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Changes in Groundwater Quality with Depth for Irrigation in Sangat Block of District Bathinda, Punjab

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Abstract

A systematic study was carried out to evaluate the spatio-temporal variation in quality of groundwater (GW) with depth for irrigation purpose in Sangat block of district Bathinda, Punjab during pre- and post- monsoon season in the year 2020. A total of four hundred water samples *i.e.,* two hundred samples from each depth from running tubewells (<25m and >25m) from different locations using geographical positioning system to uniformly cover the whole block in each of two different seasons (*i.e.,* pre-monsoon in June 2020 and post monsoon in October 2020). The post-monsoon season samples were collected from the same geo-tagged locations as the pre-monsoon season samples. On the basis of electrical conductivity (EC) from GW extraction depth <25m, 0, 82.8 and 17.2 per cent during pre-monsoon and 0, 38 and 62 percent water samples during post monsoon season and in GW depth >25m, 38.5, 59.2 and 2.3 per cent during pre-monsoon and 9.3, 79.6 and 11.1 per cent during post monsoon season were found to be fit, marginal and unfit for irrigation as per PAU classification. According to USSL classification, all GW samples from GW extraction depths <25m and >25m fall under C_3 and C_4 category based on sodium adsorption ratio (SAR) during pre- and post-monsoon seasons. On the basis of residual sodium carbonate (RSC), 82.9, 10.3, 6.8 and 0 per cent in pre-monsoon and 89.8, 6.8, 3.4 and 0 per cent samples in post monsoon having GW depth <25m and 88.4, 8.9, 1.6 and 1.1 per cent during pre-monsoon and 92.5, 6.4, 1.1 and 0 per cent during post monsoon season in GW depth >25m were found under low, medium, high and very high class, respectively. It is concluded that during post-monsoon season, using irrigation water quality (IWQ) indices RSC and SAR, the IWQ suitability increased, whereas, on the basis of EC, the IWQ suitability decreased in comparison to pre-monsoon season. The study suggests that since IWQ indices exceed the critical limits, therefore, long-term monitoring is required to assess the GW quality to prevent salt build up and potential soil health hazard for sustainable crop productivity in the study region.

Key words: IWQ indices, EC, RSC, SAR, Spatio-temporal variation, Groundwater extraction depth

Introduction

Groundwater (GW) is one of the most vital natural and fresh resources on earth which is used for drinking and irrigation purposes. In present day agriculture, most of the irrigation needs are met through the GW. Out of total GW utilization, about 3/4th part is used for irrigation purposes. The total concentrations of soluble salts, concentration of sodium and its relative proportion to calcium plus magnesium, concentration of bicarbonates and the presence of minor elements higher than the permissible amounts are the major characteristics that determine the irrigation water quality (Mishra and Banger, 2015). GW quality studies become unavoidable since its poor quality may badly affect its users (Chopra and Krishan, 2014).

Due to the country's rapid population growth and the need to fulfil rising irrigation, human, and industrial consumption demands, limited surface water resources are being depleted; and GW dependency has risen drastically, and water quality is deteriorating (Joshi *et al.,* 2009). Punjab having geographical area of about 50,362 sq. km is predominantly an agricultural state and has highest % age of irrigated land compared to total cultivable land in India. Irrigation covers 98 percent of the net sown area. About 73% of the net area is irrigated through tubewell irrigation (GW), whereas, remaining 27% is irrigated through canals (Kumar *et al.,* 2008).

To meet the demand for GW for numerous purposes, it is necessary to determine the depth of aquifer to which quality of native GW is fit, marginal or unfit for usages. The geographic information systems (GIS) as a main tool for investigating large-scale patterns and processes for mapping water quality are being widely used. The use of GIS increases not only water resource management's analytical planning, but also its ability to convey results and research findings to decision makers (Ganapathy and Ernest, 2004).

