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Assessment of Aquifer Vulnerability to Saltwater Intrusion using Modified Galdit Factors-A Case Study

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Abstract The coastal aquifer of Odisha aligned in NE-SW direction for about 430 kilometers is confronted with typical problem of saltwater intrusion and salinization. Four types of aquifer disposition are mainly encountered i) fresh water zone overlying saline water zone ii) saline water zone overlying fresh water zone iii) alternate fresh and saline water zone and iv) saline water all through. Utilization of groundwater in the area is of greater significance since coastal belts are among the most densely populated human settlements and groundwater forms the major and sometimes the only source of potable water there. The study area; Basudevpur block, Bhadrakh district, Odisha is endowded with abundance of water resources and vast stretch of fertile land. The economy is agriculture based but its development is constrained due to proximity of the Bay of Bengal and salinity hazards. Its unplanned development has upset the hydro-chemical balance leading to seawater ingress. Thus the ground water development in the terrain requires a proper understanding of hydro-geological and hydro-chemical setup and management scenarios. GALDIT method has been used to assess the vulnerability of the study area to salt water intrusion using certain hydro-geological parameters. The paper deals with the determination of the water quality and to identify the areas affected by saltwater intrusion. An attempt has been made to use the remote sensing and GIS techniques for integration of spatial database. To map the saline affected areas, different hydrogeological parameters like hydraulic conductivity, aquifer types, distance to coast, water table above mean sea level are analyzed in a modified GALDIT model. Relationship of each layer to the ground water regime has been evaluated through detailed analysis of the individual parameters. These relationships are used for the development of an algorithm to be used in spatial multi-criteria evaluation (ILWIS, SMCE) decision model. Ground water potential zones and the areas demarcating the saline hazard areas have been identified based on integration of data and various themes. The map thus generated can be of vital importance for coastal hazard mapping agencies. The coastal tract has inherent salinity problem due to both natural and man-made causes and hence should be under strict surveillance for the over-all sustainable development of coastal areas. Necessary steps like artificial recharge and conjunctive use studies are to be taken up in the area in order to protect this aquifer system from the hazards of sea water intrusion and to devise means for the optimal utilization of the water resources. It is needed to construct wells along some transverse section of the coast with piezometer nest tapping different aquifers. Regular monitoring of water quality in the aquifers should be done where the quality deteriorates and where the fresh/saline water aquifers are in direct contact with the sea.

INTRODUCTION

The integration of various thematic data to derive desired information was difficult in the past. Now, with the advent of satellite remote sensing and the analysis capability provided by GIS offer a technologically appropriate method for studying various features related to land and water resources. GIS techniques facilitate integrated and conjunctive analysis of large volumes of multidisciplinary data, both spatial and non-spatial, within the same georeferencing scheme (Saraf and choudhury, 1998). The present study aims at evaluation of saline affected zones based on integrated study of all the parameters controlling ground water regime like Groundwater occurrence, Aquifer hydraulic conductivity, depth of groundwater Level above sea, Distance from the shore (distance inland perpendicular from shoreline) and Impact of existing status of seawater intrusion prevailing in the area.

Basudevpur block with an area of 511 km^2 is bounded between latitudes 20^{0} 56' 05'' N and 21^{0} 13' 55'' N and Longitude 86^{0} 38' 51'' E and 86^{0} 53' 43'' E. (Figure-1). The coastal block Basudevpur is endowed with abundance of water resources where the population density is high and agricultural activities are intense with ever increase demands for freshwater. But its development is constrained due to proximity of the Bay of Bengal and salinity hazards. Its unplanned development has upset hydro-chemical balance leading to seawater ingress.

GEOMORPHOLOGY

The block can broadly be divided into four distinct geomorphic units (1) tidal flat (2) coastal plain (3) alluvial plain (4) flood plain. The fine sediments carried out by the rivers get deposited along the coast because of tidal action, as tidal flat / mud flat. The width of this tidal flat varies from 2 to 5 kms. Tidal flats and mud flats support growth of varieties of mangrove. The coastal plain is a gently sloping plain occurring parallel to the coast and mainly formed by fluvio–marine action and is intersected by network of creeks, which are mainly saline due to tidal action. The width of this coastal plain varies from 5 to 25 kms. The coastal plain encompasses a series of beach ridges characterized by sand dunes of varied relief and extends for kilometers, almost parallel to the coast. The gently sloping alluvial plain occurs to the west of the coastal plain and forms the most fertile part of the block. The younger alluvial plain spreads over a large area and it represents major part of the study area. This has developed due to depositional activities of the major river systems

