GEOINFORMATICS SUPPORT FOR INFORMATION BASED AGRICULTURE: A CASE STUDY OF ARID TRACT OF PUNJAB

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ABSTRACT

Information based agriculture (IBA) includes matching of agronomic practices with soil and water characteristics and their spatial variability for enhancing productivity. An attempt was made to derive agriculture management zones based on soil and water characteristics for sustainable agricultural production in Mansa district (Punjab, India). Based on physiographic analysis and semi detailed soil survey of the area was undertaken through interpretation of IRS 1C LISS-III data and the soil map was finalized on 1:50,000 scale. Georeferenced surface (0–0.15 m) soil samples from 208 sites were collected from dominant soils of the district developed on various physiographic units to study the spatial distribution of available phosphorus (P) and potassium (K). Georeferenced ground water samples from 271 working tube wells were also collected to assess the quality of ground water for irrigation purposes. A spherical model was fit using least squares in the geostatistical analysis and used to krig the entire study area for soil nutrient status and ground water quality parameters. Interpolation by kriging produced digital maps showing the geographical distribution of soil (P and K) and water parameters (EC and RSC). Based on EC and RSC limits, ground water quality map was also generated. The krigged P and K maps indicated generally lower content of these nutrients in the south and south west of the study area as the soils are relatively coarser in texture and the quality of ground water is poor. Soil and ground water quality maps were integrated using Arc Info GIS to generate map showing varying degree (high, moderate and low) and type (salinity, sodicity and both) of sensitivity to secondary salinization indicating fine textured soils as highly sensitive and medium textured soils as moderately sensitive to development of secondary salinization. The resultant map was further integrated with map for available P and K to derive agricultural management zones depicting the combined influence of soil texture and ground water quality on soil nutrients (P and K). the derived map indicated that coarse textured soils irrigated by highly saline water had low nutrient contents as compared with their content in fine textured soils irrigated by good waters.

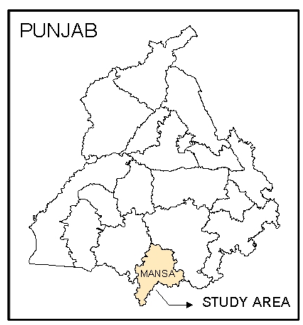
Introduction

Information based agriculture (IBA) is one of the most scientific and modern approaches to sustainable agriculture that has gained momentum in 21st century. It includes matching of agronomic practices with soil and water characteristics important for plant growth. IBA needs information about mean chemical characteristics of soil and irrigation water of relatively homogenous management units with same crop under similar management practices. These mean characteristics are obtained from soil tests for nutrient availability, soil survey and evaluation of quality of irrigation water.

Remote sensing and and geographical information system (GIS) offers appropriate techniques for identification and characterization of coherent agricultural zones depicting site specific ground conditions related to soil and water essential for IBA . The linking of soil physiography, water quality and nutrient status in the GIS domain helps in the development of a decision support system (DSS) which play a vital role in water and nutrient management (Sarangi et al, 2001). Keeping this in view, an attempt was made to arrive agriculture management zones based on soil and water characteristics for sustainable agricultural production in Mansa district (Punjab, India) using RS, GPS and GIS.

Materials and methods

The Mansa district,Punjab, India (Fig. 1) covering 2170 sq. km. forms a part of the Indo-Gangetic plain varying in age from Pleistocene to late Holocene period. The climate of the area is of continental character i.e. extreme summer followed by extreme winter. Generally moderate rainfall is followed by periods of oppressive and sultry weather. The Western Himalayas in the north and the Thar desert in the south and south-west mainly determine the climatic conditions. The soils of the area have an aridic (torric) moisture regime and hyperthermic temperature regime.



Data used and Methodology

The IRS-1C LISS-III geocoded satellite data of March, 1998 in the form of false colour composites was visually interpreted to identify and map physiographic units. Semi detailed soil survey was carried out following standard procedures (All India Soil and Land use Survey, 1970) and the soils were classified as per Soil Taxonomy (Soil Survey Staff, 1998) and Keys to Soil Taxonomy. The soil map of the area was prepared on 1:50000 scale and digitized using Arc GIS 9.0.

