Asian Journal of Water, Environment and Pollution, Vol. 17, No. 1 (2020), pp. 35–42.
DOI 10.3233/AJW200004

Simulation of Coastal Salinity Susceptibility in Bentota, Sri Lanka

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Received January 15, 2019; revised and accepted October 30, 2019

Abstract: Seawater intrusion is increasing in Bentota area, Sri Lanka while diminishing the land productivity and yielding poor food production and making several socio economic issues for the community in the area. Key innovation of this study is to model coastal salinity susceptibility in Bentota area based on the future scenario of climate change to mitigate land degradation. The temporal and spatial distributions of five parameters of soil (moisture, EC, pH, chloride, nitrate) and eleven parameters of ground water and surface water (pH, EC, TDS, DO, chloride, nitrate, sulfate, calcium, magnesium, sodium and SAR) were monitored considering the sample data collected from July 2016 to June 2017 and analyzed applying Arc GIS software. Water quality was assessed in terms of index based on the standards of World Health Organization. Soil parameters were reclassified in to respective salinity classes based on acceptable standards.

Spatial distribution of soil salinity, ground and surface water quality were integrated using multi-criteria evaluation approach to determine level of coastal salinity. Results of this analysis vigorously indicate that highly salinized, moderately salinized and slightly salinized land extent with respect to the total land extent were 3.4%, 39.6% and 57% respectively; whereas entire area is facing the threats of seawater intrusion and coastal salinity effects by year 2025. This salinity susceptibility model will facilitate for the spatial planning of future land use of this area by providing guidance to local authority in the process of allocating salinized lands for development activities.

Key words: Sea level rise, coastal salinity, susceptibility.

Introduction

Seawater intrusion (SWI) can be defined as the landward migration of seawater into freshwater coastal aquifers and subsurface movement of seawater into coastal fresh water bodies (Ivkovic et al., 2012). Depending on specific environmental conditions, the saline water mix to a smaller or larger degree with the fresh water when freshwater rivers discharge fresh water into the ocean (Augustijn et al, 2011). Seawater intrusion most often occurs in coastal aquifer systems because of both natural and anthropogenic activities (Barlow, 2003). Custodio and Bruggeman (1987) show that the principal driver for movement of the transition zone where fresh water and salt water get mixed is the change in the hydraulic head difference between fresh water and seawater of coastal areas and resulting SWI can create the salinity conditions in coastal areas. Coastal salinity can be defined as the salinity condition, which is resulted by seawater intrusion in coastal areas (Mustatea et al., 2009). Moreover, coastal salinity is one of the major problems in coastal areas that affect both environment and the livelihoods.

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Occurrences of saltwater intrusion have been noticed as early as 1845 on Long Island, New York. Seawater intrusion occurs in coastal aquifers worldwide, and it is a rising issue in the areas of North Africa, the Middle East, Mexico, the Mediterranean, China and Australia (Werner et al., 2013) and most notably, the Atlantic and Gulf Coasts of the United States and Southern California (Edwards and Evans, 2002). Moreover, South Asian countries such as India, Bangladesh (Baten et al., 2015) and Sri Lanka also (Jayasiri and Dahanayake, 2012) have been affected from seawater intrusion.

Being an Island, Sri Lanka owns crowd of advantages as well as disadvantages. One of the so far neglected yet a forthcoming mass scale disadvantage is the island's vulnerability to the sea level rise and consequent impacts. Hence the Island and the coastal population is susceptible due to the sea level rise not only in physically but also in many other aspects. However, the coastal region encompasses 22% of the country's total land extent, 32% of the country's population, 65% of the urbanized areas, four out of six cities (population >100,000) and two third of all industrial contribution of Sri Lanka (National Report on Land Degradation Sri Lanka, 2000). With the increasing incidence of extreme and slow onset events such as sea level rise and inundation, the coastal and low lying areas are particularly vulnerable to salinization. The climate change will have a variety of impacts on agriculture, human health, biodiversity and water stress, which will vary by coastal areas in Sri Lanka. The greenhouse effect on the impact of hydrological cycle will cause increasing scarcity of fresh water in coastal region of Sri Lanka. IPCC (2007) estimates sea-level rise range from 0.18 m to 0.59 m by the 2090s from the average level between year 1980 and 2000. Being an Island in the Indian Ocean, the adverse impacts of these changes will head on to Sri Lanka with more damages on the coastal region of the country.

