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ORIGINAL ARTICLE

Geo-spatial analysis of irrigation water quality of Pudukkottai district

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Abstract

Groundwater becomes a vital source of irrigation for agriculture in the recess of rainfall. The acceptable groundwater quality becomes essential for agriculture not only to get the utmost crop yield but also to protect the land from degradation. The main intent of the study is to investigate the condition of groundwater quality for crop irrigation of Pudukkottai districts using an irrigation water quality index. To achieve the objective of the study, the entire Pudukkottai district groundwater samples have been collected from twenty-six wells in the year 2000 and 2015. The water quality parameters of total dissolved substance, sodium adsorption ratio, electrical conductivity, sodium (Na^+), calcium (Ca^{+2}), magnesium (Mg^{+2}), bicarbonate (HCO_3), chlorine (Cl^-) and pH have been analyzed. The study concludes that irrigation water quality has been reduced throughout the year from 2000 to 2015, and a water quality index additionally shows the worst-case situation in terms of the status of irrigational groundwater quality of the Pudukkottai district which ends up in land degradation.

Keywords Groundwater · Irrigation · Land degradation · Water quality · Irrigation water quality index

Introduction

Agriculture may be a vital supply of financial gain and also the backbone of the Indian economy. Over 70% of the populations of the Republic of India are engaged in agriculture directly or indirectly for their supply of sustenance. It is our responsibility to preserve and augment the production of agriculture to sustain the growing population of the country. It becomes a challenge in the semiarid and arid regions of the country due to the amount and timing of rainfall which is not sufficient for the water requirement of agriculture. Effective management of available water for agriculture is most important to support the huge population of the country. Therefore, supplementary irrigation is essential to raise and support agriculture in any region particularly in the semiarid and arid regions. Groundwater becomes a significant source of irrigation for agriculture in the arid and semiarid regions. Agriculture requires good quality of water for the production of high-quality crops, which can be supplied from groundwater. As compared to surface water, groundwater is considered as purest form. But, recent population growth threats the excellence of groundwater by overutilization of chemical fertilizer, industrial discharge, land-use practices, geological formation, rainfall pattern and rate of infiltration (Hammouri and El-Naqa 2008; Patil and Patil 2010; Babiker et al 2007). The application of deteriorated water in irrigation makes a negative impact not only on the crops but also on the soil where the crops are grown (Ayers and Westcot 1985). Quality of groundwater varies from place to place (Karanth 1987) and it greatly influenced by the geological formation and anthropogenic activities (Subramani et al 2005) which decides the suitability of groundwater for drinking, irrigation, industries and other purposes. For the long-term sustainability, crop productivity can be achieved by attaining the acceptable quality of irrigation water (Bohn et al. 1985; Brady and Weil 2002) which has to be considered as the most vital aspect to decide its appropriateness to grow crops and evaluate to minimize the negative impact on farming (Mohammed Muthanna 2011). In this study, an attempt is made to assess the water quality for crop irrigation through water quality index. The water quality index may be a range that offers the standard of water at a certain location using various water quality factors. Index of water quality may be a useful and efficient technique for critical suitability of water quality and converse the data on the overall quality of water. Geographical information system (GIS) platform

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becomes the best and efficient tool for visual interpretation and overall analysis of the spatial distribution of irrigation water quality parameters (Al-Mussawi 2014; Khalaf and Hassan 2013; Delbari et al. 2016). The analysis intends to research the spatial distribution of irrigation groundwater quality and water quality index of the Pudukkottai district.

Objectives

1. To study the water quality parameter of Pudukkottai district for the years 2000 and 2015.
2. To calculate the groundwater quality index for the years 2000 and 2015.
3. To seek out the temporal changes in the irrigation groundwater quality.
4. To analyze the spatial distribution of groundwater quality for irrigation and groundwater quality index of Pudukkottai district for the years 2000 and 2015.
5. To demarcate the groundwater quality index map of Pudukkottai district for the years 2000 and 2015.

Study area

Pudukkottai is the central district of Tamil Nadu located between 78°25′ and 79°15′ east longitude and between 9°50′ and 10°40′ of the north latitude. The total area of the Pudukkottai district is 4663 km^2 with the coastline of 42 km. The district is bordered by Bay of Bengal in the east, Sivagangai district in the south, district of Tiruchirappalli in the north, Thanjavur district in the northeast and district of Ramanathapuram in the south. As per the census of India 2011, the total population of Pudukkottai district is 1,618,345. The study area has an annual rainfall of about 900 mm, and it has the climatic type of tropical maritime and monsoon. The district has very low fertility of soils with alkalinity problems in some locations. The geographical location of the district of Pudukkottai is given in Fig. 1.

Material and methodology

Pre-monsoon groundwater quality of the Pudukkottai district has been collected from the state groundwater resources, Taramani, for 2000 and 2015. Groundwater quality parameter of total dissolved substance (TDS), sodium adsorption ratio (SAR), electrical conductivity (EC), sodium ion (Na^+), calcium (Ca^{+2}), magnesium (Mg^{+2}), bicarbonate (HCO_3^-), chlorine (Cl^-) and pH has been analyzed. EC and pH are measured using portable EC meter and pH meter. Bicarbonate and chlorine have been analyzed by the titration method (Jackson 1967). Magnesium, sodium and calcium are determined using visible spectrometer (Page et al. 1982; Jackson 1967). The sodium adsorption ratio has been calculated using the following standard equation given by Ayres and Westcot 1999:

$$\mathrm{SAR} = \frac{\mathrm{Na}^{+1}}{\sqrt{\frac{\mathrm{Ca}^{+2}+\mathrm{Mg}^{+2}}{2}}} \tag{1}$$

Statistical analyses of irrigation water quality are carried out with the aid of Microsoft Excel by estimating the most extreme esteem, least esteem, average and standard deviation given in Tables 1 and 2. The groundwater quality samples are taken from twenty-six locations spread over the whole Pudukkottai district. At first, the groundwater quality is categorized and prepared by a spatial sharing map of every parameter for the years 2000 and 2015 utilizing inverse distance weighted (IDW) interpolation in ArcGIS 10.2 software. IDW interpolation is the procedure of calculating the value of unsampled sites within the area covered by existing observed points (Burrough 1986). The IDW is deemed as one of the most applied and deterministic interpolation techniques in the field of water quality assessment (Meyer 2003; Flock et al. 2005; Robinson and Metternicht 2006). The complex groundwater quality data have been converted to simple understandable information using the water quality index prepared by Meireles et al (2010) and have been considered as an efficient method (Brhane 2016; Khalaf and Hassan 2013) for analyzing water quality. Identification of parameters more relevant for irrigation use has been considered for the creation of irrigation water quality index followed by finding quality measurement values (qi) using Eq. (2) and the given aggregation weight (wi) for water quality index by Meireles et al. (2010). Values of (qi) were calculated based on acceptance limits as shown in Table. 3, which was set up according to irrigation water quality parameters proposed by the University of California Committee of Consultants (UCCC) and the criteria established by Ayres and Westcot 1999.

