GIS-BASED MAPPING ON SALT WATER INTRUSION INTO AGRICULTURAL LAND: A CASE STUDY IN NINTAVUR GRAMA NILADHARI DIVISION (GND) - 10, SRI LANKA

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Abstract

Salt water intrusion into the agricultural land is a critical issue and growing matter of concern in order to conserve the agricultural land and to promote the agricultural productivity. Therefore, this is to explore and estimate the salt water intrusion into agricultural land using GIS technique in the coastal area of Ampara District particularly in Grama Niladhari Division (GND) of Nintavur - 10. For this study, 20 soil samples were collected and Global Positioning System (GPS) was used and pinpointed for each sampling location. The matrix was developed and the field measurement carried out based on the real measured electrical conductivity (EC) and PH values for estimated GIS mapping approaches. Descriptive statistical parameters were employed for minimum, maximum, mean, standard deviation, and coefficient of variation (CV) to analyze soil property data. Also, Soil salinity indicators (EC and PH) were mapped as raster layers using the interpolation technique that Inverse Distance Weighting (IDW) in ArcGIS 10.3 environment. As a result, this study, the soil of the agricultural area closed to the seashore is seriously affected due to the saline water intrusion.

Keywords: Saltwater, agricultural land, intrusion, GIS technique

Introduction

The coastal region is the interface between the land and sea in an area of great ecological sensitivity and vulnerability. The coastal area is low-lying lands, from a perspective of water resource management, are considered as the most complicated and challenging regions in view of their higher agricultural activities, sophisticated human activities and high vulnerability to multiple hazards such as saltwater intrusion. Saltwater intrusion in coastal aquifers is a severe problem that many countries have to face at present, due to the fact that it contaminates groundwater aquifers and even surface water, leading to the unavailability of water resources for domestic, agricultural use and other consequences (Johnson, 2007). Saltwater intrusion is defined as a landward movement of the saltwater process, resulting in an increase of salt concentration into groundwater and agricultural land.

Agriculture activities are recognized as both contributors and victims of this process considering the large water demand for irrigation and the direct relationship between yields and salt concentration. Though the reactions to the salinity of different crops may differ given the distinct genes, however, obviously, when the salinity increases to the level above the limitation that the plants can no longer bear, the yields decrease. Therefore, the assessment of soil properties like soil salt level concentration is crucial for land sustainability at local and regional scale. In coastal regions of the world, saltwater intrusion is one of the main drastic phenomena due to its adverse effects on land productivity and plant growth.

Saltwater intrusion is among the common soil characteristics that effect agricultural production, and it causes severe worldwide environmental problems particularly in coastal areas. Especially traditional irrigation methods exacerbate soil salinization and deteriorate soil quality, and correspondingly destructive impacts of soil salinization on seed germination restrict plant growth (Matinfar *et al.*, 2013). Thus, saline soil prevents water intake to plants from the root zone due to the diminishing osmotic potential of soil water (Bhatt *et al.*, 2008). According to this, temporal monitoring and assessment of saltwater intrusion are highly important for reducing its adverse effects like land degradation and diminishing crop yields (Allbed and Kumar, 2013).

Traditional field-based soil salinity monitoring and measurement methods are limited in time and space, and can only be provided point-wise information. On the other hand, Spatio-temporal mapping of soil salinity is significant to support decision-making procedures for diminishing adverse effects of soil salinization. In this state, geoinformatics technology can be provided cost-effective, fast, quantitative and qualitative reliable spatial information on saltwater intrusion into an agricultural area. As well, soil analysis by utilizing modern technological tools of Remote Sensing (RS) and Geographical Information System (GIS) provides a valuable resource inventory related to the well-being of land especially those allocated for agricultural production (Manchanda *et al*., 2002).

