Surface and subsurface water quality interactions in Cauvery River Basin, India

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Abstract
A combination of statistical and hydro-geological tools was applied to identify the interactions between subsurface and surface waters of the Cauvery River basin. In this research, water quality sampling from both the river as well as ground water is undertaken at recognised periods with an aim of arriving at the river-aquifer relationships. Mapping of surface water and groundwater quality parameters using GIS indicate that groundwater in the study area is potable except for a small area of 314 km^2.

Multivariate analysis of river water quality with groundwater quality implies that rock-water interface is the predominant subsurface hydro-geochemical phenomena which decide the chemical constituents present in water. However, the GIS output, integrating surface and groundwater quality parameters show that groundwater quality is interconnected with the river water quality.

Keywords: Surface and subsurface interactions, water quality isopleth, ground water interaction, Cauvery river, water quality mapping.

Introduction
The pressing demand for water and the current need for policy changes in water management has led to the detailed examination of the interaction between ground water (GW) and surface water (SW) to formulate principles and safeguard the environment. Surface water and groundwater systems are mostly connected in many ways. Their interaction and connectivity are possible in any of the three ways, either through the inflow of groundwater into the streams; outflow of water from the streams to groundwater through the streambed or a combination of both. Sometimes, the streams are kept flowing by the subsurface contributions even after monsoon. A watercourse may have water inputs and outputs based on the ground water table nearby. Thus, the variations in the water table influence the stream flow throughout the year.

Generally, rivers, lakes and wetlands not only receive inflow from the subsurface water, but also help to recharge underground water. This inter-change between the two systems is responsible for the differences in water characteristics of a particular environment. There is a possible exchange of nutrients or other dissolved solids between surface and the groundwater system. Ground-water chemistry and surface-water chemistry are more pronounced where surface and subsurface flows interact. Thus, biogeochemical processes are highly active on both sides of the interface which ultimately affects the supply of minerals, dissolved gases and other chemical constituents[14].

In India, many surface water bodies like rivers and streams are polluted and hence knowledge of the chemical exchanges in the hyporheic zone will be helpful to prevent the contamination of shallow ground water by the contaminated stream water during low flow. Movement of flow to the groundwater through the stream is pronounced more in streams with rough channel bottoms compared to smooth beds in the hyporheic zone where huge variations in the chemical characteristics are especially noted. The interaction of ground water and surface water is a combination of physical, chemical and biological processes that take place in mixed environments.

Such studies were more prevalent only for large streams and aquifer systems in the past. Issues related to water supply, pollution of surface water bodies, contamination of ground water etc. have now led to the research on ground water and surface water interface studies in every basin[20]. Water researchers and policy makers should investigate the effects of biogeochemical processes on water quality at the interface. There is a growing emphasis towards the studies on interface between GW and SW, but very limited watercourses were studied and the available findings are minimal and inadequate.

The ever-increasing water demands associated with unpredictable availability of water owing to climate change have facilitated to consider GW and SW as a single entity for developmental studies[5,29]. Similar studies were also encouraged in order to frame guidelines and directions for the sustainable management of water resources in the world[38]. The importance of GW–SW interactions and their phenomena address not only to safeguard the aquatic resources, but also to sustain the ecosystem cycle that works in symbiosis with ground water.

Notably, a number of works done earlier focussed on assessing GW–SW interactions with the help of natural tracers [8,19,25,34-37], geophysical and dynamic studies with the applications of statistical techniques[8] or improved transient storage models[24]. Research related to the dynamic processes (hydrologic /geochemical processes) at the GW–SW interface is very limited. Hence, identifying key parameters and thorough understanding of the underlying phenomena through applications of spatial and temporal data become necessary[6,9,37].

Groundwater quality studies were aimed at investigating its contribution to the temporal variation of surface waters as well as to examine their interactions. Determining the interactions between groundwater and surface water is a crucial factor for integrated watershed management. A number of techniques are available for these studies, though due to the limitations and hypothesis associated with those methods, a combined approach involving multiple techniques is necessary to derive the exact phenomena[39].