$$Q_i = q_{i\,\mathrm{max}} - \frac{\left(X_{ij} - X_{\mathrm{inf}}\right) * q_{i\mathrm{amp}}}{X_{\mathrm{amp}}} \tag{2}$$

where $q_{i\mathrm{max}}$ is the extreme value of qi for the class; X_{inf} is the consequent value to the lesser limit of the class to which the factors belong; X_{ij} is the monitored parameter value; $q_{i\mathrm{amp}}$ is the class amplitude; and X_{amp} is the class amplitude for which the parameters belong. With the help of above qi (quality measurement parameter value) and wi (aggregated weight for the water quality parameter), water quality index can be found using Eq. (3)

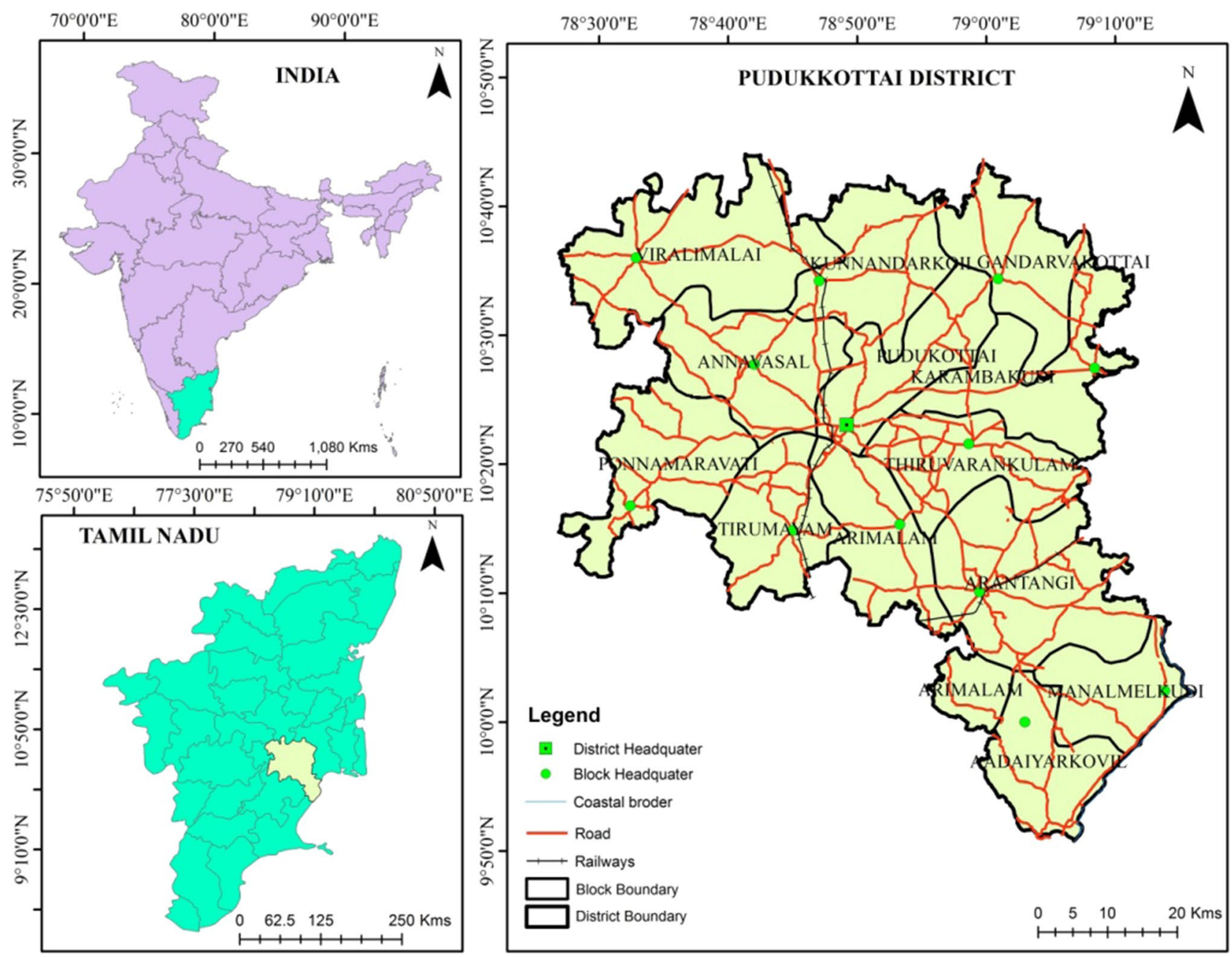


Fig. 1 Study area—Pudukkottai district

$$\text{IWQI} = \sum_{i=1}^{n} qi * wi \tag{3}$$

The value of IWQI (irrigation water quality index) is a dimensionless parameter ranging from 0 to 100 which gives the restriction for using irrigation water and has been classified by Meireles et al. (2010).

Results and discussion

Electrical conductivity (EC)

The quantity of salt present in the water is measured in terms of electrical conductivity (EC). The EC of the water is directly proportional to the ionic concentration and pollutants of the water. Electrical conductivity of the study region given in Table 1 has maximum EC of 10,000 µS/cm and minimum EC of 170 µS/cm in the year 2000, and Table 2 provides the electrical conductivity of study area for the year 2015 which has maximum EC of 7870 µS/cm and least value of 260 µS/cm. Figure 2 exhibits the spatial distribution of electrical conductivity of the groundwater for the years 2000 and 2015, respectively. The electrical conductivity value for the years 2000 and 2015 had been classified based on FAO: The value below 750 µS/cm is considered as no restriction, the value 750–3000 µS/cm is considered as moderate restriction, and EC value above 3000 µS/cm is considered as a severe restriction. Figure 2 shows that the southeastern parts of the districts have a severe restriction, middle and northwestern sides of the district have moderate restriction, whereas northeastern and southern sides of the Pudukkottai district have no

Table 1 Water quality and irrigational water quality index (IWQI) of Pudukkottai district—2000

S. no	Village	TDS (mg/l)	pH	EC (µS/cm)	SAR	HCO_3 (mmol/l)	Na (mmol/l)	Cl (mmol/l)	IWQI
1	Adanakkottai	104.36	8.20	170	1.23	1.05	0.66	0.78	31.16
2	Alangudi	206.46	8.20	330	1.25	2.57	1.09	1.00	42.08
3	Aranmanaippatti	288.72	8.60	460	2.62	6.50	2.09	0.44	51.19
4	Avudayarkoil	5276.00	8.50	9150	33.56	4.77	56.69	87.61	12.77
5	Cholagampatti	1153.35	8.30	1830	4.23	18.53	5.80	7.52	44.21
6	Karanapatti	713.54	8.30	1210	4.58	11.41	5.52	3.43	57.50
7	Karuppattipatti	273.04	8.50	470	1.54	4.54	1.44	1.78	53.87
8	Kilangadu	252.00	8.20	510	1.61	2.57	1.50	2.56	51.27
9	Manalur	2303.04	8.40	4060	12.74	10.91	21.53	34.51	27.76
10	Manamelkudi	1009.93	8.40	1780	9.76	5.76	9.61	12.95	35.70
11	Mandaiyur	703.29	7.60	1390	0.08	5.14	0.16	1.34	50.67
12	Mekkinipatti	283.69	7.90	570	2.54	3.52	2.15	2.31	57.59
13	Melpanaikkadu	386.46	8.30	840	2.84	5.43	2.53	2.65	56.93
14	Mudukulam	167.51	8.60	280	1.26	2.08	0.78	0.66	42.01
15	Muttukkadu	850.56	8.10	1420	1.58	4.09	2.71	3.00	53.75
16	Nagaram	1006.80	7.00	1860	2.72	1.90	4.46	7.74	44.57
17	Nagudi	5845.88	7.10	10,000	9.67	3.43	30.86	127.20	16.66
18	Nanjur	935.82	8.80	1240	2.97	6.12	4.59	2.31	56.39
19	Okkur	1213.17	8.60	2180	12.54	5.44	12.36	17.91	35.34
20	Peraiyur	544.99	8.60	920	2.78	11.37	3.43	2.43	56.34
21	Settippatti	316.53	8.10	600	3.79	4.76	3.09	1.34	60.30
22	Thekkattur	460.61	8.60	770	0.83	7.94	0.72	1.22	51.64
23	Thunaiyanur	281.78	8.40	470	1.31	4.54	1.22	1.78	53.93
24	Tittanviduthy	375.52	7.60	740	2.47	3.05	2.53	4.21	52.37
25	Vembanpatti	229.48	8.20	400	1.66	0.67	1.22	2.09	57.32
26	Vilappatti	605.36	8.10	1090	2.16	4.85	2.93	1.34	56.52
	Maximum	5845.88	8.80	10,000	33.56	18.53	56.69	127.20	60.30
	Minimum	104.36	7.00	170	0.08	0.67	0.16	0.44	12.77
	Average	1105.36	7.80	1922.42	5.10	5.27	7.78	16.88	46.53
	SD	1568.45	1.68	2677.45	7.22	3.93	12.96	35.83	12.88