Soil salinity has been considered a major constraint to food grain production in coastal areas of the nation. Sri Lanka coastal length is approximately1585 km. At present 59 percent of the Sri Lankan population lives in coastal districts with maritime boundaries (Nayanananda, 2007). Around the coastal area in Sri Lanka, soil salinity constitutes the most complex and common type of soil degradation generally due to seawater intrusion. Nintavur Divisional Secretariat (DSD) has had 2790 ha land for agricultural activities which out of total land 76.8 percent. GND-10 is one of good agricultural regions in Nintavur DSD. In the recent decade, Nintavur GND-10 has severely been affected that saltwater intrusion by Oluvil post harbor construction practices. Increasing salinity is a crucial issue for the agricultural land in Nintavur. Thus, it has been observed that all the coastal cultivable lands in Nintavur GND-10 are not being utilized for crop production near future, mostly due to saltwater intrusion. Increased soil salinity limits growth of standing crops and affects overall crop production, and also makes the soil unsuitable for many potential crops in the coastal region.

Materials and Method

Study Area

GND is located in south part of Nintatavur DSD in Ampara district. It lies between 81^{0} 50' 42" - 81^{0} 50' 44" E and 7^{0} 28' 04" - 7^{0} 19' 36" N. It has also consisted that the part of 57 and 58 number of 1:50000 toposheet. The location map is shown in Figure 01. The areal extent of Nintavur DSD is 38.3 sq. km. It is mainly drained by Kaliodi and Vettaru rivers. Physiography of the area exhibits flat region with covering larger part of the study area.

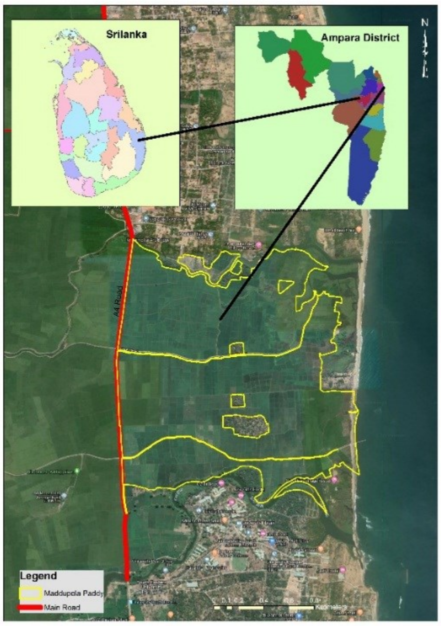

Figure 01: Study Area

Materials

The questionnaires survey were employed from varies group such as farmer, fisherman and coastal household. In addition, soil samples were collected from 20 selected places with handheld Global Position System (GPS) within the study area (see table 01). In addition, the matrix was developed that field measurement carried out by the real measured electrical conductivity (EC) and PH values with estimated ones derived from GIS mapping approaches.

Table 01: Soil Sample in the Study Area

Sample Point	X	Y	EC (ds/m)
1	81.86234830	7.310697030	10.84
2	81.86245697	7.306608424	19.99
3	81.86046930	7.304209664	5.22
4	81.85307692	7.307047737	3.9
5	81.84724031	7.302271714	2.68
6	81.86280736	7.317504927	6.09
7	81.85665254	7.310408535	4.98
8	81.86198917	7.313127583	8.6

9	81.86282004	7.320352953	17.1
10	81.86056008	7.325103650	8.16
11	81.85993378	7.331844444	6.1
12	81.85607022	7.324806643	4.25
13	81.85919764	7.320541543	6.53
14	81.85349300	7.317768661	3.04
15	81.85233973	7.330000706	3.48
16	81.84774521	7.320521713	2.18
17	81.84705632	7.313978409	1.45
18	81.84990509	7.310039867	1.54
19	81.84710993	7.305894575	2.18
20	81.84743042	7.298522542	2.12

