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Assessment of Irrigation Potential of Ground Water Using Water Quality Index Tool

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Abstract: Transforming parametric concentrations into qualitative scores irrespective of unit has made the Water Quality Index a comprehensive and easy to use tool to the decision makers. As criteria of water quality vary with purpose of use of the ground water, selection of water quality parameters, involved in working out quality index for specific use, also differs. Use of Ground Water Quality Index (GWQI) technique to assess irrigation water quality is innovative in this study. Electrical conductivity (EC), sodium adsorption ratio (SAR), and residual sodium carbonate (RSC), judged as the three most important parameters to determine irrigation quality of ground water, have been used to work out GWQI in this study. Preparation of iso index maps using water quality scores, derived through GWQI tool, vividly portray the irrigation water quality status of the study area where most of the area fall under excellent and good categories. The marked difference in water quality with respect to season in some areas of southeastern and southwestern parts of the study area may be correlatable to the recharge and discharge zones of ground water respectively.

Key words: Water quality parameters, ground water quality index (GWQI), iso index maps, recharge zone, discharge zone.

Introduction

In most of the important agriculture production areas, ground water becomes the sole source of fresh water when surface water sources have been depleted. In many concentrations of intensive agriculture, ground water offers reliability and flexibility in access to water that irrigation canals can hardly match. Worldwide, total groundwater withdrawals are estimated to be in the range 600-1100 km^3/yr or between one fifth and one third of the total global freshwater withdrawals (Döll, 2009; Shah et al., 2007; Zektser and Everett, 2004). Aquifer depletion has been reported for many semiarid and arid regions worldwide and can be attributed to agricultural usage (Ahmed and Umar, 2009; CGWB, 2006; Foster and Loucks, 2006; Guzman-Soria et al., 2009; Scanlon et al., 2007; Shah et al., 2007; Wang et al., 2009). Globally irrigation accounts for more than 70% of total water withdrawals and for more than 90% of total consumptive water use (Döll et al., 2009; FAO, 2010; Shiklomanov et al., 2000). Ground water sustains almost 60% of the irrigated land in India (MoA-GOI, 2003). On a local level, an increasing number of districts use ground water for irrigation purpose, than surface water. Here, during 1960-99 period, irrigation from tube wells and other wells grew more than four times and currently represents well over half of the country's irrigated area (MoA-GOI, 2003; Scott and Sharma, 2009). In just two decades, the groundwater irrigated lands in India have increased by 105% (IWMI-Tata Water Policy Program Report, 2005).

Quality aspect of ground water determines the suitability of its use in agriculture. Quality of ground water varies with space in its natural hydrogeological

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setting but changes of quality of ground water with time in a particular space are often attributed to anthropogenic reasons. So, to evaluate the irrigation potential of a region, ground water quality characterization reflected through a suitable representative classification scheme in a time perspective is a must. The present study has made an attempt in this regard. The objectives of the present study are (i) to evaluate water quality parameters with respect to irrigation potential, and (ii) to classify ground water of the study area, depending upon the combinations of water quality parameters with respect to suitability for irrigation. Electrical conductivity (EC), relative proportion of sodium to other cations, residual sodium carbonate etc. are important parameters, judged for quality of irrigation water (Raghunath, 2006). Considering an individual parameter for classification of water is not sufficient for all the samples of the area as it cannot properly explain which parameter should be given higher weightage or importance. Classification based on individual parameter often creates confusion to designate different locations with respect to irrigation quality of ground water of an area. Better results can be obtained by considering the combined chemistry of the parameters rather than individual one (Handa, 1964, 1965; Hem, 1985; Karmegam et al., 2010). So, to determine the irrigation water quality consisting of a number of samples in a region, a proper indexing system involving electrical conductivity, sodium adsorption ratio (SAR) and residual sodium carbonate is proposed.

The study area comprises complex nature of landuse pattern. The area is characterized by industries, agriculture, forest, urban and rural residential hubs. In recent years, a number of large, medium and small industries of different nature (like cement industries, alloy industries, polymer industries, etc.) have been set up in this area. Coal bed methane exploration and exploitation are going on in the northeastern and northwestern parts of the study area for the last few years. The effluents of these industries of various natures stay around the agricultural lands and may have control on the quality of ground water which is used for agriculture.

