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Assessment of groundwater quality in and around the solid waste dump site using multivariate plot analysis

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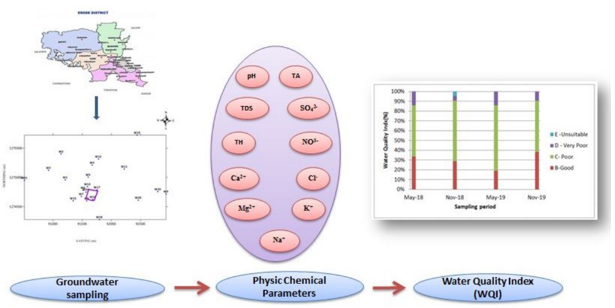
Graphical abstract



Abstract

Groundwater sources play an important role in meeting the day today needs of the present generation. Frequent monitoring of the ground water source plays an important part. The aim of this study is to analyze the quality of the ground water in and around the solid waste dumpsite near Sathyamangalam town in Erode district and to identify the variation in concentration with respect to time. Groundwater samples were collected from twenty-one locations and analyzed for pH, Electrical conductivity, Total Alkalinity, Total Hardness, Total Dissolved solids, Calcium, Magnesium, Chlorides, Sodium, Potassium, Nitrates and Sulphates. The collected groundwater samples were analysed using "Weighted Arithmetic Index" and the water quality was indicated using WQI - a number used to identify the water quality easily by the general public. From the results obtained, it is inferred that Water Quality Index changes with respect to pre-monsoon and post monsoon seasons and different time periods for the same location. The changes in water quality are not fully influenced by the open dump site and it may be due to weathering of rocks, use of fertilizers in agricultural lands. Majority of the samples are of poor quality with respect to drinking water quality index. Gibb's plot, Wilcox diagram and United States Salinity Laboratory diagram are used to assess the suitability of groundwater samples for irrigation purpose. Most of the samples are good for agricultural use. Hence frequent and continuous monitoring of the groundwater quality is necessary to identify its suitability for drinking and agricultural purpose.

Keywords: Open dumpsite, Sathyamangalam, physic-chemical parameters, water quality index (WQI), agricultural use

1. Introduction

Water is the elixir of life. India is dependent on surface and groundwater resources for most of the activities. Due to the boon in industrial, urban and agricultural sectors, most of the water resources are polluted and does not meet the standards for potability (Jyothi *et al.*, 2020; Dhayachandhran and Jothilakshmi, 2020; Jasmin and Mallikarjuna, 2014; Sudharshan Reddy Yenugu *et al.*, 2020; Mthembu *et al.*, 2021). The available groundwater is overexploited due to rapid urbanization and industrialization. Groundwater has become a precious asset in most of the arid and semi-arid regions (Sakthivel Duraisamy *et al.*, 2018).

Storm runoff with toxic pollutants, if discharged into the surface water sources may pollute them. Polluted surface sources may have a serious effect on the social, economic and sustainable development (Huihui Wu *et al.*, 2020). The improper management of Municipal Solid Waste and lack of sufficient Sanitary Land Fills pose a serious threat to the developing countries (Rowland and Omonefe, 2021). During precipitation, leachate, a liquid formed from the dumped solid wastes may infiltrate and pollute the ground water sources. Leachate with toxic substances while infiltrating into the ground, may pollute the aquifers.

The polluted groundwater may cause many ill effects to the consumers as well as the environment. The consumers may prone to life threatening diseases and the polluted ground water may take several decades to resume its original state (Sowmya Munagala *et al.*, 2020).

Open dump site forms a major pollution source it terms of water, air and soil. Present study focuses on the open dumpsite in Sathyamangalam town, its influence on the water quality in aquifers around it.

2. Water quality index

Groundwater quality depends on different factors such as recharged water quality, precipitation and geochemical processes at the sub surface. Since the groundwater moves through the porous media of aquifers and comes in contact with rock surfaces, it is expected to contain high mineral content when compared to surface water sources. It is really a hectic task to clean the aquifers once it becomes contaminated and also it may take several decades to remove the contamination (Anjali Malan and Hardeep Rai Sharma *et al.*, 2018).

Pollutants in the surface water may be same or different from the groundwater pollutants depending on the hydrogeological parameters of an area (Dhayachandhran and Jothilakshmi, 2020). Agricultural run -off, industrial effluents, municipal sewage and religious activities form the main source of organic and inorganic pollutants (Basheer A. Elubid *et al.*, 2019). For the evaluation of ground water quality, hydro chemical parameters (major cations and anions) are more important in addition to the physico–chemical properties (Madan Kumar Jha *et al.*, 2020).

The standards for potability and other uses are set by the Bureau of Indian Standards [BIS 2005], World Health Organisation (WHO 1993) (Jyothi *et al.*, 2020) [BIS 1993] and Indian Council for Medical Research (ICMR).

The suitability of ground water for drinking can be analyzed using Drinking Water Quality Index. The quality of groundwater primarily depends upon the natural conditions such as intensity and duration of rainfall, soil strata, and geochemical properties of aquifers. The variation in the quality of groundwater may be due to many reactions such as diffusion, dispersion, interception, oxidation, reduction, ion exchange etc., (Jasmin and Mallikarjuna, 2014). Decline in the quality of water poses a serious threat to the ecosystem (Olandia Ferreira Lopes *et al.*, 2020). Weathering of rocks also plays an important role in deciding the quality of groundwater. In India, both domestic and agricultural activities depend on ground water (Sudharshan Reddy Yenugu *et al.*, 2020). Ground water is one of the major water sources in arid and semi -arid region (Majid Rad Fard *et al.*, 2019).

