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Analysis of the Physical, Chemical, Nutritional and Heavy Metal Parameters of Ground Water in Selected Sites of Tiruchirappalli, Tamil Nadu, India, With a Note on Risk Assessment

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A B S T R A C T

The ground water quality of Tiruchirappalli district was tested at four stations, viz., Jamal Mohamed College Mosque (Station 1), Mannarpuram (Station 2), Trichy Cantonment (Station 3), and Trichy junction (Station 4) from April 2019 to March 2020. Results with regard to the physical parameters, showed all samples to be colourless, odourless and tasteless. Water temperature, electrical conductivity and total dissolved solids reported values of 26.6, 27.2, 30.5 and 30.0°C; 2720, 1613, 1975 and 2750µS/cm; 1904, 1129, 1383 and 1925mg/L respectively. Turbidity in all stations recorded 1NTU. The chemical parameters represented by pH, and total hardness reported values of 6.8, 6.6, 7.8 and 6.6; 730, 490, 580 and 480mg/L respectively. Total alkalinity was reported nil in all the stations. Nutrients, *viz*., calcium, magnesium, free ammonia, nitrate, nitrite, chloride, fluoride and sulphate reported values of 168, 112, 120 and 180mg/L; 74, 50, 53 and 60mg/L; 0, 0, 0.1 and 0.2mg/L; 50, 50, 2 and 2mg/L; 0, 0, 0.1 and 0.1mg/L; 660, 208, 236 and 640mg/L; 0.3, 0.3, 0.2 and 0.2mg/L; 50, 134, 7 and 7mg/L respectively. Phosphate in all stations recorded 0.1mg/L. With regard to the heavy metals, cadmium, cobalt, copper and iron were not detectable, and chromium, lead, manganese, nickel and strontium reported values of 0.06, 0.12, 0.07, 0.12 and 0.54mg/L respectively in Station 1. Whereas, in Station 2, cadmium, chromium, copper, iron, lead, manganese, nickel and strontium reported values of 0.07, 0.22, 0.07, 1.26, 1.62, 1.07, 0.20 and 0.66mg/L respectively, and cobalt was not detectable.

***Key words*:** Physical, Chemical, Nutrient, Heavy metal, Bore well, Hand pump, Open well

Water, whether on the surface or underground, is the most essential and significant natural resource for sustaining life on earth, and for the sustainable growth of socioeconomic sectors such as irrigation and industrialization [1]. A general belief is that ground water is purer and safer due to earth's mantle covering. Groundwater have their unique chemistry and characteristics at each location and depend on various climatic changes, precipitation, surface water, and recharge parameters, and their quality depends mainly on underlying rock's geochemical and lithological composition and subsurface factors [2]. Ground water is highly valued because of certain properties not possessed by surface water. The quality of ground water is the resultant of all the processes and reaction that act on the water from the moment it condensed in the atmosphere to the time it is discharged by a well or spring. Ground water is used in every state in India which accounts for about one-quarter of all fresh water used as 60% of the irrigation requirements and 85% of drinking water supplies are dependent on groundwater [3].

The major problem with the ground water is that once contaminated, it is difficult to restore its quality. Water soluble substances which are dumped, spilled, spread or stored on the land surface eventually infiltrate into the soil, and reach the ground water. Another cause of ground water quality deterioration is pumping, which may precipitate the migration of more mineralized water from surrounding strata to the well. The solution is non-trivial because of complex dynamics involved in the ground water flow, which requires simultaneous solution of complicated geochemical and hydrological problems. Hence, there is a need for and concern over the protection and management of ground water quality. Groundwater investigation consists of both quality and quantity determination. The major problem of interest is that of the quality of the water being extracted. Though, quantity is abundant, it is useful only if the quality of ground water is safe. In rural areas, the need for water is met by ground water. In many instances, ground water is used directly for drinking as

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well as for other household purposes. To safeguard the long-term sustainability of ground water resources, the quality of water needs to be continually monitored. Sources of ground water contamination range from domestic septic tanks, landfills and spills, leaky storage tanks, agriculture sources, to the chemicals desorbing from the soil matrix. Pollution of ground water impairs its suitability and creates a hazard to public health. There is a great concern over ground water because toxic, carcinogenic and teratogenicity nature of compounds accumulated due to agricultural and industrial practices with excessive manmade chemicals besides inadequate sewage system are known to be a primary cause for out breaks of water-borne diseases [4-5].

Public of Tiruchirappalli have no alternative but to be satisfied with the available ground water for all their domestic needs. The bulk of the city population, is negligent about the quality of the ground water available to them. Kuttimani *et al*. [6] reported the water quality in Tiruchirappalli, wherein Cauvery river is the lifeline in this district, and the public are dependent on the ground water as their primary source of drinking water. Hence, monitoring the quality of ground water is necessary in order to provide the public with potable water and consistent monitoring of data to characterize the quality of ground water is needed. Hence, long-term data monitoring to characterize ground water quality, even when restricted to an area of 10Km radius should be determined. Thus, owing to the present need and the important features of ground water, it was felt necessary that the ground water in selected sites of Tiruchirappalli be analyzed so as to assess its quality and usefulness to the public for various purposes.