restriction during the year 2000. In the year 2015, southeastern parts of the district have a severe restriction; middle, south and northwestern sides of the districts have moderate restriction, and only northeastern parts of the districts have no restriction.

Average EC has been reduced from 2000 to 2015, and this may be due to fail in proper harvesting of rainfall. Southeastern parts are practicing agriculture based on the availability of water which comes under the Cauvery delta region, whereas north and northwestern parts exclusively depend on the rainfall. After the year 2000, they start cultivating crop due to rainfall which consumes fertilizer.

pH

pH stands for the power of hydrogen which determines the acidic and alkaline nature of water. If the pH range is between 0 and 6.5, then the water is acidic and ranges between 6.5 and 8.4 where the water is normal for irrigation. Finally, the pH range from 8.4 to 14 is alkaline water. The study area shows the range between a minimum of 7.00 and a maximum of 8.80 in the year 2000 given in Table 1. In the year 2015, the values of pH in the Pudukkottai district range between a minimum of 6.80 and a maximum of 8.50 as given in Table 2. Figure 3 indicates that in the year 2000, the southern parts except for few areas in the southeast, north and northeast are alkaline water and all other regions are neutral groundwater ranging between 6.5 and 8.4, whereas in the year 2015 the major parts of north, northwest, northeast and eastern are alkaline water and the remaining area of the study zone is neutral water. The average pH has been

Table 2 Water quality and irrigational water quality index (IWQI) of Pudukkottai district—2015

S. no	Village	TDS (mg/l)	pH	EC (µS/cm)	SAR	HCO_3 (mmol/l)	Na (mmol/l)	Cl (mmol/l)	IWQI
1	Adanakkottai	135.00	7.20	260	0.94	0.62	0.44	3.12	45.25
2	Alangudi	233.00	7.30	430	0.71	0.62	1.78	3.89	52.26
3	Aranmanaippatti	522.00	7.70	940	2.16	2.50	4.21	10.66	43.87
4	Avudayarkoil	4163.00	7.20	7800	5.76	20.25	79.62	9.52	15.68
5	Cholagampatti	313.00	8.00	550	1.93	1.72	2.43	4.79	48.91
6	Karanapatti	1531.00	8.50	2610	5.67	9.80	18.60	6.28	27.61
7	Karuppattipatti	448.00	8.00	760	1.42	1.50	4.99	2.78	47.87
8	Kilangadu	315.00	8.20	560	0.97	0.90	3.09	3.99	52.12
9	Manalur	4669.00	8.20	7870	21.72	43.49	72.10	6.28	9.07
10	Manamelkudi	1020.00	7.90	1750	4.10	5.80	10.30	9.33	35.34
11	Mandaiyur	1864.00	7.40	3380	3.08	7.33	28.77	7.99	24.10
12	Mekkinipatti	267.00	8.30	490	1.45	1.25	1.44	5.82	49.44
13	Melpanaikkadu	507.00	8.50	890	2.83	2.87	4.99	6.66	42.61
14	Mudukulam	303.00	8.30	550	1.71	1.53	3.09	3.67	52.00
15	Muttukkadu	915.00	7.60	1500	8.47	7.80	7.64	7.61	37.71
16	Nagaram	892.00	7.60	1470	4.02	4.87	12.17	4.19	40.63
17	Nagudi	726.00	6.80	1250	3.39	4.27	8.95	2.85	45.04
18	Nanjur	701.00	8.50	1250	4.43	5.02	8.30	6.66	42.73
19	Okkur	1616.00	7.00	3000	2.13	5.02	28.55	6.66	22.61
20	Peraiyur	1693.00	7.10	3000	1.49	3.74	30.51	5.71	28.10
21	Settippatti	1118.00	8.20	1940	3.51	5.74	13.95	7.42	33.08
22	Thekkattur	541.00	8.10	940	2.37	2.43	1.65	14.08	43.80
23	Thunaiyanur	1212.00	7.90	2100	2.22	4.15	14.82	5.90	29.04
24	Tittanviduthy	192.00	8.00	360	0.73	0.59	1.09	3.86	52.28
25	Vembanpatti	281.00	8.20	500	1.28	1.12	2.65	3.07	52.38
26	Vilapatti	251.00	8.20	420	0.32	0.28	1.09	4.61	49.39
	Maximum	4669.00	8.50	7870	21.72	43.49	79.62	14.08	52.38
	Minimum	135.00	6.80	260	0.32	0.28	0.44	2.78	9.07
	Mean	1016.46	7.84	1791.15	3.42	5.59	14.12	6.05	39.34
	SD	1124.43	0.50	1994.75	4.18	8.77	20.26	2.70	12.24

Table 3 Quality measurement for *qi* calculation (Meireles et al. 2010)

qi	EC (µS/cm)	SAR	Na^+ (mmol/l)	Cl^- (mmol/l)	HCO_3 (mmol/l)
85–100	$200 \leq EC < 750$	$2 \leq SAR < 3$	$2 \leq Na < 3$	$1 \leq Cl < 4$	$1 \leq HCO_3 < 1.5$
60–85	$750 \leq EC < 1500$	$3 \leq SAR < 6$	$3 \leq Na < 6$	$4 \leq Cl < 7$	$1.5 \leq HCO_3 < 4.5$
35–60	$1500 \leq EC < 3000$	$6 \leq SAR < 12$	$6 \leq Na < 9$	$7 \leq Cl < 10$	$4.5 \leq HCO3 < 8.5$
0–35	$EC < 200$ or $EC \geq 3000$	$SAR < 2$ or $SAR \geq 12$	$Na < 2$ or $Na \geq 9$	$Cl < 1$ or $Cl \geq 10$	$HCO_3 < 1$ or $HCO_3 \geq 8.5$

increased from 2000 to 2015 due to the high consumption of fertilizer, pesticide, and insecticide.

