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Groundwater Pollution Due To Discharge Of Industrial Effluents With Special Reference To Industrial Hazard Zone In Araniyar-Kosasthalaiyar Sub Basin, Chennai Basin, Tamil Nadu, India

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ABSTRCT: India is the first country among the top ten groundwater abstracting countries and groundwater draft of India was 251 km^2 (UNFAO, 2016). Population growth, evaporation loss, land use changes, over extraction of groundwater, frequent monsoon failure and climate change have caused water scarcity in India. Tamil Nadu is an agrarian state basically depending upon groundwater for agricultural activities, food production and domestic use. Groundwater occurs in weathered, fractured and jointed rock formations. Tamil Nadu faces twin challenges of groundwater scarcity and groundwater quality. Groundwater is being polluted by many sources like discharge of industrial effluents, dumping of municipal solid wastes, pesticides and fertilizers used in agricultural activities and bio wastes. The effects of groundwater pollution are horizontally and vertically. Spread of water prone diseases is due to groundwater pollution. The groundwater geochemistry study is very essential for good water quality management for drinking and irrigation. For the assessment of groundwater quality in the Araniyar-Kosasthalaiyar sub basin, in which cluster of chemical industries located in the eastern part, spatial interpolation and Pollution Index of Groundwater (PIG) have been employed using the water quality parameters such as pH, EC, TDS, TH, Ca, Mg, Na, K, Cl, SO_4, NO_3 and F. The spatial distribution of Cl, Na, K, EC, TDS and TH shows that abnormal concentration exhibits in the industrial hazard buffer zone and proves pollutions are due to industries. The analysis of PIG confirms that 11.64 Sq.Km area in the industrial hazard zone area has the high pollution and 3.61 Sq.Km area fall in very high class in pre monsoon period and 38.o2 Sq.Km area has high class pollution and 34.54 Sq.Km area fall in very high class pollution in post monsoon period.

Keywords: Geochemistry, Araniyar-Kosasthalaiyar, PIG, groundwater pollution, buffer zone.

1. INTRODUCTION

In Tamil Nadu, there has been a fast growth in industrialization after independence. According to Rosenberg and Birdzell (1973) and North and Thomas (1986) co-linearity in industrialization and population growth or the population catastrophe is the prime cause of expansion of industrialization and vice-versa **(Figure 1).** During series of processes, the water comes into contact with harmful chemicals, heavy metals, inorganic wastes and even organic sludge (Rai, 2008). These are either dumped into rivers or other water bodies which results in accumulation of high amount of industrial waste in them. This affects the status of our eco-system as well as the health of man, plants and animals. Groundwater aquifers are highly vulnerable to industrial pollution therefore, it is significant to control pollution and monitor groundwater quality (Arivarasi et al. 2017).

Industrial sites and factories produce toxic chemicals are use them in manufacturing. The chemicals are then exposed to rainwater which causes them to be washed into the soil or directly into water resources structures. This is one of the main factors leading to an increase in industrial water pollution. Pollutants get washed into the soil and quickly contaminate the groundwater underneath. This groundwater seeps into lakes, rivers and other important water sources. Waste from industry which has been illegally dumped causes a significant amount of pollution. Often this happens near a water source where people may believe the pollution and evidence will be washed away, which has harmful consequences for the water resource. Disposal of treated and untreated waste effluents from industries contain toxic metals and their chelates which contaminate nearby aquatic resources (Mohammad and Alipoor, 2012).

Chennai City in Tamil Nadu is one of the highly populated Cities in India (Dinesh Kumar. and Tushaar Shah (2006)). It has a large number of medium and large scaled industries by which effluents of complex and diversified nature are discharged causing in turn aquatic pollution. Water quality is influenced by natural and anthropogenic effects including local climate, geology and irrigation practices (Keshav K. Deshmukh et al.2013). Occurrence of groundwater composition is influenced by geological formations and anthropogenic activities (Yuan et al. 2018). Rapid urbanization and industrialization, increase in population and chemicals in agricultural activities are severe threat to the groundwater pollution (Pawar et al. 2008; Rao et al. 2014; Panaskar et al. 2016; Varade et al. 2018; Barakat et al. 2019). In recent years, drinking water being polluted which contains fluoride, arsenic, boron, nitrate etc., has raised many health problems (Hossain et al. 2013; Pandith et al. 2017; Kadam et al. 2019).

The significance of water quality in human health has recently involved a great deal of interest(Ramamoorthy et al 2020). Therefore it is necessary to monitor the groundwater quality for reducing the impact of polluted water health problems and to improve the groundwater quality in a sustainable manner. The present paper discusses the potential consequences of the impact of the industrial effluents on the aquifer system of Araniyar-Kosasthalair sub basin.

2. STUDY AREA

The study area Araniyar-Kosasthalaiyar sub-basin is located between 12°59’20” and 13°34’00” N. Latitudes and 79°40’10” and 80°21’40” E. Longitudes. Total geographical area of the sub-basin is 1998.64 sq.km. The study area is bounded north by Andhara Pradesh State, East by Bay of Bengal, West by Nagariyar and Nandhiyar sub basins and South by

Cooum Sub Basin. The location map of the study area is shown in **Figure 1.** The total geographical extent of the study area is 1998.64 Sq.Km.

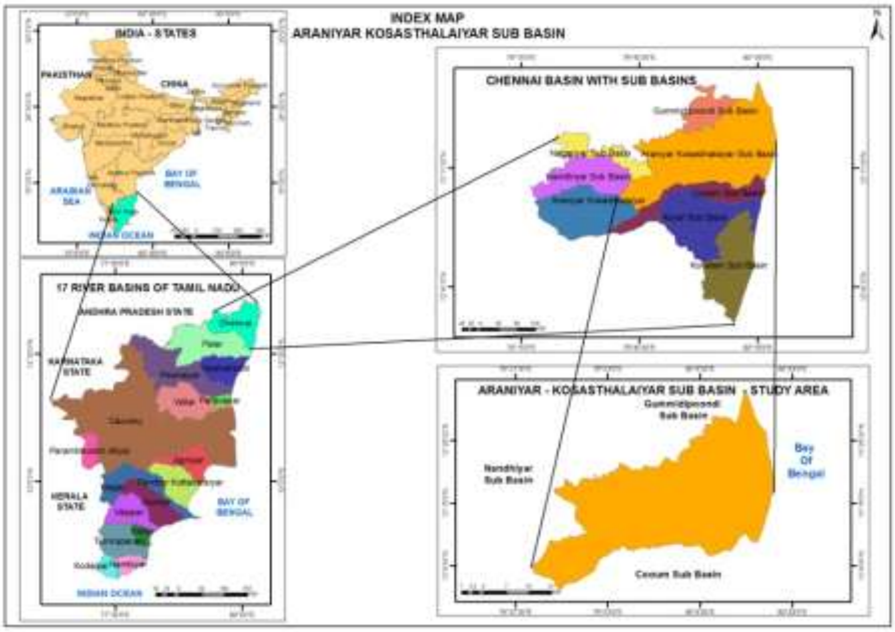

Fig.1 Location map

3. MATERIALS AND METHODS:

The Survey of India (SOI) topographic sheets numbers 57P/14, 66D/1, 2, 3, 4 and 5 on 1:50000 scales were used for delineation of sub basin boundary and mapping of surface water structures. To understand the hydro geochemical nature of groundwater, 27 groundwater samples were collected and analysed the samples within the prescribed time limit during pre-monsoon and post-monsoon seasons of 2018. Pollution Index of Groundwater in order to explore the groundwater quality is employed in this research paper. Geospatial variation maps were generated for selected geochemical parameters Also water quality index for both pre and post monsoon period were derived for the study area.

Selected water quality parameters for drinking including calcium (Ca^{2+}), Magnesium (Mg^{2+}), sodium (Na^{+}), potassium (K^{+}), chloride (Cl^{-}), sulphate (SO_4^{2-}), nitrate (NO_3^{-}), pH, electrical conductivity, total dissolved solids (TDS) and total hardness (TH) were analysed.

