Journal Homepage: - www.journalijar.com

INTERNATIONAL JOURNAL OF ADVANCED RESEARCH (IJAR)

Article DOI: 10.21474/IJAR01/17129
DOI URL: http://dx.doi.org/10.21474/IJAR01/17129

RESEARCH ARTICLE

CHARACTERISTICS OF GROUND WATER QUALITY AND DRINKING WATER QUALITY INDEX: A CASE STUDY OF CUDDALORE DISTRICT

M. Jayanthi[1] and Dr. G. Geetha[2]

1. PhD Research Scholar Department of Geography Queen Mary's College Chennai .
2. Assistant Professor & Head of Department of Geography Queen Mary's College Chennai.

Manuscript Info

Manuscript History
Received: 20 April 2023
Final Accepted: 24 May 2023
Published: June 2023

Key words:-
Drinking Water Quality, Ground Water, Geographical Information System, Cuddalore District

Abstract

The water and environment has become an emotive issue with the people and policy makers. The chief causes for the pollution of water and environment are anthropogenic activities of human beings. The primary objective of this paper is to study the groundwater quality parameters in the wells of Cuddalore district in Tamil Nadu. The data is collected from the study area for two years i.e., 2002 and 2022. The groundwater contour analysis is done by using Geographical Information System (GIS). The water quality index has calculated based on Total Dissolved Substances (TDS), Nitrate (NO3), Calcium (Ca), Magnesium (Mg), Chloride (Cl), Sulphate (SO4), Fluoride (F), Power of Hydrogen (pH) and Electrical Conductivity (EC) The study reveals that the concentration of major constituents is well within the permissible limits of Indian Standard, except in few cases where Electrical Conductivity, Chlorine and Sulphates concentrations are high. The overall ground water index reveals that the water quality in Cuddalore district has increased considerably from the year 2002 to 2022. Spatially, unsuitable area has increased from the year 2002 to 2022 similarly excellent suitability of drinking water is also increased during the same period. Hence, from the assessment it is recommended to take necessary steps to improve further for the protection of environment and human beings.

Introduction:-

India is a tropical county with a vast diversity of climate, topography and vegetation. Though blessed with fairly high annual rainfall, it is not uniformly distributed in time and space resulting in bulk of the rainfall escaping as runoff. This results in incomplete utilization of available surface water. The scarcity of surface water especially in the lean season in most parts of the country means that groundwater plays a decisive role. India has diversified geological, climatological and topographic set up giving rise to divergent groundwater situations in different parts of the country. Groundwater may be considered as one of the most precious and one of the basic requirements for human existence and the survival of mankind providing him the luxuries and comforts in addition to fulfilling his basic necessities of life and also for industrial (Krishnaoorthy & Athimoolam, 2015) (Yuvaraj & Prasad, 2022) and agricultural development (Ramachandran, 2020) thus being a very important constituent of our eco-system. . Water for home use should be clear, pale, ascented, palatable to drink and free from significant cold and hazardous impurities for well-being. It is so great that human well-being and sustainability are based on the use of clean,

Corresponding Author:- M. Jayanthi
Address:- PhD Research Scholar Department of Geography Queen Mary's College Chennai.

uncontrolled water for drinking and various local jobs. The ground water are susceptible to various pollutants depending on physical processes (Molla et al., 2023) and anthropogenic activities (Goncalves et al., 2023). The problem is serious for drinking water; public health is at high risk due to the presence of chemical contaminants. Prolonged exposure to contaminated water has been known to increase the risks of diarrheal diseases, cancer, and disorders in the kidney, liver, and reproductive organs (Fawell & Nieuwenhuijsen 2003). Ensuring the safety of drinking water is, therefore, a growing public concern. Drinking water is now recognized as a fundamental human right by the United Nations. Availability and sustainable management of good-quality water were set as one (Number 6) of the UN Sustainable Development Goals (SDGs) (United Nation, 2015). An understanding of water quality2 and its availability is vital because waterborne diseases are still a major cause of death in many parts of the developing world (WHO, 2011). Therefore, monitoring and control of drinking water quality is a top-priority policy agenda in many parts of the world (UNESCO, 2013). The present study is undertaken to investigate the qualitative analysis and some physicochemical parameters of ground water at Cuddalore district of Tamil Nadu. The values obtained by this analysis are studied and compared with the observed value of Indian standard, which tells us about the permissible limit of water for better use of water for drinking purpose.

Study Area

The total Geographical area of the district is 3678 sq. Km with coastlines of 68 km. Cuddalore District is bounded by the Bay of Bengal in the east, Villupuram District in the west, Union Territory of Pondicherry in the North and Nagappattinam District in the South. The District lies between 11°9'0.982"N to 11°54'12.735"N latitude and 78°52'38.242"E to 79°48'44.403"E longitude . It is bounded on the north by Villupuram District, on the east by the Bay of Bengal, on the south by Nagapattinam District, and on the west by Perambalur District. The district is drained by Gadilam and Pennaiyar rivers in the north, Vellar and Kollidam River (Coleroon) in the south shown in the Figure 01.

