International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 2 Issue 6, June - 2013

Developing an Irrigation Water Quality Index for Vrishabavathi Command Area

M.P. Spandana[1], K.R. Suresh[2], B. Prathima[3]

[1] Post Graduate Research Student, Department of Civil Engineering, B.M.S. College of Engineering, Bangalore.
[2] Professor, Department of Civil Engineering, B.M.S. College of Engineering, Bangalore.
[3] Assistant Professor, Department of Civil Engineering, B.M.S. College of Engineering, Bangalore.

Abstract

The sustainable rural development more and more depends on the efficient usage of available water resources. India, being a tropical country, most often, at least in one part of the year, the rain is not sufficient for plant growth and thus reduces the yield. Increase and stability of the agricultural production is possible in the irrigation conditions. The most part (around 70%) of the global water resources is used for food production. Due to urbanization and industrialization, the face of irrigated agriculture is changing with respect to water quantity and quality. Irrigation water quality indicator is used to show if the available water resources have the required quality for application in agriculture. In the present study, an Irrigation Water Quality Index (IWQI) is applied to assess the irrigation water quality of the Vrishabavathi river in its command area of Kanakapura taluk, Bangalore district. Geographical Information System (GIS) is used to evaluate the quality of irrigation waters with regard to irrigation application. From the study, it is found that even though the water is unfit for drinking purpose, it is medium to highly suitable for irrigation.

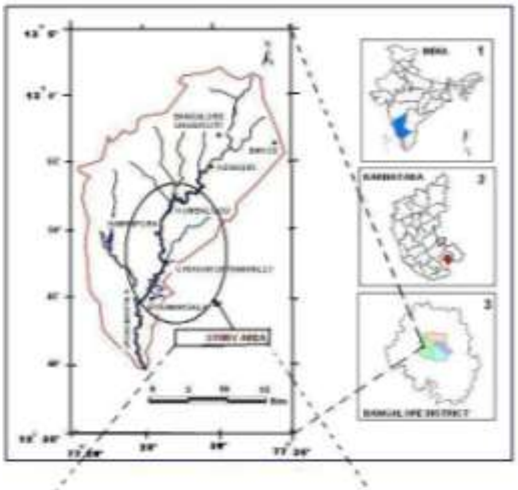
Keywords: Irrigation Water Quality Index, Salinity hazard, Infiltration hazard, Specific ion toxicity, Trace element toxicity, Spatial distribution, GIS Mapping.

1. Introduction

The demographic growth of Bangalore city in an un-planned manner, of late, has resulted in ad-hoc decisions on water supply and sewage management. This, in turn has led to the pollution of some of the vital natural water streams / water bodies, especially on the downstream regions of Bangalore. One such region, which is currently highly polluted beyond acceptable limits, is the Vrishabavathi river, which flows towards the south western region of Bangalore. The Vrishabavathi stream which used to carry fresh water from the Arkavathi basin on the northern side of Bangalore is now virtually a sewage stream. It is contaminated by an assortment of sewage of Bangalore city, industrial waste, solid waste dumps and other effluents.

Vrishabavathi river is a tertiary tributary of the river Cauvery and drains from an aerial extent of 472 km^2 before it joins Suvarnamukhi river at Bhadragundadoddi near Harohalli of Kanakapura taluk, Bangalore district. The Suvarnamukhi river in turn joins river Cauvery at Sangam in Kanakapura taluk. The drainage basin length is 51 km with river water course length of 56 km. Vrishabavathi valley extends on topo sheets 57G/8, 57G/12, 57H/5, 57H/6, 57H/9 and 57H/10 published on a scale of 1:50,000. The valley area is encompassed by North Latitude 12.66° to 13.03° and East Longitude 77.33° to 77.57°. The location map of the study area is shown in Figure 1. A database is created for the study area by collecting 332 water samples (surface and ground water) from the study area. It may be highlighted that all the physically accessible regions were covered in the study area. Water quality database is then integrated to GIS platform to create thematic layers for the salinity hazard, infiltration and permeability hazard, specific ion toxicity, trace element toxicity and miscellaneous effects to the crops. It has been an irrigation practice in this region to draw water from either surface source or through bore wells. Water sampling points in the study area are shown in Figure 2.