In the study area, several major, medium and small scale industries in various kinds of productions are spread over. The clusters of major accident hazard (MAH) industries are shown in **figure 2.** For vulnerable assessment, the possible areas which are to be vulnerable zones due to chemical industrial hazard are demarcated based on intensity of the hazards. The areas were buffered by 500 m, 1 km, 2 km, 3 km, 5 km and 10 km from the cluster of industries. The buffer zones were delineated with proximity analysis tool in ARCGIS software. The vulnerable hazard zones with fixed distance are shown in **Figure 3.**

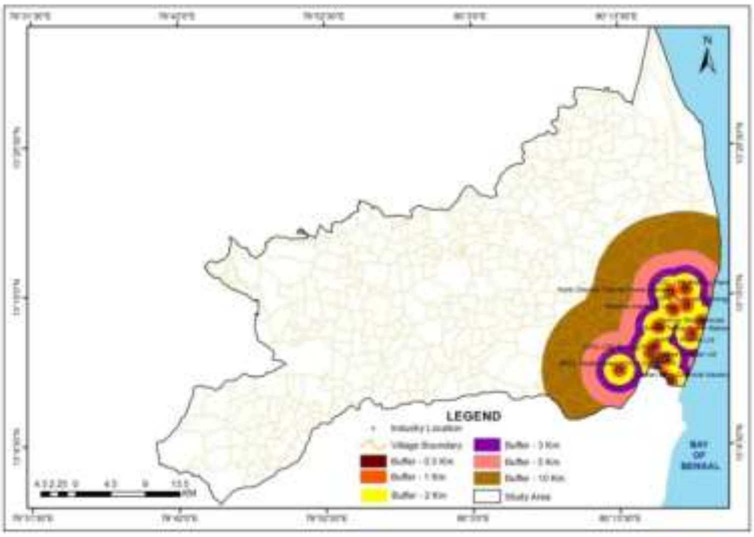

Fig. 2**.** Vulnerable Areas - Buffer zones

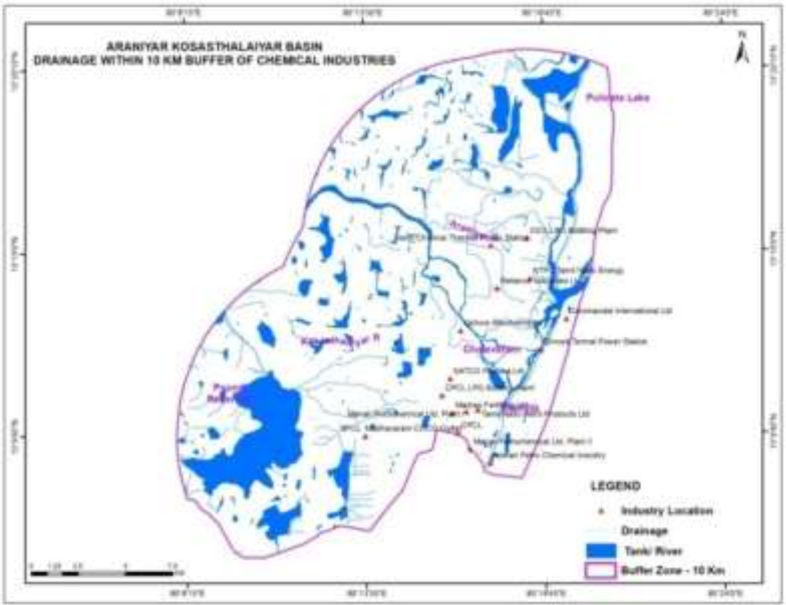

Fig.3 Surface Water Structures in 10 Km Industrial Hazard Zone

In the 10 km buffer zones of Chemical and Industrial locations, there are 186 water bodies available. In this zone a stretch of Kosasthalaiyar river and Redhills tank are the major structure and the others are small to medium in size **(Fig.3).** The total water spread area in this zone is 58.04 Sq.Km. The 10 Km industrial hazard buffer zone may be polluted due to chemical and industrial influents.

The concentration values of pH and electrical conductivity (EC) were measured using pH and EC meter; chloride concentration was measured by $AgNO_3$ titration method; sulphate by $BaCl_2$, turbidity method using a spectrophotometer. Sodium and potassium were analyzed using flame photometer; calcium and magnesium by titration method. The analytical procedures are followed as suggested by the American Public Health Association (APHA

23rd edition). The geochemical results are analysed to assess the water quality controlling mechanism and dominated hydro-geochemical facies of the study area. Statistical analysis was performed using SPSS software package (SPSS, 2001). The physico-chemical parameters of the analytical results of groundwater samples were used to generate contours using Inverse Distance Weighting (IDW) interpolation method in Spatial Analyst tool of ArcGIS 10.3 software to study the spatial distribution of the concentrations.

4. RESULTS AND DISCUSSIONS

The summary of physicochemical parameters of pre and post monsoon periods of the year 2018 and the minimum, maximum and mean concentrations of physicochemical parameters and their comparison with the Bureau of Indian Standards (2012) for drinking standards is given in **Table 1 and Table 2**.

Table 1 **P**hysico-chemical parameters for Drinking Water - Pre Monsoon (July 2018)

Sl. No.	Parameter	BIS Standard		No. of samples			Statistics		
		Desirable Limit	Permissible Limit	Within desirable limit	Within Permissible Limit	Not Suitable	Min	Max	Mean
1.	pH	6.5-8.5	-	27	-	-	7.2	8.5	7.8
2.	TDS (mg/L)	500	2000	3	21	53	328	3158	1245
3.	Hardness	200	600	10	16	1	75	1125	296
4.	Calcium (mg/L)	75	200	2	5	20	74	1858	468
5.	Magnesium (mg/L)	30	100	3	21	3	6.07	183.6	63.09
6.	Sodium (mg/L)	-	-	-	27		47	1068	277
7.	Potassium (mg/L)	-	-	-	27		0.1	86	16.65
8.	Chloride (mg/L)	250	1000	10	15	2	74	1858	467
9.	Sulphate (mg/L)	200	400	23	3	1	10	461	134
10.	Fluoride (mg/L)	1	1.5	16	11		0.12	1.3	0.75
11.	Nitrate (mg/L)	45		23		4	0	141	21
12.	Bicarbonate	200	600	8	18	1	37	605	276.47
13.	EC (µS/cm)	-	-		19	8	540	5720	2246

Table 2 Drinking water standards - Post Monsoon (January 2018)

Sl. No.	Parameter	BIS Standard		No. of samples			Statistics		
		Desirable Limit	Permissible Limit	Within desirable limit	Within Permissible Limit	Not Suitable	Min	Max	Mean
1.	pH	6.5-8.5	-	26		1	7	8.6	7.8
2.	TDS (mg/L)	500	2000	3	21	3	257	3030	1146
3.	Hardness	200	600	2	20	5	105	1260	428
4.	Calcium (mg/L)	75	200	9	16	2	26	344	103
5.	Magnesium (mg/L)	30	100	5	19	3	3.65	174	54.5
6.	Sodium (mg/L)	-	-	27			30	1044	252
7.	Potassium (mg/L)	-	-	27			0.1	90	17.17
8.	Chloride (mg/L)	250	1000	12	12	3	35	2418	426
9.	Sulphate (mg/L)	200	400	19	8		10	396	138
10.	Fluoride (mg/L)	1	1.5	21	4	2	0.24	1.68	0.75
11.	Nitrate (mg/L)	45		27			0	23	8
12.	Bicarbonate	200	600	6	21		85.4	569	286.65
13.	EC (µS/cm)	-	-	21	6		470	5470	2054

It is noticed that pH ranges from 7.2 to 8.5 in pre monsoon and it ranges from 7 to 8.6 in post monsoon period and the average pH value is 8.5 in the year 2018, indicative of the alkaline nature owing to loss of CO_2, precipitation and dissolution processes (Pawar & Kale 2006). Excess pH in prescribed limit will damage mucous membrane present in eyes, nose, mouth, abdomen, anus etc. (German Amaeli Jacintha, 2016). The maximum concentration of pH 8.50 and 8.6 is noticed in both periods. This may be due to industrial effluences and irrigation process in the study area. As per the BIS standards, all samples are within the desirable limit in pre monsoon and 26 samples are within desirable limit and one sample fall in post monsoon period.