Total dissolved substances (TDS)

TDS stands for total dissolved substances which is used for measuring the salinity of the water. If the salinity in the water increases, then it would also increase the salinity of the soil. This becomes a serious issue because if the salinity increases, then it would deposit on the root surface of the crop. This reduces the intake of water to the crop ultimately reducing the crop yield. TDS value has been classified into three categories based on FAO (1985): The value below 450 mg/l has no restriction for the usage of irrigation,

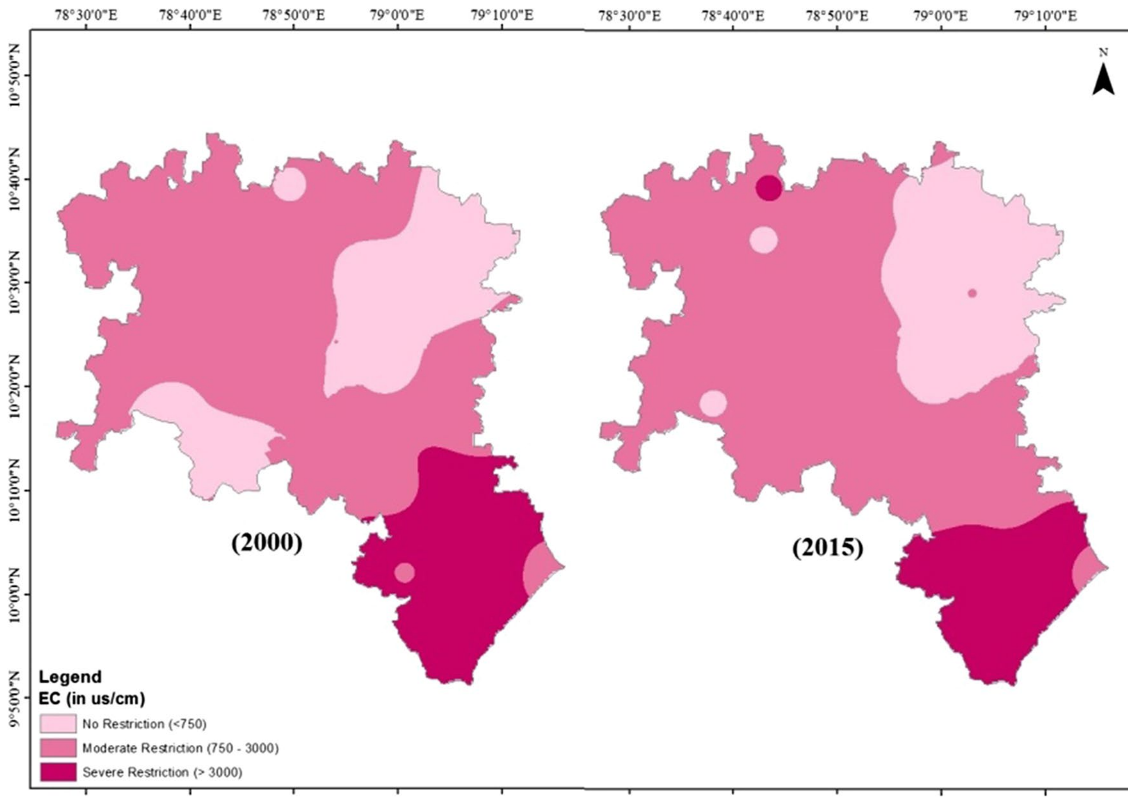


Fig. 2 Spatial distribution of electrical conductivity (2000 and 2015)

the value ranging between 450 and 2000 mg/l has moderate restriction for the usage of irrigation, and the TDS value above 2000 mg/l has severe restriction for the usage of irrigation. Tables 1 and 2 provide the value of TDS for the 26 stations in the Pudukkottai district. Figure 4 exhibits the spatial distribution of TDS for the years 2000 and 2015, respectively. In the year 2000, southeastern parts of the district are classified as severe restriction category for the use of irrigation, middle, north and northeastern sides of the study region have a moderate restriction for the usage of irrigation, whereas northeast and southern parts of the study area are classified as no restriction category for the usage of water for irrigation. In the year 2015, the southeastern side of the study area has a severe restriction for the usage of irrigation and the northeastern side has no restriction for irrigation. Middle, northwest and southern parts of the district are classified as moderate restriction for the use of irrigation. Due to inappropriate management of water bodies which prevent rainfall to percolate into the ground, the average value decreases during the study period. Southeastern parts are practicing agriculture based on the availability of water which comes under the Cauvery delta region, whereas north and northwestern parts exclusively depend on the rainfall. After the year 2000, they start practicing agriculture due to rainfall which starts to consume fertilizer.

Sodium (Na^+)

Sodium ion becomes severe for the growth of the crop if the value is above 9 mmol/l. According to FAO (1985), the sodium value is classified into three categories: no restriction for the value below 3 mmol/l, moderate restriction for the value between 3 and 9 mmol/l and severe restriction for the value above 9 mmol/l. The values of the sodium are given in Tables 1 and 2 for the years 2000 and 2015, respectively.

The highest and lowest value of sodium in the year 2000 is 56.69 mmol/l and 0.16 mmol/l, respectively. The highest and lowest value for the year 2015 is 43.49 mmol/l and 0.28 mmol/l, respectively. The southeastern side of the study area is classified as severe restriction for the usage of water for irrigation. The middle parts, few areas in the northern and northeastern regions, have moderate restriction, whereas middle, northeast, northwestern and southern parts of the study area have no restrictions for the usage of water for irrigation shown in Fig. 5. As compared to

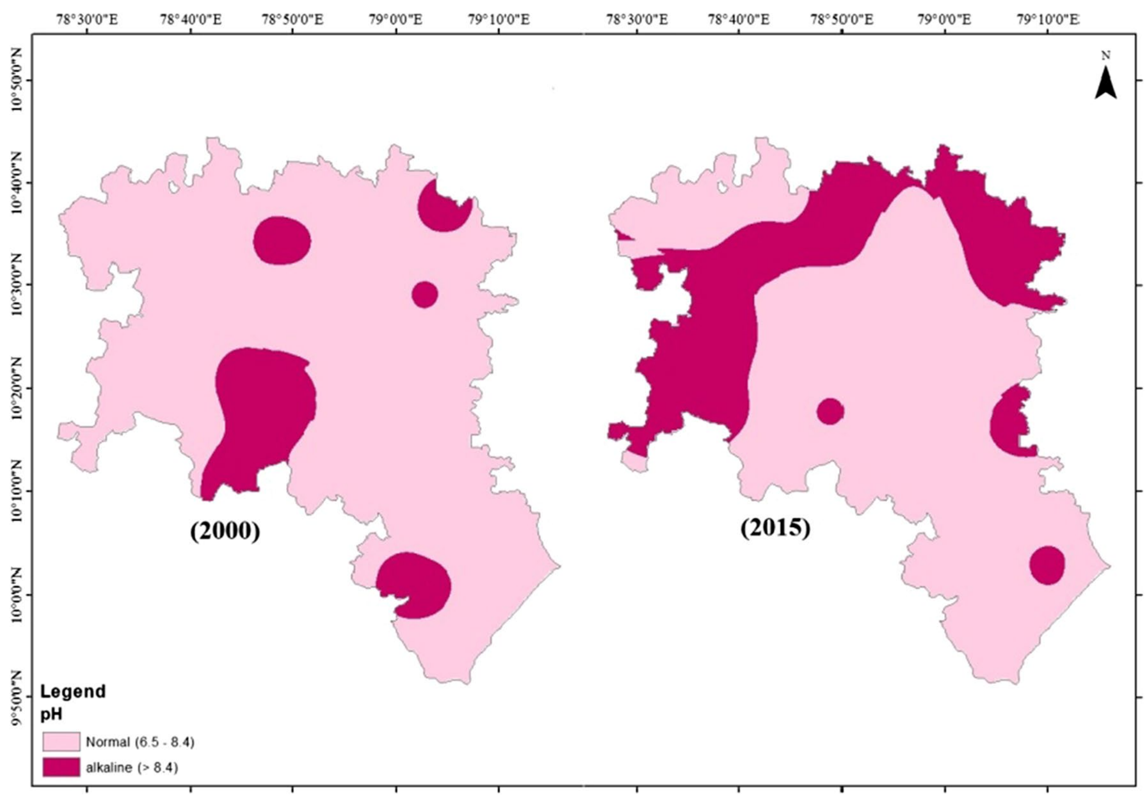


Fig. 3 Spatial distribution of pH (2000 and 2015)

