Chapter 9
Geogenic and Anthropogenic Impacts on the Water Quality of Cauvery River

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INTRODUCTION

Human civilisation has evolved generally along the banks of rivers in most of the regions around the world. Over the years, the population living along the rives have grown rapidly and several such regions have been highly urbanised. Further, several industries requiring a large amount of water are also located along the rivers. These activities along the rivers have led to the deterioration of their water quality. The groundwater in the nearby regions has also been severely affected due to the poor quality of river water. The consumption of poor-quality water has affected more than one-third of the world's population. Water quality issues have been regarded as the major environmental issue globally and are caused due to variety of natural and human influences. Natural factors include geological, topographical, meteorological, hydrological and biological characteristics of the drainage basin (Bartram and Ballance, 1996). The effect of natural factors in influencing the water quality largely depends on the seasonal variation of runoff volumes, climatic conditions and water levels.

Though rivers are not much affected by geogenic sources, the groundwater is prone to severe contamination by geogenic sources. The human activities impact significant effects on water quality and these effects are much pronounced due to the changes in hydrological conditions of the rivers, such as the construction of dams, changes in riverine and wetlands ecosystem and flow diversion. The discharge of domestic, industrial, urban waste waters into the rivers along with the runoff from agricultural land into the drainage basin are important human influences that pollutes the river basin. In addition to this, climate change also contributes indirectly to water pollution in both rivers and groundwater such as sea-level rise in coastal environments inducing seawater intrusion in coastal aquifers and changes in flow patterns in

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rivers. To understand the nature of contamination of the freshwater system, it is essential to study the sources and types of pollutants and the factors controlling the contamination in rivers. Regional basin studies are thus necessary for a better elucidation and this chapter describes the factors, sources, causes of contamination in rivers and its surrounding environments. A study carried out on these aspects on Cauvery river flowing in southern peninsular India is also presented.

FACTORS CONTROLLING CONTAMINATION OF RIVER WATER

Contamination of the river water is controlled by several factors such as meteorological, geographical, geological, hydrological, landuse/land cover conditions of the basin etc. The major environmental factors are discussed below.

Meteorological and Geographical Factors

The geographical and meteorological factors of the basin area of rivers dominate the flow in the river which in turn influences the quality of water. In temperate zones, the rainfall received is usually stored in the form of ice or snow during winter and the water infiltrates into the subsurface through recharge which then flows into rivers during summer. Tropical rivers are defined by distinct annual flow cycles with contrasting dry and wet seasons. The tropical rivers are mostly dry during summer or dry season and receive abundant rainfall in the wet season (Bartram and Ballance, 1996). The seasonal effects due to changes in wet and dry cycle are more pronounced in tropical rivers. Time period of the dry season also affects the nature of tropical river. In such arid regions, evaporation also plays a major role in controlling the riverine chemistry. Hence, this indicates that the local conditions and position of rivers within the catchment determines the flow in the river, which is a representation of a mixture of hydrological regimes.

Hydrological Factors

To interpret the water quality of rivers, it is essential to understand the discharge regime of the river. Discharge of a river reflects the environment of its catchments. The physical, chemical and biological characteristics of rivers are chiefly affected by flow variation in rivers (Zeiringer et al., 2018). Changes in discharge also influences the habitat changes in the river, since thriving of aquatic species in rivers depends on the seasonal changes in river flows (Poff et al., 1997). The residence time of the water bodies is an important concept in water contaminant studies since it is related with the time taken for recovery of an aquatic body from contamination. Rivers have a short residence time, due to rapid flow which aids in faster recovery of the aquatic system. The unidirectional flow in the river with good lateral and vertical mixing attributes to the river's self-cleansing mechanism due to rapid dispersion and transport. However, deep lakes and aquifers have long residence times that results in the slow recovery of the system from contamination, which generally ranges from years to decades.

Lithological Factors

The influence of lithology in determining the quality of river water is related to the mineralogy of the rocks, weathering of minerals and flow of river present in the basin (Haidvogl, 2018). Soil and rock leaching are also responsible for the solubilization of some elements such as cations, aluminium and iron. The erosion process in the river is responsible for sediment transported to the sea. The process of erosion varies depending on various conditions such as amount and pattern of rainfall, changes in river flow, slope, lithology, vegetation, soil type and temperature. The rates of erosion are extremely variable, where highest erosion rates occur usually in mountain streams. This is due to the fact that human intervention in such pristine locations has resulted in immense damage to vegetation, thus speeding up the erosion process. The erosion also highly depends on the lithology of basin where the susceptibility of rocks to weathering is lower for hard rocks such as granite and higher for sedimentary rocks like limestone. In smaller watersheds, the local geological conditions highly influence the variations in concentration of ions in dissolved and particulate form.

Landuse/Land Cover

The spatial variation in water quality has been highly influenced by changes in landuse/land cover pattern where the urban and agricultural areas are hotspots of anthropogenic contamination. Although the landuse change was indirect, it is one of the most severe human impact on the rivers. The large-scale shifts of land use from forests to cultivable land or urbanised land have triggered rapid surface runoff resulting in erosion, reduced the evapotranspiration, and have also increased the flow in rivers (Haidvogl, 2018). Terrestrial vegetation has also contributed for pollutant load where the production of terrestrial plants and its decomposition in the soil increases the organic carbon and nitrogen in water. In addition, growth and decomposition of aquatic vegetation and planktons will also impact the pH, dissolved oxygen, nutrients and other chemicals in water that are sensitive to oxidation/reduction conditions.