Irrigation water quality has a substantial impact on the health of the soil–plant–animal–human continuum. In order to maintain crop production in modern intensive agriculture, it is critical to create a depth-wise geographically integrated database of the quality characteristics of GW to be utilized for irrigation in a particular area. As a result, the current investigation was carried out with the primary aim of identifying the locations within a specific block in terms of GW quality for irrigation needs on the basis of GW extraction depth. This study involves collecting geo-referenced GW samples during pre- and post- monsoon seasons, and analyzing variations in different water quality parameters with depth for irrigation needs.

Materials and Methods

Bathinda district, covering an area of 3,367 km^2, lies between 29°33′ and 30°360′ N latitude and 74°38′ and 75°46′ E longitude. The study area is underlain by an alluvial complex of fluviatile origin deposited by the ancestral tributaries of the Indus River system which include the ancient Satluj River (Wadia, 1981). The aquifers in the area belong to the huge aquifer system of the lndo-Gangetic alluvial plain (Thomas *et al.,* 1995). The Sangat block of Bathinda district in south–western zone of Punjab was selected based on the previous reports of groundwater quality in this region. The mean annual rainfall in the district recorded during study period from November 2019 to October 2020 was 602.9 mm. Most of the rainfall occurs in 4 months of south-west monsoon period from June to September.

The groundwater (GW) samples from running tubewells were collected from selected sites using grid sampling technique (5 km × 5 km) during pre- and post-monsoon seasons. In first phase, sampling was carried out during pre-monsoon season (June, 2020) and a total of 200 tube-well GW samples were collected and their spatial points were recorded through global positioning system (GPS). The GW samples were classified on the basis of depth of extraction of GW *i.e.,* less than (<) 25 meters and more than (>) 25 meters. Out of total 200 GW samples, 29 samples were taken from GW extraction depth < 25 m and 171 samples were taken from GW extraction depth >25 m. Three or more than three samples were collected from each village and recorded the latitude and longitudes of the sampling sites. In post-monsoon season (October, 2020), the representative 200 GW samples were collected from the same locations from where the samples were collected during pre-monsoon season.

It was ensured that tubewell pumps were run at least for 25-30 minutes prior to the collection of water samples. After washing the bottles and lids with the same tubewell water for 2-3 times, the samples were collected in polythene bottles and stored safely for further analysis in the laboratory. Besides collection of water samples, the information regarding type of tube well (whether it is a filter or cavity), depth of extraction of GW, soil type and cropping pattern etc. was also collected from the farmers. The main sampling locations of GW water samples along with their geo-coordinates from Sangat block is given in Fig. 1.

Analysis of water samples for irrigation water quality indices

The GW water samples were analyzed for electrical conductivity (EC) (Jackson, 1967); CO_3^{2-}, HCO_3^- (Richards, 1954); Ca^{2+}, Mg^{2+} (Versenate method, Cheng and Bray, 1951); Na^+ (flame photometer method); and for computing IWQ indices like Residual Sodium Carbonate (RSC) = $(CO_3^{2-}+HCO_3^-)$ - $(Ca^{2+}+Mg^{2+})$; where, all the cations and anions are expressed in meq L^{-1} and Sodium Adsorption Ratio (SAR).

$$\text{SAR}\,(\text{mmol L}^{-1})^{1/2} = \frac{Na^+}{\frac{\sqrt{Ca^{2+}+Mg^{2+}}}{2}}$$

All the cations are expressed in mmol L^{-1}.