This study was performed to identify the existence of any interaction between surface and groundwater waters in a part of Cauvery river basin using GIS. Our objective is to explore the qualitative contributions of surface, ground and waste water flows using multivariate analysis of hydro-chemical data and GIS techniques. Specific hydrological pattern can be associated with respective water quality parameters of each sampling station and their correlation can be attributed to the anthropogenic impacts.

Material and Methods

A total of 35 monitoring sites were chosen in the Cauvery River between the latitudes 10^0 57' 24" N & 11^0 29' 35.1" N and the longitudes 77^0 42' 40.7" E and 78^0 14' 17.9" E (Fig.1) measuring the water quality parameters on a monthly basis from February 2018 till December 2018. Subsurface sampling strategy was performed on a monthly basis covering pre-monsoon (March 2018) and post monsoon (October 2018) period in 100 locations which are distributed radially along the river banks of Cauvery and its tributaries (Fig.2).

The entire sampling and analysis programme were carried out according to the standard methods for the examination of water and wastewater[2]. Multivariate analysis and GIS were then used to explore the existence of contributions between surface water and groundwater, thereby to address the impacts of anthropogenic discharge into streams. The study of groundwater and surface water interaction in the Cauvery basin is interpreted by developing a water quality isopleth map.

A water quality isopleth is an integrated mapping of water quality data with the various geological features of the terrain using GIS. Landsat TM satellite data was used and the digital data obtained from the online sources (Global Land Cover Facility) was enhanced and necessary corrections were made[11]. The Geological Survey India (GSI) maps of scale 1:50,000 were geo-referenced and were used for further interpretation.

Results

The water quality data obtained from the samples taken from the selected stations of Cauvery river is tabulated (Table 1). Similarly, the chemical nature of ground water samples obtained from the laboratory analysis is available in table 2. On the whole, the water samples from the river suited the limits for drinking according to WHO, though the dissolved solids and ionic concentrations gradually increased along the direction of flow. This increase was observed to be derived from a cluster of textile and tannery units located in the downstream banks of the river stretch.

