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Strategies for Managing Natural Resources in Coastal Waterlogged Areas at Chilika

Madhumita Das, R. R. Sethi, N. Sahoo and Ashwani Kumar

WTCER

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Preface

Salt stress in soil and water resources is the major constraints of the coastal water logged areas. Over the years, it has been aggravated, in varying degrees, in different parts of the country. In India, out of 8.6 million ha, about 3.0 million ha are coastal saline soils at present. The salinity and its related parameters substantially affect the production and decreased productivity level of the area. Although the area has the ability to support good crop growth if properly planned. But during planning of agricultural development, inadequate attention has been paid to the actual potentiality of the areas. This is partly due to lack of proper information and data. Agricultural development requires a multidisciplinary approach that integrates analysis of spatial and non-spatial data parameters, so that decision makers can implement plans for natural resources uses in salt-stricken under-productive coastal areas.

To harness potential of low yielding coastal waterlogged area, a study on "Strategies for managing natural resources in coastal waterlogged areas at Chilika" was therefore conducted under a research project in Water Technology Centre for Eastern Region, Bhubaneswar. Chilika is the largest brackish water lagoon of Asia with estuarine characteristics, spreading along the east coast in three districts of Orissa, India. Here the production system is basically rain-fed and the crop productivity (of 2800km^2 area) is low, hindered by salt stress and irrigation water scarcity at post and pre - monsoon periods. Information and the data documented in this publication are original and generated by the authors. We (authors) have documented the findings for dissemination and proper implementation of the results and will be immensely thankful to share the information with the interested organizations / Govt. or semi-Govt. departments/ research workers and the like, for further progressing of our works. Authors owe to the director WTCER, for his constant support, providing facilities and valuable suggestions to bring out this publication.

AUTHORS

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Executive Summary

The coastal region has known for its vastness both in terms of resources' potentials and diversity, where Chilika the largest brackish water lagoon of Asia maintains a unique ecosystem allying Lake Habitat, hydrology with terrestrial land potential at its periphery in Orissa. The land potential is crucial for restoring and improving ecosystem of the lagoon. This piece of the work is thus providing comprehensive information on soil, water and hydrological resources and unfolding the intricacies of the problems associated in this area. Specifically it appraised the area specific characterization of the resources with special emphasis on salt stress and diversified nature of soil, water, and hydrology at the surroundings of Chilika lagoon. The soil and water related constraints mainly salt stress for growing crops were focused. Extent of salt stress in water resources at two distinct growth seasons was highlighted. Spatial variability of soil and water properties was studied, semivariances were estimated and variogram structures of relevant parameters were formed. These enable to promote appropriate uses of diversified resources and too enhance the scope of further research in natural resource management. The hydrology of the area was also varied greatly across the space without producing any definite trend with respect to location of the lagoon. Lithological characteristics too changed both horizontally and vertically as well. However the area wise influence of Chilika lagoon on natural resources was evaluated. Thereafter to improve land and water use efficiencies, the crop based farming strategies have been formulated by giving due emphasis on potential and liabilities of the places representing the study area, where salinity and water scarcity together inhibit cultivation in rabi and summer seasons. The study has thus come up with different location friendly farming strategies by combining soil moisture, salt content and aquifer availability and qualities in different ways. Besides by considering crop area coverage and prevalent cropping pattern during post and pre monsoon periods, different options for using water (as per the quantum of availability in the existing reservoirs) have been advocated for well – fed irrigated, low saline area. To harness the land potential implementation of these strategies fitting to specific location is required to enhance cropped area and to drive productivity growth of salt stricken water logged area around Chilka.

1. INTRODUCTION

Chilika the largest brackish water lagoon of Asia with estuarine characteristics sprawls in Puri, Khurda and Ganjam districts of Orissa state along the east coast of India. It is the largest wintering ground for migratory waterfowls with rich fishery resources in this sub-continent. The main lagoon connected with Bay of Bengal by a 32 km long narrow outer channel close to the north eastern side of the lake near the village Motto. The water spreading area of Chilika varies between 1165 to 906 sq km during monsoon and summer respectively. It swells up during peak monsoon submerging adjoining land and often ends up with crop failure by inducing salt stress. Water logging owing to saline or brackish water inundation during high tide or peak monsoon period, which inducing salt stress in soil and water resources along the lake boundaries is a natural phenomenon. With the onset of rains, around 52 numbers of streams drain into the lagoon creating good water currents, which gradually pushes the sea water back and resulted to temporary salt stress unmatched with the salt effects as vivid in other conventional coastal areas.

The crop productivity of land in and around Chilika is low. It is evident from the land use and land transformation data that land degradation is prevalent and causes decline in productivity level of the catchment area. This results in accelerating poverty and producing unsustainable pressure on the natural resources which further exacerbating resource depletion process and productivity as well (www.chilika.com/about.htm). A holistic approach by considering physiographical features, soil, water and hydrology characteristics is imperative for promoting their judicious uses in farming.

The production system of the region is basically rain-fed, hindered by salt stress and irrigation water scarcity at post and pre – monsoon periods. Salinity induced low crop output and sometimes total failure of crop is widespread (ORSAC 1986). Nevertheless restoration and improving productivity of the terrestrial system is prerequisite for conserving eco-system of the lake in totality. This has not been taken in account though it ought to have.

Salinity an inherent soil property influenced mainly by the salt level of underground water in coastal region, (Bandyopadhyay 1972) and expands with the advancement of dry period (ORSAC 1986). Seasonal fluctuation of salinity in soil and water and its heterogeneity over space were focused even within a small unit of 8 ha farm land in Sundarban delta (Das and Maji 2001). This apart the coastal tract is delimited by the crystalline hard rock underlain by alluvial formation in general resulting to variable existence of groundwater both in nature and yield characteristics especially in the shallow aquifer (Das 1994). Occurrence of some prolific aquifers both with confined and semi-confined status is evident especially in the coastal districts of Orissa.(Chauhan, 2002). However the enormity of salinity variation in soil and sub-surface water coupled with water stress during non monsoon period are the major impediments of farming in coastal vis-à-vis in Chilika area of Orissa. Information on assessment of salt stress and its allies, fluctuation, distribution and intensity of stress are vital for apprehending the situation, selection of criteria to classify the area and management of natural resources for prosperous agriculture. To harness potential of low yielding constrained areas of coastal zone, an effort was initiated on appraising and evaluating the resources to formulate area specific strategies for progressing of underproductive coastal water logged areas at the neighbourhood of Chilika lagoon.

2. RESOURCE CHARACTERIZATION

2.1. Climate

The catchment area of lagoon enjoys a tropical climate with an average annual maximum and minimum temperature is 39.9^{0}C and 14^{0}C. The period from June to September is the monsoon season while October and November months are the post monsoon transition months. The mean rainfall is 1238.8mm with 72 rainy days. The rainfall generally decreases from northeast to southwest. The monsoon starts by second week of June and withdraws early in October. The wind speed is high during the month of March to July and low during winter season. Generally it varies from 5.3 to 16km/hr. During the study period (2002-2004) the received rainfall was 1753mm, 741mm and 1500mm respectively. Among this 66%, 93% and 80% of the total was received during monsoon season in the year 2002, 2003, and 2004 in order.

2.2. Hydrology

2.2.1. Hydrology profile of the area

The catchments area lies between 19^{0}30′ -19^{0}55′ North and 88^0 to 88^{0}4′ East with elevation varies from 2 to 5m msl, predominated by lateritic soil. The area constituted by two river systems. The total freshwater from these rivers/streams into the lagoon is estimated to 1,760Mm^3 per annum. In general these streams are non – perennial, supply freshwater during monsoon and become dry thereafter (CDA, 2000). The total evaporation loss from the lagoon surface estimated to 1,286Mm^3 per annum ORSAC (1988). Presence of plinthites / hard rock beneath the ground surface is prevalent. Occurrence of permanent aquifer is scarce but presence of perched water table with low salinity are available in and around at different depths from the surface. The salinity gets concentrated over time from low to high evaporative demand period with different magnitudes in the entire area.

2.2.2. Soil lithology and aquifer characteristics

Soil lithology largely varied from one to another place without reflecting any continuity with respect to location of the lagoon. Typically the lithology of the area near to sea water carrying split of the lagoon (at Bhusandpur) showed that the aquifer materials were non-uniform throughout the profile as Cu <5 in more than 80% of the samples. Hence the upper litho unit was porous though water yield was too less to meet the crop water demand of the area. The exploratory drilling test (Plate 1) also indicated the existence of first aquifer over 6m depth from the ground surface. Presence of alternate layer of sand and gravel were distinct in lithological strata (Fig.1).