ISSN: 2278-0181
Vol. 2 Issue 6, June - 2013



Co-ordinates:

Points	Latitude	Long
A	12.66°N	77.3
B	12.66°N	77.5
C	12.90°N	77.5
D	12.90°N	77.3

Figure 1: Location Map showing the Study Area

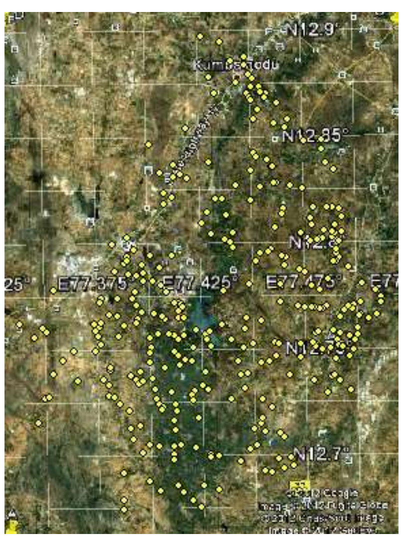


Figure 2: Figure showing the water sampling points

Water samples so collected were analyzed for 11 parameters. The chemical parameters like pH, Electrical Conductivity, Total Hardness, Total Dissolved Solids, Calcium, Magnesium, Chlorides, Sodium, Potassium, Bicarbonates, Iron and Boron. The water samples were analyzed adopting Standard Methods (APHA and AWWA).

2. Assessment of Irrigation Water Quality Index

Irrigation Water Quality is mainly assessed as a function of the level of certain quality parameters. The various parameters for determining irrigation water quality can be categorized into the following major groups: (a) salinity hazard, (b) permeability and infiltration problems, (c) specific ion toxicity, (d) trace element toxicity; and, (e) miscellaneous problems.

2.1 Salinity hazard

Salinity hazard occurs when salts start to accumulate in the crop root zone reducing the amount of water available to the roots. This reduced water availability sometimes reaches to such levels that the crop yield is adversely affected. These salts often originate from dissolved minerals in the applied irrigation water or from a high saline water table. The reductions in crop yield occur when the salt content of the root zone reaches to the extent that the crop is no longer able to extract sufficient water from the salty soil. When this water stress is prolonged, plant slows its growth and drought-like symptoms start to develop.

2.2 Permeability and infiltration hazard

Although the infiltration rate of water into soil is a function of many parameters including the quality of the irrigation water and the soil factors such as structure, compaction and the organic content, the permeability and infiltration hazard typically occurs when high sodium ions decrease the rate at which irrigation water enters the soil's lower layers. The reduced infiltration rate starts to show negative impacts when water cannot infiltrate to the roots of the crop to the extent that the crop requires. Hence, these salts start to accumulate at the soil surface. When the crop is not able to extract the required amount of water from the soil, it is not possible to maintain an acceptable yield and the agricultural production is reduced.

The two most common water quality factors that influence the normal rate of infiltration of water are the salinity of water and the relative concentrations of sodium, magnesium and calcium ions in water that is also known as the sodium adsorption ratio (SAR). The SAR value of irrigation water quantifies the relative proportions of sodium (Na+) to calcium (Ca++) and magnesium (Mg++) and is computed as:

$$SAR = \frac{Na^{+}}{\sqrt{\frac{(Ca^{++})+(Mg^{++})}{2}}} \quad [1]$$

where [Na+], [Ca++] and [Mg++] are defined as the concentrations of sodium, calcium and magnesium ions in water, respectively. A combined EC-SAR criterion is used to assess the potential infiltration hazard that might develop in a soil. While low salinity water with high SAR values has a severe infiltration hazard, high salinity water with low SAR values does not experience any infiltration problem. As both salinity and SAR operate at the same time, the levels of sodium ions in water are the determining parameters for potential infiltration hazards. It is also important to note that the these hazards typically occur in the first few centimeters of the top soil and is strongly linked to the structural stability of the surface soil and its low calcium content relative to that of sodium. It has been found that when soil is irrigated with waters of high sodium concentrations, a high sodium surface is reported to develop which in turn weakens the soil structure. The soil aggregates and then disperses to smaller particles and clogs its pores. Another important parameter is the soil's clay content. The high SAR values have a negative impact on soil structure due to the dispersion of clay particles.

2.3 Specific ion toxicity

Certain ions such as sodium, chloride and boron cause toxicity problems for plants when they are found in elevated concentrations in water or in soil. When these ions are taken up by the plant and accumulate to concentrations high enough to cause crop damage or yield reduction, they are considered to be toxic. The level of toxicity is specific to plant type and uptake rate. The permanent, perennial type crops are more sensitive to this type of toxicity when compared to the annual crops. It is also known that ion toxicity is usually accompanied by other problems such as salinity and infiltration hazards.

