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**RESEARCH ARTICLE**

**Chemical Hydrogeological Study of the Kim River Basin, South Gujarat,India: with Special Reference to Impact of Irrigation on Groundwater Regime.**

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## Abstract

The groundwater quality in the Kim River Basin, south Gujarat was evaluated for its suitability for irrigation use by setting up a network of 43 observation wells. Seasonal sampling of these wells was carried out for two consecutive years and the groundwater samples were analyzed for various physico-chemical parameters. The aquifer characterization was also done in order to understand the seasonal and spatial groundwater quality fluctuations. Analysis revealed that the pH values of all the samples were alkaline in the range of 7.5 to 8.7 with very little variation on seasonal basis. The Electrical Conductivity showed seasonal variation ranging from 340 to 7700 mS/cm which was attributed to combined effects of aquifer type and extensive irrigation practices in the region. Irrigation water quality indices such as Sodium Absorption Ratio, Soluble Sodium Percentage, Kelly's Ratio, Schoeller's Index and Puri Salt Index were applied to the analyzed groundwater samples. The results clearly indicated that the basaltic aquifers in the upstream had good water quality suitable for irrigation in all the seasons. The sedimentary aquifers in the central part of the Basin had slightly moderate water quality owing to solution weathering and thus, not acceptable for irrigation without proper dilution. The lower basin had high potential of groundwater due to presence of alluvial aquifers but the quality of water was unsuitable for irrigation due to high enrichment in various cations and anions.



## Introduction:-

Water is a vital resource for the very existence of human life and its quality is of utmost importance as it is directly related to the human health. Agriculture and industrial sectors are sprawling to meet the demands of the growing populations. Agricultural activities worldwide, account for approximately 70% consumption of freshwater resources followed by industrial and domestic segments (FAO, 2015)[4]. Moreover, the dependency on groundwater has significantly increased due to uncertainty of surface water resources in terms of its quality and quantity.

Chemical characterization of groundwater for irrigation use has been attempted by adopting internationally accepted methods such as Sodium Absorption Ratio (SAR), Kelly's Ratio (KR), Soluble Sodium Percentage (SSP), Permeability Index (PI) and Residual Sodium Carbonate (RSC) to define its suitability for irrigation purpose.

### Study Area:-

The Kim River constitutes, an independent and relatively smaller watershed basin, falling within the jurisdiction of Bharuch and Surat Districts of south Gujarat, India. Geographically it is bounded between the co-ordinates N - $21^0$ 19': $21^0$ 38' and E – $72^0$ 40': $73^0$ 27'and sprawling in 1330 $km^2$ area. The River flows in the south-west direction covering a total length of 107 km and ultimately debouches in the Gulf of Khambhat (Fig.1).The River shares its watershed boundaries with two major fluvial systems of Gujarat, viz., the Narmada River in its north and the Tapi River in its south.

The average annual rainfall of the watershed is 1000 $mm^2$. The study area constitutes a part of rich agricultural belt of south Gujarat, characterized by a very well-knitted network of canal system. The Pingut and Baldeva are the two medium irrigation schemes in the upper part of the basin; whereas middle and lower part of the basin is benefited by the Ukai-Kakrapar Irrigation canal system. The watershed area is known for growing paddy-sugarcane-cotton-pulses and a variety of cash crops.

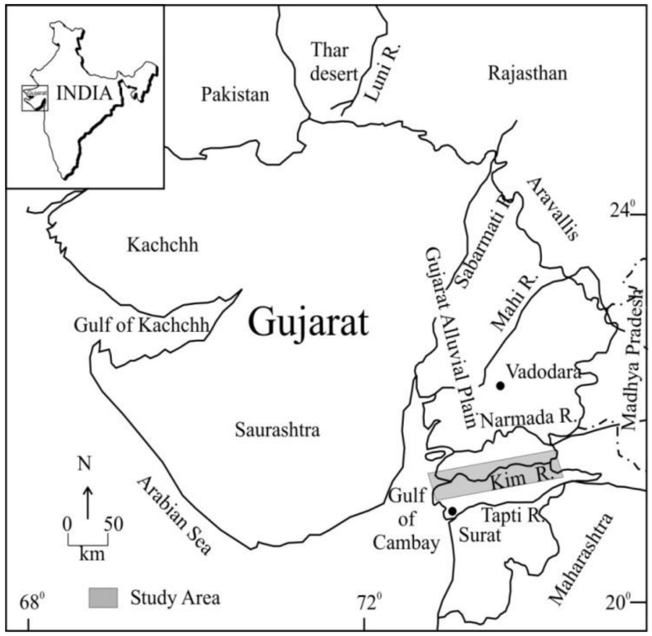


Figure 1: Location of Kim River Basin

**Hydrological Characteristics:-**

The Kim River Basin is characterized by three distinct hydrogeological units (Fig.2) viz.

i. *Consolidated Sediments:* The basaltic lava flows occupying the upper basin fall within this category. The aquifers are predominantly phreatic type restricted within the weathered and fractured parts of the basalts. Aquifers display high order (up to 10m) of seasonal fluctuations in its water table. Aquifers are characterized by low to moderate yield (120-340 liters per minute)

ii. *Semi-Consolidated Sediments:* The middle part of the basin is occupied by the Tertiary sedimentary sequence comprising conglomerate-sandstone-shale and limestones. Aquifers developed within sandstones are ideal source of water; whereas, limestones being lacking secondary porosity, develop as poor aquifers. These aquifers are also characterized by a marked seasonal fluctuation in the water table and is of moderate yield(250-450 liters per minute)

iii. *Unconsolidated Sediments:* Middle and lower parts of the basin inhibit a thick pile of fluviotile and estuarine sediments of Holocene-Quaternary age. The flood plain deposits in particular area are rich repository of groundwater. The aquifers are multi-layered phreatic to confined in nature. However on approaching towards the coast, aquifers are brackish-saline due to the factors like sediments, inherent salinity, sea water intrusion and water logging.

