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Assessment and Mapping of Water Quality of a Shallow Aquifer near an Industrial Belt using Hydro-chemical Parameters and Irrigation Water Quality Index

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ABSTRACT

Irrigation water quality issues arising from salt water intrusion or industrial pollution are experienced in many parts of Kerala state. This study was undertaken at Eloor, near Cochin, which is under the threat of industrial pollution, with the twin objectives of assessing the shallow groundwater quality of an area, and to evaluate the performance of Irrigation Water Quality Index (IWQI) as compared to hydro-chemical parameters. Water samples collected from 10 open wells during three different seasons for two years were analysed, and physico-chemical characteristics of water *viz.*, Electrical Conductivity (EC), Sodium (Na), Potassium (K), Calcium (Ca), Magnesium (Mg), Chloride (Cl), Carbonate (CO_3), and Bicarbonate (HCO_3) were determined. Sodium Adsorption Ratio (SAR), Kelly Index (KI), Sodium Percentage (Na%), and Residual Sodium Carbonate (RSC) were calculated. Further, the combined measure IWQI was also computed. The study revealed that groundwater in many parts of Eloor was of poor quality with serious quality concerns during pre-monsoon season, where the IWQI of less than 70 was seen in about 85% of the geographical area. There were wide differences between the water quality indications given by single hydro-chemical methods and the combined hydro-chemical method. The spatial interpolation of EC values suggested that groundwater over the entire region is suitable for irrigation, while as per SAR classifications only 10% of the study area has water unfit for irrigation. The IWQI indicated that 70% of the area has poor quality of irrigation water. The study showed that IWQI combines the inferences from all individual hydro-chemical parameters, and IWQI should preferably be used to provide better and more comprehensive assessment of the irrigation water quality and for informed decision on suitability of water for irrigation planning and management.

Keywords: Eloor, industrial pollution, irrigation water quality, IWQI

Presently, the state of Kerala in peninsular India is heavily dependent on the neighbouring states to meet its food demands for both cereals and vegetables. The annual vegetable consumption of the state is around 20 lakh tonnes, whereas, the production is only 14.9 lakh tonnes (Anon., 2020). In the case of rice, which is the staple food of Keralites, the state is able to produce only about one-fifth of the total requirement (Kala and Leena, 2018). To reduce the impact of dependency, the state is swiftly moving forward to enhance agricultural production of both cereals and vegetables through area expansion and intensive cropping. As a result, in recent years, there has been improvement in the production of grains (mainly paddy) and vegetables (Anon., 2017). However, the state must go a long way to improve the agricultural production and productivity. The cultivation of paddy is mainly restricted to rainy season. Though there is immense potential to grow rice in the summer, non-availability of surface irrigation water stands as a major obstacle (Mhaske *et al.*, 2015). For summer vegetable production also, the scarcity of surface water come as the major limitation. In many parts of the coastal belt of the State shallow aquifer water is available in adequate quantity, but their poor quality is a major threat for sustainable irrigated agriculture.

The shallow groundwater quality issues of the state mainly arise from two reasons viz, salt water intrusion in the coastal areas and pollution from industrial and other man-made activities (Jayathunga *et al*., 2020; Mhaske, 2020). Certain fertile areas of Kerala have gone out of cultivation due to poor quality of groundwater in the area. A typical example is Eloor, which lies in the central part of Kerala and is an island in the Periyar River near the city of Cochin (Greenpeace India, 2003). The island Eloor houses several industries including chemical and hazardous industries. Setting up of those industries after the independence have caused agricultural activities in this area to undergo serious down trends, mainly due to poor quality of groundwater (Hardaha, 2014). Dissolved salts beyond certain permissible limits in the irrigation water leads to salinity and poor permeability of the soil, a condition which is detrimental to crop production. For sustainable development of irrigated agriculture, especially in areas with poor water quality, it is important to regularly evaluate the quality of irrigation water.

Seasonal evaluation of groundwater is important as water quality changes with respect to the seasons within a year. Significant number of studies have used hydro-chemical indices like Sodium Adsorption Ratio (SAR), Kelly Index (KI), Sodium Percentage (Na%), Residual Sodium Carbonate (RSC) (Cieszynska *et al*., 2012; Brindha and Elango, 2013; Li *et al*., 2013; Fakhre, 2014) to evaluate the quality of irrigation water. The major problem in using these hydro-chemical indices is that one need to determine several such indices to assess the quality of water, and secondly, different indices will lead to different inferences with regard to the suitability of the water for irrigation. Therefore, some studies have used major chemical ion combinations (EC, Na, Cl, HCO_3) to produce better results than using a single parameter.

The Irrigation Water Quality Index (IWQI), developed as a unique indicator to assess irrigation water quality, was first put in practice by Meireles *et al*. (2010). The IWQI aims at making the process of water quality analysis more reliable, using a set of indicators and assigning suitable weights for individual indicators to get a weighted mean water quality index. The major advantage of IWQI is the reduction of water quality indicating parameters from a multitude of criterions to a single numerical value (Saeedi *et al*., 2010). IWQI is more reliable, and has been used in several studies (Sutadian *et al*., 2016; Taloor *et al*., 2020; Pak *et al*., 2021). Many studies reported that IWQI is a better measure of assessing irrigation water quality than of using individual parameters (Behairy *et al*., 2021). However, systematic studies on assessment of the suitability of groundwater using IWQI for irrigation purposes have not been reported for the state of Kerala. At the same time, there is good scope to perform groundwater quality research in many parts of the state having water quality issues resulting from industrial and business activities. As groundwater quality, especially that of shallow aquifer, vary spatially (Prasanth *et al*, 2012), a spatial mapping of the same would be necessary to make informed decisions for agricultural planning.

This study focused on spatial and temporal evaluation of water quality of shallow aquifer in an industrial belt of Kerala to provide an objective information on the quality of irrigation water availability of an area affected by industrial pollution. The study also focused on the efficacy of IWQI method over the conventional procedure of irrigation water quality assessment based on individual water quality parameters.