MATERIALS AND METHODS

Tiruchirappalli district (10.7905° N, 78.7047° E) also called Tiruchi or Trichy located 322Km south of Chennai and 374Km north of Kanyakumari is the fourth largest city located in the central part of Tamil Nadu. This city is located at the head of Cauvery delta, and its altitude is 78.8m above the mean sea level. It forms a part of a vast plain of fertile alluvial soil. The topology of Tiruchirappalli is almost flat with a few isolated hillocks rising above the surface. It receives rainfall from the northeast monsoon. The groundwater quality of this district is continuously degrading due to domestic and agricultural activities. Ground water samples from four stations, viz., Jamal Mohamed College Mosque 10.7021° N, 78.7562° E (Station 1), Mannarpuram 10.7861° N, 78.6904° E (Station 2), Trichy Cantonment 10.8013° N, 78.6810° E (Station 3), and Trichy junction 10.7950° N, 78.6857° E (Station 4) situated in and around Tiruchirappalli at a 10Km radius were selected on the basis of ground water sources (Station 1: bore well; Station 2: hand pump; Station 3: bore well; and Station 4: open well) used by the public for domestic and irrigation purposes on a daily/regular basis.

Study design

The study was conducted from April 2019 to March 2020. All the four stations were analyzed for their physical (colour, odour, taste, water temperature, electrical conductivity, turbidity, and total dissolved solids), chemical (pH, total hardness, and total alkalinity), and nutrients (calcium, magnesium, free ammonia, nitrate, nitrite, chloride, fluoride, sulphate, and phosphate) properties. Whereas, Station 1 and Station 2 only were analyzed for heavy metals (cadmium, chromium, cobalt, copper, iron, lead, manganese, nickel, and strontium) properties.

Table 1 Procedure for analysis of water parameters and permissible limits for each parameter set by standards

Parameters for analysis	Unit	Method	WHO	ISI	USEPA	ICMR	CPCB	TNPCB
			Physical					
Colour/Appearance	Hazen	Visual comparison	-	5	-	-	-	-
Odour Taste	-	Physiological sense	Acceptable	Acceptable	-	Acceptable	Acceptable	Acceptable
Water temperature	°C	Mercury-in-glass thermometer	-	-	-	-	-	-
Electrical conductivity	µS/cm	Conductivity meter	-	-	-	-	2000	2500
Turbidity	NTU	Nephelometric turbidity meter	<5	10	-	25	10	
Total dissolved solids	mg/L	Ion selective	500	500-1500	-	500	-	500
			Chemical					
pH	-	Systronic digital pH meter	6.5-8.5	6.5-8.5	6.5-8.5	6.5-8.5	6.5-8.5	6.5-8.0
Total hardness	mg/L	EDTA titration	500	300	-	600	600	300
Total alkalinity		Acid titration	120	200	200	-	600	200
			Nutrient					
Calcium	mg/L	Flame photometer	75	75	-	200	200	75
Magnesium		Complexometric EDTA titration	150	30	-	-	-	50-150
Free ammonia		UV visible spectrophotometer	0.5	1.5	-	-	-	1.5
Nitrate			45	45	50	100	100	45
Nitrite			3	45	0.5	-	-	45
Chloride		Argentometric titration	200	250	250	1000	1000	250-1000
Fluoride		SPADNS spectrophotometer	1.5	0.6-1.2	4.0	1.5	1.5	1.0
Sulphate		Nephelometer and turbidimeter	250	200	250	400	400	200-400
Phosphate		Stannous chloride	0.1	-	-	-	-	0.1
			Heavy metal					
Cadmium	mg/L	Atomic absorption spectrophotometer	0.005	0.01	0.005	0.01	-	-
Chromium			0.05	0.05	0.1	0.05	-	-
Cobalt			-	-	0.004	-	-	-
Copper			1	0.05	1.3	1.5	1.5	1.5
Iron			0.1	0.3	-	1.0	1.0	1.0
Lead			0.05	0.1	-	0.05	-	-
Manganese			0.05	0.1	0.05	0.1	0.1	0.1
Nickel			0.1	0.05	0.1	0.05	-	-
Strontium			-	-	-	-	3.5	-

WHO: World Health Organization; ISI: Indian Standards Institution; USEPA: United States Environmental Protection Agency; ICMR: Indian Council for Medical Research; CPCB: Central Pollution Control Board; TNPCB: Tamil Nadu Pollution Control Board

Sample collection

Sampling procedures for water samples were followed according to Bureau of Indian Standard (BIS) and sampling was replicated thrice for each station. Water samples (1000mL) were collected in the early morning hours in high-density polyethylene 'Tarson' brand bottles after 2-3 times rinsing with the sample. All the chemicals and reagents utilized were of analytical grade, purchased from Merck, India. Analytical grade water from Millipore water purification system (Make: Millipore, USA; Model: Elix and Synergy) was used for the preparation of all standards and solutions. The description of procedures of water quality parameters to be analyzed and compared with the standard permissible limits of water quality [7-17] are tabulated and presented in (Table 1).