To assess the quality of ground water for irrigation, georeferenced ground water samples from 271 working tube wells were collected and analysed for various chemical constituents. On the basis of electrical conductivity (EC) and residual sodium carbonate (RSC), these waters were grouped into four categories viz., good, marginal saline to highly saline , marginal sodic to highly sodic and poor. To evaluate the soil fertility, georeferenced surface (0–0.15 m) soil samples from 208 sites were collected and analysed for available phosphorus (P) and potassium (K).

The maps showing the geographical distribution of soil (P and K) and water parameters (EC and RSC) were generated by interpolation via kriging using Arc GIS. Based on EC and RSC limits, ground water quality map was also generated by reclassifying and overlaying the EC and RSC maps. Soil and ground water quality maps were integrated to generate map showing degree (high, moderate and low) and type (salinity, sodicity and both) of sensitivity to secondary salinization. The resultant map was further integrated with soil available P and K maps to derive agricultural management zones map depicting the combined influence of soil texture and ground water quality on soil nutrients. The flow chart (Fig. 1) gives the methodology followed.

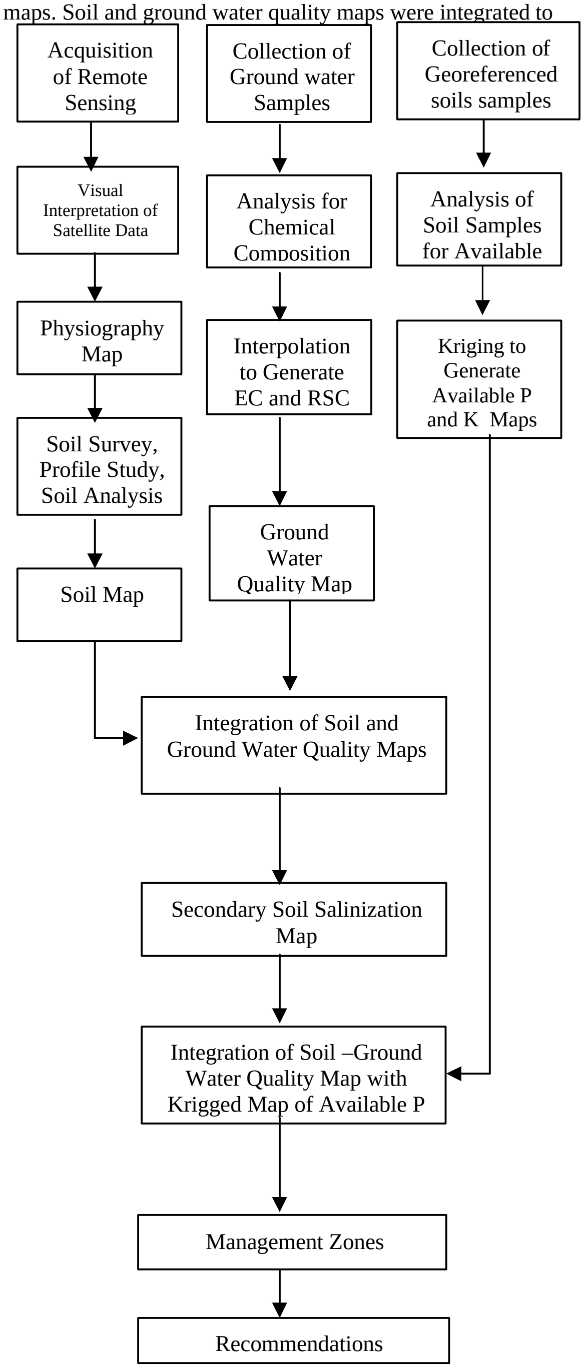
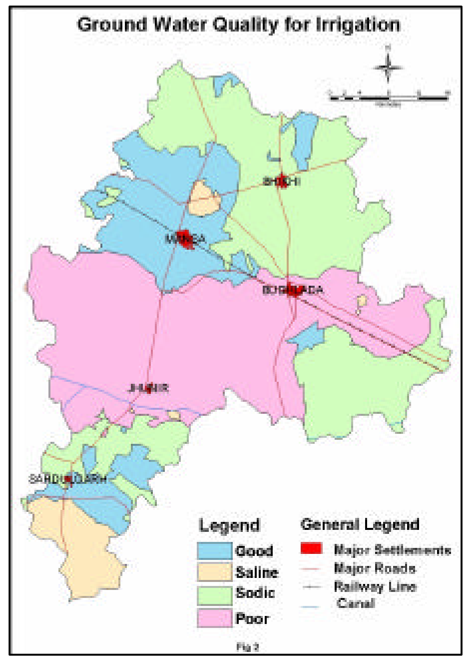