a. Sodium

The detection of sodium toxicity is relatively difficult compared to the toxicity of other ions. Typical toxicity symptoms on the plant are leaf burn, scorch and dead tissue along the outside edges of leafs in contrast to symptoms of chloride toxicity which normally occur initially at the extreme leaf tip. The sodium ion also causes hazards in the soil structure creating reduced permeability and water infiltration problems. In addition, calcium and magnesium ions are replaced by sodium ion creating an increase in soil's sodium content. While EC is an assessment of all soluble salts in water, sodium hazard is generally defined separately due to sodium's specific detrimental effects on soil physical properties and plant survival. Thus, the sodium hazard is expressed as SAR, which defines the relative proportions of sodium to calcium and magnesium ions in a water sample. In general, water with SAR values of below 3 are considered to be good quality irrigation waters.

b. Chloride

Chloride is another ion commonly found in irrigation waters. Although it is essential to crops at low concentrations, it can cause toxicity to sensitive crops at higher levels. Its toxic effects are immediately seen as leaf burns or leaf tissue deaths. Normally, injury to plant occurs first at the leaf tips and progresses from the tip back along the edges as severity increases. In excessive cases, early leaf drop or defoliation occurs. In general, waters with chloride values of below 140 mg/l are considered to be good quality irrigation waters.

c. Boron

Boron is an element that is essential for plant growth when found in soil and water in low concentrations but is considered to be toxic when its concentration exceeds certain levels. Boron toxicity symptoms normally appear first on older leaves as a yellowing, spotting, or drying of leaf tissue at the tips and edges. Drying often progresses toward the center between the veins as more boron accumulates with time. In general, boron toxicity starts to develop insensitive crops above 0.7 mg/l.

2.4 Trace element toxicity

The environmental and climatologic factors strongly influence the soil and subsurface water chemistry. These factors could increase the dissolution of numerous minerals in water and could cause toxic effects. The presence of some trace elements and various heavy metals in the irrigation water are known to be responsible for soil pollution and are particularly important for irrigation water quality due to some of their unique properties including their resistance to biodegradation and thermo-degradation.

Unlike other potential pollutants that visibly build upon soils, trace elements and heavy metals can accumulate unnoticed to extremely high toxic concentrations before affecting plant, animal and human life. When their effects on plants are considered, one could observe that they would ultimately be taken up by the plant's root system and would later be accumulated within the plant's stems and leaves. This accumulation adversely effects the plant's growth and yield, and could sometimes cause its death. In addition, the increased concentrations of these minerals in upper layers of the soil would also be transported to lower layers and eventually to groundwater table with the infiltrating water; significantly degrading the groundwater quality. Hence, it is important to continuously monitor the levels of trace elements and heavy metals within soil structure, particularly when irrigation water contains high concentrations.

2.5 Miscellaneous effects

In addition to the hazards and effects discussed in the previous sections, there are additional parameters, presence of which must be assessed carefully in irrigation waters. These are considered within the scope of miscellaneous effects to sensitive crops and include the pH value of the water as well as the concentrations of bicarbonate ion and nitrate–nitrogen.

a. pH

The pH value of irrigation water changes as a function of several parameters including contamination from various pollution sources and acid rains. The pH value influences the carbonate equilibrium, heavy metal content and the relative ratio of nitrogen components, which in turn influences soil quality and plant growth. In acidic waters, calcium, magnesium and aluminum are not absorbed properly by plants. On the other hand, basic waters provide a better environment for plant's uptake of several metals and nutrients. However, basic waters are also responsible for calcium carbonate accumulation that influences the physical structure of water. In general, the ideal pH values of irrigation waters range from 7.0 to 8.0.

b. Bicarbonate

Alkalinity is a measure of the capacity of water to neutralize an added acid. Being the major component of alkalinity, carbonate and bicarbonate ions are generally responsible for high pH values (i.e., above 8.5) of water. Elevated levels of carbonates cause calcium and magnesium ions to form insoluble minerals leaving sodium as the dominant ion in solution. Hence, it is indirectly responsible from the hazards that high sodium concentrations cause on the irrigated crops and the soil. Thus, it is possible to conclude that highly alkaline irrigation waters could intensify sodic soil conditions. In such cases, it is recommended to calculate an adjusted SAR to reflect the increased sodium hazard. In general, the bicarbonate concentration values of below 90 mg/l are considered to be ideal for irrigation.

c. Nitrate–Nitrogen

It is well known that nitrate is the primary source of nitrogen to most plants and is commonly used as a fertilizer. Nevertheless, excessive amounts of nitrate could result in the reduction in yield or quality of the crop as a result of delayed crop maturity, untimely growth or unsightly deposits on the fruit or foliage. However, many of these problems can usually be overcome by proper fertilizer and irrigation management. Furthermore, nitrate application to soils should be done with utmost care since it could easily cause nitrate pollution in local groundwater resources. In general, the ideal nitrate–nitrogen values of the irrigation waters should be below 5 mg/l. The classification of irrigation water quality based upon its Salinity, Permeability and Infiltration, SAR, Chloride, Boron, pH, Bicarbonate and Nitrate-Nitrogen values is presented in Table 1.

