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Evaluation of surface water and groundwater interaction near the coast of Cauvery river delta, Tamil Nadu, India

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Abstract

Cauvery River, one of the major rivers in the peninsular regions, is the major source of water for domestic, agricultural and industrial uses in major parts of Karnataka and Tamil Nadu. Detailed investigation of the interaction between surface water and groundwater is important for water resources management as well as the determination of migration pathways for contaminants. Geochemical processes that take place in the aquifer play a major role in spatial and temporal variations of groundwater quality. The physical parameters like EC, pH, ORP, and HDO of water samples show similar trends in the declination in surface water as well as groundwater. The trace metal like (Zn, Pb, Cu) concentration in the surface water and the groundwater also the concentration of the major ions showing an increasing trend toward the coastal region. The electrical conductivity of the surface water varies from 546.2 to 15360 $\mu\text{S}/\text{cm}$ and the electrical conductivity of the groundwater is varying from 502.2 $\mu\text{S}/\text{cm}$ to 1976.0. The maximum concentration of Na^+ is 3710 mg/L to 46 mg/L in a surface water sample and 461.50 mg/L to 44.5 mg/L in a groundwater sample. The maximum concentration of K^+ is 200 mg/L to 5.3 mg/L in the surface water and 50.64 mg/L to 3.6 mg/L in the groundwater. The results presented here demonstrated the surface water and groundwater interaction using the proxies of major and minor ions.

Keywords: major cations, anions, trace metals, and physical parameters

1. Introduction

Cauvery river delta is one of the major areas to carry out the hydrogeochemical studies to understand the surface water quality as well as the groundwater quality because the older stage of the river has to be deposit their entire suspended particles which may affect the water quality of the river Cauvery and the surrounding aquifer. The poor quality of river water also affects the groundwater quality in adjoining areas. Human health effects due to the utilization of poor quality water have been reported by several researchers (Mohsin *et al.* 2013; Dahunsi *et al.* 2014; Afroz *et al.* 2016; Rasool *et al.* 2017)^[8, 5, 1, 14]. Shrinking of river water quality is more prime in developing countries, especially in India where about 100 million people live on the river banks with poor sewerage systems (Shio *et al.* 2015, R. Ramyapriya and L. Elango (2018)^[16, 13], reported that higher values of Residual Sodium Carbonate were found in groundwater near industrial locations and coastal regions. Interactions between groundwater and surface water proceed in two ways groundwater flows through the streambed into the stream (gaining stream), and stream water infiltrates through the sediments into the groundwater (losing stream) Often, a stream is gaining in some reaches and losing in other reaches. The direction of the exchange flow depends on the hydraulic head. In gaining reaches, the elevation of the groundwater table is higher than the elevation of the stream stage. Conversely, in losing reaches the elevation of the groundwater table is lower than the elevation of the stream stage. A special case of losing streams is the disconnected stream, where the groundwater table is below the streambed and the stream is disconnected from the groundwater system by an unsaturated zone (Peterson and Wilson 1988)^[9]. Seasonal variations in precipitation patterns, as well as single precipitation events, can alter groundwater tables and stream stages and thereby cause changes in the direction of exchange flows. On a smaller scale, water flows into and out of the streambed may be induced by pressure variations on the streambed caused by geomorphological features such as pool-riffle sequences, discontinuities in slope, or obstacles on the streambed (Thibodeaux and Boyle, 1987; Savant *et al.*, 1987; Hutchinson and Webster, 1998)^[20, 15, 6]. Surface water and groundwater play a major role in groundwater quality of an area because of the inorganic minerals like sodium,

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potassium, calcium, magnesium and heavy metals like iron, manganese, lead, mercury, chromium, cadmium, nickel, cobalt, beryllium copper, etc., when it exceeds the permissible limit are harmful to all the living beings, Cauvery is major water resource in the southeastern India which is considered as a Dakshina Ganga originated from the Coorg district Karnataka (Talakaveri) and flow from Tamil Nadu, Pondicherry, Kerala and finally empties into the Bay of Bengal, across the Cauvery river 101 dams are constructed among that Lower Bhavani Dam is the largest dam in lengthwise 8797m length and 62 m height from the foundation and the height wise Pillure Dam is 88m height and 357m length from the foundation across the Bhavani river for hydroelectric and irrigation. (Water Resource Information System of India 2015).