Fig. 1 Paradigm of the Approach

Results and discussion

Ground water Quality

The chemical analysis of ground water revealed that electrical conductivity varied from 0.31 to 10.95 dS m^{-1} and residual sodium carbonate (RSC) from 0 to 10 me l^{-1}. A salinity problem related with water quality occurs if the total salt concentration, as measured by EC, is high enough for salts to accumulate in the crop root zone to the extent that yields are affected. The ground waters having EC values more than 2.0 dS m^{-1} can cause soil salinization, if used for a longer span of time. Residual sodium carbonate (RSC) is the measure of alkalinity hazard, which refers to the excess of CO_3^{2-} and HCO_3^- over Ca^{2+} and Mg^{2+}. The bicarbonate rich waters can cause precipitation of Ca and Mg in the soil thereby increasing the relative proportions of Na ions.



The Interpolation produced digital maps showing the geographical distribution of water parameters (EC and RSC). Depending upon the EC and RSC values of ground water, the area has been divided into four ground water quality zones viz. good, saline, sodic and poor (Fig. 2). The southern part of the district had a sizeable area under poor quality of ground water. It was found that 56.1 % area of the district had EC less than 2.0 dS m^{-1} whereas, the 42.8 % area had salt concentration between 2-4 dS m^{-1}. Nearly 50 % area of the district is having RSC in the normal range i.e. <2.5 me l^{-1} whereas, in the remaining 38.9 and 10.8 % area of the district is having RSC in medium (2.5-5.0 me l^{-1}) and high (>5.0 me l^{-1}) category, respectively (Table 1).

As far as the spatial distribution of ground water quality in the area is concerned, it was found in the order of poor > sodic > good > saline (Fig. 2).

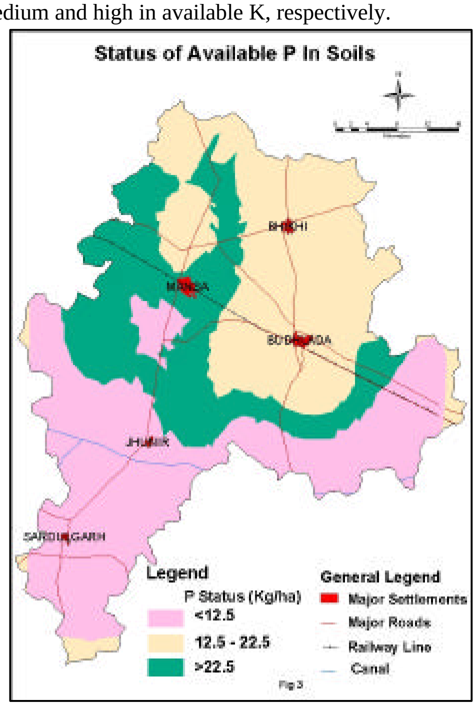
Physiography and soils

Based on interpretation of satellite data, the area has been divided into two major units viz. alluvial plain and sand dunes. The alluvial plain constitute a major portion of the district and has been further categorized as alluvial plain with sand cover having white or light tone (Ap1) covering 6.7 % area, alluvial plain, mixed tone (Ap2) covering 42.0 % area and alluvial plain, dark tone (Ap3) covering 47.0% area and alluvial plain salt affected, light tone (Ap4) covering 0.9% area of the district. The sand dunes occupying 2.1 % area are observed as low ridges within the alluvial plain.