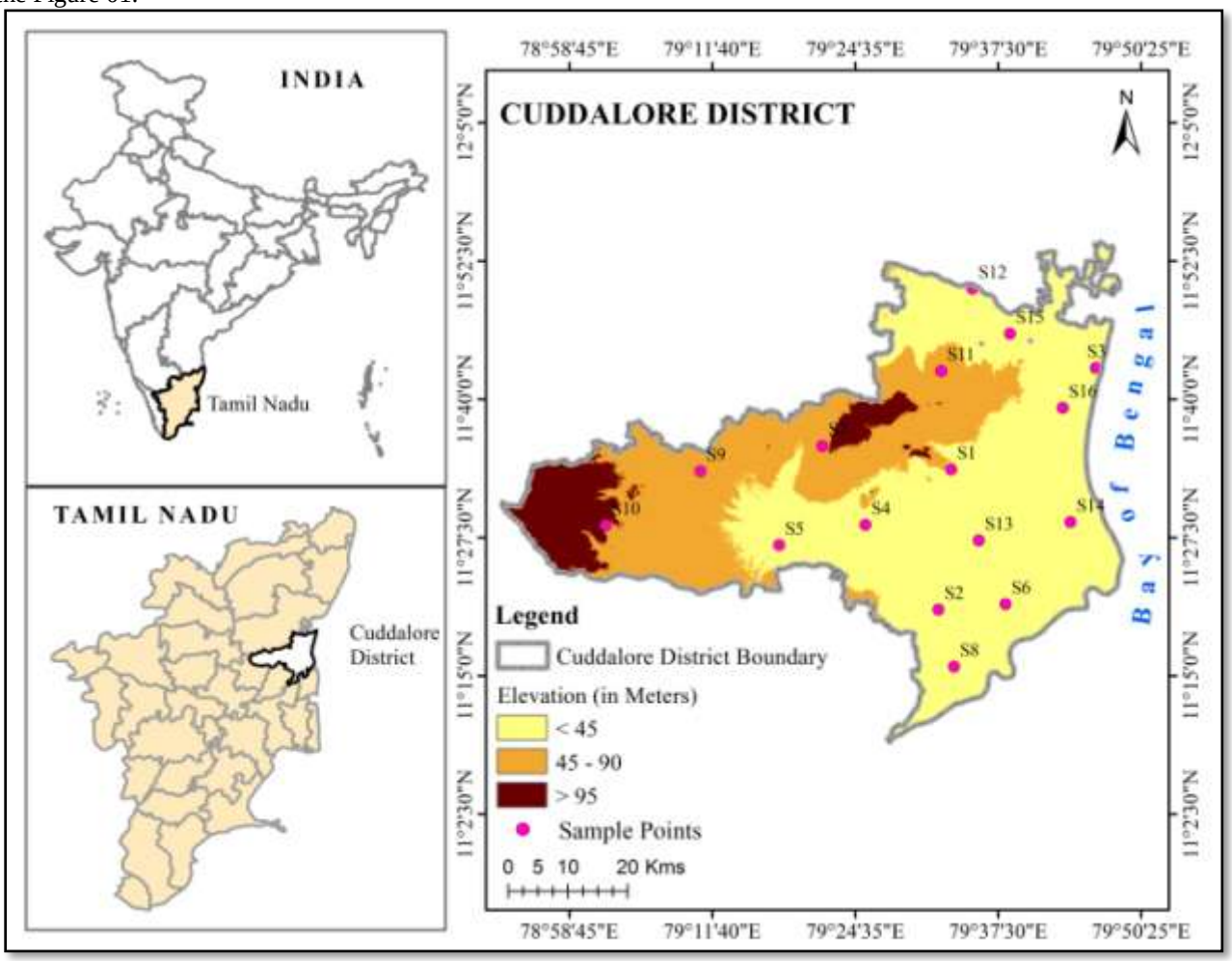

Figure 01:- Study Area – Cuddalore District.

Data and Methodology:-

The Hydro chemical data for the ground water for the Cuddalore district has been obtained for the years from 2002 and 2022 from the State Ground and Surface Water Resource data centre, Chennai, Tamil Nadu, India. Water samples collected from 16 sampling stations selected for the analysis are given in the Table 01.Nine parameter has been considered for the study they are Total Dissolved Substance, (TDS) Nitrate, Calcium, Magnesium, Chlorine, Sulphate, Fluorine, pH and Electrical Conductivity (EC).

Table 01:- Sample Station for Water quality analysis.

S. No	Station	Village
1	S1	Abatharanapuram
2	S2	Alkondanatham
3	S3	Cuddalore
4	S4	Kammapuram
5	S5	Kilpalaiyur
6	S6	Kuduvelichavadi
7	S7	Kuppanatham
8	S8	Lalpet
9	S9	M.parur
10	S10	Maligaikottam
11	S11	Marungar
12	S12	Mel Kumaramangalam
13	S13	Odaiyur
14	S14	Puduchathiram
15	S15	Thiruvandipuram
16	S16	Vazisothanaipalayam

Water quality index for drinking:

The water quality index (WQI) technique has been used to combine and summarize various parameters measured from individual sample since it is the most acceptable way to examine the water quality for drinking purposes. This technique is thought to have the greatest impact on human health among the several water quality metrics. The calculation of WQI can be broken down into the following four easy steps. As a result of each parameter's contribution to quality, weights are assigned to each one in the first phase on a sliding scale from 5 to 1, with 5 being the most essential and 1 being the least.