Most of the effects of sea level rise will be on the livelihood options of coastal population in Sri Lanka. It is essential to strengthen the linkages between climate, hazards, community resilience and climate adaptation in order to overcome the effects of sea level rise and consequences of SWI. Climate change and its effects needs to be observed, studied and predicted on a regional scale to take measures on the expectable consequences due to coastal salinity and its susceptibility. This requires improved observations, modelling and forecasting. The increased local relevancy of climate information will be highly useful to decision makers. Therefore this study intends to provide clear and understandable information upon which are to be guided to make local adaptation decisions on future susceptibility for coastal salinity.

Methods and Analysis

Bentota Divisional Secretariat Division (DSD) considered as the case study area for this research is extended about 74.5 km^2 and bounded in the left bank of Bentota River basin (21 km) and the Indian Ocean in west. Following systematic sampling method, twenty four groundwater samples were taken from the wells that were closest to the mid points of the 2 km × 2 km grids by using Global Position System technology. Seventy two soil samples were taken from same twenty four sample points at three depths at one location as 20 cm, 40 cm and 60 cm by using a hand-held soil auger. Surface water samples were taken from the mid and end points of all irrigation canals within Bentota DSD. Sampling survey was carried out from July 2016 to June 2017 by collecting and monitoring each sample once per month. In situ parameters like Electrical Conductivity (EC), pH and Dissolved oxygen (DO) values of each surface and groundwater samples were measured in the field immediately after sampling by using portable Glass Electrode pH and EC Meter and DO Meter.

The surface water and the groundwater samples were tested for the presence of Total dissolved solids (TDS), chloride (Cl^-), nitrate (NO_3^-) and sulfate (SO_4^{2-}). Sodium Adsorption Ratio (SAR) was determined after analyzing the concentrations of Na, Mg and Ca (Saxena, 1998). Soil moisture content, pH, EC, chloride (Cl^-) and nitrate (NO_3^-) were determined for the soil samples. Soil moisture determines the percentage of water in a sample by drying the sample to a constant weight. Soil pH value and electrical conductivity value in soil suspension was measured using a Glass Electrode pH and EC meter at 1:2.5, Soil: Water ratio.

Many soils vary spatially and temporally to a large degree and this affects the assessment of soil salinity. Consequently, the spatial distributions of maximum values of each soil parameters with respect to each sampling locations in Bentota DSD were derived and reclassified in to respective salinity classes based on acceptable standards by applying the spatial analysis tools of Inverse Distance Weighted interpolation and reclassifying in Arc GIS 10.5. Soil EC values were reclassified in to three classes as non-saline (0-2 ds/m), slightly saline (2.1-4.0 ds/m) and moderately saline (4.1- 8.0ds/m) based on FAO (1988). Soil pH values were reclassified in to four soil acidity classes as slightly acid (5.6-6.5), neutral (6.6-7.5), slightly alkaline (7.6-

8.5) and alkaline (>8.5) based on FAO (1988). The soil of inland area consists of chlorides from 0.051 to 0.120 percentages, which indicate averagely salinized conditions. Concentration of nitrate in soils on dry basis was varied from 4 to 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.

According to the literature, measuring Soil EC, pH, chloride are equally important for identifying soil salinity susceptibility while soil moisture and nitrate are low important (Corwin et al., 1988). The weight values for each soil parameters were calculated by comparing two parameters with each other for their relative importance in evaluating the soil salinity susceptibility based on the judgments of five professionals from environment planning related fields. According to Pair Wise Comparison Matrix (PWCM) in Analytic Hierarchy Process (Saaty, 1980). Soil EC, pH, chloride are more or less equally important for identifying soil salinity susceptibility and that is six times higher than the importance of soil moisture and soil nitrate.

