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GEOSPATIAL ASSESSMENT OF IRRIGATION WATER POTENTIAL FOR BLACK SOIL SALINIZATION

SUMMARY

The quantum of irrigation water used as supplementary or as dependent source and its quality, could contribute to the development of secondary soil salinity. This affects on the crop growth and yield as well degrades the soil over the period. River, open dug well and tube well is used in intensive sugarcane cultivation in the Krishna, Warana and Yerala basin. An attempt has been done to understand the water quality and it's spatial distribution. Water Quality Index were created based spatial distribution of hydrochemical parameters and derived indices - salinity, sodium absorption ratio, percent sodium ratio, residual sodium carbonate and permeability index. The changes in salinity of irrigation water from post to pre monsoon season indicates salt movement and addition through return flows. The order of importance of geochemical parameters suggested can act as tool for proper management through WQI. Nevertheless continuous monitoring of irrigation sources and proper drainage facilities are needed to overcome effect of poor quality irrigation water sources.

Keywords: Secondary soil salinity, Water Quality Index, Black soil, Hydrogeochemical parameters, Krishna River

INTRODUCTION

Salinization of land has threatened civilizations in ancient and modern times. About 7% (~955 M.ha) of the land surface of the earth is affected by primary soil salinity and 77 M.ha by secondary salinization due to human activities (Metternicht and Zinck, 2003). Proper irrigation water management and drainage was not provided during the rapid irrigation development of the early and mid-decades of the twentieth century. This has resulted in risen water tables and salinization of irrigated lands (Smedema et al.2000).It is estimated that the soil salinity increases by 20 to 25 tonnes/ha after a single harvest of sugarcane and the excess salinity reduces the land productivity (Ghassemi, et al., 1995).The ground water quality used in the supplementary irrigation is contaminated from agriculture activities (Singh, et al. 2010) and the long term use can cause permanent degradation. The dispersed clay particles occupy the annular pores in soil mass and develop clogging of fine textured black soils leading to reduced

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infiltration rate and hydraulic permeability. The accurate and updated spatial information on salinity parameters across the area of interest is essential for management practices (Pozdnyakova and Zhang 1999).

GIS modelling methods were used for monitoring salinization and isolating areas by indicators and weight (Eklund, Kirkby and Salim 1998).Timely installation of drainage infrastructure can help in eliminating the onset of drainage associated soil salinity problems in the irrigated areas (Qureshi et al., 2013).

Nearly 8 canal command areas in India have recorded trends of water table rise of 0.20 to 1.00m/annum. Lack of proper management of water and land resources resulted in the emergence of salinity in has Pravara river and Nira Irrigation Project in Maharashtra (Singh and Chatrath 2001). The unfavourable physiography and rainfall, presence of black (vertisol) soil, absence of natural drainage (Balpande et al. 1996) and lack of proper infrastructure and irrigation facilities may explain the higher extent of salt affected soils in the Deccan Plateau (Challa et al. 1995) where sugarcane is grown extensively for the past 2 or 3 decades. **Figure 1.a & b** show the salinity affected soils in India and irrigation induced salinity in Maharashtra state.

Krishna River and its tributaries start from western ghat (mountain range) and flows through semi-arid and arid regions of Peninsular India. Since, 1960, several reservoirs were constructed in proximity to the mountain range and that developed cultivation in their respective command areas. At present saline soil is prevalent in the Deccan (part of Peninsular India) Plateau are slightly saline (146,893 ha, 25%); slightly (261,242 ha, 45%) and strongly (154,589 ha, 27%) sodic in nature. Due to cultivation of sugarcane (70% of irrigated area in Kolhapur, Pune and Sangli districts of Maharashtra) year after year and excessive application of water to crops, the land has become waterlogged and saline over the years.

For effective management of irrigation activities, the irrigation water quality map can be used as a tool. An attempt has been in made in understanding the irrigation water quality and it’s spatial distribution by considering the relative importance of various hydro-chemical parameters and their role in soil salinity.