Relative Weight (W_i)

It is calculated using following equation

$$W_i = \frac{w_i}{\sum_{i=1}^{n} w_i}$$

Where,

w_i = weight of each individual parameter

n = number of parameters.

The second step is that calculating quality rating scale (q_i), The quality rating scale for each parameter in each sample is determined by dividing the concentration of each parameter by its respective standard (Si) given by WHO multiplied by 100

$$q_i = \frac{C_i}{S_i} * 100$$

C_i = Concentration of individual parameter (mg/l)

S_i = Maximum allowable limit for individual parameters (mg/l)

The third step is to find the sub-index (SI) and WQI using the following equation,

$$SI_I = q_i * W_i$$

$$WQI = \sum_{i=1}^{n} SI_i$$

Where,

SI_i = Sub index of individual parameters
q_i = quality rating scale of individual parameters
W_i = Relative weight of individual parameters
n = number of parameters

The final index value has been mapped and classified based on Table 02 using inverse distance weighted techniques in the GIS software

Table 02:- Ground water classification based on Quality index.

S. No.	WQI Range	Suitability
1	< 25	Excellent
2	25-50	Good water
3	50 - 75	Poor water
4	75 - 100	Very Poor Water
5	>100	Unsuitable for drinking

Results and Discussion:-

The statistics of Physio-chemical parameters of ground water of Cuddalore district for the year 2002 and 2022 has been shown in the Table 03.

Table 03:- Statistics of water quality parameter for the year 2002 and 2022.

Parameters	2002			2022		
	Avg	Max	Min	Avg	Max	Min
TDS (mg/l)	1180.70	9115.73	161.76	960.89	6783.00	102.00
Nitrate (mg/l)	7.92	28.00	1.00	4.11	17.00	0.05
Calcium (mg/l)	51.68	240.00	18.00	81.79	240.00	14.00
Magnesium (mg/l)	50.26	336.00	3.60	52.18	534.60	2.43
Chlorine (mg/l)	462.21	4750.00	25.00	369.58	3439.00	14.00
Sulphate (mg/l)	187.62	1056.00	8.00	107.13	854.00	3.00
Fluorine (mg/l)	0.32	0.88	0.09	0.40	1.69	0.05
pH	8.38	8.80	7.60	7.67	8.40	6.90
EC (µ mhos/cm)	1912.63	10000.00	210.00	1633.68	11200.00	120.00

Total Dissolve Substance (TDS)

TDS values ranged within 161.76 mg/l to 9115.73 mg/l with average of 1180.70 mg/l in the year 2002 and the range is 102 mg/l to 6783 mg/l with average of 960.89 mg/l in the year 2022 (Table 03). The According to the Indian Standard the TDS is acceptable limit is until 500 mg/l and permissible limit until 2000 mg/l. So the average value for both years is in permissible limit and the TDS value is decreased from 2002 to 2022. All the values are under the permissible limit except S3 and S14 in the year 2002 and S6 in the year 2022 which is above 2000 mg/l shown in the Table 04 and 05.

Nitrate

Nitrate is the most important nutrients in an ecosystem. Generally water bodies polluted by organic matter exhibit higher values of nitrate. In the present study water samples are in the range between 1 mg/l to 28 mg/l with average of 7.92 mg/l in the year 2002 whereas the range is 0.05 mg/l to 17 mg/l with the average of 4.11 mg/l in the year 2022 (Table 03). According to the Indian Standard the Nitrate is acceptable limit till 45 mg/l and permissible limit till 100 mg/l. So the average value for both years is acceptable limit. All the values are under the permissible limit shown in the Table 04 and 05.

Calcium

Calcium is contributed by rocks rich in calcium, mainly carbonates and sulphates, especially limestone, dolomite and gypsum. Apart from the natural sources, industrial and agricultural wastes contribute to maximum percentage of

calcium concentration. The analytical data of the present study express that Calcium values ranged in between 18 mg/l-240 mg/l with average of 51.68 mg/l in the year 2002 whereas the range is 14 mg/l – 240 mg/l with average of 81.79 mg/l in the year 2022 (Table 03). According to the Indian Standard the Calcium is acceptable limit is until 75 mg/l and permissible limit until 100 mg/l. So the average value for the years 2002 is acceptable limit and the Calcium value is in permissible limit in the year 2022. Higher concentrations of Calcium in the groundwater may lead to some adverse impacts on human beings which include coma and under worst conditions; a person consuming water with very high concentrations of Calcium may be prone to death (Adak & Purohit, 2001). All the values are under the permissible limit except S3 and S13 in the year 2002 and S6 in the year 2022 which is above 200 mg/l shown in the Table 04 and 05.