TDS ranges in between 328 and 3158 mg/L with an average of 1245 mg/L in pre monsoon. During post monsoon period, it ranges between 257 and 3030 mg/L. According to BIS standards, 11.11% samples exceed the desired limit in both the seasons. The occurrence of high of TDS is due to the industrial effluence and agricultural activities (Krishna Kumar et.al 2015). Drinking water containing high TDS leads to gastrointestinal problems (Mukate et al. 2019).

Total hardness ranges from 75 to 1125mg/L in pre monsoon and 105 to 1260 mg/L in post monsoon. 3.70 % of the sample fall in unsuitable category in pre monsoon period increased to 8.52 % in post monsoon period. High value of total hardness in drinking water leads to scale formation, encrustation in water supply pipes and urolithiasis problems in human (Wagh et al. 2016b).

Calcium concentration ranges from 74 to 1858 mg/L with an average value of 468 mg/L in pre monsoon and 26 to 344 mg/L with an average of 103 mg/L in post monsoon. In pre monsoon, 74 % of samples fall in unsuitable category, reduced to 7.4% in post monsoon period. High calcium in pre monsoon shows the discharge of effluents from industries and agricultural fields (Pawar et al. 2008). Calcium is diluted in the monsoon rainfall and hence the values are reduced.

Magnesium varies from 6.07 to 183.6 mg/L with an average 63.09 mg/L and 3.65 to 174 mg/L with an average value of 54.5 mg/L in pre and post monsoons respectively; however, 11 % of samples fall in unsuitable category in both periods. The consumption of high calcium and magnesium-rich water leads to colon cancer (Yang et al.1997).

Sodium concentration ranges from 47 to 1068 mg/L with an average of 277 mg/L and 30 to 1040 mg/L with an average of 252 mg/L in pre and post monsoon periods respectively. The high concentration of sodium is due to weathering of rock-forming minerals and industrial, domestic and animal wastes (Freeze and Cherry, 1979). The consumption of sodium content in water may cause high blood pressure, vomiting, headache, hyperosmolarity and muscle stiffness in humans (Prasanth et al. 2012).

Potassium concentration ranges from 0.1 to 86 mg/L with an average of 16.65 mg/L in pre monsoon and it ranges from 0.1 to 90 mg/L with an average of 17.17mg/L in post monsoon period Potassium is a naturally occurring element and higher concentration is due to excess use of potassium for agricultural activities. The lower concentration of potassium in water is because of the high degree of stability of potassium bearing minerals (Ramamoorthy and Rammohan, 2014). Potassium concentration remains quite lower compared with calcium, magnesium and sodium. An excessive amount of Potassium in water gives bitter taste to drinking water (Wagh et al. 2016b).

Chloride concentration ranges from 74 to 1858 mg/L with an average of 467 mg/L in pre monsoon period. In post monsoon period, the concentration ranges from 35 to 2418 mg/L with an average of 426 mg/L. In pre monsoon, 7.41 % of the sample fall in unsuitable category is increased to 11.11% in post monsoon period. Industrial effluents, seawater intrusion and irrigation return flow is responsible for the increase of chloride in groundwater (Jeevanandam et al. 2012 and Sarath Prasanth et al. 2012). Higher concentration of chloride in drinking water results salty taste and produces a laxative effect on people not habituated to it. Higher concentration may lead to alterations in taste, corrosion and palatability (Mukate et al. 2019).

In pre monsoon period, the minimum concentration of Sulphate is 10 mg/L, maximum is 461 mg/L and the average is 134 mg/L. In pre monsoon, 3.70% of the samples fall in unsuitable category, which may be use of fertilizers in the study area. During post monsoon, minimum concentration is 10 mg/L. The maximum concentration is 396 mg/L and the average is 138 mg/L. The drinking of sulphate-rich water may be the cause of catharsis, laxative effect, gastrointestinal and dehydration problems (WHO, 2011).

The concentration of fluoride in pre monsoon ranges between 0.12 and 1.3 mg/L with a mean value of 0.75 and in post monsoon period and it ranges between 0.24 and 1.68 mg/L with a mean value of 0.75 mg/L. During the pre monsoon period, all the samples are fall in the permissible limit of fluoride is 1.5 mg/L (BIS, 2012). In post monsoon period, 2 samples fall in unsuitable category. Low concentration of fluoride damages the muscles and high concentration damages the teeth and bones (Gopala Krishnan et al. 2015).

Nitrate concentration varies in between 0 and 141 mg/L with a mean value of 21 mg/L in pre monsoon it varies between 0 and 23 mg/L with an average of 8 mg/L in post monsoon. During pre monsoon period, 14.81% of the samples fall in unsuitable category and in post monsoon period all samples are fall in within desirable limit. Higher concentration noticed in pre monsoon is due to the use of fertilizers, and raw domestic an industrial sewage (Wagh et al. 2019). Excess usage of nitrate in drinking water may lead to 'blue baby syndrome' or methemoglobinemia, which is a typical state where a baby's skin becomes blue due to a reduced amount of haemoglobin in the blood (WHO 2011). Bicarbonate value ranges from 37 to 605 mg/L with 276.47 mg/L mean value in pre monsoon and it ranges from 85.4 to 569 mg/L with 286.65 mg/L mean value in post monsoon. Except one sample, which fall in unsuitable category in pre monsoon, all other sample fall within permissible limit in both periods. The concentration is reduced in post monsoon period.

Electrical Conductivity concentration varies from 540 to 5720 µS/cm with an average of 2246 in pre monsoon and it varies from 470 to 5470 µS/cm with an average of 2054 µS/cm) in post monsoon. In pre monsoon, 30% of the samples fall in unsuitable category. The higher concentration in pre monsoon period is due agricultural, industries and domestic activities (Morrison et al. 2001).

Spatial Distribution

The spatial distribution on selected parameters, which are main deciding parameter of pollution was made for both pre and post monsoon periods of the year 2018 using ArcGIS software. The inverse distance weightage (IDW) interpolation method was used by many researchers for interpolating point data (Rawat et. Al. 2012). By using this interpolation method in Arc GIS 10.3 with spatial analyst tool, spatial distribution of chloride, electrical conductivity, Potassium, Sodium, TDS and Total Hardness for both monsoon periods were prepared to exhibits the pollution in the study area.

Electrical Conductivity (E.C)

Higher concentration of E.C in pre monsoon is noticed in Villivakkam, Thiruvallur and the entire Minjur block **(Fig.5A).** In the 10 km hazard zone, 17 villages are fall in not permissible limit of E.C. During the post monsoon period, higher concentration of E.C is noticed in Gummidipoondi, Sholavaram, Arakkonam, Villivakkam, Thiruvallur and the entire Minjur block **(Fig.5B).** In the 10 km hazard zone, 22 villages are fall in not permissible limit. Six villages in 5 km buffer hazard zones and Kattupalli, Arivanvayal and Puzhithivakkam villages in 3 Km buffer hazard zones are fall in under not permissible limit.

