Seasonal Assessment of Groundwater Quality for Irrigational Suitability in Hirehalla Sub-Basin, Bellary and Davanagere Districts, Karnataka, India.

Ajaykumar N. Asode[1], A. Sreenivasa[2], Mahesh C. Swami[3] and Veeresh Menasinkai[4]

[1, 2 & 3] *Department of Studies in Geology, Karnatak University, Dharwad – 580 003, India.*

[4]*Associate Professor, SKSVMA College of Engg. & Technology Laxmeshwar, Gadag. India.*

***Abstract*— Partial physico-chemical analyses for major cations and anions were carried out in parts of Bellary and Davanagere districts, Karnataka. Major cations and anions include Ca, Mg, Na, K, CO_3, HCO_3, Cl and SO_4. While physical parameters include pH, electrical conductivity, total dissolved solids and hardness. 70 representative water samples were collected each for both pre- and post- monsoon seasons from borewells and surface water sources to study their suitability for irrigation. Partial physico-chemical analyses were performed following the standard procedures of APHA. Irrigational quality parameters such as SAR, RSC, Na %, PI, MH and MR were calculated and the samples classified on these bases. Results indicate that nearly 63% of samples of both the seasons fall under the category "Good to Permissible" based on their conductivity values. USSL diagram for assessing salinity and alkalinity hazard of water used for irrigation identified different categories indicating "Moderate to Medium" hazard. Wilcox diagram for suitability of irrigation water classified nearly 60% of samples in class range Excellent to Permissible. Ayer's classification based on RSC concentration categorized waters to be safe.**

Keywords*— Hirehalla sub-basin, Karnataka, Irrigation, USSL diagram, Salinity, RSC.

I. INTRODUCTION

In a developing country like India, agriculture is the largest provider of livelihood in rural areas and also it plays vital role in nation's economy. With the failure of monsoons leading to droughts and with limited and restricted surface water resources, groundwater is the only alternative resource to carry out agricultural practices. And with advances in agricultural technology, exploring and exploiting groundwater is inevitable so as to yield better crops and optimize production.

Due to growing population, agriculture expansion, and urbanization, the groundwater quality assessment needs more attention to cope with the increasing water demand in semi-arid zone with limited water resources. As water moves through sediments, its composition is modified by dissolution, leaching, precipitation, ion exchange, impact of agriculture, and urbanization. Understanding the integrated role of natural processes, agricultural and urbanization impact is a baseline from which management and protection

of groundwater resources could be properly achieved (Ahmed & Mohamed, 2009).

Many different researchers from India and the world have studied the groundwater quality suitability for domestic and irrigational purpose in different regions using conventional methods and also using GIS applications (Paliwal 1972, Saleh et al 1999, Sreedevi 2002, John Devdas et al 2007, Subba Rao 2006 & 2008, Arumugam & Elangovan 2009, Goyal et al 2010, Subramani et al 2010, Ravikumar & Somashekar 2011, Vasanthavigar et al 2011).

In the present study, which is a typical hard rock terrain wherein no such detailed study has been carried out earlier for its suitability for irrigation. Thus an attempt has been made to study the irrigational parameters and its suitability for irrigation and suggest measures for sustainable management and development of groundwater resources in study area.

II. STUDY AREA

The Hirehalla sub-basin covers parts of Hoovina Hadagli of Bellary and Harapanahalli of Davanagere districts respectively, Karnataka, India. The study area is spread over 485 km^2 and covered in the Survey of India (SOI) toposheets numbered 48M/16, 48N/13 and 57B/01, and geographically falls between 75°45' and 76°15' east longitudes and 14°45' and 15°15' north latitudes (Fig. 1).

Physiographically, major portion of the study area is covered by denudational plateau and some areas are covered with hills and valleys. Topographically, the highest and lowest elevations are 964m and 497m respectively. The main soil types include red sandy soil and black soil. The study area is a typical semi-arid type of region. Rainfall being scanty with April and May months being the hottest while December and January is cooler.