Magnesium

The analytical data presented in the Table 03 indicates that the concentration of Magnesium ranged from 3.6 mg/l - 336 mg/l with average of 50.26 mg/l in the year 2002 whereas the range is 2.43 mg/l to 534.6 mg/l with average of 52.18 mg/l in the year 2022 (Table 03). All the values of Magnesium in for both the years are found to be within the permissible levels of 100 mg/l as per Indian Standard. All the values are under the permissible limit except S3 and S13 in the year 2002 and S6 in the year 2022 which is above 100 mg/l shown in the Table 04 and 05.

Chloride

Chloride occurs in all types of natural waters. The high concentration of chloride is considered to be an indication of pollution due to high organic waste of animal origin. Chloride values obtained in the study are found in the range between 25 mg/l to 4750 mg/l with average of 462.21 in the year 2002 and the range is 14 mg/l to 3439 mg/l with average of 369.58 mg/l in the year 2022 (Table 03). According to the Indian Standard the Chloride is acceptable limit is until 250 mg/l and permissible limit until 1000 mg/l. So the average value for both years is in permissible limit and the chloride value is decreased from 2002 to 2022. All the values are under the permissible limit except S3 in the year 2002 and S6 in the year 2022 which is above 1000 mg/l shown in the Table 04 and 05.

Sulphate

The analytical data presented in the Table 03 indicates that the concentration of Sulphates ranged from 8 mg/l - 1056 mg/l with average of 187.62 mg/l in the year 2011 whereas the range from 3 mg/l and 854 mg/l with average of 107.13 mg/l in the year 2022 in the study area (Table 03). Average values of Sulphates in both the years are found to be within the acceptable levels as per Indian Standard. All the values are under acceptable limit except the location S2, S3 and S4 are above the permissible limit in the year 2002 (Table 04) whereas location S8 comes under permissible limit and location S6 is comes under unsuitable for drinking (Table 05).

Fluoride

The analytical data presented in the Table 03 indicates that the values of Fluoride in the study area ranged from 0.09 mg/l – 0.88 mg/l with average of 0.32 mg/l in the year 2002 whereas the range for the year 2022 is 0.05 mg/l and 1.69 mg/l with average of 0.40 mg/l (Table 03). Average values of Fluoride in the study area are within the acceptable levels as per Indian standard. All the values of the sample location are under permissible limit except the location S12 which has 1.69 mg/l (Table 05).

pH

pH is one of the important parameters that determine the groundwater quality. pH has no direct impact on the health of humans, but all biochemical reactions directly depends on the range of pH (Jeyakumar & Indra, 2003). pH alters presence of many water quality parameters and hence the taste. The geology of the catchment area and the buffering capacity of water influence the pH of water (Weber & Stumm, 1963). A drop or a raise in pH of groundwater sources beyond the permissible range would indicate the extent of pollution stress.

The analytical data presented in the Table 03 indicates that the pH values ranged from 7.6 - 8.8 with average of 8.38 in the year 2002 whereas the pH range between 6.9 & 8.4 in the year 2022 (Table 03). This shows that the groundwater quality in the study area is near neutral to slightly alkaline in nature. Average values of the year 2002 and 2022 indicate that both years are in neutral shown in the Table 03. All the values of pH in both years are within the acceptable levels as per Indian Standard (BIS, 2012) i.e. 6.5 to 8.5, except six samples (S5, S6, S9, S11, S12 and S14) in the year 2002, recorded to have a pH of above 8.5, higher than the permissible limit 8.5 (Table 04).

Electrical conductivity

Conductivity is a measure of current carrying capacity. Thus, as concentration of dissolved salts increases conductivity also increases. Many dissolved substances may produce aesthetically displeasing color, taste and odor. The values obtained are in the range 210 µ mhos/cm to 10000 µ mhos/cm with average of 1912.63 µ mhos/cm in 2002 and the range is 120 µ mhos/cm to 11200 µ mhos/cm with average of 1633 µ mhos/cm in 2022 (Table 03). According to the Indian Standard the electrical conductivity is acceptable limit till 700 µ mhos/cm and permissible limit till 3000 µ mhos/cm. So the average value for both years is in permissible limit. Two samples (S3 and S14) in the year 2002, recorded to have a EC of above 3000 µ mhos/cm, higher than the permissible limit (Table 04). Similarly, in the station S6 is above the permissible limit of 3000 µ mhos/cm in the year 2022 (Table 05).

Table 04:- Analysis of physico-chemical parameter in the year 2002.