Statistical analysis

Correlation analysis, a useful statistical tool to determine the extent to which changes in the value of an attribute are associated with the changes in another attribute [18] was used for this study, since, a systematic statistical study of correlation of the parameters not only helps to assess the overall water quality but also to relate its parameters and provide necessary clue for implementation of rapid water quality management. Correlation matrix analysis was performed for all parameters except heavy metals utilizing SPSS software programme to determine the relationship between parameters responsible for influencing the groundwater quality of the study area using Pearson’s linear correlation with $P<0.05$ significant threshold [19].

RESULTS AND DISCUSSION

The results of the physical, chemical and nutrient parameters of ground water in the study area are given below. The values given for each parameter are in the order for Station 1, Station 2, Station 3, and Station 4 respectively. All samples were found to be colourless, odourless and tasteless. Water temperature, electrical conductivity and total dissolved solids reported values of 26.6, 27.2, 30.5 and 30; 2720, 1613, 1975 and 2750; 1904, 1129, 1383 and 1925 respectively. Turbidity in all stations recorded a value of 1 (Fig 1). pH and total hardness reported values of 6.8, 6.6, 7.8 and 6.6; 730, 490, 580 and 480 respectively. Total alkalinity was reported nil in all the stations (Fig 2). Calcium, magnesium, free ammonia, nitrate, nitrite, chloride, fluoride and sulphate reported values of 168, 112, 120 and 180; 74, 50, 53 and 60; 0, 0, 0.1 and 0.2; 50, 50, 2 and 2; 0, 0, 0.1 and 0.1; 660, 208, 236 and 640; 0.3, 0.3, 0.2 and 0.2; 50, 134, 7 and 7 respectively. Phosphate in all stations recorded a value of 0.1 (Fig 3). Cadmium, cobalt, copper and iron were not detectable, and chromium, lead, manganese, nickel and strontium reported values of 63, 127, 77, 125 and 547 respectively in Station 1. Whereas, in Station 2, cadmium, chromium, copper, iron, lead, manganese, nickel and strontium reported values of 75, 225, 75, 1260, 1626, 1073, 208 and 668 respectively, while cobalt was not detectable (Fig 4). The correlation matrix between the water parameters are displayed in (Table 2). Correlation analysis performed arrive at a fair idea of the quality of the groundwater, and the correlation parameters of groundwater revealed that all the parameters were more or less correlated with one another. Kuttimani *et al*. [6] has provided an overview of the groundwater quality of Tamil Nadu, wherein the potential sources of ground water contamination include storage tanks, septic systems, uncontrolled hazardous waste, landfills, atmospheric contaminants, and chemical and road salts.