2. Study area

The Cauvery river is one of the major peninsular rivers of

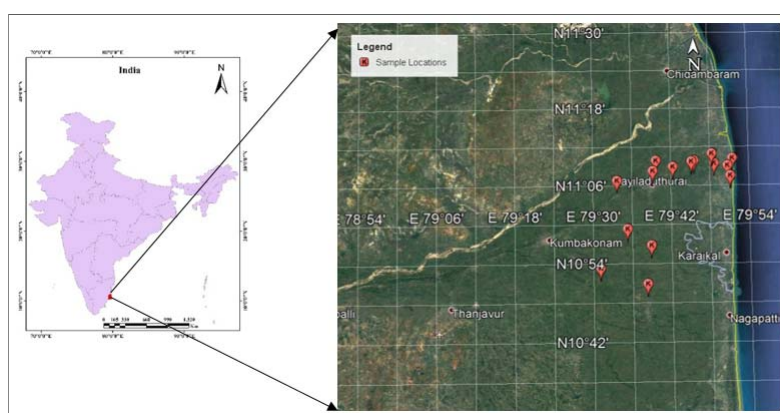


Fig 1: Location map of the study area

2.1 Geology and Hydrogeology

Geologically, the Cauvery basin consists of peninsular gneiss, laterite, closepet granite, charnockite, alluvium, and sandstone. The dharwar group consists of garnet, slates, phyllites, biotite, schists with chlorite, and hornblende which is predominantly present in the basin (Pichamuthu 1978) [10]. Closepet granite bounteously exists in the upper part of the watershed as a plagioclase, quartz, perthite, microcline, apatite, biotite, zircon, rutile, and irregular fluorite (Radhakrishna 1956; Jayananda *et al.* 2000) [11]. The middle part of the basin consists of pyroxene, granulite, charnockite, granitoid gneiss, fissile hornblende biotite gneiss. The peninsular gneisses and granites are composed of adamellite, hornblende granitic gneiss, granodiorite, biotite granitic gneiss, pegmatite, and diorite (Pichamuthu 1978; John *et al.* 2005) [10]. The lower part of the basin is abounding with cretaceous sediments of coralline limestone, conglomeratic sandstone, and shale (Sundaram and Rao 1981; Subramanian and Selvan 2001) [19, 18]. The Cauvery basin consists of diverse aquifers which are namely Archean, Cretaceous and Eocene, Miocene, and Quaternary alluvial aquifers, according to the CGWB report (2002) [3]. The Miocene aquifers mostly comprise of sandstones & limestone. The depth of the Archean aquifer is about 10 to 12 m and the cretaceous sandstone aquifer has a maximum depth of 50 m and the width of the Eocene sandstone aquifer is about 80 m. The lower Miocene is the Orthanadu deep aquifer and the upper one is an artesian aquifer. The thickness of Orthanadu aquifer is about 30 to 70m and the depth of 150m (CGWB 2002,

India which is covering an area of 81,155 km². The river originated from Talakaveri, in the southwest corner of Karnataka, is originated high up in the green Brahmagiri mountain at an elevation of 1340 m above msl. The regional slope runs in the eastward direction. It flowing 800 km to reach the bay of Bengal (Fig. 1). The region enjoys a tropical monsoon climate, with a mean daily maximum temperature ranging from 19.5 to 33.7 °C, whereas the mean daily minimum varies from 9.1 to 25.2 °C. relative humidity from 60 to 70% and the river is non-perennial, generally flowing along the entire course from October to January.

The coastal region of the basin is very vulnerable to numerous disastrous cyclones and torrential rains due to the pressure variation generated in the Bay of Bengal. (Rajamanickam *et al.* 2006; Clare Arni *et al.* 2009; Sivakumar and Elango 2010) [12, 4, 17].

NWM National action plan for climate change 2008) [3].

