Journal of AgriSearch, 6(3):139-145
An Open Access International Peer Reviewed Quarterly
ISSN : 2348-8808 (Print), 2348-8867 (Online)
https://doi.org/10.21921/jas.v6i03.16216

Assessment of Groundwater Quality for Irrigation Purpose in Mansa District (Punjab, India) through GIS Approach

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ARTICLE INFO

Received on	:	30-07-2019
Accepted on	:	29-08-2019
Published online	:	01-09-2019

ABSTRACT

A study was undertaken to map the spatial distribution of different water quality parameters and generate water quality map for Mansa district using geo-statistical interpolator (Kriging). Geo-referenced groundwater samples were collected and analysed for different quality parameters *i.e.* pH, Electrical Conductivity (EC), Carbonate and Bicarbonate (CO_3^{2-}, HCO_3^-), Chloride (Cl^-), Total Hardness (Ca^{2+}+Mg^{2+}) and Sodium (Na^+) content; and Residual Sodium Carbonate (RSC) was calculated. Salinity and alkalinity hazards were evaluated using national and international standards and the overall, water quality was assessed to judge its suitability for irrigation purpose. Quality of groundwater for irrigation was found to be marginal in major part of district Mansa covering an area of 200156.7 ha (92.3% of its Total Geographical Area) which can be used for irrigation purpose only after some amelioration. Extreme salinity (EC>4 dSm^{-1}) and alkalinity (RSC> 5 meq l^{-1}) hazards were prevalent only in small patches in Sardulgarh and Budhlada blocks covering 26.7 and 2.9% of TGA of the respective blocks. Mixing of canal water with groundwater, use of suitable amendments, like gypsum, selection of appropriate crops and cropping systems should be in regular practice for improving the water quality in one hand and preventing further deterioration in other.

KEYWORDS

groundwater quality, irrigation, GIS, Mansa

INTRODUCTION

The quality of irrigation water is as important as its quantity. Suitability of groundwater for irrigation purposes depends upon the salinity, conductivity and hardness of water (Atekwand *et al.,* 2004). The kind and quantity of the salts present in groundwater depend partly upon the sources for recharge of the groundwater and the strata through which it flows. On the other part, increasing anthropogenic pressure and crop intensification are also imparting their adverse impact on water quality which is influenced by both non-point pollution from farming activities and point-source pollution from sewage treatment and industrial discharge as principal sources. High susceptibility of groundwater to pollution from natural and anthropogenic factors has been reported by Jain and Sharma (2000).

Application of poor quality of water in the field for irrigation is harmful to crop health and may also induce salinity and sodicity hazards in the soil in the long term. Therefore, quality assessment studies for irrigation water are gaining more importance now a day to identify different water management zones in an area for precise and sustainable distribution of the input.

The benefits of an integrated geographical information system (GIS) and a geostatistical approach to accurately model the spatial distribution pattern of irrigation water quality parameters are widely reported (Demir *et al.,* 2009 and Adhikary *et al.,* 2010). Among different interpolation techniques, Kriging is the most popular one for making optimal, unbiased estimates of regionalized variables at unsampled locations using the structural properties of the semivariogram and the initial set of data values (David 1977). The accuracy of interpolation methods for spatially predicting soil and water properties has been analyzed in several studies (Robinson and Metternicht, 2006; Safari, 2002).

Irrigation water quality assessments through GIS approaches have been attempted in different districts of Punjab also. Such assessments should be carried out on a regular basis to comply with the continuously changing constraints related to the quality of groundwater for irrigation purpose. Therefore, the present study attempted to assess and map the quality of irrigation water in the Mansa district of Punjab with the help of spatial variability maps of quality determining parameters generated using the interpolation technique in a GIS environment.