Study Area

The area under investigation belongs to the Survey of India toposheet No 73M/6 and 73M/7 lying between latitudes 23°25´N and 23°48´N and longitudes 87°10’E and 87°35’E, covering an area of almost 600 sq km (Figure 1). The river Ajoy forms the northern boundary and river Damodar marks the southern boundary. Northern and western part of the study area consist of coal bearing Raniganj Formation of Gondwana Supergroup which is overlain by alluvium (CGWB, 2006). The eastern and southeastern part is constituted by alluvium blanket comprising alluvium, laterite, sand, gravel, clay etc. of Upper Tertiary-Quaternary age (CGWB, 2006). The Quaternary alluvial fill tends to thicken towards east and southeast. Towards west, it thins out on Tertiary Gondwana terrain. In the study area, aquifer ranges in thickness from 20 to 120 m (CGWB, 2006). As the alluvium thickness increases towards east, a number of intervening structures within alluvial aquifer are present. This results in a complex nature of hydrogeology which leads to formation of many temporary aquifer systems in the region. Few deeper aquifers in the eastern side of the area occur under confined condition, whereas, in most of the areas aquifers occur under unconfined to semiconfined state. The climate of the area is semi-arid. It is characterized by a hot and dry summer followed by the monsoon rains from June to September and a cool pleasant winter.

Lithology

Two broad types of lithologies are found within the study area. Around western part of the study area, coarse to moderate grained sandstone, shale and laterite occur. In the west, coarse gritty soil blended with rock fragments is formed from the weathering of pegmatitic rock’s quartz, pebbly sandstone, weathered granitic rocks and sandstone (ADDA Status Report, 2006). Towards the eastern side, the lithotype comprises mostly of clay, shale and argillaceous limestone which overlie the granular zone comprising gravels, coarse grained sandstone forming the archean basement. The clay beds are associated with the Tertiary sediments. These sediments are of two types: first, lithomergic clays associated with laterites, and second, white clays associated with Durgapur beds (wbenvironment.nic.in/status7.htm).

Groundwater Condition of the Study Area

Geological control of the occurrence of ground water indicates that ground water in the area occurs generally under unconfined to semiconfined state. Continuous sequence of sand and gravel facilitate infiltration of rainfall to the groundwater body. Water table in post-monsoon season lies at a height of 60-120 m while water table height in pre-monsoon season ranges between 50 and 90 m from mean sea level. This considerable seasonal fluctuation of water table is the result of combined effect

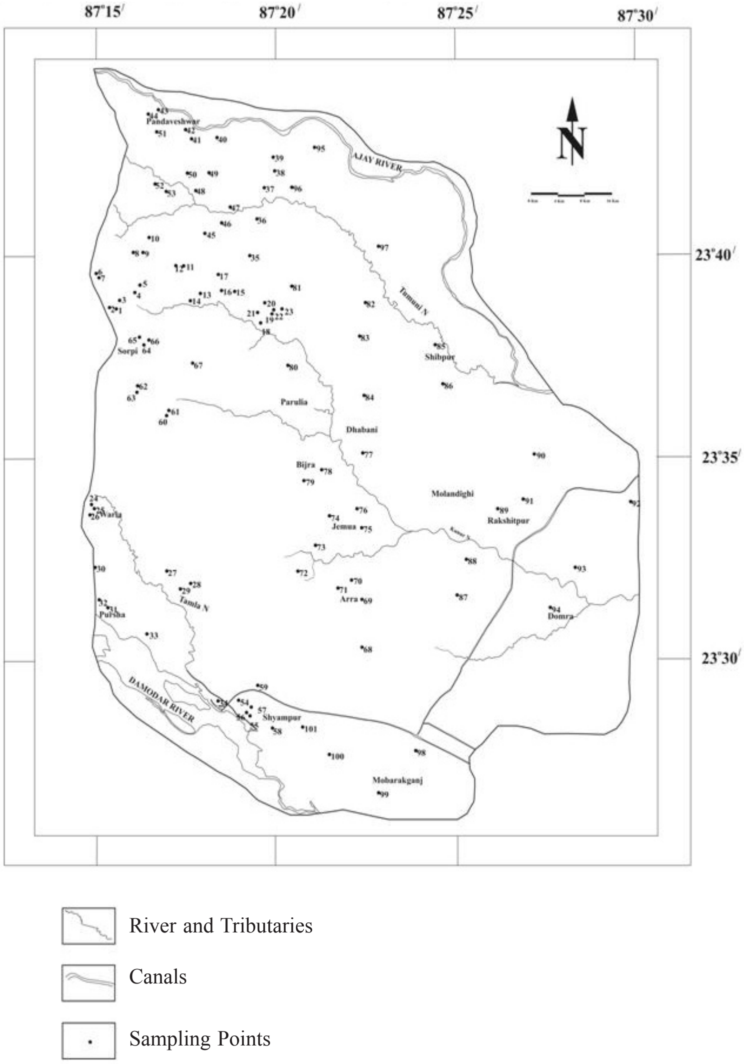

Figure 1: Study area.

of evapotranspiration and discharge of ground water by outflow and artificial draft. Groundwater contour maps of pre-monsoon (Figure 2) and post-monsoon season (Figure 3) show the flow pattern of the area. The contours are shown in metres. There is no marked difference in the flow pattern between pre-monsoon and post-monsoon seasons (Figures 2 and 3). Regional flow of ground water is towards southeast. Water table contour maps suggest greater permeability of the eastern part in comparison to the western part of the study area. In the post-monsoon season water table in the eastern part and southwestern part almost reached the surface. A groundwater high near Ukhra in the western part is envisaged. In pre-monsoon season a groundwater depression with steep gradient (Figure 2) is noticed in the southeast of Pandaveshwar in the northern part of the study area.