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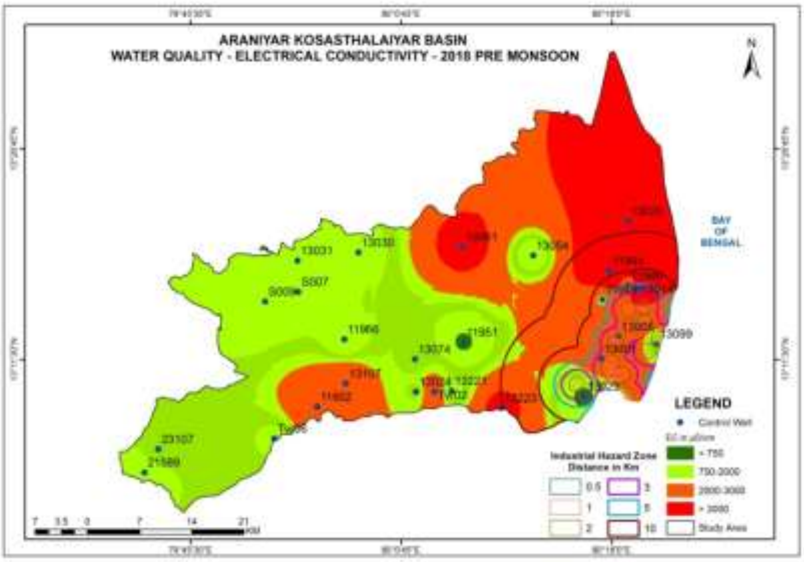

Fig.5A E.C with Industrial Hazard Zone - Pre Monsoon

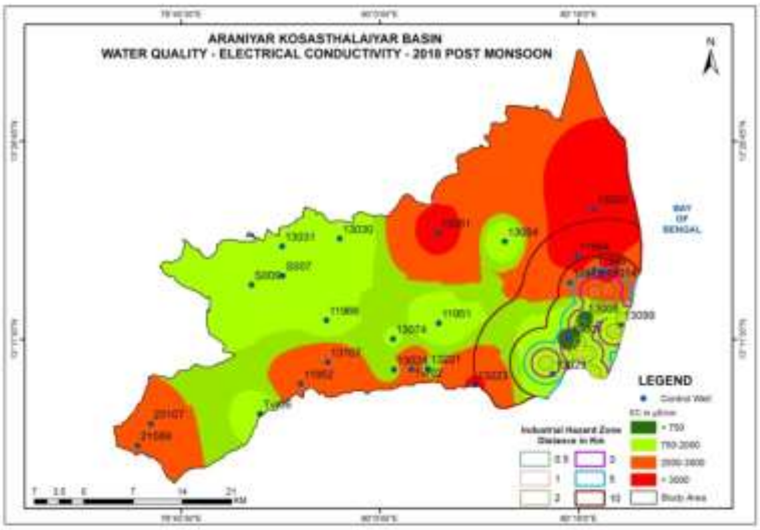

Fig.5B E.C with Industrial Hazard Zone - Post Monsoon

Chloride (Cl)

The spatial distribution of pre monsoon show that few patches in Thiruvallur, Villivakkam and Gummidipoondi blocks and Minjur block have chloride value in the range of 600 to 750 mg/L **(Fig.6A)**. Each 3 villages coming under 5 Km and 3 Km industrial hazard zone, each 2 villages in 2 Km and 1 Km buffer zones have the chloride value in the range of 600 to 750 mg/L. Chloride value in the range of 750 to 1000 mg/L is observed in the 10 Km industrial hazard zone in 6 villages, Voyalur village in 5 Km zone and Neithavoyal, and Puzhuthivakkam villages in 3 Km zone are also having the Chloride value in the range of 750 to 1000 mg/L. 17 villages falling in the 10 Km industrial hazard zone have the abnormal chloride concentration ranging between 1000 to 1850 mg/L.

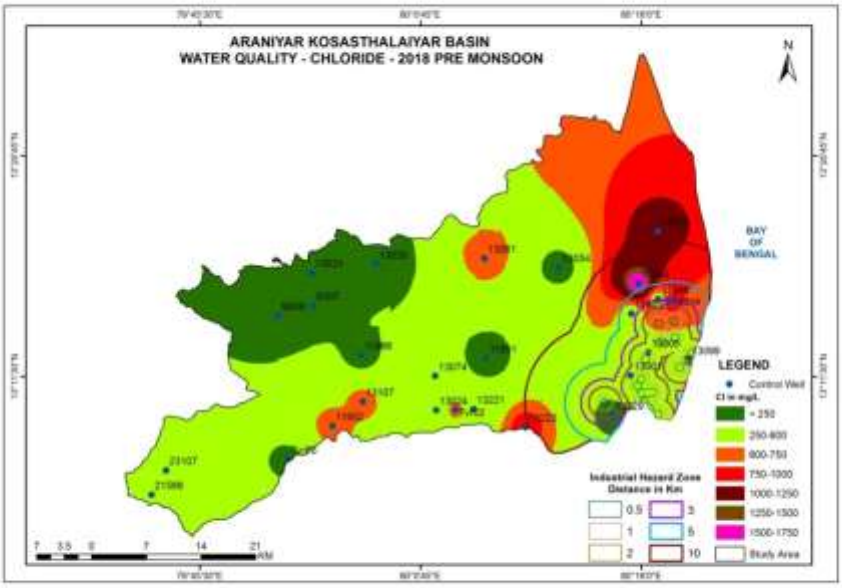

Fig.6 A Chloride with Industrial Hazard Zone – Pre Monsoon

Spatial distribution of chloride in post monsoon period **(Fig. 6 B)** shows that 600 to 750 mg/L range is noticed in a small patch area in Villivakkam and Gummidipoondi blocks and in large extent in Minjur block. 4 villages fall in 10 Km industrial hazard zone, 1 village in 5 Km buffer zone, 3 villages in 3 Km zone, and 1 village in 2 Km zone have 600 to 750 mg/L chloride concentration. Some extent of Minjur block has the higher concentration in the range of 750 to 1000 mg/L. The 10 Km industrial hazard zone of 6 villages, 5 Km zone of 3 villages and 1 village in 2 Km zone village have the higher concentration in the range of 750 to 1000 mg/L. Very high concentration 1000 to 1500 mg/L is noticed only in the Minjur block in 9 villages which are coming under 10 Km industrial hazard zone. Abnormal chloride concentration in the range of 1500 to 2250 mg/L is also noticed in 11 villages fall in 10 Km industrial hazard zone in Minjur block.

Sodium (Na)

The spatial distribution of sodium during pre monsoon period shows that not permissible limit greater than 200 mg/l in the range of 200 to 400 mg/L is noticed in the parts of Arakkonam, Thiruvanalgadu, Poondi, Ellapuram, Thiruvallur, Villivakkam, Puzhal, Gummidipoondi, Sholavaram and Minjur blocks **(Fig. 7A).** Nearly 50 percent of the study area including the industrial hazard zones occupied 200 to 400 mg/L range of sodium concentration. Higher concentration in the range of 400 to 600 mg/L is exhibiting in the parts of Thiruvallur, Gummidipoondi and Minjur blocks. 11 villages falling in 10 Km industrial hazard zone and 2 villages in 5 Km zone have the higher concentration range of 400 to 600 mg/L. 6 villages fall in the 10 Km industrial hazard zone have the very high concentration range of 600 to 700 mg/L and 3 villages have more than 700 mg/L of sodium.