3. Materials and method

3.1 Field procedures and sampling methods

The present study was carried out in the delta region of the Cauvery basin in January (2016). Surface water and the groundwater samples were collected from seven stations and its locations are given in Table 1. Water samples were collected using clean polyethylene bottles of 500 ml capacity. The samples are analysed for Electrical conductivity, pH, total dissolved solids, salinity, high dissolved oxygen, oxygen reduction potential using a multiparameter probe. The concentration of CO₃²⁻ and HCO₃⁻ were measured in the field using. Aquamerck (1.11, 9.00) alkalinity test kit.

3.2 Laboratory analysis

The detailed laboratory analysis was carried out to understand the major cations such as Calcium and magnesium were measured by the EDTA method. In the case of calcium, 1N sodium hydroxide was added to the sample and titrated against 0.01M EDTA using the murexide indicator. The total concentration of calcium and magnesium was measured using ammonia buffer and Eriochrome Black-T indicator by titrating against EDTA. The magnesium concentration was obtained by subtracting calcium concentration from the total concentration. Sodium and potassium content of water samples was determined by flame photometry. Standard solutions of different concentrations of Na⁺ and K⁺ were prepared using NaCl and KCl salts. A standard curve was

drawn from the values obtained using these solutions in the flame photometer. The water samples were then atomized in the flame photometer. The concentrations of sodium and potassium were obtained from the standard curve. Sulphate concentration was measured by the turbidimetric method (APHA, 1998) [2]. The method is based on the principle that SO_4^{2-} is precipitated in an acetic medium with barium chloride (BaCl_2), to form barium sulphate crystal of uniform size. 50 ml of standard (prepared from $\text{MnSO}_4 \cdot \text{H}_2\text{O}$) or samples were measured in a volumetric flask and 10 ml of buffer solution (prepared by dissolving 30 gm of $\text{MgCl}_2 \cdot 6 \text{H}_2\text{O}$, 5 gm of sodium acetate, 1 gm potassium nitrate and 0.111 gm of sodium sulphate and 20 ml of acetic acid in 500 ml of distilled water and then the total volume was made-up to 1000ml) was added and mixed with the help of magnetic stirrer. While stirring a spoonful of BaCl_2 crystal was added. This mixture was stirred for 60 seconds at a constant speed. After the stirring period, the solution was poured into absorbance cell of the photometer and absorbance reading was taken at 420 nm after 5 minutes. Sulphate concentration of the sample was determined by comparing the reading with the calibration curve.

3.2.1 Trace metal analysis

Voltammetric determination of Zn, Cd, Pb, and Cu were performed with Trace Metal Analyzer (797 VA Computrace, Metrohm AG Ltd, Switzerland) with three-electrode system consisting hanging mercury drop electrode (HMDE) as working electrode, platinum (Pt) as auxiliary electrode and $\text{Ag}/\text{AgCl}/\text{KCl}$ (3 molL^{-1}) as reference electrode. 10 mL^{-1} ultra-pure water and 1ml of acetate buffer (pH 4.6) were taken in a polarographic vessel and then the measurement was started under the given parameters after this voltammogram of the blank was recorded. 1 ml of water sample was added to the polarographic vessel and then the voltammogram of the sample solution was recorded under the same conditions. After the sample voltammogram was recorded, 0.1 ml of 1 mg L^{-1} mixed standard of (Zn, Cu, and Cd, Pb) was added twice and then the voltammogram of the standard was recorded. ASV is the two-step measurement. In the first step, metal ions like Zinc, Cadmium, Lead, Copper present in the test solution are get deposited on the mercury electrode surface (amalgamation) at deposition potential of -1150 mV. In the

second step, all the deposited ions are anodically stripped by scanning the potential range from -1150 to + 100mV. All the measurements are done by standard addition technique in which first the sample was taken into the polarographic vessel and the current was measured. After the addition of 100 μL of standard solution, the procedure was repeated three times and the current was measured. After all the measurement extrapolation curve was plotted between current and concentration. The extrapolation curve will show the concentration of metals present in the sample solution. All the analysis was done with an automatic blank subtraction feature of instrument.

