An assessment of groundwater quality in Kottukal microwatershed in Thiruvananthapuram district, South Kerala

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The Kottukal microwatershed is an uplifted sedimentary watershed of recent origin formed due to large scale neo-tectonic activity. The groundwater from this watershed is largely abstracted for both irrigation and local public drinking water supply schemes. The present communication is an attempt to assess the detailed groundwater quality of the unconfined aquifers and the stream water system within the microwatershed. The Hill–Piper diagram indicates majority of groundwater samples are found to be Na–Cl followed by a mixed and Ca–HCO_3 type. The Na–Cl characterization of groundwater in this elevated terrain is not due to primary salinity, but could be attributed to combined effects of irrigation salinity and improper sanitation facilities. The values of total dissolved solids and electrical conductivity in groundwater samples are low as compared to stream water samples, suggesting distinct imprints of hydro-geochemical behaviour. The Wilcox diagram indicates, 90% of water samples falls in the C1–S1 sector depicts its suitability for irrigation. The total coliform and faecal coliform count of >1600 MPN is noted in 88% of water samples. The alkaline trend and high bacteriological contamination points to the prevalence of a non-sterile environment resulted from agronomic practices and poor environmental sanitation facilities within the watershed.

Keywords: Groundwater recharge, groundwater quality, Kottukal stream, micro-watershed.

THE Kottukal ‘todu’ situated in the south-western part of Thiruvananthapuram district, is a short narrow stream of recent origin. The stream has an average width of 10 m and a total length of 9 km stretched along a major lineament trending NNE–SSW. The stream is situated in an undulating sedimentary terrain confined within a microwatershed close to the shoreline. It originates from Attaramoola of Balaramapuram Panchayath, dissecting the sedimentary laterites and upper tertiary formation. It drains through Kottukal Panchayath and ends up in the Arabian Sea near Karinkulam (Figure 1 *a*). The area receives an average annual rainfall of 1900 mm through SW and NE monsoon that contribute to the groundwater system. In addition to natural rainfall, Chowara branch canal and Poovar west canal encircling, the stream system transfers water from the adjacent Neyyar reservoir into the watershed during summer months for about 120 days in a year. The canal trench that runs across upper hilly areas of the watershed helps groundwater percolate into the substrata. The groundwater flows across the valley through and within the inclined sedimentary beds. Thus the watershed area is supported by good artificial drainage network, irrigation canals and adopted best agronomic practices that facilitate optimum groundwater recharge. There are about 24 public drinking water supply schemes that exist within the watershed area tapping unconfined aquifers, of which 4 are situated in the stream bed abstracting groundwater from infiltration galleries.

The Kottukal watershed is confined to a total geographic area of about 19.36 sq. km. The neo-tectonic disturbances in the form of folded sedimentary sequences, largely control the occurrence and movement of groundwater in the area[1]. It was found that the majority of terrain is highly undulating and falls in the contour values ranging from 40 to 60 m. Moderate to steeps slope ranging from 30° to 40° were noticed in most of the area. The northern side of the watershed is bounded by Precambrian crystallines that comprise the Khondalite group of rocks, whereas the southwestern side of the watershed is marked by a narrow strip of quaternery sediments consisting of beach sand and recent alluvium (Figure 1 *b*). The area in between is occupied by upper tertiary formations consisting of Warkalli sandstone and layers of clay and lignite intercalations ranging in thickness between 30 and 90 m above the crystalline basement. The laterites and red Teri sands capped over the crystallines and Warkalli sandstone form major unconfined aquifers in the region[2]. The stream situated in an elongated ‘V’ shaped valley dissecting the laterites and red Teri sands, forms the major drainage basin. The stream bed is deep and narrow at the northern end and is progressively shallow and wider towards the mouth. The water level in the stream ranges from 0.30 to 2.30 mbgl with shallow water levels noticed at the mouth. The groundwater levels in the unconfined aquifer vary from 0.75 to 24.5 mbgl. The groundwater levels are generally deep in the upper hilly areas and often irregular due to undulating topography. The inclined beds of sedimentary strata act as water table aquifers that intersect along the vertical stream cut boundaries, promoting natural groundwater discharge into the stream channel. The stream flow is further augmented by good artificial drainage network, irrigation canals and best agronomic practices, which facilitate optimum groundwater recharge giving an effluent nature to the stream. The conservation of groundwater along the stream bed is optimized by 15 check dams constructed along its length. These artificial barriers strongly influence the groundwater potential of shallow aquifer zone.