MATERIAL AND METHODS

Irrespective of its source, all irrigation water contains dissolved salts, the type and quantity of which depend on its origin and also on its course before use. The crops in this region are irrigated by monsoon rainfall (June-September), lift irrigation schemes and groundwater from shallow dug wells that receives the agriculture return flow. Hence, water samples were collected from the river, dug and bore wells during pre and post monsoon periods. Chemical composition of these waters was tested to determine the Irrigation Water Quality Index. Interpolation method (inverse distance weighing) was used in interpolating the point information. This study has been carried out over the regions, bounded by rivers Krishna, Warana and Yerala (**Figure 1.c**)

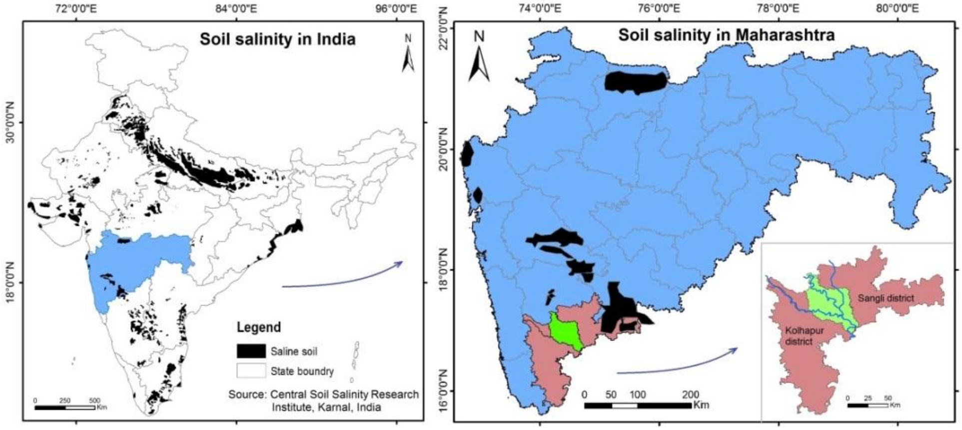

Figure 1: Location (a, salinity affected areas in India; b, irrigation induced salinity in Maharashtra; c, study area bounded by Krishna, Warana & Yerala river)

Black soil form shallow ground water table that extends from 1 to 10m bgl and tube wells exploit the weathered and fractures in massive Deccan basalts and amygdaloidal basalts below 15m bgl. **Figure 2** shows the water level at post monsoon (October-November) season. It is observed that regions in proximity to river are in the 0-2m. This proximity is found to develop salinity situations. The return flow from irrigation is estimated be 20-30%.Total 136 samples from open dug well, 12 from bore wells and 13 river water samples were collected for irrigation water analysis (**Figure 3**). The salinity variation between pre and post monsoon period is shown in **Figure 4**. The pH and electrical conductivity (EC) was measured with Spectralab's multi-parameter instrument. The measured electrical conductivity was converted to standard temperature of 25^0C. The sodium and potassium concentrations were determined by Equiptronics EQ850A flame photometer. The calcium and magnesium were calculated using Versonate method. The chloride was determined by titration with silver nitrate (APHA 1995).

Sodium absorption ratio (SAR), percent sodium, calcium & magnesium ratio, Residual sodium carbonate (RSC), Permeability index (PI) etc were determined in deriving water quality index (WQI). Sodium absorption ratio and salinity are used as an indicator in evaluating the suitability of irrigation waters (Zhang, et al. 2012). The SAR is represented when all ions expressed in meq/l as,

$$SAR = Na^{+} \Big/ \sqrt{(Ca^{++} + Mg^{++})/2}\ .$$

Bicarbonate ions tend to precipitate calcium ions after evaporation of irrigation. Hence, the effect of bicarbonate together with carbonates evaluated through RSC. When all the values expressed in meq/l, RSC is represented as

$$RSC = (CO_3^{--} + HCO_3^{-}) - (Ca^{++} + Mg^{++})$$

It is considered undesirable, when the proportion of bicarbonates is greater than calcium ions. The water quality is categorized as safe to use, when it <1.25;

with certain management practice when it is 1.25 – 2.25 and unsuitable for irrigation, when it is > 2.25 (Chabra 1996).