MATERIALS AND METHODS

Study area

Mansa is situated in the cotton belt of Punjab and therefore fondly called the "Area of white gold". It lies between the latitude of 29˚32'19" to 30˚13'00" north and longitude of 75˚09'49" to 75˚47'00" east and is spread over 2,171 sq. kms. The district is roughly triangular in shape and is bounded on the northwest by Bathinda, on the northeast by Sangrur, on the north by Barnala district of Punjab and on the south by Haryana State. It has five Blocks Mansa, Bhikhi, Jhunir, Budhlada and Sardulgarh and 244 villages. The climate of the district is more or less typical of Punjab plains. It has an extremely hot and dry summer season. The normal annual rainfall of Mansa district is 480 mm in 23 days which is unevenly distributed over the district. The southwest monsoon contributes about 83% of annual rainfall and rest 17% of the annual rainfall occurs during non-monsoon months of the year.

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Groundwater sampling and chemical analysis

Georeferenced groundwater samples from 138 running tube wells were collected during post-monsoon season 2013-14 (December-February). The samples were analyzed for pH, electrical conductivity, total hardness (Ca^{2+}+Mg^{2+}), total bi-carbonate (CO_3^{2-}+ HCO_3^-), chloride (Cl^-) and sodium (Na^+) quantitatively using standard methods (APHA, 1992). Residual Sodium Carbonate (RSC) was calculated using the formulae:

$$RSC\ (me/L) = (CO_3^{2-} + HCO_3^-)\ (Ca^{2+} + Mg^{2+})$$

The locations of water sampling sites were marked using Global Positioning System (GPS) (Fig. 1). The point file was created for the locations (x, y coordinates) of tube wells in Arc GIS and analytical data of each well point were attached as database.

Categorization of groundwater samples

Salinity and sodicity hazards were evaluated separately by USSL (Richards, 1954) and EEC classification (Lloyd and Heathcote, 1985), respectively (Table 1). The overall quality of groundwater for irrigation purpose was judged considering both EC and RSC (Sharma *et al.*, 2008) as mentioned in Table 2.

Table 1: Criteria for the classification of standard irrigation water

Criteria	Parameter	Value range	Suitability for irrigation
EEC classification	RSC (meq/l)	<1.25	Suitable
(Lloyd and Heathcote,		1.25-2.5	Marginal
1985)		>2.5	Unsuitable
USSL (Richards, 1954)	EC (dS/m)	<0.25	Excellent
		0.25-0.75	Good
		0.75-2.25	Permissible
		2.25-4.0	Doubtful
		>4.0	Unsuitable

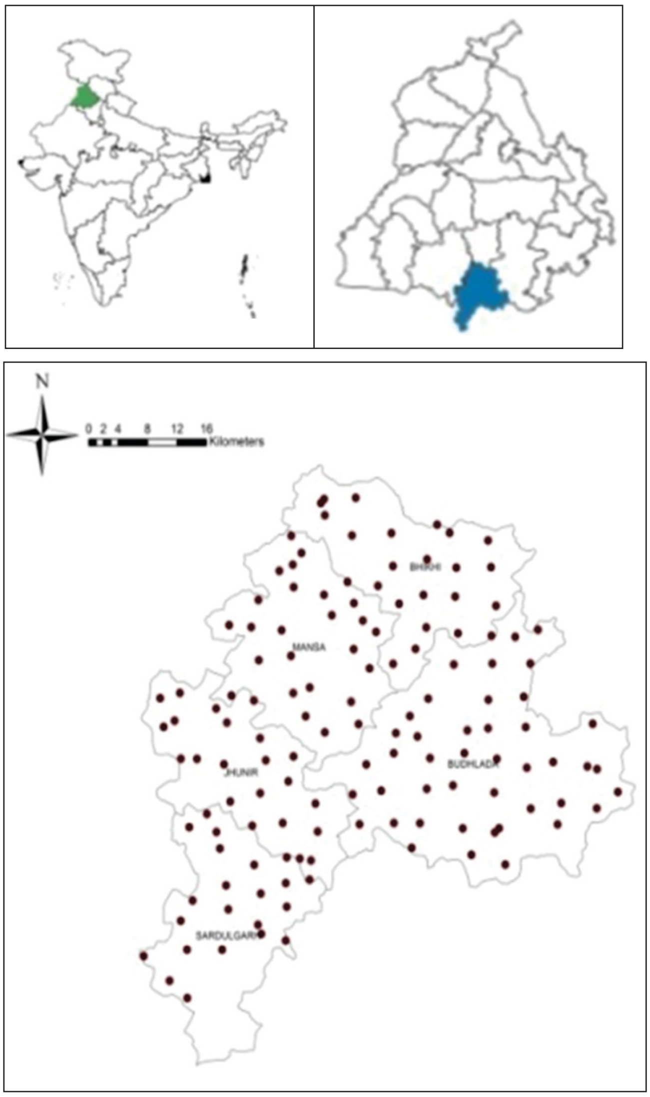

Fig. 1: Study area and groundwater sampling locations

Table 2: Rating limits for evaluating the suitability of groundwater for irrigation in Punjab