Materials and Methods

Ninety nine and 119 number of groundwater samples were collected in pre-monsoon and post-monsoon season respectively (December 2008 to June 2010) from different locations of the study area. Electrical conductivity and pH of the samples were measured within four hours of sample collection. The parameters like chloride, nitrate, potassium, sodium, magnesium, calcium, sulphate, bicarbonate were analysed.

Analysis of samples has been done according to standard methods adopted by APHA. The pH and EC are measured by means of pH meter (Eutech pH 1100) and conductivity meter (Eutech Con 510) respectively. TDS has been computed from EC multiplied by a factor (0.55–0.75), depending on relative concentrations of ions. Na^+ and K^+ are determined by flame photometer

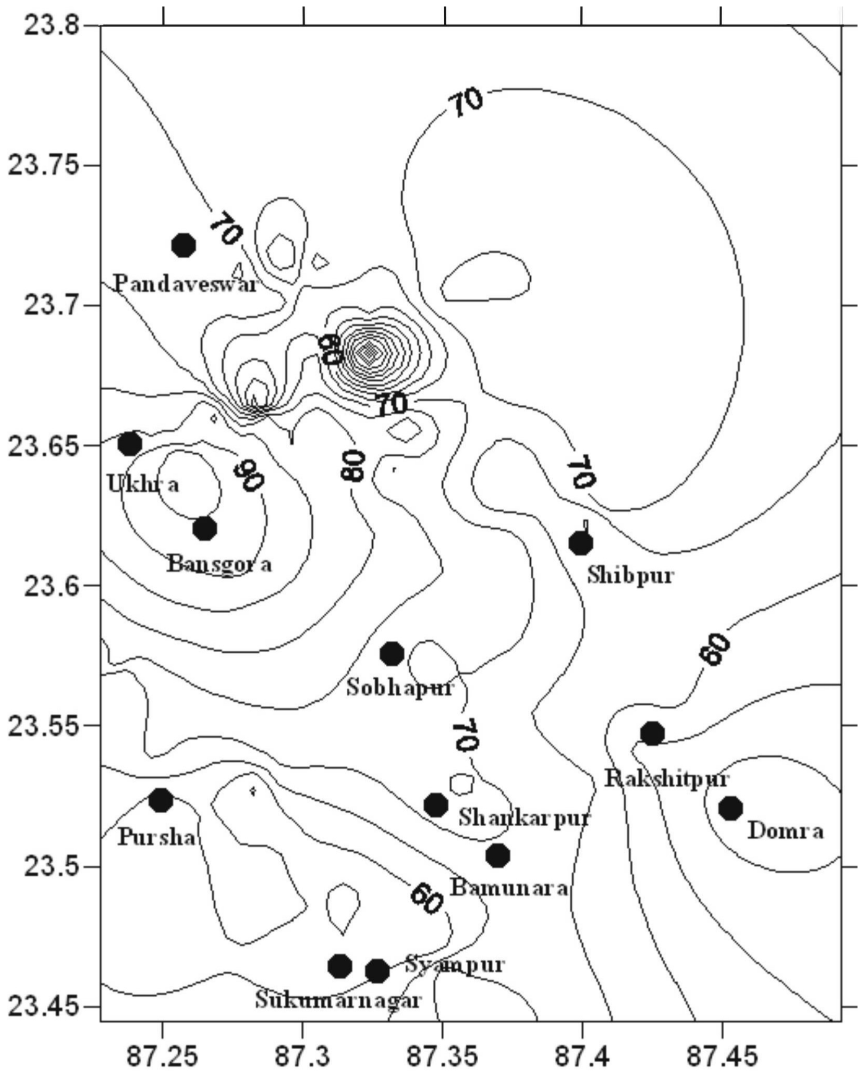

Figure 2: Water table contour map of pre-monsoon season.

(Techcomp UV-2300). NO_3^- and SO_4^{2-} are analyzed by spectrophotometer. TH and TA as $CaCO_3$, Ca^{2+}, HCO_3^- and Cl^- are analysed by titrimetric method. Mg^{2+} is calculated from TH and Ca^{2+} contents. The ion-balance-error computation, taking the relationship between the total cations (Ca^{2+}, Mg^{+2}, Na^+, K^+ and Fe^{2+}) and the total anions (PO_4^{3+}, NO_3^- , SO_4^{2-}, CO_3^{2-}, HCO_3^- and Cl^-) for each set of complete analyses of water sample, is observed to be within the range of acceptability (±5%) used in most laboratories (Domenico and Schwartz, 1990).