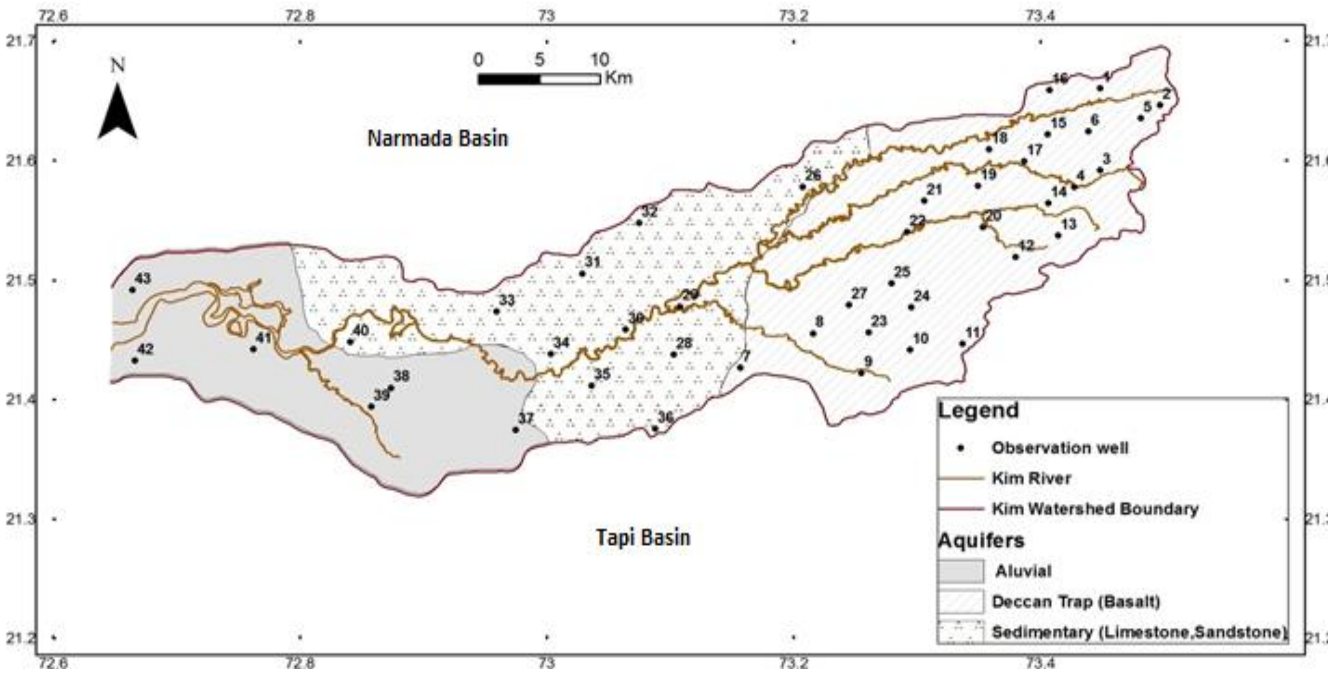


***Figure 2: Hydrogeological Map of Kim Watershed***

As the canal irrigation in this region is very well developed, the groundwater resources are almost neglected. Thus water intensive cropping pattern and over irrigation has resulted in excessive returned irrigation seepage that has led to slow and steady rise in the water table and overall quality deterioration. This study is an attempt to capsulate the chemical characterization of groundwater based on seasonal changes and spatial variations; and also evaluating its suitability from irrigation point of view by application of appropriate scales and indices.

***Methodology:***

For monitoring the groundwater on seasonal basis, the study area was divided into equal grids (3km x 3km) and a network of observation wells was set up. In all, 43 groundwater sampling locations were selected which were all dug wells so that the water table can be monitored (Fig. 2).Observation wells located in the upstream of the river system, had partially weathered basalt or amygdaloidal basaltic aquifers which would usually run dry during the summer season. Thus, the number of sampling locations in the upstream is slightly more than those in the rest of the river basin. The sampling was carried out for two consecutive years of 2012 and 2013 on seasonal basis. Pre-monsoon sampling was done in May while the Post-monsoon sampling was carried out in October.

Groundwater samples were collected in clean, sterile, white cans of 1L capacity. Conductivity, pH and temperature were measured in-situ while rests of the parameters were analyzed in the laboratory using Standard Methods for Water Analysis[9]. (Table 1)

| Sr. No. | Parameter | Method/Instrument |
|---|---|---|
| 1. | pH | pH Meter |
| 2. | Electrical Conductivity | EC meter |
| 3. | TDS | Gravimetric Method |
| 4. | Hardness | EDTA Complexometric Titration |
| 5. | Chlorides | Argentometric Titration |
| 6. | Phosphates | Stannous Chloride Colorimetric Method |
| 7. | Sulphates | Barium Chloride Precipitation Method |
| 8. | Carbonates and Bicarbonates | Sulphuric Acid Titration |
| 9. | Sodium and Potassium | Flame Photometer |

***Table 1: Methods Used for Chemical Analysis***

## Results and Discussion:-

Study on regional groundwater quality in irrigation use and impact of irrigation on groundwater quality holds a vital significance in understanding the geo-environmental implications.

10 observation wells located in the upstream of the river were dry during the pre-monsoon sampling and so, are not considered for calculation purpose. Table 3(a) and 3(b) reveal the seasonal chemical composition of groundwater in the Kim River Basin.

Olabode et al (2013) studied the hydro chemical evolution of groundwater in the Akure region of Western Nigeria and calculated parameters such as SAR, SSP, PI, KR and chloro alkaline indices to determine its suitability for irrigation purpose[9]. Similarly, Islam and Shamsad (2009) carried out similar suitability studies for waters of Bogra District in Bangladesh[5].Ackahet (2011) assessed the groundwater quality to meet the criteria for drinking and agricultural purposes in farming and sprawling settlement located in East Municipality of Ghana[1].

India is an agricultural country and majority of farming is based on rain-fed irrigation. For round-the-year farming practices and uncertainty in the monsoon season, various irrigation schemes have come up in different parts of the country to provide sufficient waters for irrigation activities. Khan and Abbasi (2013) assessed the groundwater quality in the Ganga-Nim River Sub Basin in the central Ganga Plain[7], while Ramesh and Bhuvana (2012) analyzed the hydro chemical characteristics of groundwater in Periyakulam Taluka of Theni district of Tamil Nadu[10].Agrawal et al (2013) carried out similar studies in area around Raisar District of Bikaner, Rajasthan[2].Nag and Das(2014) carried out a GIS based study of Suri I and II blocks of Birbhum District in West Bengal to evaluate the groundwater quality for irrigation and domestic purposes[8].

