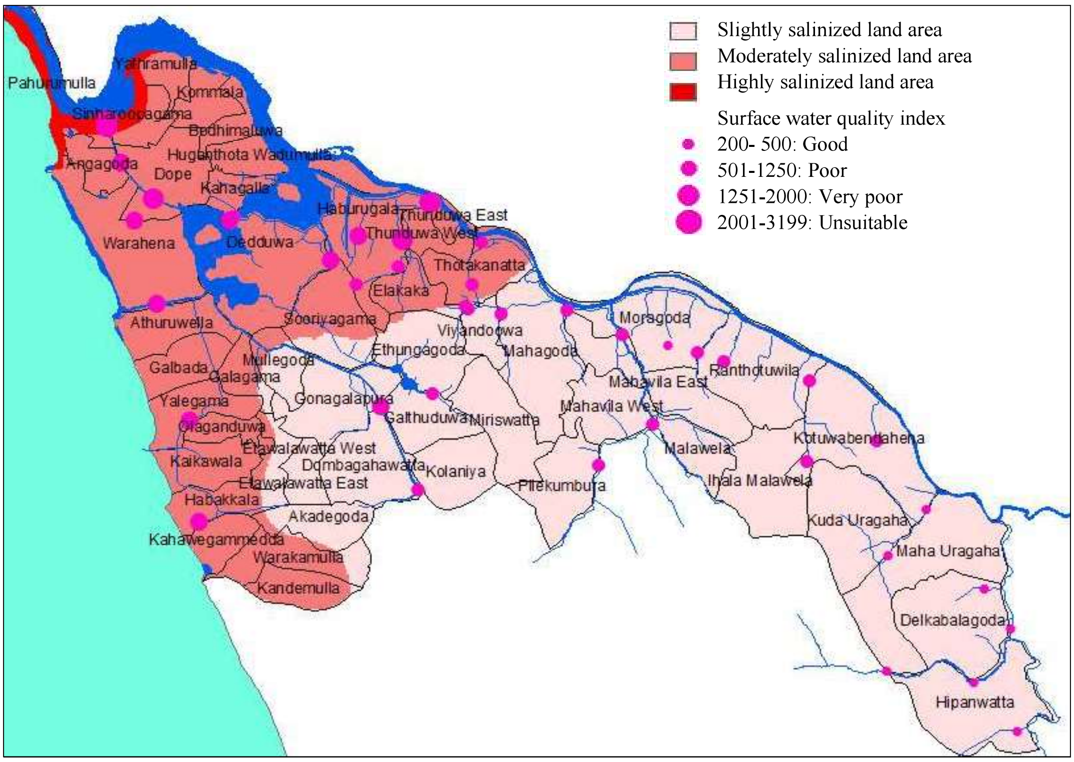

Figure 2: Spatial distribution of coastal salinity in Bentota DSD: scenario two

Accordingly, the developed GIS–based salinity risk assessment weighted overlay model indicated that 43 % of the total land extent of Bentota DSD has been moderately salinized while 57 % of the total land extent has been slightly salinized. Second Scenario assumes that the prevailing coastal salinity impacts and SWI conditions in the area will be increased with the sea level rise of 0.125 % per year. Parameter values were increased by 1 % by year 2025 considering year 2017 as the base year. The map of spatial distribution of coastal salinity under scenario two was overlaid with land use layer, forecasted total monthly rainfall pattern, agro-ecological regions and the slope layer of this area. This overlaid identified the salt stress conditions in the area where paddy lands were abandoned and identified whether the predicted rainfall, temperature and topographic conditions are suitable for cultivating crops such as paddy, tea, rubber, coconut, cinnamon, local fruits and vegetables. Accordingly, this area will comprise the suitable spatial distribution of total monthly rainfall (200 – 400 mm) and suitable slope conditions (0 –14 degrees) for cultivating these crops. Finally, simulated flood inundation areas and levels were overlaid on coastal salinity layer to identify future flood inundation areas that should be reserved as flood buffer zones. The developed salinity susceptibility model based on scenario two vigorously indicates that 3.4 % of total land extent of Bentota DSD is highly salinized. Consequently, 39.6 % and 57 % of the total land extent have been moderately and slightly salinized, with the entire area facing the threats of SWI and coastal salinity effects by year 2025 under climate change and sea level rise situations (Figure 2).