WQI is a dimensionless value which is used to identify the overall quality of water. Various water quality parameters are used to identify this water quality index (Huihui Wu *et al.*, 2020; Sudharshan Reddy Yenugu *et al.*, 2020). It is easy for the public to predict the quality of water with the help of WQI (Douglas Kwasi Boah *et al.*, 2015). It is an effective tool to judge the water quality (Olandia Ferreira Lopes *et al.*, 2020). The WQI was supported by the National Sanitation Foundation's Index (NSF –WQI). WQI helps the public to easily understand the quality of water (El-Sayed and Shaban, 2019). Heavy metal Evaluation Index (HEI) is used to rate the quality of water with respect to the concentration of heavy metals in the water sample (Md. Morshedul Haque *et al.*, 2020). In this study, "weighted arithmetic index" method, a universally accepted mathematical tool was used for assessing the water quality index (Basheer A. Elubid *et al.*, 2019).

The objectives of the present study are (i) to identify the physico chemical parameters of ground water, (ii) to infer the WQI of the groundwater samples and their suitability for drinking and agricultural purposes (iii)to identify the influence of open dumpsite and other sources on the water quality in the aquifers around the open dumpsite

3. Study area

Sathyamangalam is a municipal town located on the foothills of the Western Ghats extending towards the east of Nilgiri Mountain, in Erode district of Tamil Nadu state in India. It lies on the banks of river Bharani, a tributary of Cauvery. It is about 70 km from Coimbatore and 450 km from Chennai. The area of the Municipality is 29.24.sq. km. The population of the town is 37805 as per the 2011 census. The floating population is around 5000. The population density of the town as per the 2011 census is 1293/ sq.km [Census of India, 2011]. The Urban Local Body (ULB) consists of 27 wards. The general topography of this town is covered by sloping lands. The river Bhavani flows at the center of the town from west to east. Agricultural wetlands are predominant on both sides of the river and drylands are predominant on the northern side of the town. The latitude and longitude of Sathyamangalam are 11° 30' 17.1936'' N and 77° 14' 18.2256'' E.

The open dumpsite is located towards the Eastern side of the town at about 2 km and it is on the Southern side of Sathyamangalam Athani - Bhavani Main Road. The Malaiyadipudur dump site has been operating since 1970. The quantity of solid waste generated in the town is 16.0 MT/day. The per capita waste generation is 412 grams/day. The dump height is around 3 to 4 m above the ground level and 1 m below the ground level. Out of the total waste generated, the vegetable waste from the market is crushed to uniform size using a vegetable crusher and made into compost by windrow composting. The waste from the residential area is collected without separation and dumped without any daily or intermediate cover. The lining is not provided at the bottom of the dump. The dump is protected by fencing on all four sides. The layout of the study area with groundwater sampling locations with respect to the state and district is shown Figure 1a, 1b and 1c.

3.1. Geology and hydrogeology (from TNAU)

The study area is located in a tropical semi-arid region with an average annual rainfall record of 717 mm. This area recorded an average maximum temperature of 33.9° C and an average minimum temperature of 21.6° C. The average wind velocity prevailing in this area is 3.2 kilometre per hour. The average evaporation rate is 4.3 mm per day with sunshine hours ranging from 3.7 to 7 per day.

The area consists of reddish brown to yellowish brown loam, sandy loam and clayey loam soil. The soil is either calcareous or non - calcareous, well drained to poorly drained, neutral to alkaline nature, single grain, granular and sub angular blocky having low content of macro and micro nutrients. The soil is generally shallow to moderately deep. The soil type along the banks of the river Bhavani is mostly alluvial in nature. The Sathyamangalam taluk includes schistose – quartzite, sillimanite – quartzite, sillimanite – quartzite, talc – tremolite / Actinolite schist / hornblende schist, Amphibolite and Gabbroanorthosite and Pyroxenite. Schistose rocks occur as enclaves near Sathyamangalam. Sathyamangalam is a major multicrop station in Erode district and engaged in research activities of many agricultural and horticultural crops. The hydorgeological map of the study area is shown in Figure1d [Reference: tnau.ac.in/ars-bhavanisagar/establishment/].