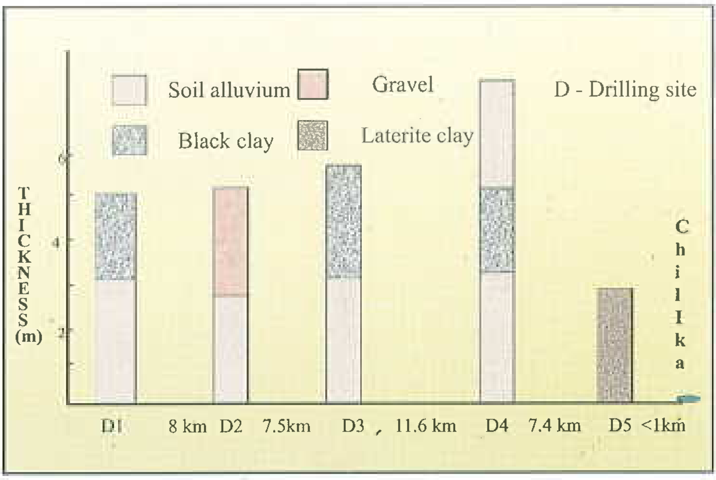


Fig 1: Lithological status of Bhusandpur area

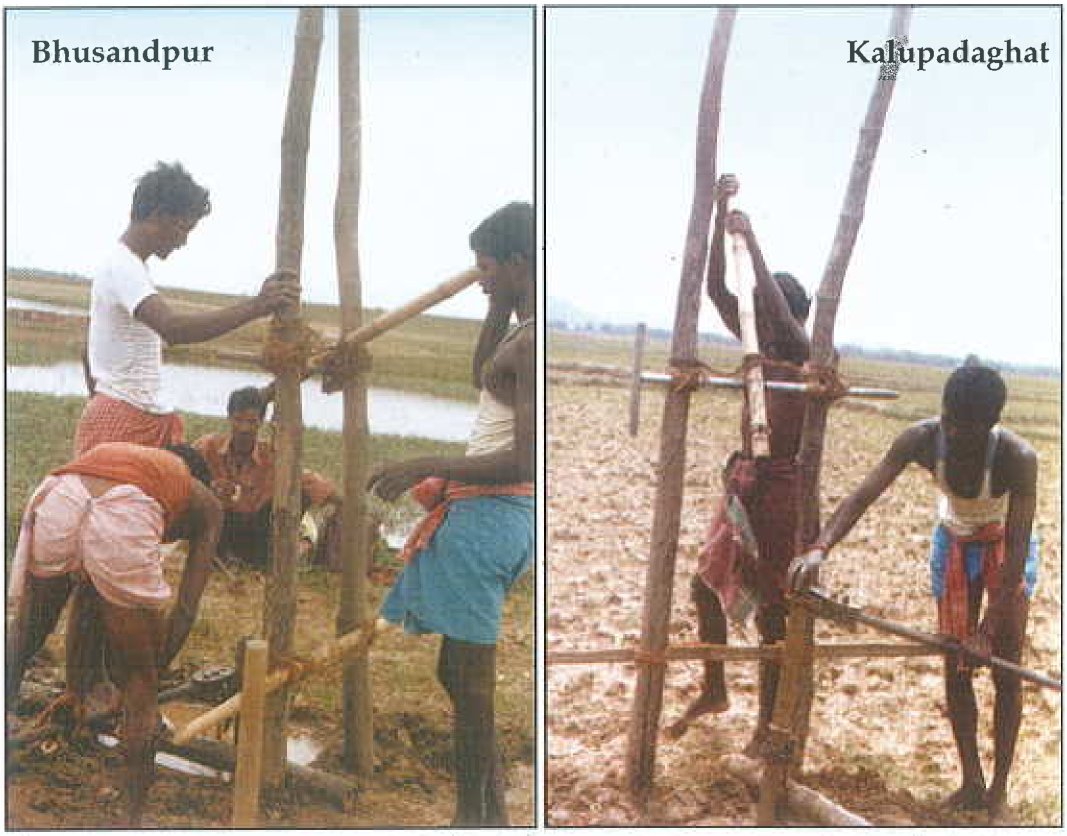


Plate – 1: Process of acquiring hydrological information in the study area

The recharge rate of the aquifer up to 0 - 5m away from the lagoon varied from 5.44m^3/hr to 8m^3/hr during non-monsoon and up to 10m^3/hr during monsoon season while transmissivity varied from 214 - 312m^2/day. Occurrence of aquifer at different depths and with various levels of salinity is presented in Fig. 2.

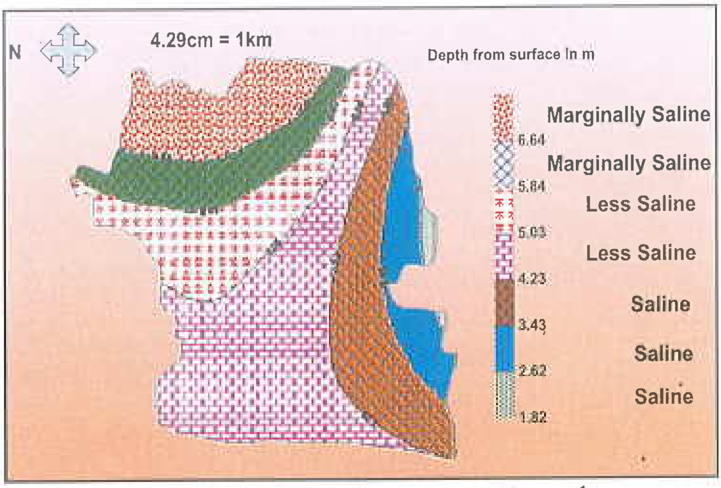


Fig 2: Aquifer characteristics of Bhusandpur area

The lithological profile of the area adjacent to the lagoon (Kalupadaghat) showed that up to the distance of 0 -10m from Chilika, aquifer thickness varied within 4.5 to 6m depth below surface. Appearance of hard soil layer at 3m down from the ground level followed by 0.6 – 1.5m wide stretch of gravel layer was vivid in lithological strata (Fig.3). The soil and water salinity varied from marginal to low saline up to the depth of 6m from surface. The radius of influence was <5m from periphery of the lagoon.

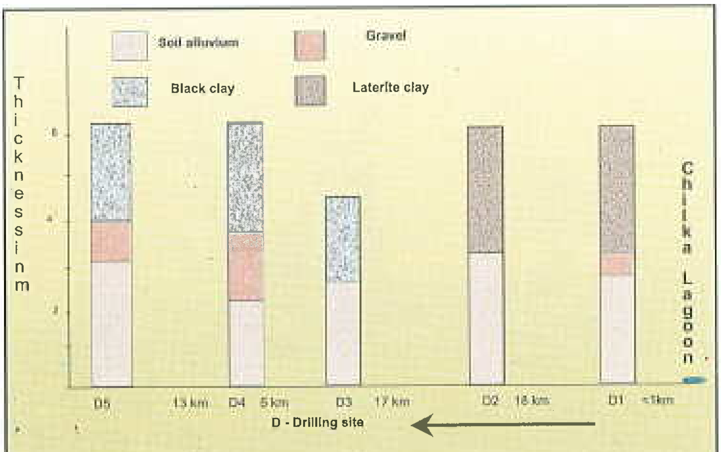


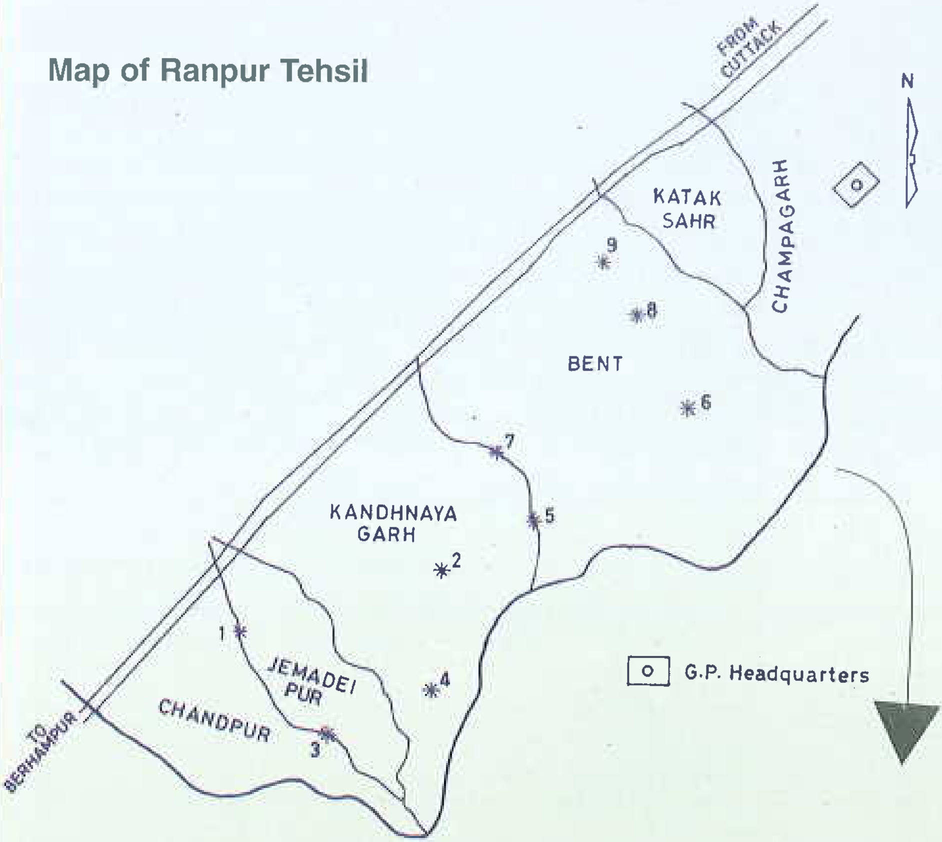
Fig 3: Soil lithology attributes of Kalupadaghat area