MATERIALS AND METHODS

Study Area and Water Sample Collection

Eloor, one of the important industrial hubs of Kerala, is an island surrounded by the river Periyar, the largest river of Kerala state in Indian peninsular. It is located in Ernakulam district, between 9º 3´N and 10º 6´ N and 76º 20´ E and 76º 28´ E, with a geographical area of 14.21 km² (Fig. 1). Eloor island has been formed between two distributaries of river Periyar, and houses more than 247 industries of different kinds (Greenpeace India, 2003). This has led to decrease in agricultural area and production. Figure 2 shows the digital contour map of Eloor island prepared with a contour interval of 5 m which clearly shows that the study area has an elevation ranging from (-)4 to 27 m. Towards the north and west of Eloor, the elevation is considerably lower compared to the south and the east. The flow of surface and shallow groundwater in the area is expected towards this area. The locations of industries and the effluent disposal site in the study area are shown in Fig. 2, and the locations of sampling wells are presented in Table 1.

In the year 2003, Green Peace India Organization fighting against environmental pollution rated Eloor as one of the toxic hotspots of the world. Towards

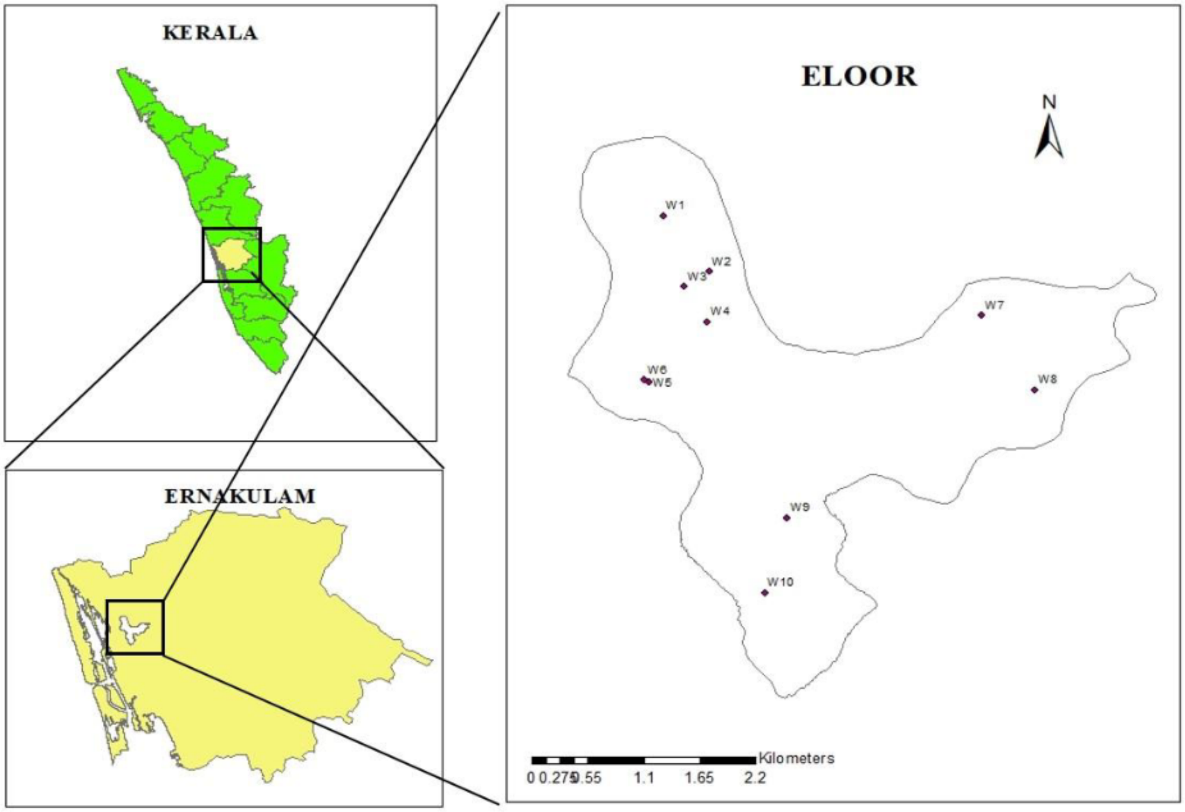

Fig. 1: Study area with groundwater sampling open wells

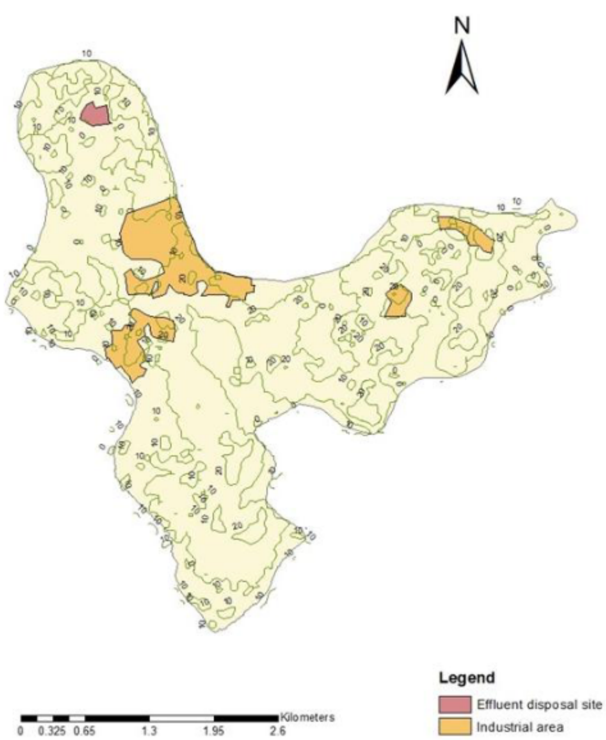

Fig. 2: Study area in Eloor with contours, industrial area, and effluent disposal site

the north of Eloor, there are more than 200 industries whose effluent is disposed to a paddy field (contaminant source) and to the River Periyar flowing around the island. The effluent from the industries reaches the paddy fields through underground pipelines and then flow down in the South-West direction, thus contaminating the wells in the area. As a result, the area which was once potential site for paddy and vegetable cultivation is now facing scarcity of good quality irrigation water. This has led to decrease in agricultural production in the area. In the study area, 10 open wells with an average depth of 7 - 9 m from the ground levels were selected, and are spread over the entire geographical area, with the exception of the central region for the collection of water samples (Fig. 1 and Table 1).