Table 1: Irrigation Water Quality Criteria classification (Ayers and Westcot, 1985)

Sl. No	Potential Irrigation Problem	Quality factor	Degree of restrictions of use		
			Slight	Slight to Moderate	Severe
1	Salinity (Affects crop water availability)	EC in dS/m	< 0.7	0.7 to 3.0	> 3.0
		TDS in mg/l	< 450	450 to 2000	> 2000
2	Permeability (Affects infiltration rate of soil)	SAR= 0 -3 & EC	> 0.7	0.7 to 0.2	< 0.2
		SAR = 3-6 & EC	> 1.2	1.2 to 0.3	< 0 .3
		SAR = 6-12 & EC	> 1.9	1.9 to 0.5	< 0.5
		SAR = 12-20 & EC	> 2.9	2.9 to 1.3	< 1.3
		SAR = 20-40 & EC	> 5.0	5.0 to 2.9	< 2.9
3	Specific ion toxicity (Affects sensitive crops)	Sodium as in SAR	< 3.0	3.0 to 9.0	> 9.0
		Chloride mg/l	< 4.0	4.0 to 10.01	> 10.0
		Boron mg/l	< 0.7	0.7 to 3.0	> 3.0
4	Miscellaneous (Affects susceptible crops)	Nitrate mg/l	<5	5 to 30	> 30
		Bicarbonate mg/l	<90	90 to 500	>500
		pH	6.5 to 8.4	-	-

In the present study, Irrigation Water Quality Index (IWQI) is developed based on the method given by Celalettin Simsek and Orhan Gunduz. It is based on the linear combination of the five different groups of irrigation water quality parameters that have potential negative impacts on soil quality and crop yield. In the technique of computation of IWQI, all five groups are simultaneously included in the analysis and are combined to form a single index value, which is then assessed to determine the suitability of the irrigation water. The water quality parameters from these groups are selected based on the guidelines presented in Table 1. These parameters not only best characterize the associated hazard but also combine with others to form a general pattern of water quality for the particular resource. Furthermore, these parameters are arranged such that the results obtained from this tool would make sense to a non-technical decision maker and that he/she could use the method without difficulty.

Table 2: Irrigation water quality criteria classification (Ayers and Westcot, 1985)

Hazard	**Weight**	**Parameter**	**Range**	**Rating**	**Suitability**
Salinity Hazard	5	Electrical Conductivity (EC) dS/m	EC<0.7	3	High
			0.7≤EC≤3.0	2	Medium
			EC>3.0	1	Low
Infiltration and Permeability Hazard	4	Details in Table 3			
Specific ion toxicity	3	(i) Sodium Adsorption Ratio (SAR)	SAR<3	3	High
			3.0≤SAR≤9.0	2	Medium
			SAR>9.0	1	Low
		(ii) Boron (mg/l)	B<0.7	3	High
			0.7≤B ≤3.0	2	Medium
			B>3.0	1	Low
		(iii) Chlorine (mg/l)	Cl<140	3	High
			140≤Cl ≤350	2	Medium
			Cl>350	1	Low
Trace element toxicity	2	(i) Iron (mg/l)	Fe<5.0	3	High
			5.0≤Fe≤20.0	2	Medium
			Fe>20.0	1	Low
Miscellaneous effect on sensitive crops	1	(i) Bicarbonate (mg/l)	HCO_3<90	3	High
			90≤ HCO_3≤500	2	Medium
			HCO_3>500	1	Low
		(ii) pH	7.0≤pH≤8.0	3	High
			6.5≤pH≤7.0 & 8.0≤pH≤8.5	2	Medium
			pH<6.5 and pH>8.5	1	Low

ISSN: 2278-0181
Vol. 2 Issue 6, June - 2013

Table 3: Classification for infiltration and permeability Hazard

	SAR					**Rating**	**Suitability**
	<3	**3 – 6**	**6 - 12**	**12 – 20**	**>20**		
EC dS/m	>0.7	>1.2	>1.9	>2.9	>5.0	3	High
	0.7 – 0.2	1.2 – 0.3	1.9– 0.5	2.9 – 1.3	5.0 – 2.9	2	Medium
	<0.2	<0.3	<0.5	<1.3	<2.9	1	Low

The IWQ index is then calculated as:

$$\textbf{WQI Index}=\sum_{i=1}^{5} G_i \qquad [2]$$

Where 'i' is an incremental index and G represents the contribution of each one of the five hazard categories that are important to assess the quality of irrigation water resource.

The first category of hazard is the salinity that is represented by the EC value of the water and is formulated as:

$$\mathbf{G_1 = w_1 r_1} \qquad [3]$$

where 'w_1' is the weight value of this hazard group and 'r' is the rating value of the parameter.