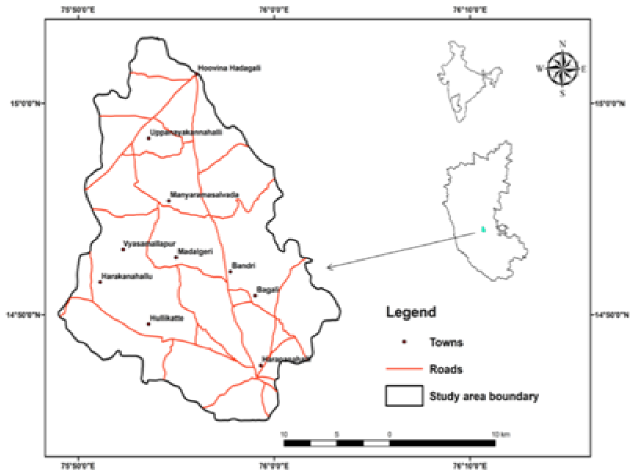

Fig. 1 Location map of Hirehalla sub-basin

III. GEOLOGY OF THE STUDY AREA

In the study area, Peninsular Gneissic Complex (PGC) of Archean age forms the basement rock. The major rock types include granites and gneiss, greywackes with banded iron formations, conglomerate and metabasalts. While the PGC is intruded by basic dolerite dykes in the southern part and criss-cross quartz veins are seen in the eastern part of the study area. The rocks are weathered and fractured and thus the groundwaters occur in an unconfined aquifer conditions. Thus, the study area forms a hard-rock terrain, typical of most parts of the Peninsular India (Fig. 2).

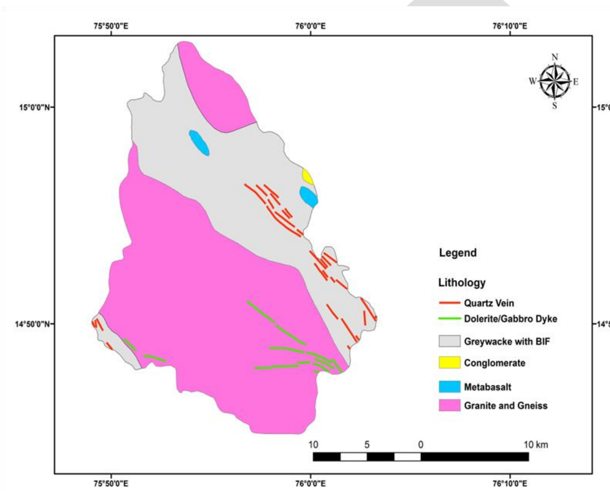

Fig. 2 Geology of Hirehalla sub-basin

IV. MATERIALS AND METHODS

Analysis of partial physio-chemical parameters for both seasons pre- and post- monsoon were carried out following standard guidelines of APHA (1992). Water samples were collected in one litre polyethylene cans which were prewashed in laboratory and washed again in the field using the sample to be collected. pH and EC measurements were carried out on-site using hand-held digital instruments. Concentration of TDS was arrived-at by multiplying EC value by a factor of 0.65 (Todd, 1980). Sodium and Potassium were analysed using Atomic Absorption Spectrophotometer. Hardness, calcium, magnesium, carbonate, bicarbonate, chloride and sulphate were analysed by conventional trimetric method. Table 1 depicts the computational results of partial physio-chemical analyses for both pre- and post- monsoon seasons.

Spatial distribution maps of different parameters were prepared in GIS environment using ArcGIS 10v, wherein spatial analyst tools were applied to generate different thematic maps.

Following are the various irrigational parameters employed to assess the groundwaters suitability for irrigation practices in the Hirehalla sub-basin.

1. Electrical Conductivity (EC) (Sarma, 1982)
2. Total Dissolved Solids (TDS) (Davis & DeWiest, 1966)
3. Sodium Absorption Ratio (SAR) and USSL diagram (Richard, 1954)
4. Sodium Percent (Na %) (Richard, 1954) and Wilcox diagram (Wilcox, 1955)
5. Residual Sodium Carbonate (RSC)
6. Permeability Index (PI) (Doneen, 1964 ; Raghunath, 1987)
7. Magnesium Hazard (MH) and Magnesium Ratio (MR)
8. Ayer's Classification (Ayer, 1977)
   (a) Based on Cl
   (b) Based on HCO_3
   (c) Based on SO_4
   (d) Based on EC
   (e) Based on RSC

Table 1 Results of partial physico-chemical analyses of water samples of pre- and post-monsoon periods