Station	TDS	Nitrate	Calcium	Magnesium	Chlorine	Fluorine	pH	EC	SO4
S1	296.16	9.00	30.00	24.00	110.00	0.15	7.60	510.00	33.00
S2	425.00	1.26	31.00	15.00	160.00	0.40	8.40	980.00	**1056.00**
S3	**9115.73**	2.00	**240.00**	**336.00**	**4750.00**	0.35	7.80	**10000.00**	**730.00**
S4	1849.13	1.00	44.00	88.80	355.00	0.27	8.30	3000.00	25.00
S5	422.33	1.00	34.00	27.60	71.00	0.25	**8.60**	710.00	42.00
S6	501.00	11.06	28.00	22.00	347.00	0.33	**8.60**	1610.00	22.00
S7	161.76	2.00	28.00	3.60	25.00	0.10	8.50	210.00	79.00
S8	310.62	5.00	34.00	22.80	53.00	0.28	7.80	610.00	8.00
S9	806.45	28.00	126.00	28.80	188.00	0.42	**8.80**	1210.00	28.00
S10	350.00	22.40	36.00	28.00	376.00	0.21	8.50	2500.00	**586.00**
S11	521.00	5.88	22.00	38.00	440.00	0.19	**8.70**	2320.00	86.00
S12	927.02	6.00	22.00	34.80	216.00	0.39	**8.70**	1570.00	132.00
S13	**3635.61**	2.00	64.00	**115.20**	936.00	0.09	8.40	**5280.00**	56.00
S14	949.24	17.00	56.00	38.40	216.00	0.88	**8.60**	1460.00	48.00
S15	216.68	1.00	18.00	10.80	43.00	0.29	8.30	340.00	45.00
S16	486.70	7.00	42.00	14.40	135.00	0.16	8.50	790.00	26.00

Table 05:- Analysis of physico-chemical parameter in the year 2022.

Station	TDS	Nitrate	Calcium	Magnesium	Chlorine	Fluorine	pH	EC	SO4
S1	351.00	1.00	100.00	9.72	138.00	0.05	7.70	690.00	70.00
S2	715.00	1.00	60.00	15.80	238.00	0.36	7.90	1200.00	79.00
S3	174.00	2.00	54.00	2.43	14.00	0.33	8.00	300.00	8.00
S4	411.00	4.00	44.00	26.73	113.00	0.18	7.40	740.00	11.00
S5	326.00	0.05	28.00	19.44	43.00	0.30	7.50	530.00	56.00
S6	**6783.00**	1.00	**240.00**	**534.60**	**3439.00**	0.92	7.30	**11200.00**	**854.00**
S7	102.00	0.05	22.00	3.65	21.00	0.14	7.80	150.00	19.00
S8	1735.00	1.00	64.00	94.77	815.00	0.12	7.80	3010.00	211.00
S9	1158.00	12.00	180.00	65.61	383.00	0.68	6.90	2030.00	144.00
S10	830.00	7.00	102.00	19.44	191.00	0.25	7.20	1310.00	79.00
S11	122.00	4.00	14.00	3.65	14.00	0.40	8.00	120.00	3.00
S12	731.00	17.00	102.00	31.59	199.00	**1.69**	7.50	1270.00	29.00
S13	1308.00	2.00	56.00	29.16	340.00	0.14	8.40	2440.00	50.00
S14	363.00	1.00	64.00	14.58	106.00	0.71	7.80	600.00	42.00
S15	346.00	2.00	28.00	25.52	71.00	0.22	8.20	600.00	7.00
S16	1579.00	6.00	196.00	26.73	496.00	0.34	7.80	2790.00	52.00

Drinking Water Quality Index

DWQI indicates the quality of water in terms of index number which represents overall quality of water for any intended use. It is defined as a rating reflecting the composite influence of different water quality parameters were taken into consideration for the calculation of drinking water Quality index (DWQI). The indices are among the most effective ways to communicate the information on water quality trends to the general public or to the policy makers and in water quality management. In formulation of water quality index the relative importance of various

parameters depends on intended use of water. The water quality index data showed that one location that is S7 is excellent suitability of drinking water, 10 sample location (S15, S1, S8, S5, S16, S6, S2, S12, S9 and S14) are good suitability of drinking water, three location (S11, S10 and S4) are comes under poor quality of drinking water. Two location (S13 and S3) are comes under unsuitable category of drinking water in the year 2002. Similarly, the water quality index data showed that two location that is S7 and S11 are excellent suitability of drinking water, 9 sample location (S3, S5, S15, S4, S14, S1, S2, S10 and S12) are good suitability of drinking water, three location (S13, S9 and S16) are comes under poor quality of drinking water. One location each on very poor and unsuitable category of drinking water in the location of S8 and S6 respectively in the year 2002. Mostly it is done from the point of view of its suitability for human consumption. Study reveals that more than 126 sq.km area comes under excellent suitability of water, more than 1523 sq.km which is 41 percent of the area comes under good suitability of water., 1549 sq.km area of Cuddalore district comes under poor suitability of water which is 42.1 percent of the total area followed by 246 sq.km area of Cuddalore comes under very poor suitability of water (6.7 percent). Around 232 sq.km that is 6 percent of the area comes under unsuitable for drinking water for the year 2002 shown in the Table 06 and Figure 04.