In this region, groundwater samples were collected during pre-monsoon (April to May), monsoon (June to November), and post-monsoon (December to March) seasons during the years 2019 and 2020 for assessing quality of irrigation water. Water samples for physical and chemical analysis were collected in a clean container which was a 2 litre plastic can. The container was filled using a bucket and the lid was

Table 1. Locations and other details of open wells in study area

Well identity	Longitude, °E	Latitude, °N	Elevation, m	Depth, m
W1	76.29117	10.08832	9.50	7.25
W2	76.29528	10.08306	10.20	7.00
W3	76.29306	10.08167	10.30	7.55
W4	76.29508	10.07837	11.10	7.72
W5	76.28989	10.0728	10.50	8.05
W6	76.28943	10.07298	10.90	8.15
W7	76.31972	10.07889	18.30	9.00
W8	76.32444	10.07194	16.70	8.70
W9	76.30221	10.06007	15.20	8.80
W10	76.30015	10.05311	15.80	8.65

Table 2. Laboratory procedures followed for determining water quality indicators

Parameter	Test procedure	Instrument used	Reference
Sodium (Na) Potassium (K)	Potentiometric method	Flame photometer (Systronics, model 130)	Langhoff and Steiness (1982)
Carbonate (CO_3) Bicarbonate (HCO_3) Calcium (Ca), Magnesium (Mg)	Complexometric titration [American Public Health Association Standards (APHA)]	Burette (Borosil)	Tsunogai *et al*. (1968)
Electrical Conductivity (EC)	Conductivity meter	Conductivity meter (Systronics, model 304)	Musser *et al*. (1998)
Chloride (Cl)	Argentometry (APHA standards)	Burette (Borosil)	Djuma and Talaen (2014)

closed carefully. The screw cap was closed tightly and the sample bottle was labelled with well number, location, date and time of sample collection.

Irrigation Water Quality Parameters

To quantitatively assess the groundwater quality for irrigation in the study area, water quality indicators viz. electrical conductivity (EC), sodium (Na), potassium (K), calcium (Ca), magnesium (Mg), chloride (Cl), carbonate (CO_3), and bicarbonate (HCO_3) were determined using the standard laboratory procedures (Table 2).

Parameters like SAR, Kelly ratio, Na percentage, RSC were computed from the water quality parameters such as Na, K, Ca, Mg, CO_3, and HCO_3. In addition, IWQI values were computed using EC, Na, Cl, SAR, and HCO_3 parameters following the procedures reported by Abbasnia *et al.* (2018) and Spandana *et al.* (2013). The irrigation water quality of the Eloor locality was then categorized on the basis of the water quality parameter's intervals as given in Table 3 (Yıldız and Karakus, 2020).

SAR (Sodium Adsorption Ratio)

Richards (1954) first introduced this parameter to assess the propensity of dissolved cations to enter cation exchange zones in soil and the propensity of Na ions to adsorb on soil.

This is computed using Eq. 1 as given below:

$$SAR = \frac{Na}{\sqrt{(Ca+Mg)/2}} \quad ...(1)$$

Na percentage (Na%)

The sodium percent (Na%) is an important parameter that is used to evaluate the groundwater quality and its appropriateness for irrigation. Based on Na percentage, the groundwater is classified into five classes, namely, excellent water ($0 \leq$ %Na $\leq 20\%$), good water (20% <%Na $\leq$ 40%), permissible (40% <%Na $\leq$ 60%), doubtful (60% <%Na $\leq$ 80%), and unsuitable (80% <%Na $\leq$ 100) (Yıldız and Karakus, 2020).

For this classification, the %Na was determined using the Eq. 2 (Wilcox, 1955).

$$Na\% = \frac{Na + K}{Ca + Mg + Na + K} * 100 \quad ...(2)$$

Kelly ratio (KI)

Na, Ca, and Mg concentrations in water represent

Table 3. Irrigation water quality classification based on different parameters

Parameter	Value range	Classification
Electrical conductivity, µS.cm^{-1}	<250	Excellent
	250-750	Good
	750-2000	Permissible
	2000-3000	Doubtful
	>3000	Unsuitable
Sodium Adsorption, Ratio (SAR)	0-6	Good
	6-9	Doubtful
	>9	Unsuitable
Kelly ratio (KI)	<1	Suitable
	1>	Unsuitable
Sodium percentage, Na %	<20	Excellent
	20-40	Good
	40-60	Permissible
	60-80	Doubtful
	>80	Unsuitable
Residual Sodium Carbonate (RSC) (meq.L^{-1})	<1.25	Good
	1.25-2.5	Suitable
	>2.5	Unsuitable
Irrigation Water Quality Index (IWQI)	85-100	Excellent
	70-85	Good
	55-70	Poor
	40-55	Very poor
	0-40	Unsuitable

Source: Yıldız and Karakus (2020)

alkali hazard (Dhembare, 2012). For calculation of KI parameter, Na concentration is measured against Ca and Mg, and in most waters Ca and Mg preserves their equilibrium state.

KI is calculated using the Eq. 3 (Kelley, 1940).

$$KI = \frac{Na}{Ca+Mg} \quad ...(3)$$

Residual sodium carbonate (RSC)

Residual Sodium Carbonate is the sum of concentration of carbonate plus bicarbonate in meq.l^{-1} minus the concentration of calcium plus magnesium in meq.l^{-1} (Hem, 1985).

The parameter RSC was computed using the Eq. 4.

$$RSC = [CO_3 + HCO_3) - [Ca + Mg\} \quad ...(4)$$

Irrigation Water Quality Index (IWQI)

The IWQI index defines irrigation water quality by a single number. It is based on the comparison of water quality parameters by assigning different weights. The parameters such as EC, Na, Cl, SAR, and HCO_3 are used in the given equation to calculate the index.

Contrary to the WQI-based procedure employed by the World Health Organization (WHO) for drinking water, this method specifies a different quality evaluation process (Meireles *et al*., 2010). The IWQI indices were assessed using the value of each parameter evaluated for the irrigation water quality parameters suggested by the University of California Committee of Consultants (UCCC), and the criteria established by Ayers and Westcot (1999). The suggested upper limits for continuous water use for all soil types serve as the foundation for the irrigation water quality index.

In this study, the IWQI was evaluated considering the value of water quality measurement parameter q_i, their limiting values, and the assigned weights W_i as given in Table 4 (Spandana *et al*., 2013; Abbasnia *et al*., 2018). The classification of groundwater quality was subsequently done based on the value ranges of IWQI as given in Table 5 (Batarseh *et al.*, 2021). The higher the value of IWQI, better is the quality of irrigation water and vice versa.