Category	Sub-Category		EC (dS m^{-1})	RSC (me L^{-1})	Suitability for Irrigation
I. GOOD	I	Good Non-Saline and Non-Sodic	<2.0	<2.5	Suitable for all conditions
II. MARGINAL	II a	Slight to Moderately Saline	2.0 - 4.0	<2.5	Suitable for coarse-textured soil/salt-tolerant crops with periodic monitoring of salt accumulation in soils.
	II b	Moderate to highly Saline	4.0 - 6.0	<2.5	Suitable after mixing with canal water.
	II c	Slight to moderately Sodic	<2.0	2.5 - 5.0	Suitable with recommended gypsum application
	II d	Moderate to highly Sodic	<2.0	5.0 - 7.5	
	II e	Slight to Moderately Saline-Sodic	2.0 - 4.0	2.5 - 5.0	Suitable after mixing with canal water and recommended gypsum application
	III a	Slight to Moderately Saline-Moderate to highly Sodic	2.0 - 4.0	5.0 - 7.5	Unsuitable for irrigation
III. POOR	III b	Extremely Sodic	<4.0	>7.5	
	III c	Extremely Saline	>6.0	<2.5	
	III d	Highly Saline_Sodic	>4.0	>5.0	

Geostatistical analysis and Water Quality mapping

Geostatistics deals with spatially autocorrelated data (Isaaks and Srivastava, 1989) that have a basic structure or spatial patterns which can be manifested in (semi) variogram analysis. (Semi) the variogram is a characterization of the spatial correlation of the variables under study and shows the relationship between the lag distance on the horizontal axis and the semivariogram value on the vertical axis. The semivariogram valueincreases from low to high values indicating higher spatial autocorrelation at the small lag distance (Nayanaka *et al.,* 2010). Theoretically, to calculate the semivariogram, the following formula is commonly used:

$$\gamma(h) = \frac{1}{2n(h)} \sum_{i=1}^{n(h)} [Z(xi) - Z(xi+h)]^{2}$$

Where,

γ (h) is the semivariogramvalue for the lag distance (h),

n(h) is the total number of the variable pairs separated by a lag distance (h), and

Z(x) is the value of the variable.

Spatial distribution of major quality parameters (pH, EC, total bi-carbonate, total hardness, sodium, chloride content, RSC)was mapped through geostatistical interpolation (Kriging) using Geostatistical Analyst Tool in Arc Map 10.3. Exploratory data analysis was performed to explore the data under study to check data consistency, removing outliers and identifying statistical distribution where data came from. Data transformation was executed wherever required before generating a prediction surface to reduce the skewness of the dataset and increase validity. Then, spatial variability maps for each of the parameters were generated using different types of Kriging in the combination of suitable models (Johnston *et al.,* 2001). Spatial dependence of groundwater quality parameters was judged on the basis of the classification suggested by Mehrjardi *et al.,* 2008 and Nayanaka *et al.*, 2010. The area under various levels of salinity and alkalinity was calculated from the prediction surface. Finally, water quality map was generated for the district by uniting spatial variability maps for EC and RSC in Analyst Tool in Arc Map and area under different categories of water was computed. Data associated with each of the sampling points were used to compute values and statistical parameters of groundwater quality for individual blocks of the district and the whole district.