The landuse changes occurring during the urbanisation, industrialisation and agricultural activities have changed the surface and subsurface characteristics of watersheds which thereby affect the quality and quantity of water. In general, areas subjected to high land use changes that are associated with human are often found to have high concentration of water pollutants, whereas the pristine areas such as forest have good water quality (Camara et al., 2019). However, understanding of such relationships on a catchment scale during various seasons is not yet carried out due to difficulties in monitoring over large areal extent (Rodrigues et al., 2018).

TEMPORAL VARIATION IN WATER QUALITY

The variability in flow cycles is a fundamental characteristic of rivers and is essential for proper functioning of their ecosystems (Poff et al., 1997). Flow variation of the river depends on time scales, from hours to days, seasons, years and for longer time scales. The water cycle and climatic conditions of each catchment acts as a boundary condition for the hydrological regimes. These in turn would define the distinct seasonal and daily flow patterns in rivers. Water quality differences in the rivers results due to internal or external processes in riverine system. The internal processes are cyclic and for a shorter duration, which occurs either daily or seasonal whereas the external processes, for example, contamination of the riverine system, depends on the flow regimes and longer water residence times.

The quality of water in a system differs spatially as well as temporally. The influence of time period in water quality is categorised into five types (Bartram and Ballance, 1996):

- Variations in water quality during minute to minute time period occurs due to fluctuations in pollutant inputs which would result in irregular water mixing. These type of water quality variations are much more pronounced in smaller water bodies.
- Diurnal variations in water quality results due to biological cycles and day/night cycles of the water system. These diurnal patterns also arise due to the cyclic nature of discharge of sewage and effluents from domestic and industrial sources.
- Irregular variations in quality of water arises from the discharge of agricultural runoff which consists of fertilisers, pesticides and herbicides and food processing wastes. These types of variations in water quality are evident for a few days to months.
- Seasonal biological and hydrological cycles changes depend on the flow regime of the river and also on wet and dry conditions of water body. This effect is much significant in riverine systems.
- Year-to-year trends in water quality occur due to the increased anthropogenic activities in the watershed. Similarly, the differences in water quality at different times in a year would be much pronounced for a stream than for a large river.

The sampling frequency is much essential to interpret the water quality of the water. Sampling in adherence to sampling protocols would minimize the error and would produce accurate results. Hence, the sampling frequency follows the order: rivers > streams > lakes.

SOURCES AND TYPES OF CONTAMINATION

Natural Source

Geogenic contamination is more pronounced in groundwater rather than river water due to the increased period of rock water interaction. The river water carries the eroded weathered particles, which in turn also increases the dissolved concentration of river water. The increase of dissolved constituents depends on the type of weathered rocks. In groundwater, increased salinity could be due to leaching of ions from the host rock. Groundwater contamination due to fluoride, arsenic and uranium is well-known example of geogenic contamination. Other than these, the presence of microorganisms also affects the river water quality to a greater extent. Though the presence of pathological components such as cyanobacteria and microcystins are common in rivers, increase of their counts degrades the quality of water causing algal blooms.

Anthropogenic Sources

Anthropogenic sources include agricultural activities, urbanisation, industrialisation and mining. Agricultural activities are the most common anthropogenic activity in the river basins especially for developing countries like India that is heavily dominant on agricultural practices for livelihood and, hence, the number of crop lands is high. Pesticides and insecticides are common pollutants originating from agricultural activities. The run-off water from such croplands carries a high amount of salt which also increases the dissolved ionic concentration in surface water. Disposal of untreated or partially treated sewage effluents along with dumping of solid wastes in the rivers is the most common after-effect of urbanisation. Untreated disposal of industrial effluents to the river would increase the dissolved load of river thereby deteriorating the river water quality. Mining activities also enhance the weathering of the rocks and the erosion of soil increases the dissolved concentration in rivers.

SOURCES OF ANTHROPOGENIC CONTAMINATION

The anthropogenic contamination is further divided as point source and non-point source which is classified based on the entry of contaminants into the river.

Point Source

Point source water pollution refers to the contaminants that enters the water bodies from a single distinguishable source. Sources could be specific locations of anthropogenic activities, which would result in discharge of sewage and industrial effluents, dumping of solid wastes, animal feedlots and quarries. The effect of point source pollution on the receiving water body mostly depends on the population of the area or size and nature of activity in the area, quantum of waste discharged and also the self-cleansing capacity of water body.

Non-point Source

Non-point source pollution is the contamination which does not have single discrete source as an origin. It is mostly a cumulative effect, which usually consists of smaller amounts of various contaminants that are gathered from a large area. The non-point source arises from diffuse sources such as run off carrying pesticides and fertilisers from agricultural fields which thereby contaminate the rivers and groundwater. Nutrient run off in stormwater in the form of "sheet flow" over an agricultural field or forest is the best example of non-point source. The sewage from latrines and septic tanks in rural, semi urban and urban areas are considered as diffuse sources due to monitoring difficulties.