Research method

Descriptive statistical parameters were employed that minimum, maximum, mean, standard deviation, and coefficient of variation (CV) to analyze soil property data. These approaches overlook spatial variability among sample points. A geo-statistical analysis is employed to analyze the spatial distribution of soil properties in earth surface (Goovaerts; López-Granados, Jurado-Expósito, Pena-Barragan, & García-Torres, 2005). Thus, Geostatistics is generally used for assessment and map soil properties across spaces.
In this study, soil salinity indicators (EC and PH) were mapped by created as raster layers in ArcGIS 10.3 environment. The 'Inverse Distance Weighted' surface interpolation technique was used to create an interpolation raster from the point shape file (Zahir and Kaleel, 2014). Hence, using the interpolation technic of Inverse Distance Weighting (IDW) of the selected studies based on following that field measurement and laboratory analysis. The soil salinity is estimated by the EC and PH of the soil measured at the survey sites. Based on the result, the analysis is made to determine the relationship between the value of the samples of soil EC and PH in the study area.

Results and Discussion

The difference in reflectance allows one to determine the soil type at the surface layer. Validation samples were taken from different land use/ land cover types, including paddy rice field, coconut garden, bare land, and cropland. The sample locations are selected at different salinity intrusion degrees. A higher level of salinity rate (EC, ds/m) shows its high correspondence with the coastal area (see figure 02). Therefore, this study generates salinity maps for the entire Nintavur GND-10 using GIS model Soil salinity is classified into five levels based on the global standard salinity ranges risk level and extent of the study area (see table 02).

Table 02: Classification of Soil Salinity on Electrical Conductivity Values

EC (ds/m)	Risk Level of Soil Salinity Class	Extent (ha)	(%)
< 2	Not Salinity	184	34.6
2 – 4	Low Salinity	172	32.3
4 – 8	Average Salinity	105	19.7
8 – 16	High Salinity	48	9.0
> 16	Very High Salinity	23	4.3

The electrical conductivity (EC) of soil samples analyzed ranged from 1.4 to 19.9 ds/m with an average value of 6.0 ds/m (table 03). According to this results, 45 percent of the total samples were classified as not meet salinity level, 30 percent of the samples were classified as low, 10 percent of the samples were classified as average, 5 percent of the samples were classified as high and another 10 percent of the samples were classified as severely saline soils in the study area. The geospatial interpolation result depicted that (Figure 02) the study area is characterized by low to high salinity level.