2000 in the year 2015, a few parts are converted to moderate restriction areas from no restriction area. Southeastern parts have a severe restriction, middle parts, northwestern parts and southern parts are categorized into moderate restriction areas, whereas northeastern and few parts in the middle of districts have no restriction. The average value of sodium is doubled from 2000 to 2015 due to the high consumption of chemical fertilizer and connected with rainfall (Khatri and Tyagi 2015; Lahermo et al. 1990). Southeastern parts are practicing agriculture based on the availability of water which comes under the Cauvery delta region, whereas north and northwestern parts exclusively depend on the rainfall. After the year 2000, they start practicing agriculture due to rainfall which starts to consume fertilizer.

Bicarbonate (HCO_3)

Bicarbonate is a significant anion in the quality of water for irrigation. The highest and lowest value of bicarbonate in the year 2000 is 18.53 mmol/l and 0.67 mmol/l, respectively, whereas the highest and lowest value of bicarbonate in the year 2015 is 14.08 mmol/l and 2.78 mmol/l, respectively, given in Tables 1 and 2. For spatial distribution of bicarbonate in the year 2000 (Fig. 6), the entire region is a moderately restricted (1.5–8.5 mmol/l) for the usage of water for agriculture except for few parts in the southwest, north and southeast which are severely restricted with the value greater than 8.5 mmol/l. The spatial distribution of bicarbonate in the year 2015 indicates that severe restriction of bicarbonate for the irrigation water is established in southern parts and few regions of the southeastern parts of the districts, whereas the remaining fraction of the districts are in moderate restriction of usage of water for agriculture. High consumption of fertilizer leads to an increase in the average bicarbonate value from the year 2000 to 2015.

Chlorine (Cl^-)

It is also a significant ion found in the irrigation water; if it exceeds in toxic, it would affect the leaf tissue. The highest and lowest value of the chlorine in the year 2000 is 127.20 mmol/l and 0.44 mmol/l, respectively, given in Table 1. The highest and lowest value of the chlorine in the year 2015 is 76.62 mmol/l and 0.44 mmol/l, respectively.

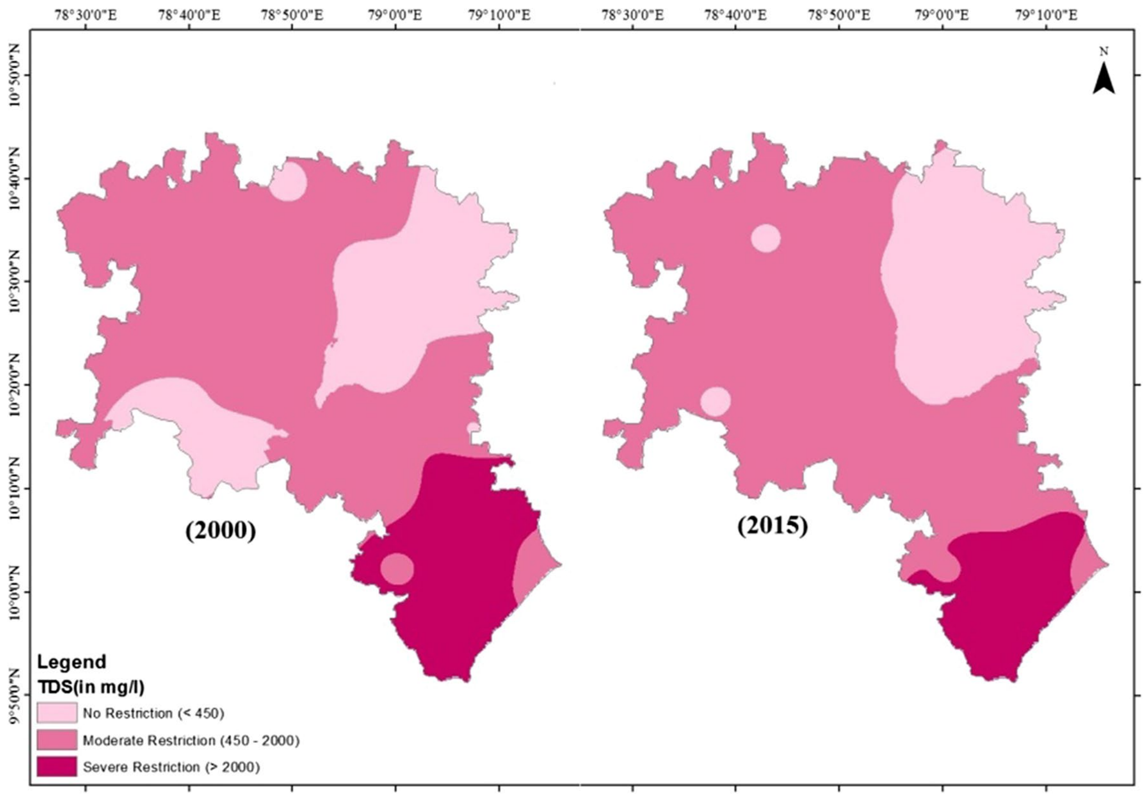


Fig. 4 Spatial distribution of TDS (2000 and 2015)

Spatial distribution of chlorine in the year 2000 has severe restriction for the usage of water for agriculture (greater than 10 mmol/l) spread on the southeastern parts of the district, moderate restrictions are spread in the middle parts of the districts, whereas entire north, south, northwest and southern parts have no restriction for the usage of water for agriculture (FAO 1985). In the year 2015, severe restriction of chlorine is spread on the northwestern parts, southern and southeastern parts of the districts. The middle part of the study area has a moderate restriction (4–10 mmol/l), and low restriction of chlorine is spread on the northeastern parts of the district shown in Fig. 7. The severity of chlorine in the district has been increased due to the inappropriate use of chemical fertilizer. Southeastern parts are practicing agriculture based on the availability of water which comes under the Cauvery delta region, whereas north and northwestern parts exclusively depend on the rainfall. After the year 2000, they start practicing agriculture due to rainfall which starts to consume fertilizer.

Sodium adsorption ratio (SAR)

The presence of high sodium ion in the irrigation water reduces the rate of infiltration into the soil that shows a negative impact on the growth of crop (Simsek and Gunduz 2007) and decrease in the crop yield.