The second category of hazard is the infiltration and permeability that is represented by EC-SAR combination and is formulated as:

$$\mathbf{G_2 = w_2 r_2} \qquad [4]$$

Where 'w_2' is the weight value of this hazard group and 'r' is the rating value of the parameter.

The third category of hazard is the specific ion toxicity that is represented by SAR,

Boron and Chloride ions in the water which is formulated as weighted average of the three ions as:

$$\mathbf{G_3} = \frac{w_3}{3}\sum_{j=1}^{3} r_j \qquad [5]$$

Where 'j' is an incremental index, 'w_3' is the weight value of this group and 'r' is the rating value of each parameter.

The fourth category of hazard is the trace element toxicity that is represented by the elements given in Table 4 and is formulated as:

$$\mathbf{G_4 = w_4 r_4} \qquad [6]$$

Where 'w_4' is the weight of this group of elements and 'r' is the rating value of the parameter under consideration.

The fifth category of hazard is the Miscellaneous (affects susceptible crops) toxicity that is represented by bicarbonate and the pH which is formulated as:

$$\mathbf{G_5} = \frac{w_5}{2}\sum_{j=1}^{2} r_j \qquad [7]$$

where 'j' is an incremental index, 'w_5' is the weight of this group of elements and 'r' is the rating value of this parameter.

Table 4: Irrigation Water Quality Index (IWQI)

IWQI	**WQI, %**	**Suitability of water for irrigation**
<22	<48 %	Low
22-37	48 – 82%	Medium
>37	>82%	High