The *qi* values for the five water quality parameters viz. qEC, qNa+, qCl, qSAR, and $qHCO_3$ were determined using the Eq. 5.

Table 4. Irrigation water quality parameters, their proposed weights, and limiting values

Qi	EC, µS. cm^{-1} (0.211)*	SAR, meq.l$^{-11/2}$ (0.204)	Na+, meq.l^{-1} (0.202)	Cl, meq.l^{-1} (0.194)	HCO_3 meq.l^{-1} (0.189)
85-100	200-750	<3	2-3	<4	1-1.5
60-85	750-1500	3-6	3-6	4-7	1.5-4.5
35-60	1500-3000	6-12	6-9	7-10	4.5-8.5
0-35	<200 or>3000	>12	<2 or >9	>10	<1 or >8.5

**Values in parenthesis indicate the weights assigned in estimating IWQI*
[Source: Abbasnia et al. (2018); Spandana et al. (2013)]

Table 5. Classification of groundwater quality based on the value of IWQI

IWQI values and type of restriction	Type of plant	Recommendations for crops and soil
85-100 (No restriction)	No toxicity	Groundwater can be used for all types of soil as low risk of soil salinity and sodicity is prevailed
70-85 (Low restriction)	Avoid use of salt sensitive plant	Groundwater can be used for light soil texture with high sand content, moderate to high permeability
55-70 (Moderate restriction)	Moderate salt tolerance plants	Groundwater can be used for moderate to high permeable soil taking in consideration moderate soil leaching processes
40-55 (High restriction)	Moderate to high salt tolerance plants	Groundwater can be used for permeable soil without compact layers and taking in consideration the high frequency of the irrigation schedule for irrigation water with EC > 2000 µS/cm and SAR >7
0-40 (Severe restriction)	High salt tolerance plants only	Groundwater can't be used to irrigate soil under normal conditions

Source: Batarseh et al. (2021)

$$qi = q_{max} - \left\{\frac{[(x_{ij} - x_{inf}) * q_{iamp}]}{x_{iamp}}\right\} \quad ...(5)$$

Where,

q_{max} = Upper value of the corresponding class of qi,

x_{ij} = Data points of the parameters,

x_{inf} = Lower limit value of the class interval to which the observed parameter belongs,

q_{iamp} = Class amplitude for qi classes (for example, if the EC value belongs to qi class 1, then the amplitude will be 100-85 =15), and

x_{iamp} = Class amplitude to which the parameter belongs. (as shown in the above example, the class amplitude will be 750-200 = 550).

Finally, the IWQI was determined using the following summation equation:

$$IWQI = \sum_{1}^{n} q_i * W_I \quad ...(6)$$

Where,

n = Number of parameters considered,

q_i = Quality value, and

W_I = Weightage.

Spatial Variability Maps

The Arc GIS 7.1 software package was used to produce GIS zoning maps for the investigated groundwater quality parameters for the study area. The spatial variability map for the various irrigation indices were produced by performing the ordinary Kriging interpolation method with spherical semi-variogram model. With the Kriging method, the spatial covariance structure of the sampled points was first determined by fitting a variogram; and then weights derived from the covariance structure were used to interpolate values for un-sampled points across the spatial field. These spatially interpolated maps can give the quantification of the percent of area lying under each irrigation quality class.

RESULTS AND DISCUSSION

Irrigation Water Quality Parameters

Electrical conductivity

The spatial variation of electrical conductivity (EC) with respect to different seasons (pre-monsoon, monsoon, post-monsoon) from 10 sampling points are shown in Fig 3. Electrical conductivity is a parameter which indicates the total concentration of ionized constituents of water. A higher electrical conductivity indicates higher presence of ionised salts and corresponding degree of impurities in the water. The results showed that the electrical conductivity is comparatively higher in the wells W1, W2, W4, and W5. All these wells were in the proximity of the industry effluent discharging areas of Eloor. Amongst the seasons, the electrical conductivity was highest during the pre-monsoon season as compared to monsoon and post-monsoon season. The pollutants from the industries could be the root cause for the increased EC in these wells.

Comparing the two years under investigation, the year 2019 recorded higher EC values. It was presumed that

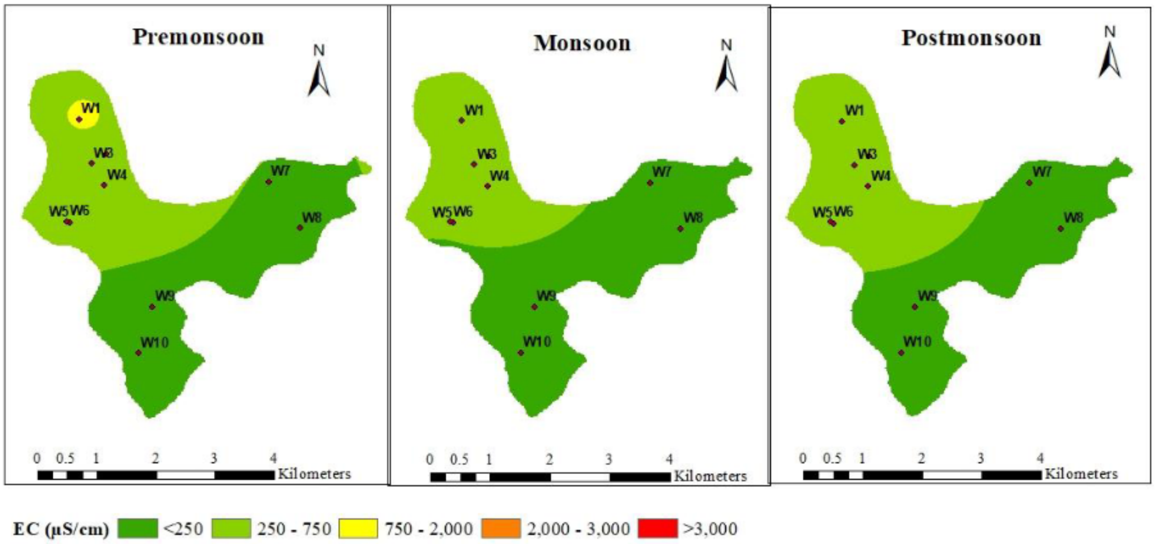

Fig. 3: Map showing spatial variation of EC for different seasons

the higher values could be the after-effect of 2018 flood of Kerala. As per IS: 11624:2019 guideline (BIS, 2019), the quality of irrigation water was satisfactory when the electrical conductivity was less than 2000 µS.cm^{-1}. The EC was under this limit in all wells in the study area during all seasons. Hence, the total concentration of salts in the groundwater was not too harmful for the agriculture of Eloor. The spatial map of EC showed that the entire northern part and a small portion of the central region had got EC values ranging from 250 µS.cm^{-1} to 750 µS.cm^{-1}. These results corroborated with the findings of Umadevi *et al*. (2010). EC was in the range of 95 µS.cm^{-1} to 1072 µS.cm^{-1}, and was significantly higher in few samples from the western and northern region of Eloor indicating the presence of ionic contaminants.