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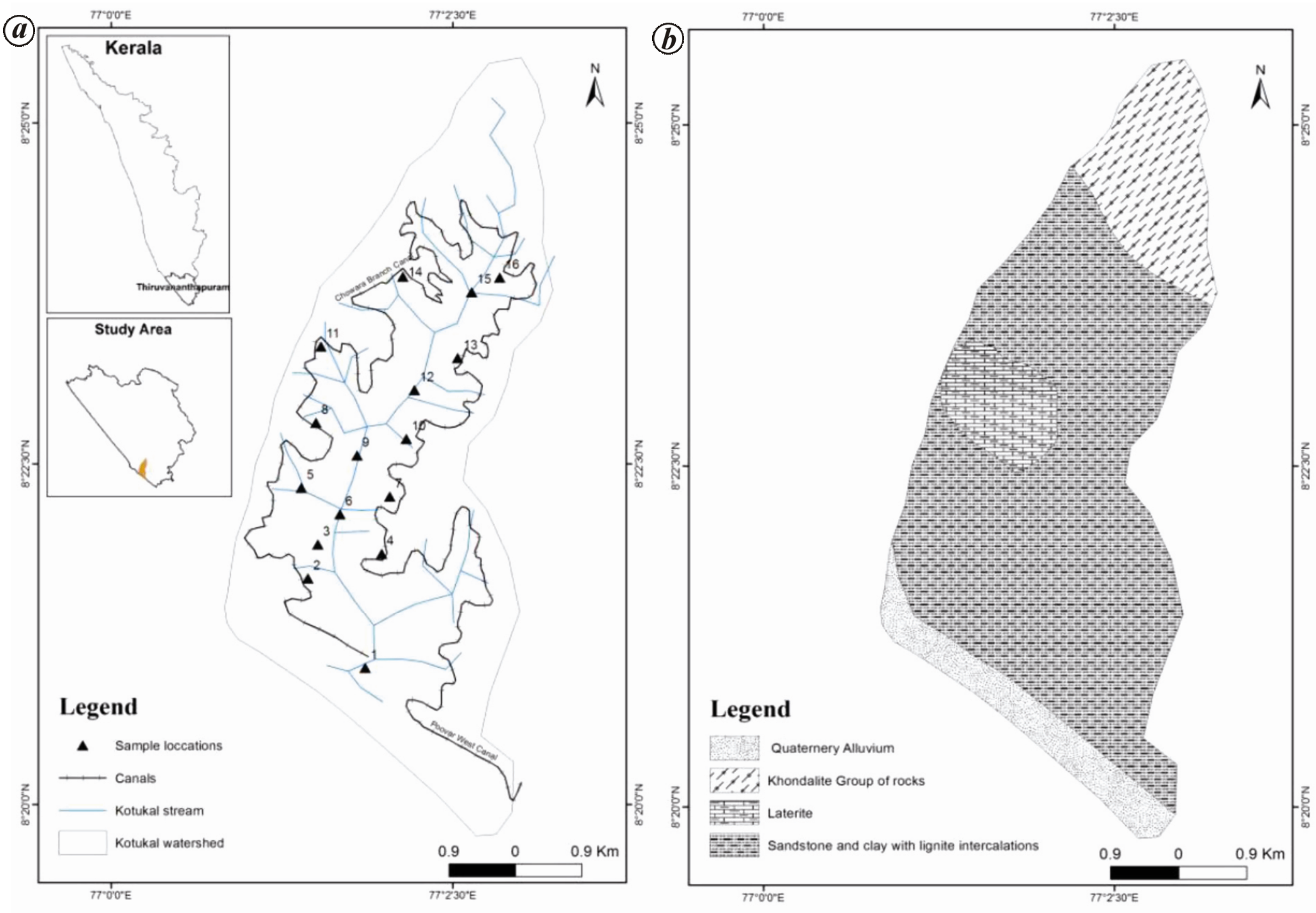

Figure 1. ***a***, Location map with sampling points. ***b***, Geological map of the study area.

The groundwater development from the same aquifer in the watershed system appears to be successful in meeting the agricultural, domestic and drinking water demands. However, the quality of groundwater for various purposes in the watershed has not been studied yet. Hence a detailed assessment of groundwater quality was carried out with an objective of appreciating the significance of artificial groundwater recharge on water quality in the area.