CLIMATE CHANGE

Climate change impacts the hydrological nature of rivers, which limits the carrying capacity of chemical load into the oceans. The decreasing trends of rainfall have decreased runoff in the rivers, which subsides the dilution effect in rivers increasing the major ion concentrations in the rivers (Khan et al., 2017). Increasing temperature caused by climate change also enhances the rate of rock weathering which leads to release of large amount of major ion concentrations in river water (Miriyala et al., 2017). Also, rise in sea levels has impacted the groundwater near the coastal regions causing seawater intrusion in the aquifers.

TYPES OF POLLUTANTS

Chemical pollutants in water are grouped as inorganic and organic pollutants. These pollutants are further divided upon their concentration of pollutants. A proper assessment of pollution in natural water depends on the following conditions:

(a) type and origin of pollutants, (b) availability of analytical methods to identify the chemical concentrations, (c) understanding the processes that determines the transport and fate of chemicals, (d) transport and fate mathematical models which would predict the future contamination scenario and (e) quantification on the adverse effects of chemicals (Schwarzenbach et al., 2010).

Inorganic Pollutants

Inorganic pollutants are classified as macro and micropollutants. Macropollutants are in which the concentration is at a higher range of milligrams per litre whereas micropollutants are in micrograms per litre. The most common macropollutants in river are the major ions such as calcium, magnesium, sodium, potassium, bicarbonate, sulphate, chloride, nitrate and phosphate. Other than nitrate, the major ions could have been derived from weathering of rocks present in the basin as well as anthropogenic activities whereas nitrate originated mainly from anthropogenic activities. High nitrogen and phosphate nutrient loads would increase production of biomass causing algal blooms and depletion of oxygen. Increase in salinity of water could be due to agricultural runoff and leaching of road salts, domestic waste sludge etc.

Inorganic micropollutants such as heavy metal and metalloids e.g., Cr, Ni, Cu, Zn, Cd, Pb, Hg, U, Se, As) could have originated from the geogenic and anthropogenic sources such as release of untreated industrial effluents from dyeing and tanning industries. These could also have been originated from the solid hazardous wastes dumped in the riverbanks and from municipal wastewater. The main challenge of environmental risks regarded to these pollutants is that they depend on the redox conditions. Most of the elements do not undergo biodegradation and their fate and transport depends on chemical reactions such as oxidation, reduction, complexation, absorption, adsorption, precipitation and dissolution (Schwarzenbach et al., 2010).

Organic Pollutants

Organic pollutants are diverse in nature and are originated from various sources. The common organic pollutants are persistent organic pollutants originating from multiple sources like dumping of waste sites, spills, agriculture and urban wastewater. Some of the common examples of persistent organic pollutants are polychlorinated biphenyls, DDT, polyaromatic hydrocarbon, triazines. Pharmaceutical wastes, hormones such as dicyclophene, ethinylestradiol, personal hygiene products (PPCPs) like cosmetics, flame retardants, perfumes, waterproofing agents, plasticisers and endocrine-disrupting chemicals (EDCs) are other types of organic contaminants originating from urban wastewater and industrialised effluents (Schwarzenbach et al., 2010). The chemical structure, especially the reactivity of functional group or substituent regulates the transformation of the organic micropollutants (Schwarzenbach et al., 2010). Presence of such pollutants in the environment leads to adverse toxic effects such as mutagenicity, estrogenicity, and genotoxicity. Prevalence of antibiotic-resistant organisms in water is also one of the major risks to microbial ecosystems.

Microbial Pollutants

Bacteria are significant indicators of microbial pollution in river water since they actively respond to environmental changes. Salmonella species, *E. coli* and Vibrio species are important bacteria species found in water. Faecal coliforms and intestinal enterococci are excellent indicators of faecal pollution. These microbial pollutants are found in the aquatic systems due to the discharge of untreated/partially sewage originating from domestic households, dumping of solid wastes and biomedical and also run off from agricultural land. Microbial contamination of rivers by faecal pollutant poses serious risks to human and animal health if consumed as they carry numerous pathogens (Reischer et al., 2008). Knowledge about the hydrologic nature and the sources of pollution in the catchment is more essential to identify microbial pollution. Long-term monitoring of the sources of microbial pollution and the quality of water bodies is essential to identify the extent of microbial pollution (Reischer et al., 2008).

WATER QUALITY PARAMETERS

The complete assessment of the water quality involves the evaluation and assessment of chemical and physical characteristics of the water (Gorde and Jadhav, 2013).

- Chemical analyses of water involve the determination of major/minor ions, trace elements, nutrients, inorganic and organic pollutants, biochemical oxygen demand (BOD), chemical oxygen demand (COD)
- Physical measurements of water include measurement of temperature, pH, conductivity, turbidity, ORP, dissolved oxygen
- Microbiological analysis – estimation of microbial species

Physical Parameters

pH

The pH of water is one of the major limiting factors that governs solubility and bioavailability of the chemical constituents. pH is defined as the logarithmic scale of acidity of a solution or water. The pH scale normally ranges from 0 to 14. The liquids with pH value of 7 such as pure water said to be neutral and where the pH is below 7.0 are considered acidic. Liquids with pH greater than 7.0 are considered basic or alkaline.

Electrical conductivity

Electrical conductivity (EC) is a numerical expression on the ability of an aqueous solution to transmit electric current and is generally used to estimate the total amount of dissolved ions present in water. The dissolved ions in water are composed of inorganic elements and some organic matter and hence EC acts as a good indicator of water quality. The EC of water is influenced by factors such as total concentration of ions, and their valence states, mobility, and temperature of water.