Sodium adsorption ratio

The sodium adsorption ratio (SAR) is an indication of exchangeable sodium in water. A higher amount of exchangeable sodium reacts with the soil to form impermeable layers, and hence, water with higher SAR is not suitable for irrigation. As per IS: 11624: 2019 (BIS, 2019) guidelines for irrigation water, the value of SAR should be less than 10 for its use without any probable hazards.

In the study area, the SAR was within this limit (< 10), except for the well W1 during the pre-monsoon season of the year 2019. As shown in Fig. 4, the SAR values of the well waters of W7, W9, and W10 located near the central and eastern part of the study area were almost near to zero. These wells were in the residential areas

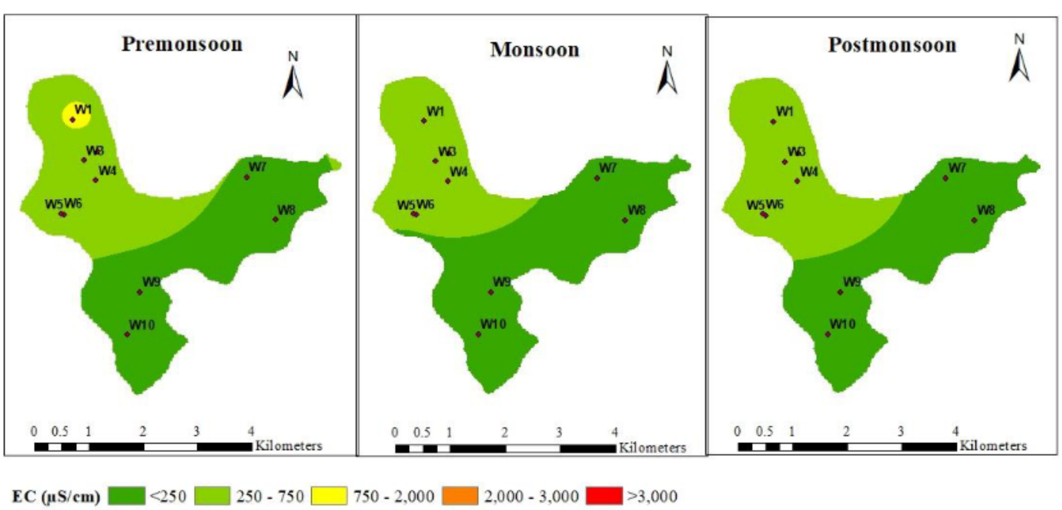

Fig. 4: Map showing spatial variation of SAR for different seasons

away from industries. Like the current study, Ninal and Benny (2015) also reported the SAR values less than 10 for all samples in the selected areas of Ernakulam, and reported as fit for irrigation.

Kelly index

Kelly Index is an indication of the amount of sodium ions in water. Kelly Index >1 represents an excess amount of sodium ions in water, which causes alkali hazards.

In the study area, the samples taken from the wells 1 - 6 showed KI values (Fig. 5) higher than one, which in turn indicated that the water from these wells were unsuitable for irrigation. All these wells were in the close proximity to the effluent disposal field, and that could be the reason for their higher KI values. However, Ninal and Benny (2015) reported KI in the range of 0.002 to 0.030 in the selected areas of Ernakulum District, indicating almost all samples were suitable for irrigation and unlike the results obtained under the current study. This could be mainly due to the close proximity of sampling sites to the effluent disposal field.

Sodium percent

The percent of sodium present in the shallow groundwater of the study area is shown in the spatially interpolated map (Fig. 6). More than 50% Na was found in wells W1 - W5 (North-West part of study area)