Parameter	Unit	Minimum		Maximum		Average	
		Pre	Post	Pre	Post	Pre	Post
Ca	mg/ltr	8.01	17.63	113.83	81.76	29.15	38.70
Mg	mg/ltr	1.84	1.94	127.37	191.78	47.85	46.97
Na	mg/ltr	15.45	20.74	323.87	323.87	148.18	162.01
K	mg/ltr	0.02	0.001	2.79	3.21	0.30	0.39
CO_3	mg/ltr	0	0	65	0	1.50	0
HCO_3	mg/ltr	30	30	220	170	102.14	113.79
Cl	mg/ltr	31.24	41.18	592.14	570.84	192.15	223.91
SO_4	mg/ltr	22	58	350	380	125.49	160.36
F	mg/ltr	0.05	0.25	5.69	2.9	1.39	1.23

Hardness	mg/ltr	80	92	772	780	278.09	250.6
pH	-	7.67	7.44	8.92	8.98	8.14	8.27
EC	µS/cm	323	338	2646	2554	1155	1148
TDS	-	210	220	1720	1660	750.43	746.14
SAR	-	0.46	0.55	11.70	6.20	4.33	3.02
RSC	meq/ltr	-9.91	-14.77	0.79	-0.58	-3.67	-3.93
%Na	-	13.67	22.84	84.68	77.68	53.82	54.38

V. RESULTS AND DISCUSSION

Irrigational Quality Parameters

1) *Electrical Conductivity (EC)*

EC values in the water samples of Hirehalla sub-basin range from 323 to 2646 µs/cm and 338 to 2554 µS/cm for pre- and post- monsoon season respectively. The classification of quality of water for irrigation based on EC has been given in Table 2 and it is observed that 62.85% of the water samples of both pre- and post- monsoon fall in permissible category and 27.14% and 31.42% of water samples of pre- and post- monsoon respectively fall in good category.

Table 2 Quality of irrigation water based on EC (Sarma et al 1982)

EC in µS/cm	Water Class	No. of Samples falling in pre-/post- seasons			
		Pre-	%	Post-	%
<250	Excellent	-	-	-	-
250-750	Good	19	27.14	22	31.42
750-2000	Permissible	44	62.85	44	62.85
2000-3000	Doubtful	07	10.00	04	5.71
>3000	Unsuitable	-	-	-	-

2) *Total Dissolved Solids (TDS)*

TDS values in the water samples of Hirehalla sub-basin range from 210 to 1720 and 220 to 1660 for pre- and post- monsoon season respectively. Water samples were classified based on the classification scheme of Davis and DeWiest (1966), which is shown in Table 3 and it was found that water samples for both pre- and post- monsoon are suitable for drinking and irrigation purposes.

Table 3 Classification based on TDS (Davis and DeWiest, 1966)

Water Class	TDS mg/l	No. of Samples falling in pre-/post- seasons			
		Pre-	%	Post-	%
Desirable for drinking	<500	53	75.71	51	72.85
Permissible for drinking	500-1000	17	24.28	19	27.14
Useful for irrigation	1000-30000	-	-	-	-
Unfit for drinking & irrigation	>30000	-	-	-	-

3) *Sodium Absorption Ratio (SAR) and USSL diagram*

SAR is a parameter to measure sodium (alkali) proportion in waters suitability for irrigation. Excess of sodium content compared to calcium and magnesium affects soil characters of permeability and thus restricting supply of required water and nutrients to plants. SAR is used to predict the sodium hazard of high carbonate waters, especially if they contain no residual alkali. SAR is calculated using:

$$\mathbf{SAR} = \frac{\mathbf{Na}}{(\mathbf{Ca+Mg})^{1/2}/2}$$

where all concentrations are in meq/l.

Water samples in the study area were classified based on SAR values as given in table 4 and it was found that 99% and 100% of water samples for pre- and post- monsoon fall under the class Excellent.

Similar classification based on salinity and alkalinity hazard of irrigation water using US salinity laboratory diagram (USSL, 1954) revealed that 40% and 38.57% of samples of pre- and post- monsoon respectively fall in field C3S1 indicating that medium salinity and low sodium hazard and 28.57% and 32.85% of water samples of pre- and post- monsoon respectively fall in field C3S2, indicating medium salinity and medium sodium hazard while 20% and 21.42% of water samples of pre- and post- monsoon respectively fall in field C2S1, indicating moderate salinity and low sodium hazard (Fig. 3 & 4 and Table 5).