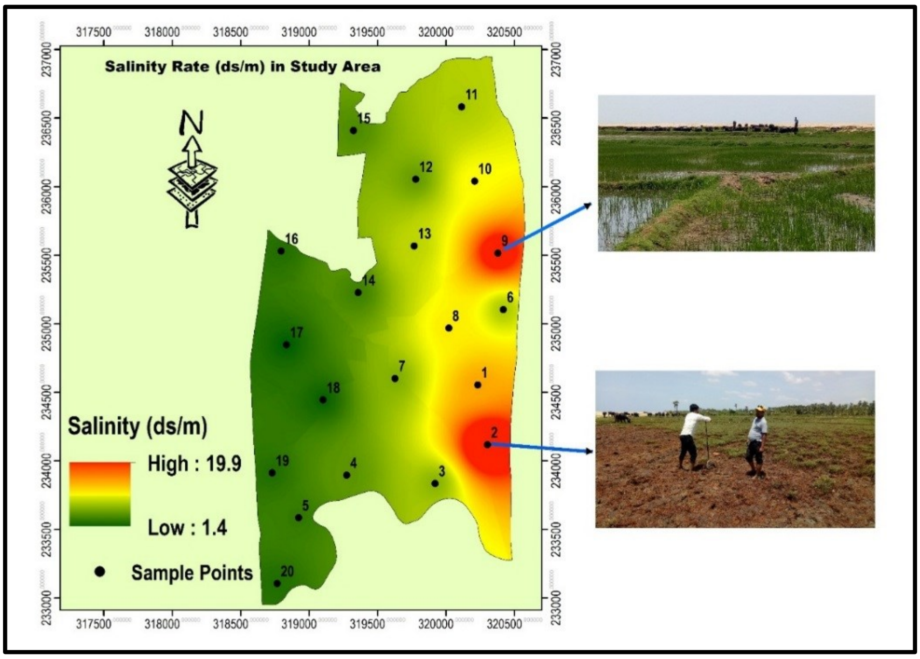

Figure 02: Salinity Rate of Study Area

According to the average deviation diagram that location number 1 to 2 and 8 to 10 have consisted of more than 8 ds/m that higher salinity rate in the study area. This location not only near seashore but human activities that Oluvil harbor construction is key factor that intrusion of saltwater into agricultural land the study area. 71 ha (13.3 percent) area has consisted of higher salinity concentration in soil of study area (see table 02); from past times, farmers used these lands as paddy cultivation activities. These lands are lowlands mainly in which cultivation is not possible due to saltwater intrusion after construction activities of Oluvil harbor. Due to this state, the increment of sodium surface adsorption ratio in these soils and on the other hand, reduction of soil permeability as well as poor drainage. It is necessary to amplify these lands with management application and with abatement of uncontrolled by the saltwater intrusion in the study area.

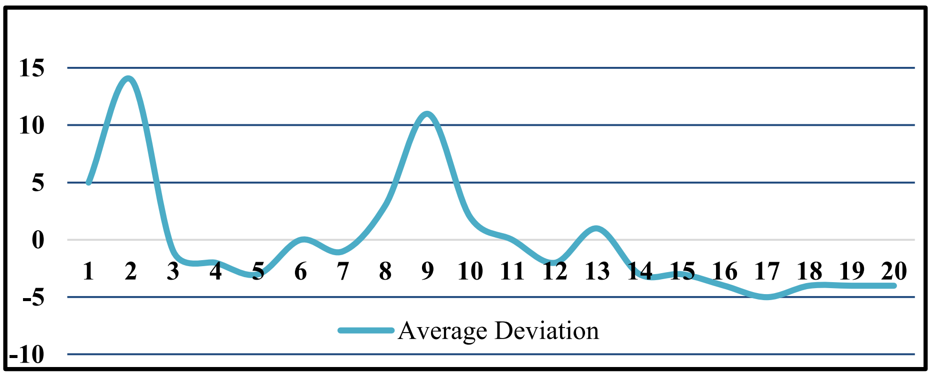

Figure 03: Average Deviation of Salinity of Study Area

The high CV of 81.7 percent (table 03) confirms the variations of the EC values over the study area. The vast majority of the scheme (66.9 percent) is classified under low levels of salinity risk, whereas 19.7 percent of the total area is classified under high salinity hazards as well 13.3 percent of the total area is classified under higher salinity hazards in the study area (see table 02).

Table 03: Descriptive Statistics of EC and PH

Parameter	Min	Max	Mean	SD	CV (%)
EC ds/m	1.4	19.9	6	4.9	81.7
pH	5.4	7.6	6.6	0.5	7.6

Soil pH of the study area ranged from 5.4 to 7.6 with a mean of 6.6 and CV of 7.6 percent (table 03). According to soil alkalinity rating, soils of the irrigation scheme varied from medium to moderately alkaline soil. 15 percent of the total soil samples were classified as medium to moderate alkaline soils, whereas 85 percent of the soil samples were classified as under medium alkaline soils. Likewise, the GIS analysis result showed that (figure 04) 85.7 percent of the total land is classified by medium alkaline soils, whereas 14.3 percent is defined by moderately alkaline soils.