Result and Discussion

Chemical constituents that affect the suitability of water for irrigation are total concentration of soluble salts (broadly related to the electrical conductivity of water), relative proportion of sodium to calcium and magnesium (SAR), relative proportion of bicarbonate to calcium and magnesium (RSC) (Karanth, 2006). Electrical conductivity determines the salinity hazard. Water with high Na^+ and low in Ca^{2+} may enrich the soil with Na^+ by ion exchange, which destroys the soil structure due to dispersion of clay particles. Higher salinity causes lower osmotic activity of plants (Subramani et al., 2005). The classification of ground water based on salinity hazard as per US Salinity Lab (USSL) for irrigation purpose (Table 1) reveals that only 5% of the pre-monsoon samples and 7% of post-monsoon samples are unsuitable for irrigation. The electrical conductivity values signify that water quality in the

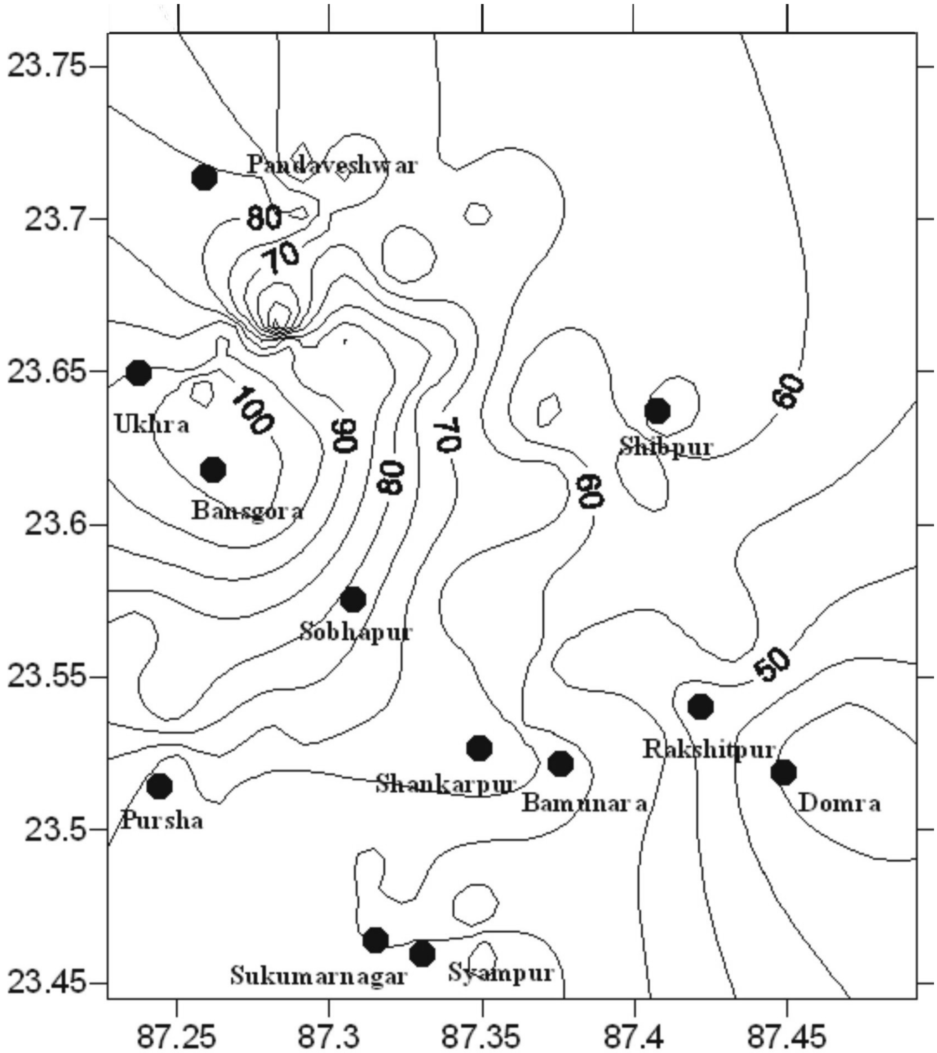

Figure 3: Water table contour map of post-monsoon season.

study area is mostly in good to doubtful category for irrigation. Dissolved salt increases the osmotic potential of soil water and an increase in osmotic pressure of the soil solution increases the amount of energy that plants must expend to take up water from soil. As osmotic pressure increases, respiration increases and growth of most plants decline progressively. High salt content by means of high electrical conductance in water leads to formation of saline soil and high sodium content by means of high sodium adsorption ratio (SAR) produce an alkaline soil (Raghunath, 2006). Alkali soil, having unfavourable structure, peddles easily and restricts the aeration. Increase of sodium concentration deteriorates soil properties by reducing permeability (Kelley, 1951; Tijani, 1994).