**pH:-**

All the samples of pre- and post-monsoon (Table 3a and b) were found to have alkaline pH in the range of 7.5 to 8.7. Not much variation was seen in the pH values on the seasonal basis. The values were within the permissible limit of (6.5-8.5) of Irrigation Water Quality Standards. (IS:2296).

| Well No. | Village | Parameters | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | pH | | EC (mS/cm) | | TDS | | $Cl^-$ | | $Ca^{+2}$ | | $Mg^{+2}$ | | $Na^+$ | | $K^+$ | |
| | | Pre | Post | Pre | Post | Pre | Post | Pre | Post | Pre | Post | Pre | Post | Pre | Post | Pre | Post |
| 1 | Tadphalia | 7.3 | 7.5 | 681 | 563 | 436 | 360 | 53 | 53 | 59 | 101 | 32 | 24 | 21 | 17 | T | T |
| 2 | Pingut | 7.6 | 7.7 | 572 | 340 | 366 | 218 | 71 | 62 | 50 | 97 | 18 | 12 | 16 | 12 | T | T |
| 4 | Maujha | 7.6 | 8.2 | 719 | 563 | 460 | 360 | 89 | 53 | 63 | 126 | 22 | 9 | 28 | 23 | T | T |
| 7 | Dungri | 8.2 | 7.8 | 1403 | 1500 | 898 | 960 | 195 | 178 | 88 | 134 | 46 | 28 | 160 | 104 | 4 | 1 |
| 8 | Chandaniya | 7.7 | 7.6 | 884 | 1438 | 566 | 920 | 107 | 186 | 55 | 151 | 25 | 47 | 33 | 33 | T | T |
| 9 | Amkhuta | 7.9 | 8.3 | 747 | 281 | 478 | 180 | 107 | 80 | 59 | 105 | 25 | 12 | 25 | 22 | T | T |
| 10 | Jharni | 7.7 | 7.4 | 444 | 1344 | 284 | 860 | 89 | 71 | 34 | 67 | 16 | 27 | 14 | 13 | T | T |
| 13 | Nasarpor | 8.2 | 7.7 | 547 | 344 | 350 | 220 | 89 | 36 | 55 | 55 | 32 | 20 | 26 | 27 | T | T |
| 15 | Chaswad | 7.5 | 8.6 | 809 | 1063 | 518 | 680 | 107 | 107 | 29 | 143 | 62 | 25 | 32 | 28 | T | T |
| 23 | Wankal | 7.2 | 8.6 | 1581 | 2594 | 1012 | 1660 | 391 | 231 | 88 | 210 | 134 | 77 | 41 | 32 | T | T |
| 24 | Pataldevi | 7.8 | 7.9 | 628 | 781 | 402 | 500 | 53 | 71 | 29 | 76 | 36 | 27 | 44 | 30 | T | T |
| 26 | Deshad | 7.6 | 7.6 | 4534 | 3781 | 2902 | 2420 | 781 | 657 | 88 | 252 | 177 | 75 | 340 | 154 | T | T |
| 28 | Naogama | 7.5 | 7.6 | 834 | 1063 | 534 | 680 | 124 | 124 | 46 | 256 | 45 | 165 | 77 | 70 | T | T |
| 29 | Simodra | 8 | 8.7 | 2250 | 2656 | 1440 | 1700 | 533 | 533 | 34 | 172 | 82 | 46 | 370 | 163 | 7 | 7 |
| 30 | Limbada | 8.5 | 7.6 | 7191 | 6938 | 4602 | 4440 | 1491 | 1456 | 176 | 340 | 257 | 90 | 760 | 501 | 63 | 48 |
| 31 | Nandav | 7.5 | 8.5 | 2234 | 2531 | 1430 | 1620 | 426 | 355 | 34 | 260 | 101 | 17 | 270 | 134 | 27 | 13 |
| 32 | Dinod | 8 | 8.5 | 5644 | 2063 | 3612 | 1320 | 710 | 302 | 160 | 130 | 195 | 45 | 330 | 98 | 439 | 163 |
| 33 | Kosamba | 7.9 | 7.6 | 6384 | 5406 | 4086 | 3460 | 1331 | 799 | 361 | 365 | 84 | 28 | 560 | 190 | 9 | 3 |
| 34 | Hathoda | 8.3 | 8.2 | 3691 | 4438 | 2362 | 2840 | 888 | 994 | 46 | 126 | 120 | 149 | 580 | 436 | 219 | 164 |
| 35 | Warethi | 8 | 7.6 | 2231 | 2219 | 1428 | 1420 | 515 | 275 | 17 | 50 | 34 | 30 | 490 | 194 | T | T |
| 36 | Tadkeshwar | 7.8 | 7.5 | 1072 | 938 | 686 | 600 | 178 | 133 | 63 | 105 | 35 | 36 | 610 | 51 | 3 | 1 |
| 37 | Pipodra | 8 | 8.4 | 1772 | 2125 | 1134 | 1360 | 355 | 293 | 21 | 50 | 36 | 45 | 420 | 180 | 2 | 1 |
| 38 | Simalthu | 8.3 | 8.2 | 1894 | 1813 | 1212 | 1160 | 497 | 391 | 17 | 29 | 21 | 36 | 460 | 194 | 9 | 6 |
| 39 | Kachhab | 8.6 | 8.5 | 3034 | 3375 | 1942 | 2160 | 817 | 577 | 42 | 46 | 28 | 38 | 650 | 436 | 20 | 25 |
| 40 | Vadoli | 8.3 | 8.5 | 7156 | 6844 | 4580 | 4380 | 2396 | 1500 | 122 | 113 | 113 | 184 | 1300 | 671 | 12 | 8 |
| 41 | Koba | 8.2 | 8.4 | 6894 | 4125 | 4412 | 2640 | 2325 | 1207 | 109 | 118 | 104 | 69 | 1450 | 626 | 33 | 26 |
| 42 | Karanj | 8.4 | 8.6 | 5100 | 2094 | 3264 | 1340 | 994 | 160 | 38 | 67 | 67 | 61 | 740 | 162 | 95 | 69 |
| 43 | Kantiajal | 8.1 | - | 1522 | - | 974 | - | 337 | - | 25 | - | 67 | - | 210 | - | 82 | - |
| **Irrigation Water Quality Standards (IS:2296)** | | **6.5-8.5** | | **2250** | | **2100** | | **600** | | **-** | | **-** | | **-** | | **-** | |

***(Note: 1. The TDS and all ionic concentrations are in mg/l 2. *T=Trace, Below Detectable Limit 3. Pre= Pre-monsoon Season, Post =Post-monsoon Season)***