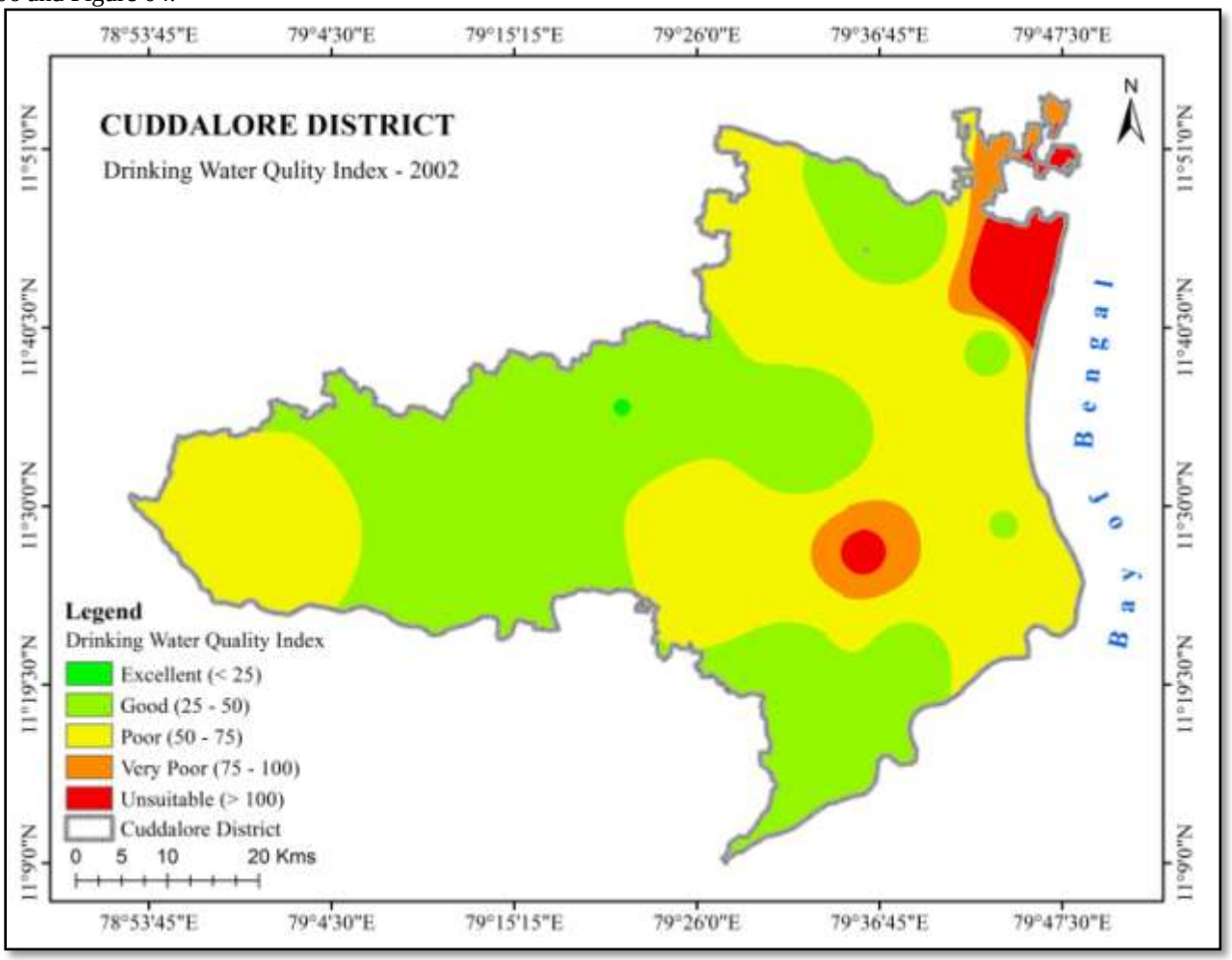

Figure 02:- Spatial Distribution of Drinking Water Quality Index – 2002.

From the Figure 02, the unsuitable water is in North eastern side of the Cuddalore district, whereas central, central north and central south of the district good suitability of drinking water.

Table 06:- Area Distribution of Drinking water quality Index – 2002.

Range	Suitability	AREA	Percent
<25	Excellent	126.54	3.44
25-50	Good	1523.11	41.41

50-75	Poor	1549.35	42.12
75-100	Very Poor	246.58	6.70
>100	Unsuitable	232.41	6.32
Total		3678	100

Table 07:- Area Distribution of Drinking water quality Index – 2022.

Range	Suitability	Area	Percent
<25	Excellent	177.84	4.84
25-50	Good	2064.63	56.13
50-75	Poor	826.59	22.47
75-100	Very Poor	299.96	8.16
>100	Unsuitable	308.95	8.40
Total		3678	100

In the year 2022, excellent suitability of water occupies 177 sq.km which is 4.8 percent, good suitability of water occupies 2064 sq.km which is 56.1 percent, poor water occupies 826 sq.km which is 22.4 percent of the total study area. Very poor suitability of water occupies 299 sq.km of the total area which is 8.1 percent and finally 308 sq.km of area comes under unsuitable for drinking water which is 8.4 percent of the total area shown in the Table 07 and Figure 04. From the Figure 03, South eastern parts of the district has unsuitable drinking water whereas western, north and north eastern parts are covered with excellent to good suitability of water.