Table 1: Salinity hazard classes based on USSL classification

Salinity hazard class	*EC in micro-mhos per cm*	*Remark on quality*	*Numbers of pre-monsoon samples*	*Numbers of post-monsoon samples*
C1	100-250	Excellent	11	13
C2	250-750	Good	31	31
C3	750-2250	Doubtful	52	68
C4 and C5	>2250	Unsuitable	05	07

SAR is estimated by the formula

$$\text{Sodium Adsorption Ratio } (SAR) = \frac{Na^+}{\sqrt{\frac{(Ca^{++} + Mg^{++})}{2}}}$$

where all ionic concentrations are expressed in epm. According to the US Salinity Laboratory classification for irrigation water based on SAR values, almost 98% of pre-monsoon samples of the study area are of excellent type (Table 2). Relative proportion of sodium to calcium and magnesium can be determined by means of percent sodium which can be calculated by the formula

$$\% Na = [(Na^+)+(K^+)] \times 100/(Ca^{++} + Mg^{++} + Na^+ + K^+)$$

where all ionic concentrations are expressed in epm. The classification of groundwater samples in terms of percent sodium (Table 3) exhibits that almost 83.2% post-monsoon samples fall under good to permissible category, whereas almost 62.5% pre-monsoon samples fall under permissible to doubtful category. In irrigation water, sodium increases the dispersion of colloids of clays when it comes in contact with soil and displaces the divalent cations Ca^{2+} and Mg^{2+}. This has a negative effect on the structure of the soil and reduces its capacity to conduct water and air through its profile (Castellanos et al., 2000), as a consequence of which the damage in soil fertility takes place.

Excess of calcium and magnesium brings higher carbonate and bicarbonate which leads to much greater alkali formation. The greater alkali formation is indicated by SAR and RSC which effects agriculture unfavourably (Eaton, 1950; Richards, 1954). RSC values of the ground water of the present area suggest that almost 88% of pre-monsoon samples and 80.87% of post-monsoon samples represent good quality as water having less than 1.25 epm of RSC.

Ground Water Quality Index for Irrigation

Assessment of ground water quality index with respect to different uses and purposes has been carried out by several workers around the world. Stigter et al. (2006a, b) used groundwater quality indices for evaluating influence of agriculture activities on several key parameters of groundwater chemistry and potability. Mohen Saeedi et al. (2010) used the ground water quality index to identify the places with best drinking water quality in the Qazvin Province, West Central Iran. Sharma and Patel (2010) used the water quality index (WQI) method to determine the pollution potential of ground water of Surat City, India. Reza and Singh (2010) used the technique to evaluate the potability of ground water in Angul-Talcher area, Orissa, India. Ramakrishnaiah et al. (2004) used the tool to assess the suitability of ground water of Tumkur, Karnataka, India for human consumption.

Each of the essential parameters considered for irrigation water quality like EC, SAR, RSC shows variation in the study area. Though each of these parameters indicates that most of the samples fall under excellent to good category of water for irrigation, location-wise water categories differ when judged on the basis of any single parameter. No single parameter is sufficient for classification of water for suitability to irrigation. Each of these parameters has its own

Table 2: Sodium hazard classes based on USSL classification

Sodium hazard class	*SAR in equivalents per mole*	*Remark on quality*	*Numbers of pre-monsoon samples*	*Numbers of post-monsoon samples*
S1	10	Excellent	97	119
S2	10-18	Good	02	Nil
S3	18-26	Doubtful	Nil	Nil
S4 and S5	>26	Unsuitable	Nil	Nil

Table 3: Sodium percent water class

Sodium (%)	*Water class*	*Pre-monsoon samples*	*Post-monsoon samples*
<20	Excellent	02 samples	17 samples
20-40	Good	28 samples	63 samples
40-60	Permissible	40 samples	36 samples
60-80	Doubtfull	22 samples	03 samples
>80	Unsuitable	07 samples	Nil

significance on quality of water. Classification on the basis of any individual parameter cannot properly explain the suitability of the sample as a representative of whole water chemistry in terms of irrigation. Instead of using a number of classifications on the basis of individual parameters one significant classification scheme based on combination of relative importance of essential parameters with respect to irrigation potential will be worthy in decision making.