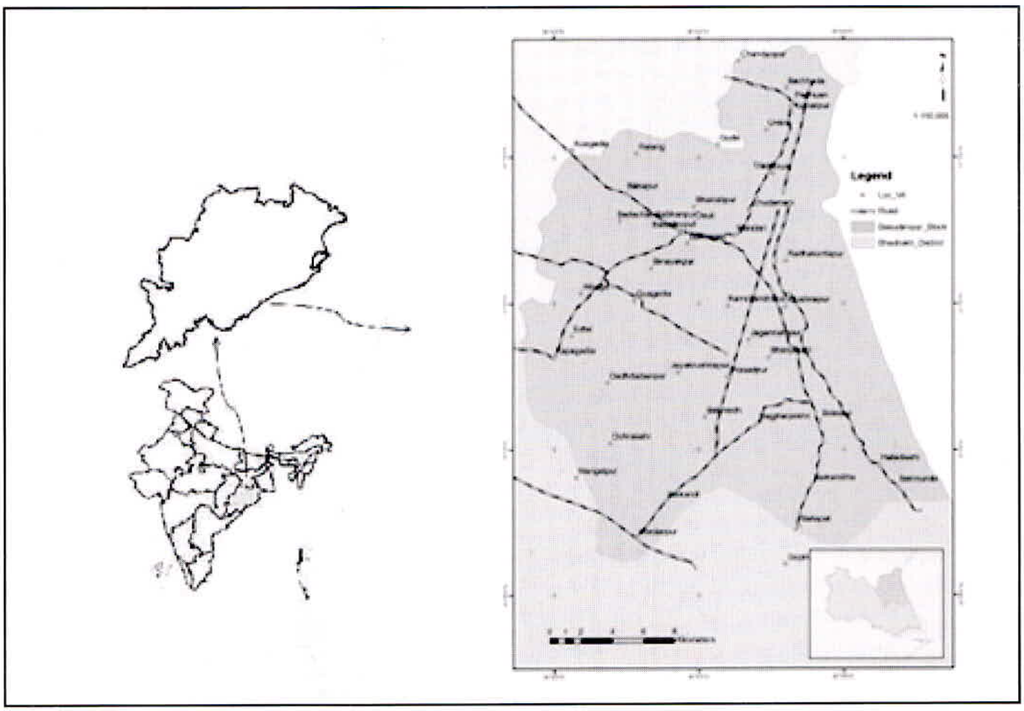

Fig. 1. Location Map of the study area

in a fluviatile environment. It also encompasses geomorphic units like palaeo channel, meander scars, ox-bow lakes of smaller dimension. The area is well drained by kansbans river in the north, gomai/ chudamani river in the middle and by the upper reaches of matei river in the southern part. All the three rivers are tidal in nature and saline water commonly enters into the kansbans and gomai/ chudamani river during summer. The flood plain zones are the areas adjacent to these rivers and mostly built up by river-borne deposits during high floods. Flood plains primarily consist of unconsolidated materials like sand, gravel and silt. The area is thickly populated and depends mainly on agriculture for its development.

GEOLOGY

Geologically the area is occupied by alluvial deposits of deltaic origin. Generally sand predominates over clay and is of terrestrial in nature. Commonly the sand is white- yellow- light brown coloured, medium to coarse grained and moderately sorted. However a light bluish grey moderate to poorly sorted subangular sand zone found at deeper horizons in Narsinghpur, Mandari, Chudamani and Untira sites are undoubtedly marine in origin. The sandy facies are commonly overlain by 6 to 8 meter thick impervious grey clay layer. The area east of Ricket and Odisha Coast canal is characterized by thick marine clay of 10 to 18 m and is deposited in an old tidal flat environment. Therefore the piezometers constructed near to this are characterized by the predominance of clay facies. Again the thick clay zone found at Bachada and Chudamani village are due to the extension of the tidal flat through the tidal rivers like Kansbans and Gomai/ Chudamani.(CGWB Report, 2005)

To assess the vulnerability of coastal aquifers different hydrogeological, hydrochemical and other aquifer characteristics were studied in a well-defined way. The most important mappable factors that control the seawater intrusion are briefly described below. Similar approach has been studied by taking the modified GALDIT parameters by. (2005)