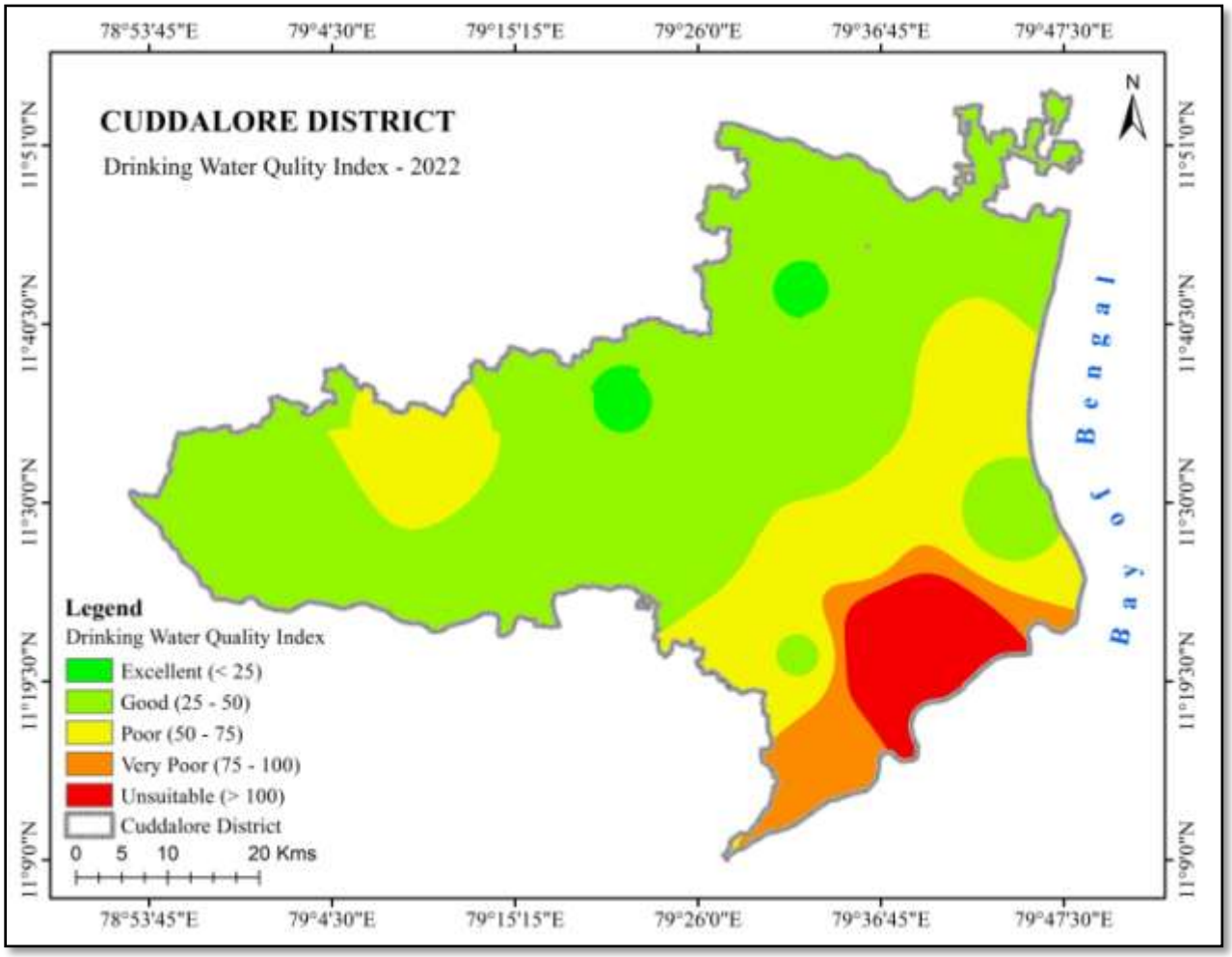

Figure 03:- Spatial Distribution of Drinking Water Quality Index – 2022.