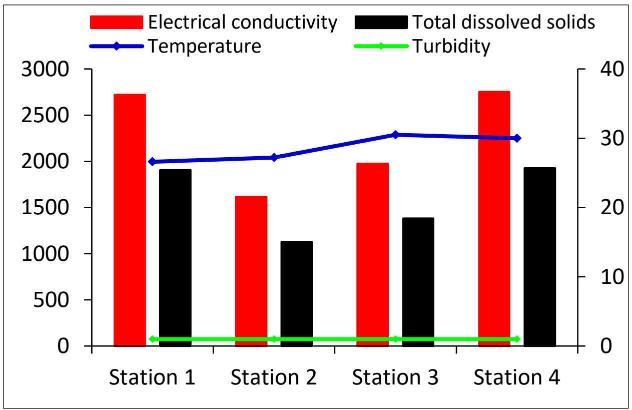

Fig 1 Physical water parameters of the study area

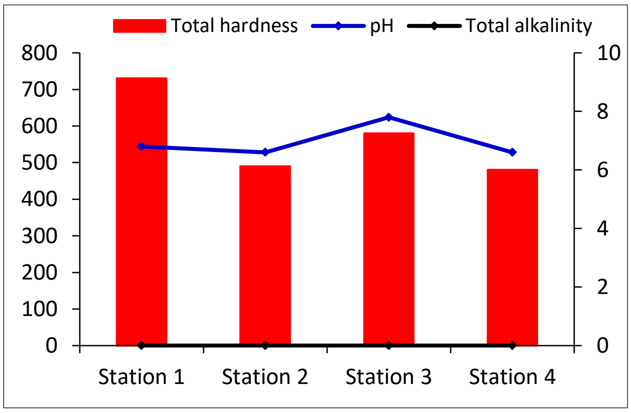

Fig 2 Chemical water parameters of the study area

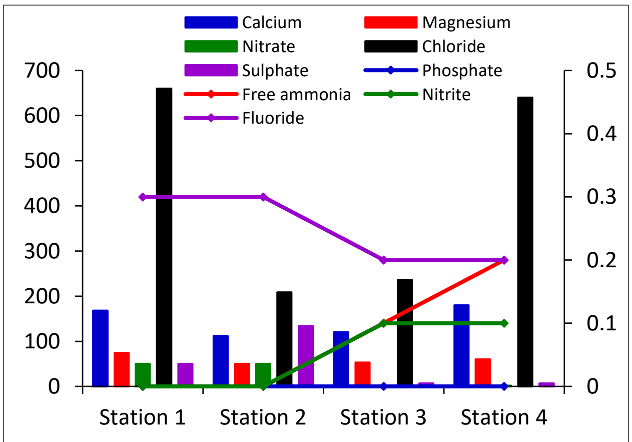

Fig 3 Nutrient water parameters of the study area

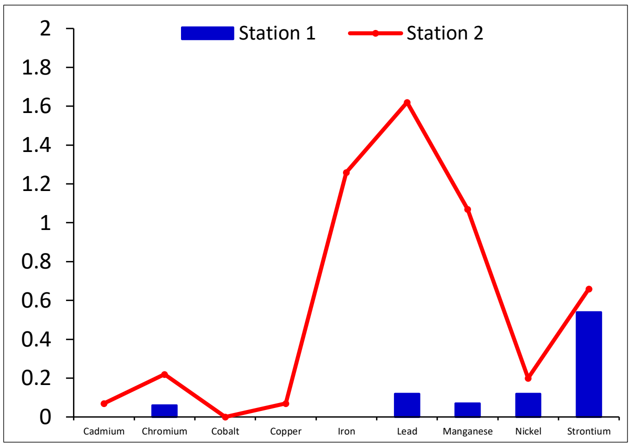

Fig 4 Heavy metal water parameters of the study area

Table 2 Correlation matrix of physical, chemical and nutrient water parameters of the study area

	WT	EC	TU	TDS	PH	TH	TA	CA	MA	FA	NTA	NTI	CH	FL	SU	PHO
WT	1															
EC	0.039	1														
TU	NA	NA	NA													
TDS	0.039	1	NA	1												
PH	0.566	-0.264	NA	-0.263	1											
TH	-0.462	0.400	NA	0.401	0.220	1										
TA	NA	NA	NA	NA	NA	NA	1									
CA	0.008	0.978*	NA	0.978*	-0.433	0.247	NA	1								
MA	-0.435	0.826*	NA	0.826*	-0.247	0.800*	NA	0.758*	1							
FA	0.848*	0.421	NA	0.421	0.090	-0.511	NA	0.460	-0.154	1						
NTA	-0.986	-0.200	NA	-0.201	-0.502	0.399	NA	-0.169	0.297	-0.904	1					
NTI	0.986*	0.200	NA	0.201	0.502	-0.399	NA	0.169	-0.297	0.904*	-1	1				
CH	-0.153	0.974*	NA	0.974*	-0.457	0.392	NA	0.982*	0.858*	0.292	-0.009	0.009	1			
FL	-0.986	-0.200	NA	-0.201	-0.502	0.399	NA	-0.169	0.297	-0.904	1	-1	-0.009	1		
SU	-0.737	-0.624	NA	-0.624	-0.493	-0.157	NA	-0.524	-0.281	-0.741	0.819*	-0.819	-0.434	0.819*	1	
PHO	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	1

'-NA-': Not Applicable
Pearson correlation coefficient (r) among the parameters in the groundwater tested
*Statistically significant correlation values at $P<0.05$

WT: Water temperature; PH: pH; CA: Calcium; NTI: Nitrite; EC: Electrical conductivity
TH: Total hardness; MA: Magnesium; CH: Chloride; TU: Turbidity; TA: Total alkalinity
FA: Free ammonia; FL: Fluoride; TDS: Total dissolved solids; NTA: Nitrate; SU: Sulphate; PHO: Phosphate

Physical parameters

Groundwater quality comprises of its physical, chemical, and biological qualities. Colour, odour, taste, temperature, electrical conductivity, turbidity, and dissolved solids make up the list of physical water quality parameters [6]. Colourless, odourless, and tasteless water reported in all stations of the present study. Water temperature, a key physical feature, depends on the depth of the water column, climatic and topographic changes [20], and is influenced by precipitation and accessibility of light. Water temperature affects the biotic and abiotic stream processes such as the amount of dissolved matter, organic and inorganic pollutants [21]. High temperatures have a profound effect on the physicochemical properties, and the biotic spectrum present within the water, whereas low temperature achieves the darkening impact [22]. Naturally, water remains at low temperature and evaporates to high temperatures, when heated waters or effluents are discharged from industries or power plants. This was observed in Station 3 and 4 of the present study.