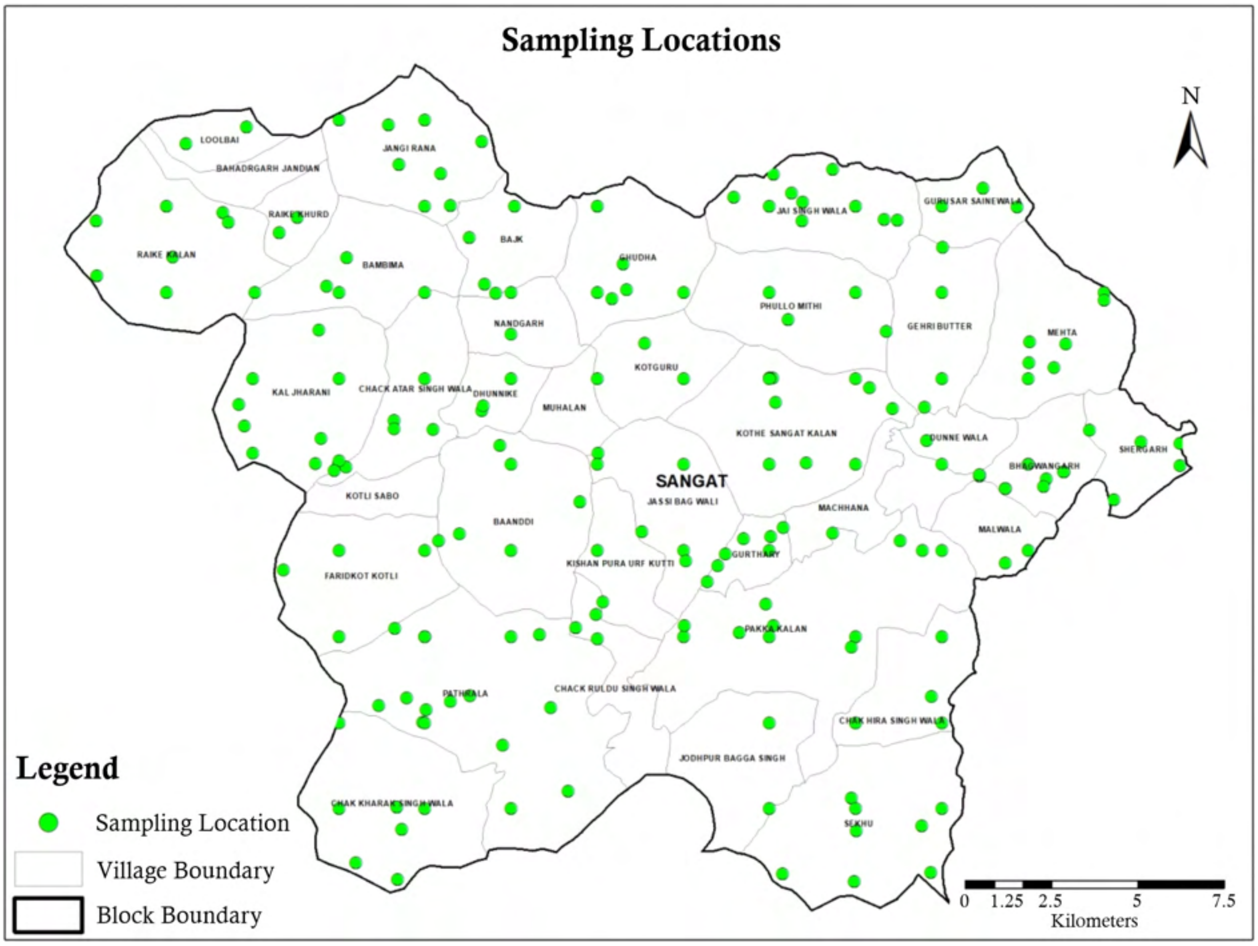

Fig. 1 Groundwater sampling location map of block Sangat, district Bathinda, Punjab

Classification of water samples based on IWQ indices

The GW samples were classified into different categories on the basis of IWQ indices being used in Punjab Agricultural University, originally developed by Bhumbla and Abrol (1972) and USSL Staff (1954) classification. The details are given below:

Groundwater quality classes on the basis of EC and RSC, (according to PAU classification)

EC (dS m^{-1})	Irrigation water quality	RSC (meqL^{-1})	Irrigation water quality
<2.0	Fit	<2.5	Fit
2.0-4.0	Marginal	2.5-5.0	Marginal
>4.0	Unfit	5.0-7.5	Poor but still be used with management such as amendment (gypsum)
-	-	>7.5	Unfit

Salinity classes of irrigation water (USSL, 1954)