The total economic loss due to seawater intrusion risk of the area could be assessed as 7,529,698.50 USD/year, making a huge threat for the sustainable development of the area (Table 4). Further, the highest economic loss (3,624,000 USD per year) occurred due to the loss of annual income from agriculture due to seawater intrusion and land degradation in the area. Therefore, 52 % from the total population was economically not active with the reduction of agricultural sector in the area. Most of the vulnerable paddy areas have been already affected from seawater intrusion and most have been converted into marshy lands. Coastal salinity risk is increasing in the area while diminishing land productivity and increasing land degradation which results in a considerably poor yeild in food production in the Bentota DSD.

Table 4: Economic loss in Bentota DSD due to salt water intrusion

Details			USD/year
1370 hectares of abandoned paddy lands in WL2a zone	Maximum specific yield of WL2a zone per year (Yala and Maha) × area × value 1 kg of paddy	1260 kg/ha × 1370 ha × USD 0.35	604,170
15 hectares of abandoned paddy lands in WL1a zone	Maximum specific yield of WL1a zone per year (Yala and Maha) × area × value 1 kg of paddy	1290 kg/ha × 15 ha × USD 0.35	6,772.5
1510 farmer families depend on major irrigation schemes	No of families × annual income from agriculture	1510 × USD 2400	3,624,000
4828 families affected by the use of the water supply for some commercial or industrial uses	No of families × annual loss	4828 × USD 667	3,220,276
1330 families depend on pipe borne water due to poor ground water quality	No of families × annual expenditure for pipe borne water	1330 × USD 56	25,200
TOTAL			7,529,698.50 USD/year

Future development trends, land use demand and land optimisation

Future development trends of the area were identified applying a stakeholder perception-based approach. Community participants believe that there will not be an upward development trend in all indicators excluding the indicator of innovation in agriculture and conservation practices. Communities believe that new technological innovations in agriculture and conservation practices will be developed and will be helpful in future towards the enhancement of land productivity, if they tend to cultivate abandoned paddy lands. The statements made by the community participants were scrutinised to come up with the three development objectives, which are supposed to be reflected in the process of land use optimisation. These development objectives focus that this area will be able to survive from the area itself in terms of agricultural production of paddy, coconut, local vegetables and fruits by introducing suitable strategies for optimising the land productivity of abandoned paddy lands in the future. There is potential for promoting commercial crops such as tea and cinnamon to enhance the local economy of the area. Preservation of marshy and abandoned paddy lands in highly and moderately flood affected areas is necessary to compromise its nature as flood buffers.

The land demand for different uses by year 2025 was predicted using statistical data and applying the theory of land carrying capacity, the principle of ecological footprint and population growth models. The population of the area by 2025 can be predicted as 54,029 including 13,507 families based on average household size as 4 persons. Paddy demand by the population in Bentota DSD in year 2025 will be 6,240,349 kg. Paddy yield gained by cultivating 444.76 ha of cultivated paddy lands in the area in year 2017 was 3,621,236 kg. There is a deficit of 2,619,113 kg paddy yield if the population will sustain from the paddy yield of the Bentota DSD itself only. According to LPM analysis, 80.13 ha and 342.03 ha of abandoned paddy lands located in moderately and slightly salinized areas which are possible to re-cultivate paddy should be cultivated by year 2025 in order to meet the above deficit paddy demand (Table 5). Land use optimisation under each salinized area derived from LPM analysis is given in Table 5.