Turbidity

Turbidity is a measure of the degree of water at which it loses its transparency. Turbidity of water is because of the presence of suspended particles in water. Higher the amount of total suspended solids in water, higher would be the turbidity of water. Turbidity is also used as an indicator for light penetration in aquatic systems.

Oxidation-reduction potential

Oxidation-reduction potential (ORP) measures the ability of a river to self-cleanse. In other words, it measures the oxidising nature of contaminants and biological matter. High ORP value indicates higher oxygen presence which would enable rapid oxidation process.

Temperature

Temperature of the water is also an important parameter in controlling the water chemistry. Higher temperature generally fastens the rate of chemical reactions in water. Increase of water temperatures rapidly dissolves more minerals from the host rocks leading to increase in electrical conductivity of water.

Dissolved oxygen

Dissolved oxygen (DO) represents the amount of oxygen dissolved in water. It is an important representation of the quality of water since high DO in water causes degradation of contaminants and facilitates better aquatic health of the riverine system. The dissolved oxygen levels vary at diurnal intervals and also during seasonal time periods. Water temperature and altitude are the major factors which controls dissolved oxygen concentration in water. Cold water holds more oxygen than warm and less oxygen is observed at higher altitudes.

Chemical Parameters

Major ions, minor ions and trace elements

The river water is known to have dissolved and particulate inorganic matter which is derived from precipitation, mineral weathering and groundwater. Anthropogenic activities also contribute some amount of the dissolved and particulate ions rather than natural sources. Some of the major ions are calcium, magnesium, sodium, potassium, chloride, sulphates, bicarbonate and carbonate and nutrients like nitrate and phosphate. Fluoride and arsenic are the most common minor ions, where their concentrations are high in groundwater of specific regions. Their concentrations are less in river in comparison with the groundwater due to lesser rock water interactions. Heavy metals such as Ni, Cu, Pb, U are among the common trace elements which occurs due to geogenic and anthropogenic activities.

Alkalinity

It is a measure of the buffering capacity of water which neutralises acid and bases, thus maintaining the pH of water. Higher alkalinity levels in surface water will buffer the acidity in surface water thus maintaining pH which would avoid the harmful effects to aquatic ecosystem. The common chemicals present in water that increases alkalinity are carbonates, bicarbonates, phosphates and hydroxides.

Nutrients

Nitrogen and phosphate are important nutrients present in fresh water, especially in rivers. Though nitrogen and phosphorous are present in rivers through natural sources such as decomposition of organic matter, rainfall and soil, the anthropogenic contribution is very high. Phosphorus and nitrogen are largely derived from runoff from agricultural land due to high usage of fertilizers, sewage, yard waste, etc. Both nitrogen and phosphorus are essential elements for both terrestrial and aquatic plant growth but higher concentrations of phosphorous causes algal blooms and higher concentration of nitrogen are converted to ammonia and has degradation effects on aquatic life.

Biochemical oxygen demand

Biochemical oxygen demand (BOD) is the quantification of amount of dissolved oxygen required by aerobic biological organisms to metabolize the organic material in water at a certain temperature over a specific time period. BOD is indicator of organic pollution in streams and is usually considered for 5 days. Greater the BOD values, the depletion of oxygen in river water is rapid.

Chemical oxygen demand

Chemical oxygen demand (COD) is defined as the amount of oxygen consumed for the decomposition of organic matter and also for the oxidation of inorganic chemicals such as ammonia and nitrite. The quantification of oxidizable pollutants in water is understood from COD.

METHODS TO IDENTIFY ANTHROPOGENIC AND GEOGENIC CONTAMINATION IN RIVERS

Microbial Identification

Bacteria such as total coliforms, faecal coliforms, *Escherichia coli* and intestinal enterococci found in excreta of humans and warm-blooded animals are considered as the indicators of faecal pollution. When partially treated sewage enters into the rivers, these bacteria survive even in those conditions preserving their pathogenicity. *E. coli* is one of the significant indicators of faecal contamination in water, especially in tropical and temperate regions and hence thorough assessment of the bacterial density of water is essential (Páll et al., 2013). These microbial pathogens are the most suitable indicators of anthropogenic contamination especially faecal contamination (Páll et al., 2013).

Isotopic Identification

Tracers have been used for various purposes in riverine environments, viz. (1) identification of contaminant origin (2) analysis of the fate and transport of contaminant and (3) evaluation of biogeochemical cycling of an element in the aquatic systems. Isotopes are the excellent tracers used in different aspects of environmental chemistry. Isotopes such as lead, copper, zinc, bromide, boron and several heavy metals act as excellent proxies for differentiating the anthropogenic and natural sources in the environment (Chetelat and Gaillardet, 2005; Chen, Gaillardet and Louvat, 2008;

Sivry et al., 2008). Isotopic fractionations occur during biological process, adsorption of metal, chemical diffusion, and column elution.

IDENTIFICATION USING MAJOR IONS

Mass balance approach can be used to differentiate anthropogenic sources and natural sources. Chloride is a conservative ion and could be used as tracer. The residual chloride can be calculated by the method proposed by Meybeck (Meybeck, 1983). Residual chloride is the remaining chloride obtained by subtracting the rainwater's chloride concentrations from chloride concentrations of the river. These could be used to estimate the atmospheric corrected concentrations of other major ions which would help in tracing the source of ions. Nitrate ions are also used for such anthropogenic identification, where a high amount of nitrate in aquatic system could be originated from agricultural water and urban waste water (Huang et al., 2018).