***Table 3a. Seasonal Chemical Composition of Groundwater in 2012***

| Well No. | Village | Parameters | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | pH | | EC | | TDS | | $Cl^-$ | | $Ca^{+2}$ | | $Mg^{+2}$ | | $Na^+$ | | $K^+$ | | $CO_3^{-2}$ | | $HCO_3^-$ | |
| | | Pre | Post | Pre | Post | Pre | Post | Pre | Post | Pre | Post | Pre | Post | Pre | Post | Pre | Post | Pre | Post | Pre | Post |
| 1 | Tadphalia | 7.8 | 7.4 | 500 | 603 | 320 | 386 | 89 | 43 | 38 | 57 | 67 | 25 | 21 | 12 | T | T | 90 | Ab | 122 | 92 |
| 3 | Pingut | 7.8 | 7.7 | 492 | 781 | 315 | 500 | 53 | 43 | 25 | 79 | 43 | 20 | 18 | 12 | T | T | 60 | Ab | 92 | 61 |
| 4 | Maujha | 7.8 | 7.7 | 344 | 431 | 220 | 276 | 53 | 28 | 29 | 57 | 60 | 14 | 25 | 10 | T | 1 | Ab | Ab | 488 | 214 |
| 7 | Dungri | 7.9 | 7.9 | 1281 | 1338 | 820 | 856 | 178 | 142 | 46 | 77 | 93 | 42 | 99 | 102 | 6 | 2 | 120 | Ab | 427 | 61 |
| 8 | Chandaniya | 7.9 | 7.8 | 937 | 1588 | 600 | 1016 | 89 | 213 | 21 | 121 | 77 | 59 | 31 | 34 | T | T | Ab | Ab | 397 | 275 |
| 9 | Amkhuta | 7.9 | 7.8 | 906 | 1034 | 580 | 662 | 71 | 92 | 21 | 106 | 53 | 38 | 27 | 27 | T | T | 60 | Ab | 122 | 31 |
| 10 | Jharni | 7.9 | 7.3 | 344 | 619 | 220 | 396 | 53 | 36 | 34 | 59 | 26 | 25 | 13 | 9 | T | T | Ab | Ab | 336 | 92 |
| 13 | Nasarpor | 8.1 | 7.6 | 1063 | 494 | 680 | 316 | 53 | 36 | 55 | 57 | 28 | 21 | 20 | 13 | 1 | T | Ab | Ab | 305 | 183 |
| 15 | Chaswad | 8 | 7.7 | 1781 | 1088 | 1140 | 696 | 124 | 99 | 50 | 87 | 50 | 39 | 60 | 29 | T | T | Ab | Ab | 336 | 122 |
| 23 | Wankal | 7.8 | 8.1 | 2531 | 1069 | 1620 | 684 | 373 | 142 | 143 | 45 | 71 | 67 | 30 | 21 | T | T | Ab | Ab | 397 | 275 |
| 24 | Pataldevi | 8 | 7.9 | 2906 | 716 | 1860 | 458 | 71 | 43 | 25 | 45 | 41 | 32 | 31 | 24 | T | T | 30 | Ab | 336 | 153 |
| 26 | Deshad | 7.8 | 7.5 | 2031 | 425 | 1300 | 272 | 852 | 36 | 126 | 101 | 162 | 138 | 183 | 38 | 1 | 2 | Ab | Ab | 458 | 366 |
| 28 | Naogama | 7.9 | 7.3 | 1250 | 1122 | 800 | 718 | 89 | 128 | 143 | 32 | 118 | 68 | 56 | 75 | T | 1 | Ab | Ab | 519 | 427 |
| 29 | Simodra | 8 | 7.6 | 3844 | 2631 | 2460 | 1684 | 692 | 575 | 147 | 34 | 66 | 123 | 193 | 181 | 21 | 4 | 60 | Ab | 305 | 214 |
| 30 | Limbada | 7.9 | 7.8 | 6250 | 3084 | 4000 | 1974 | 1207 | 639 | 235 | 30 | 149 | 162 | 253 | 300 | 45 | 20 | 90 | Ab | 732 | 641 |
| 31 | Nandav | 7.7 | 7.9 | 2813 | 1788 | 1800 | 1144 | 444 | 234 | 176 | 44 | 65 | 80 | 143 | 124 | 24 | 22 | Ab | Ab | 824 | 31 |
| 32 | Dinod | 7.8 | 8 | 7625 | 1866 | 4880 | 1194 | 1118 | 192 | 340 | 102 | 170 | 31 | 178 | 93 | 326 | 141 | Ab | Ab | 488 | 397 |
| 33 | Kosamba | 7.6 | 7.8 | 3813 | 2231 | 2440 | 1428 | 692 | 355 | 147 | 143 | 122 | 44 | 168 | 114 | 4 | 3 | Ab | Ab | 214 | 92 |
| 34 | Hathoda | 7.8 | - | 3500 | - | 2240 | - | 994 | - | 113 | - | 150 | - | 293 | - | 191 | - | 90 | - | 610 | - |
| 35 | Warethi | 8.1 | 8.4 | 2656 | 2216 | 1700 | 1418 | 337 | 341 | 25 | 18 | 45 | 34 | 233 | 76 | 1 | 1 | 60 | 120 | 427 | 366 |
| 36 | Tadkeshwar | 7.8 | 7.8 | 4719 | 1153 | 3020 | 738 | 195 | 163 | 29 | 129 | 104 | 23 | 35 | 54 | 1 | 1 | Ab | Ab | 366 | 336 |
| 37 | Pipodra | 8.3 | 8.4 | 2034 | 2041 | 1302 | 1306 | 337 | 284 | 84 | 17 | 39 | 46 | 203 | 189 | 4 | 2 | 90 | 60 | 519 | 366 |
| 38 | Simalthu | 8.1 | 8.2 | 1625 | 2506 | 1040 | 1604 | 426 | 568 | 46 | 34 | 11 | 28 | 223 | 710 | 7 | 8 | 120 | Ab | 275 | 61 |
| 39 | Kachhab | 8.3 | 8.5 | 3156 | 3903 | 2020 | 2498 | 799 | 873 | 50 | 55 | 54 | 75 | 318 | 420 | 34 | 42 | 60 | 60 | 458 | 427 |
| 40 | Vadoli | 8 | 8 | 7500 | 6272 | 4800 | 4014 | 1953 | 1527 | 67 | 67 | 239 | 214 | 443 | 565 | 11 | 9 | 30 | Ab | 427 | 397 |
| 41 | Koba | 7.6 | 7.7 | 3469 | 7738 | 2220 | 4952 | 799 | 2123 | 84 | 176 | 34 | 165 | 308 | 505 | 35 | 21 | 30 | Ab | 1007 | 854 |
| 42 | Karanj | 8.4 | 8.5 | 3031 | 7541 | 1940 | 4826 | 408 | 1072 | 25 | 27 | 19 | 168 | 253 | 645 | 75 | 123 | 150 | 120 | 519 | 549 |
| 43 | Kantiajal | 8.2 | 8.3 | 1250 | 4428 | 800 | 2834 | 178 | 781 | 21 | 60 | 38 | 100 | 87 | 315 | 77 | 64 | 90 | 60 | 427 | 458 |
| **Irrigation Water Quality Standards (IS:2296)** | | **6.5-8.5** | | **2250** | | **2100** | | **600** | | **-** | | **-** | | **-** | | **-** | | **-** | | **-** | |