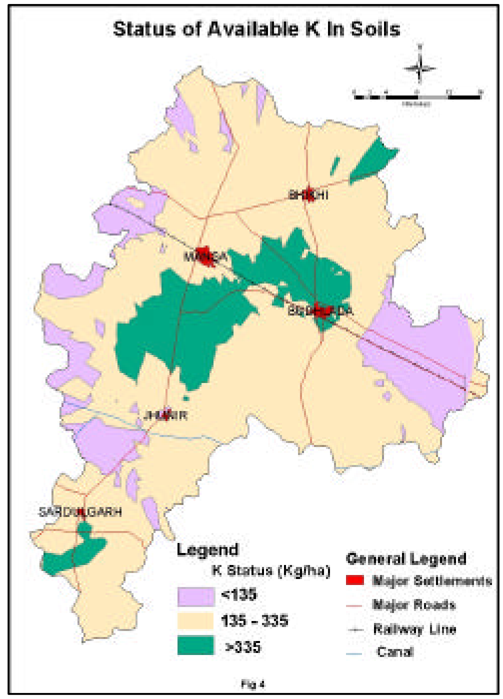
The soils of the area exhibit a great deal of heterogeneity with respect to texture depending upon the topographic position. The pH of soils varied from 8.5 to 9.0 indicating alkaline nature which is mainly due to calcareous parent material. The pH of the salt affected soils varied from 9.9 to 10.1. The EC of normal and salt affected soils varied from 0.08 to 1.00 dS m^{-1} and 4.04 to 11.23 dS m^{-1}, respectively. Calcium and magnesium are the dominant bases on the exchange complex followed by Na and K.

Soil Nutrients

The organic carbon ranged from 0.02 to 0.40 %, available P from 0.80 to 26.6 mg kg^{-1} and available K from 30 to 380 mg kg^{-1}. In general, available P ranged from low to medium, but high values of available P are also found in some part of the area. About 45 % soil samples tested low, 17 % medium and 38 % high in available P content. The available potassium content of these soils is generally medium to high, and only 3 % soil samples tested low in available K. About 52 and 45 % samples was found to be medium and high in available K, respectively.



A spherical model was fit using least squares in the geo-statistical analysis and used to krig the entire study area for soil P and K status. The krigged maps of P and K (Fig. 3 & 4) indicated generally lower content of these nutrients in the south and south west of the study area as the soils are relatively coarser in texture



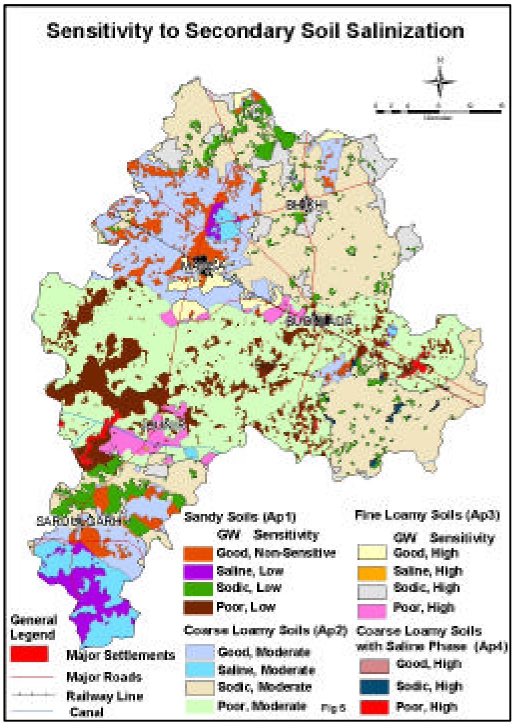
Generation of Sensitivity to Secondary Salinization Map

The main reservoir of salinity in the arid areas is ground water (Buchoci et al., 1968). the continuous use of ground waters in the study area for irrigation purpose will pose various types of hazards like: salinity, alkalinity or sodicity which may render many areas unproductive. The weathering processes result in accumulation of water soluble salts as they are not removed from the place of their formation because of lack of precipitation.

The soil and ground water quality maps were integrated using Arc Info GIS to generate map showing varying degree (high, moderate and low) and type (salinity, sodicity and both) of sensitivity to secondary salinization (Fig. 5).