3. Thematic Maps

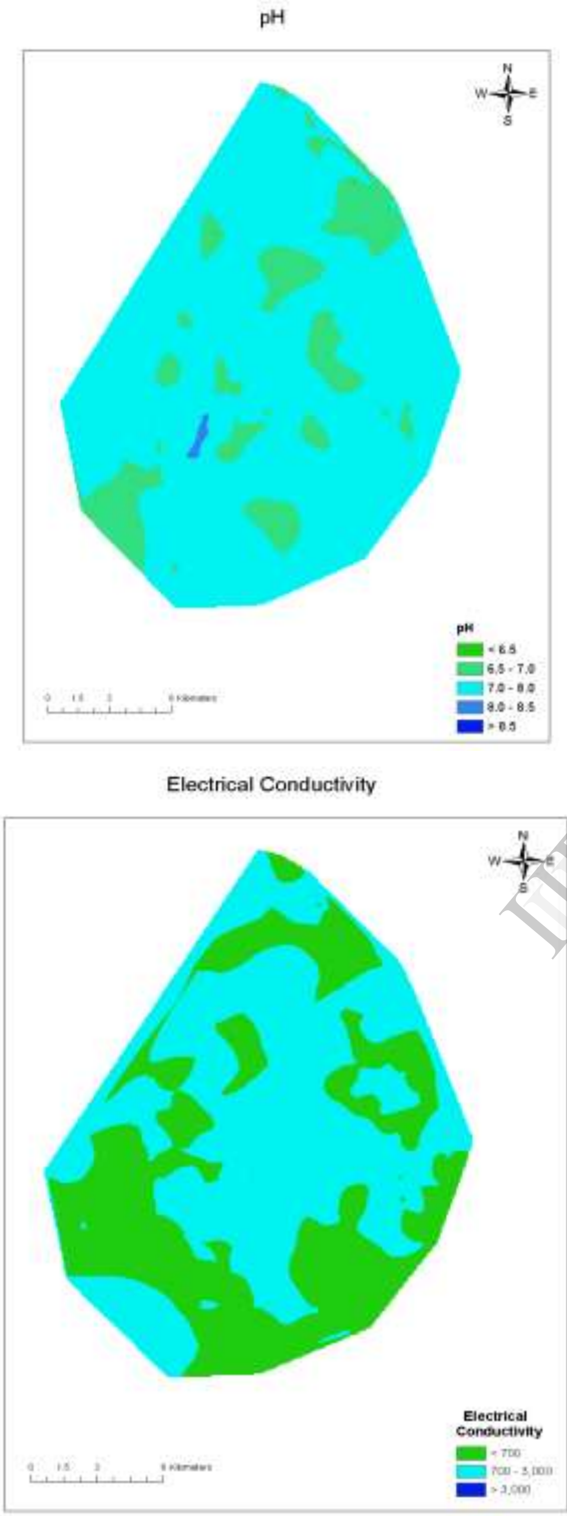


Figure 3: Spatial distribution of pH and Electrical Conductivity of water

Figure 4: Spatial distribution of TDS and Potassium of water

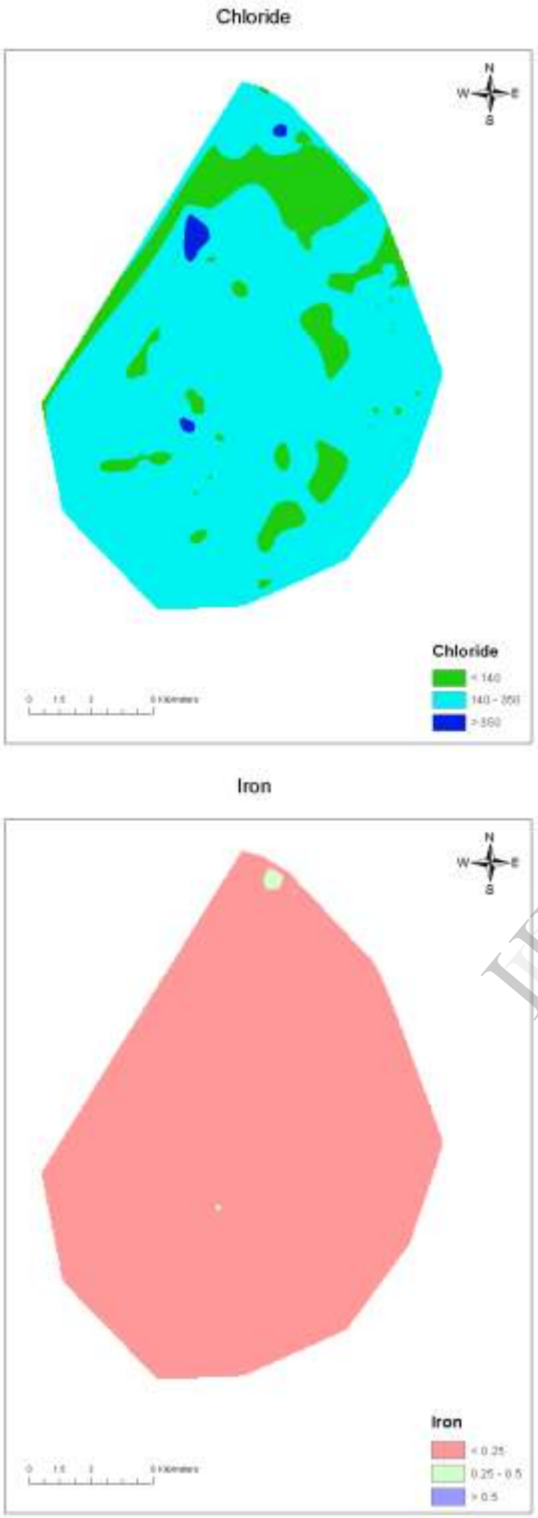


Figure 5: Spatial distribution of Chloride and Iron of water

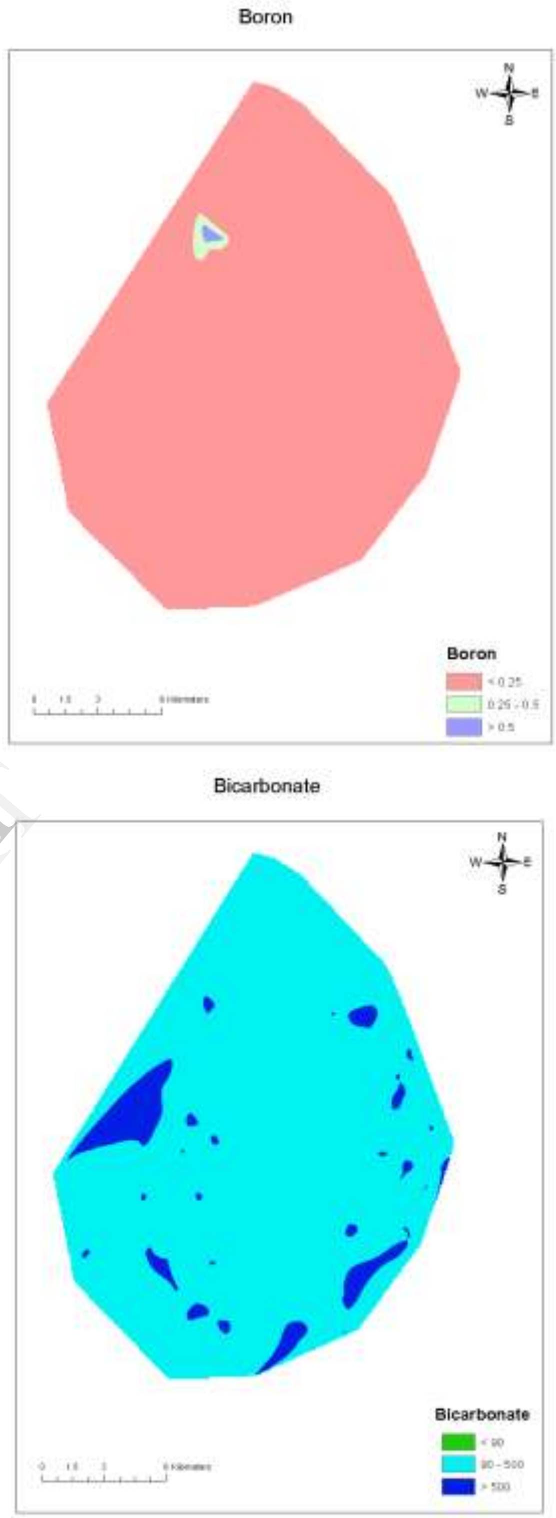


Figure 6: Spatial distribution of Boron and Bicarbonate of water

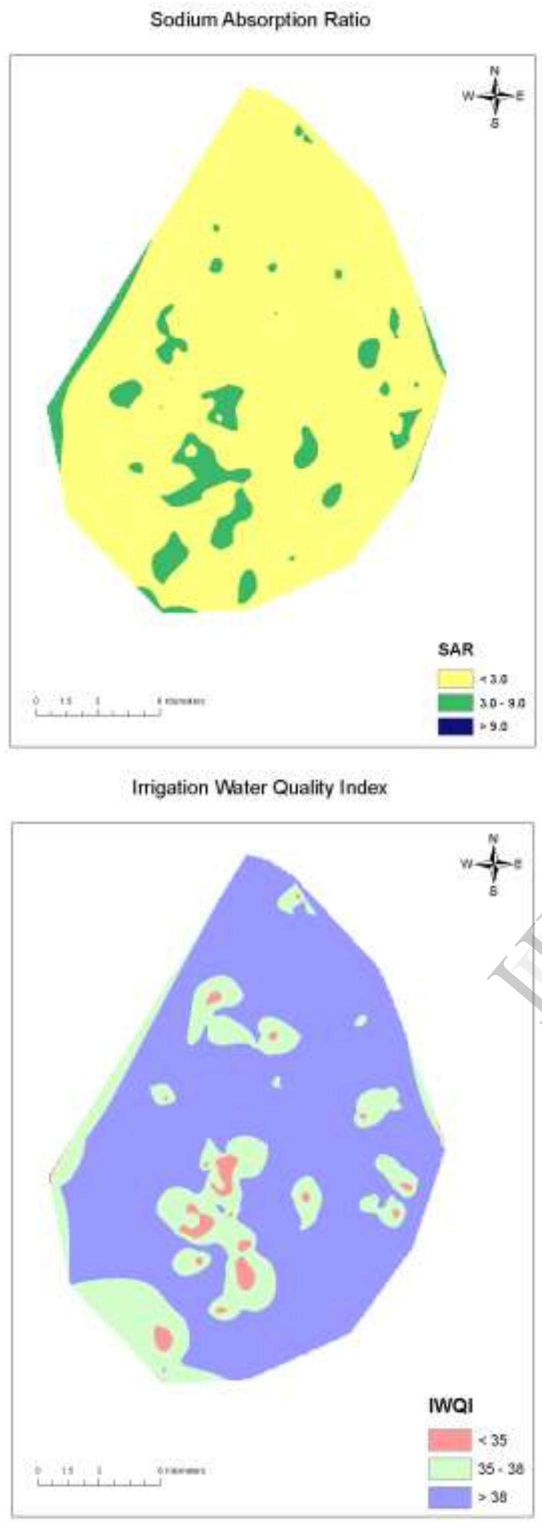


Figure 7: Spatial distribution of SAR and IWQI of water

4. Results and Discussions

1. A careful study of the thematic maps indicated that the sample points have irrigation parameters spread more or less uniformly across the study area. There appears to be a lack of strong trend in the pattern.
2. Figure 3 shows the spatial distribution of pH in the study area. It can be noted that pH of most of the water samples are in the desirable range (7.0 - 8.0). However, in a small region, near the vicinity of the water body of the Byramangala tank, the pH is marginally on the higher side (8.0 - 8.5) and a small percentage of area has a pH between 6.5 and 7.0. It can thus be seen that it falls under the category of high to medium suitability.
3. The spatial distribution of Electrical Conductivity of the water samples analyzed is shown in Figure 3. It can be noted that most of the samples have an EC value ranging from 500 to 1000 μS/cm. The analysis of the data indicated that almost 50% of the samples have EC values in the high suitability range (<700 μS/cm) and 48% of the samples have medium suitability (700 - 1500 μS/cm).
4. The spatial distribution of Total Dissolved Solids in the study region is presented in Figure 4. It can be noted that, here also, the water samples are high to moderately suitable. The number of sample points for high suitability for irrigation is about 57% (<450 mg/l) and 43% of the samples are moderately suitable (450 - 2000 mg/l).
5. Figure 5 shows the spatial variation of the Chloride content in the study region. It is observed that 23% of the samples have a Chloride content of less than 140 mg/l, which corresponds to high suitability. The remaining region falls under the category of medium suitability (140 - 350 mg/l), barring a small region of about 1.5%, which has a chloride content of more than 350 mg/l corresponding to low suitability.