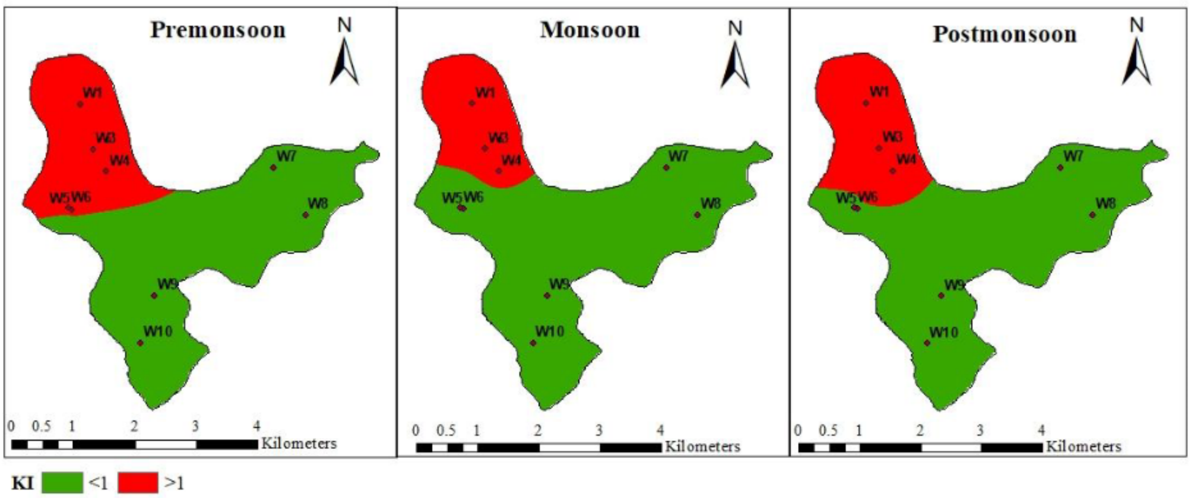

Fig. 5: Map showing spatial variation of KI for different seasons

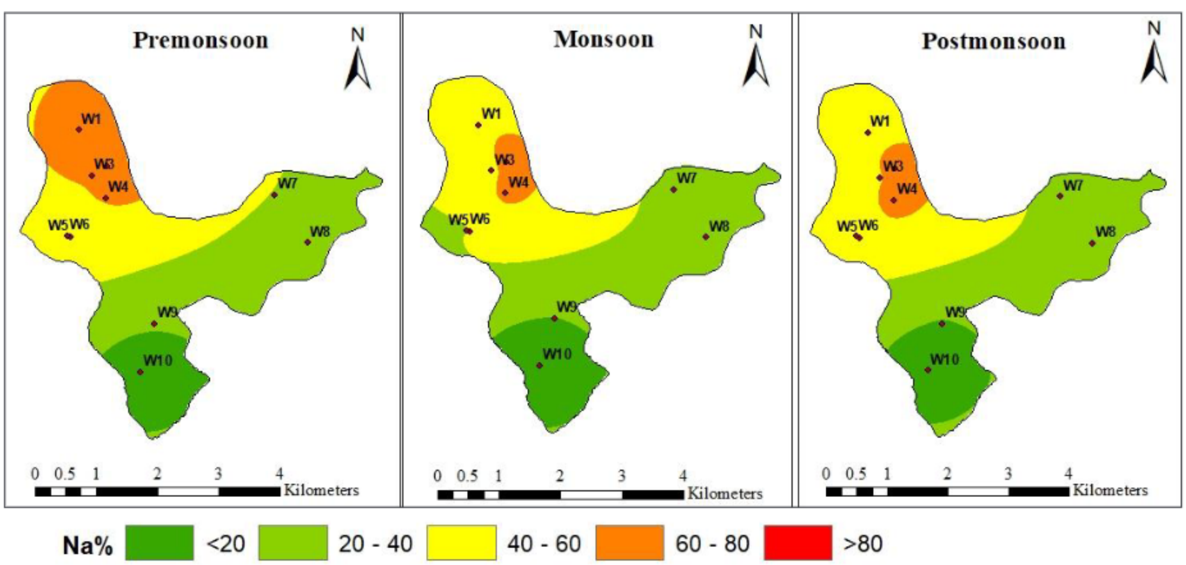

Fig. 6: Map showing spatial variation of Na% for different seasons

during all seasons. The percentage of Na in wells W6 and W7 were close to 50% for all seasons, and slightly above 50% during non-rainy seasons, making the water not fit for irrigation. The major problem of irrigation water with higher concentration of Na is that it would make the soil surface impervious. Other cations Ca^{++}, Mg^{++}, and anions HCO_3^- would also decrease the permeability of the irrigated land. The leachate from industrial wastes containing excess sodium might be reaching the groundwater and making it alkaline. The soluble sodium percentages in these wells were higher than 50% making the water not good for irrigation. Maximum sodium hazard was seen in the pre-monsoon season, and the percentage area coverage is 15 per cent. Sreekesh *et al*. (2018) also reported Na percentage of groundwater samples along the coast of Ernakulam district in the range of 8.45 to 82.76 with an average value of 43.78, which was almost in close agreement with the result obtained in the current study with Na percentage varying in the range of 20 – 80 per cent.

RSC map

The RSC maps for the observation wells are shown in Fig. 7. As per IS: 11624: 2019 (BIS, 2019) guidelines, the RSC should not exceed 2.5 meq.l^{-1} for water to be used for irrigation without any hazards. As shown in Fig. 7, the water samples of the wells W1, W2, W4, and W5, lying in the North-Eastern part of the study area, exceeded this limit during pre-monsoon and monsoon seasons of the years 2019 and 2020, making the groundwater unfit for irrigation. However, Jayasree and James (2021) reported RSC at Chendamangalam, a flood prone area in Ernakulam district, Kerala, to be less than 1.25 meq.l^{-1} during all seasons, indicating suitability of water for irrigation purpose unlike the result obtained from the current study.

Irrigation Water Quality Index

Irrigation water quality index (IWQI) values spatially interpolated map is presented in Fig. 8 for the three seasons. The IWQI zoning map of the study area prepared through Kriging method in GIS with five different groups with class ranges of 0-40, 40-55, 55-70, 70-85, and 85-100. Higher IWQI values indicate better quality of irrigation water and vice versa. The water having IWQI in the range 85-100 is non-toxic and is best suitable for irrigation, and has been classified as excellent category.

Pre-monsoon values of IWQI of the water sources were generally lower in both years considered in the study. However, there were some exceptions. The pre-monsoon values of the IWQI for the year 2019 ranged with minimum value of 35 in the wells W2, W3, and W4 to maximum value of 76 in the well W10. In the year 2020, the IWQI values also showed comparable results for the 10 wells within the same season. The results indicated that the variations of IWQI amongst the seasons in the year 2020 also followed the same trends as that of the year 2019. The results of higher IWQI values for monsoon and post-monsoon seasons were in line with the expectations that with abundant rain and groundwater recharge the quality of groundwater generally improves. Further, it indicated