Fig 3: Soil lithology attributes of Kalupadaghat area

2.2.3. *Well hydraulics*

Area at 10 – 15 km away from the lagoon belong to Ranpur Tehsil are dotted with open wells of different capacities which have been used as irrigation source during rabi and summer seasons. The recharge rate of the wells differs based on nature of aquifer and soil. Detail pattern of the recharge (well wise) is depicted in Table 1 and Fig.4 as follows:

Map of Ranpur Tehsil



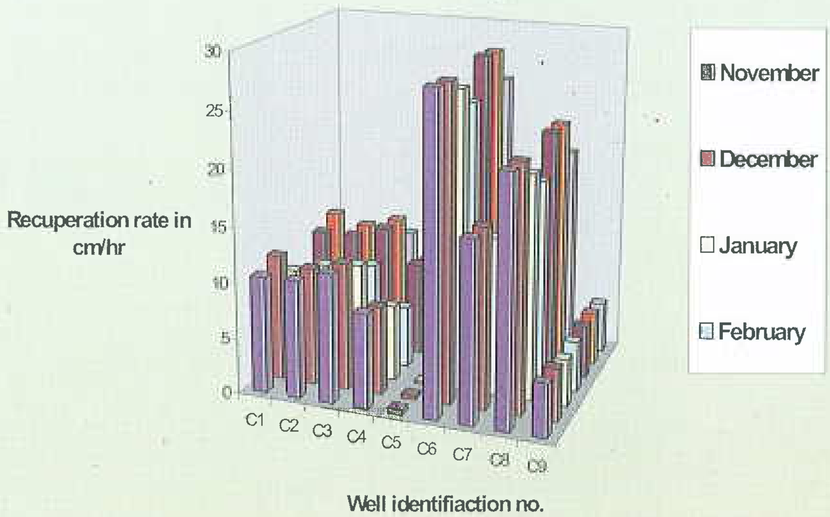


Fig 4: Recharge rate of the wells in well - irrigated area

Table 1: Important soil characteristics of the area at different zones of the lagoon

Sample location with respect to lagoon	Soil profile / horizon id.	SHC cm/ min	AWC cm^3/cm^3	Texture	BD gm/cm^3	pH	EC_2 dS/m	Available P (ppm)	Exch. K (me/ 100 gm)	Exch. Ca (me /100 gm)	Exch. Mg (me /100 gm)	Organic C %	Available N (%)
Upper part of northern sector	P1- 1st	0.66	0.21	sl to cl	1.66	7.35	1.20	13.69	7.04	7.13	5.25	0.26	0.02
	2nd	0.02	0.21	scl to c	1.51	7.10	0.85	8.22	8.71	8.13	8.00	0.23	0.02
	3rd	0.06	0.20	sc to cl	1.58	6.80	1.60	5.00	9.21	15.13	9.88	0.10	0.01
	4th	0.39	0.21	scl	1.50	7.00	0.70	3.80	4.83	6.50	6.13	0.09	0.01
Lower part of northern sector	P2 -1st	0.02	0.17	c	1.32	5.50	1.05	5.80	13.25	6.63	12.88	0.75	0.06
	2nd	0.79	0.16	cl to c	1.31	5.75	0.85	5.66	13.43	6.50	11.25	0.36	0.03
	3rd	2.5E-03	0.13	scl	1.32	5.40	0.30	2.81	15.39	4.00	9.00	0.22	0.02
	4th	0.28	0.10	ls	1.43	5.30	0.20	5.62	5.37	2.25	2.25	0.06	5.0E-03
Central	P3 - 1st	0.44	0.09	sl to ls	1.56	6.70	0.37	7.27	7.43	3.67	2.75	0.34	0.03
	2nd	0.42	0.08	scl to ls	1.60	6.60	0.20	4.76	6.92	3.25	2.25	0.16	0.01
	3rd	0.26	0.12	sl to scl	1.60	6.20	0.10	4.66	8.95	4.00	2.63	0.07	0.01
	4th	0.21	0.07	s to scl	1.38	6.05	0.15	4.73	10.21	3.75	1.75	0.01	$1.0E^{-03}$
Southern sector	P4 - 1st	1.55	0.07	sc	1.06	5.60	2.00	13.47	18.62	5.00	2.50	0.52	0.04
	2nd	$1.0E^{-04}$	0.13	sl	1.84	6.10	1.10	11.15	20.40	3.00	4.25	0.39	0.03
	3rd	$2.0E^{-04}$	0.14	sl	1.82	6.60	0.60	2.53	21.48	4.50	3.50	0.01	$1.0E^{-03}$
	4th	$3.0E^{-04}$	0.14	ls	0.75	6.80	0.30	2.19	12.17	3.50	2.00	0.01	$1.0E^{-03}$

2.3. Soil

The chilika lagoon has been divided into four distinct sectors viz. Northern, Southern, Central and Sea water carrying outer channel, accordingly the nature of soil and water resources adjacent to those sectors are presented in Table 1. Basically the soils were neutral in reaction, marginal to low in salinity, had wide variety of textures, available water capacity and hydraulic conductivity. The fertility parameters, viz. N, P, K, Ca and Mg contents were also changed differently in soil profiles. With respect to salt stress the upper Northern sector (NS) of the lagoon was 8 to 44% more saline than the Southern (SS) and lower portion of Northern sectors. Soil near to Central (CS) part was virtually non saline. Regarding fineness of texture, the soil at NS excelled over CS and SS. Likewise the moisture holding capacity and hydraulic conductivity of soil were also altered. On consideration of available N, P, K, Ca, Mg and organic carbon contents the soil at NS had emerged as generously fertile followed by soil at SS and CS in sequence.

2.3.1. Location specific soil appraisal

A. Area near to outer channel of the lagoon at Bhusandpur location

Bhusandpur (0.85 km^2) is located at 85^0 28′ 20″ N and 20^{0}1′ E, near to northern sector and dredged Magarmukh channel of Chilika.

Soils were fine textured and marginal to moderately acidic in reaction while salt content widely varied. The soil of the area at <100 m distance was little more acidic in reaction than the soils at 100 - 200 and > 200m distances away from Chilika. On visualization of salt stress distribution (Plate 2) and its subsequent effect on plant growth an exhaustive estimates of salt concentration at 1:2 (EC_2) and at saturation (EC_e) soil moiotura level both at surface (0-0.2m) and sub-surface (0.2-0.4m) depths were carried out during peak pre-monsoon period. The stress was unevenly distributed across the space irrespective of depths (Fig. 5). It was maximum at north-east corner which is close to the brackish water source and may thus reflect the influence of lagoon in that

Plate 2: Salt stress patches in Bhusandpur area

area. Classification of soil in different salinity classes revealed that the salinity (EC_2) of class III was prevailed along the edges of the sampling location but no such trend was vivid in EC_e. The assemblage of low saline (class II) to saline (class IV - EC_e) soils was marked at south direction.

High soil moisture level at north - west to west corners of the area and relatively low moisture content at southern part was evident (Fig. 6). Notably the area along the edges of north to west sides of the area was good to very good in field moisture capacity and found appropriate to grow pulses in residual soil moisture preceded by rice during monsoon. The moderate to high value of soil moisture at saturation in those corresponding sites also indicate the suitability of growing rice or other high water consuming crop as well.

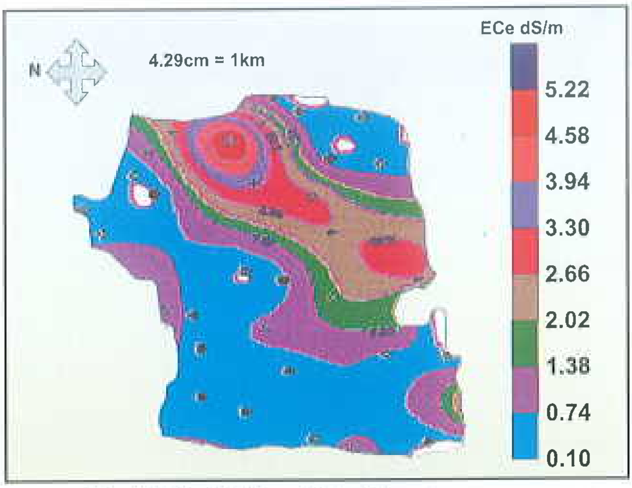


Fig 5: Salinity distribution in Bhusandpur area

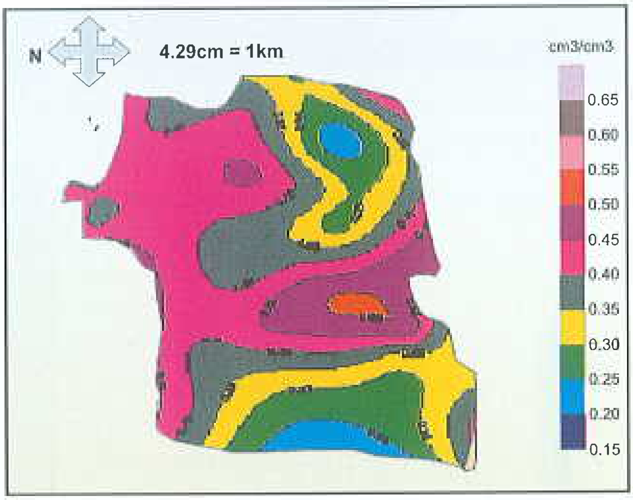


Fig 6: Soil moisture variation in Bhusandpur area

B. Area adjacent to the lagoon at Kalupadaghat location

Area selected at Kalupadaghat covers 0.835 km^2 adjacent to the lagoon and lies between 19^{0}52′42″ N and 85^{0}24′53″ E.