4. Result and discussion

The physical parameters like pH, ORP, TDS, EC, and HDO of water samples show similar trends in the declination in surface water as well as groundwater. The pH value of the water sample is important because it gives quality based on carbon dioxide, carbonate, and bicarbonate concentration present in the water sample. The maximum pH value of surface water 8.52 was recorded in the place of Kuthalam station-G and the minimum pH 6.97 was recorded in Agraharam station-D, accordingly, the pH value of groundwater maximum of 7.96 was recorded in the Manjalaru and the minimum pH 6.88 was recorded in the Thirupampuram station-E. Some of the surface water results show faintly alkaline nature it might be due to the weathering of carbonate rocks or might be using faulty irrigation practice (salty irrigation water SAR, RSC). The electrical conductivity is the ability of ions to transmit electrical current to the aqueous solution it mainly depends upon the Total dissolved solids present in the water sample. The electrical conductivity of the Surface water sample maximum reported 15360 $\mu\text{S}/\text{cm}$ at Poombuhar station-A and the minimum is reported 546 $\mu\text{S}/\text{cm}$ at Kuthalam and the maximum electrical conductivity of the Groundwater sample was reported 1976 $\mu\text{S}/\text{cm}$ at Poombuhar Station-A and the minimum was 502 $\mu\text{S}/\text{cm}$ reported at Agraharam station-D and the maximum Electrical conductivity was shown in station-A both in the Surface water and the Groundwater because of the seawater influence to the groundwater system and which may influence to the abundance of ions in the groundwater.

Table 1: Physical characteristics of the surface water and the groundwater of the Cauvery river delta.

Stations	Sample ID	Locations	Latitude	longitude	Elevation in (M)	pH	EC	TDS	HDO	ORP	Salinity	HDO%
A	S-W	Poombuhar	11.136511	79.857094	0.5	7.9	15360	9830.4	6.12	161	31.35	95.4
	GW	Poombuhar	11.143773	79.85284	3	7.57	1976	1264.64	6.4	191	8.92	87
B	S-W	Manjalaru	11.092594	79.851148	1	7.79	11390	7289.6	6.98	139	6.46	96.1
	GW	Chinnangudi	11.094553	79.852353	2.5	7.96	1682	1076.48	3.99	94	0.84	51.4
C	S-W	Melaperumbalam	11.148353	79.804978	9	8.3	552	353.28	6.99	97	0.26	91.3
	GW	Melaperumbalam	11.148843	79.804688	8.6	7.43	535.7	342.848	5.86	-12	0.25	75.5
D	S-W	Ponsai	11.128533	79.752197	8	8.2	549.2	351.488	7.01	91	0.26	99
	GW	Agraharam	11.130863	79.75908	12	6.97	502.2	321.408	4.62	-45	0.24	60.7
E	S-W	Thirupampuram	10.956189	79.587019	15	7.78	556.9	356.416	5.99	86	0.26	77.1
	GW	Thirupampuram	10.95509	79.588385	17	6.88	1000	640	5.18	-11	0.48	69.6
F	S-W	Mayiladudhurai	11.111225	79.705008	16	8.21	549.6	351.744	6.47	74	0.26	86.1
	GW	Mayiladudhurai	11.115034	79.70452	17	7.52	538.3	344.512	4.9	-77	0.25	65.4
G	S-W	Kuttalam	11.080408	79.561111	20	8.52	546.2	349.568	7.14	58	0.26	94.1
	GW	Kuttalam	11.079441	79.561953	21	7.3	691.6	442.624	4.62	68	0.33	61.2