STATISTICAL ANALYSIS

Correlation analysis, analysis of variance, principal component analysis, regression analysis, cluster analysis, discriminant analysis, redundancy analysis are the commonly used statistical techniques for distinguishing the anthropogenic contamination from geogenic contamination (Wang et al., 2007; Ouyang et al., 2006). The clusters and different components by statistical methods are derived using chemical composition, which depicts differences in chemical indices differentiating anthropogenic and geogenic contamination.

Case study 1: Assessment of groundwater and river water quality along the Cauvery river

Description

The Cauvery river is one of the most important river of southern India, which originates in the Western Ghats and flows along the length of about 800 km. The river forms a delta before draining into the Bay of Bengal (Fig. 1). The western part of the river part mainly receives rainfall during south-west monsoon (July-September) and the eastern regions receive rainfall during north-east monsoon (October-December). The river flows entire course mostly during October to January and hence is non-perennial. Harangi, Hemavati, Shimsha, Akkravati, Kabini, Suvarnavathi are the tributaries which join Cauvery in upper region, while Sarabangaha, Bhavani, Noyyal and Amravathi join at the middle region, where the lower region has 7 principal distributaries (India WRIS, 2015).

Though the water distribution has been a problem for decades, water quality of the river is of greater concern due to pollution load carried by the river. Cauvery and

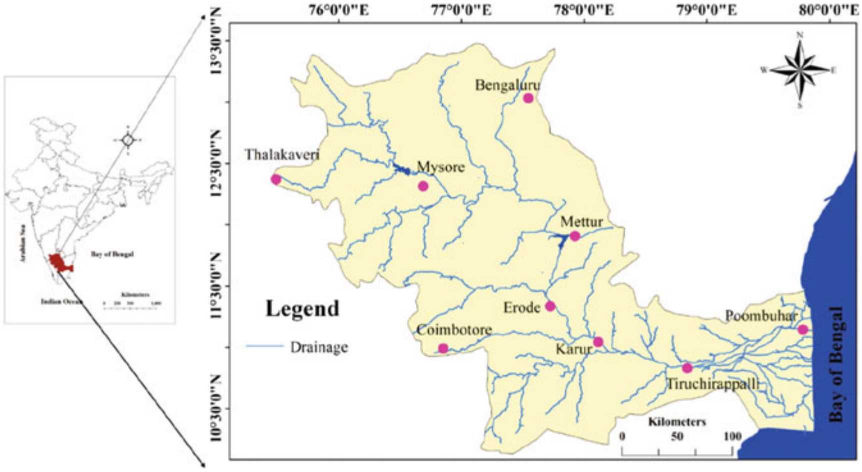

Figure 1. Cauvery river basin.

its tributaries, Noyyal and Sarabangaha have been regarded as one of the most pollutant rivers in India (CPCB, 2014). Several water quality assessment studies in surface water and groundwater in the basin (Susheela et al., 2014; Basu and Lokesh, 2012; Solaraj et al., 2010; Brindha and Kavitha, 2015; Suresh et al., 2010; Vetrimurugan et al., 2017a, but these are carried out only in certain smaller sections of the Cauvery river. Hence, it is essential to evaluate the water quality for the entire stretch of the river for a better understanding of the factors influencing the water quality and identification of locations of anthropogenic contamination, on a larger scale, but only few studies (Pattanaik et al., 2013; RamyaPriya and Elango, 2018) have carried out such exercise in the river.

Sampling Methodology

Sampling was carried out from 2013 to 2019, approximately once in four months. The exact period of sampling was decided based on the monsoonal conditions of the basin. As this basin receives rainfall during two different monsoons (south-west monsoon) and (north-east monsoon), each of about three months duration. It was decided to carry out sampling during these monsoons as well as during the non-monsoon period in a year. Hence, sampling was carried out three times every year considering the changes in the monsoon pattern. The water samples were collected from 28 locations along the river where the distance between each sampling location was fixed at an interval of 18 to 25 km. Care was taken to select the sampling locations such that it represents the natural hydrogeochemistry of the river. Sampling locations were determined based on the landuse of the region such that it covers the urban areas, industrial locations, confluence of tributaries and reservoirs. The collected samples were analysed for major and minor ions.

Surface Water Quality in the Basin

Previous studies on this basin have reported about the poor river water and groundwater quality (Solaraj et al., 2010; Basu and Lokesh, 2012; Susheela et al., 2014; RamyaPriya and Elango, 2018). Though the river water quality for both drinking and irrigation purposes along the river is deemed to be excellent based on major ionic concentrations during significant flow periods (RamyaPriya and Elango, 2018), the non-conservative parameters show the representation of poor quality of river water. The surface water along the KRS dam stretch in Cauvery river was assessed which indicated that BOD and COD concentrations are high, clearly indicating pollution in Cauvery river. High values of Cl is also observed around the KRS dam stretch along with high levels of total and faecal coliform indicating anthropogenic pollution. The pollution in river Cauvery at the upper stretches, especially at KR Nagara (location 23, and location 24, Fig. 2) was also escalating over the years due to indiscriminate human activities and agricultural uses along the river (Basu and Lokesh, 2012). The river water quality at the deltaic regions was also evaluated which indicates that during monsoonal periods where the phosphate concentration is greater. The high concentration of phosphate in water samples indicates that pollution have been