Characteristically the soil was coarse textured, high to moderately acidic in reaction (pH 4.2 - 6.4) and low to medium in salt content though the area remains empty after growing paddy in monsoon. Site specific salt patches were find. These occurred without revealing any consistency with respect to the distance apart from the lagoon

C. Area away from the lagoon at Ranpur Tehsil

Places 10 – 15km (radial distance) away from the lagoon are on laterite belt, interrupted with Plinthite mines and partly used for double cropping. The area has been cultivated by pumpkin, tomato, ladies finger, beans, pulses, maize, groundnut, sunflower, sesame etc after paddy during monsoon. Soil depth varies from 0.05 to > 1m. Soils are being put up after digging out the laterite slabs to make the depth effective for growing crops (Plate 3). However the soils were non saline, slightly acidic in reaction and low in organic carbon content (Table 7). Salinity gets enriched from wet to dry periods but not reached the level harmful for crops.

Plate 3 : Displacement of plinthites by soil in Ranpur area

2.3.2. Relationships among parameters

A. Establishing relationships between salient soil parameters

i) Soil Salinity

Soil EC_e didn't show any relation with soil water either at field capacity (θ_{fc}) or at saturation (θ_s). But these in conjunction with EC_2 showed a significant relation with EC_e (Table 2). The EC_2 and EC_e both were found interrelated separately for two soil

Table 2 : Relations between ECe and relevant parameters

Variable, x (EC in ds/m & θ in cm³/cm³)	*Expressions*	*R^2*	*F- ratio (significant at 0.01 level)*
At 0-0.2 m depth	1) 0.13 + 2.34 x2)	0.84	235.56
EC_2	2) $0.34x^{0.95}$	0.78	-
EC_2, θ_s	$0.58 + 2.36x - 0.68x_1$	0.85	117.57
EC_2, θ_{fc}	$0.45 + 2.39x - 0.93x_1$	0.85	119.59
At 0.2-0.4 m depth	1) 0.28 + 1.68x	0.71	105.64
EC_2	2) $0.37x^{0.92}$	0.71	-
EC_2, θ_s	$0.64 + 1.67x - 0.50x_1$	0.71	52.02
EC_2, θ_{fc}	$0.33 + 1.68x - 0.13x_1$	0.71	33.96
At both depths	1) 1.99x + 0.21	0.81	338.33
EC_2	2) $2.14x^{0.83}$	0.79	-
EC_2, θ_s	$0.49 + 1.98x - 0.41x_1$	0.78	155.19
EC_2, θ_{fc}	$0.48 + 2.02x - 0.72x_1$	0.79	162.37

depths and for the whole as well. These relationships could be utilized as devices to estimate actual salt content of soil at any time in that region.

ii) Soil hydraulic parameters

Applying the concept of three region Campbell (TRC) model the unsaturated hydraulic conductivity (K_h) at macro and mesopore regions correspond to soil matric potential (Ψ) > 10 and < 316cm H_2O were estimated. In this approach the slope (b) of soil - water retention (θ at 0, 100, 200 and 300 cm H_2O) curve was estimated from Log(θ) – Log(Ψ) coordinate and then the K_h in cm/day was determined by following Campbell's expression $K_h = K_s(\theta/\theta_s)^{-\beta}$, where K_s is hydraulic conductivity at saturation and ß equal to 2b+3.

In a second approach, it was estimated by keeping the slope of Log(K) - Log(θ) coordinate system at ß. Relations between K_h with different logical soil attributes was evaluated. The Campbell expression of K_h displayed in Table 3 shows better relation with different soil parameters than others. This would help in selecting appropriate irrigation and water management strategies for growing crops.

Table 3: Relation between K_h (cm/day) with logical soil properties

Parameters, x in gm / 100gm	K_h - at different pressure head (cm H_2O)					
	Campbell expression Pressure in cm of water			Using slope of Log(K) -Log(θ) Pressure in cm of water		
	100	200	300	100	200	300
Coarse sand	$1.51e^{-0.072x}$, $R^2 = 0.17$	$0.24e^{-0.075x}$, $R^2 = 0.18$	$0.09e^{-0.076x}$, $R^2 = 0.21$	-	-	-
Fine sand	$0.005e^{0.181x}$, $R^2 = 0.23$	$0.001e^{0.18x}$, $R^2 = 0.23$	$0.0004e^{-0.156x}$, $R^2 = 0.19$	-	-	-
Silt	-	$0.001e^{0.1327x}$, $R^2 = 0.11$	$0.002e^{0.136x}$ $R^2 = 0.12$	$1.09x^{0.99}$, $R^2 = 0.11$	$1.37e^{0.094x}$, $R^2 = 0.12$	$0.98e^{0.098x}$, $R^2 = 0.13$
Organic Carbon	$0.93x^{-1.23}$, $R^2 = 0.13$	$0.17x^{-1.37}$, $R^2 = 0.16$	$0.01x^{1.42}$, $R^2 = 0.20$	-	-	-

2.3.3. Seasonal variation

A. Bhusandpur

Soil salinity (EC_e) rose to the tune of 1.12 - 1.89, 1.0 - 2.35 and 1.97 - 5.43 times at the places > 200, 100 – 200 and < 100m distances away from the lagoon from post to pre monsoon period respectively. The salt build up from 0 to 60 cm soil depth was not prominent even at <100m distance apart from the lagoon from January to March and a decreasing trend was vivid with the depth down in soil profile.

Soil pH varied from 5.9 to 7.8 up to 60 cm depth from January to May without showing any direction either with time or distance from Chilika.

B. Kalupadaghat

The salt stress (EC_e) was progressed by 1.0 - 2.5, 3.08 - 4.28 and 1.69 - 4.05 times at >200, 100 - 200 and < 100m distances away from Chilika in order from post to pre monsoon period. But soil pH changed unevenly within 4.2 - 6.4, in the profile. In both the areas, no significant change in other relevant soil parameters was marked.

2.3.4. Heterogeneity on space

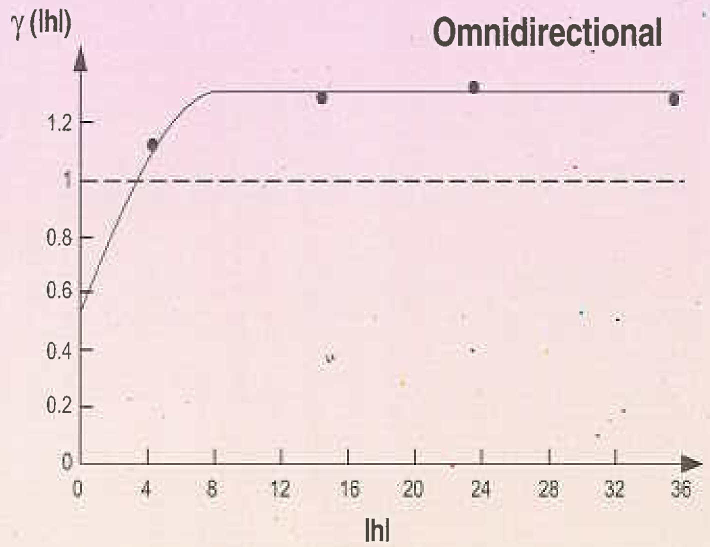
The soil properties changed abruptly over space and with time. Among the time dependent parameters only salinity a key component of assessing salt stress in coastal areas showed diverse nature on space during pre monsoon period. However the hydro-physical properties viz. saturated hydraulic conductivity (K_s 0.000078 – 0.217 cm/min), bulk density (0.75 – 1.836 Mg/m^3) and apparent EC_2 (0.25 - 1.25 dS/m) were also changed considerably across the sampling locations. The degree of scattering of these parameters is presented in Table 4.