Electrical conductivity of water samples in the present study varied between 1613 and 2750µS/cm and the values were slightly above the permissible limits. Electrical conductivity reflects the water mineralization and varies according to the concentration of dissolved salts and is influenced by temperature because it acts on the dissolution of salts in water [23]. Its measure of salinity greatly affects the taste and thus has a significant impact on the user acceptance of the water as potable [24]. Electrical conductivity discuses about the conducting capacity of water which in turn is determined by the presence of dissolved ions and solids. Higher the ionizable solids, greater the electrical conductivity, and when it exceeds, crop germination would be affected leading to reduced yield [25].

The turbidity of water depends on the quantity of solid matter present in the suspended state. It is a measure of light emitting properties of water and the test is used to indicate the quality of waste discharge with respect to colloidal matter [26]. High values of turbidity minimize the filter runs which cause pathogenic organisms to be more hazardous to human life. Studies have proved that consumption of high turbid water causes liver, thyroid, dermal and ocular diseases and also alterations in immunological and reproductive systems [27]. However, in the present study, turbidity recorded a value 1NTU in all the four stations, and were within the permissible limits.

Naturally, ground water contains mineral ions which slowly dissolve from soil particles, sediments, and rocks, as the water travels along mineral surfaces in the pores of the unsaturated zone. They are referred to as dissolved solids, and can be divided into three groups: major constituents, minor constituents, and trace elements. The total mass of dissolved constituents is referred to as the total dissolved solids concentration. In water, all of the dissolved solids are either positively charged ions (cations) or negatively charged ions (anions). Excess of ions in the water increases the water's electrical conductivity, by which the concentration of the total dissolved solids in water can be indirectly determined. At high concentrations, water becomes saline. Water with a total dissolved solids above 500mg/L is not recommended for use as drinking water, and above 1,500 to 2,600 mg/l is generally considered problematic for irrigation use on crops with low or medium salt tolerance [6]. Total dissolved solids varied between 1129 and 1925mg/L in the present study, which was above the permissible limits set by standards. High values of total dissolved solids in ground water are generally not harmful to human beings, but high concentrations may affect persons suffering from kidney and heart diseases, provoking paralysis of the tongue, lips, and, face, irritability, dizziness and at times even disturbing the central nervous system [28].

Chemical parameters

pH is a basic biogeochemical parameter, which assumes a vital role in natural processes. It is the measure of acidity or alkalinity of water, and is reflected as a noteworthy characteristic factor, conveys information on various kinds of geochemical balance [29], and is the major deciding component to water destructiveness [22]. pH is positively correlated with electrical conductance and total alkalinity [30], and is also important in determining the corrosive nature of water as low pH values indicate high corrosiveness nature of water. pH of ground water samples are in the range of 6.9-8.2 and the acceptable range of pH for drinking water is 6.5-8.5 [9]. In the present study, pH ranged from 6.6 to 7.8. The pH is influenced by the origin of water and the nature of the crossed terrain, volume of water and soil type. Slight changes seen in the values of all the four stations may be attributed to different types of buffers normally present in the ground water. This was corroborated by Weber and Stun [31]. The variations in pH are relatively small. However, the pH values of Station 3 revealed the slight alkaline nature of the ground water which indicates the presence of weak basic salts in the soil [32]. This was supported by the findings of Miriam and Samuel [33] who inferred that the ground water of Tiruchirappalli was slightly alkaline in nature. Low pH values (<6.5) of groundwater discontinues making of vitamins and minerals in the human body, and can cause gastrointestinal disorders especially hyperacidity, ulcers and burning sensation [34], while pH values >8.5 makes the taste of water more salty and causes eye irritation, and >11 causes skin disorder [35].

Total hardness is an important parameter of water quality irrespective of water used for domestic, industrial or agricultural purposes. It is due to the presence of salts of calcium, magnesium and iron in excess [36]. Consumption of hard water have an undesirable taste and little utility [37]. In the present study they were above the permissible limits set by standards as they ranged from 480 to 730mg/L.

Total alkalinity is the sum total of components in the water that tend to elevate the pH to the alkaline side. The main sources of natural alkalinity are rocks, which contain carbonate, bicarbonate, hydroxide compounds and phosphates. Since, alkalinity is composed primarily of carbonates and bicarbonates, it acts as a stabilizer for pH and together with hardness, affect the toxicity of many substances in the water [38]. Alkalinity in itself is not harmful to human being, but in large quantity, imparts bitter taste to water, and may cause eye irritation in human [39], however its values were nil in the present study for all the four stations.