Model builder tool in Arc GIS 10.5 together with IDW, reclassifying and weighed overlaying were applied to derive the spatial distribution of soil salinity in Bentota DSD. The multi-criteria evaluation (MCE) approach was used in weighted overlay analysis. 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 1). 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.

$$\text{Soil salinity} = (0.32 \times \text{soil EC}) + (0.30 \times \text{soil pH}) + (0.28 \times \text{soil chloride}) + (0.05 \times \text{soil moisture}) + (0.05 \times \text{soil nitrate}) \quad (1)$$

This spatial distribution of soil salinity in Bentota DSD (Figure 1) emphasizes that soils near shoreline and Bentota River has become saline due to the landward encroachment of the salt in the area with respect to the seawater intrusion conditions. Accordingly, 64.4% of total land extent of Bentota DSD has slightly salinized while 35.6% of total land extent has moderately salinized.

The spatial distributions of maximum values of each groundwater parameter with respect to each sampling location in Bentota DSD during one-year period were derived and reclassified in to respective salinity classes applying the spatial analysis tools of IDW interpolation and reclassifying in Arc GIS 10.5. Highest value range of all GW parameters were found near to the estuary of Bentota River, Dedduwa lake and Coastal belt during the months of August, September 2016 and January, February, March 2017 while the wells located in inland part of the region indicating lowest value range in all parameters.

The spatial salinity distribution of ground water and surface water were derived by assessing the overall quality of groundwater for drinking purposes and surface water for irrigation purposes in terms of water quality index values (WQI) based on WHO (2011) standards. WQI is defined as a rating by following set of defined equations and reflecting the composite influence of different water quality parameters (Hadithi, 2012). The maximum value of all ground water and surface water parameters with respect to each sampling location during the period of July 2016 to June 2017 were considered to calculate maximum water quality index of each sampling location that can be reached to the maximum in present context of the area. The wells located near to shore line, river and irrigation canals have been shown high ground WQI values making the groundwater quality in poor and very poor condition due to high SWI conditions in the area (Figure 2).

The spatial distribution of maximum surface WQI values indicates very poor and unsuitable conditions in surface water near to the estuary of Bentota River, Dedduwa Lake, the canals that are originated from the river near to the estuary and the canals which drop down to sea in coastal belt (Figure 3). Simulation of coastal salinity susceptibility based on the future scenario of climate change is essential to avoid further land degradation. Therefore, the level of coastal salinity in Bentota DSD was evaluated based on following two scenarios:

Scenario One: Evaluate the level of coastal salinity susceptibility if prevailing coastal salinity impacts and SWI conditions in the area will be continued in same manner up to year 2025.

Scenario Two: Evaluate the level of coastal salinity susceptibility if prevailing coastal salinity impacts and SWI conditions in the area will be increased with the climate change and sea level rise circumstances by year 2025.

The spatial distribution of coastal salinity of this area was demarcated by overlaying the above resultant spatial distributions of soil salinity, GWQI and SWQI conditions. Before applying the model builder tool, all the raster layers, which have different resolutions, were resampled to the same cell size (30 m). All the layers were with a spatial resolution of 30 m. Contamination of surface water due to SWI is affected to move salt water into the GW circumstances in the area as same as landward encroachment of saltwater. Therefore, the canals, which indicate poor, very poor and unsuitable quality in surface water, were considered by assigning a 100 m buffer zone of around each where the high level of susceptibilities to salinity risks prevails.

The weight values for coastal salinity factors were calculated by comparing two parameters with each other for their relative importance in evaluating the coastal salinity susceptibility based on the judgments of above same five professionals from environment planning related fields. According to PWCM, soil salinity and