Table 4 : Statistical measurement of degree of scattering

Estimate of degree of scattering	SHC (K_s), cm/min	BD (Mg/m^3)	Apparent EC_2, dS/m
Mean	0.33	1.49	0.712
Median	0.056	1.44	0.737
Standard deviation	0.501	0.16	0.457
Variance	0.251	0.026	0.21
Kurtosis	1.11	-0.601	-1.75
Skewness	1.55	0.93	-0.118

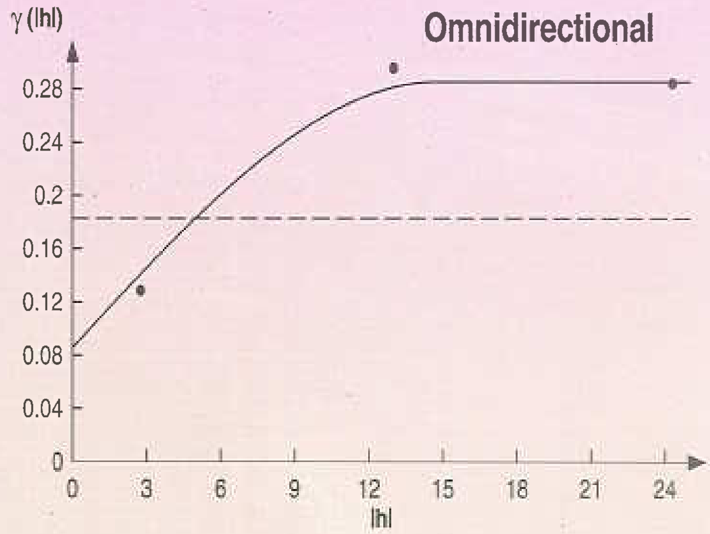
The probability density function P(u) = (i - 0.5)/n, where 'i' is the i^{th} no. of sample and 'n' is the sample number was used to produce fractal diagram, which showed that all parameters were normally distributed. Then from the population standard variation' the sample numbers required to determine the corresponding parameters were estimated. Thereafter the vertical averages of corresponding properties were used for fractal and variogram analysis. The variogram structures are illustrated in Fig. 7.

Applying geostatistics the shape of variability of soil properties on space was assessed. It is an excellent tool but tedious and hence it should be applied to those properties which could be played decisive role in area characterization for problem



Bulk Density

$\gamma(h) = 0.55 + 0.77$ Sph.8.082 (h), Anisotropy : 1 and goodness of fit := 1.001e-03



Apparent salinity (EC_2)

$\gamma(h)$: 0.08 + 0.2 Sph.14.79 (h), Anisotropy : 1 and goodness of fit = 1.5998e-02

Fig 7: Spatial structures of bulk density and salinity of soil

focusing and farm planning. With these considerations the tool was applied on bulk density, saturated hydraulic conductivity (K_s) and salinity (EC_2) of soil. The bulk density in alliance with K_s evaluates the soil compaction while EC_2 reveal the salt stress and these two salient parameter characterize the soils at Chilika neighborhood. The semivariances of the whole area were calculated and variogram were made for different lag intervals. The modeling of variogram contains mainly

A. Spherical model

$\gamma(h) = C_0 + C[1.5 (h/A) - 0.5 (h/A)^3]$ for $h \leq A$

$\gamma(h) = C_0 + C$ for $h > A$

where $\gamma(h)$= semivariance for interval distance class h, h = lag interval, C_0 = nugget variance ≥ 0, C = structural variance $\geq C_0$, $C_0 + C$ is the total variation or sill and A is the range of influence, and

B. Exponential model

$\gamma(h) = C_0 + C [1 - \exp(-h/A)]$

where A_0 = Range parameter, the effective range $A = 3A_0$, which is the distance at which the sill ($C_0 + C$) is within 5% of the asymptote.

The variogram (Fig 7) of BD progressively varied up to 8km while up to 13km in apparent salinity and then became almost parallel with X - axis. This variation was omnidirectional. In K_s the spatial variation was evident though not consistent enough to produce a shape for getting modeled. But the models of other two perfectly reveal the shape of variation and provide reliable tools for applying krigging. The krigging interpolation is so far available as a most cost effective option for producing confidant output of variable in not-sampled places. In this way the iteration of collecting and analyzing samples for carry out other agricultural activities can be avoided.

2.4. Water

The status of water was tremendously varied both with location and type of water resources, and also time of collecting water samples.

2.4.1 Quality of irrigation sources

In respect of groundwater quality no consistent trend was visible either with depth of groundwater table or with distance apart from the lagoon. Regarding salinity of the lagoon, it varies depending on sea water current, physiography and quantum of fresh water flow at a time. The salt stress distribution in lagoon water with season is presented in Table 5.

2.4.2. Seasonal variation

The salinity distribution of water resources (Table 6) indicates that among the surface sources the salinity of rivulet / canal excelled all followed by tube well at a depth of

Table 5: Salinity of Chilika lagoon at different sectors with time

Sectors of the lagoon	Time Salt stress in ppt		
	Monsoon	Oct. – Dec.	Nov. – March
Outer channel	3.0 – 5.0	No stress	≅ sea water
Northern sector	1.8 – 2.0	1.8 – 4.5	2.0 – 6.0
Southern sector	6.0 – 10.0	7.0 – 8.0	9.0 – 11.0
Central sector	1.8 – 2.0	1.8 - 4.5	8.0 – 13.0

Source: Chilika Development authority

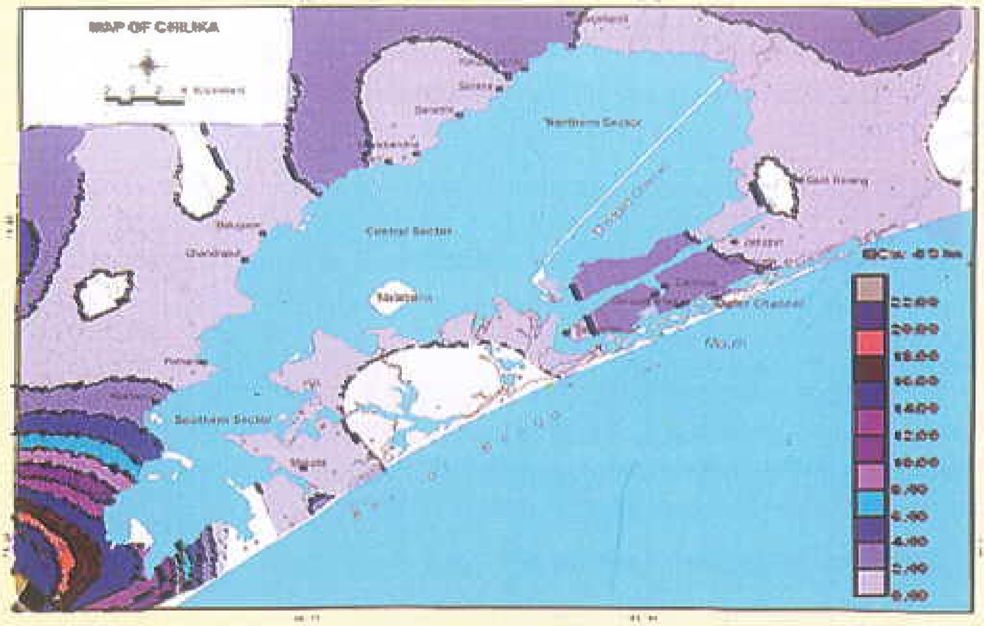
Table 6: Distribution of salt stress and pH in water resources with time

A. Salt stress

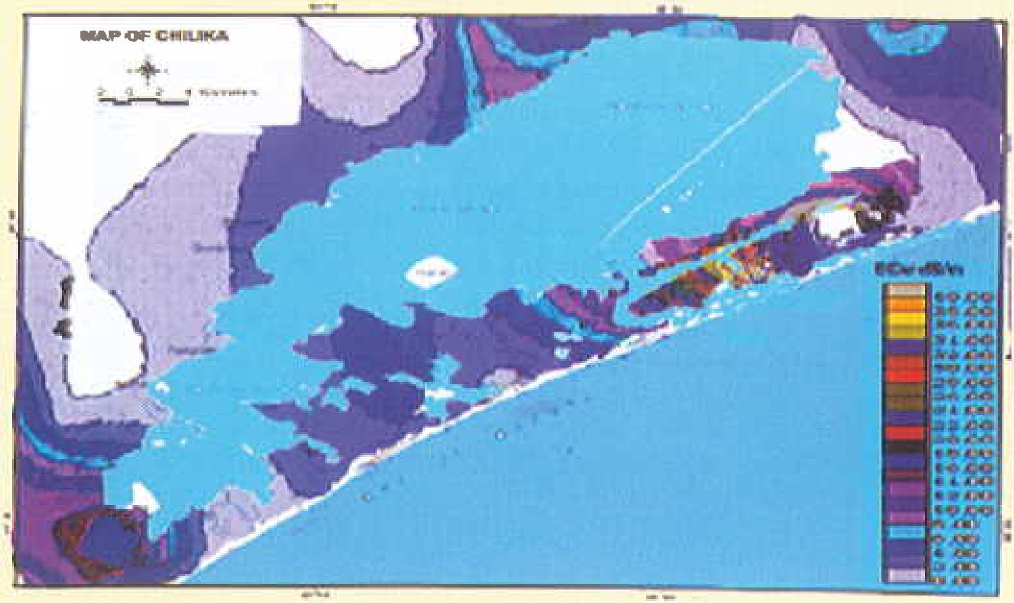
Water resources		Salinity (ECw) dS/m			
Type	Depth (m)	Post monsoon		Pre monsoon	
		Range	Mean	Range	Mean
Open well	≤ 7.5	0.10 – 5.70	2.12	0.50 – 9.50	2.98
	> 7.5	0.50 – 4.40	2.31	0.70 – 6.70	2.44
Pond	-	0.10 – 11.00	1.75	0.40 – 14.00	3.83
Rivulet / canal	-	0.41 – 10.30	3.77	1.40 – 15.90	4.40
Tube well	≤ 30	0.40 – 1.70	0.81	0.60 – 2.50	1.80
	30 – 152	0.39 – 4.40	2.53	2.10 – 5.10	3.40
	> 152	0.50 – 4.10	2.51	1.90 – 4.90	3.41