The concentration of sodium (Na^{+}), magnesium (Mg^{2+}) and calcium ions (Ca^{2+}) in the water influences the rate of infiltration of water into the soil also called sodium adsorption ratio. The highest and lowest value of SAR for the year 2000 is 33.56 and 0.08, respectively, as given in Table 1. The highest and lowest value of SAR for the year 2015 is 21.72 and 0.32, respectively, as given in Table 2. The spatial distribution of SAR for the district is shown in Fig. 8 for the year 2000. Southeastern parts of the districts have a high concentration of SAR, middle parts and few parts in the north and northwest have a moderate concentration of SAR, whereas remaining parts have a low concentration of SAR where infiltration of water is not affected. Figure 8 also shows the spatial distribution of SAR for the year 2015. The area of high concentration of SAR in the southeastern region has been reduced, the moderate concentration of SAR has been increased in

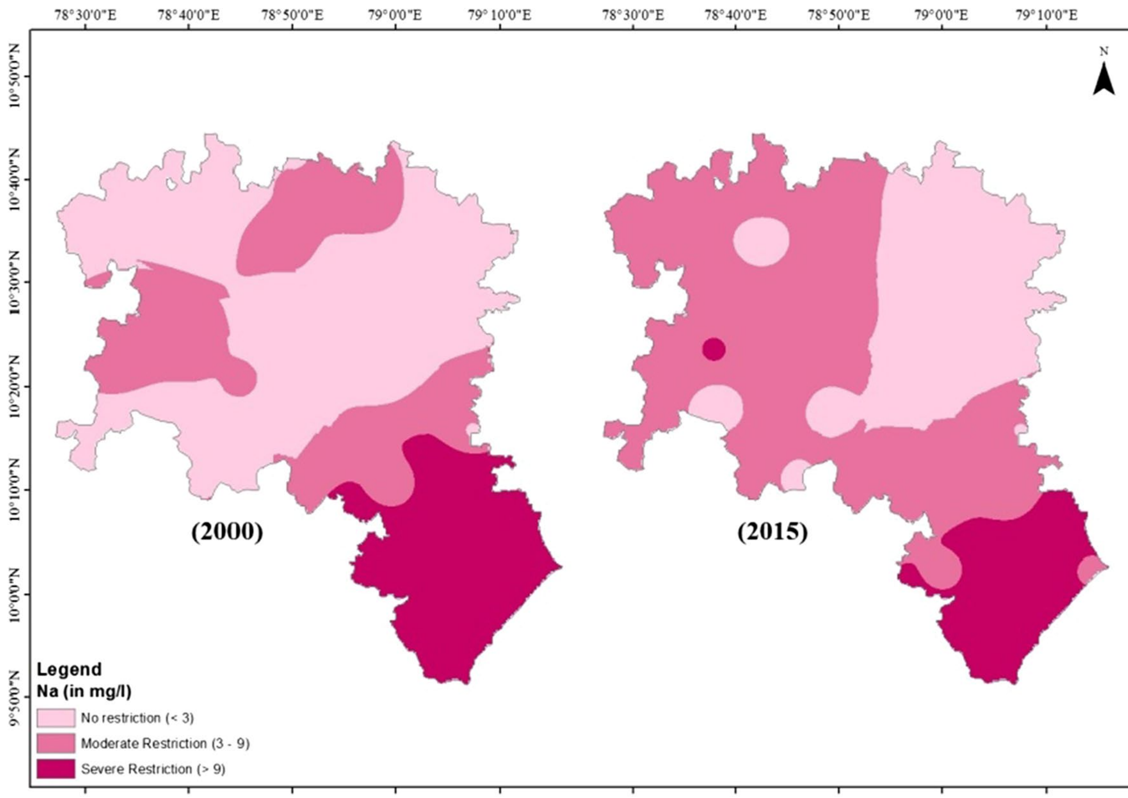


Fig. 5 Spatial distribution of sodium (2000 and 2015)

the southeastern and northwestern parts of the districts, whereas middle parts, northeastern and southern parts of the districts have a low concentration of SAR. Due to inappropriate use of chemical fertilizer in the study area, southeastern parts are practicing agriculture based on the availability water which comes under the Cauvery delta region, whereas north and northwestern parts exclusively depend on the rainfall. After the year 2000, they start practicing agriculture due to rainfall which starts to consume fertilizer.

Irrigation water quality index (IWQI)

IWQI for the Pudukkottai district has been found based on the Meireles et al. (2010) which has helped to locate the area having suitable water quality for agrarian purpose. Meireles et al. (2010) suggested the five most important and dominant parameter for finding IWQI: They are electrical conductivity, bicarbonate, chlorine, sodium and sodium adsorption ratio. Table 1 shows the value of IWQI for the year 2000, and Table 2 provides the value of IWQI for the year 2015. The minimum value of IWQI for the years 2000 and 2015 is 12.77 and 9.07, respectively, whereas the maximum value of IWQI for the years 2000 and 2015 is 60.29 and 52.38, respectively (Table 4).

According to the Meireles et al. (2010) classification of irrigation water quality index, the study area is classified into three classifications: moderate restriction, high restriction and severe restriction in the year 2000, whereas this classification is reduced into two classifications: high restriction and severe restriction in the year 2015. Around 23.07% of the samples have a severe restriction, 46.15% of the samples have a high restriction, and 30.76% of the samples have moderate restriction as shown in Table 5. The spatial distribution of the irrigation water quality index for the years 2000 and 2015 is shown in Fig. 9. Southeastern side of the districts has severe restriction with value of 0 to 40 for the usage of water for crop irrigation, north, south, middle and northeastern sides of the study area have high restriction with value of 40 to 55 for the usage of water for irrigation, whereas northwestern parts of the district have moderate restriction with the value of 55 to 70 for the usage of water for irrigation. The spatial distribution of irrigation water quality index for the year 2015 has shown that southeastern,