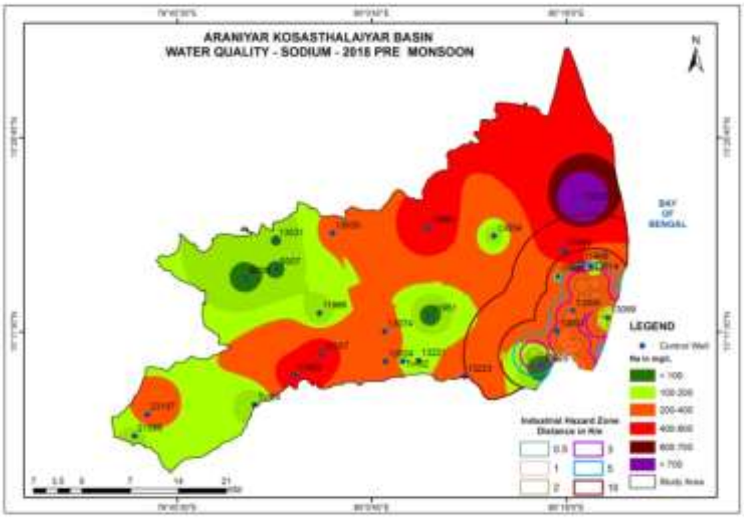

Fig.7A Sodium with Industrial Hazard Zone – Pre Monsoon

During post monsoon period, the not permissible limit 200 to 400 mg/L is noticed in parts of Arakkonam, Poondi, Thiruvallur, Ellapuram, Villivakkam, Sholavaram and Minjur blocks **(Fig. 7B)**. 14 villages fall in 10 Km industrial hazard zone and 6 villages fall in 5 Km zone have the not permissible limit of 200 to 400 mg/L. Also, 5 villages fall in 3, 2 and 1 Km buffer zones experienced the not permissible limit. 5 villages fall in 10 Km zone have the very high value of 600 to 700 mg/L and the 3 villages have more than 700 mg/L of sodium.

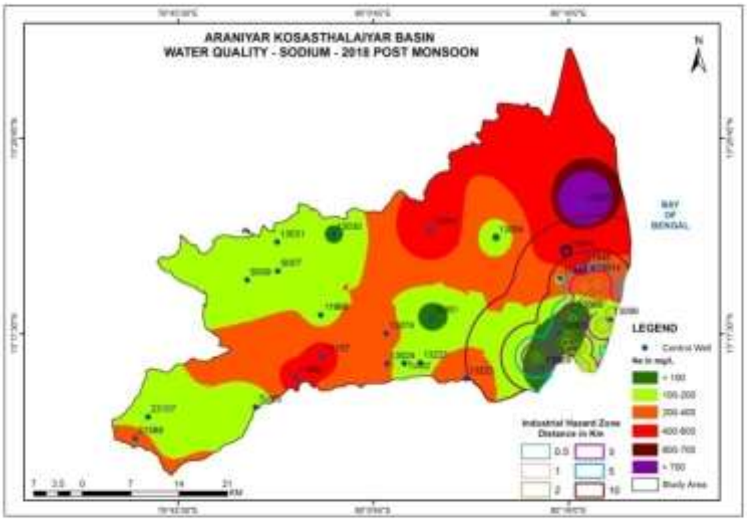

Fig.7B Sodium with Industrial Hazard Zone – Post Monsoon

Potassium (K)

Potassium distribution in pre monsoon period shows that parts of Ellapuram, Sholavaram, Villivakkam and Puzhal blocks have the range of 12 to 20 mg/L**(Fig. 8 A).** Thirty three villages falling in the 10 Km industrial hazard zone, 19 villages in 5 Km zone, 6 villages in 3 Km buffer zone, 6 villages in 2 Km buffer and 3 villages in 1 Km buffer have also the potassium range of 12 to 20 mg/L Gummidipoondi block, part of Minjur Sholavaram, Puzhal and Ellapuram block have 20 to 50 mg/L. The 10 Km industrial hazard zone having 10 villages 3 villages in 5 Km zone, 4 in the 3 Km zone, 14 villages in 2 Km zone and 6 villages in 1 Km zone have the potassium range of 20 to 50 mg/L.

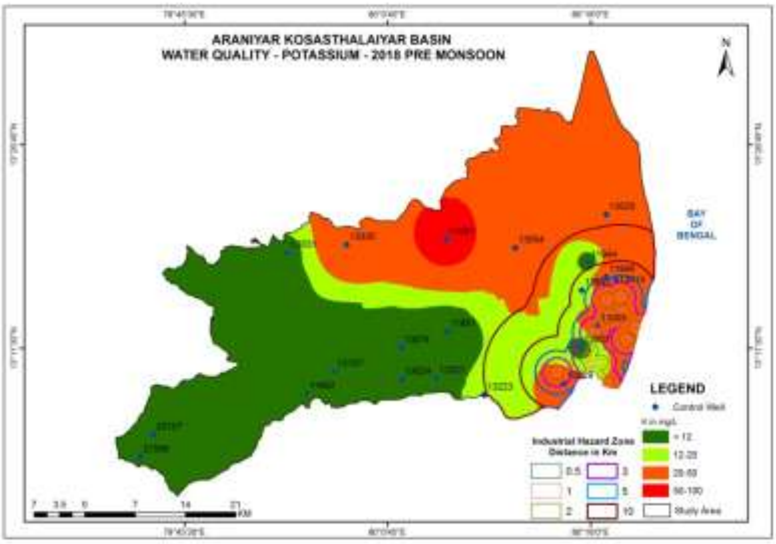

Fig.8A Potassium with Industrial Hazard Zone – Pre Monsoon

During the post monsoon period, the spatial distribution of potassium shows that the similar spatial extents are noticed as in the potassium range of 12 to 20 mg/L and range of 20 to 50 mg/L in pre monsoon period **(Fig.8A)**. The potassium range of 50 to 100 mg/L has expanded in some extent in Ellapuram and Gummidipoondi blocks.

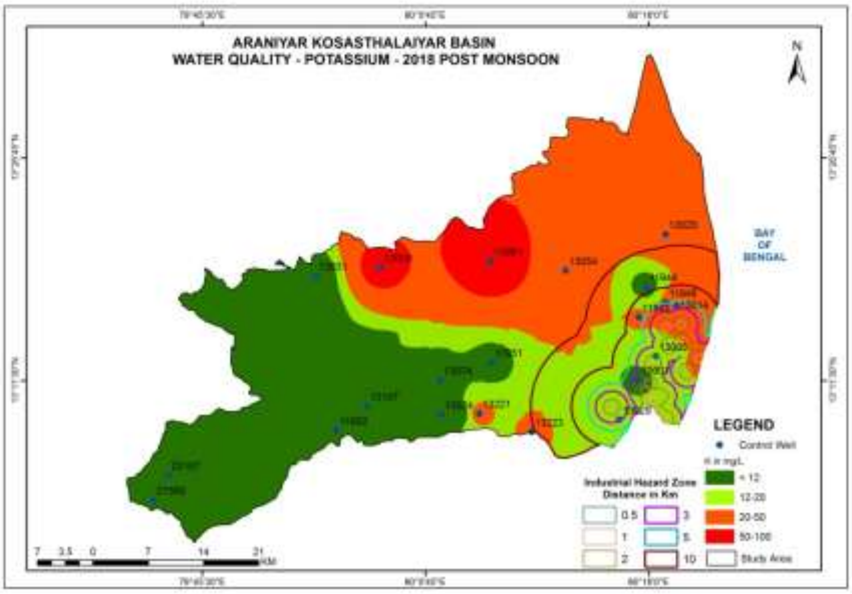

Fig.8B Potassium with Industrial Hazard Zone – Post Monsoon

Total Dissolved Solids

Higher concentration of TDS 1200 to 2000 mg/L is noticed in Thiruvallur, Villivakkam, Sholavaram, Puzhal and Minjur blocks **(Fig. 9A).** In the industrial hazard 10 Km zone, 55 villages have the higher concentration, 20 villages in 5 Km buffer zone, 17 villages in 3 Km, 18 villages in 2 Km, each 12 villages in 1 Km and 500 m zone are having higher concentration. Very higher concentration in the range of greater than 2000 is noticed in the villages of Palavakkam, Mangalam in Gummidipoondi block, Pondavakkam, Arani, Madhavaram in Sholavaram block. These villages are having medium to large scale industries. 20 villages falling in 10 Km industrial buffer zone are having very higher concentration.