The fine textured soils (fine loamy, physiographic unit Ap3) having low permeability and leaching, are more prone to secondary salinization if irrigated with saline, sodic or poor quality of water. These soils have been categorised highly sensitive to salinity, sodicity or both. The medium textured soils (Coarse loamy, physiography Ap2) have been categorised as moderately sensitive, whereas coarse textured soils of sand dunes and alluvial plain with sand cover pose low sensitivity to secondary salinization. The coarse textured soils, have low water holding capacity, thus salts are leached very easily. If irrigated land is well drained, enough water can move through the soil to leach the salts out of the top soil and prevent excessive build up of salts. However, in poorly drained or fine textured soils, where leaching is limited, the salts do not move downwards from upper soil layers, but instead accumulate over time facilitating secondary salinization. The salt affected soils were assigned high sensitivity to salinity and sodicity. Non sensitive areas represent soils having good ground waters and are not prone to secondary soil salinization.

The area statistics of different categories of sensitivity to secondary salinization is given in Table 2, indicating only 19.01 per cent area of the district (4.23 % of Ap1, 12.72 % of Ap2 and 2.06 % under Ap3) as non-sensitive as these area are irrigated with good quality water. Low sensitivity in coarse textured soils was in the order of poor>sodic>saline quality of ground waters and the moderate sensitivity in Ap2 soils upon the use of ground water as irrigation source, was in the order of sodic > poor > saline. The high sensitivity in the fine textured soils (Ap3) was in the order of sodic > poor > saline. It has been found that 28.3 and 27.5 % area of the district is moderately sensitive to secondary soil salinization in the coarse loamy soils of Ap2 if irrigated with sodic water or poor water, respectively.



Generation of Agricultural Management Zones

The resultant map of soil and ground water quality was further integrated with individual soil available P and K map to derive agricultural management zones map depicting the combined influence of soil texture and ground water quality on soil nutrients (available P and K). It showed that coarse textured soils irrigated by highly saline water had low nutrient content as compared to those irrigated by good waters.

The available P and K in the soils of different physiographic units was found in the order of Ap1 < Ap2 < Ap3. These results are in conformity with the findings of Verma *et al* (2006). The available P was lower in sodic soils than the normal soils. It is evident from Table 2 that soils of all physiographic units (Ap1, Ap2, Ap3 and Ap4) had higher area under deficient category (<12.5 kg / ha P) when irrigated with saline, sodic or poor quality water. This may be due to cation and anion effect on soil colloids, which had direct impact on available P in soil. The higher pH of sodic soils may cause precipitation of P, thereby, reducing availability of P in the soils. In certain pockets of Ap2 and Ap3 units, the soils had medium category of P when irrigated with sodic water. This may be due to the application of higher doses of phosphatic fertilizers under cotton-wheat rotation over the years.

The area statistics of available P in three-way form (soil family, ground water quality and available P) is given in Table 3. An area of 2.01, 6.46 and 1.04 % of the district have high P content in the soils of Ap1, Ap2 and Ap3 respectively when irrigated with good quality water. Similarly, application of poor quality of irrigation water to soils of Ap1, Ap2 and Ap3 had resulted in deficiency of P in 4.62, 11.72 and 1.59 % area of the district respectively.

The soils of all physiographic units (Ap1, Ap2, Ap3 and SA) had higher area under medium category (135-335 kg / ha) of K when irrigated with saline quality water. As the saline waters of Mansa district have considerable amount of dissolved potassium and irrigation with such waters results in higher amounts of available K in these soils. In addition to this, the higher content of available K is attributed to the prevalence of Illite - a potassium rich mineral in these soils (Bhangu and Sidhu, 1993). An area of 6.1 % is suffering from deficiency of available K in the coarse loamy soils of Ap2 when irrigated with poor quality water (Table 4). This may possibly be due to low caly content, thereby, lower release of K minerals in these soils. The deficiency of K was negligible in all other units.

Conclusion

The spatial data, thus generated would be helpful for location specific nutrient management. Keeping in view the quality of soil and ground water, it was recommended that improved cultural practices including land and water management with water supply from tube well (with respect to quality and timing) could be adopted in relatively homogenous zones of the district which have direct and positive impacts on the yield of crops.