Coconut demand by the population in Bentota DSD in year 2025 will be 5,943,190 nuts. However, coconut nuts obtained from the existing coconut lands in the area (347 hectares) is 2,433,858 and there is a deficit of 3,509,332 nuts in order to survive in terms of coconut consumption. According to LPM analysis, consequently, 292.28 ha and 346.75 ha of lands in moderately and slightly salinized areas should be optimised for coconut cultivation by year 2025 in order to meet this deficit coconut demand. Hence, all scrub lands and 20 % of home gardens in moderately salinized areas and 138 ha of scrubs lands and 20 % of home gardens in slightly salinized areas are needed to be utilised for coconut cultivation to meet the future coconut demand (Table 5).

There will be similar amounts of vegetable and fruit demands as 4,052,175 kg by the population in Bentota DSD in year 2025. There is a deficit vegetable yield of 2,076,845 kg and a deficit fruits yield of 4,000,105 kg in order to survive for the population. According to LPM analysis, 129.5 ha of abandoned paddy lands in slightly salinized areas could be promoted for cultivating vegetables, while 147 ha of abandoned paddy lands in slightly salinized areas could be promoted for cultivating fruits. This will meet the deficit demand of vegetables and fruits by the population in the area during year 2025 (Table 5). The LPM application show that it is not required to utilise the abandoned paddy lands located in moderately salinized area for vegetable or fruit cultivations since the required demand would be fulfilled only from slightly salinized areas (Table 5).

Housing deficit of this area by year 2025 could be calculated as 963 houses, and 9,630 perches of land extent should be allocated for residential development considering minimum lot size as per 10 perch. The current and predicted land allocation for a home garden of 1910 ha and 1527 ha correspondingly indicates the adequacy of land availability for the future population (13,507 families) in terms of their housing need (401.9 ha) considering the lot size as even 20 perches (Table 5). Current economic trend of the area indicates that respectively, 979 ha, 145.3 ha and 263 ha of land extent will be used for cinnamon, tea and rubber cultivations by year 2025. The existing 343 ha of rubber lands in the area will be reduced to 263 ha, and 76 ha of current rubber lands and 108 ha of land extent from current scrub lands located in slightly salinized areas would be converted into cinnamon cultivations in order to meet 184 ha of excess cinnamon demand over the current extent of cinnamon cultivation (795 ha). Tea plantations will demand extra 4 ha of land by conversion of current rubber land. Highly and moderately flood affected areas scattered in 622 ha of land will be conserved and preserved as marshy lands which play the role of flood buffer.

Strategies for land use optimisation and management

Strategies for optimising the land productivity of salinized areas were identified in actual ground-level situations based on land use optimisation models and community perceptions. Accordingly, this area makes a huge demand for renovation of existing canal system to supply irrigation water for paddy lands by enhancing proper connectivity among separate small canals, lakes, rivers and the proposed water retention ponds. This strategy was accepted by 100 % of the stakeholders that were interviewed as the priority task which should be implemented towards laying the foundation for cultivating 80.13 ha of abandoned paddy lands in moderately salinized areas and 342.03 ha of abandoned paddy lands in slightly salinized areas. If necessary facilities will be provided by the intervention of the Government, all farmers who interviewed mentioned that they like to re-cultivate their paddy lands to meet the paddy demand by the population in the area in year 2025.