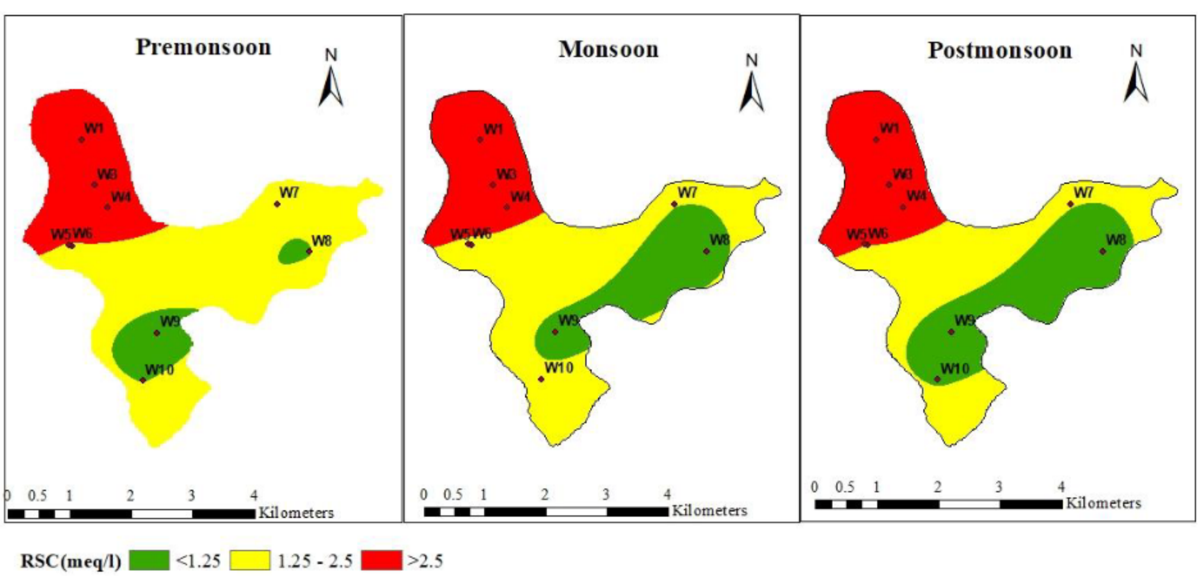

Fig. 7: Map showing spatial variation of RSC for different seasons

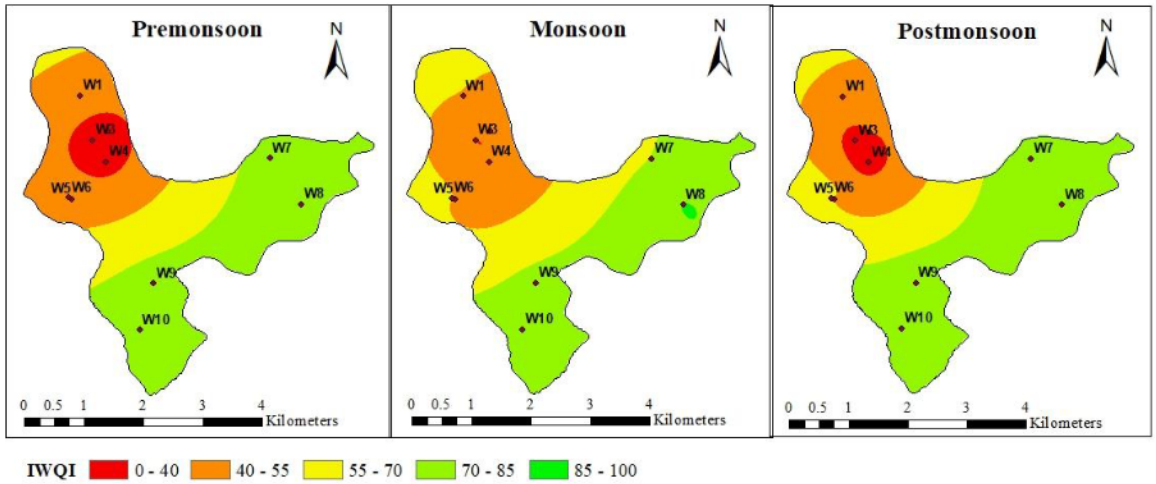

Fig. 8: Map showing spatial variation of IWQI for different seasons

that chemical impurities on the soil surface were less. If chemical substances are present on the surface, it would move to the groundwater along with infiltrated and percolated water.

The water samples taken from the well W8 (at Eastern boundary of study area) had highest IWQI, and varied from 45 to 94 temporally. The well W8 showed an IWQI value greater than 90 during the monsoon and post-monsoon seasons. It could be inferred that the higher elevation and far-away location of this well from the waste disposal site could be the main reasons for the availability of good quality water in this well. The spatial maps also showed that the region covered by this well had excellent quality of groundwater for irrigation. The wells W7 and W9 had IWQI values within the range of 55-70 during most of the seasons in the years 2019 and 2020, which indicated that the aquifer water represented by these wells could be used for irrigation by adopting moderate restriction policies. These two wells were also at considerable distance from the effluent disposal site. These wells were at substantially lower elevation than that of well site of W8. In the case of well W10, the value of IWQI was in the range of 75 – 85 for the years 2019 and 2020. Thus, the area surrounded by this well could yield good quality of irrigation water. This well was also far away from the effluent disposal site and lied at a moderate elevation level. The highest IWQI values were seen in the South-West part of the study area with an average areal extent of 6.3 km^2. The water samples from W6 showed IWQI in the range of 40-55%, which indicated that the groundwater from that area could only be used to irrigate moderate salt tolerant crops. The wells W2, W3, and W4 had very low IWQI (<40), which indicated that aquifer water of this area was highly contaminated and could be used to irrigate high salt tolerant crops only. All these wells were within about 1.5 km radial distance from the effluent disposal field. The areal extent of this severely restricted class of aquifer was 0.9 km^2 in pre-monsoon, and 0.5 km^2 in the post-monsoon seasons. The percentage of area with IWQI values less than 70 was 46% and 42% for pre-monsoon and post-monsoon seasons, respectively. Moreover, they were situated at lower elevation compared to the other wells. Percentage of wells for various seasons as per IWQI classification is shown in Table 6.

By considering the average value of IWQI for the full study period of years 2019 and 2020, it was found

Table 6. Percentage of wells for various seasons as per IWQI classification

IWQI values and type of restriction	Percentage of wells					
	Pre- monsoon 2019	Monsoon 2019	Post- monsoon 2019	Pre- monsoon 2020	Monsoon 2020	Post- monsoon 2020
85-100 (No restriction)	0	0	0	0	0	0
70-85 (Low restriction)	10	20	30	20	0	20
55-70 (Moderate restriction)	20	40	30	20	40	30
40-55 (High restriction)	40	30	10	30	40	30
0-40 (Severe restriction)	30	10	30	30	20	20

that during the pre-monsoon time period, about 5.9% of the study area fell under IWQI<40, 38.5% area under IWQI range of 40-55, 33.7% area under IWQI range of 55-70, and 21.81% area under IWQI range 70-85 (Table 7). Therefore, about 78% of the total geographical area had the threat of adverse effect of poor quality of groundwater during the pre-monsoon season, which coincides with the summer season when there is high demand for irrigation water. During the monsoon period, about 79% of the total geographical area had the threat of adverse effect of poor quality of irrigation water. The percent of geographical area with IWQI value less than or equal to 70 during the monsoon season was nearly equal to that of pre-monsoon season. At the same time, the extent of area with very poor-quality water during monsoon season was very low compared to that of pre-monsoon season (5.9% for pre-monsoon, 1.47% for monsoon). In the post-monsoon season, about 72% of the total geographical area had poor quality irrigation water having an IWQI value less than or equal to 70.