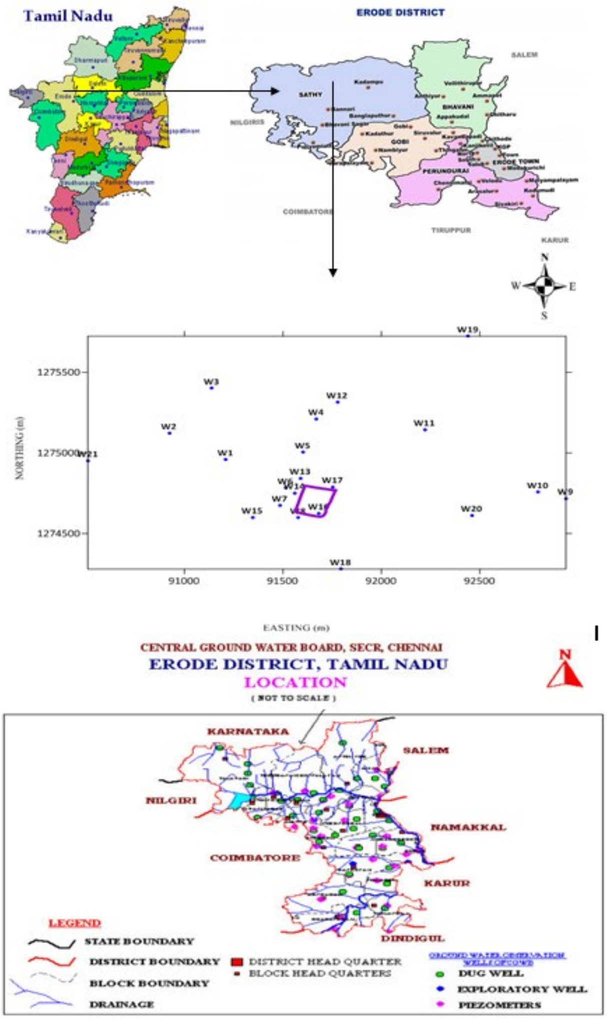


Figure 1. Source: traveldealsfinder.com Figure 1a. Location of Erode in TamilNadu State MapSource: districts.ecourts.gov.in Figure 1b. Location of Sathyamangalam in Erode District Map Figure 1c. Layout of the study area (Sathyamangalam Open Dumpsite) with groundwater sampling locations Figure 1d Hydrogeological map of Erode District Source: https://cgwb.gov.in/District_Profile/TamilNadu/Erode.pdf

4. Materials and methods

4.1. Solid waste composition

To identify the composition of solid waste generated in the town, the solid waste samples were collected from the trucks during disposal for five days consecutively. The collected fresh solid waste was mixed thoroughly and separated by coning and quartering method. One part of the solid waste was taken for analysing the composition and weighed before segregation. The weighed solid waste was separated into different categories such as paper, plastics, wet waste, inert, metal, glass, cloths/textiles, silt etc., and their individual percentage composition was calculated with respect to the total weight (Kanmani and Gandhimathi, 2013). Since most of the vegetable (wet) wastes were separated, grinded into fine pieces using organic shredder and made into compost, the generation of leachate is nearly very less. Table 1 shows the waste generation rate from different areas in Sathyamangalam and clearly indicates that out of the total waste generated, around 60% are from residential area.

Table 1. Type of area and waste generation rates.

S.No.	Type of area	Waste Generation Rate (Metric Tonnes/day) *
1.	Residential	9.5
2.	Markets	1.0
3.	Commercial	5.0
4.	Industrial	Nil
5.	Silt	1.5
6.	Construction & demolition waste	Nil
	Total	16.0

**Source: Sanitary Division - Commissioner Office – Sathyamangalam*

4.2. Groundwater sample collection

Random sampling method was adopted to collect the groundwater samples for physicochemical analysis. Ground water samples were collected from 21 locations around the open dumpsite, by considering the topography, type of use and location with respect to the dumpsite. The collection was done for two consecutive years 2018 and 2019 during pre-monsoon (May, 2018 and 2019) and post monsoon (November -2018 and 2019) (Hossain and Patra, 2020); (Kale *et al.*, 2010). Out of the 21 samples collected, 5 samples were from open wells and the remaining 16 samples were from bore wells. The location of the sampling points was identified using the GPS device Juno SA Version 5.86 and shown in Table 2 (Zhaoshi *et al.*, 2018). Water samples from both the open wells and tube wells were pumped for 5 to 15 minutes before sampling. The collected water samples were stored in 1 L capacity polypropylene bottles. The bottles were rinsed and washed with respective sample water before collection. After collection, they were preserved at 4°C in a refrigerator and the physicochemical parameters were analysed within a period of 2 days as per the specific standards (Zakir *et al.*, 2020). The pH and electrical conductivity (EC) of the collected water samples were recorded immediately in the laboratory before storage (Sowmya Munagala *et al.*, 2020; Zhaoshi *et al.*, 2018; Ragab El Sayed Rabeiy, 2017; Hossain and Patra, 2020; (Kanmani and Gandhimathi, 2013).

Table 2. Details of sampling location

Water sample locations	Type of well	Northing (m)	Easting (m)
W1	Open well	1274959	91209
W2	Open well	1275121	90922
W3	Open well	1275401	91139
W4	Bore well	1275210	91670
W5	Bore well	1275003	91602
W6	Bore well	1274782	91514
W7	Bore well	1274674	91485
W8	Bore well	1274598	91578
W9	Bore well	1274718	92936
W10	Bore well	1274756	92795
W11	Bore well	1275144	92219
W12	Bore well	1275314	91776
W13	Open well	1274842	91589
W14	Bore well	1274752	91560
W15	Bore well	1274600	91345
W16	Bore well	1274624	91683
W17	Open well	1274789	91753
W18	Bore well	1274280	91794
W19	Bore well	1275724	92441
W20	Bore well	1274612	92460
W21	Bore well	1274951	90509

Table 3. Water Quality parameters, Weight, Relative weight and WHO standards (Jasmin and Mallikarjuna, 2014)