RESULTS AND DISCUSSION

Status of irrigation water quality in Mansa district

The values of all the quality parameters varied widely within the district, even within the blocks (Table 3) because of the differences in the strata which feed a particular tube-well. The reaction of groundwater varied from near neutral to alkaline in all the blocks of Mansa ranging from 6.63 to 8.92 in the district. The average value of electrical conductivity was between 2 to 3 dS/min the district and its blocks except for Bhikhi, though the values for individual samples ranged from low to very high values. Considerably high values of EC in the groundwater samples indicated higher dissolution co-efficient of minerals present in the substratum. The

Table 3: Range of values of different water quality parameters in Mansa district

Blocks	Range of values	pH	EC (dS m^{-1})	Ca^{2+}+Mg^{2+} (me L^{-1})	Na^{+} (me L^{-1})	$CO3^{-2}$+$HCO3^{-}$ (me L^{-1})	Cl^{-} (me L^{-1})	RSC (me L^{-1})
Mansa	Minimum	6.77	0.96	2.35	5.87	3.00	1.60	-25.0
	Maximum	8.92	6.34	29.07	56.50	22.00	17.60	18.74
	Mean	7.46	3.16	9.60	23.32	8.92	7.38	-0.68
	SD	0.52	1.47	5.59	14.74	4.15	4.54	8.20
Jhunir	Minimum	6.63	0.38	1.53	8.91	0.00	1.00	-25.2
	Maximum	8.27	7.47	31.21	80.84	16.00	49.80	11.45
	Mean	7.33	3.07	12.04	30.53	9.13	13.37	-2.41
	SD	0.33	2.06	9.32	22.20	4.52	14.39	11.57
Sardulgarh	Minimum	6.97	0.53	1.70	4.35	4.00	0.80	-8.60
	Maximum	8.19	4.74	15.60	41.29	15.00	18.80	10.30
	Mean	7.46	2.25	5.92	19.80	8.60	6.97	2.92
	SD	0.30	1.34	3.68	12.02	2.89	6.02	4.53
Budhlada	Minimum	7.21	0.55	1.84	7.82	2.00	1.20	-24.3
	Maximum	8.58	7.08	30.60	104.52	16.00	41.60	13.65
	Mean	7.90	2.75	8.07	43.20	9.11	10.56	1.04
	SD	0.33	1.50	7.11	28.53	3.26	10.00	8.82
Bhikhi	Minimum	7.40	0.58	1.43	4.78	3.00	1.00	-7.59
	Maximum	8.63	3.50	14.59	29.55	13.00	12.60	9.57
	Mean	7.83	1.86	5.62	16.13	8.46	5.40	2.84
	SD	0.29	0.84	2.89	7.81	2.77	3.31	3.79
Mansa district	Minimum	6.63	0.38	1.43	4.35	0.00	0.80	-7.59
	Maximum	8.92	7.47	31.21	104.52	22.00	49.80	9.57
	Mean	7.64	2.64	8.28	29.07	8.89	8.99	2.84
	SD	0.43	1.53	6.60	22.81	3.52	9.11	3.79

concentration of total carbonate and bicarbonate was dominant over that of calcium and magnesium in most of the blocks. Therefore average RSC value was calculated to be positive in the district and most of the blocks (except Mansa and Jhunir) with an expected sodicity hazard. The total concentration of calcium and magnesium, i.e., the hardness of groundwater was within the usual range (0-20 meq/l). Sodium concentration was high in groundwater of Mansa with the highest mean value of 42.28 meq/l in Budhlada block. Standard deviation in dataset pertaining to each parameter varied depending on the level of local variation in point sources.

Spatial variability mapping

Logarithmic data transformation was executed for dataset pertaining to calcium and magnesium, sodium and chloride content in groundwater to reduce skewness and increase validity, whereas, no transformation was needed for pH, EC, total carbonate and bicarbonate and RSC dataset (Table 4). Spatial distribution of different groundwater quality parameters for irrigation purpose was mapped using geostatistical interpolator (Kriging). Types of kriging used, its combination with different models and associated statistical details are presented in Table 4. Spatial dependence of each of the parameters was judged bythe nugget and sill value of the variogram model (Table 4). Spatial dependence of EC was very strong (16%), whereas, that of RSC was moderate but tending towards weak class (68%). The near weak spatial dependence of the RSC has been manifested in the large nugget effect in the semivariogram model (Table 4) which is due to the high micro-scale variation and error (Santara *et al.*, 2008). Data related to pH value and; calcium and magnesium content in groundwater was found to be moderately dependent on their spatial distribution. In the case of sodium, chloride and total carbonate and bi-carbonate contents though the values for the same were in moderate, the near strong range (26, 30 and 30%, respectively).