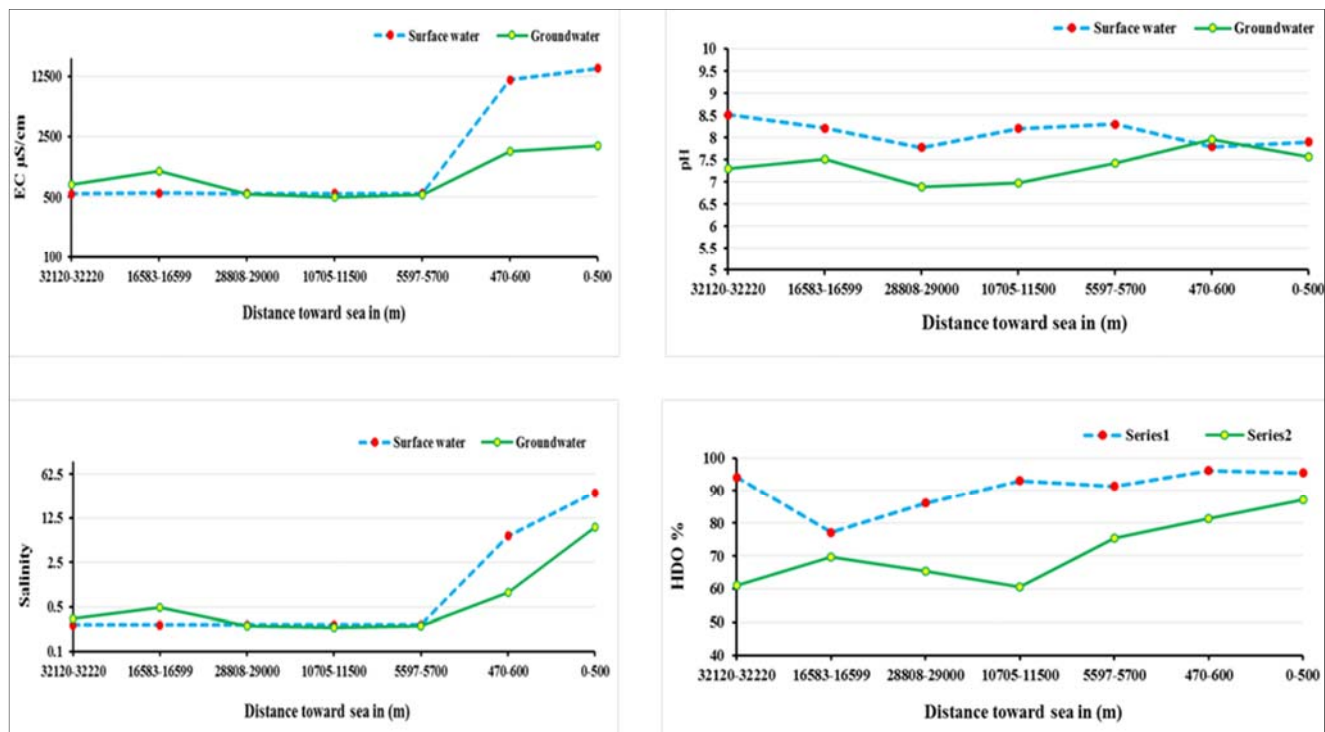


Fig 2: spatial variations of EC, pH, salinity, HDO% in surface water and groundwater sample.

The maximum concentration of the calcium present in the surface water sample was reported 550 mg/L at Poombuhar station-A the minimum was reported 31mg/L at Ponsai station-D and the maximum concentration of the calcium in the groundwater sample was reported 170mg/L at Poombuhar station-B and the minimum was reported 10mg/L at Agraharam station-D. The maximum concentration of the magnesium present in the surface water sample was reported 60 mg/L at Poombuhar station-A the minimum was reported 10.8mg/L at Meleperubalam station-C and the maximum concentration of the calcium in the groundwater sample was reported 62mg/L at Kuthalam station-G and the minimum was reported 4.8mg/L at Agraharam station-D. The sodium concentration is varies from each stations the concentration of sodium was maximum reported in the surface water 3710mg/L at the place of Poombuhar station-A and the minimum was reported 48.3 mg/L at the Mayiladuthurai station-F and the maximum concentration of the sodium present in the groundwater sample was reported 461.5 mg/L at Poombuhar region Station- A and the minimum was reported 44.5 mg/L Mayiladidhurai station- F. The concentration of chloride maximum was reported in the surface water samples 6045mg/L Poombuhar station-A and the minimum was reported 47.79mg/L in Kuthalam station-G and the groundwater sample concentration of chloride maximum was reported to 343.82mg/L. in poombuhar station-A and the minimum was reported 35.56mg/L in Agraharam station-D. The abundance of the chloride in both the surface and groundwater was reported in the station-A due to the presence of seawater interaction to the coastal aquifer. The concentration of the potassium in the surface water sample was maximum reported 200mg/L at Poombuhar station-A and the minimum was reported 5.3 mg/L at Thirupampuram station-E and the maximum concentration of potassium in the