The classification scheme, presented in this study, has been devised on the basis of relative importance of the most significant irrigation water quality parameters—SAR, EC and RSC. The whole Water Quality Indexing (WQI) System was carried out through three steps:

In the *first step*, each of the three parameters is assigned a weight according to their relative importance in irrigation purpose. Assigning weight to individual parameters, keeping the order of importance or priority of parameters (SAR > EC > RSC) intact, is based on knowledge and experience of the individual. SAR is assigned a weight of 5, as it is directly related to sodium proportion among the other cations and signify maximum importance for irrigation purpose. EC is considered as second important parameter for irrigation and is assigned a weight of 3 as it suggests salinity hazard. RSC is signified as third important parameter and assigned a weight of 2 as it predicts the accumulation of sodium in the soil based on the potential precipitation of calcium and magnesium carbonate. The weightage (intensity of importance) of individual parameters has been adopted from the "scale of relative importance" proposed by Saaty (1980) as shown in Table 4.

Relative weight (W) of individual parameter is determined. For SAR it is calculated as

$$W_{SAR} = 5/(5 + 3 + 2), \text{ i.e., } 0.5;$$

$$W_{EC} = 0.3 \text{ and } W_{RSC} = 0.2$$

Second step computes the relative weight (W_i) of individual parameter where weight of individual parameters (w_i) is divided by the summation of weight of all the parameters (n) involved

$$W_i = \frac{w_i}{\sum_{i=1}^{n} w_i}$$

In the *third step* a quality rating (Q_i) for each parameter is determined in the following manner

$$Q_i = \frac{C_i}{S_i} \times 100$$

where Q_i is the quality rating of individual parameter, C_i is the concentration of individual parameter in each water sample and S_i is the standard concentration value for irrigation quality of the individual parameter. In this study the standard values of individual parameters have been taken from mean values of doubtful category of USSL Classification of water for irrigation purpose (Tables 1 and 2).

For final computation of GWQI, subindex (SI) of individual parameter of each water sample is worked out using the relationship

$$SI_i = W_i \times Q_i$$

In this study the subindex of parameters are SI_{SAR}, SI_{EC} and SI_{RSC}. Finally, the Ground Water Quality Index of each water sample is determined as

$$(\text{GWQI})_i = \sum(SI_{SAR})_i + (SI_{EC})_i + (SI_{RSC})_i$$

This process transforms the concentrations of all parameters of individual water samples into a unitless number which may be termed as "quality score" for irrigation use of that sample of ground water. The derived quality scores or index values have been grouped into three classes:

GWQI	*Quality of water*
<39	Excellent
39-100	Good
>100	Unsuitable

The basis of this classification has been fixed with reference to the average values of excellent category and doubtful category of SAR and EC of USSL classification (Tables 1 and 2) and on the average value of excellent and unsafe category of RSC (Table 5). The derivation of cutoff quality scores or index values of three classes of present classification scheme is shown below:

Quality score of a sample may possess negative sign which indicates negative RSC value of that sample. Negative RSC value implies that alkaline earth dominates over the carbonate and bicarbonate and can be considered having excellent irrigation potential with respect to only RSC. Suppose quality score of two samples are 130 and –130, both the values in this case fall under unsuitable category and the sample, having value "–130" indicates alkali hazard (if any) is not due to carbonate and bicarbonate.

Based on the quality score or index values of individual samples the sampling locations have been contoured to generate isoindex maps of both pre-monsoon (Figure 4) and post-monsoon (Figure 5)

Category							*GWQI*
Excellent	C_{SAR}	10	C_{EC}	175	C_{RSC}	1.25	39
	S_{SAR}	22	S_{EC}	1500	S_{RSC}	1.9	
	Q_{SAR}	45	Q_{EC}	11.6	Q_{RSC}	65.8	
	W_{SAR}	0.5	W_{EC}	0.3	W_{RSC}	0.2	
	SI_{SAR}	22.7	SI_{EC}	3.5	SI_{RSC}	13.16	
Unsuitable	C_{SAR}	22	C_{EC}	1500	C_{RSC}	1.9	100
	S_{SAR}	22	S_{EC}	1500	S_{RSC}	1.9	
	Q_{SAR}	100	Q_{EC}	100	Q_{RSC}	100	
	W_{SAR}	0.5	W_{EC}	0.3	W_{RSC}	0.2	
	SI_{SAR}	50	SI_{EC}	30	SI_{RSC}	20	

Table 4: Scale of relative importance

Intensity of importance	*Definition*	*Explanation*
1	Equal importance	Two activities contribute equally to the objective
3	Weak importance of one over another	Experience and judgement slightly favour one activity over another
5	Essential or strong importance	Experience and judgement strongly favour one activity over another
7	Demonstrated importance	An activity is strongly favoured and its dominance demonstrated in practice
9	Absolute importance	The evidence favouring one activity over another is of the highest possible order of affirmation
2, 4, 6, 8	Intermediate values between the two adjacent judgements	When compromise is needed
Reciprocals of above non-zero	If activity *i* has one of the above non-zero numbers assigned to it when compared with activity *j*, then *j* has the reciprocal value when compared with *i*.	