Table 4: Methods used for mapping spatial variability of groundwater quality parameters for irrigation and associated statistical details

Statistical parameters	Water quality parameters						
	pH	EC	Ca^{2+}+Mg^{2+}	Na^{+} (me L^{-1})	CO_3^{2-}+HCO_3^{-} (me L^{-1})	Cl^{-} (me L^{-1})	RSC (me L^{-1})
Transformation	None	None	Log	Log	None	Log	None
Kriging type	Simple	Ordinary	Simple	Simple	Simple	Simple	Simple
Model used	Exponential	Exponential	Exponential	Gaussian	Exponential	Exponential	Exponential
Nugget	0.093117	0.35736	0.22000	0.20000	3.3000	0.30000	52.82738
Partial Sill (C)	0.10872	1.82836	0.30845	0.55000	7.7000	0.70000	24.15807
Nugget/Sill	0.46134	0.16349	0.41631	0.26666	0.3000	0.3000	0.6862
RMSE	0.3684	1.46848	6.43784	16.9500	3.25756	8.79350	8.13437
Spatial dependence	moderate	strong	moderate	Moderate, but tending to strong	Moderate, but tending to strong	Moderate, but tending to strong	Moderate, but tending to weak
Range (m)	0.35239	0.06336	0.11769	0.19029	0.05343	0.19689	0.12445
R^2	0.692	0.98100	0.86000	0.67700	0.98700	0.85000	0.54800

The correlation coefficient (R^2) between the observed value and model predicted values for each of the parameters was found to be above 0.5. The value was very high for EC and total carbonate and bicarbonate content (>0.9) whereas, comparatively poor for RSC (0.54).

From the spatial distribution maps of the groundwater quality parameters for irrigation purpose, the following observations were made. No area was found in the district with groundwater with pH below 7.0 or above 8.5, *i.e.,* the reaction of groundwater was tested to be neutral in the whole district. But, an increasing trend was observed in pH values while moving from western to the eastern part of the district (Fig. 2a).

In terms of salinity, groundwater was not excellent or even good (Table 1) in any part of the district. In 70099.3 ha area, groundwater EC was found only within the permissible limit (0.75-2.25 dS/m) whereas in 18365.2 ha area groundwater was highly saline (EC>4 dS/m) and hence unsuitable for irrigation purpose. In the rest part of the district, groundwater EC varied between 2.25 to 4 dS/m. groundwater salinity tends to be higher in the middle part of the district with some highly saline patches in Jhunir and Budhlada blocks (Fig. 2b). High salinity in groundwater of Mansa has also been reported earlier by Water Quality Assessment Authority, Govt. of India. Groundwater reaction was within neutral range probably because of such high salinity.

Calcium and magnesium content of groundwater was found to be higher in the middle part of the district, mainly in parts of Jhunir, Mansa and Budhlada (Fig. 2c) as compared to other blocks suppressing the hazard of sodicity. A higher concentration of calcium and magnesium ions over that of carbonate and bicarbonate yields a negative value for RSC and reduces the chance of sodicity hazard in groundwater.Groundwater was tested to be rich in sodium concentration in the middle part of the district, particularly in Budhlada block (Fig. 2d).