S.No.	Parameters	Weight (w_i)	Relative weight (W_i)	BIS/WHO standards (S_i)
1	pH	5	0.135	8.5
2	TDS	5	0.135	500
3	TH	4	0.108	100
4	Ca^{2+}	4	0.108	75
5	Mg^{2+}	3	0.081	50
6	Na^{+}	4	0.108	200
7	K^{+}	2	0.054	12
8	Cl-	4	0.108	200
9	NO^{3-}	2	0.054	45
10	SO_4^{2-}	3	0.081	200
11	Total Alkalinity	1	0.027	500
		$\sum w_i = 37$	$\sum W_i = 1.000$	

4.3. Analytical methods

The physicochemical parameters such as total hardness (TH), total alkalinity (TA), major anion such as chlorides (Cl^-), and major cations such as calcium (Ca^{2+}), magnesium (Mg^{2+}) were analysed by titrimetric methods. Cations such as Sodium (Na^+) and Potassium (K^+) were analysed using flame photometer (Zhaoshi *et al.*, 2018). Nitrate (NO^{3-}) and Sulphate (SO_4^{2-}) were analysed using PC based double beam UV spectrophotometer. The total dissolved solids (TDS) was analysed by gravimetric method. The Electrical conductivity (EC) was measured using conductivity meter. Hydrogen potential (pH) was measured using electrode pH meter. All the physico chemical parameters were analysed as per APHA standard methods [APHA, 1998]; (Ragab ElSayed Rabeiy, 2017; Kanmani and Gandhimathi, 2013).

4.4. Quality control in the analysis

Buffer tablets of pH 4.0, 7.0, 9.0 and 12.0 were used to calibrate the pH meter electrode. Standard Potassium chloride solution 0.01M (1413 µScm-1) was used to calibrate EC meter electrode. In order to maintain the accuracy in the analytical results, blank sample (ie., deionized water) was analysed for all the parameters. Analytical reagent grade chemicals were used for the analysis of collected water samples. The glass wares used for the analysis were washed with acid solution and deionized water to avoid contamination (Zakir *et al.*, 2020; Kanmani and Gandhimathi, 2013).

4.5. Water quality index (WQI)

Water Quality Index (WQI) provides an explicit picture about the suitability of water for different purposes such as drinking, agricultural and industrial use. The quality of groundwater for drinking and agricultural purposes can be identified using Water Quality Index (Jasmin and Mallikarjuna, 2014; Douglas Kwasi Boah *et al.*, 2015; Ghulam Shabir Solangi *et al.*, 2019; Mthembu *et al.*, 2021).

4.6. Drinking water quality index (DWQI)

WQI is a numerical value which clearly communicates about the overall quality of water to the concerned users.

This is calculated by weighted index method. In this study eleven parameters namely pH, Total Dissolved Solids, Total Hardness, Total Alkalinity, Calcium, Magnesium, Potassium, Sodium, Nitrates, Chlorides and Sulphates. Weights (w) were assigned to individual water quality parameters(i), based on their importance in deciding the quality of water (Jasmin and Mallikarjuna, 2014; Indrani Gupta *et al.*, 2015; Sudharshan Reddy Yenugu *et al.*, 2020; Majid Rad Fard *et al.*, 2019; Ghulam Shabir Solangi *et al.*, 2019). National Sanitation Foundation Water Quality Index (NSFWQI) is used to find the ground water quality index (Jyotiprakash Nayak *et al.*,2020; Sowmya Munagala *et al.*, 2020; Divahar *et al.*, 2020).

Based on the weight assigned, relative weight(W_i) was computed using the equation (1)

$$W_i = \frac{w_i}{\sum_{i=1}^{n} w_i} \quad (1)$$

Where w_i = individual weight of water quality parameter, n = total number of water quality parameters.

The water quality parameters were assigned individual weights in a 5-point scale based on their importance in deciding the quality of water. The individual weights assigned, and the relative weights were shown in Table 3. The water quality parameters such as pH and Total Dissolved Solids were given the highest weightage of 5 due to their importance in the drinking water quality assessment. Alkalinity was given the lowest weightage of 1, since is it not very significant in the assessment of water quality. The remaining parameters such as total hardness, major anions and cations were assigned a weightage in between 1 and 4 based on their importance in the assessment of water quality (Jasmin and Mallikarjuna, 2014).

Table 4. Drinking Water Quality Index (DWQI) (Sudharshan Reddy Yenugu *et al.*, 2020; Majid Rad Fard *et al.*, 2019)

S.No.	WQI Value	Grading	Water Quality Rating
1	Below 50	A	Excellent
2	50 -100	B	Good
3	101 - 200	C	Poor
4	201 -300	D	Very Poor
5	Above 300	E	Unsuitable for drinking purpose

For each parameter, a quality rating scale (q_i) was calculated using equation (2),

$$q_i = \frac{C_i}{S_i} * 100 \quad (2)$$

Where C_i = the concentration of concerned water quality parameter (i) in the respective units and S_i = Standards of water quality parameter with respect to WHO standards [WHO 1993] (Douglas Kwasi Boah *et al.*, 2015).

The sub index (SI_i) of each water quality parameter was determined using equation (3),

$$SI_i = W_i * q_i \quad (3)$$

Drinking Water Quality Index (DWQI) was calculated using equation (4),

$$DWQI = \sum SI_i \quad (4)$$

The water quality was classified based on DWQI and specified in (Table 4). The maximum, minimum, mean and standard deviation of the water quality parameters collected during the four periods were shown in (Table 5).