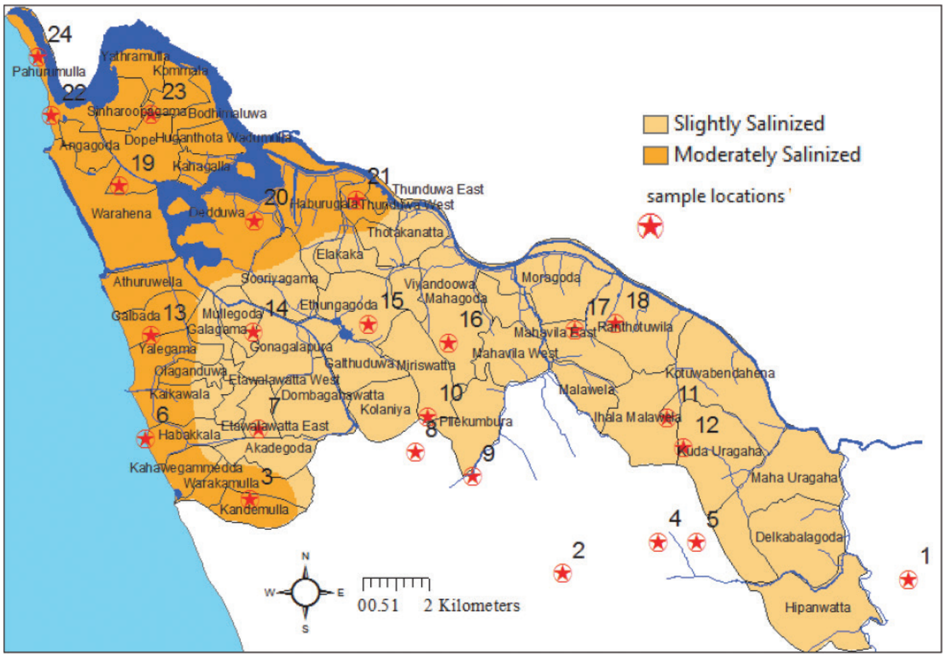

Figure 1: Spatial distribution of soil salinity in Bentota DSD.

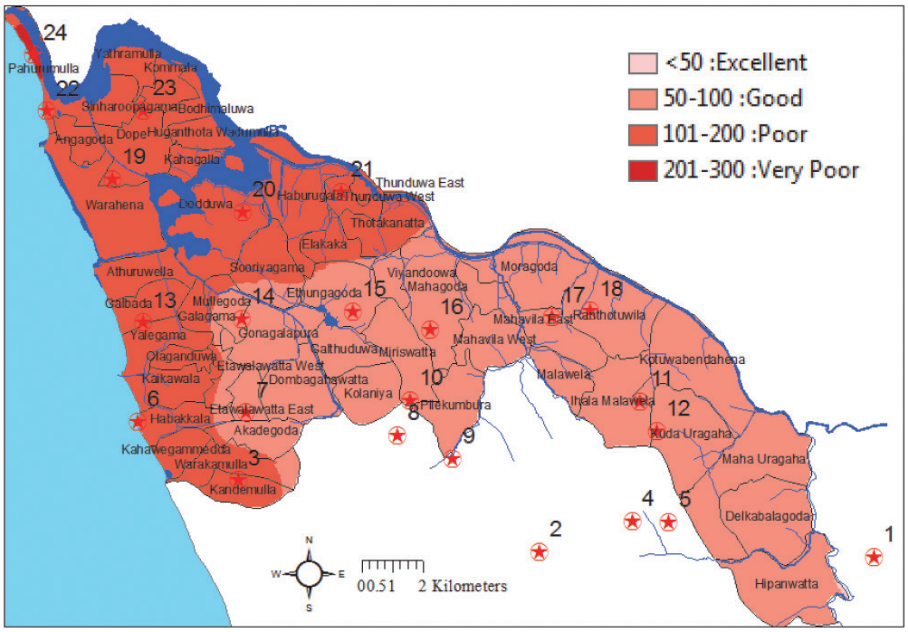

Figure 2: The spatial distribution of maximum GWQI value in Bentota DSD.

ground water quality are more or less equally important for identifying coastal salinity susceptibility, whereas surface water quality is comparatively moderately important. The spatial distribution of soil salinity was weighted as 40% while the spatial distributions of GWQI and SWQI were weighted as 35% and 25% consequently. Model builder tool in Arc GIS 10.5 together with IDW, reclassifying and weighted overlaying were applied to derive the spatial distribution of coastal salinity in Bentota DSD. The multi-criteria evaluation approach was used in weighted overlay analysis. 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 2).