The sodium content when gets adhered to soil particles, causes excessive expansion with moisture and can cause severe soil permeability problem. The excess carbonates and bicarbonates combine with calcium and magnesium to precipitate as carbonates of calcium and magnesium. Permeability index of water when exceeds 75 is considered suitable for irrigation (Janardhanan, N.J. 2007).

$$PI = \frac{Na^{+} + \sqrt{HCO3^{-}}}{Ca^{++} + Mg^{++} + Na^{+}} \times 100$$

Parameter Weight assignment: The guidelines for water quality standards which can be used for irrigation have been proposed by (Ayers & Westcot, 1985), BIS code (IS 11624). The water quality determination by using index has been discussed with reference to potability standards (Vasanthavigar et al., 2010). The weights have been assigned to concentrations of these ions based on their relative importance in overall quality of water. The order of importance is suggested to relate toxicity of ions in suagar cane is SO_4>Na>Cl>Mg (Joshi & Naik, 1980), whereas to identify the effect on soil permeability due to irrigation, order is suggested as Na>K>Mg>Ca (Smith, Oster, & Sposito, 2014).

The weights (wi) have been assigned to physico-chemical parameters based on their toxicity plants and role in salinity potential of soil as in **Table 1** with order as EC> pH=HCO_3>Na>SAR>Cl. The EC is overall concentration of salts, hence highest weightage is given. The higher content of sodium can only seriously affect if the high pH or higher values of bicarbonates convert the calcium and magnesium salts to insoluble forms. Hence equal weightage is given to pH and bicarbonates. The amount of sodium is higher than potassium, hence Sodium is rated higher than SAR. The relative weight is computed as:

$$Wi = wi / \sum_{i=1}^{n} wi$$

Where, Wi is the relative weight; wi is the weight of each parameter; n is the number of parameters. The quality rating for each parameter is calculated by dividing its concentration in each water sample by its respective standards **Table 1** and multiplied the results by 100.

$$q_i = (C_i / S_i)x100$$

Where, qi is the quality rating based on concentration of ith parameter; Ci is the concentration of each chemical parameter in each sample in milligrams per litre; Si is the irrigation standard for each chemical parameter in milligrams per litre (Ayers & Westcot, 1994). The sub-index (SI) is first determined for each parameter. $SI_i=W_iXq_i$

The sum of SI values gives the water quality index (WQI).

$$WQI = \sum_{i=1}^{n} SI_i$$

While putting the values of lower and higher limits from the moderately suitable class for every physico-chemical parameter, the limits for water quality index were identified.

Table 1 Relative weights of physic-chemical parameters

Parameter	Permissible Value	Weights (wi)	Relative weight (Wi)
Electrical conductivity (dS/m)	<0.7	5	0.263
pH	6.5-8.4	4	0.210
SAR (meq/l)	<10	2	0.105
Bicarbonate (mg/l)	<91.5	4	0.210
Sodium (mg/l)	<69	3	0.158
Chloride(mg/l)	<140	1	0.053
		$\sum$wi=19	0.999

RESULTS AND DISCUSSION

Summary statistics for various parameters is shown in **Table 2**.