A total number of 16 water samples were collected, of which 11 were from the open wells situated along the hill slopes and 5 were from the stream channel. The samples were collected during the pre-monsoon period of 2014 (Figure 1 *a*). The wells were selected such that they represent the local hydro-geological conditions of the study area. After taking the pH and EC measurements in the site, the samples were neatly labelled and taken to the lab for further analysis. The physico-chemical parameters of water samples, viz. sodium, potassium, calcium, magnesium, chloride, carbonate, bicarbonate, iron, sulphate were determined. The samples were analysed as per the standard analytical procedures for water analysis[3]. The results of the water quality were compared with the Indian Standards (IS) specification for drinking water[4]. The chemical relationship among groundwater samples of different localities was identified using Hill–Piper diagram. The irrigation quality of groundwater was also determined through Wilcox diagram.

The results of chemical analysis of groundwater and stream water samples from the study area (presented in Table 1) are discussed below.

The pH values of groundwater samples in the study area ranged from 4.8 to 8.5. The permissible limit of pH proposed by IS code is 6.5–8.5. The groundwater samples from all stations except sample number 4, fell within the permissible limit of the IS standard. Sample number 4, situated along the hill slope on the SE side of the watershed, was acidic in nature with a pH of 4.8. The excess removal of basic portions from the soil by plants, resulted in a net acidic condition. The biological transformation by weathering and plant uptake influenced the acidity of the soil. Besides the above, all other groundwater samples were more alkaline, which was significant throughout the watershed. The pH values of all stream samples were above 7 indicating their alkaline nature (Table 1). Alkaline compounds in water such as bicarbonates,

Table 1. Water quality parameters of Kottukal watershed (April 2014)

Sample no.	Source	Water level (m bgl)	Depth of the well (m)	Diameter of the well (m)	Aquifer material	pH	EC (micro mhos/cm)	TDS (mg/l)	Na^+ (mg/l)	K^+ (mg/l)	Ca^{2+} (mg/l)	Mg^{2+} (mg/l)	Fe (mg/l)	Cl^{2-} (mg/l)	HCO_3^- (mg/l)	CO_3^{2-} (mg/l)	SO_4^{2-} (mg/l)	Total coliforms (MPN)	Faecal coliforms (MPN)
1	ST	0.40	–	–	–	7.2	217	130	34	1.5	6	4.8	0.9	58	22	0	8.1	≥1600	≥1600
2	OW	4.13	6.3	1.25	TS	6.8	120	72	18	1.6	8	2.5	0.9	32	12	0	11	≥1600	≥1600
3	OW	0.75	3.1	0.95	TS	8.5	2500	1500	395	11	30	43	3.4	700	146	14.4	7	1600	1600
4	OW	6.75	8.9	0.90	TS	4.8	67	40	12	0.4	6	1.2	0.2	20	3	0	2.8	≥1600	1600
5	OW	15.40	19.0	1.50	TS	6.6	131	79	20	0.6	6	1.2	0.8	34	7.3	0	3	1600	1600
6	ST	1.35	–	–	–	7.6	157	94	17	3.6	10	3.7	1.6	29	37	0	17	≥1600	≥1600
7	OW	21.40	22.5	1.25	TS	7.5	81	49	10	0.8	4	3.7	1.4	19	22	0	5	≥1600	≥1600
8	OW	22.85	25.1	1.90	LT	7.9	102	61	18	0.3	4	1.2	0.2	29	3	0	5.1	1600	1600
9	ST	1.90	–	–	TS	8.1	164	98	21	3.4	10	3.7	1	30	41	0	13	≥1600	≥1600
10	OW	9.25	13.6	1.30	TS	7.8	138	83	11	1.2	20	0	4.6	16	46	0	4.5	900	900
11	OW	24.45	26.2	1.90	LT	7.6	95	57	15	0.7	4	1.2	0.2	24	3	0	1	240	240
12	ST	2.10	–	–	TS	8.2	175	105	19	3.9	12	2.4	1.7	31	29	0	14	≥1600	≥1600
13	OW	13.25	14.8	1.60	TS	7.	111	67	15	5.0	4	1.2	0.4	25	3	0	12	1600	1600
14	OW	11.91	17.0	1.70	TS	7.7	128	77	14	0.7	14	0	0.6	21	41	0	5.2	≥1600	≥1600
15	ST	2.30	–	–	TS	8.0	224	134	22	4.1	18	2.4	3.8	35	66	0	11	≥1600	≥1600
16	OW	2.35	5.0	1.00	LT	7.8	99	59	13	1.9	8	1.2	1.3	16	29	0	8	≥1600	≥1600

OW, Open well; TS, Teri sand; ST, Stream; LT, Laterite.