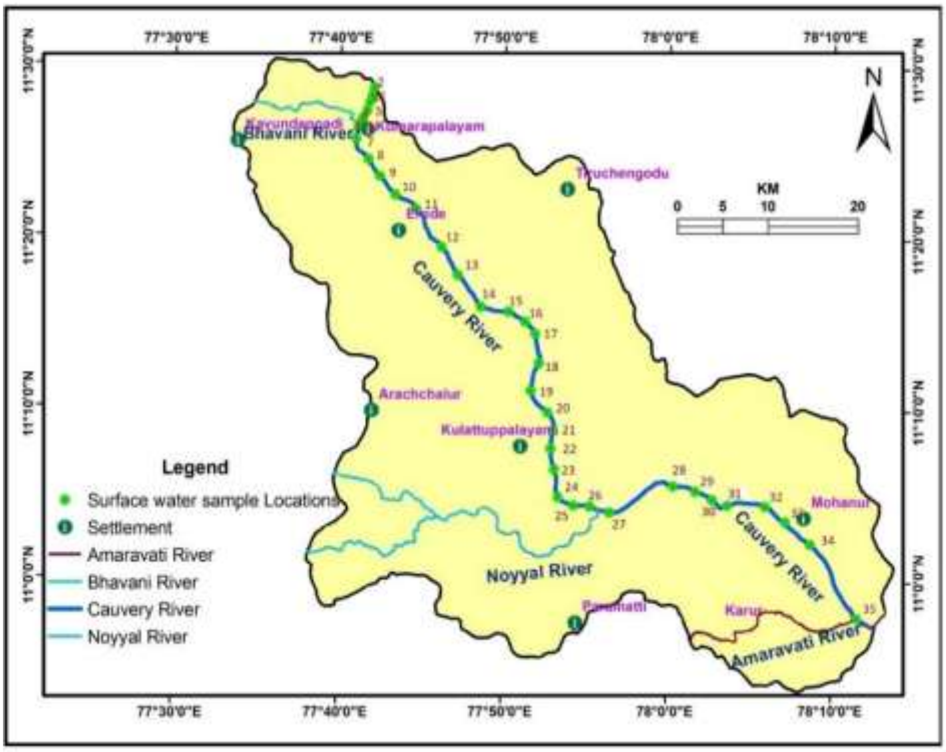

Figure 1: Surface water sampling sites in Cauvery river basin

Most importantly, huge variations in water quality are noted near the confluence point of its tributaries with the main river, thus indicating the contribution by its receiving waters. Similarly, the groundwater samples were found to be saline in nature with the pH ranging from 6.8 to 8.7. Ground water showed high electrical conductivity and a prominence of sodium and chloride levels near the Noyyal river and the confluence of Amaravathi river with Cauvery river. Generally, the ground water was observed to have high levels of calcium, magnesium and bicarbonate ions and comparatively lower values for potassium and carbonate ions.

Multivariate Analysis: Multivariate analysis is a widely preferred tool for data analysis of surface waters[14,18,31] which have helped in the interpretation of complex data matrices to understand the quality and ecological status of the river systems. The water-quality parameters were analysed statistically using SPSS-18 software to assess the variation within the sampling sites and water data[15].

Table 1
Surface water quality parameters in Cauvery river.

Parameters (mg/L)	Maximum	Minimum	Mean	Median	Standard Deviation
pH*	8.5	6.3	7.5	7.4	0.3
EC**	1830.0	260.0	418.6	510.0	111.7
TDS	1230.0	161.0	288.0	338.0	99.1
Phenolic Alkalinity	12.0	0.0	0.4	0.0	2.3
Total Alkalinity	315.0	100.0	167.5	185.0	35.6
Total Hardness	430.0	101.0	170.6	170.0	37.1
Na+	350.0	6.0	56.9	59.0	59.2
K+	21.0	0.0	3.4	5.0	3.4
Ca2+	62.0	23.0	30.6	28.0	7.4
Mg2+	31.0	2.0	18.3	24.0	5.3
Cl-	407.0	22.0	65.4	51.5	77.3
HCO^{3}-	524.0	121.0	180.0	226.0	55.6
CO_3^{2-}	54.0	0.0	40.0	51.0	8.5
NO3-	12.0	13.0	13.0	10.0	1.6
$SO_4$2-	389.0	62.0	280.0	355.0	19.6
F-	1.3	0.1	0.5	0.4	0.2

**no unit*
***(µmho/cm)*

Table 2
Characteristics of the groundwater samples.

Parameters (mg/L)	Pre-monsoon (March 2018)		Post-monsoon (October 2018)	
	Average Values	Range	Average Values	Range
pH*	7.42 ± 0.3	6.8 - 8.8	7.3 ± 0.25	6.8 - 8.6
EC**	1260 ± 1070.6	260 - 5060	1020.4 ± 370.3	160 - 4020
TDS	1020 ± 760	180 - 3600	890 ± 360	180 - 4600
Total Alkalinity	312 ± 112	150 - 600	112 ± 50	140 - 490
Total Hardness	381.5 ± 225	169 - 1090	242.5 ± 23	145 - 1190
Na+	140.5 ± 173	10 - 1040.0	40.5 ± 66	10 - 860.0
K+	24.21 ± 22.71	4.6 – 360.5	20.3 ± 22.6	4.01 – 276.4
Ca2+	77.86 ± 63.66	2.0 – 355.56	45.25 ± 43.5	10.2 - 330.0
Mg2+	79.45 ± 40.23	4.5 – 222.32	30.72 ± 24.84	8.5 - 221
Cl-	201 ± 302	20.3 - 1435	254.78 ± 283.4	29.3 - 1590
HCO3-	440± 256.31	36.84- 1720	335.51 ± 250.6	25.8 - 1400
CO32-	0	0	0	0
NO3-	39.1 ± 36.4	1.0 – 183.05	38.02 ± 35.8	3.0 – 130.08
SO42-	74.19 ± 65.2	2.4 – 436.8	67.19 ± 55.2	14 – 334.8
F-	0.6 ± 0.4	0.1 – 2.0	0.5 ± 0.4	0.1 – 2.0

**no unit*
***(µmho/cm)*

The parameters determined in the water quality analysis were evaluated by choosing 'Concentration' and 'Water quality parameters' as the determining criteria which depicted the sequence Mg<Ca< SO_4<HCO_3<Cl<Na. Hence, minerals like Mg, Ca and SO_4 were noted as predominant factors whereas Na and Cl were least significant. The presence of calcium and magnesium may be attributed due to the weathering of rocks and SO_4 might be sourced either from leaching of rocks or may be from precipitation. Therefore, mineral water interactions prevail in the basin which is also depicted by the water quality variations in each site, especially near the contaminant zones in Cauvery.