1. Groundwater occurrence (aquifer type: unconfined, confined and leaky confined)
2. Aquifer hydraulic conductivity
3. Depth of groundwater Level above sea
4. Distance from the shore (distance inland perpendicular from shoreline)
5. Impact of existing status of seawater intrusion in the area

Preparation of Different Thematic Maps for Generation of Vulnerability Index Map to Salinity Ingress

Ground Water Occurrence

In nature, groundwater aquifers can be categorized as confined, unconfined, or leaky confined. Depending on the aquifer type, the vulnerability of the aquifer to saltwater intrusion changes. The confined aquifer is more vulnerable due to a larger cone of depression and instantaneous release of water to wells during pumping. From the various exploration programmes conducted by CGWB, the data reveals that the study area is underlain by 6 to 8 meters thick impervious clay layer and phreatic aquifer is absent. Therefore dug wells are virtually absent in the study area. Ground water mostly occurs under confined condition. So a uniform ranking is given to the factor while consideration of the vulnerability of the aquifer system.

Aquifer Hydraulic Conductivity

By definition, aquifer hydraulic conductivity is the ability of the aquifer to transmit water. Hydraulic conductivity is the measure of interconnected pores spaces (effective porosity) in the unconsolidated sediments and in fractures zones in consolidated rocks within an aquifer. For a given hydraulic head, a high value of hydraulic conductivity leads to larger inland movement of seaward front. The high hydraulic conductivity also results in wider cone of depression during pumping and may result in greater intrusion if located close to the coast. The magnitude of seawater front movement is influenced by hydraulic conductivity—higher the conductivity, higher the inland movements of the seawater front. The hydraulic conductivity map is depicted in Figure-2A. While calculating the vulnerability factor for the salinity ingress, higher values of rating importance have been given for the points which show high values of hydraulic conductivity.

Depth to groundwater Level above sea

The depth of groundwater table with respect to mean sea level is a very important factor in evaluating the seawater intrusion in an area primarily because it determines the hydraulic pressure availability to push the seawater front back. According to Ghyben-Herzberg relation, the theoretical interface between the salt water and fresh water occurs at a depth below sea level that is 40 times the height of freshwater above sea level. The values pertaining to minimum ground water level that is pre-monsoon water level has been taken to prepare the pre-monsoon water level map. The DEM generated from the SRTM DEM is substracted from the pre-monsoon depth to water level map to get the water table map above mean sea level (Figure-2B).

Distance from the Coast

The impact of seawater intrusion generally decreases towards inland at right angles to the shore. The maximum impact is observed closed to the coast and in creeks under favourable hydrogeological conditions. The distance from the coast map has been prepared from the cadastral map (Figure-2C). Highest values of the ratings have been given to the areas which are near to the coast while preparing the vulnerability map.

Impact of existing status of seawater intrusion

The area under mapping is invariably under stress and this stress has already modified the natural hydraulic balance between seawater and fresh groundwater. This fact should be considered while mapping aquifer vulnerability to seawater intrusion. The impact of existing status of seawater intrusion can be assessed using the ratio of Cl^- and ($CO3^-$ + $HCO3^-$). Cl is the dominant ion in sea water and is available in small quantities in ground water while HCO_3 is plentily available in ground water and is present in very small quantities in sea water. Higher is the ratio of Cl^- and ($CO3^-$ + $HCO3^-$), higher is the intrusion and vice-versa. The ratio Cl^-/ (HCO_3+CO_3) map has been prepared from the available data and is depicted in Figure-2D.

SMCE Methodology and Generation of Final Output Map

Geographic Information System (GIS) is "A decision support system involving the integration of spatially referenced data in a problem solving environment". The Spatial Multi-Criteria Evaluation (SMCE) application assists and guides a user in doing Multi-Criteria Evaluation (MCE) in a spatial way. The input for the application are the different thematic maps discussed above which are termed as criteria, and each criteria are grouped, standardized and weighed to evaluate the final output map. The parameters discussed above are ranked, weighed and normalized (Table-1) to generate the salinity ingress vulnerable map (Figure-3). The analysis is a knowledge driven approach, based on scientific database generated from field investigations, existing maps in the study area. The aquifer zones containing fresh water all through, occupy the western part of the study area while the aquifer zones contain saline and fresh water at different depths in the narrow eastern part. The saline tract is triangular in shape with a wide base of 12 to 15 km in the southern part. The Bachhada – Untira – Chudamani aria – Mandari – Balimedh and Naikandiha line demarcates the saline tract on the east side from the rest part. The spatial distribution of the fresh water and saline water bearing areas are shown in Figure-3. It is observed that the map generated through GIS data