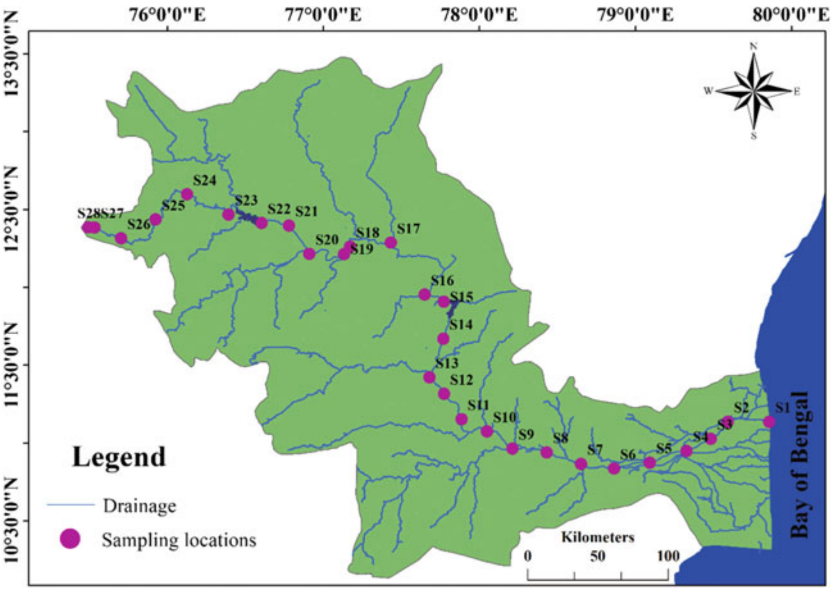

Figure 2. Surface water and groundwater sampling locations.

originated from runoff from agricultural fields, sewage and other non-point sources. Surface water in Cauvery river deltaic was also highly contaminated due to high TDS during non-monsoon seasons (Solaraj et al., 2010; Brindha and Kavitha, 2015).

Groundwater Quality in the Basin

Groundwater in locations near the urbanised, agricultural land and near the regions surrounding the principal tributaries Noyyal and Amaravathi have been severely contaminated due to the release of high sewage and effluent pollutant load to the river continuously (RamyaPriya and Elango, 2018). Due to low flow in rivers, the groundwater in deltaic part has also been severely affected. Along with high major ionic concentration, high levels of heavy metals like silver, lead, nickel, aluminium, boron, cadmium, copper, iron and manganese were also determined in the groundwater of delta regions of the basin. Poor-to-unsuitable water quality was found in most of the regions. The human exposure risk due to groundwater consumption was high due to presence of chemicals such as silver, lead, manganese, cadmium and lithium (Vetrimurugan et al. 2017a, b). The concurrence of all these elements in groundwater indicated that both geogenic processes and anthropogenic activities such as agricultural runoff, industrial effluent discharge and sea water intrusion have caused contamination.

Impact of river water recharge on groundwater quality

Since the quality of groundwater in nearby wells to the river was deteriorated (RamyaPriya and Elango, 2018), the study was carried out in the Cauvery river to identify the impact of recharge from river water to the adjacent groundwater quality. Major ion concentration in river water was found to vary spatially. The concentration of ions, in general, was found to increase along the flow direction of the river except in certain regions of anthropogenic activities. This increase in ions towards the flow direction could be due to the changes in precipitation chemistry, ocean spray effects along with weathering and anthropogenic disturbances (Fig. 3). The concentration of river water during full flow conditions of the river remains fairly constant and low due to dilution effect. Groundwater shows an irregular pattern, and the major ion concentration in groundwater were higher than surface water in all locations due to rock water interaction. But, temporally, similar variation in the ionic concentration is observed between the surface water and groundwater indicating the influence of river recharge on groundwater. For example, Fig. 4 explains the surface water-groundwater interactions at location 14 during various time periods. The recharge of groundwater from river water improves the groundwater storage and also the quality since the concentration of groundwater is low during months of significant river flow. This could be attributed due to the surface water-aquifer