B. Alkalinity

Water resources		pH			
Type	Depth (m)	Post monsoon		Pre monsoon	
		Range	Mean	Range	Mean
Open well	≤ 7.5	6.30 – 8.80	7.49	6.20 - 8.60	7.78
	> 7.5	7.10 – 8.90	8.09	7.15 – 8.40	7.95
Pond	-	6.60 - 8.10	7.42	7.66 – 8.90	8.10
Rivulet / canal	-	5.20 – 8.30	6.97	7.30 – 8.60	7.89
	≤ 30	7.10 – 8.60	7.63	7.40 – 8.80	8.04
Tube well	30 – 152	7.30 - 7.78	7.46	6.90 – 8.30	7.75
	> 152	6.70 – 8.70	7.49	7.09 – 8.31	7.67



Post monsoon (October – December) Periods



Pre monsoon (January - March) Period

Fig 8: Salt stress contours of water resources in different time at Chilika neighbourhood

30 – 150m in post monsoon while pond in pre monsoon periods. The pH ranged between slightly acidic to slightly alkaline with lowest estimate registered in open well (>7.5m) and in pond during post and pre monsoon periods in general. Irrespective of sources the season wise salinity contours of Chilika neighbourhood (covering around 2800 km^2) were prepared and presented in Fig 8.

These categorically reveal that >50% to ≅35% of resources fall under less to moderately saline categories. Presence of saline sources was concentrated mainly at the tail end of the lagoon during post monsoon while it distributed in southern sector and near to sea water carrying split in pre monsoon period. Nonetheless the less saline zone prevails unlike the coastal zone of Bay of Bengal.

Comparing lagoon salinity (Table 5) with the salinity of water resources at its peripheral area in two distinct periods (Fig 8) evidently reflects its influences at different sectors, as the salt stress was relatively more at the precincts of southern sector and outer channel. While few saline patches were vivid at central and extreme end of the northern sector.

2.4.3. Location specific water quality appraisal

A. Area near to outer channel of the lagoon at Bhusandpur location

The salinity (EC) of sub-surface water varied from 4.7 to 7.6 dS/m within <100m, 3.5 to 4.9 dS/m at 100 - 200m and 2 to 3.5 dS/m at >200m distances apart from the lagoon, while the overall pH ranged within 7.3 to 7.7. The depth of groundwater table varied from the surface during November to January and goes below 2m afterwards.

Besides a distinct difference in water salinity (EC) at the same distance from the lake was also notable at different sites. Occurrence of some fresh water streams might have diluted the impact of salt water of the lagoon on groundwater sources. Along the coastal belt the presence of fresh water through rainwater infiltration in the sandy layer over the saline ground water is also reported by Gupta *et al.* (2000).

B. Area adjacent to the lagoon at Kalupadaghat location

The water table fluctuated from 0.6 - 1.5m from January to May, with lower depth (<1.0m from surface) prevalent in the area near to the lake (< 50m) and higher (> 1.0m) at >100m distance away from the lake.

The pH of the groundwater varied from 7.8 to 8.9 and EC 5 to 6.67 dS/m. But a zone of non saline water was also traced at the depth of 0.5 to 1.3m in the area 50 - 100m away from the lagoon. The pH of the water ranged from 8.1 to 8.5 but EC varied from 1.2 to 1.4 dS/m and indicating the prevalence of low saline zone in the area. Notably groundwater available in the area closer to the lagoon (> 50m) had pH 7.8 to 8.4 and EC 2.5 to 4.0 dS/m.

C. **Area away from the lagoon at Ranpur Tehsil**

The well – waters were low saline and almost neutral in pH throughout the period from November to February. The soil and water quality parameters are presented in Table 7.

Table 7: Important quality parameters of soil and water

Well id.	Water		Soil quality parameters			
	pH	EC dS/m	pH	Organic carbon %	Bulk Density Mg m^{-3}	Saturated hydraulic conductivity (K_s) cm min^{-1}
C_1	6.30 – 6.63	0.18 – 0.25	6.50	0.91	1.39	**0.38**
C_2	6.40 – 6.51	0.19 – 0.23	7.00	0.68	1.56	**0.01**
C_3	5.50 – 6.73	0.29 – 0.31	7.20	0.28	1.24	**0.15**
C_4	6.20 – 6.52	0.10 – 0.36	6.30	0.35	1.23	**0.04**
C_5	6.73 – 7.00	0.20 – 0.48	7.30	0.23	1.36	**0.19**
C_6	6.60 – 7.66	0.10 – 0.57	6.80	0.34	1.61	**0.01**
C_7	6.90 – 8.03	0.10 – 0.43	7.10	0.27	1.25	**0.18**
C_8	6.40 – 7.91	0.10 – 0.45	7.20	0.51	1.35	**0.20**
C_9	6.60 – 7.50	0.10 – 0.35	7.10	0.32	1.32	**0.21**

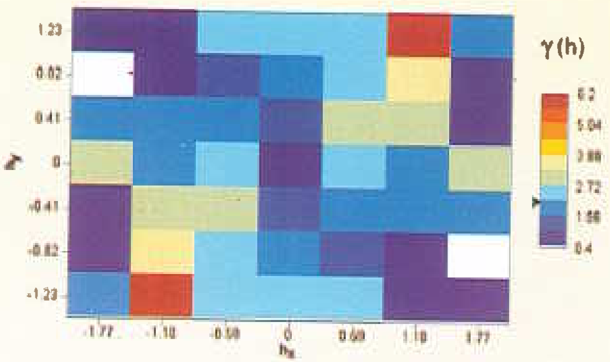
2.4.4. Spatial variability analysis

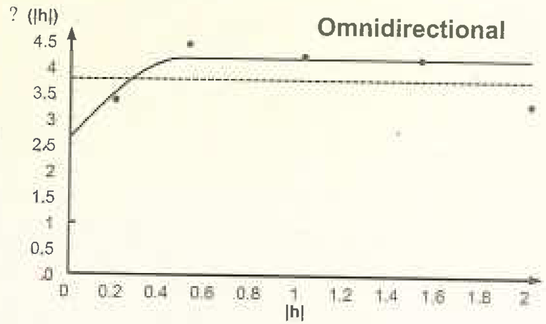
The ECw was normally distributed on space in both the periods. This was utilized to determine sample numbers required for precise estimation of the corresponding parameter at different levels of confidence as narrated below:

Variation of salt stress both with seasons and on space were studied geostatistically for its convenient utilization in planning and management of natural resources. On the basis of nos. of sampling locations and the area coverage, the variogram analysis was carried out in two specific viz. north – east and south – west directions. The variogram surface maps (Fig 9) supplies the information on nature of variation of the respective parameter and allowed to identify the anisotrophy quickly and accurately.

Maps of semivariance in every compass direction (the center marks the origin of each variogram) allowed the axis of maximum variation to be easily identified.

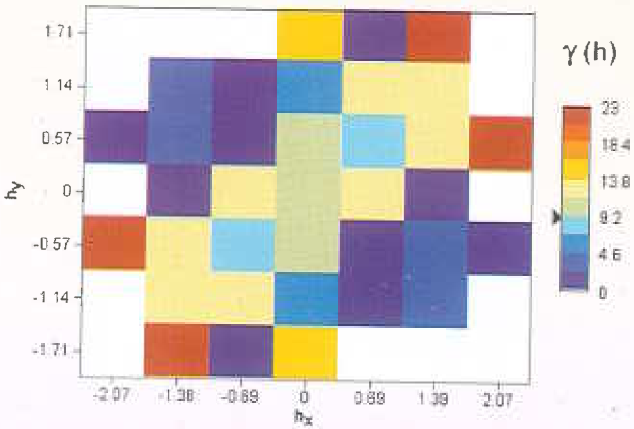
In all cases after nugget the semivariances increased gradually with lag distance up to 0.58km in post monsoon, decreased thereafter, and followed a plateau region in north-eastern side. But the enhancement with lag interval was not appreciable (indicating

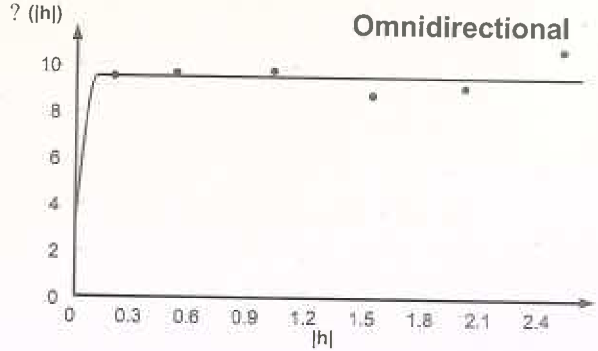




$\gamma(h) = 2.64 + 1.55$ Sph.0.4898 (h)
Anisotropy : 1 and goodness of fit : 1.5506e-02