Nutrient parameters

Calcium and magnesium occur in large concentrations in natural sources. High values may be due to the seepage of effluent and domestic wastes or due to cationic exchange with sodium [40-41]. However, low values do not mean that it is not influenced by the pollutants but it might be due to the reverse cationic exchange with sodium. (i.e.) sodium ions replace calcium and magnesium ions thereby reducing their concentration in ground water after percolation. The present study reported calcium (112-180mg/L) and magnesium (50-74mg/L) values below the permissible limits.

Free ammonia is a product of decomposition of organic matters which tends to be high in water polluted by sewage, and its presence in percolation indicates anthropogenic contamination, besides from bacterial activity of the soil, agriculture and industrial wastes [42]. In the present study, Station 1 and 2 reported nil values which may be due to increased anaerobic decomposition of dissolved organic matter, while Station 3 and 4 reported values of 0.1 and 0.2mg/L respectively, which were below the permissible limits.

Nitrate in raw water is in the form of molecular nitrogen, produced from chemical and fertilizer factories, animal matters, decayed vegetables, domestic and industrial discharge. Leaching of nitrate present on the surface with percolating water contaminates ground water [43]. High nitrate concentration in groundwater might be associated with animal or human waste, septic or sewage releases as well as lawn and garden fertilization [44]. Mason [45] reported that increased levels of nitrates are due for influx of sewage and industrial effluents into the natural water. High nitrate values indicate pollution load [46], and consumption of such water in large quantities can lead to methemoglobinemia. However, in the present study the values were below the permissible limits.

Nitrites originate from degradation of organic matter, reduction of nitrates and oxidation of ammonia, and its unreasonable presence in excess in ground water presents a wellbeing danger and poses health hazards due to their poisonous oxidizing power [47]. However, in the present study, Station 1 and 2 reported nil values, while Stations 3 and 4 reported a value 0.1mg/L which were below the permissible limits.

Natural and raw water contains chlorides, which comes from activities carried out in agricultural area, industrial activities and from chloride stones. Chlorides are important in detecting the contamination of groundwater by waste water [48]. High concentration of chloride can be due to the invasion of domestic wastes and disposals by human activities. Increased rate of percolation of industrial, agricultural and domestic wastes also increases the chloride level in ground water. In the present study, the values of chloride ranged between 208 to 660mg/L which was below the standard values.

Fluoride is found universally in water, soil, and air, and occurs as fluorspar (fluorile), rock phosphate, triphite, and phosphorite crystals in nature. Factors which control the concentration of fluoride, are the climate of the area and the presence of accessory minerals in the rock minerals assemblage through which the ground water circulates [49-50]. Fluoride contamination is a severe problem in groundwater [51], and has a direct impact on the health of human beings, animals, and plants due to exceeded limits. The occurrence and development of fluorosis are directly related to the fluoride content in the environment, particularly in water, and especially in ground water. Fluoride is considered to be beneficial for human health if taken in controlled quantity, and the fluoride content in the present study ranged from 0.2 to 0.3mg/L which was well below the permissible limits set by standards. A fluoride level of 1.5-3.0mg/L causes dental, skeletal and non-skeletal manifestations, moulted enamel, and initiation of tooth decay in children of age group 7-12, from 3.0-4.0mg/L, stiffens brittle bones, and more than 4.0mg/L can cause osteosclerosis and crippling fluorosis [52], and when in extreme cases above 20mg/L, causes bruising of the liver, thyroid, kidney and other organs with a toxic effect, including deformation in bone and teeth spotting/flaking [53-54].

Sulphate originates from sedimentary and igneous rocks [55], and is a common soluble ion present in water. Sulphate enters ground water by industrial or anthropogenic additions in the form of sulphate fertilizers, and are present in small quantities [43]. Sulphate is the ionic form of sulphur after its combination with oxygen and exists in soil and rocks in organic or mineral forms, and is mainly derived from the dissolution of salts of sulphuric acid and abundantly found in almost all water bodies [50]. High concentration of sulphate may be due to oxidation of pyrite and mine drainage, cause corrosion of pipes, reduce the effectiveness of chlorination, and produces bitter taste to water [26]. In the present study, the sulphate values recorded in all the four stations were found to be well within the permissible limits set by standards.

Phosphate enters into ground water from phosphate containing rock, fertilizers and percolation of sewage and industrial wastes. Normally, ground water contains only a minimum phosphate level because of the low solubility of native phosphate minerals and the ability of ions to retain phosphate [50]. The major cause for phosphate concentration in ground water may be agricultural runoff from irrigated lands containing phosphatic fertilizers [43]. Phosphate in the present study was 0.1mg/L in all stations, which was in par with the permissible limits.