Table 5: Land use optimisation by applying linear programming models

1. Extent of suitable paddy lands to be cultivated to meet the deficit paddy demand by the population in year 2025	
• Objective function: Minimize ZP = (Pm + Ps) × Rs114,000 • Constraints: Pm × 8,142 kg × 60 % +Ps × 8,142 kg × 80 % > = 2,619,113 kg 80.13ha < Pm < 209.63 ha 116.55ha < Ps < 891.54 ha • Non negativity constraints: $Pm \geq 0$, $Ps \geq 0$ • Solutions: Pm, Ps {(80.13,891.54), (209.63,891.54), (209.63,244.9), (80.13,342.03)} Pm = 80.13 ha and Ps = 342.03 ha	• ZP is total input cost for paddy cultivation. • Consequently, Pm and Ps are the extent of abandoned paddy lands which are possible to re-cultivate paddy in moderately and slightly salinized area. • Input cost for one hectare of paddy is Rs 114,000 (DASL). • Predated paddy yield (Kg per ha) in Maha and Yala (4149 + 3993) = 8142kg • Assumed the paddy yield gained from moderately and slightly salinized area is 60 % and 80 % of the predicted paddy yield of 1 ha of normal paddy land.
2. Extent of suitable lands for cultivating coconut to meet the deficit coconut demand by the population in year 2025	
• Objective function: Minimize ZC = (Cm+ Cs) × Rs120,000 • Constraints: Cm × 7,014 + Cs × 7,014 × 60 % >= 3,509,332 nuts 173.28ha < Cm < 292.28 ha 208.8 ha < Cs < 550.8ha • Non negativity constraints: $Cm \geq 0$, $Cs \geq 0$ • Solutions: Cm, Cs {(292.28,346.75), (169.85,550.8), (292.28,550.8)} Cm = 292.28 ha and Cs = 346.75 ha	• ZC is the total input cost for coconut cultivation. • Consequently, Cm and Cs are the suitable land extent of home gardens and scrublands located in moderately and slightly salinized area. • Yield of coconut nuts per ha is 7,014. • Input cost for one hectare of coconut land is Rs 120, 000 (DASL). • Assumed coconut yield gained from slightly salinized area is 60 % of the yield of 1 ha of normal coconut land due to less favourable salinity condition.
3. Extent of suitable lands for cultivating local vegetables to meet the deficit vegetables demand by the population in year 2025	
• Objective function: Minimize ZV= (Vm+ Vs) × Rs 325,000 • Constraints: Vm ×16,000kg × 50 % + Vs ×16,000kg >= 2,076,845 kg Vm < 64.75ha Vs < 274.76ha • Non negativity constraints: $Vm \geq 0$, $Vs \geq 0$ • Solutions: Vm, Vs {(64.75,97.62), (64.75,274.76), (0,274.76), (0,129.5} Vm = 0 ha and Vs =129.5ha	• ZV is the total input cost for vegetable cultivation. • Consequently, Vm and Vs are the extent of abandoned paddy lands which are possible to cultivate vegetables in moderately and slightly salinized area • Input cost for one hectare of vegetable land is Rs 325,000 (DASL). • 1 ha of normal vegetable land will yield 16,000 kg. • Assumed the vegetable yield gained from moderately salinized area as 50 % of the yield of 1 ha of normal vegetable land.
4. Extent of suitable lands for cultivating local fruits to meet the deficit fruits demand by the population in year 2025	
• Objective function: Minimize ZF= (Fm+ Fs) × Rs 175,000 • Constraints: Fm ×6,800kg × 50 % + Fs × 6,800kg >= 4,000,105 kg Fm <=64.75ha Fs <=274.76ha • Non negativity constraints: $Fm \geq 0$, $Fs \geq 0$ • Solutions: Fm, Fs {(64.75,114.62), (64.75,274.76), (0,274.76), (0,147)} Fm =0 ha and Fs = 147 ha	• ZF is the total input cost for fruit cultivation. • Consequently, Fm and Fs are the extent of abandoned paddy lands which are possible to cultivate vegetables in moderately and slightly salinized area • Production cost for 1 ha of fruit land is Rs 175, 000 (DASL). • 1 ha of fruit land will yield 6,800 kg. • Assumed the fruit yield gained from moderately salinized area is 50 % of the yield of 1 ha of normal fruit land.