4.7. Suitability of water for agricultural use

The suitability of groundwater for agricultural purposes was determined by finding the Sodium Adsorption Ratio (SAR), Magnesium Adsorption Ratio (MAR), Kelly's ratio (KR), Soluble Sodium Percentage (SSP) and Permeability index using the equations 5-9 (Md. Morshedul Haque *et al.*, 2020; Basheer A. Elubid *et al.*, 2019; Mthembu *et al.*, 2021). SAR values less than 10, 10 to18, 18 to 26 and greater than 26 are considered to be excellent, good, doubtful and unsuitable for irrigation purposes respectively. High SAR values are proved to be a great threat to the plant growth. Presence of Na^+ ion in irrigation water may reduce air circulation, porosity and ultimately affect the plant (Md. Morshedul Haque *et al.*, 2020). Kelly's ratio is the ratio between Sodium ion concentration and Calcium – Magnesium ion concentration. If KR is less than 1, the water is suitable for irrigation and if it is greater than one it is not suitable for irrigation.

Wilcox diagram, a semi-log scatter plot with SAR on the Y –axis and the salinity hazard (Electrical conductivity) on the Y- axis was plotted to identify the sodium hazard. USSL (United States Salinity Laboratory Staff, 1954) diagram was used for the classification of water samples for irrigation (Majid Rad Fard *et al.*, 2019). USSL diagram a semi log scatter plot with SAR (Sodium Hazard) on the Y –axis and the salinity hazard (Electrical conductivity) on the Y- axis was plotted to identify the sodium hazard. S1, S2, S3 and S4 represent low, medium, high and very high Sodium Hazard. C1, C2, C3 and C4 represents low, medium, high and very high salinity hazard (Priyanka *et al.*, 2017).

$$SSP(Na\%) = \frac{Na^+ + K^+}{Ca^{2+} + Mg^{2+} + Na^+ + K^+} * 100 \quad (5)$$

$$SAR = \frac{Na^+}{\frac{\sqrt{(Ca^{2+} + Mg^{2+})}}{2}} \quad (6)$$

$$MAR = \frac{Mg^{2+} * 100}{Ca^{2+} + Mg^{2+}} \quad (7)$$

$$KR = \frac{Na^+}{Ca^{2+} + Mg^{2+}} \quad (8)$$

$$PI = \frac{Na^+ + \sqrt{HCO_3^-}}{Ca^{2+} + Mg^{2+} + Na^+} \quad (9)$$

4.8. Evolution of groundwater chemistry

In order to detect the sources of dissolved chemical components such as precipitation dominance (PD), rock dominance (RD) and evaporation dominance (ED) in the study area, Gibbs diagrams are plotted. In Gibbs diagram the anions $Cl^-/(Cl^- + HCO_3^-)$ and cations $Na^+/(Na^+ + Ca^{2+})$ are plotted against TDS (Sudharshan Reddy Yenugu *et al.*, 2020; Youzef Nazzal *et al.*, 2014; Mthembu *et al.*, 2021).

5. Results and discussion

The study area was delineated, the water sampling stations and the water quality index in and around the dumpsite for the four different periods were shown in the maps drawn using Surfer 16 software and represented in Figures 2(a),2(b),2(c) and 2(d).

5.1. Physic chemical parameters of water samples

5.1.1. pH

pH of the water sample is dependent on the concentration of carbon dioxide, carbonates and bicarbonates. Chemical constituents in water may be harmful to living beings (Arulnangai *et al.*, 2020). The pH of most of the water sample collected was within the limit specified by WHO (6.5 to 8.5) except the sample WS16 collected inside the open dump site and shown in (Table 5). The sample location is inside the dumpsite. It had a pH of 8.94 which is slightly alkaline. The alkalinity may be due to the dissolution of gases and carbonate minerals (Arulnangai *et al.*, 2020; Sudharshan Reddy Yenugu *et al.*, 2020) or may be due to the presence of biodegradable organic compounds (Basheer A. Elubid *et al.*, 2019).

5.1.2. Electrical conductivity

The electrical conductivity is dependent on the concentration of dissolved salts present in the sample. The EC of all the collected samples exceeded the permissible limit specified by WHO (600 µmho/cm). This may be due to the presence of excess salt content in the water samples (Arulnangai *et al.*, 2020; Sudharshan Reddy Yenugu *et al.*, 2020). The excess salt content may be due to the disintegration of rocks or may be due to evaporation, since the Gibb's diagram represented in Figure 4 shows that the area is prone to evaporation and rock weathering dominance and none of them are prone to precipitation dominance. Presence of excess salt in the water sample may make it unfit for drinking as well as agricultural purpose. The EC of the samples ranged from 793 µmho/cm to 5030 µmho/cm as shown in Table 5.

5.1.3. Total dissolved solids (TDS)

Presence of total dissolved salts in water affects its taste. The highest concentration of TDS was 3825 ppm. TDS includes inorganic salts and small amounts of organic matter present in solution in water. This may be due to the disintegration/dissolution of rocks in the underground aquifers, since the area is more prone to evaporation and rock weathering dominance as clearly indicated in Gibb's diagram in Figure 4. This may lead to increase in hardness and corrosion and it depends upon the type of rocks present under the ground surface The permissible limit for TDS as per WHO (500 ppm) (Arulnangai *et al.*, 2020; Sudharshan Reddy Yenugu *et al.*, 2020).