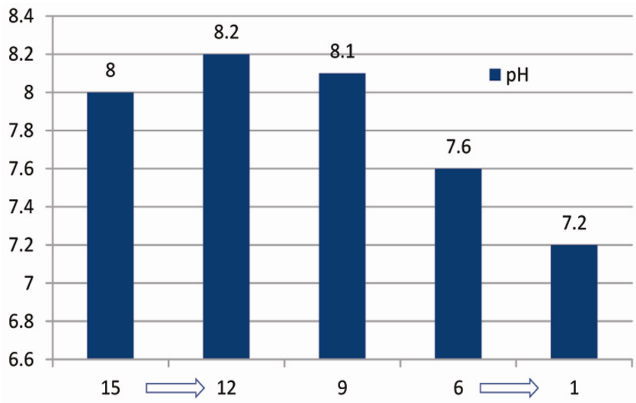

Figure 2. pH values along the Kottukal downstream.

carbonates and hydroxides remove H^+ ions and lower the acidity of stream water (which means increased pH). The stream water samples indicated a downstream decrease in pH values except at the beginning of the stream which marked a value slightly lower than the adjacent groundwater aquifers (Figure 2). Alkalinity in the stream was influenced by various processes within the watershed such as active groundwater recharge through lateritic soils, presence of salts released from fertilizers, certain plant activities, and other bio-degradation and agronomic measures adopted within the watershed. The check dams constructed across the stream channel reduced the stream flow, thus maximizing groundwater recharge along the channel bed. The decreasing pH values of the stream indicated the release of material from organic residues and fertilizers reaching the Kottukal stream through the artificial drainage system. This was further influenced by the slow movement of water along the stream channel. A portion of groundwater used for irrigation finally reached the water table as return flow in non-acidic condition and was re-circulated into the terrain elsewhere. This increased the alkalinity in the groundwater samples in other localities.

The total dissolved solids (TDS) represent the dissociation of various minerals present in water samples. The presence of various minerals was evaluated in terms of mg/l by weight of ions. The TDS of groundwater samples in the watershed ranged from 49 to 72 mg/l, except for sample number 3. The highest TDS value of 1500 mg/l observed in the groundwater (sample no. 3) in the SW portion of the watershed indicated that the area was tidal prone due to the truncation of a narrow tidal inlet extended into the terrestrial segment. The TDS values along the Kottukal stream ranged from 94 mg/l to 134 mg/l exhibiting higher set of values than its terrestrial derivatives (Figure 3). The lower TDS values observed in groundwater samples may be attributed to the active groundwater recharge that takes place in the terrain.

A close examination of TDS values along the Kottukal stream indicated a downward decrease except at the end point (sample no. 1). The slow stream discharge along the channel and mixing of fresh water derived from the adjacent water table aquifers might be responsible for the downstream decreasing trend of TDS in the Kottukal todu. The enrichment of dissolved solids in the downstream end indicated accumulation of salts near the channel mouth, where the stream flow was rather slow and the stream bed was shallow and enriched with muddy sediments.

Electrical conductivity represents the ability of a substance to transmit electric current and is the reciprocal of electrical resistivity. Chemically pure water has low conductance. However, with the presence of dissociated ions in solution it conducts electricity. The specific conductance increases approximately linearly with the quantity of dissolved solutes in the solution and is different for each salt. The distribution of EC in groundwater samples ranged from 67 to 131 mmohs/cm, except for sample number 3 (Figure 4). Sample number 3 depicted an anomalous increase in the EC value of 2500 mmohs/cm. The highest EC value in the area may be due to the waterlogged condition and the influence of tidal channel that promotes the accumulation of salts in the local area. Typical EC values of around 2500 mmohs/cm under similar conditions were reported from the coastal areas of Chellanam[5]. The EC values across the stream channel ranged from 157 to 224 mmohs/cm. The values showed a progressive decreasing trend except at the downstream end. The enrichment of dissociated ions in the downstream end was due to reduced stream flow especially at the mouth of the stream. The study of EC indicated that the values of groundwater were comparatively lower than stream water samples. The general water quality in the Kottukal watershed area was rather fresh as the area received significant recharge from natural and artificial sources. The recharge induced by the Chowara Branch Canal and Poovar West Canal along with various terrain treatments and agronomic practices adopted in the watershed were largely reflected in the values of electrical conductivity with respect to groundwater samples in the watershed.