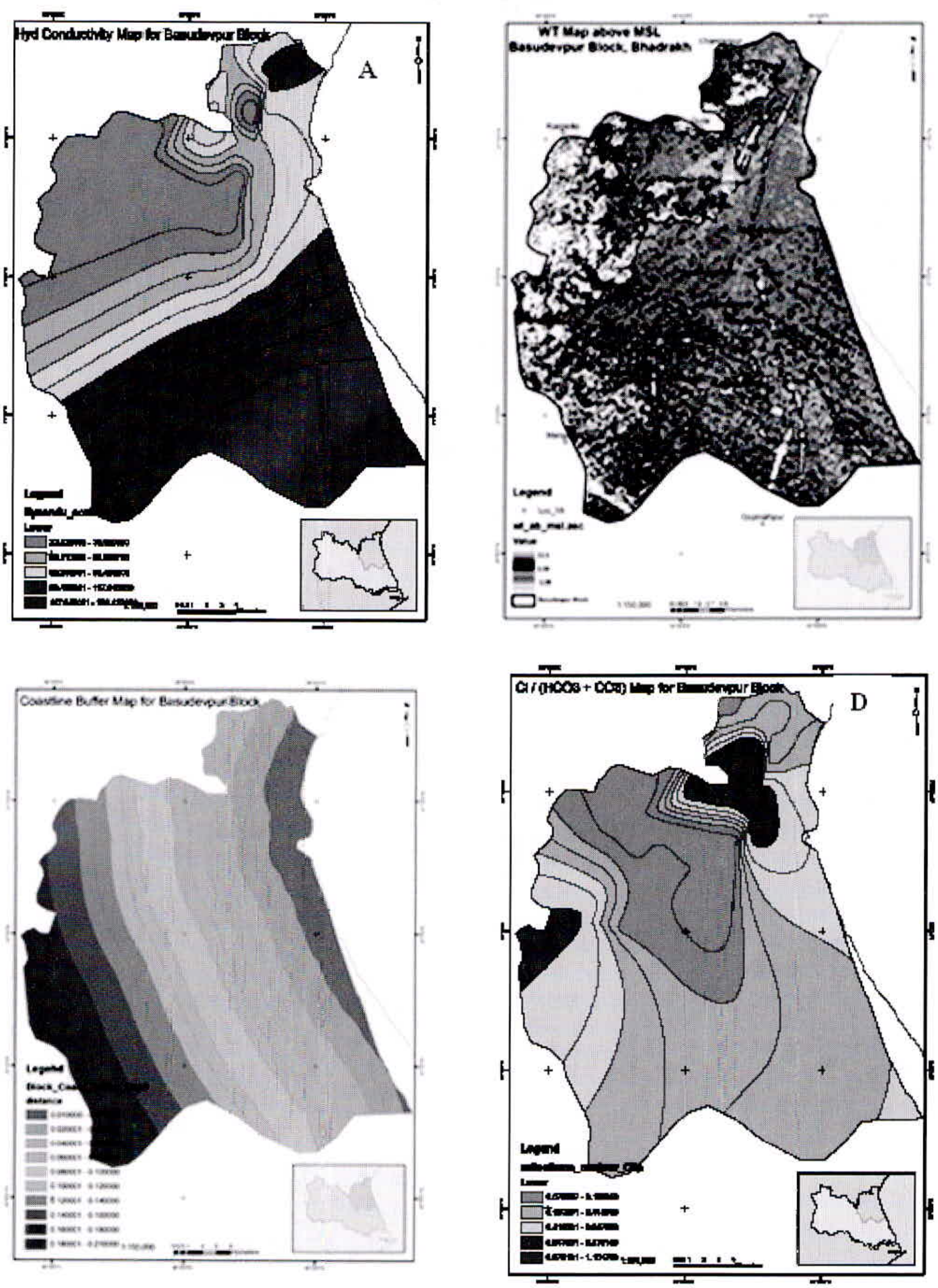

Fig. 2. Different Thematic Maps prepared for the Analysis of final output map in SMCE

Table 1. Weights and Ranks assigned to different thematic layers for Salinity Vulnerable map.