5.1.4. Hardness

Carbonates and bicarbonates of calcium and magnesium are responsible for hardness in water. Hardness of most of the samples exceeds the WHO standards (500 ppm). Excess hardness may cause scales in boilers used in industries (Arulnangai *et al.*, 2020). The leaching of calcium and magnesium ions may impart high hardness to the water samples (Sudharshan Reddy Yenugu *et al.*, 2020). In the collected samples, the minimum hardness was 150 ppm and the maximum was 910 ppm.

5.1.5. Ions

5.1.5.1 Calcium

Calcium is found to be anti- carcinogenic. It is essential for the development of bones. Calcium content in the water samples ranged from 21 ppm to 301 ppm. The permissible limit for Calcium as per WHO is 100 ppm. In most of the samples the concentration exceeded the permissible limits, this may be due to the extraction of Calcium from the soil, when water infiltrates through it (Arulnangai *et al.*, 2020).

5.1.5.2 Magnesium

Magnesium is essential for efficient functioning of the heart, but elevated levels prove to be harmful. It may have some purgative effect in drinking water. The magnesium concentration ranged from 1 ppm to 50 ppm in the analyzed water samples, which were found to be within the WHO permissible limit of 150 ppm (Arulnangai *et al.*, 2020).

5.1.5.3 Chloride

Chloride concentration is mostly associated with sodium chloride which is a common constituent in groundwater sources. Chloride values of water samples varied between 97 ppm and 896 ppm. Chloride concentration in many ground water samples exceeded the WHO permissible limit of 250 ppm. This may be due to the contamination of groundwater with fertilizers applied to the agricultural fields or may be due to the disintegration of rocks (Arulnangai *et al.*, 2020) or may be due to leaching of the topsoil by domestic activities and dry climate (Sudharshan Reddy Yenugu *et al.*, 2020).

5.1.5.4 Sodium

The sodium concentration varied between 23 ppm and 140 ppm. Agricultural practices carried in the region may contribute to the highest concentration of sodium (Sudharshan Reddy Yenugu *et al.*, 2020).

5.1.5.5 Potassium

The potassium concentration varied between 5 ppm and 35 ppm. High concentration may be due to leaching into the aquifers through the soil. Sodium and potassium, if exceed the permissible limit may prove to be harmful to human health, causing many disorders (Sudharshan Reddy Yenugu *et al.*, 2020).

5.1.5.6 Nitrate

Nitrate due to its high mobility will not stick to soil particles or aquifer geologic materials. High concentration of nitrate leads to a disease called blue baby syndrome or methamoglobinemia in children. Nitrate concentration in the samples varied from 5 ppm to 16 ppm and found to be within the permissible limit of WHO (50 ppm) (Arulnangai *et al.*, 2020).

5.1.5.7 Sulphate

The water sample values varied between 10 ppm and 92 ppm. Permissible limit of sulphate as per WHO standard is 50 ppm (Arulnangai *et al.*, 2020). Mineral dissolution and other anthropogenic sources such as the application of Gypsum (an important fertilizer and a soft sulphate mineral) to the agricultural fields.

5.2. Drinking water quality index (DWQI)

Figure 2(a) shows the status of Water Quality Index around the open dump site during the pre-monsoon period (May 2018), 33%, 52% and14% of the samples are of good, poor and very poor quality respectively and none of the sample is either excellent or unsuitable for drinking purpose. Figure 2(b) depicts that out of the total 21 samples 29%, 62%, 5% and 5% are of good, poor, very poor quality and unsuitable for drinking purpose respectively and none of the sample is excellent for drinking purpose. Figure 2(c) shows the status of water quality index for the samples collected during the pre -monsoon period in 2019. Of the 21 samples none of the sample was of excellent quality and also none was unsuitable for drinking purpose. 19%, 67%, 14% were of good, poor, very poor quality respectively. The water quality index during the post monsoon period in 2019, shown in Figure (2d) depicts that 38%, 52% and 10% of samples are of good, poor and very poor quality respectively. No sample was excellent or unsuitable for drinking purpose.

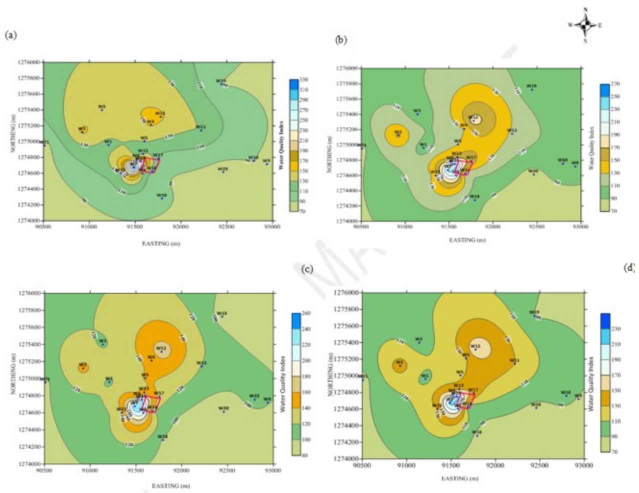


Figure 2. (a)(b)(c)(d). Water Quality Index around the open dump site during (May 2018), (November 2018) (May 2019) and post-monsoon (November 2019)

The percentage of excellent (A), good (B), poor (C), very poor (D) and unsuitable (E) samples with respect to WQI index, for all the twenty-one locations during the pre and post monsoon period (May and November) are shown in Figure 3. The WQI contour maps show that the water quality is not fully influenced by the wastes dumped in the open dump site since the quality variation is not proportion to the open dumpsite location. It may be due to the agricultural activities practiced around the dump site or may be due to the natural attenuation process or to some extent may be due to the solid waste dumping. The variation in water quality index is also not uniform. This may be due to the varying rainfall duration and intensity throughout the year and also the changes in the anthropogenic activities in and around the dumpsite.