Coastal salinity = (0.40 × soil salinity) + (0.35 × ground water quality) + (0.25 × surface water quality) (2)

In the output raster, two classes were obtained from the model, ranging from 1 to 2, where the moderate

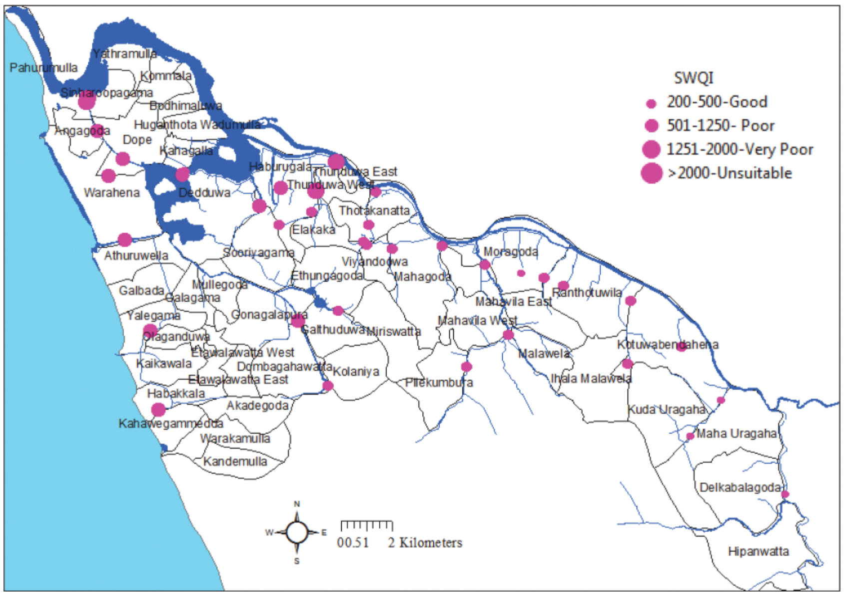

Figure 3: The spatial distribution of maximum SWQI value in Bentota DSD.

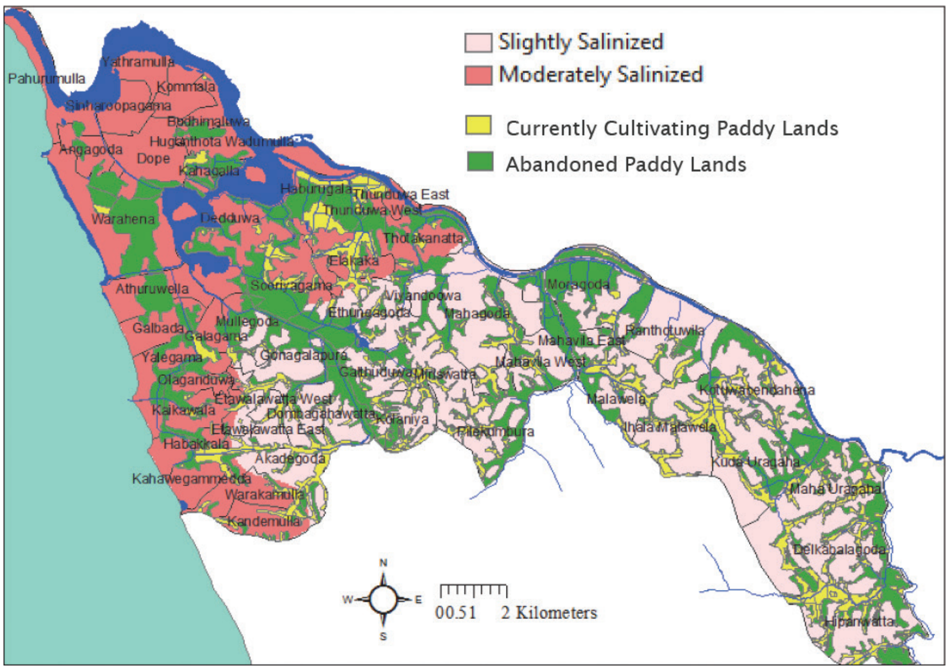

Figure 4: Spatial distribution of coastal salinity and paddy lands in Bentota DSD: Scenario one.

raster class 2 represents the areas with moderate coastal salinity levels, while the lower raster class 1 represents areas with slightly coastal salinity levels (Figure 4).