groundwater sample was reported 50.64 mg/L at Kuttalam station-G and the minimum was reported 3.6 mg/L at Agrharam station-D. The alkalinity of the surface and the groundwater sample shows that the most of the surface water and the groundwater samples are fall in bicarbonate alkalinity. The maximum concentration of the carbonate present in the surface water sample was reported 33mg/L at Poombuhar Station-A and the minimum was reported 24mg/L at Kuttalam station-G and the concentration of the carbonate can't identify in any of the ground water sample. The maximum concentration of the bicarbonate present in the surface water sample was reported 472.55 mg/L at Poombuhar station-A and the minimum was reported 220.6 mg/L at Kuttalam station-G and the maximum concentration of the bicarbonate in the groundwater sample was reported 581.4 mg/L at Poombuhar station-A and the minimum was reported 195.23 at Agrharam station-D. The nitrate concentration of the surface water sample maximum was reported 47mg/L at Poombuhar station-A and the minimum was reported 16.8mg/L at Manjalaru station -B and the groundwater sample maximum nitrate was reported 46.2mg/L at Thirupampuram station-E and the minimum was reported 11.6 mg/L at Poombuhar station-A. The concentration of the nitrate in the groundwater sample has higher in the Thirupampuram may be due to the presents excess usage of nitrate fertilizers in the soil which may causes the gradual increase of nitrate in the groundwater system. The maximum concentration of the sulphate in the surface water sample was reported 699.4mg/L at Poombuhar station- A and the minimum was reported 4.44mg/L at Thirupampuram station -E and the groundwater shows the maximum concentration of the sulphate reported 134.7mg/L at the Manjalaru station-B and the minimum was reported 2.16mg/L at Thirupampuram station-E.