Table 4 Alkalinity hazard classes based on SAR

SAR	Alkalinity Hazard	Water Class	No. of Samples falling in pre-/post- seasons			
			Pre-	%	Post-	%
<10	S1	Excellent	69	99	70	100
10-18	S2	Good	01	1	-	-
18-26	S3	Doubtful	-	-	-	-
>26	S4	Unsuitable	-	-	-	-

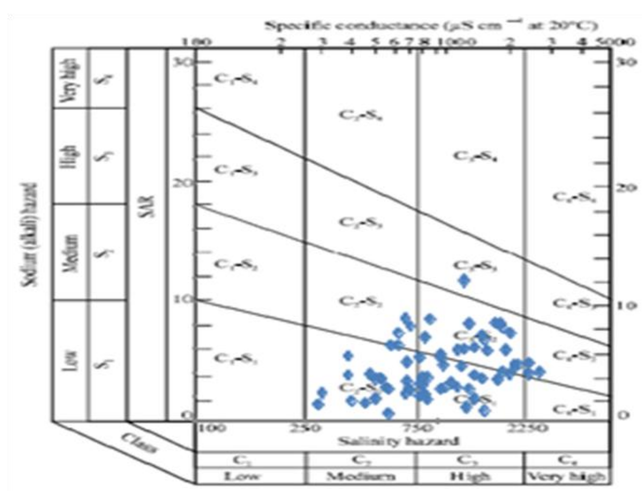

Fig. 3 USSL classification of irrigation waters for premonsoon

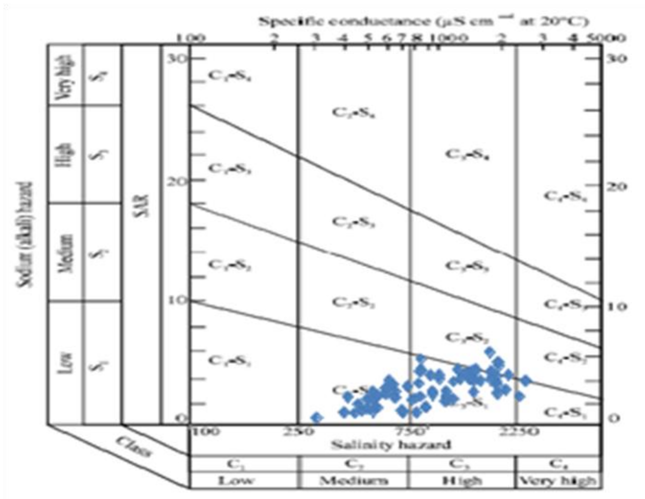

Fig. 4 USSL classification of irrigation waters for postmonsoon

Table 5 Salinity and alkalinity hazard of irrigation water in USSL diagram

CLASSIFICATION USSL Diagram by Richards, 1954						
Salinity	**SAR**	**Type**	**Pre-**	**%**	**Post-**	**%**
Low	Low	$C_1 S_1$	-	-	01	1.42
Low	Medium	$C_1 S_2$	-	-	-	-
Low	High	$C_1 S_3$	-	-	-	-
Low	Very-High	$C_1 S_4$	-	-	-	-
Moderate	Low	$C_2 S_1$	14	20	15	21.42
Moderate	Medium	$C_2 S_2$	04	5.71	-	-
Moderate	High	$C_2 S_3$	-	-	-	-
Moderate	Very-High	$C_2 S_4$	-	-	-	-
Medium High	Low	$C_3 S_1$	28	40	27	38.57
Medium High	Medium	$C_3 S_2$	20	28.57	23	32.85
Medium High	High	$C_3 S_3$	01	1.42	-	-
Medium High	Very-High	$C_3 S_4$	-	-	-	-
High	Low	$C_4 S_1$	01	1.42	01	1.42
High	Medium	$C_4 S_2$	02	2.85	02	2.85
High	High	$C_4 S_3$	-	-	01	1.42
High	Very-High	$C_4 S_4$	-	-	-	-

4) Sodium Percent (Na %) and Wilcox diagram

Methods of Wilcox (1955) and Richards (1954) have been used to classify and understand the basic character of the chemical composition of water, since the suitability of the water for irrigation depends on the mineralization of water and its effect on plants and soil (Saleh et al 1999). Sodium percent can be computed using formula:

$$\text{Na \%} = \frac{(Na + K) * 100}{(Ca+Mg+Na+K)}$$

where all concentrations are in meq/l.