Table 2. Hydro geochemical parameters

Details	Dug Well (n=136)				Tube Well (n=12)				River (n=13)			
	Mean	SD	Min.	Max.	Mean	SD	Min.	Max.	Mean	SD	Min.	Max.
ECw	2.02	1.25	0.37	7.33	2.38	1.19	0.93	5.64	0.41	0.20	0.13	0.79
pH	7.51	0.30	6.87	9.00	7.25	0.43	6.39	8.14	7.43	0.23	7.10	8.00
HCO_3^-	369.5	113.5	85.4	817.4	411.8	132.5	219.6	658.8	217.7	90.8	91.5	381.2
Cl^-	260.0	175.0	55.0	1063.5	301.6	147.1	120.0	634.8	59.6	48.8	24.8	160.0
SO_4^{--}	545.3	579.5	0.1	3947.9	672.5	551.0	73.0	1991.7	45.7	147.9	1.8	538.0
Ca^{++}	189.9	142.4	12.0	821.6	223.4	183.4	60.1	709.4	20.7	30.7	2.0	96.2
Mg^{++}	79.2	62.6	26.7	362.1	98.2	59.5	41.3	255.2	51.1	35.7	12.2	145.8
Na^+	200.7	247.6	23.0	1762.2	229.8	132.2	30.0	449.8	22.9	40.2	2.5	139.9
K^{++}	4.9	11.4	0.0	68.0	1.2	1.6	0.0	4.0	1.1	0.7	0.5	3.0
SAR	3.09	3.4	0.5	17.4	3.5	2.2	0.6	8.3	0.5	0.7	0.1	2.2
% Na	31.1	16.7	8.5	76.5	34.5	16.9	12.2	63.6	11.6	9.5	4.2	34.9
RSC	-9.8	8.9	-44.4	2.6	-12.5	12.0	-40.2	1.0	-1.6	2.5	-9.6	-0.4
PI	43.7	16.2	18.2	96.2	45.2	17.0	24.6	78.0	47.9	7.8	36.8	57.5

The pH of groundwater is slightly saline. For river water and tube wells, pH was found to be well within range of 7.25 to 8.15 whereas wide variation of pH was found in dug well water. The dug wells with high pH were associated with higher sodium percentage (>60%) and high water table, which indicates contribution from agricultural return flows through saline soils. The high pH reduces phosphorous availability to crop and converts calcium into insoluble form which will increase detrimental effect of sodium like decreasing hydraulic conductivity (Subba Rao, 2008). The dug wells were not available in the central part of the study area as the black soil thickness varies upto 10 meters and slope stability issue arising in construction of open dug well, but it the zone where soil salinity was more prominent. The EC measures ability of water to carry current which is proportional to amount of salts getting dissolved. For tube wells situated near settlements, the EC was higher as compared to other tube wells in agricultural areas. The higher EC in tube wells can be attributed to anthropogenic activities. As compared to river water, dug well and tube well samples found to have approximately 10 times concentrations of Cl^-, SO_4^{--}, Ca^{++} and Na^+ ions.

Salinity class and sodium hazard: The water samples were grouped into C1 to S4 salinity classes based on EC (Richards 1954). Eleven river samples are grouped as C2 and 2 samples as C3 (doubtful for irrigation use). These samples (C3) were collected from Warana river in downstream of villages and possibly show contamination occurring due to non- point anthropogenic sources. However, river samples signify by the absence of sodium hazard. All the tube well samples are classified as C3 and C4 with average value of EC as 2.35 dS/m. 18 dug well samples are grouped as C2 (good quality); 93 as C3 (doubtful) and 43 as C4 (unsuitable). Based on SAR, 93% dug well samples are grouped into S1 and the rest as S2. 5% of dug wells belong to S3-S4 and C3-C4 classes. It reveals that this region is more prone to salinity than sodicity hazard. With the exception of 4 dug well samples, other samples indicate RSC less than 2.5 meq/l, indicating that there is no bicarbonate hazard. While considering PI, the 87% of samples are found to be unsuitable for irrigation. However, any definite pattern was not observed in their distribution.

A correlation matrix was prepared to identify relation of various parameters as in **Table 3.** The ions concentrations were converted to meq/l and related with each other. EC showed strong correlation with chlorides and sulphates whereas with calcium magnesium and sodium it has low correlation. Additionally a strong correlation is found for calcium, sodium and SAR for tube well and river water samples respectively. Chloride showed low correlation with sulphates, magnesium and SAR while for river water it showed strong correlation with sodium and SAR. Sulphates showed strong correlation with sodium. A correlation more than 0.8 is assumed to be strong whereas between 0.5 and 0.79 is considered as low.