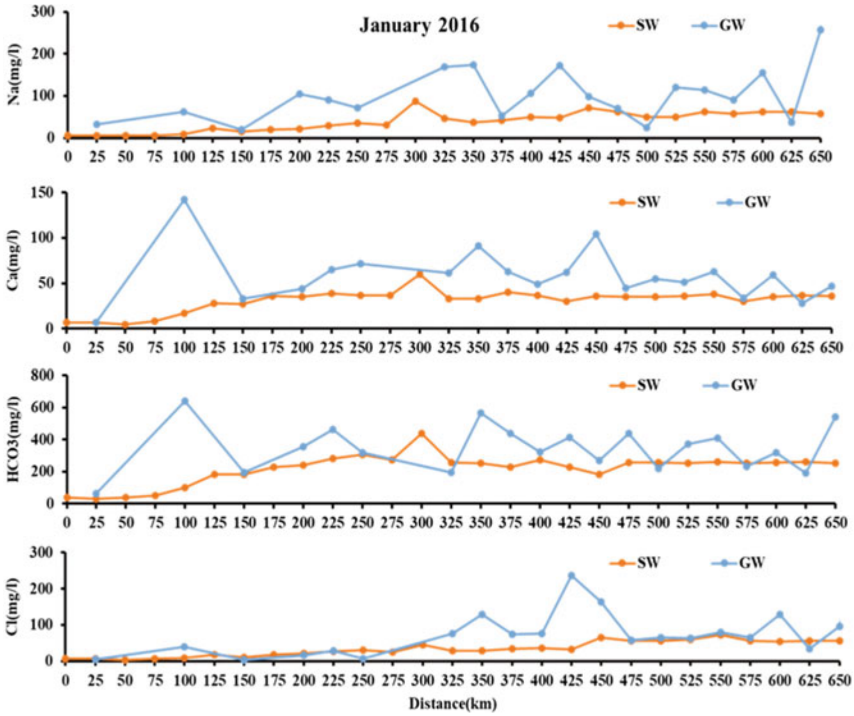

Figure 3. Spatial variation of major ions.

exchange which depends on topography, elevation, lithology and flow characteristics of the aquifer and river.

FACTORS INFLUENCING RIVER WATER QUALITY IN CAUVERY BASIN

Meteorological Conditions

The basin lies in the tropical zone and experiences the contrasting monsoonal changes. The western part of the basin receives rainfall during south-west monsoon and the eastern part of the basin receives rainfall during north-east monsoon and the middle region receives rainfall during both the seasons. The highest rainfall in the basin is usually received during the months of June-September due to prevalent south-west monsoon wind (India Wris, 2015). Hence, the river is dry during summer and flows completely during August-January. Though the quantum of rainfall during north-east monsoon is lesser than the south-west monsoon, it is important especially to the lower part of the basin since it is one of the major source of water for the

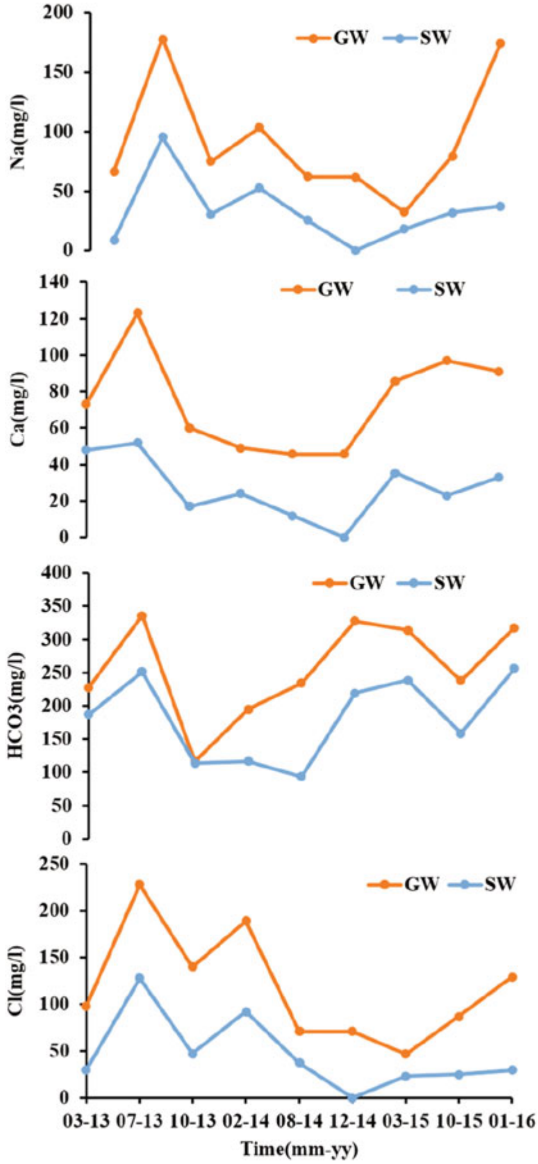

Figure 4. Temporal variation of major ions in surface water and groundwater.

agricultural activities in the deltaic region. Hence, the flow of Cauvery river is intermittent and thus the seasonal climatic wet and dry periods of the basin severely impacted the water quality of Cauvery river. The major ion concentrations of the river water and its adjacent groundwater are less during the river flow, whereas during the dry season their concentration is greater. (RamyaPriya and Elango, 2018). The conservative variables such as Na, K, Ca are found to be greater during pre-monsoon and lesser during the post-monsoon seasons in the river water of upper parts of Cauvery basin.

Hydrological Factors

Cauvery is a non-perennial river and hence the flow characteristics are major factors in determining the water quality of the river. Cauvery river, when compared with other rivers of the world like Amazon and Ganges, carries lesser dissolved load due to low discharge, but the average ionic concentrations of riverine are greater than the average values of Asian rivers and the global rivers as reported by RamyaPriya and Elango (2018). During the monsoons, the ionic concentrations in the river decreases due to dilution, which on recharge also reduces groundwater ionic concentration. (Brindha and Kavitha, 2015).

Since the river does not flow for most of the months, the groundwater quality, especially in lower part of the basin, has been affected to a greater extent. The solute transport model for deltaic part of Cauvery river basin indicated high concentration of chloride and nitrate in the aquifers of Cauvery deltaic region. Higher concentrations of chloride and nitrate in the aquifers were observed in the coastal area. This is due to accumulation of ions in aquifers which has happened because of the absence of dilution effect and has also declined the soil quality. The model predicted that the dilution effect would be prominent in groundwater only if the river flows for at least 90 days in a year. (Vetrimurugan et al., 2017b).