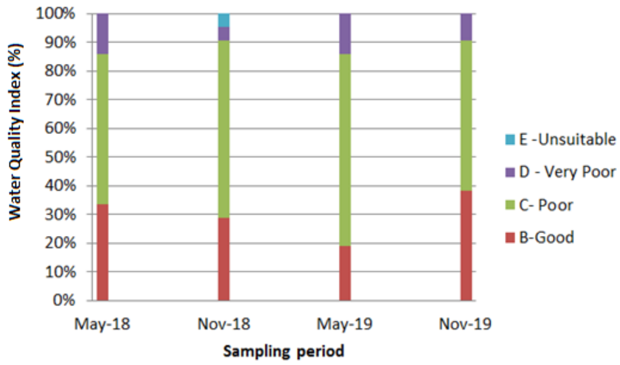


Figure 3. Proportion of water quality grades

Figure 3 shows the proportion of different water quality grades in four periods. From the figure it is inferred that the WQI is not the same during the pre and the post monsoon periods of the same year. Also the WQI is not the same during the pre-monsoon and post-monsoon seasons of two consecutive years. The fluctuation in water quality index may be due to the non – uniform rainfall in the study area, may be due to rock water interaction in the aquifers and may be due to various anthropogenic activities happening around the open dump site.

5.3. Hydrogeochemical evolution

From the Gibb's diagram Figures 4(a) to 4(h), it is observed that the maximum number of collected ground water samples fall in between rock dominance and evaporation dominance. Figures 4(a)-4(b), 4(c)-4(d), 4(e)-4(f), 4(g)-4(h), represents the dominance during the pre and post monsoon seasons during May 2018, November 2018, May 2019 and November 2019 respectively. Weathering of rocks and anthropogenic activities may be the cause for the above said dominance. It is clearly inferred that the groundwater chemistry in this study region is much influenced by rock –water interaction (Sudharshan Reddy Yenugu *et al.*, 2020); (Youzef Nazzal *et al.*, 2014). From the Figure 4, it can be clearly seen that the TDS concentration around the open dumpsite ranges from 500 mg/L to 4000 mg/L and $Na^+/(Na^+ + Ca^{2+})$ range for most of the samples fall between0.20 to 0.60. This ratio indicates that the Na^+ content in the water samples is lower or almost equal to that of Ca^{2+}.

The range of $Cl^-/(Cl^- + HCO_3^-)$ is between 0.05 to 0.80. Most of the concentration lie between 0.2 and 0.4, which indicates that the content of $Cl_-$is less than HCO_3^-. Few water samples are seen outside the boundary line. This may be due to some other factors controlling the chemical composition of groundwater such as ion exchange processes. None of the water samples are in the precipitation dominance area, which indicates that no direct connection exists between the hydraulic conditions and atmospheric precipitation. This clearly shows that there is no effect on the evolution of hydro geochemical properties of ground water due to open dump site.

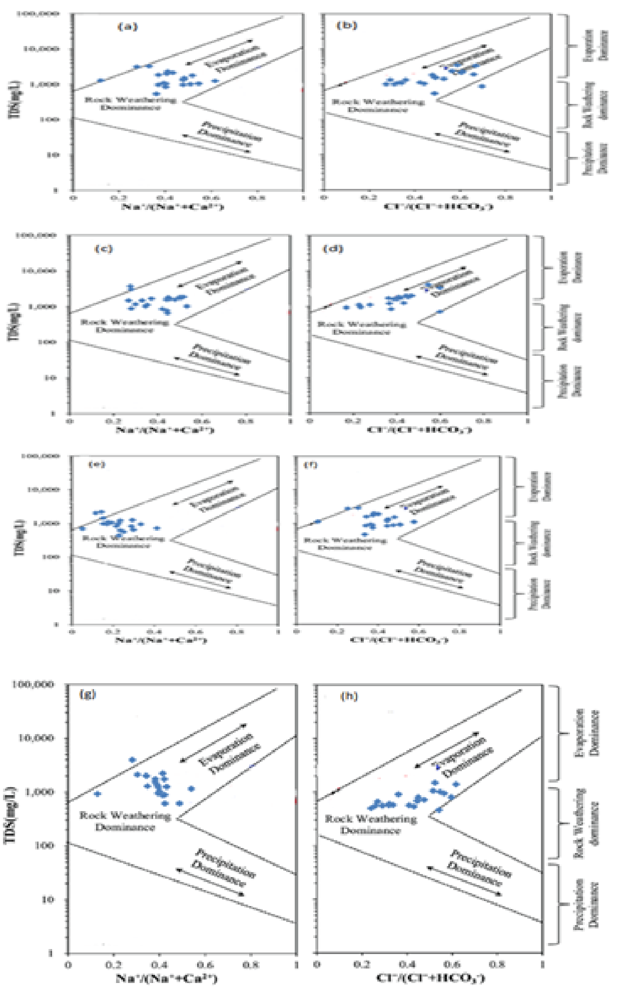


Figure 4. Hydrogeochemical evolution of ground water during: a-b) May 2018, c-d) November 2018, e-f) May 2019 and g-h) November 2019