Sl.No	Ground water Controlling Parameters	Range	Normalised Priority Value
1	**Hydraulic Conductivity**		
	Very low	<22.5	0.142
	Low	22.5-56.5	0.357
	Medium	56.5-90.4	0.571
	High	90.4-124.4	0.785
	Very high	124.4-158.4	1
2	**Depth of WT above msl**		
	Low	<2.38	1
	Medium	2.38-6.99	0.603
	High	6.99-11.6	0.205
3	**Distance to Coast**		
	Very Near	<0.001	1
	Near	0.001-0.06	0.762
	medium	0.06-0.11	0.524
	Far	0.11-0.16	0.286
	Very Far	0.16-0.21	0.048
4	**$Cl/HCO_3+CO_3)$**		
	Very low	<0.075	0.068
	Low	0.075-0.333	0.303
	Medium	0.333-0.59	0.536
	High	0.59-0.84	0.164
	Very high	0.84-1.1	1

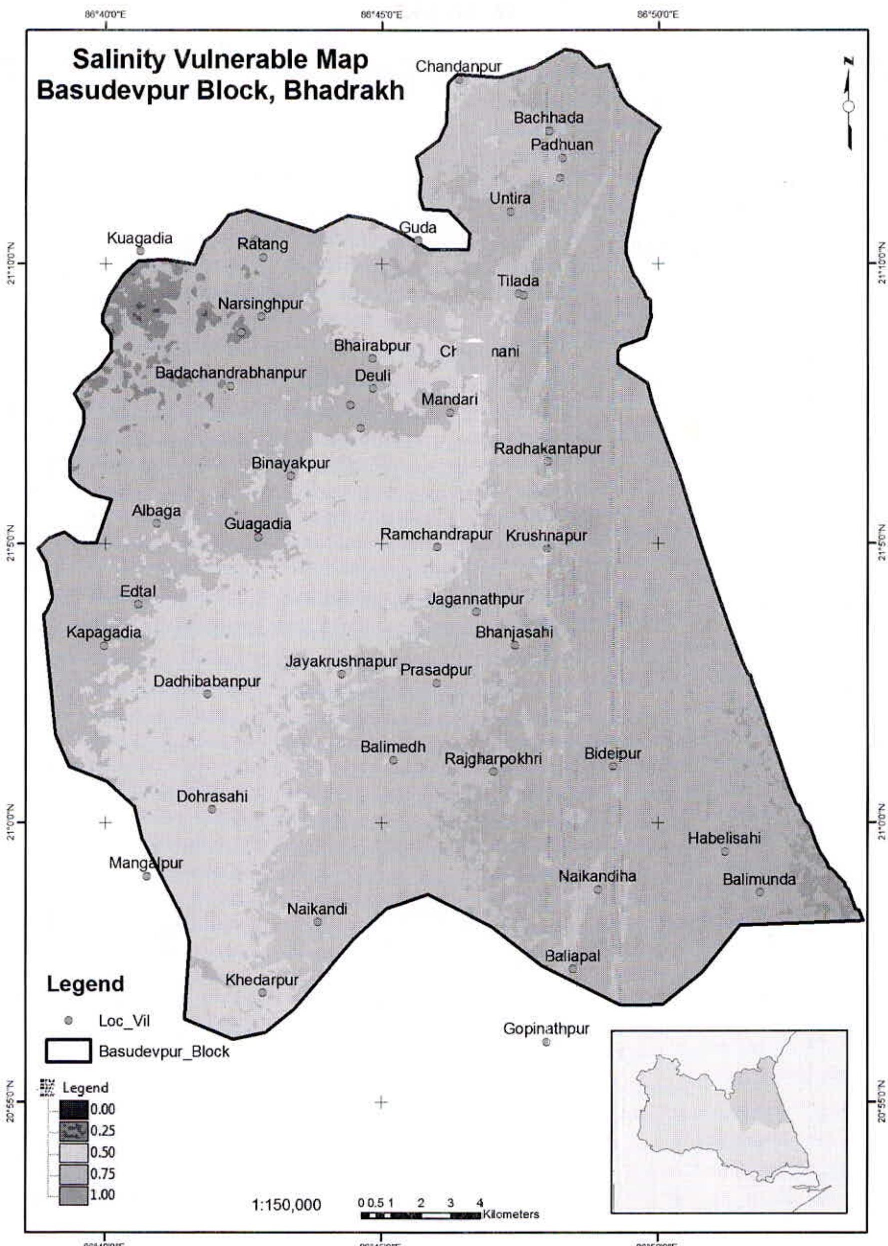

Fig. 3. Salinity vulnerable Map of Basudevpur Block, Bhadrakh District, Odisha, Generated through spatial data analysis.