The groundwater samples from various locations of Kottukal watershed have been classified using the well established Trilinear plot proposed by Hill[6] and Piper[7]. The difference in hydrochemical facies of the same watershed at different places indicated difference in processes influencing groundwater quality. The analysis indicated that 11 samples including groundwater and stream water fell in field 3 indicating the presence of alkaline water with prevailing chloride which is classified as Na–Cl type (Figure 5). This refers to primary salinity, where combined concentrations of sulphate, chloride, magnesium and calcium exceed 50% of total meq/l. But by considering very low individual concentration of different cations, anions and presence of fluvial sedimentary strata and the effluent nature of the stream, these samples indicated irrigation salinity rather than salinity from natural sources. Apart from the accumulation of salts from root zones derived from fertilizers, the unlined septic tanks and sewage disposal also allowed the downward percolation of salt and other impurities into the water

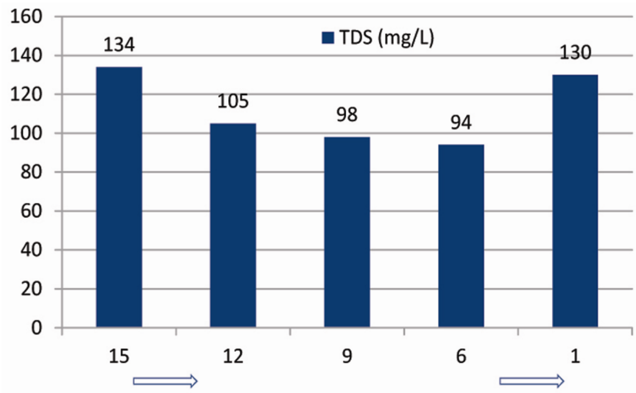

Figure 3. TDS values along Kottukal downstream.

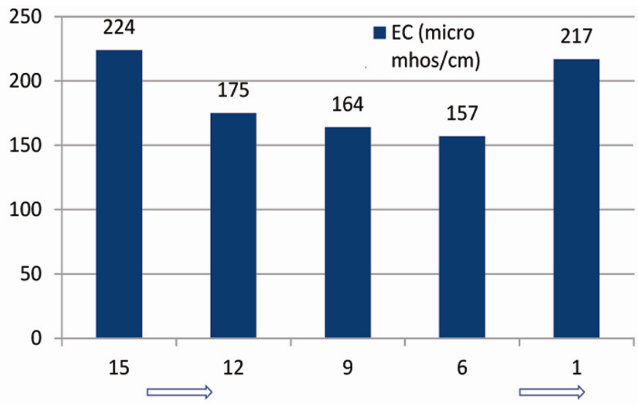

Figure 4. Electrical conductivity along Kottukal downstream.

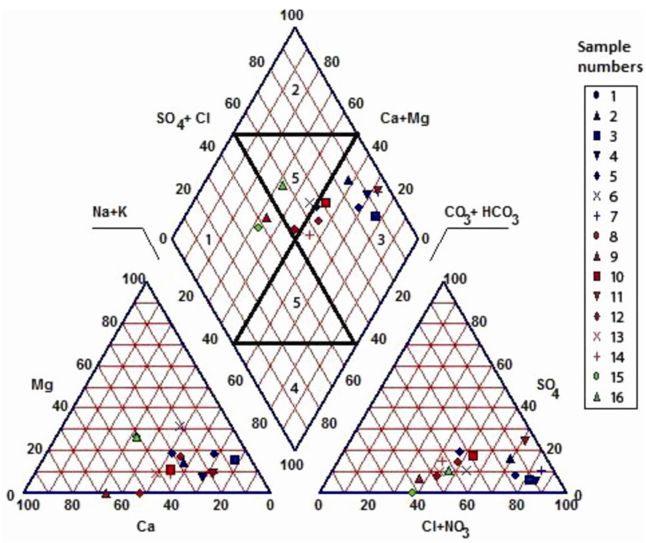

Figure 5. Hill–Piper diagram showing different hydrochemical facies of Kottukal microwatershed.