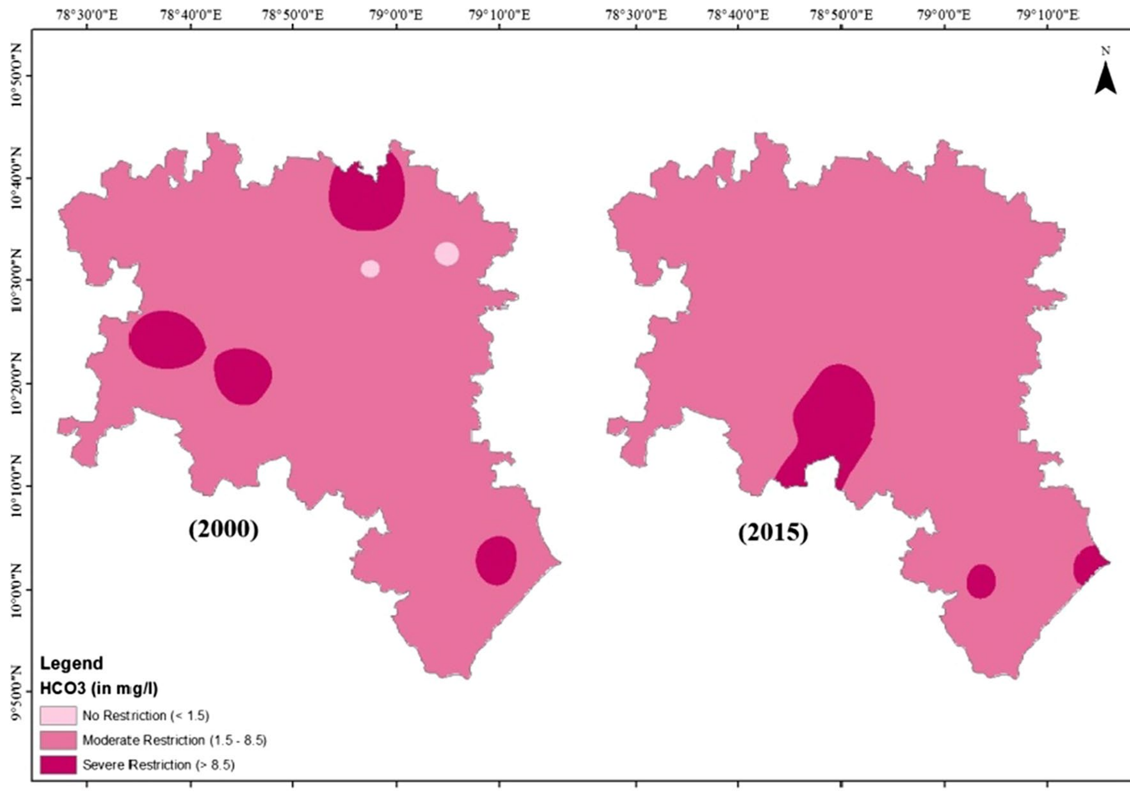


Fig. 6 Spatial distribution of bicarbonate (2000 and 2015)

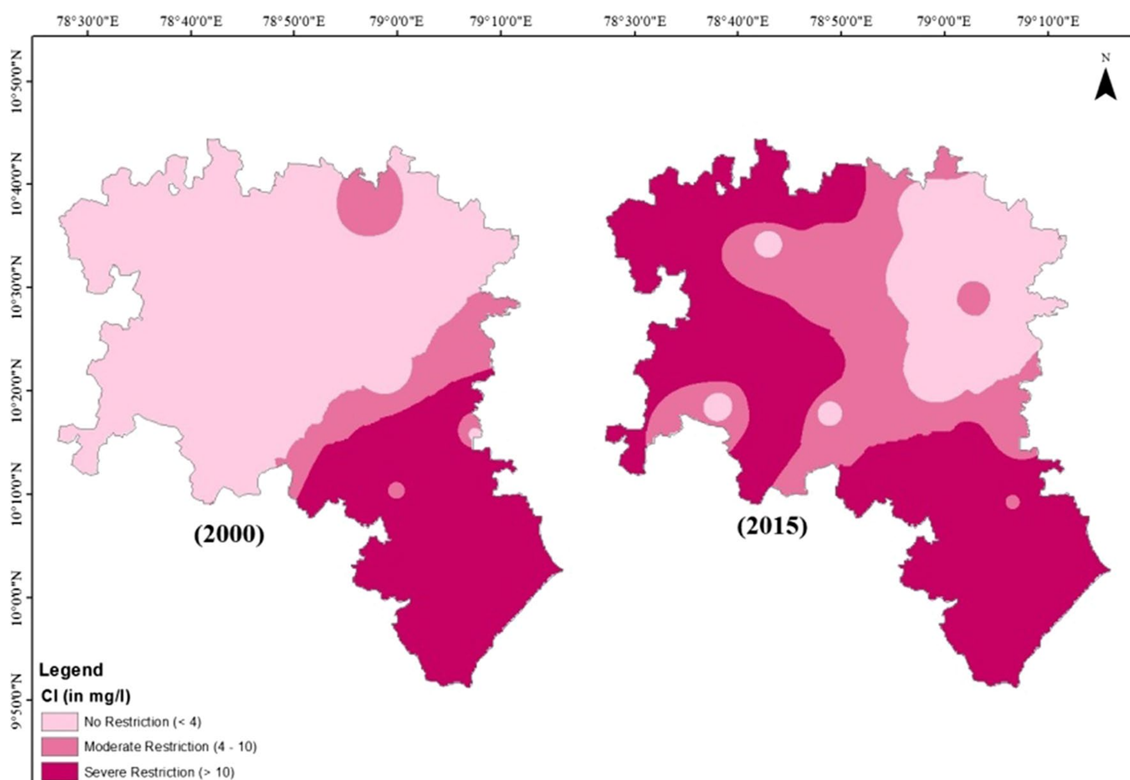


Fig. 7 Spatial distribution of chlorine (2000 and 2015)

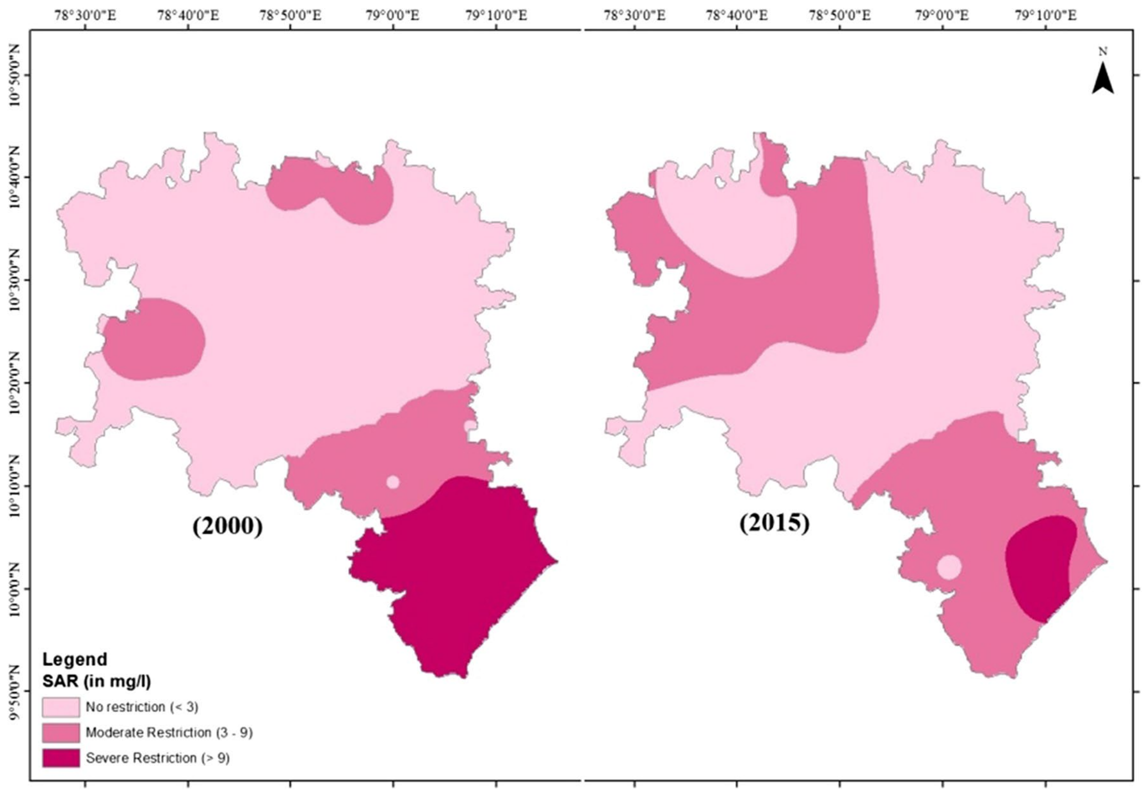


Fig. 8 Spatial distribution of SAR (2000 and 2015)

Table 4 Weights for the IWQI parameters (Meireles et al. 2010)

S. no	Water quality parameters	*wi*
1	Electrical conductivity (EC)	0.211
2	Sodium (Na^+)	0.204
3	Chloride (Cl^-)	0.194
4	Bicarbonate (HCO_3^-)	0.202
5	Sodium adsorption ratio (SAR)	0.189
6	Total	1.00

south and northwestern sides of the study area are classified as severe restriction, whereas the north and middle parts of the district are classified as high restrictions. Around 38.46% of the samples have severe restriction, and 61.53% of the samples have a high restriction of water for irrigation as shown in Table 5.