interpretation is almost compatible with the earlier published map demarcating the saline and non saline areas (Figure-3 (a)) (CGWB Atlas, 2002). From the chemical data analysis, high values of EC, Cl, and Sodium Absorption Ratio (SAR) are recorded from the areas in Chandanpur, Bacchada, Untira in the northern part and in Naikandiha, Irum, Chudamani, Ramchandrapur in south eastern part of the area.

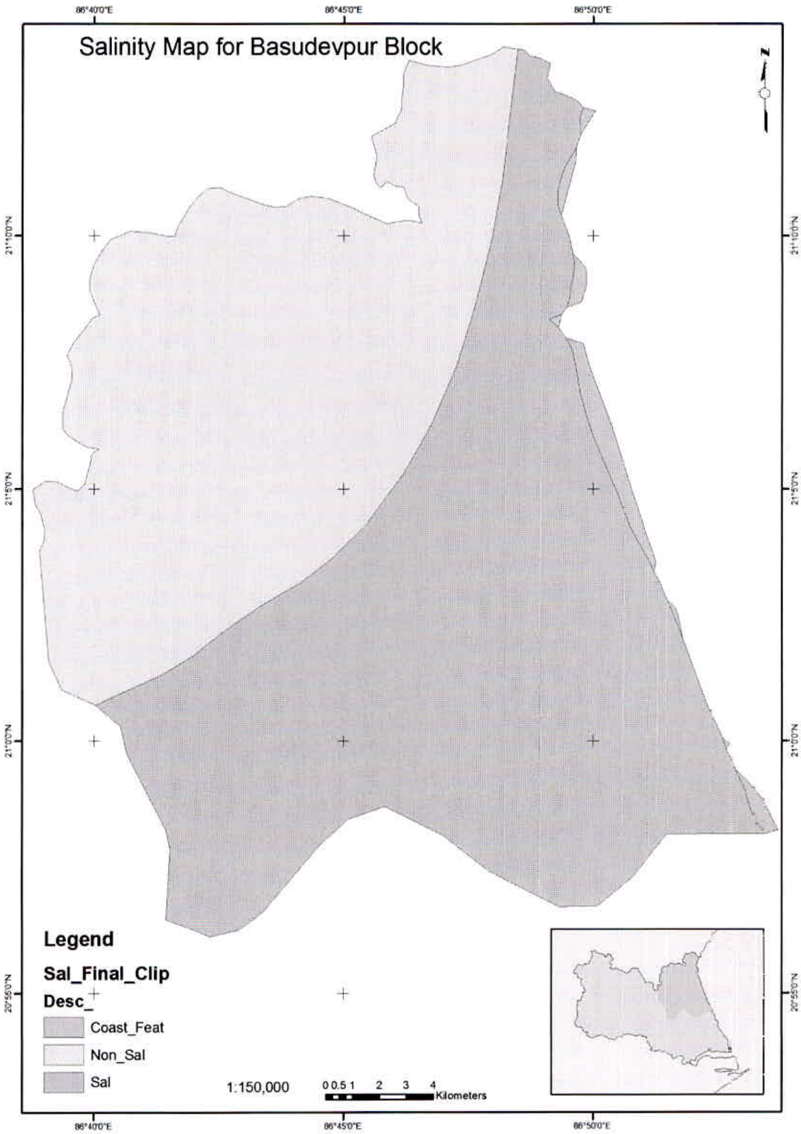

Fig. -3 (a). Existing Map showing saline-non saline areas based on ground water exploration, Basudevpur Block, Bhadrakh District, Odisha (CGWB Atlas-2002).

CONCLUSION

As the population of the block is increasing with more stress on Agricultural use, ground water withdrawal is likely to increase in near future. The unscientific exploitation of groundwater has already created a water stress condition with some salinity problems in the area. This alarming situation calls for a cost and time-effective technique for proper evaluation of groundwater resources and management planning like construction of artificial recharge structures for arresting salinity ingress. As demonstrated successfully in this study, the integrated remote sensing and GIS can provide appropriate platform for convergent analysis of large volume of multi-disciplinary data for decision making in groundwater management studies.

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