table. The sources of Na^+ and Cl^- derived from septic effluents and municipal landfills have been reported earlier[8]. The increased concentration of salts in groundwater due to agricultural and anthropogenic activities in similar parts of Cooum River, Chennai was identified[9]. In the study area homestead irrigation practices and improper sanitation facilities were common. Irrigation return flow and artificial recharge from the canal system during pre-monsoon season promoted Na–Cl type of groundwater within the watershed. Three groundwater samples fell in the field 5 indicating mixed Ca–Mg–Cl type. The presence of clay and sand enriched unconfined aquifer formation in the sloppy terrain promoted low acidic condition and the well-drained nature of the soil quickly released calcium, magnesium, potassium and sodium[10]. This might be attributed to the presence of mixed type groundwater in the watershed in some locations. The water samples from the beginning and the midstream portion (sample 15 and 9) that fell in field 1, were of Ca–HCO_3 type indicating a predominant freshwater source. In field 1, the combined concentrations of calcium, magnesium and bicarbonate exceeded 50% of the total dissolved constituent load in meq/l. The Ca–HCO_3 type water in the stream channel suggests seepage of fresh groundwater from the adjacent aquifer along the vertical boundaries of the stream and other fresh water inputs from terrestrial sources are dominant in certain locations of the stream channel. A major discharge point of the groundwater aquifer in the stream at Karichal contributing submarine groundwater discharge along the nearby Vizinjam coastal tract identified[2] also supports this view.

The suitability of groundwater for irrigation was evaluated through Wilcox diagram. Wilcox[11] used percentage of sodium and specific conductance in evaluating the suitability of groundwater for irrigation. The sodium percentage determines the ratio of sodium to the total cations, viz. sodium, potassium, calcium and magnesium. In the Wilcox plot, all the water samples except sample no. 3 and 16 were clustered in the C1–S1 sector (Figure 6). The low salinity hazard and sodium (alkali) hazard in the particular sector indicates that the quality of water is generally good for irrigation. Nearly 90% of the samples fell in this sector. The groundwater sample 16 that falls in the C2–S2 sector indicates increase in conductivity values but is still classified as good water for irrigation. However, sample 3 that falls in the C4–S3 sector indicates high conductivity values and high sodium hazard which is not suitable for irrigation. This groundwater sample representing the SW side of the watershed is waterlogged and has derived more salts due to its proximity to the tidal channel. In addition, the soil is highly porous and permeable and subjected to active groundwater recharge irrespective of its geographic location indicating that groundwater is suitable for irrigation.

Bacteriological studies are important for detecting biological pollution of groundwater. Most pathogenic bacteria found in water are indigenous to the intestinal tract of animals and humans. The presence or absence of Coliform group of bacteria in a water sample is a direct indication of safety of the water for drinking purposes. Coliforms are reported as the most probable number (MPN) of coliform group organisms in a given volume of water.

The analysis of water samples indicated excess presence of coliforms in all samples irrespective of the geographic location (Figure 7). Total coliform count of >1600 was recorded in 14 samples out of the 16. Two wells noticed a lower count of 900 and 240 from sample numbers 10 and 11 respectively. Sample no. 10 was from a domestic dug well situated along the slope on the eastern side of the stream, whereas sample no. 11 was from another domestic dug well situated on the western slope of the stream. Both groundwater samples were collected from domestic wells situated adjacent to the natural tributary of the stream. Both the wells were unlined and recharged by the canal flow and also by natural percolation. The periodic maintenance and chlorination might

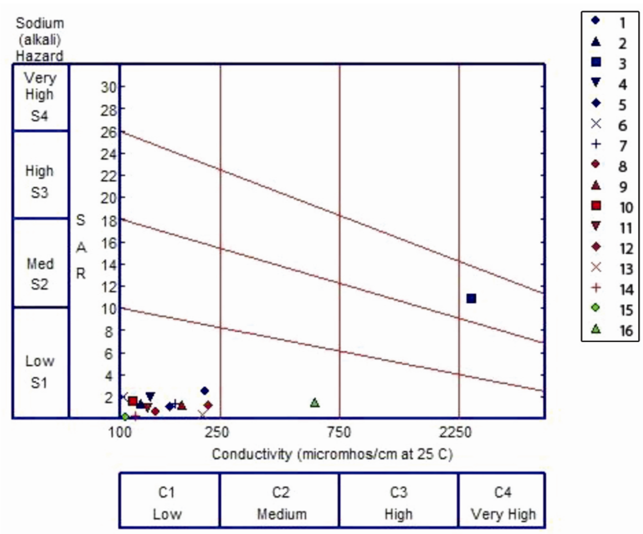

Figure 6. Wilcox diagram of water samples from Kottukal micro-watershed during pre-monsoon 2014.