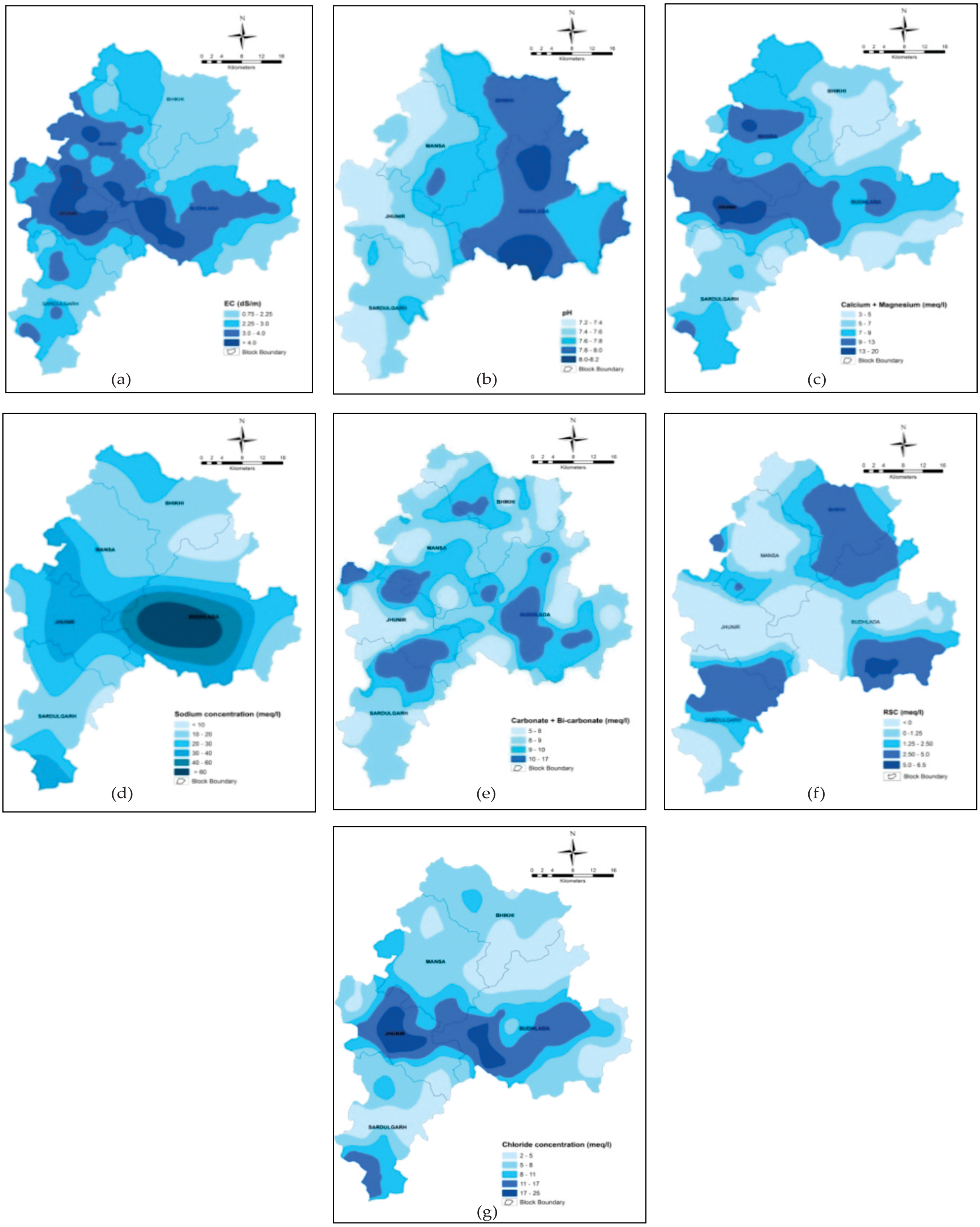

Fig. 2: Spatial variability maps for (a) EC (b) pH (c) Total Hardness (d) Sodium content (e) Total carbonate and bicarbonate content (f) RSC and (g) Chloride content in groundwater of Mansa

Total carbonate and bicarbonate content in groundwater varied widely within the district. In around 45% of total geographic area (TGA) of the district, groundwater contained more amounts of carbonate and bicarbonate as compared to calcium and magnesium deteriorating groundwater quality for irrigation purpose (Fig. 2e & f). The potential for sodium hazard is increased as RSC increases. In water, with a high concentration of carbonate and bicarbonate, less soluble ions such as calcium and magnesium tend to precipitate out and are removed from the solution. As a consequence, sodium percentage increases in water resulting in higher sodium adsorption on soil particles. Water with high RSC has high pH and lands irrigated by such water become infertile, owing to the deposition of sodium carbonate (Eaton, 1950).