Salinity of irrigation water EC (µS cm^{-1})	Salinity (EC) class	Salinity hazard
100-250	C_1 (Low salinity)	Low
250-750	C_2 (Medium salinity)	Medium
750-2250	C_3 (High salinity)	High
>2250	C_4 (Very high salinity)	Very High

Groundwater classification on the basis of SAR (USSL, 1954)

SAR -Water Class	SAR	Suitability
S_1 Low sodium hazard	0-10	Little or no hazard
S_2 Medium sodium hazard	10-18	Can be used with management
S_3 High sodium hazard	18-26	Unsuitable for most of the crops
S_4 Very high sodium hazard	>26	Unsuitable for irrigation

Results and Discussion

Depth-wise classification of GW on the basis of EC

It was observed that in <25m GW extraction depth, no GW sample falls under fit category (EC <2.0 dSm^{-1}) for irrigation on the basis of EC in both the seasons (Table 1), as per PAU classification. During the pre-monsoon season, 82.8 percent of GW samples fall into the marginal category (EC 2.0-4.0 dS m^{-1}), which decreased to 38 percent in the post-monsoon season, whereas, 17.2 percent of samples fall into the unsuitable category (EC >4.0 dS m^{-1}), which increased to 62 percent in GW extraction depth of < 25 m. Similarly, 38.5 percent of samples in GW extraction depth >25 m fall into the fit category, which decreased to 9.3 percent in the post monsoon season, while 59.2 and 2.3 percent of samples fall into the marginal and unfit categories in the pre-monsoon season, respectively, which increased to 79.6 and 11.1 percent in the post monsoon season (Table 1).

As per USSL classification (1954), the data presented in Table 2 revealed that during pre-monsoon, 3.4% GW samples fall under C_3 class which increased to 6.8% in post monsoon season, 96.6% under C_4 class in pre-monsoon which decreased to 93.2% in post monsoon season in GW extraction depth <25 m. In GW extraction depth >25 m. 47.3% samples come under C_3 class in pre-monsoon and it decreased to 18.7% during post monsoon season, 52.7% of the samples fall under C_4 class in pre- monsoon which increased to 81.3% in post monsoon season. No GW sample falls under C_1 (100-250 µS cm^{-1}) and C_2 (250-750 µS cm^{-1}) class in both the seasons. The EC of water samples obtained in the post monsoon season was generally higher than that of water samples collected in the pre-monsoon season especially in GW extraction depth >25m. This may be due to the mixing of salts geogenically present in the soil profile and use of these poor- quality waters for raising the crops in the region. While GW evaporates, salts remain stored in the interstice or pores in clay and are leached back into the GW during rainy seasons (Singh *et al.,* 2013).

Depth-wise classification of GW on the basis of RSC

The results showed that on the basis of RSC, during pre-monsoon season, 82.9% of the samples fall under low sodium hazard having RSC <2.5 meq L^{-1} with GW extraction depth <25 m (Table

Table 1. Depth-wise classification of GW on the basis of EC (dS m^{-1}) in block Sangat during pre- and post-monsoon season 2020

Depth of GW extraction (m)	EC (dS m^{-1}) Suitability (% water samples)					
	<2.0		2.0-4.0		>4.0	
	Pre-monsoon	Post- monsoon	Pre-monsoon	Post- monsoon	Pre-monsoon	Post- monsoon
<25	-	-	82.8	38	17.2	62.0
>25	38.5	9.3	59.2	79.6	2.3	11.1

PAU, Classification

Table 2. Depth-wise classification of groundwater on the basis of EC in block Sangat during pre- and post-monsoon season 2020

EC limit (µS cm^{-1})	Suitability (% water samples) Depth of GW extraction (m)				
	Salinity class	<25	>25	<25	>25
		Pre-monsoon		Post-monsoon	
100-250	C_1	-	-	-	-
250-750	C_2	-	-	-	-
750-2250	C_3	3.4	47.3	6.8	18.7
>2250	C_4	96.6	52.7	93.2	81.3