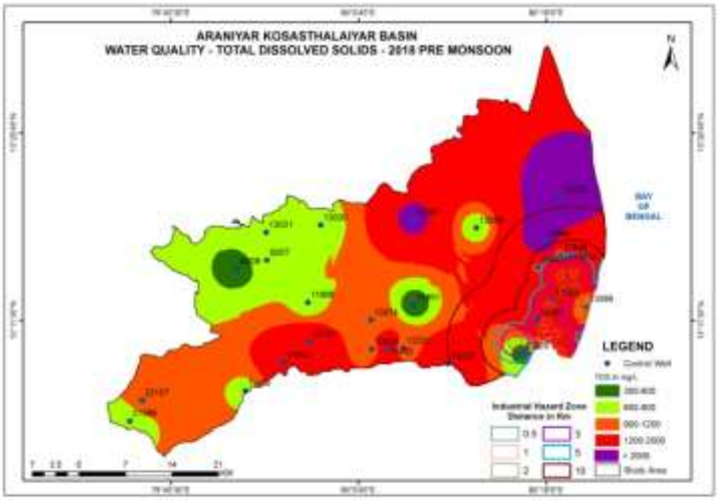

Fig.9A TDS with Industrial Hazard Zone – Pre Monsoon

In post monsoon period, higher concentration of 1200 to 2000 mg/L is noticed in Arakkonam, Thiruvallur Villivakkam, Minjur and Gummidipoondi blocks **(Fig. 9B).** The 10 Km hazard buffer zone of 5 villages are exhibiting higher TDS concentration. 5 villages in the 5 Km zone, 3 villages in 3 Km zone, 4 villages in 2 Km buffer zone and 2 villages in 1 Km zone are also have higher concentration. Not allowable limit greater than 2000 mg/L is noticed in Palavakkam and Mangalam in Gummidipoondi block, Pondavakkam, Arani, Chinnambedu and Malliankuppam in Sholavaram block. Also 15 villages are fall in 10 Km industrial hazard zone have more than 2000 mg/L concentration of TDS.

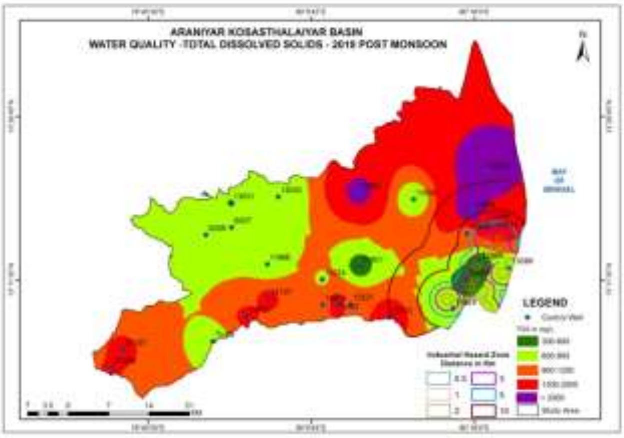

Fig.9B TDS with Industrial Hazard Zone – Post Monsoon

Total Hardness

The spatial distribution of total hardness during pre monsoon shows that nearly 30 percent of the study area including Poondi, Ellapuram, Puzhal, Villivakkam, Thiruvallur, Minjur and Sholavaram blocks have very hard category in the range of 150 to 300 mg/L **(Fig.10A)**. Full extent of Arakkonam, Thiruvalangadu, Kadambathur and Gummidipoondi blocks and partially covered blocks of Minjur, Thiruvallur, Poondi, Ellapuram and Puzhal blocks have experienced abnormal value of 300 to 600 mg/L. 30 villages in the 10 Km industrial hazard zone, 16 villages in 5 Km zone, 7 villages in 3 Km zone, 10 villages in 2 Km zone and 6 villages in 1 Km zone are having abnormal value of 300 to 600 mg/L. Voyalur and Puzhuthivakkam in 5 Km zone, Naithavoyal in 3 Km zone Kattupalli, Nandhiyambakkam and Athipattu in 2 Km zone have the abnormal concentration of greater than 600 mg/L.

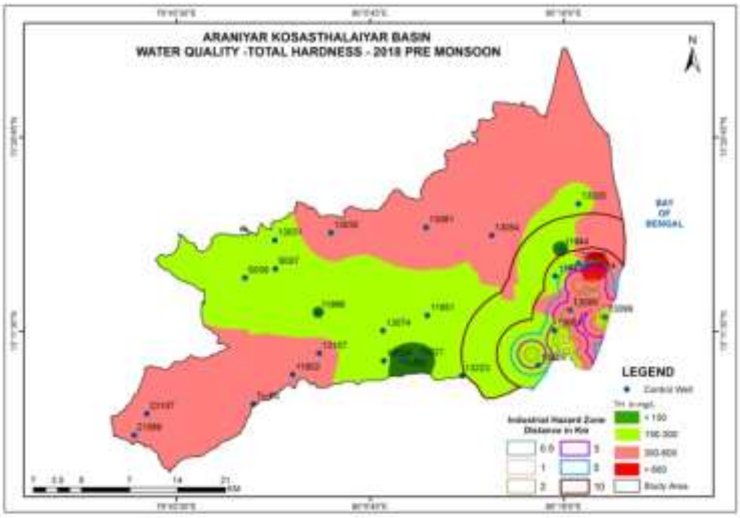

Fig.10A Total Hardness with Industrial Hazard Zone – Pre Monsoon

Spatial variation in post monsoon period shows that very hard category range of 150 to 300 mg/L is partially covered in Poondi, Ellapuram, Thiruvallur, Sholavaram, Puzhal and Minjur blocks. 5 village fall in the 5 Km industrial hazard zone, 7 villages in 3 Km zone, 6 villages in 2 and 1 Km zones have very hard category range of 150 to 300 mg/L **(Fig.10B)**. Thiruvalangadu, Kadambathur, Villivakkam, Gummidipoondi, Puzhal, Sholavaram and Minjur blocks are partially spread over the abnormal value in the range of 300 to 600 mg/L. 31 villages fall in 10 Km industrial hazard zone, 16 villages in 5 Km zone, each 9 villages in 3 and 2 km zones and 7 villages in 1 Km zone are having the range of 300 to 600 mg/L. Total Hardness value more than 600 mg/L is noticed in few villages in Arakkonam and Villivakkam blocks. In Minjur block, 11 villages fall in 5 and 10 Km industrial hazard zones, 2 villages in each 2 and 3 Km zones have the Total Hardness value more than 600 mg/L.

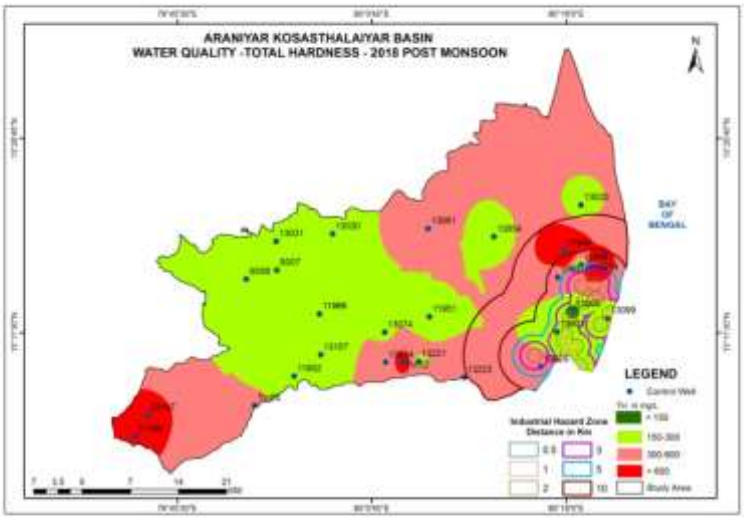

Fig.10B Total Hardness with Industrial Hazard Zone – Post Monsoon

Pollution index of groundwater (PIG)

To evaluate the pollution of groundwater in the study area, Pollution Index of Groundwater (PIG) method by Subba Rao (2012) is applied. This index ascertains the status of relative impact on individual water quality parameter. PIG is represented in numerical scale for quantifying the degree of water pollution and it gives a composite pressure of a single water quality variable on overall groundwater quality of a location. The index value has been calculated using the water quality parameters Power oh Hydrogen, Electrical Conductivity, Total Dissolved Solids, Total Hardness, Calcium, Magnesium, Sodium, potassium, Chloride, Sulphate, Nitrate and Fluoride. Depending upon the importance of the parameters for drinking water, the relative weight (Rw) of one to five scales was assigned to each parameter. Hence, the minimum weight of 1 was assigned to K; 2 was given to EC; 3 was considered to Ca; for Na and Cl, 4 was assigned; and the highest weight of 5 was assigned to pH, TDS, TH, Mg, F, SO_4 and NO_3. Further, the weight parameter (Wp) was derived for each water quality variable to evaluate its relative share on overall quality of groundwater as in Equation1. The status of concentration (Sc) was calculated by dividing the content of each water quality variable by its respective drinking water standards (Ds) as in Equation 2. The overall water quality (Ow) was also obtained by multiplying the values of Wp with Sc as in Equation 3. To evaluate the influence of contaminants on the groundwater quality, PIG was calculated by summing of all Ow values as in Equation 4. The chemical parameters, relative weight (Rw) and weighted parameters (Wp) with their drinking water standards are given in **Table 3**.