***(Note: 1. The TDS and all ionic concentrations are in mg/l 2. *T=Trace, Below Detectable Limit . Pre= Pre-monsoon Season, Post =Post monsoon Season)***

***Table 3b. Seasonal Chemical Composition of Groundwater in 2013***

**Electrical Conductivity:-**

The Electrical Conductivity (Table 3a & b) shows marked seasonal variation ranging from 340 to 7700 mS/cm. The lower reaches of river basin point to very high EC values indicating high salinity. It was observed that the groundwater samples collected from the wells comprising basaltic aquifers had low EC during the pre-monsoon season while in the post-monsoon season; there has been a significant rise. This change may be ascribed to dissolution of salts due to rock-water interaction and flushing effect. On the contrary, the samples collected from the sedimentary and alluvial aquifers point to lower EC values in post-monsoon seasons because of higher degree of dilution occurred in the groundwater systems in the central and lower parts of the river basin. 54% of samples in the pre-monsoon seasons and 68% samples in the post-monsoon seasons were having the EC within the permissible limit of 2250mS/cm. (IS: 2296)

| Well No. | Indices | Sodium Absorption Ratio | | Kelly's Ratio | | Soluble Sodium Percentage | | Schoeller's Index | | Puri Salt Index | | Permeability Index | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **Village** | **Pre** | **Post** | **Pre** | **Post** | **Pre** | **Post** | **Pre** | **Post** | **Pre** | **Post** | **Pre** | **Post** |
| 1 | Tadphalia | 0.5 | 0.4 | 0.14 | 0.11 | 12 | 10 | 0.52 | 0.54 | -133 | -312 | 28 | 32 |
| 3 | Pingut | 0.5 | 0.3 | 0.17 | 0.09 | 14 | 8 | 0.57 | 0.63 | -102 | -367 | 35 | 25 |
| 4 | Maujha | 0.7 | 0.4 | 0.20 | 0.13 | 17 | 11 | 0.41 | 0.38 | -97 | -363 | 52 | 52 |
| 7 | Dungri | 2.7 | 2.2 | 0.63 | 0.55 | 38 | 35 | -0.07 | 0.00 | -301 | -13 | 48 | 46 |
| 8 | Chandaniya | 0.8 | 0.6 | 0.24 | 0.13 | 19 | 12 | 0.50 | 0.74 | -29 | -497 | 44 | 29 |
| 9 | Amkhuta | 0.7 | 0.6 | 0.21 | 0.15 | 18 | 13 | 0.53 | 0.57 | -68 | -392 | 39 | 20 |
| 10 | Jharni | 0.4 | 0.3 | 0.17 | 0.09 | 15 | 8 | 0.70 | 0.66 | -98 | -252 | 66 | 30 |
| 13 | Nasarpor | 0.6 | 0.6 | 0.19 | 0.20 | 16 | 16 | 0.49 | 0.14 | -154 | -173 | 53 | 45 |
| 15 | Chaswad | 1.1 | 0.6 | 0.30 | 0.15 | 23 | 13 | 0.41 | 0.58 | 29 | -419 | 53 | 30 |
| 23 | Wankal | 0.6 | 0.5 | 0.11 | 0.10 | 10 | 9 | 0.86 | 0.78 | -389 | -490 | 27 | 35 |
| 24 | Pataldevi | 1.1 | 0.7 | 0.36 | 0.22 | 26 | 18 | 0.04 | 0.25 | 48 | -162 | 62 | 44 |
| 26 | Deshad | 3.7 | 1.8 | 0.59 | 0.33 | 36 | 25 | 0.50 | -0.02 | 749 | -390 | 39 | 59 |
| 28 | Naogama | 1.4 | 1.3 | 0.35 | 0.28 | 24 | 21 | 0.05 | 0.12 | -137 | -347 | 27 | 56 |
| 29 | Simodra | 5.6 | 3.0 | 1.27 | 0.61 | 52 | 38 | 0.24 | 0.52 | 927 | 336 | 50 | 49 |
| 30 | Limbada | 5.8 | 7.4 | 0.77 | 0.88 | 42 | 47 | 0.42 | 0.35 | 1458 | 1044 | 41 | 58 |
| 31 | Nandav | 3.8 | 2.4 | 0.80 | 0.51 | 42 | 33 | 0.22 | 0.25 | 492 | -111 | 48 | 43 |
| 32 | Dinod | 3.0 | 2.0 | 0.42 | 0.47 | 29 | 32 | 0.12 | -0.19 | 20 | -101 | 27 | 56 |
| 33 | Kosamba | 4.7 | 2.4 | 0.69 | 0.43 | 39 | 30 | 0.49 | 0.57 | 533 | -495 | 37 | 39 |
| 34 | Hathoda | 7.2 | 6.2 | 1.37 | 1.01 | 54 | 50 | 0.08 | 0.18 | 1730 | 1504 | 51 | 48 |
| 35 | Warethi | 11.1 | 3.9 | 3.93 | 1.27 | 76 | 55 | -0.25 | 0.29 | 1651 | 488 | 84 | 81 |
| 36 | Tadkeshwar | 8.0 | 1.1 | 2.27 | 0.27 | 47 | 22 | -1.76 | 0.45 | 1339 | -313 | 34 | 44 |
| 37 | Pipodra | 8.7 | 4.9 | 2.85 | 1.50 | 68 | 60 | -0.37 | 0.02 | 1256 | 732 | 72 | 83 |
| 38 | Simalthu | 12.6 | 17.6 | 5.32 | 4.78 | 82 | 77 | -0.12 | -0.34 | 1503 | 2040 | 92 | 91 |
| 39 | Kachhab | 13.2 | 10.4 | 4.17 | 2.75 | 76 | 72 | 0.06 | 0.02 | 2123 | 1830 | 79 | 77 |
| 40 | Vadoli | 13.0 | 9.1 | 2.24 | 1.28 | 62 | 56 | 0.41 | 0.37 | 3769 | 2560 | 52 | 59 |
| 41 | Koba | 15.4 | 9.5 | 3.19 | 1.65 | 74 | 60 | 0.21 | 0.41 | 3795 | 2030 | 85 | 58 |
| 42 | Karanj | 13.0 | 7.8 | 4.10 | 1.33 | 80 | 55 | -0.16 | -0.47 | 2255 | 1729 | 95 | 72 |
| 43 | Kantiajal | 3.8 | 6.4 | 1.11 | 1.20 | 52 | 55 | -0.15 | 0.31 | 607 | 1235 | 80 | 66 |

***(* Pre= Premonsoon Season, Post =Post monsoon Season)***

***Table 4 : Indices for Irrigation Water Quality***

Table 4. shows the Water Quality Indices for groundwater samples in the study area. All the above indices were first calculated using various cations and anions for individual seasons and then the average of the obtained indices was taken for pre-monsoon and post -monsoon seasons for graphical and spatial representation.