Comparison of Hydro-chemical Method and IWQI

The comparison of irrigation water quality as indicated by the hydro-chemical parameters and IWQI for the average values for years 2019 and 2020 is presented in Table 7. The comparison is made for the pre-monsoon seasons of the years 2019 and 2020 for water sources of all 10 wells as quality of groundwater during pre-monsoon season is more important than of other seasons from the point of view of irrigation. Since the pre-monsoon season correspond with the summer season, the crops are dependent on irrigation water.

In the case of well 1 (W1), the hydro-chemical parameter EC suggested that the water is safe for irrigation. But, IWQI suggested that high restrictions need to be imposed on the use of water for irrigation. Similarly, the values of the parameters EC, SAR, and Na%, for the wells W2, W3, and W4 suggested that the water is good for irrigation. At the same time, IWQI suggested that severe restrictions need to be observed in using those waters for irrigation. In the case of W6 and W8, all hydro-chemical parameters suggested that the water is irrigable. However, IWQI indicated that high restrictions are required. As IWQI integrates effect of different hydro-chemical parameters by assigning different weights, it could be inferred that the combined measure of IWQI gives more reliable indications on the suitability of the available water for irrigation. Similar findings have been reported in several studies worldwide (Batarseh *et al.*, 2021; Behairy *et al.*, 2021).

Seasonal Variation in Each Water Quality Parameters

Water quality parameters and their season-wise areal extent corresponding to each water quality parameter and IWQI are given in Table 8. From the stand point

Table 7. Comparison of irrigation water quality as indicated by hydro-chemical parameters and IWQI for average values for year 2019 and 2020

Well	EC#	SAR	RSC	KI	Na%	IWQI
W1	1300	10.1	10.1	3.2	76.7	47.2
W2	1000	4.00	6.37	3.2	76.3	35.0
W3	460	2.64	4.23	1.7	68.2	35.0
W4	440	2.51	3.51	1.1	56.5	35.0
W5	400	1.16	2.35	0.9	51.5	48.1
W6	380	1.00	1.47	0.8	47.6	47.3
W7	160	0.67	1.16	0.3	31.1	70.8
W8	160	0.47	0.84	0.3	26.3	45.3
W9	150	0.31	0.81	0.3	21.4	59.4
W10	60	0.26	0.81	0.1	12.3	76.8

Excellent	Good	Suitable	Permissible
Doubtful	Poor	Very Poor	Unsuitable

Note: #EC= Electrical conductivity; SAR= Sodium Adsorption Ratio; RSC= Residual Sodium Carbonate; KI= Kelly ratio; Na%= Sodium percentage; IWQI= Irrigation Water Quality Index

Table 8. Extent of area lying under each *irrigation water quality parameter

Parameter	Value	Area, %		
		Pre-monsoon	Monsoon	Post-monsoon
Electrical conductivity, $\mu S.cm^{-1}$	<250	50.00	56.70	50.00
	250 - 750	39.00	33.6	39.50
	750 - 2000	1.40	0.00	0.00
	2000 - 3000	0.00	0.00	0.00
	>3000	0.00	0.00	0.00
Sodium adsorption ratio (SAR)	<6	100.00	100.00	100.00
	6 – 9	0.00	0.00	0.00
	>9	0.00	0.00	0.00
Residual sodium carbonate (RSC), $meq.l^{-1}$	<1.25	8.80	20.91	29.17
	1.25 – 2.5	55.00	46.19	36.05
	>2.5	26.00	23.16	25.35
Kelly ratio (KI)	<1	63.00	71.33	67.11
	>1	27	18.94	23.16
Sodium percentage, Na%	<20	11.90	13.73	12.8
	20 - 40	38.20	41.69	39.08
	40 - 60	24.30	30.77	33.23
	60 - 80	15.50	4.08	5.14
	>80	0.00	0.00	0.00
Irrigation water quality index (IWQI)	0 - 40	6.19	0.00	3.30
	40 - 55	24.00	23.32	20.14
	55 - 70	15.40	27.04	19.15
	70 - 85	44.50	40.56	47.74
	85 - 100	0.00	0.35	0.00

of EC, about 50% of the geographical area of Eloor had excellent quality of groundwater for irrigation during pre-monsoon and post-monsoon; and the corresponding area increased to about 60% during monsoon. The rest of the area of Eloor had good quality of water based on EC.

In the case of SAR, its value was less than 6 in all areas during all seasons, indicating good quality irrigation water. In the case of RSC, only about 40% of the area had unsuitable groundwater for irrigation, and the rest of the area had good quality irrigation water. There were minor variations in these values amongst seasons.

From the IWQI view point, only 45% of the study area had 'good' quality irrigation water, and 'very poor' quality water was observed in about 30% of the area during the pre-monsoon season. The sodium percentage, Kelly ratio, and IWQI values indicated that an area of about 25% fell under 'unsuitable/poor' water quality condition, especially during the pre-monsoon period. These suggested the need for establishing water quality monitoring networks, promoting conjunctive use of poor and good quality water, ground water recharging, selection of tolerant and semi-tolerant crops to meet the challenges of poor water quality in the region.

CONCLUSIONS

The study revealed that the Eloor island, one of the major industrial belts of Kerala, had been severely affected by irrigation water quality issues as indicated by hydro-chemical parameters and Irrigation Water Quality Index (IWQI). The main reason for poor water quality could be attributed to the effect of effluent discharges. During pre-monsoon season, IWQI was less than 70 in about 85% of the geographical area. Wide variations were noticed between water quality recommendations given by individual hydro-chemical parameters and the combined parameter given by IWQI. The spatial interpolation of EC suggested that groundwater over the entire region was suitable for irrigation, while as per SAR only 10% of the study area had water unfit for irrigation. However, as the IWQI values in 70% of the area had poor quality of irrigation water, it was observed that water from the wells lying in the North-Western part of the study area cannot be used for irrigation; whereas the groundwater of the other regions could be utilised for irrigation with necessary precautions. The IWQI method was more comprehensive, easy to handle, and reliable to evaluate irrigation water quality, and should preferably be used for comprehensive assessment of irrigation water quality. Similar studies in other areas of the State having water quality issues will be helpful for sustainable management of land and water resources of the state.

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