Factor Analysis: Factor analysis is another promising technique, that enables identification of elements based upon their strong association or correlation. In this technique, elements are grouped into factors possessing strong correlations and these factors were defined by factor matrix after varimax rotation[1,7]. By determining the spatial distribution and the existence of exchanges between surface and groundwater[3,27], two possible groups were identified, the total variance arrived was about 76.86% for the Cauvery river with two factors explaining most of the variability (Table 3).

Factor 1, termed chemical factor, exhibits 53.16% of share, which is highly contributed by dissolved solids calcium, magnesium, sodium, chlorides and bicarbonates with a moderate influence from nitrates and potassium. This factor seemed to predict the inorganic and mineral constituents of water quality. Such chemical pollutions were from all kinds of discharges (domestics, industries, farming), while the solutes were due to leaching, subsurface flows, rock-dissolution and surface erosions. Also, the nitrate pollution was high during and after monsoon, which indicated the extended agricultural activities[17]. A significant contribution of nitrates was also made by the ground water flow into the basin.

The second factor comprises 15.51 % contribution depicting dominancy for sulphates and F^-. Sulphates could have occurred naturally or as a result of domestic or trade discharges. The natural occurrence may be sourced either from rock dissolution or soil containing gypsum and other minerals. Studies report that the interaction of water with fluoride containing rocks is a major factor for the presence of this pollutant in water whose availability is favoured by alkaline environments. Remaining 8.18% of variance is contributed by factor 3 with pH as the influential factor. The instabilities in acidity and alkaline nature are due to the receiving waters and also due to the geological characteristics of basin. Thus, CA and factor analysis techniques were suitable to identify and quantify the source contributions with limited information about the data of indirect impacts to the river.

Water quality Isopleth mapping using GIS: Lineaments are linear geographical features available on the rock units or crystalline rocks. Their presence and their interconnections offer a significant potential for the occurrence and distribution of groundwater when sensed through remote sensing data[22]. The very existence of lineaments implies the flow of groundwater movement which may also result in additional porosity[21]. The lineaments observed in the basin depicted its trend from NNE-SSW to ENE–WSW with medium to steep reversal of dips (SW to NE) indicating a closed series of antiform and synforms. This was proved during the field tests which indicated low water level fluctuations in high dense regions and vice versa.

Also, the nature of soil and its infiltrating characteristics determine the ability of ground water recharge and its related phenomenon. Hydraulic characteristics of the soil and its grain size distribution are the major factors affecting the rate of percolation.

Table 3
Principal factors of the variables

Parameters (mg/L)	Component		
	PC1	PC2	PC3
pH	.089	.353	.853
EC	.962	-.009	.020
TDS	.949	-.083	.061
NO3-, as N	.730	-.552	.120
Total alkalinity	.864	-.014	-.062
Total Hardness	.848	.105	-.104
Ca++	.602	-.178	-.322
Mg++	.703	.294	.047
Na+	.928	-.086	.116
K+	.843	-.163	.104
Cl-	.901	-.041	.090
$SO_4$2-	.490	.783	-.042
HCO3-	.860	-.036	-.051
F-	.348	.533	-.429