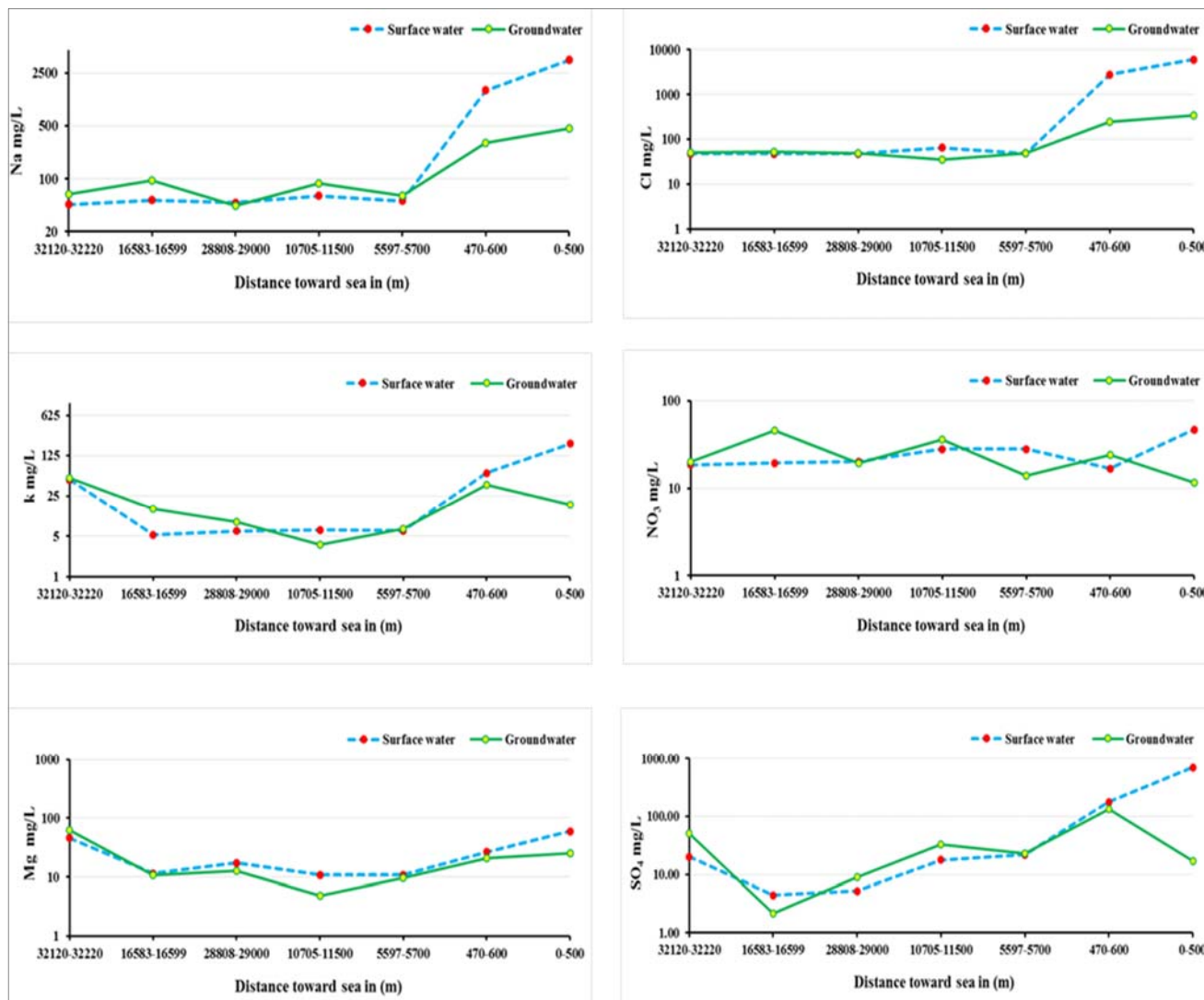


Fig 3: Spatial variations of Na⁺, K⁺, Mg²⁺, Cl⁻, NO₃⁻, SO₄ in surface water, and the groundwater.

4.1 Trace elements in groundwater and surface water

The trace metal like (Zn, Pb, Cu) concentration in the surface water and the groundwater where measured. The maximum concentration of the Zn was reported 17.1 µg/L at poombuhar region station-A and the minimum was below the detection limit (BDL) and the groundwater the maximum concentration reported 46.16 µg/L at Manjalaru station-B and the minimum was reported 16.072 µg/L at Agraharam station-D. The maximum concentration of the Pb in the surface water was reported 2.73 µg/L in the Kuthalam region station-G and the minimum was reported 1.34 µg/L in poombuhar region. The concentration of Pb in the groundwater sample was maximum reported 3.713 µg/L in Kuthalam station-G and the minimum was reported 1.83 µg/L in Mayiladudhurai station-E. The maximum concentration of the Cu was reported 1.924 µg/L at Ponsai region station-D and the minimum was reported 0.77 µg/L Poombuhar station-A and the groundwater the maximum concentration reported 4.82 µg/L in Agraharam station-D and the minimum was reported at Kuthalam 1.49 µg/L station-G.

5. Conclusions

The present study was carried out to understand the surface water and groundwater interaction in the Cauvery basin, especially the southeastern part of the Tamil Nadu region.

Most of the region surface water and groundwater were of good quality but towards the seaward side around 1 to 2 km away from the seashore the quality of both the surface water and the groundwater gets depleted due to the saline water interaction to the groundwater, the salt flats in the Chinnangudi region discarding huge amount of sodium wastage into the manjalaru river get affected up to 0.5 km, the groundwater chemistry of this region is comparatively higher than the other stations this may due to the interaction of the manjalaru river to the surrounding aquifer. The general order of dominance of cations in the surface water and groundwater of the study area is Na²⁺>Ca²⁺> K⁺ >Mg²⁺ and that in anions is Cl⁻> HCO₃⁻>SO₄²⁻. Thus, Na⁺, Ca²⁺, Cl⁻ and HCO₃⁻ are the dominant ions present in surface water and groundwater. Based on this study there will be a proper management is required on the coastal aquifers of the cauvery delta region.