Lithology

The river basin is composed of precambrian rocks which are closepet granite, granitic gneiss, charnockites, sandstone and alluvium (Pichamuthu, 1978). The upper and the middle regions of the basin are covered by peninsular granites and gneisses (Pichamuthu, 1978; John et al., 2005) and the coastal regions at lower reaches is composed of sandstone, limestone, and shale (Sundaram and Rao, 1981; Subramanian and Selvan, 2001). The weathering of the gneissic rocks at the upper reaches of the Cauvery river is greater as reported by several researchers (Vaithiyanathan et al., 1988; Pattanaik et al., 2013). At higher temperatures, the rate of chemical weathering increases which increase the dissolved ion concentration in rivers. Silicate weathering is dominant in the basin and the riverine dissolved and suspended load reflects the dominance of weathering (Vaithiyanathan et al., 1992). The dissolved load carried by Cauvery river to sea was lower, but the dissolved load yield per area is higher than most of the rivers around the world indicating active chemical weathering in the basin (RamyaPriya and Elango, 2018).

LANDUSE/LAND COVER

The basin undergoes rapid urbanisation along with industrialisation and significant conversion of barren lands to agricultural land also occurs in the basin. Agriculture is widely practiced in this river basin. The deltaic regions are the most fertile regions of the basin and are extensively irrigated where major crops being rice and sugarcane. About 96 dams and 16 major and minor irrigation projects are present in the basin (India Wris, 2015). Forest lands also occupy significant portion of land use in the basin. About 36 districts are present in the basin consisting a population of about 3,18,89,280 (Census, 2011). Urbanisation has been rapid in this river basin, where many locations along this river over the past few decades has been transformed from rural areas to semi-urban and urban locations. The major urban cities along the river are Mysore, Erode, Karur, Tiruchirappalli and Kumbakonam. Industrial hubs were also present at many regions around the river, where several textiles, dyeing, cement, sugar, chemical and mineral processing industries are present. In addition to that, many small scale to medium scale industries are present in the basin. The changes in the land use have also made a greater impact on the surface water and groundwater quality of the river basin.

Studies on the river water quality in the river reported that the ionic concentration in river generally increases along the flow direction of the river. But few regions are exempted from such patterns where a high amount of ionic concentration was found in both river water and groundwater. The region of anomalies in water chemistry was found to be locations of industries, urban areas, agricultural lands and the confluence of tributaries. Mass balance studies using chlorine as the tracer were carried out using river water and rainfall chemistry to identify the regions of anthropogenic contamination. It is evident that the river and groundwater water quality in locations near to industries and confluence of the tributaries especially Noyyal and Amravathi and urban locations were severely affected by anthropogenic activities (RamyaPriya and Elango, 2018). It could also be deciphered from Fig. 5 that the locations 12, 6, 11, 9, 10 have been highly contaminated since these locations are urban (location 12 and 6), industrial areas (location 11) and confluence of tributaries (location 9 and 10).

CONCLUSION

Water quality studies for rivers are gaining momentum in recent years due to increasing concern for public and aquatic health. This article describes the sources and types of contamination in rivers, the factors which influence the contamination in rivers, identification of anthropogenic sources in riverine water chemistry, temporal variation of water quality with an emphasis on a major non-perennial tropical river of Southern India, Cauvery. River Cauvery flows across four states on southern India and has been extensively utilised for drinking and irrigation purposes. The

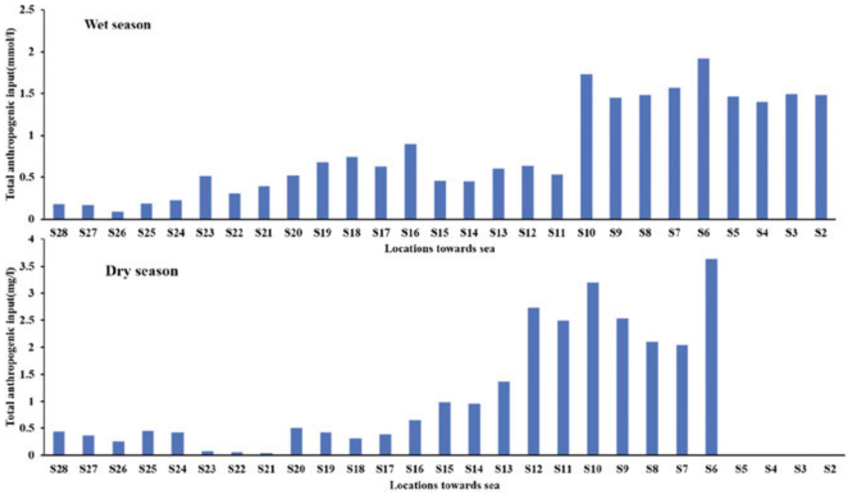

Figure 5. Spatial variation of concentration of ions from anthropogenic origin.

general scenario of the river water and groundwater quality in the basin is also described. Along with this, factors influencing the riverine water quality in the Cauvery basin is also discussed. Thus, this chapter emphasises that studies on assessment of water quality in such riverine environments are essential and continuous periodical long-term monitoring studies are needed to keep in check of the riverine quality.

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