Water samples from the study area were classified based on sodium percent as shown in table 6 and it revealed that 60% of the water samples for both pre- and post- monsoons fall under permissible category. Water samples were also plotted on Wilcox diagram (Wilcox, 1955) (Fig. 5 & 6) and compared which yielded similar results for both pre- and post- monsoon season as shown in table 7. Fig. 7 & 8 showing spatial distribution of sodium percent values in pre- and post- monsoon periods.

Table No. 6 Suitability of groundwater for irrigation based on Percent Sodium (Na %)

% Na	**Class**	**No. of Samples falling in pre-/post-seasons**			
		Pre-	**%**	**Post-**	**%**
<20	Excellent	02	2.85	-	-
20-40	Good	10	14.28	11	15.71
40-60	Permissible	31	44.28	31	44.28
60-80	Doubtful	26	37.14	28	40
>80	Unsuitable	01	1.42	-	-

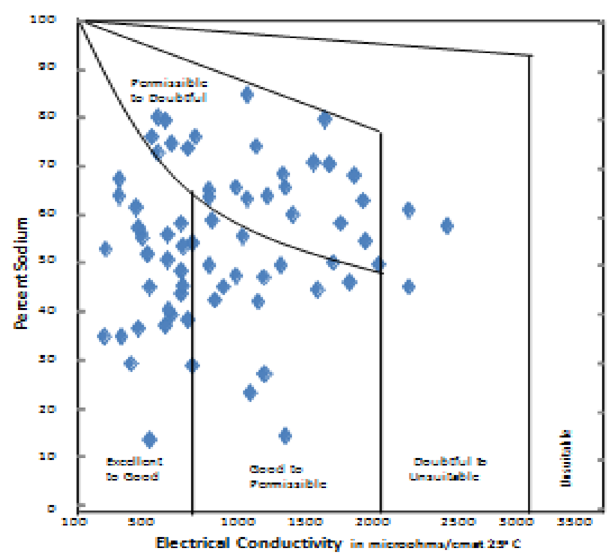

Fig. 5 Classification of irrigated waters for premonsoon based on Wilcox, 1955

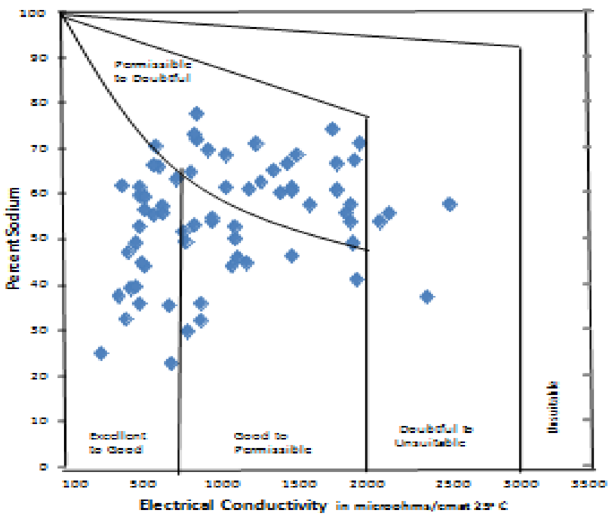

Fig. 6 Classification of irrigated waters for postmonsoon based on Wilcox, 1955

Table 7 Classification of irrigation waters (Wilcox, 1955)

Classification	No. of Samples in			
	Pre-monsoon	%	Post-monsoon	%
Excellent to Good	27	38.57	22	31.42
Good to Permissible	15	21.42	15	21.42
Permissible to Doubtful	25	35.71	29	41.42
Doubtful to Unsuitable	03	4.28	04	5.71
Unsuitable	-		-	-