Table 3 Correlation analysis for dug well water samples

	ECw	pH	HCO_3^-	Cl^-	SO_4^{--}	Ca^{++}	Mg^{++}	Na^+	K^+	SAR
ECw	1									
pH	0.1	1								
HCO_3^-	0.15	0.1	1							
Cl^-	**0.9**	0.1	0.16	1						
SO_4^{--}	**0.85**	0.09	0	0.69	1					
Ca^{++}	0.53	-0.26	0.06	0.42	0.45t	1				
Mg^{++}	0.54	0.15	0.11	0.55	0.68	0.04	1			
Na^+	0.79	0.28	0.15	0.73	**0.81**	0.03	0.53	1		
K^+	0.2	0.03	0.1	0.18	0.16	0.03	0.14	0.16	1	
SAR	0.65	0.32	0.21	0.58	0.66	-0.12	0.38	**0.95**	0.16	1

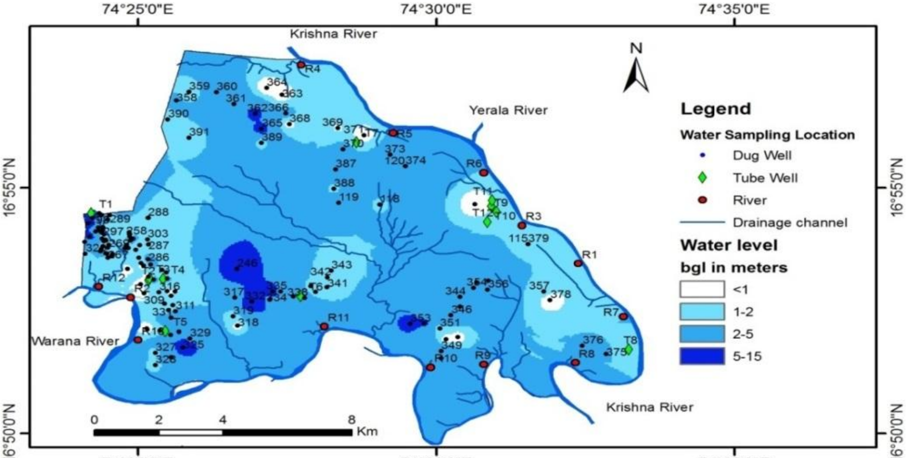

Figure 2 Water level in post monsoon

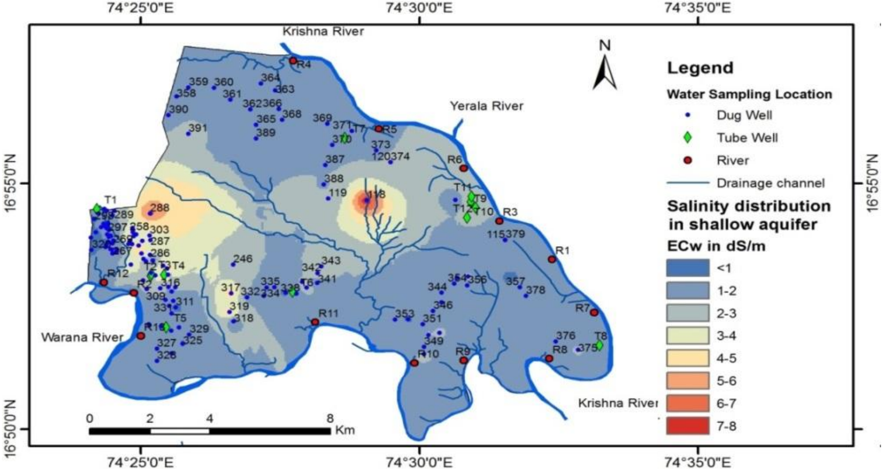

Figure 3 Water sample location and salinity distribution

Sodium ratio is sodium concentration divided by sum of calcium and magnesium, all expressed in meq/l. The water sources with sodium ratio higher than one are assumed to be not fit for irrigation. While estimating sodium ratio, only 8% dug wells have such critical value. These dug wells were identified in the saline soil areas. The Chaddha (1999) diagram (**Figure 5**) was used to find possible ionic combinations facies in irrigation sources. River water samples are aligned in zone 5 indicating there are enough Ca-Mg species to get combine with bicarbonates and the hardness is of temporary in nature. The tube well samples fall in zone 6 indicating higher concentrations of calcium and magnesium species with chlorides and sulphates; and dug well samples spread over zone 4 and 7, indicating major species as combination sodium with chlorides and sulphates. The river water is categorized as Mg-HCO3-Cl type whereas dug well and tube well waters were of combinations of cations and anions in varying degree.