POST MONSOON ECw in NORTH – EAST DIRECTION





$\gamma(h) = 3.10 + 6.40$ Sph.0.11 (h)
Anis: 1, Indication of goodness of fit : 5.4898e-03

PRE MONSOON ECw in NORTH – EAST DIRECTION

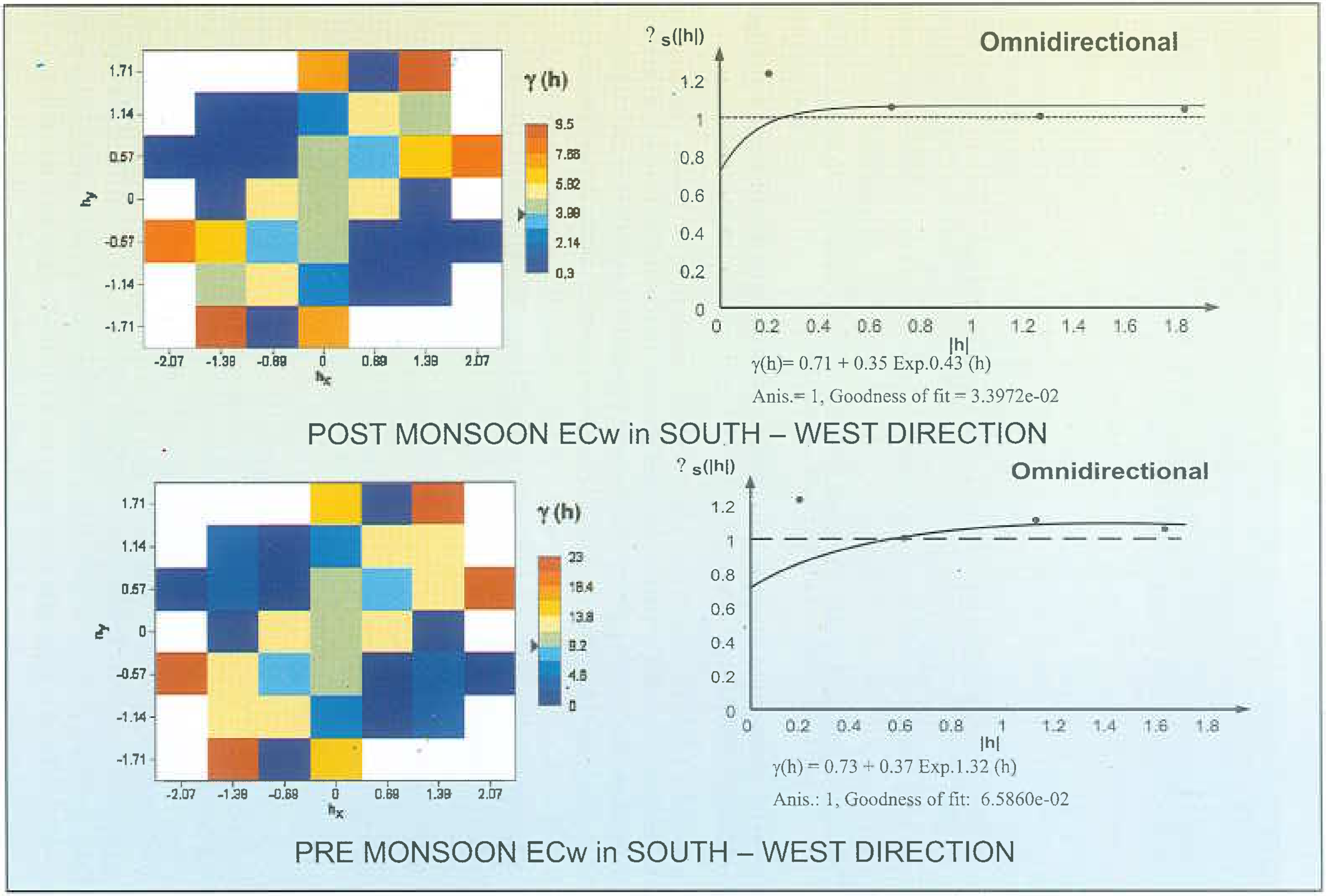


Fig 9: Variogram of salt stress in water resources at Chilika neighbourhood

Table 8: Estimation of sample numbers for estimating ECw at different levels

Level of confidence	Northeastern direction w. r. t. Chilika lagoon					
	Post-monsoon period			Pre-monsoon period		
	Sample nos. with different per cent of best estimate			Sample nos. with different per cent of best estimate		
	10% d	15% d	20% d	10% d	15% d	20% d
0.01	253	112	63	428	190	107
0.05	146	65	36	247	110	62
0.10	103	46	26	174	77	43
0.50	17	8	4	29	13	7
Southwest direction w. r. t. Chilika lagoon						
0.01	1636	727	409	1139	506	285
0.05	947	421	237	659	293	165
0.10	667	297	167	465	206	116
0.50	112	50	28	78	34	19

'd' is the per cent best estimate of the sample population

low level of variation) in pre monsoon period - ECw. It virtually followed a straight line with slight decrease and increase at 1.5 - 2.0 and > 2.4km lag distances.

But in south - west direction it was started from nugget to up to 0.2km lag distance and thereafter decreased progressively and became horizontal at 0.5 and 0.7km lag distances in general under post and pre monsoon periods. Besides the spatial structure (best fit model) under south - west direction was exponential while it was spherical in other side.

The depiction of spatial structure of water resources salinity (Fig. 9) indicates the type of variability existing and the dependence and relation of the parameter with time and also across the locations. Furthermore the modeling of variogram furnishes the basic information vital for applying krigging interpolation technique. With the help of this technique the soil or water property of non-sampled or difficult locations can be precisely estimated.

3. FARMING STRATEGIES

Appraisal and assessment of natural resources evidently revealed that two soil characteristics i.e. texture and salinity, and only salinity of water sources were differentially distributed on space. The hydrology of the area also varied from one to other location. Actually soil texture along with lithology indicates the existence of aquifer while quality reveals its usability, and recuperation rate reflects the availability of water in the aquifer. These in combination with relevant soil attributes, local preferences for growing crops were used, to determine the crops suitable to be grown and different farming strategies feasible to be adopted. Practice of these will help to improve production scenario of the entire area at the vicinity of Chilka.

3.1.1. Farm planning for whole area

In the Northern part of the lagoon, the faint sign of soil salinity along with availability of low saline water resources (Fig 8) indicate their preferences to grow moderately salt tolerant crops like tomato, chilli, maize, cucumber etc. These could be taken up with recommended crop oriented package and practices during rabi and summer seasons. Occurrence of saline water sources at southern part could have been utilized by growing spinach, sweet palak and the like. The pulses like greengram, horsegram and blackgram can also be grown after monsoon paddy in residual moisture, where soil has fine tilth and moderate degree of water holding capacity as conspicuous at northern side of the lagoon (Table 1). During pre monsoon, the salt stress was relatively high at southern sector, near to sea water carrying split and visible in patches at the area near to central and terminal end of north side of Chilika. Therefore after monsoon moderate to high salt tolerant crop like barley, safflower, beet, sugarbeet, cotton, tomato, chilli can be grown without taking any preventive measures for salt stress in those areas (Fig 8).

3.1.2. Location friendly farm planning

A. Area near to outer channel of the lagoon at Bhusandpur location

The status and diversified occurrence of salt patches along with soil moisture suggest that high water requiring and medium salt tolerant crops are feasible to grow at the north and north-west corner of the area during rabi and summer season (Fig. 10). Based on salt tolerance limits of crops (Maas, 1990) it has been found that

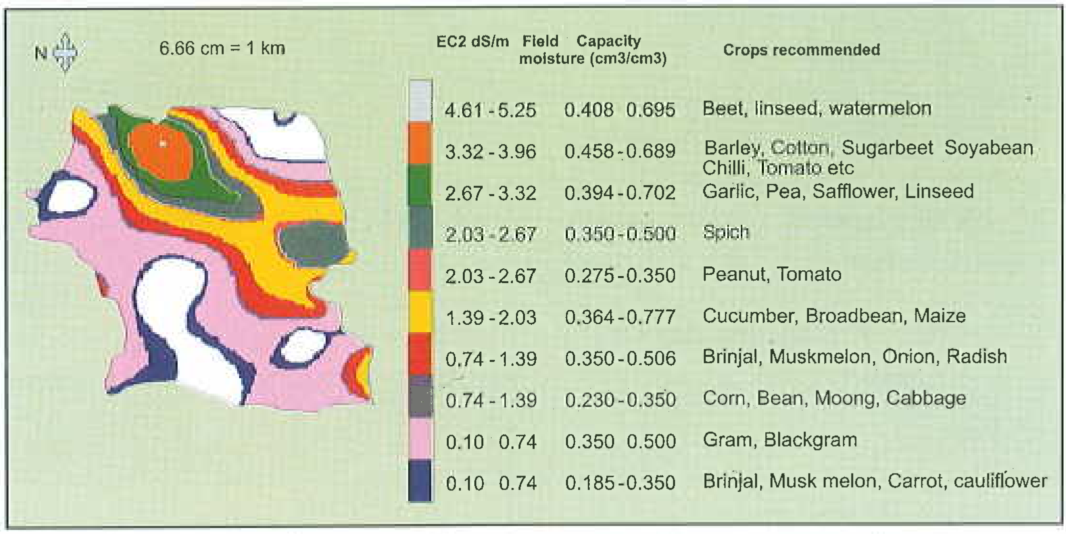


Fig. 10: Salinity and soil moisture specific crop planning for Bhusandpur area

the saline patches with relatively less water retention capacity are suitable for barley, safflower, sugerbeet etc at north - central to north – eastern part of the area. Besides the feasibility of growing vegetables e.g. chilli and tomato (tolerant to salinity) is large at the extreme end of north-east to eastern parts of the area. Rests are suitable to grow any crop subject to availability of water for irrigation during post monsoon period.