Construction of water retention ponds in selected high water saturated and abandoned paddy lands, out of the remaining unutilised abandoned paddy lands (273.01 ha) was feasibly accepted by 80 % of stakeholders by emphasising its importance for promoting inland fishery and entertainment activities. According to the perceptions of 75 % stakeholders, multiple possibilities are available for popularising aquatic flora cultivations related to food and flower species which could be cultivated in part of the 129.5 ha of abandoned paddy lands located in slightly salinized areas. Introduction of 'floating farm tradition' for 129.5 ha and 147 ha of abandoned paddy lands located in slightly salinized areas which are supposed to be converted into vegetable and fruit cultivations, respectively was possibly accepted by 60 % of stakeholders. According to the Paddy Land Acts No 1 of 1958 and No 30 of 1958 and Agrarian Development Act, No. 46 of 2000, there will not be any legal barrier for this type of land use conversion since it is not distressing the role of these lands that act as flood buffer.

All stakeholders mentioned that they have not cultivated 'salt tolerant rice varieties' so far, but they have awareness on this. Farmers who belong the 197.9 ha of paddy lands located in moderately salinized areas should be encouraged to use salt tolerant rice varieties by ensuring the expected harvest illustrating with successful practical cases. Farmers (60 %) who prefer to practice traditional and organic farming should be encouraged by providing suitable incentives and by introducing a proper market for their products. Farmers (90 %) mentioned that their children are not interested to engage in farming and even the children are not interested about them engaged in farming. Younger generation should be encouraged to engage in paddy farming by changing their attitudes and myths on consideration of paddy farming as a socially unacceptable and unfortunate income source in contemporary society. Government should take responsibility to empower the younger generation to get them involved in paddy cultivation by introducing new technological innovations for agriculture.

All stakeholders who were interviewed mentioned that they are not aware of salt tolerant plants that tolerate the high salinity levels and grow. All stakeholders mentioned that there is a huge potential to develop the available abandoned paddy lands (part of 129.5 ha) for reed cultivation to encourage reed-based products, which have good demand from foreigners. Stakeholders (70 %) mentioned that this industry is not much effective since cheaper and safe plastic bottle caps are available in the market. However, 30 % of stakeholders mentioned that this industry could be enhanced for providing bottle caps for Ayurveda medicine by laying a proper production line from the ground to market. This industry may reduce the spread of *Wel Aatha* (*Annona glabra*) species by limiting it to a certain extent of marshy lands.

All ASD officers who were interviewed mentioned that utilisation of several selected inland scrub lands (108 ha out of 342 ha) located in slightly salinized areas for cinnamon cultivation is more profitable. This action is environmentally compatible rather than leaving these lands for spreading unnecessary tree species. The utilisation of abandoned paddy lands for cinnamon cultivation is strictly prohibited since this will convert low lands into high lands in long-term scenario. Deployment of coastal scrub lands (119 ha) located in moderately salinized areas and inland scrub lands (138 ha) located in slightly salinized areas for coconut cultivation is possible after doing a proper investigation of the environment context of each land plot. Stakeholders (85 %) who were interviewed mentioned that people in this area are very interested to allocate 20 % of their home gardens for coconut cultivation, if they were provided coconut plants, which could be harvested within a short period and do not grow large.

Paddy Land Act and Agrarian Development Act in Sri Lanka give provisions for cultivating non-perennial crops in paddy lands. However, farmers in the area are not aware of it and the agrarian officers are also not much capable to take the approval of the Commissioner General for such kind of crop conversions in paddy lands since these inconvenient legal procedures are consuming more time and resources. Therefore, many paddy lands in Benota DSD are abandoned due to SWI and other issues without utilising those for any productive use. All stakeholders mentioned that the Paddy Land Act was not amended after 1966. There is a huge requirement to amend this act including the provisions for conversion of paddy lands into additional crop cultivation, and the procedure to follow up for examining the possibilities for converting long-term abandoned paddy lands or scrub lands into coconut or cinnamon cultivations.