Table 5: Residual sodium classes (after Eaton, 1950)

RSC (epm)	*Remark on quality*	*Number of pre-monsoon samples*	*Number of post-monsoon samples*
<1.25	Good	88	96
1.25-2.5	Medium	04	11
>2.5	Bad	07	12

seasons (where along X-axis and Y-axis, longitude and latitudes are plotted respectively in degrees). These figures show almost all the samples (97% both in pre-monsoon and post-monsoon seasons) grouped under excellent to good category. Only 3% samples in both pre- and post-monsoon seasons are of unsuitable category. Isoindex maps exhibit the areas like Pursha and Bansgora fall under unsuitable category. Characteristically all these areas are agriculture-intensive zones with close proximity to industrial activities. Very little seasonal fluctuation of water table (Table 6) suggests that the areas like Pursha, Sukumarnagar and Bansgora are groundwater discharge zones (most of the flow components of ground water follow the regional trend i.e., towards south and southeast) and accumulates carbonate, bicarbonate and sodium in large proportion in these zones which during post-monsoon season becomes diluted. Water table contour maps and seasonal fluctuation of water table suggest that the areas like Rakshitpur, Shibpur and Shankarpur possess near-surface higher permeable aquifers and groundwater recharge areas. During monsoon greater amount of salts from surface and zone of aeration gets dissolved in the percolating solution and contributes to the zone of saturation. Higher amount of EC and RSC of these areas may make the ground water unsuitable for irrigation. Industrial effluents, huge dewatering of deeper aquifers (usually contains high TDS) and its surfacial discharge in CBM exploration may play a role in deteriorating groundwater quality

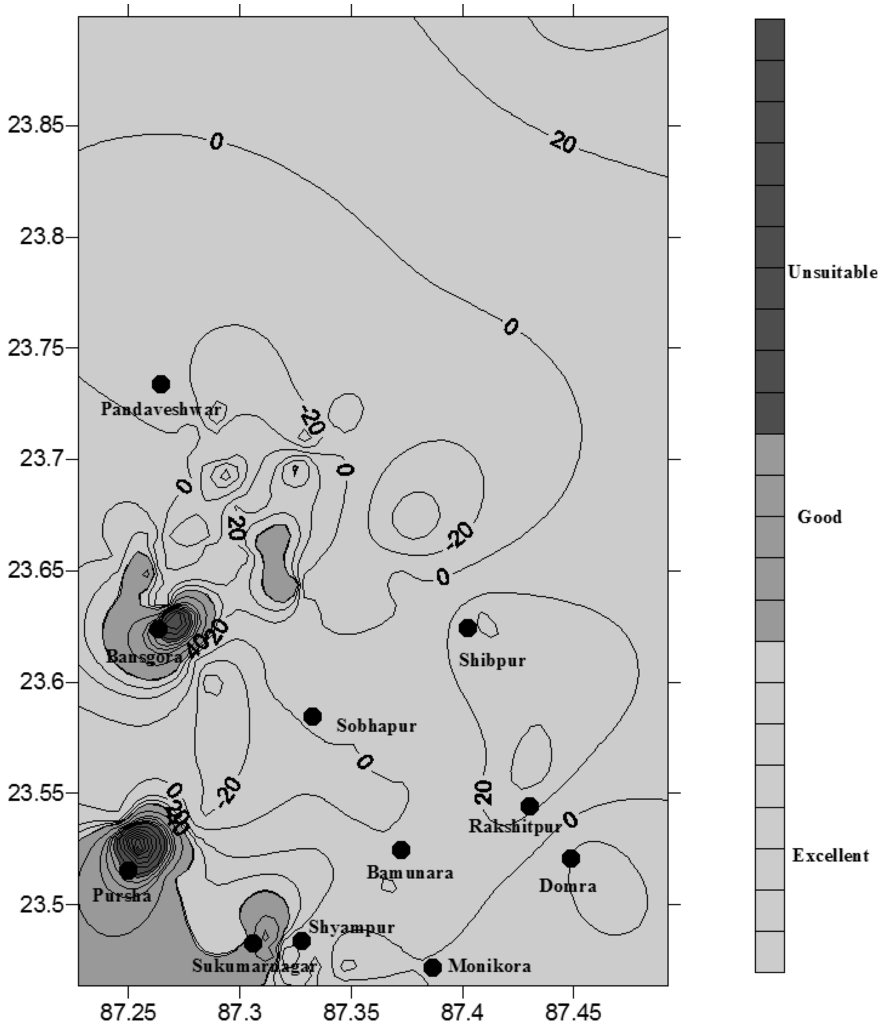

Figure 4: Isoindex map of the study area in pre-monsoon season.