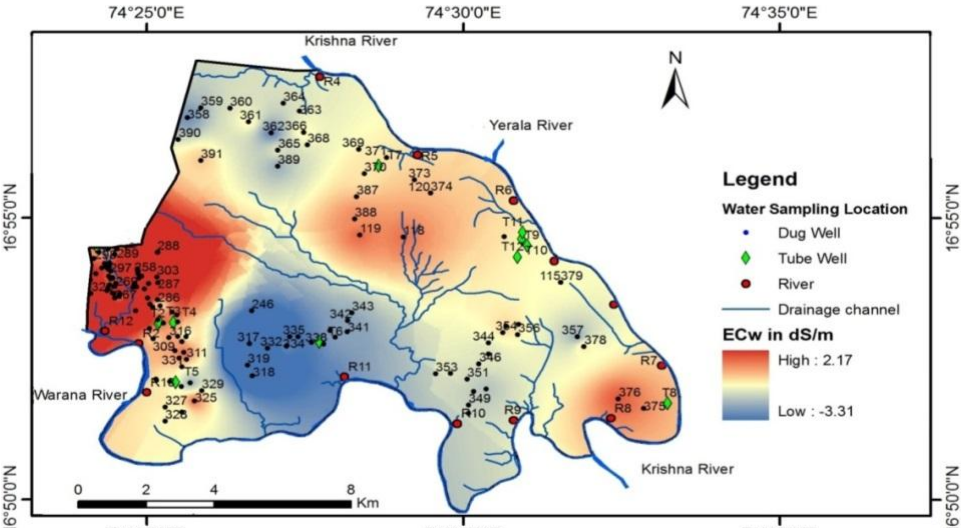

Figure 4 Variation in salinity of water between post and pre monsoon

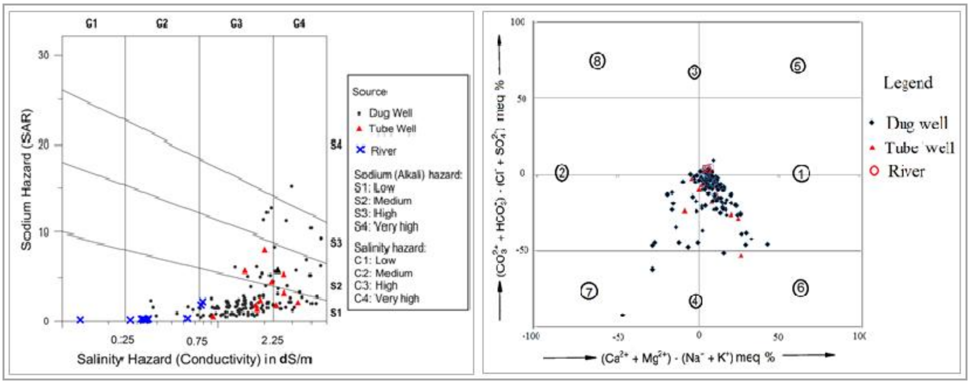

Figure 5 Salinity and Sodium hazard in Wilcox diagram and ionic combination

The water level was close to ground level (0-2 m) in vicinity of river along with some parts in central region, along with EC ranging from 2-7 dS/m as in **Figure 2** and **Figure 3**. The wells with lowest water table (5-15 m) have higher salinity (2-5 dS/m) than the surrounding areas indicating they might be acting as sinks in salt transport mechanism. The **Figure 4** shows salinity variation from post to pre monsoon season. The whole area is mainly composed of black soils with higher clay content which severely affects drainage characteristics. As the season progress from October to May, the need of irrigation arises which is met by river, dug wells. The increase of EC in groundwater is found in the area affected by soil salinity, which shows movement of salts from fields to wells. The reduction of EC was found in wells where water table was at high depth (>5).

The irrigation water quality in the area was assessed through WQI. The water quality source is permissible when (WQI <100) for irrigation use; moderate to destructive effect (WQI 100 and 340); severe effect (WQI > 340) on the soil and crops. Based on WQI, 10 tube well samples were classified as moderate with average WQI as 260 and remaining 2 belong to severe category which