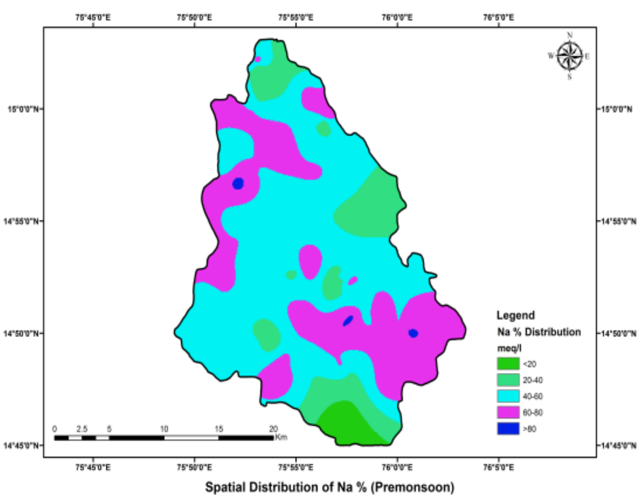

Fig. 7 Spatial distribution of Na % in premonsoon

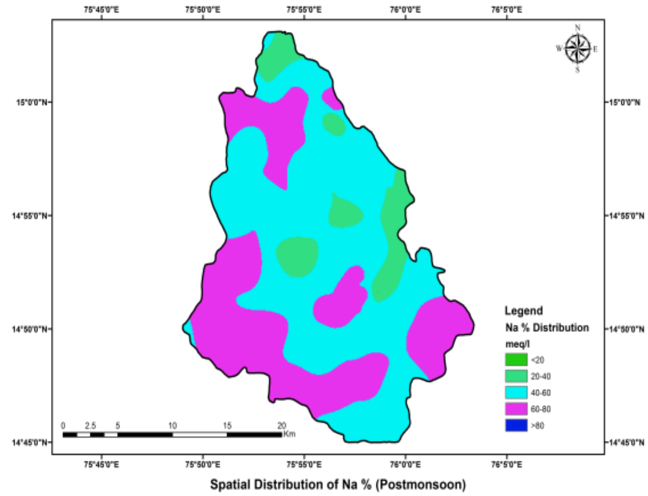

Fig. 8 Spatial distribution of Na % in postmonsoon

5) Residual Sodium Carbonate (RSC)

The sum of excess carbonate and bicarbonate in groundwater over calcium and magnesium also determines its suitability for irrigation. This is expressed as residual sodium carbonate (RSC) and is computed using: (Ragunath, 1987)

$$RSC = (HCO3 + CO3) - (Ca + Mg)$$

where all concentrations are in meq/l.

RSC classification of water samples in study area is given in Table 8. It is found that all the water samples fall in the category Good for pre- and post- monsoon seasons.

Table 8 Quality of groundwater based on RSC after Ragunath, 1987

RSC	Remark	No. of Samples			
		Pre-monsoon	%	Post-monsoon	%
<1.25	Good	70	100	70	100
1.25-2.5	Doubtful	-	-	-	-
>2.5	Unsuitable	-	-	-	-

6) Permeability Index (PI)

Permeability Index values also indicate the suitability of groundwater for irrigation (Doneen, 1964; Ragunath, 1987) and are calculated as:

$$PI = \frac{(Na + HCO_3^{-1/2}/2) * 100}{(Ca + Mg + Na)}$$

where all concentrations are in meq/l.

PI classification of Hirehalla sub-basin is presented in table 9 and it is found that 72.85% of water samples fall in the class Allowable and 27.14% of water samples in the class Unsafe for both pre- and post- monsoon season. Fig. 9 & 10 shows the spatial distribution of PI values for pre- and post- monsoon seasons.

Table 9 Classification of irrigation water based on PI (Doneen, 1964)

Classification	Range	No. of Samples falling in pre-/post- seasons			
		Pre-	%	Post-	%
Safe	<25%	-	-	-	-
Allowable	25-75%	51	72.85	51	72.85
Unsafe	>75%	19	27.14	19	27.14