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Table 1. Area under different categories of Electrical Conductivity(EC), Residual Sodium Carbonate (RSC) and Ground Water Quality

Parameter	Category	Area	
		Sq Km	%
EC ($dS\ m^{-1}$)	<2.0	1217.8	56.1
	2.0-4.0	928.2	42.8
	>4.0	24.4	1.1
RSC ($me\ l^{-1}$)	<2.5	1091.2	50.3
	2.5-5.0	844.4	38.9
	>5.0	234.6	10.8
Water Quality	Good	412.88	19.03
	Saline	121.22	5.59
	Sodic	797.24	36.74
	Poor	838.27	38.63

Table 2. Sensitivity to Secondary Soil Salinization upon use of Ground Water for Irrigation

Soil Physiography	Soil Family	Ground Water Quality	Sensitivity to Secondary Soil Salinization	Area	
				Sq Km	% of TGA
Ap1	Sandy (Sand, Loamy sand)	Good	Non-Sensitive	91.88	4.23
		Saline	Low	45.84	2.11
		Sodic	Low	90.27	4.16
		Poor	Low	182.25	8.40
Ap2	Coarse loamy (Sandy loam, Loam)	Good	Non-Sensitive	275.93	12.72
		Saline	Moderate	75.06	3.46
		Sodic	Moderate	613.31	28.26
		Poor	Moderate	597.00	27.51
Ap3	Fine loamy (Loam, Silt loam)	Good	Non-Sensitive	44.74	2.06
		Saline	High	0.30	0.01
		Sodic	High	90.07	4.15
		Poor	High	47.44	2.19
Ap4	Coarse loamy with saline phase	-	High	16.81	0.77

Table 3 : Available P in soils as a result of irrigation by different quality of ground waters

GW Category	P Category	Soil Family							
		Sandy soils (Ap1)		Coarse loamy (Ap2)		Fine loamy (Ap3)		Coarse loamy with saline phase (Ap4)	
		Area		Area		Area		Area	
		Sq km	%	Sq km	%	Sq km	%	Sq km	%
Good	**Low**	28.88	1.33	71.27	3.28	9.72	0.45	0.567	0.026
	Medium	21.84	1.01	70.76	3.26	12.50	0.58	0.000	0.000
	High	43.52	2.01	140.28	6.46	22.60	1.04	0.000	0.000
Saline	**Low**	37.58	1.73	48.07	2.22	0.29	0.01	0.000	0.000
	Medium	4.64	0.21	6.04	0.28	0.00	0.00	0.000	0.000
	High	1.29	0.06	6.25	0.29	0.00	0.00	0.000	0.000
Sodic	**Low**	44.02	2.03	194.78	8.98	6.50	0.30	2.793	0.129
	Medium	39.36	1.81	340.74	15.70	71.11	3.28	0.514	0.024
	High	8.76	0.40	67.34	3.10	12.56	0.58	0.873	0.040
Poor	**Low**	100.21	4.62	254.31	11.72	34.55	1.59	11.882	0.548
	Medium	28.76	1.33	136.46	6.29	10.99	0.51	0.191	0.009
	High	57.96	2.67	217.06	10.00	3.11	0.14	0.400	0.018

Table 4 : Available K in soils as a result of irrigation by different quality of ground waters

GW Category	K Category	Soil Family							
		Sandy soils (Ap1)		Coarse loamy (Ap2)		Fine loamy (Ap3)		Coarse loamy with saline phase (Ap4)	
		Area		Area		Area		Area	
		Sq km	%	Sq km	%	Sq km	%	Sq km	%
Good	**Low**	14.17	0.65	32.67	1.51	0.41	0.02	0.63	0.03
	Medium	75.04	3.46	222.41	10.25	30.26	1.39	0.00	0.00
	High	5.00	0.23	28.07	1.29	14.26	0.66	0.00	0.00
Saline	**Low**	0.46	0.02	1.45	0.07	0.24	0.01	0.93	0.04
	Medium	37.62	1.73	46.50	2.14	0.05	0.00	3.26	0.15
	High	5.59	0.26	12.69	0.58	0.00	0.00	0.00	0.00
Sodic	**Low**	15.36	0.71	75.37	3.47	2.65	0.12	4.08	0.19
	Medium	73.84	3.40	461.60	21.28	72.25	3.33	0.00	0.00
	High	3.22	0.15	67.61	3.12	15.52	0.72	0.00	0.00
Poor	**Low**	44.76	2.06	132.31	6.10	10.49	0.48	0.63	0.03
	Medium	121.38	5.60	356.51	16.44	29.91	1.38	0.00	0.00
	High	21.34	0.98	120.76	5.57	8.41	0.39	0.00	0.00