6. The water samples of the study area have an Iron content of less than 0.25 mg/l in nearly 99% 0f the region, as seen in Figure 5. This is an indication of high suitability of water for irrigation.
7. The variation of the Bicarbonate content in the study area is presented in Figure 6. Here, it is noted that almost 85% of the region is of medium suitability (90 – 1500 mg/l) and the remaining 15% is of low suitability (>500 mg/l).
8. The analysis of water samples for Boron indicates that 99% of the samples possess Boron content less than 0.25 mg/l, which is highly suitable for irrigation. This can be seen in Figure 6. A small region in the north-west corner of the study area corresponds to Boron content more than 0.25 mg/l.
9. The spatial distribution of Sodium Absorption Ratio in the study area, which is the ratio of

ISSN: 2278-0181
Vol. 2 Issue 6, June - 2013

Sodium to Calcium and Magnesium ions, presented in Figure 7, also indicates high suitability of water for irrigation. Nearly 76% of the samples are found to be highly suitable for irrigation (<3). The remaining 24% is found to be of medium suitability (3 - 9).

10. As already discussed, Irrigation Water Quality Index is influenced by all the above mentioned parameters. The spatial distribution of IWQI in the study area is presented in Figure 7. Table 4 shows the range of values of IWQI for Suitability of water for irrigation. It is interesting to note that almost 85% of the region is highly suitable for irrigation (IWQI > 37). The remaining 15% of the region is moderately suitable for irrigation (IWQI, 22 - 37).

5. Conclusions

1. The parameters influencing Irrigation Water Quality Index, such as pH, Electrical Conductivity, Total Dissolved Solids, Chloride, Iron, Boron, Sodium Absorption Ratio (influenced by Sodium, Calcium and Magnesium) are found to be in medium to highly suitable ranges. The only parameter which is of low suitability is Bicarbonate.