***Sodium Absorption Ratio (SAR):***

Sodium Absorption Ratio (SAR) (Richards,1954) indicates the degree to which water tends to enter into cation-exchange reactions in the soil. The sodium or alkali hazard in groundwater is determined by the concentration of cations and is expressed in terms of SAR. If groundwater used for irrigation is high in sodium and low in calcium, the cation-exchange complex may become saturated with sodium.

Thus, SAR value for a given groundwater provides a useful index of the sodium hazard. The SAR is calculated as-

***(All the values are in meq/l)***

$$\mathbf{SAR} = \frac{Na}{\sqrt{\frac{Ca + Mg}{2}}}$$

The U.S. Salinity Laboratory has given a diagram interrelating the SAR and EC to find out the degree of suitability of ground waters in terms of Salinity and Alkalinity hazards(Richards,1954)[9].

| Salinity Hazard Class | EC (mS/cm) | Hazard Class | Percentage of Samples | |
|---|---|---|---|---|
| | | | Premonsoon | Post monsoon |
| C1 | <250 | Low | 0 | 0 |
| C2 | 250-750 | Medium | 14 | 21 |
| C3 | 750-2250 | High | 39 | 46 |
| C4 | >2250 | Very High | 26 | 32 |

***Table 5a : Salinity hazard classification on the basis of EC Values (After Richard, 1954)***

| Sodium Hazard Class | SAR | Hazard Class | Percentage of Samples | |
|---|---|---|---|---|
| | | | Premonsoon | Post monsoon |
| S1 | <10 | Low | 79 | 89 |
| S2 | 10-18 | Medium | 21 | 11 |
| S3 | 18-26 | High | 0 | 0 |
| S4 | >26 | Very High | 0 | 0 |

***Table 5b : Sodium Hazard Classification on the Basis of SAR Values***

Figure 3, Tables 5a & b represent the degree of salinity and alkalinity hazards in the Kim River Basin. The values reflect the difference of SAR on seasonal basis, which shows that the overall quality of groundwater in post-monsoon season is better than the pre-monsoon period. This may be attributed to dilution effect of rainwater. Almost 79% of groundwater samples in pre-monsoon and 89% samples in post-monsoon seasons have SAR<10 which is suitable for irrigation use. According to the U.S.Salinity Chart, only 14% of groundwater samples in the pre-monsoon and 21% in the post-monsoon season fall in the class C2-S1 indicating 'Good Water'. 36% of pre-monsoon and 34% samples of post- monsoon are categorized as moderate waters belonging to C3-S1 and C3-S2 classes for irrigation, while 50% samples in premonsoon and 29% in the post monsoon fall in the class of bad waters which indicate that the waters are unsuitable for irrigation as they are subjected to salinity and alkalinity hazards.

(After Richards, 1954)

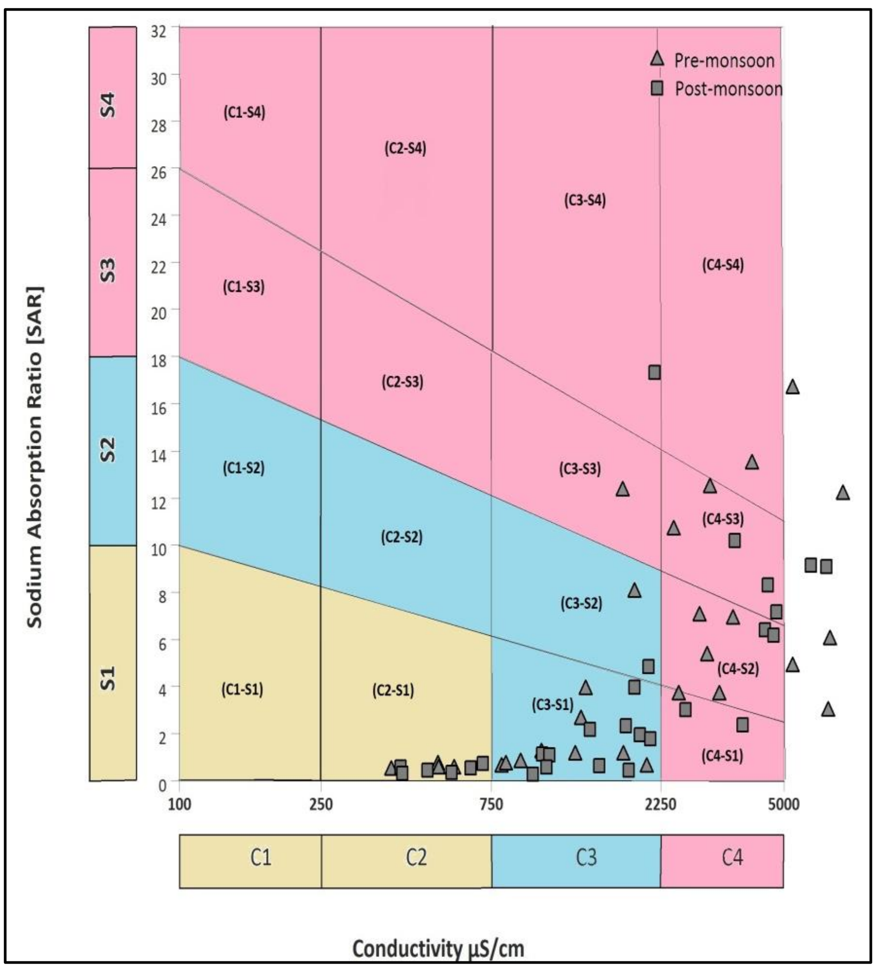


*Figure 3:U.S. Salinity Diagram for Classification of Irrigation Water (After Richards, 1954)*