Flood resistive green home gardening model could be introduced to flood inundating areas of Thunduwa and Yathramulla to reduce the risk attached to individual housing units by increasing its resistance to flood occurrences. Rainwater harvesting mechanism practiced during 1980's in the area can also be utilised to solve water supply matters in coastal areas and in other areas during dry periods as a successful traditional practice via the intervention of Bentota Pradeshiya Sabha when

Table 6: Land use optimization under each salinized area

Land use type	Moderately salinized areas Gonagalapura ASD		Slightly salinized areas Pahalagamhaya ASD		Bentota DSD	
	2017 (ha)	Land use optimization in 2025 (ha)	2017 (ha)	Land use optimization in 2025 (ha)	2017 (ha)	2025 (ha)
Paddy (total)	407.53		1138.4		1545.93	1545.93
Paddy (cultivated)	197.9	197.9 (already used for paddy)	246.86	246.86 (already used for paddy)	444.76	444.76
Paddy (abandoned)	209.63		891.54		1101.17	
-possible to re-cultivate paddy	80.13	80.13 (will be used for paddy)	116.55	116.55 (will be used for paddy)	196.68	422.16
-Remaining un-utilized	129.5	Will be used for proposed tourism development project and rush and reed industry	774.99	– 225.48 (will be used for paddy) – 129.5 (will be used for vegetables) – 147 (will be used for fruits) – 273.01(remaining un-utilized)	904.49	273.01
Coconut	332	332 (already used for coconut)	15	15 (already used for coconut)	337	976.08
Cinnamon	102	102 (already used for cinnamon)	693	693 (already used for cinnamon)	795	979
Tea		Not available	141	141(already used for tea)	141	145
Rubber	30	30 (already used for rubber)	313	Will be reduced to 263 ha	343	263
Home garden	866.4	173.28 (will be used for coconut)	1043.7	208.8 (will be used for coconut)	1910	1527.92
Scrub/grasslands	119	119 (will be used for coconut)	342	138 (will be used for coconut) 108 (will be used for cinnamon)	461	96
Chena and croft (fruits and vegetables)			60.2	60.2 (already used for fruits and vegetables)	60.2	336.7
Marshes	212		410		622	622

approving building permits. Perceptions regarding the development trend of commercial crops in the area revealed that rubber cultivation will no longer exist in the area since rubber lands are rapidly converting to cinnamon cultivations. Stakeholders (70 %) expect that tea cultivation may have same growth rate until year 2025. Fifty percent stakeholders expressed their interest to do cow husbandry by utilising abandoned paddy lands for grass cultivation. This study identified that area-specific research and development initiatives are not implemented at the ground level where the actual benefits are far away from the people who really need it due to the poor nexus among the researchers in academic institutions and development institutions in the area. Hence, there should be a proper mechanism to integrate the institutional nexus.

The groundwater quality of the coastal part of this area that has comparatively high population and building density will be unsuitable or very poor in condition with the context of climate change impacts and sea level rise in the future which was analysed under scenario two in this study (Figure 2). Coastal water resource managers, city planners, industries and the agriculture sector should have a proper understanding of the existing condition of coastal groundwater quality and vulnerable areas in order to find ways for managing the contaminated coastal aquifers during specific times of each year and to supply alternative water sources for the community who live in this area.

CONCLUSION

The developed sustainable land use pattern will enhance the land productivity of 39.6 % of moderately salinized areas and 57 % slightly salinized areas of the Bentota DSD. This optimised land use pattern will support future spatial planning by providing guidance to the local authority in the process of allocating salinized lands for optimising its use. Community and the farmers in this area can be made aware about predicted spatial and temporal distribution of total monthly rainfall during two major seasons, flood occurrence periods, and magnitude of SWI under future climate and sea level rise scenarios by year 2025. Development planners and agricultural scientists can formulate land use planning and land management strategies considering the findings of this research study. Development initiatives should be introduced among stakeholders in the area, who would be the pillars for regaining the successive agriculture in Bentota area by enhancing its land productivity towards sustainable land management.

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