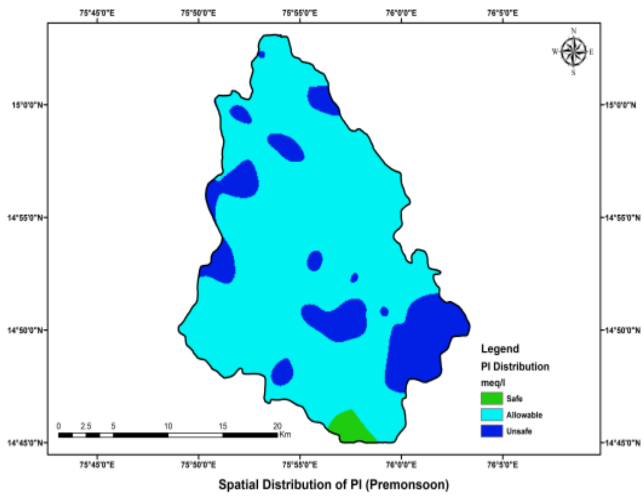

Fig. 9 Spatial distribution of PI values in premonsoon

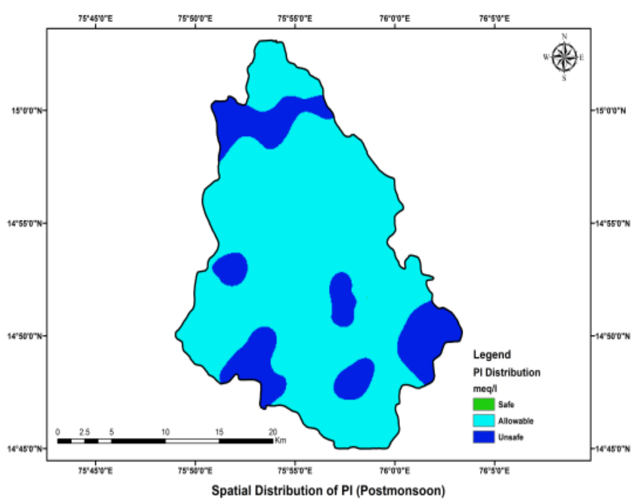

Fig. 10 Spatial distribution of PI values in postmonsoon

7) Magnesium Hazard and Magnesium Ratio

Magnesium hazard (MH) is expressed as:

MH = Mg / (Ca + Mg) *100
and
MR = Mg / Ca
where all parameters are in meq/l

MH value >50% adversely affects the crop yield due to increase in soil alkalinity. Based on this the study area water samples were classed and represented in Table 10 and it was found that 80% of pre-monsoon samples and >57% of post-monsoon samples are not-suitable for irrigation as they have reported >50% MH.

Further, based on magnesium ratio (MR), water samples were classified for their suitability for irrigation as mentioned in Table 11 and it was observed that >58% of samples of study area are unsafe for irrigation during pre-monsoon period while only >27% of samples were unsafe during post-monsoon period. Fig. 11 & 12 shows the spatial distribution of MR values for both season.

Table 10 Classification of waters for irrigation based on Magnesium Hazard

Classification	Range	No. of Samples falling in pre-/post- seasons			
		Pre-	%	Post-	%
Suitable for irrigation	<50%	14	20	30	42.85
Unsuitable for irrigation	>50%	56	80	40	57.14

Table 11 Classification of waters for irrigation based on Magnesium Ratio

Classification	Range	No. of Samples falling in pre-/post- seasons			
		Pre-	%	Post-	%
Safe	<1.5	18	25.71	34	48.57
Moderate	1.5-3.0	11	15.71	17	24.28
Unsafe	>3.0	41	58.57	19	27.14