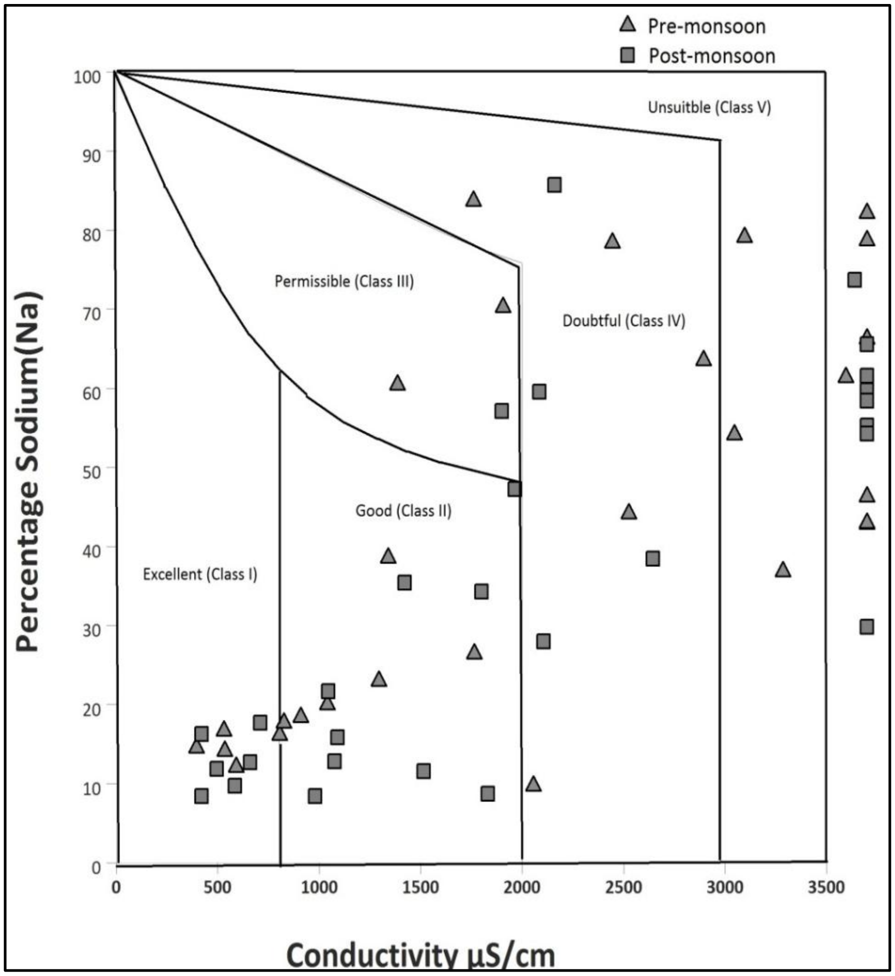


Figure 4: Wilcox Diagram for Sodium Percentage (After Wilcox,1955)

***Soluble Sodium Percentage (SSP):***

Soluble Sodium Percentage (SSP) determines the ratio of sodium to total cations viz., sodium, calcium and magnesium present in the water. Wilcox (1955) used Percentage Sodium and Electrical Conductance to determine the suitability of water for irrigation purpose.[10] SSP is calculated as-

$$SSP = \frac{Na}{Ca + Mg + Na} \times 100$$

***(all the values are in meq/l)***

Wilcox classified the suitability of irrigation water by a diagrammatic method in which the percent sodium is plotted against EC values and suggested five distinct categories of water-

| Class | Category of Irrigation Water | % Samples | |
|---|---|---|---|
| | | Pre monsoon | Post monsoon |
| I | Excellent | 18 | 21 |
| II | Good | 21 | 32 |
| III | Permissible | 7 | 3 |
| IV | Doubtful | 18 | 14 |
| V | Unsuitable | 36 | 29 |

***Table 6: Wilcox Classification of Irrigation Water based on Sodium Percentage***

From, Wilcox diagram (Fig. 4), it can be discerned that, the groundwater during post monsoon season is more suitable for irrigation as compared to pre monsoon season. From Table 6,it can be summarized that 46% of pre monsoon samples and 56% of post monsoon samples are suitable for irrigation purpose and the rest belong to categories of doubtful to unsuitable and can pose a threat to the crops if used for irrigation. Most of the water of the basaltic aquifers located in the upstream of the river fall in the suitable category of water for irrigation, while the quality starts deteriorating it approaches the middle and lower parts of the basin, which may be accounted to the factors of waterlogging and excessive use of agrochemicals.

***Kelly's Ratio (KR):***
Suitability of water for irrigation purposes is also assessed on the bases of Kelly's Ratio. Kelly et al. (1951) proposed that the potential sodium problems in irrigation water can be evaluated on the basis of following formula-

$$KR = \frac{Na}{Ca + Mg}$$

***(all the values are in meq/l)***

This ratio reflects the alkali hazards of water. A Kelly's Ratio (KR) >1 indicates an excess level of sodium in waters. Hence, waters with a KR < 1 are suitable for irrigation, while those with a KR >1 are unsuitable for irrigation. The observed KR values show that 61% of pre-monsoon and 68% groundwater samples in the post-monsoon seasons had KR <1.Most of these groundwater samples were from the basaltic and sedimentary aquifers. Remaining ones showing higher KR (>1) belong to the alluvial aquifers in the lower parts of the basin.

***Schoeller's Index (SI):***
Schoeller (1959) used an index to determine the probable ion exchange reactions occurring in groundwater. The value of the index changes as the groundwater quality varies. The Schoeller's Index(SI) is given by-

$$SI= \frac{Cl- (Na +K)}{Cl}$$

***(all the values are in meq/l)***

The positive value of the index indicates direct base exchange reaction in the groundwater, i.e. Sodium and Potassium is exchanged with Calcium and Magnesium, while the negative value of the index is indicative of indirect cation-anion exchange. 75% samples in the pre-monsoon and 90% samples in the post-monsoon seasons (Table 4) showed that the SI was positive and thus, direct base exchange reactions were dominant.25% samples in pre-monsoon and only 10% samples in post- monsoon seasons showed negative value of SI indicating indirect cation-anion reactions (Fig.5).Groundwaters in the basaltic aquifers point to direct base exchange reactions in all the seasons, while the chloro-alkali disequilibrium was commonly observed in places having limestone and alluvial aquifers and water-logging is observed as a prominent phenomenon.