Table 6: Seasonal variation of parameters

Locations	*DTW (m)*		*EC (micro-mhos per cm)*		*RSC (epm)*		*SAR (epm)*	
	Pre	*Post*	*Pre*	*Post*	*Pre*	*Post*	*Pre*	*Post*
Pursha	2.3	2.13	1342	1985	10.07	-9.65	5.85	0.91
Sukumarnagar	3.66	3.13	842	605	1.76	-2.07	15.34	.876
Bansgora	2.64	2.42	1432	2180	18.42	-11.29	4.26	1.53
Domra	4.11	2.49	2340	3330	-7.39	.5	1.28	1.18
Rakshitpur	4.68	3.27	1614	1922	-.05	7	1.7	1.72
Shibpur	5.25	4.32	951	1092	1.03	7.42	.77	.63
Shankarpur	6.5	4.79	1363	1682	-2.44	9.61	1.95	1.71

in near future of this region. Keeping in consideration the quantum of industries in the study area, particularly coal-based power plants and steel industries, the fly ashes and other dusts, released through chimneys, may indirectly contaminate ground water.

Conclusion

Instead of separate use of various parameters in determining irrigation potential of ground water of an area, use of GWQI technique, applied in this study, is

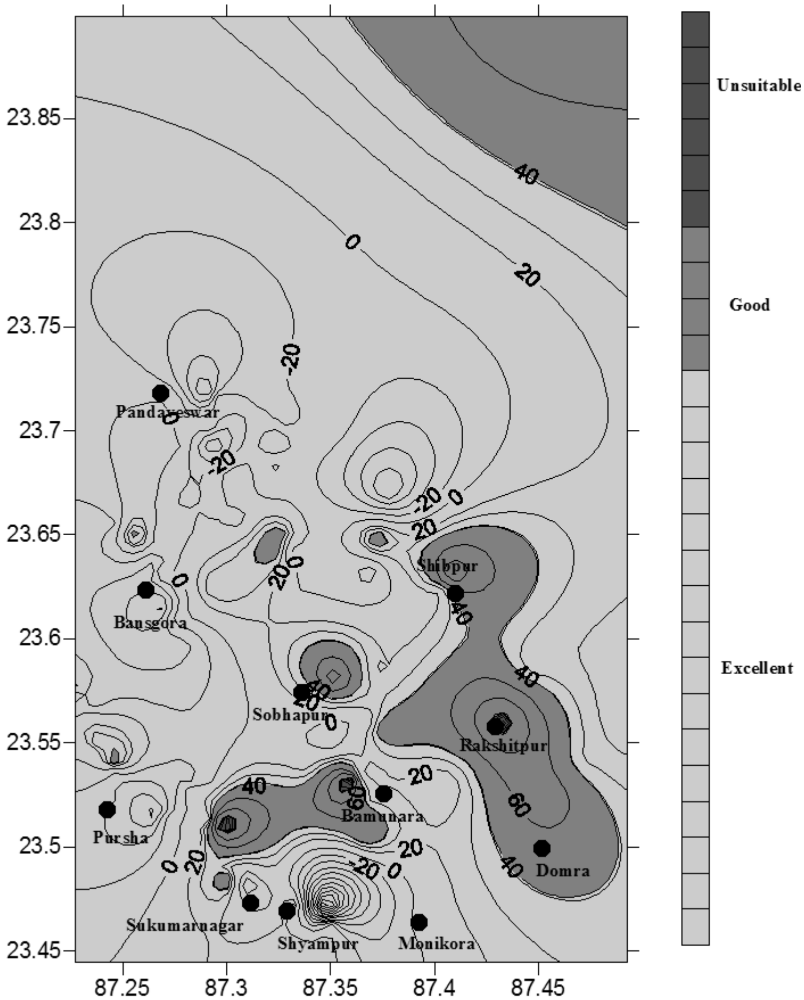

Figure 5: Isoindex map in post-monsoon season.

the better option in decision making. The technique involves three most important parameters—SAR, EC and RSC—of irrigation water quality in computing the indices or quality scores. Isoindex maps based on indices clearly demonstrate without ambiguity the irrigation potential of water of an area. In the present case study isoindex maps show seasonal variation of water qualities in terms of irrigation in few locations of southeastern and southwestern parts of the study area. The higher concentrations of carbonate, bicarbonate and sodium ions increase the values of RSC and SAR in certain areas of southwestern part in post-monsoon but in the pre-monsoon these areas fall under excellent category. Few areas in the southeastern part show good quality in the pre-monsoon and excellent quality in the post-monsoon season. Hydrogeologically the areas of concern in the southwestern and southeastern parts belong to groundwater recharge zones and groundwater discharge zones respectively. These discharge and recharge zones are correlatable with the seasonal accumulation of carbonate, bicarbonate, sodium ions in pre-monsoon and TDS (including high carbonate and bicarbonate) in post-monsoon seasons respectively.

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