2. The Irrigation Water Quality Index is found to be medium to highly suitable for growing crops, the region of high suitability being significantly high. There are no well-defined regions of either medium suitability indices or high suitability indices. The range of values is found to be spread randomly across the region. Apparently, there is no influence of the topological profile of the region.
3. Although the study region is apparently highly polluted, in terms of drinking water quality, the Irrigation Water Quality Index analysis indicates contrary results for growing crops. Indeed, the Irrigation Water Quality Index indicates 85% of the region to be highly suitable for irrigation and the remaining 15% to be in medium suitability range.

References

1. Alloway, B. J., and Ayers, D. C., Chemical principles of environmental pollution. Oxford, UK: Blackie Academic and Professional. An imprint of Chapman and Hall, 1993, 291 p.
2. Ayers, R. S., and Westcot, D. W., Water quality for agriculture, FAO Irrigation and Drainage Paper No. 29, Rev. 1, 1985, U. N. Food and Agriculture Organization, Rome.
3. Ayers, R. S., Quality of water for irrigation. Journal of Irrigation and Drainage Div. ASCE, 103 (IR2), 1977, 135–154.
4. Celalettin Simsek and Orhan Gunduz, IWQ Index: A GIS Integrated Technique to Asses Irrigation Water Quality, Environment Moint Assess, Vol. 128, 2007, pp277-300
5. Eaton, F. M., Boron in soil and irrigation waters and its effects on plants, with particular references to the San Joaquin Valley of California, U.S. Department of Agriculture Technical Bulletin No. 448, Washington, District of Columbia, 1935, 131 p.
6. Skidmore, A.K., Witske Bijer., Karin Schmidt., and Lalit Kumar, K., Use of Remote Sensing and GIS for sustainable land management, ITC Journal, 1997, 3(4) 3022-315.
7. Spandana, M. P., M.Sc. (Engg.) thesis, Visvesvaraya Technological University, Belgaum, 2012.
8. Watson, D., "Contouring: A Guide to the Analysis and Display of Spatial Data", Pergamon Press, London, 1992.
9. Wilcox, L. V., The quality of water for irrigation use, U.S. Department of Agriculture Circular No. 962, Washington, District of Columbia, 1948, 40 p.