USSL, 1954

3) which increased during post monsoon season to 89.8%; 10.3% under medium class having RSC 2.5-5.0 meq L^{-1} and it decreased to 6.8% in post monsoon season; 6.8% of the samples fall under high sodium class having RSC 5.0-7.5 meq L^{-1} which decreased in post monsoon season to 3.4%; and no sample fall under very high sodium class having RSC >7.5 meq L^{-1} during pre- and post-monsoon season, using IWQ classification being used in Soil and water testing laboratories of PAU. Similarly, in GW extraction depth >25 m, 88.4% of the samples fall under low sodium class which increased during post monsoon season to 92.5%, 8.9% in medium class and it decreased to 6.4% in post monsoon season, 1.6% under high sodium class which decreased in post monsoon season 1.1%; and rest of 1.1% of the samples fall under very high sodium class and no sample fall under very high sodium class during post monsoon season (Table 3). Results revealed that the RSC concentrations were greater in pre-monsoon season water samples than in post-monsoon season water samples. This might be due to bicarbonates dominating calcium and magnesium ions in water samples. Carbonates and bicarbonates increased the sodium hazard by precipitating calcium and magnesium ions. Venkateswarlu (2001) found a similar trend in RSC values of Krishna River, Pendlipaka tank, and VogeruEru in the summer compared to the post-monsoon season.

Depth-wise classification of GW on the basis of SAR

The results presented in Table 4 revealed that during pre-monsoon season, 6.7 and 15.2% of the samples fall under S_1 class which increased to 14 and 24.2% during post monsoon season, 44.8 and 40% under S_2 class which increased to 51.4 and 48.2% in post monsoon season, 38.2 and 33.7% of the samples fall under S_3 class which decreased to 31.2 and 26.1% in post monsoon season; and 10.3 and 11.1% of the samples come under S_4 class and it decreased to 3.4 and 1.5% in post monsoon season having GW extraction depth < 25 m and > 25 m, respectively (Table 4).

SAR values were higher in pre-monsoon GW samples than in post-monsoon water samples. High SAR values in the pre-monsoon season

Table 3. Depth-wise classification of groundwater on the basis of RSC in block Sangat during pre- and post-monsoon season 2020

RSC limit (meq L^{-1})	Suitability (% water samples)				
		Depth of GW extraction (m)			
	Sodium hazard	<25	>25	<25	>25
		Pre-monsoon		Post-monsoon	
<2.5	Low	82.9	88.4	89.8	92.5
2.5-5.0	Medium	10.3	8.9	6.8	6.4
5.0-7.5	High	6.8	1.6	3.4	1.1
>7.5	Very high	-	1.1		-

PAU, Classification

Table 4. Depth-wise classification of groundwater on the basis of SAR in block Sangat during pre- and post-monsoon season 2020

SAR limit (mmol L^{-1})$^{1/2}$	Suitability (% water samples)				
		Depth of GW extraction (m)			
	Water class	<25	>25	<25	>25
		Pre-monsoon		Post-monsoon	
0-10	S_1	6.7	15.2	14	24.2
10-18	S_2	44.8	40	51.4	48.2
18-26	S_3	38.2	33.7	31.2	26.1
>26	S_4	10.3	11.1	3.4	1.5

USSL, 1954

suggested that relative adsorption of Ca^{+2}+ Mg^{+2} was low in the summer, but the opposite was true in the post-monsoon season. These results are in line with the results reported by Venkateswarlu (2001) who found higher SAR values during pre-monsoon season in comparison to the post monsoon period. In the groundwaters of Nainital District, Uttarakhand, Jain *et al.* (2012) reported a similar trend, as did Diana *et al* (2016) in South West Punjab.

Conclusions

From this study, it is concluded that on the basis of EC, majority of the GW samples were found under marginal and unfit category for irrigation during pre-monsoon season in GW extraction depth <25m and >25m, and the percentage of samples unfit for irrigation increased in post-monsoon as per PAU classification. Based on RSC, most of the GW samples exhibited low RSC values thereby qualifying for fit category for irrigation in both seasons, however, percentage of GW samples falling under fit category for irrigation purposes marginally increased with GW extraction depth >25m.

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