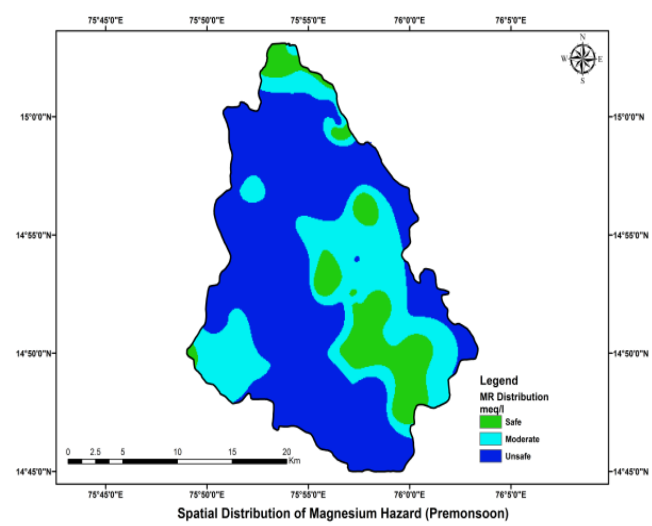

Fig. 11 Spatial distribution of MR values during premonsoon

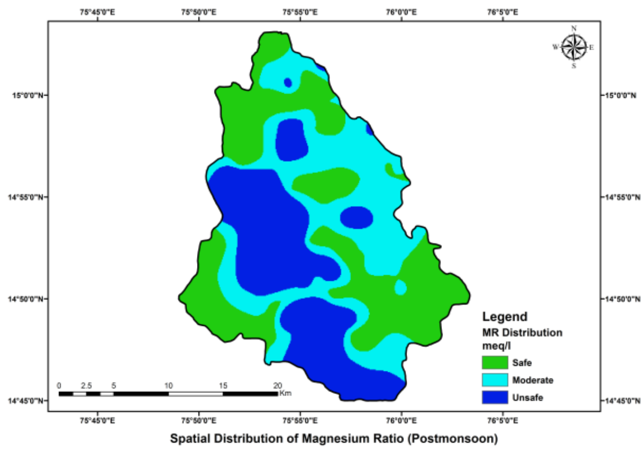

Fig. 12 Spatial distribution of MR values during postmonsoon

8) Ayer's Classification

Based on the classification scheme of Ayer (1977), water samples were classified using the concentration of Cl, HCO_3, SO_4, EC and RSC, and the same are presented in Tables 12 to 16. Accordingly, based on Cl concentration it was found that nearly 70% of samples were classed in Increasing Problem and nearly 20% with Severe Problem. Based on HCO_3 concentration nearly 70% of samples was reported in class Increasing Problem and nearly 29% in class No Problem. Based on SO_4 concentration, majority of samples fall in class Excellent and some in Good and Permissible. Based on EC concentration, nearly 75% of samples fall in class Increasing Problem and nearly 24% in No Problem. And based on RSC concentration, all samples are classed as Safe for irrigation.

Table 12 Classification based on Cl concentration

Classification	Range	No. of Samples falling in pre-/post-seasons			
		Pre	%	Post	%
No Problem	<4	09	12.85	05	7.14
Increasing Problem	4-10	47	67.14	54	77.14
Severe Problem	>10	14	20	11	15.71

Table 13 Classification based on HCO_3 concentration

Classification	Range	No. of Samples falling in pre-/post-seasons			
		Pre-	%	Post-	%
No Problem	<1.5	24	34.28	17	24.28
Increasing Problem	1.5-8.5	46	65.71	53	75.71
Severe Problem	>8.5	-	-	-	-

Table 14 Classification based on SO_4 concentration

Classification	Range	No. of Samples falling in pre-/post-seasons			
		Pre-	%	Post-	%
Excellent	<4	59	84.28	49	70.00
Good	4-6.5	10	14.28	18	25.71
Permissible	6.5-12	01	1.42	03	4.28
Doubtful	12-20	-	-	-	-
Unsuitable	>20	-	-	-	-

Table 15 Classification based on EC concentration

Classification	Range	No. of Samples falling in pre-/post-seasons			
		Pre-	%	Post-	%
No Problem	<0.75	17	24.28	16	22.85
Increasing Problem	0.75-2.75	53	75.71	54	77.14
Severe Problem	>2.75	-	-	-	-

Table 16 Classification based on RSC concentration

Classification	Range	No. of Samples falling in pre-/post-seasons			
		Pre-	%	Post-	%
Safe	<1.25	70	100	70	100
Marginal	1.25-2.25	-	-	-	-
Not Suitable	>2.25	-	-	-	-

CONCLUSION

The irrigational quality of waters of Hirehalla sub-basin based on SAR, RSC and Na % values, we suggest that most of samples are suitable for irrigation except in some areas attention is required where salinity is comparatively higher. Therefore it is suggested that the farmers crop salt-tolerant plants. The area is typical hard rock terrain where the rocks are highly weathered and fractured thus acts as conduits for storage and flow of groundwaters. Groundwaters are found in unconfined aquifer conditions.

USSL diagram shows the water samples plotting in the field C_2S_1, C_2S_2 C_3S_1 and C_3S_2, indicating waters characterized by medium-salinity and low-to-medium sodium hazard. Wilcox diagram indicated most of the water samples falling in Excellent to Good, and Good to Permissible category thus found to be suitable for irrigation purposes.

Permeability Index (PI) reveals 72.85 % of water samples fall in class allowable and suitable for irrigation. Magnesium hazard (MH) in the Hirehalla sub-basin showed 80% and 40% of water samples in pre- and post- monsoons range greater than 50%, which has an adverse effect on crop yield as it increases soil alkalinity. Thus farmers are suggested to test the soil and water seasonally and necessitate action.

Based on Ayer's (1977) parameters chloride (Cl), bicarbonate (HCO_3) and EC were classified which indicated average 70% of water samples falling under the class Increasing Problem. While parameters RSC and SO_4 were categorized as Safe and Excellent to Good respectively for irrigational suitability.

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