**no unit*
***(µmho/cm)*

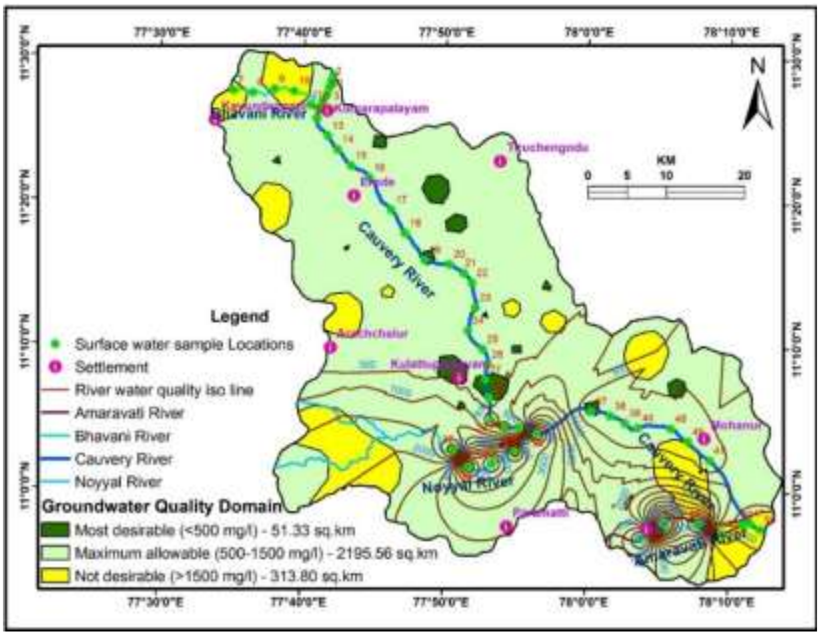

Figure 3: Water quality isopleth map of Cauvery river basin

Soil map of the study area was sourced from Soil Survey of India district maps of Tamil Nadu. It was found that red calcareous soil is predominant in the study area followed by red non-calcareous soil and alluvium.

Geomorphology is another important attribute that determines the hydraulic characteristics in any region. Hydro-geomorphological studies are highly important in the planning and implementation of water projects and surface water is one of the main geomorphological elements responsible for landscape terrain and topography. Another crucial geological feature to be considered in such studies is ‘Slope’, which can simulate the infiltration and recharge of GW system. On the whole, the groundwater prospects of an area can be estimated by knowing the nature of slope in combination with other features in the region.

The river basin in the study area comprises of ‘very steep’ slope (> 30°) and ‘steep’ slope (15° to 30°) morphology. In this basin, around 11 major geomorphological units were detected and delineated from the satellite data. The data of water quality parameters from the surface water as well as ground water samples were given as inputs and then mapped with geo-features for further analysis using ArcGIS software. The interpolation map was generated using inverse distance method with the help of spatial analysis tools and a water quality isopleth map was obtained after analysis.

The outcome reveals the combined synergy of groundwater spatial variation and surface water quality variation (Fig. 3). The investigation proves that hydro-geochemical (rock-water interaction) process is the main reason for the variations in GW chemistry and quality. Nevertheless, the southern parts of the basin seemed to be influenced by the impacts of river water over the subsurface water. Thus, the Cauvery River is highly degraded by the receiving waters from its tributaries, mainly, Noyyal and Amaravathi with additional impacts from sewage and waste disposal from the river banks. Also, the isopleth map depicts that the groundwater quality is found to have a close association with the confluencing rivers which can be seen in the lower parts of the study area.

Conclusion

The nature of chemical or mineral transformation between surface and ground water is a determining factor in water resources management. For an effective river basin management, ground water protection is also crucial to conserve drinking water. In addition to this, SW-GW interactions are the major factors contributing bio-chemical changes in the major water systems of earth as a part of the hydrologic cycle. Knowledge of such inter-relations is essential not only to manage water resources, but also to remediate polluted sites, to make policy changes in effluent discharges and to restore natural resources and environment.

Multivariate statistical study of river water quality with groundwater quality indicates that rock-water interaction is the predominant subsurface hydro-geochemical process that governs the nature of chemical constituents present in groundwater. However, the GIS output integrating surface and groundwater quality parameters indicate that in the lower parts of the study area, ground water seems to have a good correlation with the river water quality. Also, these findings illustrate the need for pollution prevention in water sources or catchment areas which can also reduce the rates of several chemical reactions that may increase the rate of contamination.

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