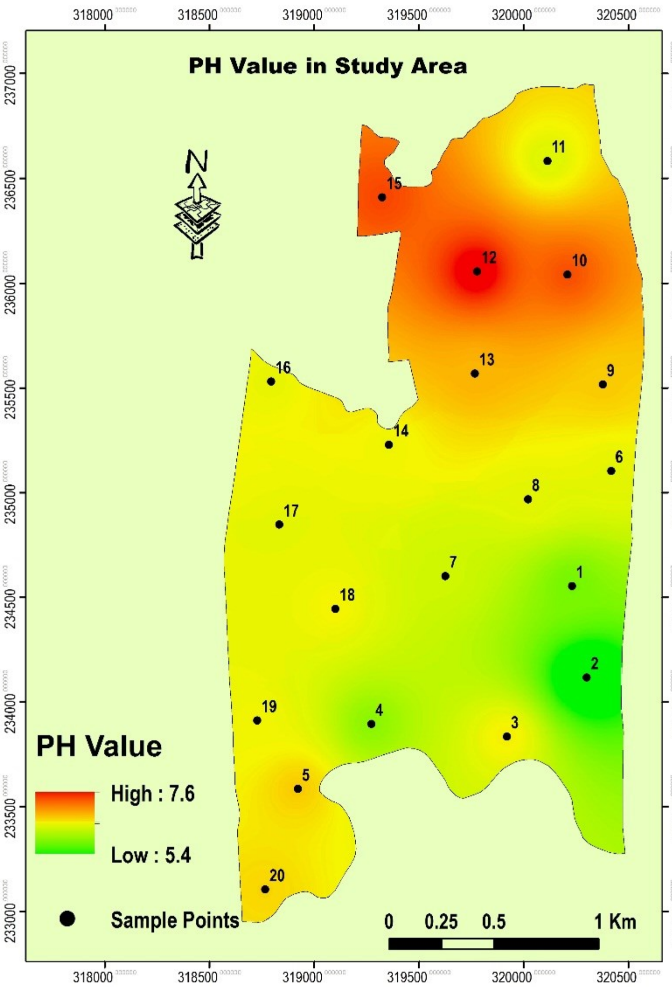

Figure 04: pH Rate of Study Area

The low CV of 7.6 percent (table 03) approved the similarity of soil pH values over the study area. The vast majority of the agricultural land (85.7 percent) has pH value of less than 7, and a small portion of the land (14.3 percent has pH value of 7.0 to 7.6. This showed that the study area is not dominated by strongly alkaline soils. The result is in consistence with the preliminary expectation that the irrigation scheme could not be alkaline soils in the study area.

According to the result is keen some a little bit from the preliminary expectation that small part of the irrigation system is not induced salinity level. Spatially, salinity hazards existed in the coastal area of the agricultural landscape where traditional irrigation practices have been executed for long period of time using shallow ground water. The agricultural irrigated land areas were affected partly by salinity, and seawater intrusion and it's the distribution was associated with shallow ground water. This is because seawater intrusion can bring severely salts by losing water through evapotranspiration and concentrating the dissolved salts in soil solution. Salt soils frequently have visible salt deposits on the surface of a soil (Horneck et al., 2007). In this state, study area figure 02 shows salt deposits on the surface of the soil of close to the coastal area where irrigation has been performed traditionally for a period of time.

Conclusion and Recommendation

GIS-based techniques were widely used to predict the values of soil salinity over un-sampling areas of the earth's surface. In the statistical tools that the semi-variogram model was used to estimate the values of soil salinity parameters in the un-sampled locations within the study area, and a raster layer of soil salinity map was generated using IDW interpolation technique. IDW is described by a range of salinity levels based on soil chemical properties that EC and pH. They are classified as non-affected, and salt soil each with different levels according to the salinity concentration. The total area of 86.7 percent is classified under the permissible levels of salinity risk, whereas 13.3 percent of the total area is classified under high salinity hazards in the study area. As a result, this study pointed out that in soils of the agricultural area that the close to the seashore where seawater intrusion time to time due to Oluvil harbor practices. There is a salinity hazard and is building up gradually as the intrusion saltwater is continuing. Increasing salt concentration in the soils will increase toxicity and finally will damage the growth of irrigated crops. Therefore, we should be introduced to reclamation measures to soils of the agricultural area that to consider the following mechanisms starting from leaching, fertilization, and selecting salinity-resistant crop varieties. The appropriate management approaches should be implemented to appreciate the optimum production capacity of the soil in the study area.

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