Table 3: Particulars of PIG (Rao et al. 2018)

Chemical parameter	Relative weight (Rw)	Weight parameters (Wp)	Drinking water standards (Ds)
pH	5	0.104167	7.5
EC	2	0.041667	500
TDS	5	0.104167	500
TH	5	0.104167	300
Ca	3	0.061224	75

Mg	5	0.104167	30
Na	4	0.083333	200
K	1	0.020833	10
Cl	4	0.083333	250
F	5	0.104167	1.5
SO4	5	0.104167	150
NO3	5	0.104167	45
Sum	49		

In evaluation of the PIG, the relative input of water quality variables of every water sample was considered. Given the overall quality of water (Ow) is greater than 0.1; then, it accounts for 10% of the value of 1.0 of the PIG, which signifies the influence of contamination on the quality of groundwater (Table 4). Rao et al. (2018) suggested a PIG classification into five categories, i.e.: insignificant pollution (<1.0); low pollution (1.0–1.5); moderate pollution (1.5–2.0); high pollution (2.0–2.5); and very high pollution (>2.5) (Table 5). This classification has been used to classify the groundwater quality into insignificant pollution to very high pollution in a numerical way.

Table 4 PIG Value

Sl. No.	**Sample ID**	**Location**	**Pollution Index of Groundwater**	
			Pre Monsoon	**Post Monsoon**
1	13221	Mitnamalli	1.061	1.173
2	13223	Thirumullaivoyal	2.173	2.047
3	Tvr02	Palavedu	2.369	2.203
4	13099	Ennore	0.995	0.924
5	13001	Andarkuppam	1.532	0.627
6	13029	Madavaram	0.675	1.099
7	11945	Seemavaram	1.047	1.384
8	13005	Palaya Napalayam	1.191	0.488
9	11951	Puchi Attipattu	0.621	0.594
10	Tvr06	Kadambathur	1.028	1.060
11	13024	Pakkam	0.988	1.271
12	13074	Komagambedu	0.910	1.206
13	13107	Kalyanakuppam	1.586	1.581
14	11952	Thiruvallur	1.674	1.684
15	11966	Moonavedu	0.707	0.964
16	S007	Ammambakkam	0.996	1.150
17	S009	Vellathukottai	0.820	0.920
18	23107	Mosur	0.882	1.802
19	21589	Cheyyur	0.950	1.914

20	13054	Vellanodai	0.831	0.970
21	13030	Palavakkam	1.159	1.345
22	13014	Nandiyambakkam	2.497	2.974
23	13031	Nandhimangalam	1.063	0.969
24	11946	Koranjur	1.207	1.599
25	13020	Kattur	2.221	2.913
26	11944	Kalpakkam	2.653	4.173
27	13061	Arani	1.869	2.492

Table 5 Classification of PIG for Monsoon seasons

PIG Range	**Pollution classification**	**No. of samples**		**% of samples**	
		Pre Monsoon	**Post Monsoon**	**Pre Monsoon**	**Post Monsoon**
<1.0	Insignificant	8	5	29.63	18.52
1.00 -1.5	Low	10	11	37.04	40.74
1.5-2.0	Moderate	4	5	14.81	18.52
2.0-2.5	High	3	3	11.11	11.11
>2.5	Very High	2	3	7.41	11.11

$$Wp = \frac{Rw}{\sum R_w} \quad \text{------------------ (1)}$$

$$Sc = \frac{C}{Ds} \quad \text{--------------------(2)}$$

$$O_w = Wp * Sc \quad \text{-------------------- (3)}$$

$$PIG = \sum O_w \quad \text{--------------------(4)}$$

The PIG value in pre monsoon period varies between 0.62 and 2.55 with an average value of 1.32 **(Table 4).** The PIG classification shows that 14.81 % of samples fall in moderate pollution class; 11.11 % of samples fall in high pollution class and 7.41 % of samples fall in very high pollution class **(Table 5).** In the post monsoon period, the PIG value ranges from 0.49 to 4.17 with an average value of 1.54 **(Table 4).** The classification of PIG in post monsoon period shows that **(Table 5)**, 18.52 % of sample fall in moderate pollution class; each 11.11 % of samples fall in high and very high pollution classes. It is noticed that the number of samples fall in moderate, high and very high pollution classes are increased in post monsoon period.

Spatial Distribution of PIG

By using interpolation method in Arc GIS 10.3 with spatial analyst tool, PIG spatial distribution maps with industrial hazard buffer zones of 10 km, 5 km, 3 km, 2 km 1 km and 0.5 km for pre monsoon **(Fig.11)** and post monsoon **(Fig.12)** periods were prepared. The aerial extent of the water quality categories is also derived using GIS and shown in **Table 6.**