Results and Discussion

Under scenario one, the results of this analysis purely indicate that 43% of total land extent of Bentota DSD has been moderately salinized while 57% of total land extent has been slightly salinized while entire area is facing the threats of SWI and coastal salinity susceptibilities. This coastal salinity effect has been caused for the increasing percentage of abandoned lands in Bentota DSD. According to the exploration of recent land use and land cover change in Bentota DSD showed that 2524 hectares of paddy lands cultivated in year 1983, only 245 hectares have been cultivated during 2013 due to salt stress conditions on plants in the area. However, it is depressed to identify 1385 hectares of abandoned paddy lands remaining without utilizing for any purposes while 894 hectares of paddy lands have been converted to other uses such as marshes, scrubs and grasslands.

The map of spatial distribution of coastal salinity was overlaid with land use layer for identifying the locations where salt stress conditions have been affected for abandoning the paddy lands and other crops. Figure 4 indicates the salinized areas, currently cultivating paddy lands and abandoned paddy lands during last three decades including converted abandoned paddy lands in to marshes, scrubs which have been used for paddy cultivation during 1980's. In the questionnaire survey for validating the soil salinity, water quality and coastal salinity models, 48 community people including one farmer and one community people from each of twenty four sampling locations in the area were requested to present the details on the level of groundwater quality in their residence and the surroundings, the reasons for having poor or very poor quality of ground water, source of water supply for paddy cultivations, suitability of canal water for paddy cultivation, reasons for making poor suitability of soil and reasons for abandoning paddy lands.

As a result communities who live in the groundwater sample locations of 24, 23, 22, 21, 20, 19, 13, 6 and 3 mentioned that water in their wells are not suitable for drinking, cooking, bathing and washing. These locations are situated in moderately salinized area of the coastal salinity distribution map. Communities who live in the ground water sample locations of 24, 23, 22, 21, 20, 19, 15, 13, 14, 7, 6 and 3 mentioned that water of the canals located in the surroundings of their paddy lands are not suitable for paddy cultivation specially during the months of January, February, March, April, July, August in most years due to absence of rainwater. These locations are situated in moderately salinized area of the coastal salinity distribution map. They mentioned that most of paddy lands in their surrounding area (moderately salinized area) cultivated during 1980's are currently abandoned. They believe this was due to the intrusion of salt water via coastal aquifer, river and canals. Accordingly, this developed coastal salinity model is highly compatible with the actual ground level situations of this area. Communities mentioned that the main reasons for abandoning the paddy lands are the poor maintenance of irrigation canals in the area, lack of skilled labourer and saltwater intrusion. Other than those, farmers have to face economic difficulties due to high input cost and poor harvest which due to insufficient agrarian service regarding to provision of paddy seeds, fertilizers, harvesting calendar which is not compatible with current climate conditions etc.

Finally, the spatial distribution of coastal salinity was evaluated if prevailing coastal salinity impacts and SWI conditions in the area will be increased with the climate change and sea level rise circumstances by year 2025. The tide gauge stations positioned along the coastal beds of North Indian Ocean has been measuring the fluctuations of the sea level during decades. The received tide gauge data reveals an average of sea level rise as 12.9 cm per century along the coasts of Indian Ocean (Solomon et al. eds., 2007). Weiqing et al. (2010) clearly shows the vulnerability of Sri Lanka as an island to the effects of sea level rise in near future, which will be average +12 cm per century.

Accordingly, sea level of Indian Ocean assumes to be increasing 0.125% per year and this was based to predict the maximum values of each soil, GW, SW parameters with respect to each sampling location in Bentota DSD by year 2025. Parameter values were increased by 1% (0.125% × 8 years) by year 2025 considering the year 2017 as the base year. The same method explained in above was followed to evaluate the spatial distribution of coastal salinity under the scenario two on climate change and sea level rise circumstances by year 2025. The results of this analysis vigorously indicate that 3.4% of total land extent of Bentota DSD has been highly salinized while consequently 39.6% and 57% of total land extent have been moderately and slightly salinized being entire area is facing the threats of SWI and coastal salinity effects by year 2025 under the climate change and sea level rise scenario (Figure 5).