6. Acknowledgements

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7. References

1. Afroz R, Banna H, Masud MM, Akhtar R, Yahaya SR. Household's perception of water pollution and its economic impact on human health in Malaysia. *Desalination and Water Treatment*. 2016; 57(1):115-123.
2. APHA, AWWA & WEF. Standard methods for the estimation of water and waste water. American Public Health Association, Washington, 1998.
3. CGWB. Report on Status of Ground Water Quality in Coastal Aquifers of India, 2002. <http://cgwb.gov.in/WQ/Costal%20Report.pdf>.
4. Clare Arni. Cauvery Basin: Its Culture, Places of Historical Significance, Birth Place, Climate, Precipitation, Catchment, Tributaries, State-Wise Spread, Landuse, 2009. <https://www.indiawaterportal.org/articles/cauvery-basin-its-culture-places-historical-significance-birth-place-climate-precipitation>.
5. Dahunsi SO, Owamah HI, Ayandiran TA, Oranusi SU. Drinking water quality and public health of selected towns in South Western Nigeria. *Water Qual Expo Health*. 2014; 6(3):143-153.
6. Hutchinson PA, Webster IT. Solute Uptake in Aquatic Sediments due to Current-Obstacle Interactions, *J Environ. Eng.* 1998; 124(5):419-426.
7. India Wris Wiki. Cauvery. <http://www.india-wris.nrsc.gov.in/wrpinfo/index.php?title=Cauvery>. Accessed on 21 Sept, 2015.
8. Mohsin M, Safdar S, Asghar F, Jamal F. Assessment of drinking water quality and its impact on residents health in Bahawalpur city. *Int J Humanit Soc Sci*. 2013; 3(15):114-128.
9. Peterson DM, Wilson JL. Variably saturated flow between streams and aquifers. Tech Completion Rep 233. Socorro: New Mexico Water Resources Research Institute, 1988.
10. Pichamuthu CS. Archaean geology investigations in southern India. *Geol Soc India*. 1978; 19(10):431-439.
11. Radhakrishna BP. The closepet granite of Mysore State, India. Mysore Geologists' Association Special Publication, Bangalore, 1956, 1-110.
12. Rajamanickam GV, Subramaniyan BR, Baba M, Ramesh R, ElangoL, Prithviraj M. 26th December 2004 tsunami: causes, effects, remedial measures pre and post tsunami disaster management: a geoscientific perspective. New Academic Publishers, New Delhi, 2006.
13. RamyaPriya R, Elango L. Evaluation of Geogenic and Anthropogenic Impacts on Spatio-Temporal Variation in Quality of Surface Water and Groundwater along Cauvery River, India. *Environmental Earth Sciences*. 2018; 77(1):2.
14. Rasool A, Xiao T, Farooqi A, Shafeeqe M, Liu Y, Kamran MA *et al*. Quality of tube well water intended for irrigation and human consumption with special emphasis on arsenic contamination in the area of Punjab, Pakistan. *Environ Geochem Health*. 2017; 39(4):847-863.
15. Savant SA, Reible DD, Thibodeaux LJ. Convective Transport within stable river sediments, *Water Resour. Res.* 1987; 23(9):1763-1768.
16. Shio T, Maddocks A, Carson C, Loizeaux E. 3 Maps explain India's growing water risks, 2015. <http://www.wri.org/blog/2015/02/3-maps-explain-india%E2%80%99s-growing-water-risks>. Accessed on 5 Oct.
17. Sivakumar C, Elango L. Application of solute transport modeling to study tsunami induced aquifer salinity in India. *J Environ Inform*. 2010; 15(1):33-41.
18. Subramanian KS, Selvan TA. Geology of Tamil Nadu and Pondicherry, 1st edn. Geological Society of India, Bangalore, 2001, 192.
19. Sundaram R, Rao PS. Lithostratigraphy of Cretaceous and Palaeocene rocks of Tiruchirapalli District, Tamil Nadu, South India. *GSI Rec.* 1981; 115(5):9-23.
20. Thibodeaux LJ, Boyle JD. Bedform-generated convective transport in bottom sediments, *Nature*. 1987; 325:341-343. Todd DK, Mays LW. *Groundwater Hydrology*, Wiley, Hoboken, 2005.
21. US. Environmental Protection Agency (USEPA). Volunteer Stream Monitoring: A Methods Manual. EPA 841-B-97-003. November. Office of Water, Washington, DC., 1997, 211.