Bala and Mukherjee [56] reported that the correlation study was more appropriate when correlation coefficient 'r' approaches to one, and in this limit the correlations among different parameters are true. Correlation coefficient in the present study established the relationship between the variables by Spearman's correlation matrix, and indicated that groundwater has been contaminated which might be due to excess application of fertilizers, and anthropogenic activities. The variation of these relationships may indicate the complexity of the hydrochemical components of groundwater where natural water always contains dissolved and suspended substances of mineral origin [57-58].

Heavy metal parameters

Heavy metals from anthropogenic sources as well as natural sources contaminate groundwater [59]. Heavy metals discharged from residential areas, industries, and agricultural land contaminate surface, subsurface and ground water systems, and have been reported to have more than the permissible concentration in drinking water [12], [60-62]. Contamination by heavy metals is currently considered one of the most marked threats to ground water quality. Due to their toxicity, non-degradation, and bioaccumulation, they render water unsuitable for drinking and cause severe risk to human beings [63-64]. Heavy metals are non-degradable harmful pollutants because of their high environmental toxicity, abundance, and persistence in various environmental counterparts, and are considered to be systemic toxicants, recognized to trigger multiple organ harm even at trace amounts in the human body [65], and cause damage to nervous system and internal organs [66]. Heavy metals, categorized as biologically essential and nonessential are regularly added to our food chain through excessive use of agrochemicals, municipal wastewater, and industrial effluents. Copper, chromium, iron, and manganese are essential for animals and human beings because they play an important role in different metabolic functions, enzymatic activities, sites for receptors, hormonal function, and protein transport at specific concentrations [67]. Nonessential heavy metals like cadmium, lead, and strontium have no known essential role in living organisms and they exhibit extreme toxicity even at very low exposure levels and have been regarded as the main threats to all forms of life especially human health [68].

Cadmium is a relatively mobile element, and is considered to be hazardous metal because of its toxicity and accumulation capacity in the living system [69]. Cadmium levels in the environmental are greatly enhanced by the industrial operations as cadmium is commonly used as pigment in paint, plastics, ceramics and glass manufacture [70]. Exposure to small concentrations of cadmium may affect the physiology and health of life. Toxic effects of cadmium are renal failure, hyperactivity, softening of bones, slowed growth, muscle and joint pain, and carcinogenic effect [71]. In the present study, cadmium reported nil values in Station 1 while it recorded a value of 0.07mg/L in Station 2, which indicated that it exceeded the permissible limits set by standards.

Chromium is implemented in various industrial activities including tanning, electroplating, ceramics, dyeing, painting, wood and paper processing, and explosives. Chromium become immobile when absorbed to the sediment, and a small part of it will end up in water [70]. High intake of chromium contaminated water may cause kidney damage, liver failure, damage to the circulatory system, breakdown of nerve tissue, allergic reactions, neurotoxic [71] and genotoxic [72] effects. In the present study, the station 1 and 2, reported values of 0.06 and 0.22mg/L respectively, which indicated that chromium level in Station 1 marginally exceeded the permissible limits, and for Station 2 they relatively exceeded the permissible limits set by standards.

Cobalt is a naturally occurring element widely distributed in rocks, soil, water and vegetation, and is usually found in association with nickel [73]. Anthropogenic release of cobalt to the environment are by metal mining, smelting, pulp and paper industries, landfills, production of alloys and chemicals containing cobalt, sewage effluents, urban run-off, and agricultural run-off to the aquatic environment. Cobalt is a beneficial element for leguminous plants for their growth, metabolism, and development of root nodules, however higher concentrations have toxic effects, including leaf fall, leaf necrosis and interveinal chlorosis, inhibition of greening, premature leaf closure and reduced shoot weight, leading to numerous dysfunctions in the plant system [74], and in the case of human it may induce lung cancer [75]. Nevertheless, cobalt reported nil values in the present study.

Copper is a widely distributed essential element for all living system. Higher values of copper noticed in summer is considered as pollutant which may be due to the sewage of domestic and agricultural inputs [76], and its low value may be the result of adsorption process by the soil which reduces the concentration of the heavy metals in water. Excessive copper may be detrimental to plants when copper-enriched liquid waste are used as irrigation water in agricultural land [77]. Copper toxicity to human include diarrhoea, nausea, headache, dizziness, stomach cramps, and kidney damage [71]. In the present study, copper was absent in Station 1, while Station 2 reported a value 0.07mg/L, which was well within the permissible levels.

Entry of iron into the water body may be through the tinkering and electroplating shops, paint factory, electrical engineering works contributing to the increase in the heavy metal content. Iron is one of the key blood constituents in human and other living organisms, and an essential element for human nutrition and metabolism, yet in excess quantities results in toxic effect like haemochromatosis in tissues [22], [78]. The permissible limit of iron content in drinking water is <0.1 mg/L [14], [79]. High iron in ground water causes severe impacts on human health, such as diabetes, arthritis, heart failure and diseases, liver cancer and cirrhosis, and infertility [71], [80]. Iron content in the present study recorded nil in Station 1 and at 0.12mg/L in station 2, and the fell within the permissible limits.