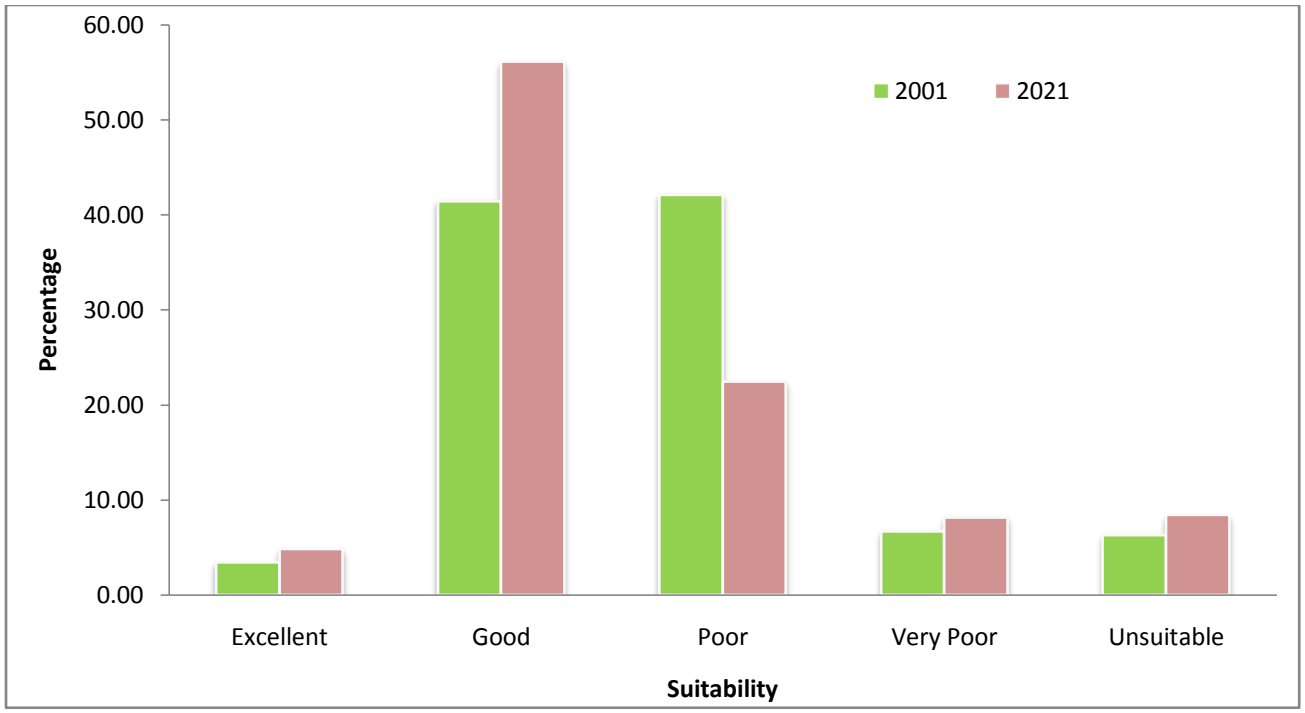

Figure 04:- Area of Drinking water quality index for the year 2002 and 2022.

Conclusion:-

The analysis of physico-chemical characters of groundwater reveals the water quality parameters like TDS, magnesium, calcium, magnesium, chlorine, pH, EC and sulphate which are above the permissible limits in one or two location in the year 2002 and 2022 as prescribed by Indian standards. The quality of groundwater has been found varied from location to location by the complexed geological systems. The overall ground water index reveals that the water quality in Cuddalore district has increased considerably from the year 2002 to 2022. Spatially, unsuitable area has increased from the year 2002 to 2022 similarly excellent suitability of drinking water is also increased during the same period. Hence, from the assessment it is recommended to take necessary steps to improve further for the protection of environment and human beings.

Reference:-

1. Adak, M. D., & Purohit, K. M. (2001). Status of Surface and Ground Water Quality of Mandiakudar-Part I: Physico-Chemical Parameters. Pollution Research, 20(1), 103-110.
2. BIS. (2012). "Indian Standards Specification for Drinking water" IS 10500.
3. Fawell, J., & Nieuwenhuijsen, M. J. (2003). Contaminants in drinking waterEnvironmental pollution and health. British medical bulletin, 68(1), 199-208.
4. Gonçalves, V., Albuquerque, A., Carvalho, P., Almeida, P., & Cavaleiro, V. (2023). Groundwater vulnerability assessment to cemeteries pollution through GIS-Based DRASTIC index. Water, 15(4), 812.
5. Jeyakumar, T., & Indira, S. (2003). Thillai Aasu p. Status of ground water quality and public health around Tiruchendur Indian J. Env. Prot, 23(3), 256-260.
6. Krishnamoorthy, S., & Athimoolam, M. (2015). Assessment of groundwater quality in Cuddalore district, Tamilnadu. Retrieved October, 20, 2020.
7. Molla, M. H., Chowdhury, M. A. T., Muhibbullah, M., Ali, K. M., Bhuiyan, M., Rahman, H., ... & Islam, S. (2023). Suitability of drinking water quality in Chittagong Metropolitan City, Bangladesh: research on urban water bodies (UWBs) using multivariate analytic techniques. H2Open Journal, 6(2), 140-156.
8. Ramachandran Muthulakshmi, Y. (2020). Geo-spatial analysis of irrigation water quality of Pudukkottai district. Applied Water Science, 10(3), 1-14.
9. UNESCO 2013 UN-Water: An Increasing Demand, Facts and Figures. UN-Water, coordinated by UNESCO in collaboration with UNECE, Paris.

10. United Nations (UN). (2015). Transforming our world: The 2030 agenda for sustainable development. UN General Assembly.
11. Weber Jr, W. J., & Stumm, W. (1963). Mechanism of hydrogen ion buffering in natural waters. Journal-American Water Works Association, 55(12), 1553-1578.
12. WHO 2011 Guidelines for Drinking-Water Quality, 4th edn. WHO Press, Geneva, Switzerland.
13. Yuvaraj, R. M., & Prasad, S. (2022). A mathematical approach to groundwater quality and pollution of Adyar sub-basin, Tamil Nadu, India. Ecocycles, 8(2), 74-86.