were situated near to villages. Two dug well samples were found to be in permissible category; 84% of samples were in moderate category and remaining 14.5% were unsuitable for irrigation which were located in saline soil area. All the river samples fall in permissible category with average 75 WQI. The spatial distribution of WQI is shown in **Figure 6**.

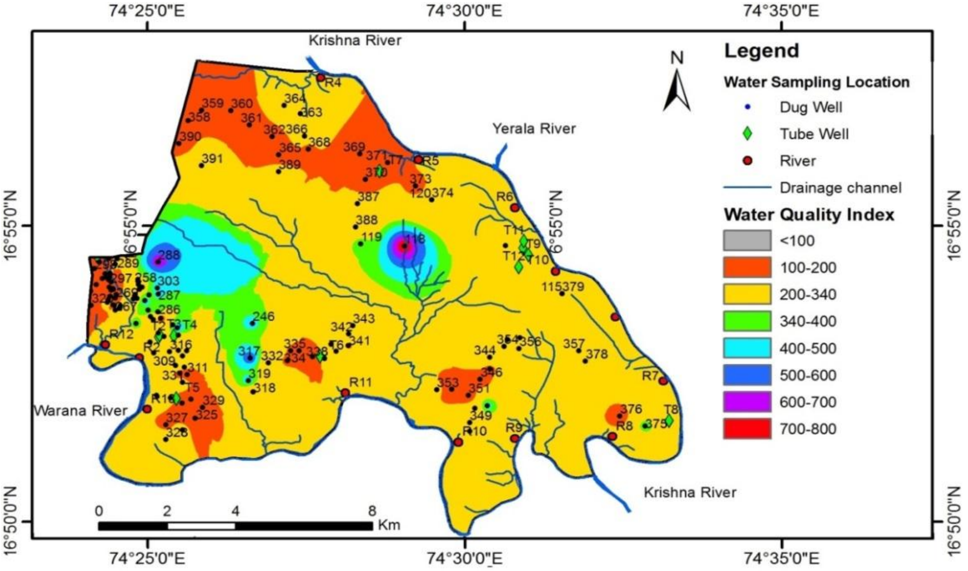

Figure 6 Ground water quality index map

CONCLUSION

The hydrochemical facies of river water fall in Mg-HCO3-Cl type, whereas for tube well and dug well samples were of mixed variety. The salinity in dug wells is more than 0.7 dS/m with tube wells showing excessive salinity which shows contamination of ground water. The salinity increase after post monsoon season shows the transport of salts in dug wells mostly through irrigation return flows. The flow towards river from dug wells with lower water table shows salt movement towards rivers and consequent leaching action. To enhance the salt movement, more number of drains spread over larger area should be provided along with maintenance of natural drainage channels. The WQI technique can be utilized for assessment of irrigation water. The order of importance of parameters suggested can prove to be a guideline while considering the detrimental effect on crop and soil. Continuous monitoring needs to be employed for understanding the factors contributing to soil salinity.

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