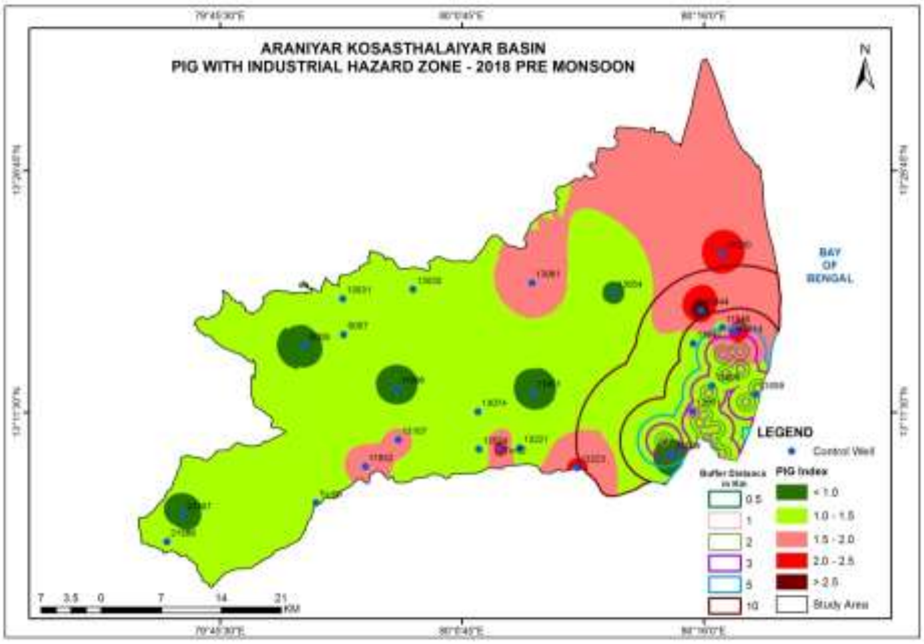

Fig.11 PIG Map - Pre Monsoon

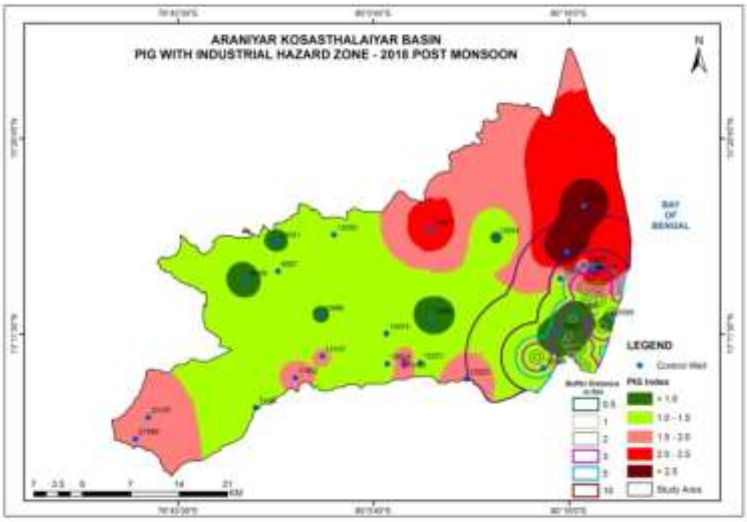

Fig.12 PIG Map - Post Monsoon

The pre monsoon spatial distribution map of PIG **(Fig.11)** shows that 547.27 Sq.Km of area has moderate pollution class which is 27..38 % in the total area **(Table 6)**. High pollution class has 37.39 Sq.Km (1.87 %) of aerial extent and Very High pollution class spread over 4.48 Sq.Km (0.22 %) of area. Low pollution class and insignificant class spread over about 60 % and 4 % in the total study area during pre monsoon period.

Table 6 Aerial Extent of the Water Quality Category

PIG Range	Pollution classification	Aerial Extent in Sq.Km	
		Pre Monsoon	Post Monsoon
<1.0	Insignificant	88.80 (4.44 %)	111.46 (5.58 %)
1.00 -1.5	Low	1320.69 (60.08 %)	1052.01 (52.64 %)
1.5-2.0	Moderate	547.27 (27.38 %)	483.64 (24.20 %)
2.0-2.5	High	37.39 (1.87 %)	277.88 (13.90 %)
>2.5	Very High	4.48 (0.22 %)	73.65 (3.68 %)

The spatial distribution of PIG **(Fig.12)** in post monsoon period shows that 483.64 Sq.Km of area has moderate pollution class which is 52.64 % in the total area **(Table 6)**. High pollution class has 277.88 Sq.Km (13.90 %) of aerial extent and Very High pollution class spread over 73.65 Sq.Km (3.68 %) of area. Low pollution class and insignificant class spread over about 53 % and 6 % in the total study area during pre monsoon period. Spatial distribution shows that moderate pollution class area reduced in post monsoon but the aerial extent of high and very high classes increased by 12 % and 3.5 % respectively. The spatial extent of pollution in the Industrial Hazard Zones in pre monsoon period is given in **Table 7.**

Table 7 Pollution classes in Industrial Hazard Zones – Pre Monsoon

PIG Range	Pollution Class	Industrial Hazard Buffer Distance in Km					
		0.5	**1**	**2**	**3**	**5**	**10**
<1.0	Insignificant	0.5	1.14	3.62	4.51	2.49	0.97
1.00 -1.5	Low	9.4	19.26	43.26	30.76	47.92	86.69
1.5-2.0	Moderate	1.15	4.38	8.88	6.31	18.82	86.29
2.0-2.5	High	0.43	1.12	1.23	1.61	1.78	11.64
>2.5	Very High			0.02	0.66	0.16	3.61
Total Area (Sq.Km)		**11.48**	**25.90**	**57.01**	**43.85**	**71.17**	**189.20**
Area of moderate to Very High Class (Sq.km)		**1.58**	**5.50**	**10.13**	**8.58**	**20.76**	**101.54**
% of the Area		**13.76**	**21.24**	**17.77**	**19.57**	**29.17**	**53.67**

According to **Table 7**, High pollution is noticed in 0.43 Sq.km area in 0.5 km industrial hazard buffer zone, 1.12 Sq.Km area in 1 Km buffer zone, 1.23 Sq.Km area in 2 Km buffer zone, 1.61 Sq.Km area in 3 Km buffer zone, 1.78 Sq.Km area in 5 Km buffer zone and 11.64 Sq.Km area in 10 Km buffer zone in pre monsoon period. Very high pollution is noticed in 0.02 Sq.Km area in 2 Km buffer zone, 0.66 Sq.Km area in 3 Km buffer zone, 0.16 Sq.Km area in 5 Km buffer zone and 3.61 Sq.Km area in 10 Km buffer zone. Moderate to very high pollution areas are covered in 101.54 Sq.Km in pre monsoon, which is 54 % in the total area of 10 Km buffer zone.

Table 8 Pollution classes in Industrial Hazard Zones – Post Monsoon

PIG Range	**Pollution Class**	**Industrial Hazard Buffer Distance in Km**					
		0.5	**1**	**2**	**3**	**5**	**10**
<1.0	Insignificant	6.2	10.42	21.08	10.28	3.68	
1.00 -1.5	Low	3.67	10.16	25.76	22.39	42.66	73.96
1.5-2.0	Moderate	1.14	3.96	5.77	6.30	6.93	42.69
2.0-2.5	High	0.48	1.37	3.70	3.04	15.09	38.02
>2.5	Very High			0.71	1.83	2.82	34.54
Total Area (Sq.Km)		**11.49**	**25.90**	**57.02**	**43.85**	**71.18**	**189.21**
Area of moderate to Very High Class (Sq.km)		**1.62**	**5.32**	**10.17**	**11.17**	**24.84**	**115.24**
% of the Area		**14.10**	**20.55**	**17.84**	**25.48**	**34.90**	**60.91**

According to **Table 8**, High pollution is noticed 0.48 Sq.km area in 0.5 km industrial hazard buffer zone, 1.37 Sq.Km area in 1 Km buffer zone, 3.70 Sq.Km area in 2 Km buffer zone, 3.04 Sq.Km area in 3 Km buffer zone, 15.09 Sq.Km area in 5 Km buffer zone and 38.02 Sq.Km area in 10 Km buffer zone in post monsoon period. Very high pollution is noticed in 0.71 Sq.Km area in 2 Km buffer zone, 1.83 Sq.Km area in 3 Km buffer zone, 2.82 Sq.Km area in 5 Km buffer zone and 34.54 Sq.Km area in 10 Km buffer zone. Moderate to very high pollution areas are covered in 115.24 Sq.Km in post monsoon, which is 61 % in the total area of 10 Km buffer zone. The spatial areas of pollution are increased in post monsoon due to discharge and leaching of chemical and industrial effluents during the monsoon.

5. CONCLUSION

In the industrial hazard zone, high pollution class is noticed in 11.64 Sq.Km area and Very high pollution is noticed in 3.61 Sq.Km area. Moderate to very high pollution areas are covered by 101.54 Sq.Km in pre monsoon, which is 54 % in the total area of industrial hazard buffer zone. In the post monsoon period, high pollution is noticed 38.02 Sq.Km area and very high pollution is noticed in 34.54 Sq.Km area in the hazard buffer zone. Moderate to very high pollution areas are covered in 115.24 Sq.Km in post monsoon, which is 61 % in the total area of hazard buffer zone. The spatial areas of pollution are increased in post monsoon due to discharge and leaching of chemical and industrial effluents during the monsoon.

This research study concludes that the groundwater aquifer in the Minjur block is affected than other areas of the Araniyar-Kosasthalaiyar basin. The study proved that due to the cluster of chemical and other industries in the Minjur block of the eastern side basin, major portion of the Minjur block is poor water quality due to discharge of the industrial effluents. As the slope of the terrain in the Minjur block from the cluster of Industries is towards north and north eastern, the spatial extent of poor water quality I seen in the north and north eastern side of the Minjur block of the basin..

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