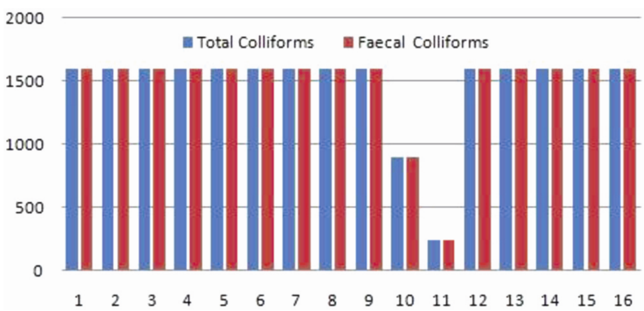

Figure 7. Distribution of total coliforms and faecal coliforms in Kottukal microwatershed in MPN.

have reduced the coliform count in the two groundwater samples.

Faecal coliform bacteria are a kind of coliform associated with human or animal wastes. *Escherichia coli* is part of the group of faecal coliforms. The analysis of water samples indicated excess presence of faecal coliforms in all samples irrespective of their source. Faecal coliform count of >1600 was recorded in 14 samples (Figure 7). However, sample numbers 10 and 11 recorded a lower count of 900 and 240 respectively. The presence of faecal coliforms in environments may indicate that water is contaminated with the faecal material of humans or other animals. Faecal coliform bacteria can enter rivers through direct discharge of waste from mammals and birds, from agricultural and storm runoff, and also from human sewage. The Kottukal watershed is a closed system with well-drained soil. The natural and artificial drainage system contribute to the replenishment of the aquifer. Large irrigational holdings, farm animals and improper sanitation facilities might contribute to the faecal contamination of water in the environment.

The Kottukal watershed is identified as a sedimentary watershed formed due to large scale nontectonic activities. Majority of the terrain is highly undulating with steep to moderate slopes ranging from 30° to 40° which is not favourable for natural groundwater recharge. However, artificial drainage system, large scale agronomic measures, irrigation canals, etc. adopted in the watershed largely promote active groundwater recharge sustaining the natural groundwater aquifers.

The quality assessment during pre-monsoon period indicated that various chemical constituents of groundwater in the area were significantly low. Though the pH values were well within the limits according to the drinking water standard, a more alkaline trend was generally observed. The EC and TDS values of groundwater samples were low and ranged from 67 to 131 mmohs/cm and 49 to 72 mg/l respectively. However, a slightly higher set of values of EC ranging from 157 to 224 mmohs/cm and TDS from 94 to 134 mg/l were observed in stream water samples, which indicates that both the groundwater and stream water are chemically fresh. Further, the downstream decreasing trend of TDS and EC values of stream water samples were in good agreement with each other indicating multiple stream inputs carrying appreciable dissolved constituents, mixing of fresh water from adjacent water table, slow movement of water due to artificial barriers, etc. The highest TDS value of 1500 mg/l and EC value of 2500 mmohs/cm noticed in the SW portion of the watershed indicated that the area is tidal prone.

The chemical classification of groundwater carried out through Hill–Piper diagram indicates that most of the samples were of Na–Cl type. The Na–Cl characterization of groundwater in the undulating sedimentary terrain was not due to primary salinity, but due to the combined effects of irrigation salinity and improper sanitation facilities existing in the watershed area. The groundwater recharge through and within the formation is cyclic in nonacidic condition, which keeps the groundwater chemically fresh. The predominance of Ca–HCO_3 in the beginning and mid stream portions of the segmented channel indicates that the fresh water sources from the adjacent groundwater aquifers contribute to stream discharge. In the Wilcox diagram, 90% of the samples fell in the S1–C1 sector indicating that the groundwater samples and stream water samples were suitable for irrigation.

The high bacterial contamination and alkaline nature of water noticed in all samples irrespective of the geographic location indicated that the water table aquifer and stream water were exposed to a non-sterile environment. From the present study it may be concluded that the watershed is highly sensitive and the chemical behaviour of groundwater and stream water is largely influenced by various natural and artificial recharging processes taking place within the watershed.

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