Table 5 Irrigation water quality index change in area (km^2)

Water quality index	2000		2015	
	Area (km^2)	Sample (%)	Area (km^2)	Sample (%)
No restriction (85–100)	0	0	0	0
Low restriction (70–85)	0	0	0	0
Moderate restriction (55–70)	829.65	30.77	0	0
High restriction (40–55)	2901.92	46.15	2236.14	61.54
Severe restriction (0–40)	931.43	23.08	2426.86	38.46
Total area	4663	100	4663	100

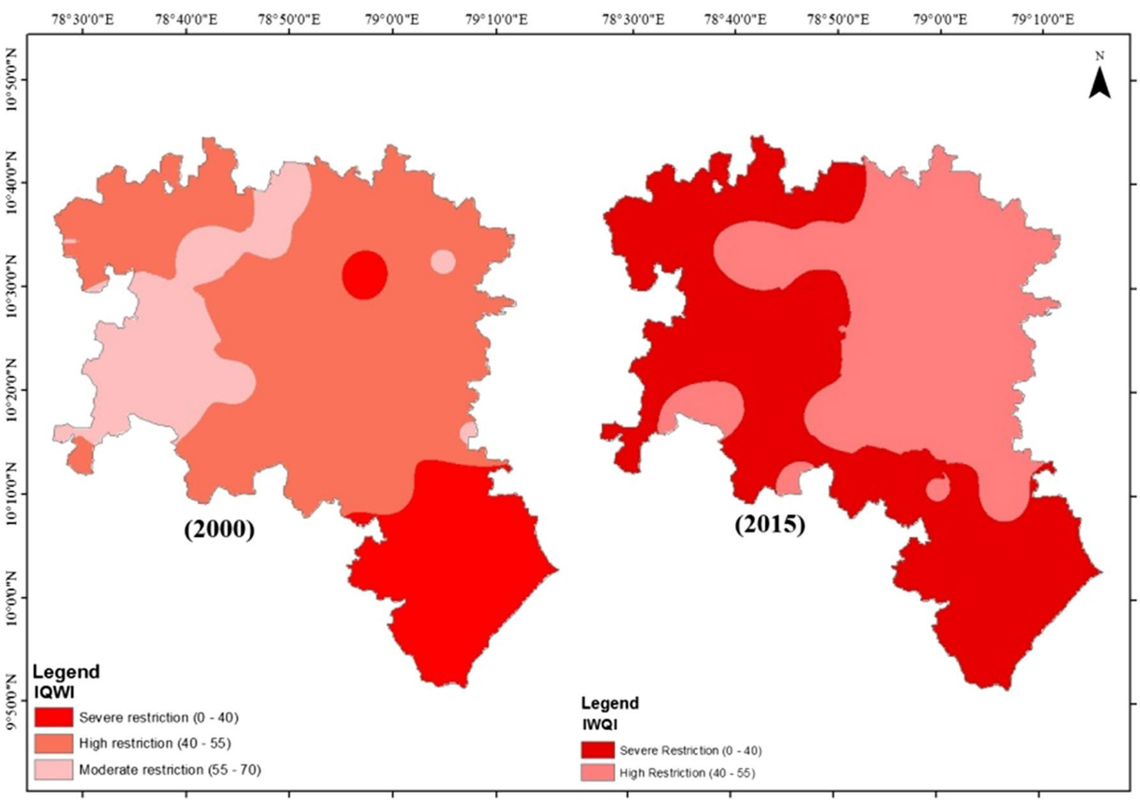
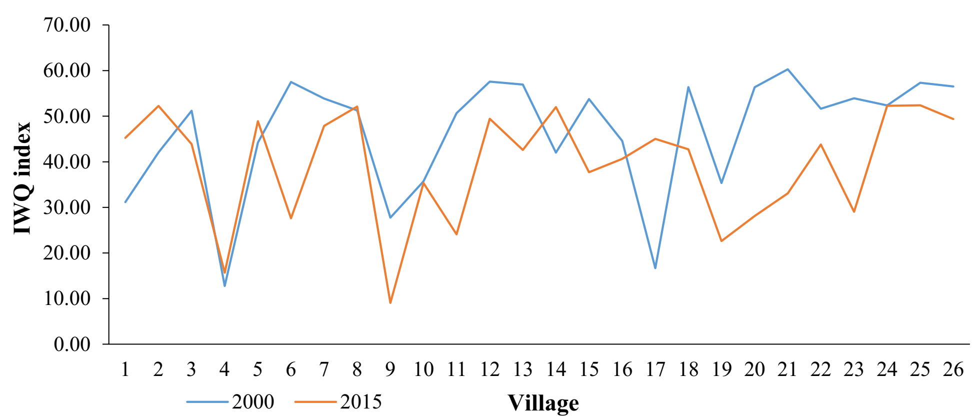


Fig. 9 Spatial distribution of IWQI (2000 and 2015)

Fig. 10 Irrigation water quality index (2000 and 2015)



Conclusion

This research has been conducting to study the water quality status of the Pudukkottai district. It reveals that IDW interpolation in the GIS tool is extremely useful for the study comparing the spatial distribution of water quality parameters. It is found that SAR, TDS, chlorine, EC and sodium are present in a low concentration in the north and northwestern sides of the study area and high concentration on the southeastern side of the study region. pH is safe in the entire region except for few patches in the south and southeastern parts of the district. Bicarbonate has a moderate concentration in the entire region, except for a few parts of north and northwest that were highly concentrated in the year 2000. In the year 2015, chlorine severity has been increased and TDS, EC, bicarbonate, sodium, SAR and pH also have been increased as compared to 2000. Table 5 provides the area change, and Fig. 10 shows the variation of the water quality index for irrigation for the years 2000 and 2015. Hence, it concludes that there is no area of safe groundwater (no restriction) or low restriction of groundwater for agriculture. In the year 2000, the moderate restriction area was 829.65 km^2, the area of high restriction irrigation groundwater was 2901.92 km^2, and the area of severe restriction of groundwater for agriculture was 931.43 km^2 in the Pudukkottai district. In the year 2015, the district has 2236.14 km^2 of high restriction area, whereas 2426.86 km^2 of area has severe restrictions. Therefore, there is no area of safe groundwater for irrigation. This may be due to the severe and inappropriate application of chemical fertilizer for intensive agriculture and in the Pudukkottai district. Urgent needs must be taken to develop the superiority of water for the district of Pudukkottai that would improve agriculture as well as the fertility of the land that results in land degradation.

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Compliance with ethical standards

Conflict of interest The author declares that there is no conflict of interest.

Ethical approval This article does not contain any studies with human participants or animals performed by the author.

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