Lead in the urban environment is released from both natural and manmade sources. Nevertheless, it was reported that the major manmade sources are industrial activities such as mining, manufacturing, and fossil fuel burning, in addition to different agricultural and domestic applications as well as traffic emissions and weathering of materials [81]. Lead at a concentration of 100-500µg/L cause acute toxicity of aquatic plants, and the enzymes needed for photosynthesis are inhibited when lead exceeds 0.5µg/L in algae [82]. Consumption of lead contaminated water affect the gastrointestinal tract, liver, and central nervous system, breaks blood brain barrier and interferes with infant's natural brain development [83]. Further, it affects memory and concentration problems, causes high blood pressure, carcinogenic effects, and problems to systems of hearing, digestion and reproduction [71], damage to nervous system and immune function, blood pressure, abdominal pain, kidney damage, gliomas, lung, and stomach cancer [84]. The present study reported values of 0.12 and 1.62mg/L in station 1 and 2 respectively, which indicated that the lead level in station 2 exceeded much higher when compared with the permissible limits.

Manganese present in water as a soluble divalent ion, is non-toxic to animals but is objectionable, causes tenacious stains to laundry and plumbing fixtures, and is not suitable for domestic purpose [85]. High values of manganese may be due to the influence of industrial effluents and domestic sewage entering into the river system. The present study reported values of 0.07 and 1.07mg/L in station 1 and 2 respectively, and these values exceeded the permissible limits set by standards.

Notably, Mining activities, besides oil and coal combustion, nickel metal refining, and sewage sludge incineration are reported sources of nickel contamination. Sources of nickel in water include effluents and sludge from sewage treatment plants, and industries like ceramics, steel and alloys, electroplating, and refractory are its contributors to surface/ground water [86]. Ingestion of nickel contaminated water can cause fatal cardiac arrest and hypertension [87], and its toxic effects include hair loss, cancer risk, skin toxicity, irritation and diseases, and decrease in body weight [71]. Nickel values in station 1 (0.12mg/L) was in par with the permissible limits, however its values in station 2 (0.20mg/L) exceeded the permissible limits.

Strontium is an alkaline-earth metal, and a common trace element in most rocks, soils, sediments, and waters [88], and due to the dissolution of its natural compounds, it can be found in air, soil, and water [89]. The primary exposure pathways of strontium to humans are dermal contact (taking a bath) and oral intake (drinking water) [90]. Though strontium holds good to bone health, long-term drinking of water having a relatively high concentration of strontium will affect the bone mineralization [91] and can lead to rickets, a common bone disease in infants and children [92], and is also associated with teeth mottling [93]. Strontium values for the present study in station 1 (0.54mg/L) and station 2 (0.66mg/L) were well within the permissible limits set by standards.

Station 2 of the present study witnessed a high level of cadmium, chromium, lead, manganese and nickel in the ground water which may be due to increased industrial activities. Above all, the toxicity of a metal is dictated by numerous factors including concentration and duration of action, ambient temperature, oxygen content in water, pH, hardness of the water, and presence of compounds with which the metal may complex. Rise of water temperature, oxygen deficit, decrease of pH, and hardness usually enhance the metal toxicity for hydrobionts [94].

Groundwater the great hidden resource is the most available fresh water, and its quality in an area is largely to a great extent dictated by disintegration and precipitation of minerals, groundwater speed, nature of revive water, and collaboration with different kinds of water spring, and anthropogenic exercises [95]. It's more like the water within a saturated sponge, moving slowly through the earth's pores and cracks and it is replenished locally. Although most of groundwater supplies are clean, they get contaminated, due to human neglect and carelessness, and are vulnerable and threatened. As reported, geostatistics [96], groundwater contamination [97], groundwater quality [98- 99], for storage and reservoir capacity [100] has to be applied as a decision-making tool for groundwater analysis in Tiruchirappalli.

CONCLUSION

The nature of groundwater relies upon different substance constituents and their fixation is for the most part developed from the topographical information of the specific district. By and large, the nature of groundwater relies upon the part of energize water, the cooperation between water and soil, soil-gas connection, rocks with which it comes into contact in the unsaturated zone, and responses that occur inside. The regular substance nature of groundwater is commonly acceptable, yet raised centralizations of various constituents, can mess up water use. Thus, groundwater data provides critical proof to its recharge, movement, development, capacity and storage, and future studies on water analysis in other areas of Tiruchirappalli are recommended as they would enhance the understanding of available ground water in Tiruchirappalli.

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