Chloride concentration in the ground was higher again in the middle part of the district covering major parts of Jhunir and Budhlada blocks (Fig. 2g) increasing the tendency of salinity hazard. Quality of groundwater is ascertained by not only the concentration of a particular cation or anion, but it is the ratio of different ions that determines its suitability for irrigation purpose.

Delineation of water quality zones

On the basis of EC and RSC, groundwater samples were grouped into different categories and subsequently sub-categories (Table 2).Ground Water Quality Map for Mansa district (Fig. 2) was generated in Arc Map 10.3 by uniting spatial variability maps of ECand RSC. Groundwater quality in Mansa was found to be marginal in 200374.9 ha of the area covering 92.3% of its TGA which can be used for irrigation purpose after some amelioration.The maximum area was covered by Slight to Moderately Saline groundwater (56.7% of TGA) followed by Slight to Moderately Sodic water (14.7% of TGA). Good quality of water suitable for irrigating crops in all conditions was identified in only 6.7% of its TGA whereas, poor quality of water was found only in a small patch covering 2121.22 ha area in Budhlada block (Fig. 3).

CONCLUSION

Ground water in Mansa district was marginally suitable for irrigating field crops in most of its part. Extreme salinity (EC>4 dSm^{-1}) and alkalinity (RSC> 5 meq l^{-1}) hazards were prevalent only in small patches in Sardulgarh and Budhlada blocks covering 26.7 and 2.9% of TGA of the respective blocks.

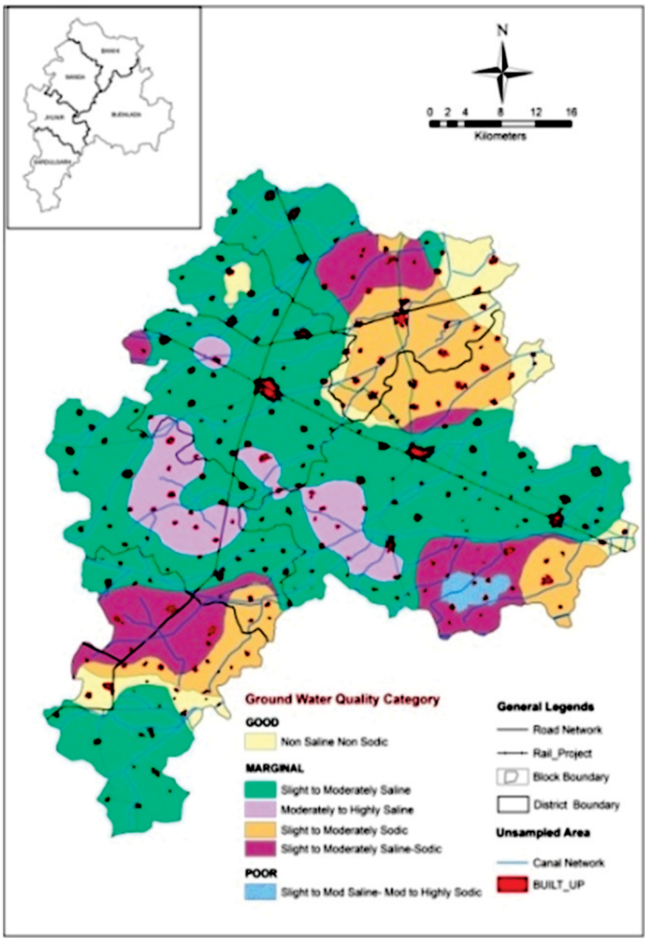

Fig. 3: Water Quality Map of Mansa

Mixing of canal water with groundwater, use of suitable amendments, like gypsum, selection of appropriate crops and cropping systems should be in regular practice for improving the water quality in one hand and preventing further deterioration in other.

ACKNOWLEDGMENT

We would like to thank State Government of Punjab (Department of Agriculture) for sponsoring the project "Evaluation of Soil and Water Related Constraints to Crop Productivity" under which the study was conducted in Punjab remote Sensing Centre, Ludhiana, Punjab.

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Citation:
Kundu D and Sood A.2019.Assessment of groundwater quality for irrigation purpose in Mansa District (Punjab, India) through GIS Approach. *Journal of AgriSearch* **6**(3): 139-145