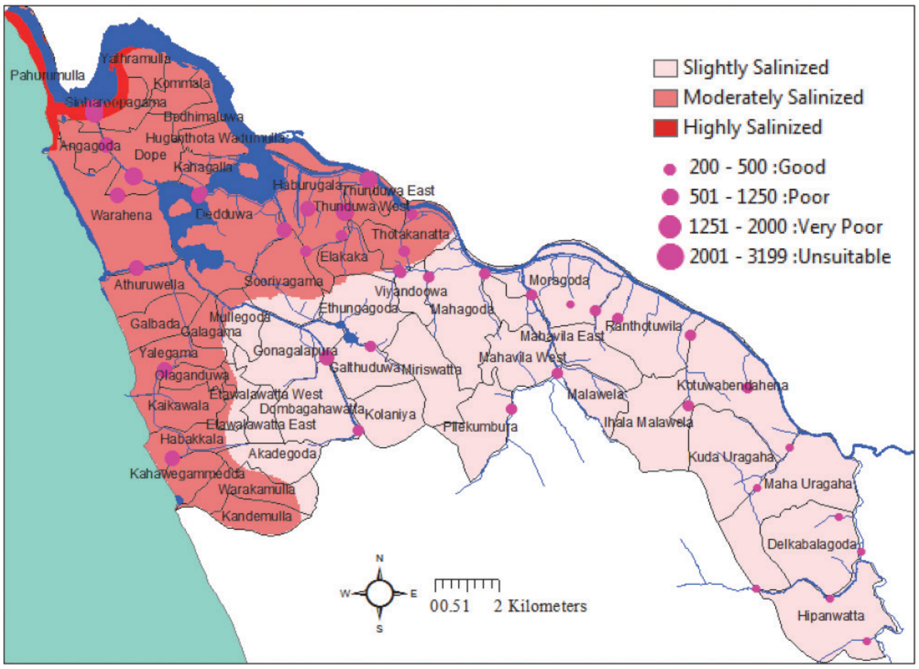

Figure 5: Spatial distribution of coastal salinity in Bentota DSD: Scenario two.

According to the Ritung et al. (2007) land suitability classification, 3.4% of highly salinized area can be considered under Class N-Not Suitable area, which the range of inputs required, is unjustifiable. 39.6% of moderately salinized area can be considered under Class S3-Marginally suitable—meaning land having limitations which in aggregate are severe for sustained application of the given land utilization type and will so reduce productivity or benefits, or increase required inputs, that any expenditure will only be marginally justified. 57% of slightly salinized area can be considered under Class S2 moderately suitable and land having limitations which in aggregate are moderately severe for sustained application of the given land utilization type. The limitations will reduce productivity or benefits and increase required inputs to the extent that the overall advantage to be gained from the use, although still attractive, will be appreciable compared to that expected from Class S1 highly suitable land.

Conclusions

This study was enabled to forecast Coastal Salinity Susceptibility in Bentota area based on the prevailing coastal salinity impacts and SWI conditions in the area will be continued in same manner up to year 2025 and based on the prevailing coastal salinity impacts and SWI conditions in the area will be increased with the climate change and sea level rise circumstances by year 2025. Consecutively both scenarios indicate that 43% and 57% of total land extents have been moderately and slightly salinized and 3.4%, 39.6% and 57% of total land extents have been highly, moderately and slightly salinized while entire area is facing the threats of SWI and coastal salinity susceptibilities. Under Scenario two, the total economic loss due to seawater intrusion risk of the area would be assessed as 7,529,698.50 USD/year thus making huge threat for the sustainable development of the area. Further, highest economic loss (3,624,000 USD per year) will be occurred due to the loss of annual income from agriculture due to the seawater intrusion and land degradation in the area. Coastal salinity risk is increasing in the area while diminishing the land productivity and increasing the land degradation which is poor for yielding considerable food production in Bentota. Development planners and agricultural scientists can formulate land use planning and land management strategies to mitigate the land degradation further more based on the spatial distribution of coastal salinity susceptibility of this area modelled in this study. New technological innovations as outcome of this research study and development initiatives can be introduced and promoted among stakeholders in the area who would be the pillars for regaining the successive agriculture in Bentota area by enhancing its land productivity towards the sustainable land management.

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