B. Area adjacent to the lagoon at Kalupadaghat location

The groundwater status, soil salinity, light texture and related characteristics together indicate for developing tube well of suitable depth beyond 50m away from the lagoon. This would be useful to supply non saline irrigation water during post monsoon period. This area has been found favourable for cultivating any crop after Kharif rice subject to availability of the water as salt concentration was below critical level. Besides the lithogical attributes suggests for creating small water harvesting structure at or within 3m depth for tapping non-saline water to deal with water scarcity for irrigating crops after monsoon.

C. Area away from the lagoon at Ranpur Tehsil

The area is dotted with small wells surrounded by variety of crops like pumpkin, tomato, ladies finger, beans, pulses, maize, groundnut, sunflower, sesame etc. The salt concentration of well water was below the permissible level of crops and hence it has been used for raising crops during post monsoon period.

The capacity of well depends on the extent of area covered by supplying water though the estimate varies with seasonal change of recharge rate from November to February. However by assuming 7cm water per application as normal practice (in border method) and frequency of application (determined from hydraulic conductivity of soil), the area under different wells were estimated and displayed in Table 10. The mean of all months were considered as ultimate command area of well and displayed in Table 11.

Table 9: Water transmission status of different well – fed area

Area description	Water transmission status in soil stratum (K_s in cm min^{-1})		
	Rapid	**Slow**	**Moderately Slow**
Grouping of well – fed area under different soil	**C1, C8, C9**	**C3, C5, C7**	**C2, C4, C6**

Table 10: Command area estimate as per water availability in different wells

Well Id.	Area, m^2	Depth, m	Recharge Rate, m^3/day	Amount after loss, m^3	Increase in water level, m	Classification of recharge rate	*Command area, m^2
C1	7.26	5.10	9.15	8.05	1.26	Moderate	115.00
C2	4.14	4.10	11.18	9.84	2.70	Rapid	140.52
C3	9.45	3.50	10.57	9.30	1.12	Slow	132.82
C4	11.77	3.20	7.17	6.31	0.61	Slow	90.11
C5	0.22	3.80	0.27	0.24	1.22	Slow	3.37
C6	13.72	3.20	27.02	23.78	1.97	Moderate	339.68
C7	7.62	4.50	14.99	13.19	1.97	Moderate	188.38
C8	9	4.50	20.69	18.21	2.30	Rapid	260.13
C9	1.59	5.00	4.54	3.99	2.86	Rapid	57.01

* Command area estimated by considering 7 cm irrigation per application at every day

Here the peasants prefer to cultivate their land first for seasonal vegetables and then other crops like pulses, cereals etc. Keeping this in mind and considering water requirement of different vegetables, pulses, spices, oilseeds and cereals (ICAR, 1987), the following farming strategies have been formulated.

In general 6.0cm water per application is sufficient for growing maize, oilseeds and vegetables and 3.5cm for chilli, onion, spices and pulses. Assessing percolation loss through soil strata, the irrigation supply was planned and accordingly the command area under different wells was estimated. In this way the use efficiency of irrigation water can be modified.

Strategy 1 - For growing only seasonal vegetables, 60 cm water per vegetable crop for the season @ 6cm per irrigation is required. On accounting the water loss through runoff, deep percolation and conveyance, 7cm per application (daily) is necessary and accordingly the command area was determined and presented in Table 11. But the estimate will differ if the area cultivate for chilli, spices or pulses. It will enhance to the tune of 1.4 times more than the estimates presented in Table 11.

Strategy 2 – Use the land at 6 : 4 basis, (60% for vegetable and rest 40% for oilseeds and spices due to relatively high market value of the vegetables) the command area would be extended by 16% over the present estimate. In this way the judicious use of land and water can be achieved.

Table 11: Extent of well – command area for different utilization options

Command area, m^2							
Well id.	Esti-mated comm-and area	7 cm water as per soil water flow	As 6 : 4 ratio			@ 4 cm per irrigation to meet crop water requirement	@ 3 cm per irrigation to meet crop water requirement
			@ 7 cm per irrigation for 60% coverage	@ 5 cm per irrigation for 40% coverage	Total area		
*C_1	115.00	115.00	69.00	64.40	133.40	201.25	268.33
◆C_2	140.52	281.03	168.62	157.38	326.00	491.81	655.75
C_3	132.82	398.45	239.07	223.13	462.20	697.29	929.72
◆C_4	90.11	180.21	108.13	100.92	209.05	315.37	420.49
⅄C_5	3.37	10.12	6.07	5.66	11.73	17.70	23.60
◆C_6	339.68	679.36	407.62	380.44	788.06	1188.88	1585.17
⅄C_7	188.38	565.15	339.09	316.48	655.57	989.01	1318.68
*C_8	260.13	260.13	156.08	145.68	301.76	455.24	606.98
*C_9	57.01	57.01	34.21	31.93	66.13	99.77	133.03

Note: Estimation was made by supplying irrigation at *one day, at ◆alternate day and at ⅄three days interval

<u>*Strategy 3*</u> - Growing only low water requirement crop during rabi and summer seasons the command area of the well could be further enhanced (to the tune of 0.75 to 6.0 times) as follows:

3.2. Projected productivity scenario

The aim of the effort was to improve production by effective utilization of soil and water in the area in and around Chilika. The typical characteristic of it is easy accessibility to go into the lagoon for fishing shrimp or prawn which is more remunerable than farming. This is also persistent because of less investment and more return compared to other means of livelihood. Therefore in farming those interventions with minimum effort would hold promise in improving production of the salt afflicted water logged coastal area.

Presently 0.85km² land in Bhusandpur and 0.835km² in Kalupadaghat are solely cultivated for paddy during monsoon and a small portion of it is being used for growing rabi crops mainly pulses. However by following this resource based suggested strategies i.e. 1) use of land potential and 2) tapping of good aquifer by developing water harvesting structures, at least 30% of land (which are otherwise left barren) can be brought under cultivation during rabi / summer seasons. Besides modified use of irrigation sources and selecting suitable crops would hold promise to improve the production level of irrigated area. The productivity scenario of the targeted area is projected in Table 12. For Bhusandpur the yield was estimated by considering a break up of 30% area as 30 : 40 : 20 : 10 for pulses (gram, blackgram,

Table 12: Area specific projected yield scenario in the neighbourhood area of Chilika

Location	Area focused, ha	Present practice	Present production, t		Excess production due to intervention, t	Overall productivity scenario, t
Bhusandpur	83.5	Monsoon paddy	141.95		84.42	226.37
Kalupadaghat	85	Monsoon paddy	127.5		127.5	255
Ranpur Tehsil	5.5	Paddy - vegetables	Kharif 9.62	Rabi & Summ er25.68	4.62 (by 16 to 20% increase of area)	39.92

pea, moong) : vegetables (cucumber, sugarbeet, chilli, tomato etc) : cereals (maize, barley): oilseeds (safflower) @ 0.7, 5.0, 1.5 and 0.7t/ha in sequence. But in Kalupadaghat owing to low soil moisture content but relatively low salt stress both in soil and water sources, creation of water harvesting structures is the only way out for growing crops in succession of rice during monsoon. Considering use of these water sources for growing high value crops e.g. vegetables, the vegetable yield was calculated and presented in Table 12.

In the area under Ranpur Tehsil by adjusting irrigation supply in tune with type of crop to be grown, 16 to 20% of the present area covered could be easily enhanced under each well irrigation system. Besides by following simple management practices a 13% more yield can be achieved from the existing setup.

4. SALIENT FINDINGS

The study provides a comprehensive view on soil, water and hydrology of the area at the neighborhood of Chilika lagoon in Orissa. It unravels

- Potentials and constraints of soil and water resources
- Provides tools to assess soil salinity or moisture *in situ*
- Offers variogram models for spatially varied important soil and water quality attributes and thereby the devices for determining the respective parameter
- Classification and characterization of land resources with respect to gravity of salt stress in cropping seasons

- Farming strategies for promoting integrated use of resources
- Giving a variety of location friendly options for improving production.

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