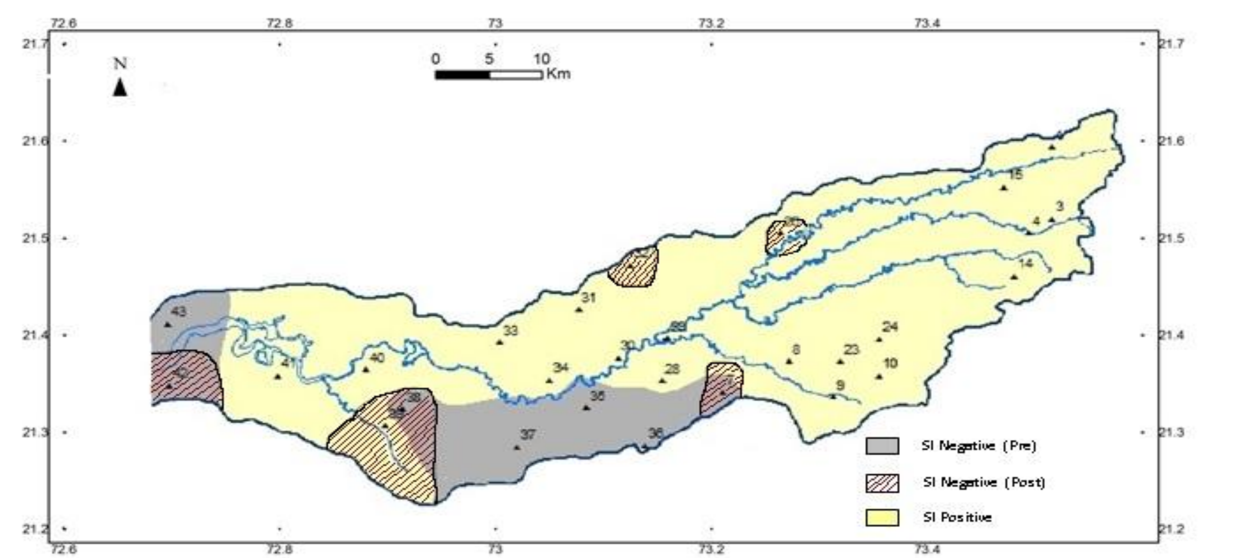




***Figure 5: Schoeller's Index for Pre and Post Monsoon Seasons***

***Puri's Salt Index (PSI):***

It is also used for predicting sodium hazard. It is the relation between $Na^+$, $Ca^{2+}$, and CaCO3 present in irrigation water. Puri's Salt Index (PSI) is calculated by the following formula-

$$\mathbf{PSI = (Total\ Na) - (total\ Ca\text{-}Ca\ in\ CaCO_3) \times 4.85}$$

***(All the values are in mg/l)***

PSI is negative for all good water and positive for those unsuitable for irrigation. 46% of pre-monsoon and 61% of post-monsoon groundwater samples indicate negative salt index which classified them under the good water category. The spatial distribution of PSI clearly shows that all the groundwater from the basaltic aquifer along with few samples from sedimentary aquifers had groundwater suitable for irrigation purpose irrespective of the seasonal variation, while all the samples from the alluvial aquifers and few samples from sedimentary aquifers show positive index, indicating that the water is not suitable for irrigation purpose. (Fig.6)

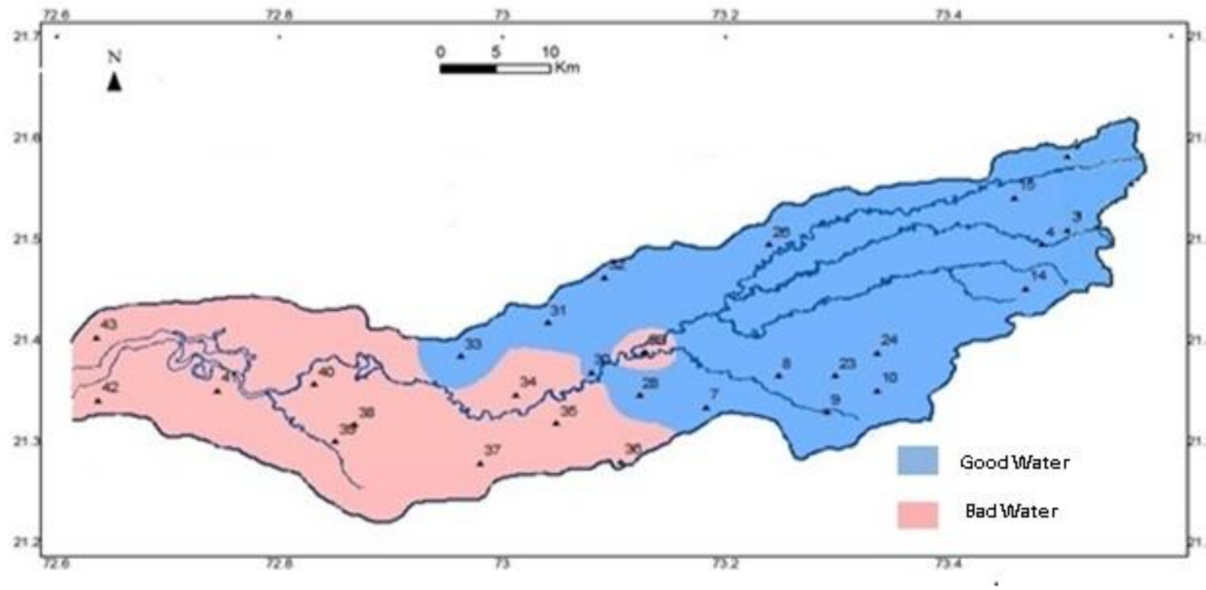


***Figure 6: Spatial and Temporal Behaviour of Groundwater in terms of Puri's Salt Index (PSI) in the Kim Basin***

***Conclusion:***

The results of physico-chemical analysis of groundwater samples collected from the various observation wells in the Kim River Basin and the calculated irrigation water quality indices show varied groundwater quality, which may be attributed to presence of different types of aquifers and anthropogenic activities. The consolidated, partially weathered basaltic aquifers in the upstream region have good water quality suitable for irrigation. The semi consolidated sedimentary aquifers of the central part of the Kim River Basin are all year round source of water; however groundwater quality is not acceptable for irrigation due to solution weathering. Groundwater being slightly high in TDS can be used for irrigation after dilution. The unconsolidated alluvial aquifers of the lower basin have high potential of groundwater but the quality of water is not suitable for irrigation as they show high enrichment in various cations and anions. This region being under irrigation canal command area, undergoes extensive agricultural practice throughout the year and so the use of groundwater is restricted. Also the returned irrigation seepage further adds to the groundwater, thus allowing slow and steady rise and also deterioration in the quality due to enrichment in salts. Many regions are facing serious problem of waterlogging which has degraded the soil as well as groundwater quality in the lower reaches of the Kim River Basin.

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