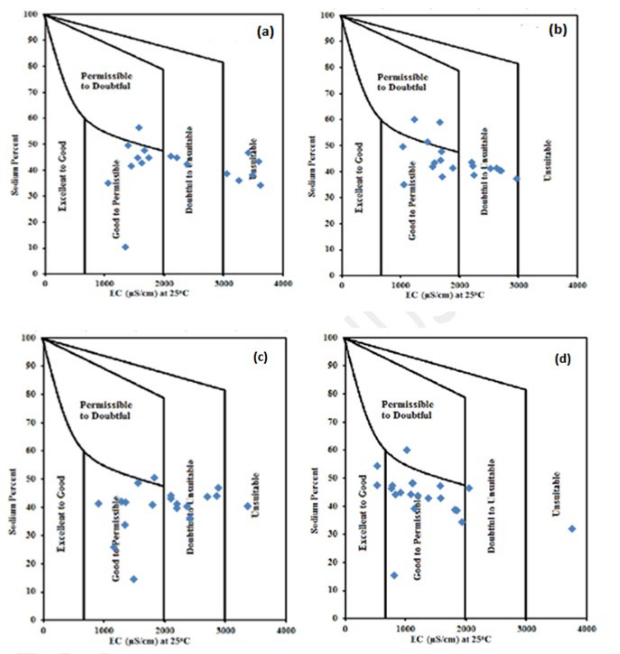


Figure 5. (a-d). Classification of water for irrigation using Wilcox Diagram (a) Samples collected during May 2018, (b) Samples collected during November 2018, (c) Samples collected during May 2019, (d) Samples collected during November 2019

Figure 5 (a-d) shows the classification of water samples for irrigation purpose. The samples collected during the different periods are classified as Good to permissible and Doubtful to unsuitable for irrigation use. More number of samples are unsuitable during the period 2018. Out of the total samples collected during post monsoon period 2019, only 5% are unsuitable for irrigation purpose, 5% falls under doubtful to unsuitable category, 5% of the permissible samples are doubtful to use for irrigation and the remaining samples are good to be used for agriculture purpose. The variation in the quality of water for irrigation use may be due to uneven rainfall intensity and duration.

With respect to Kelly's ratio (KR) 95% of the samples were suitable for irrigation and only around 5% is not suitable for irrigation.

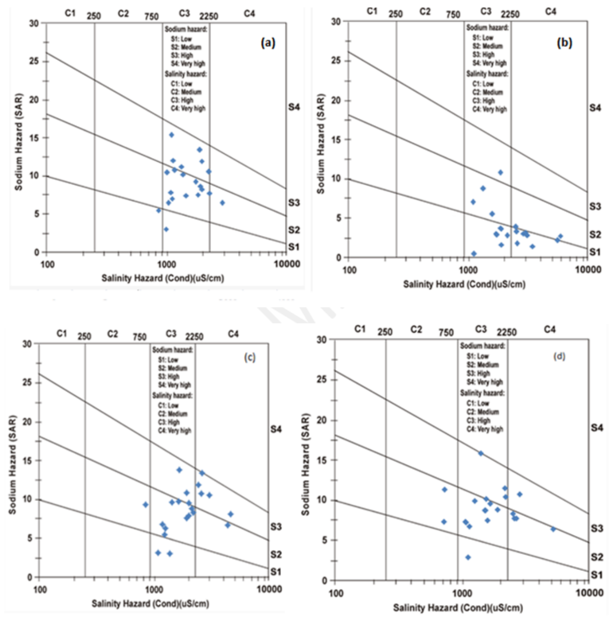


Figure 6. (a-d). Classification of water for irrigation using USSL Diagram

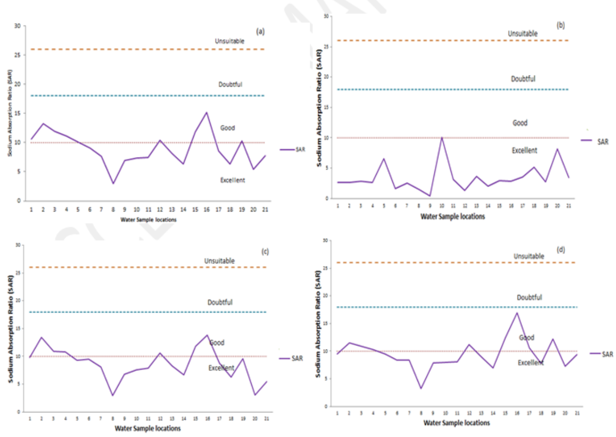


Figure 7. (a-d). Classification of ground water for irrigation with respect to SAR

Figures 6(a-d) shows the classification of water for irrigation using USSL diagram. Out of the total samples collected during May 2018, major percentage i.e., 57% of the samples showed medium sodium hazard and high salinity hazard. 5% of the samples were of low sodium and high salinity hazard, 5% of the samples were of low sodium and medium salinity hazard, 28% of the samples were of high sodium and high salinity hazard.43% of the samples collected during November 2018 were of low sodium and very high salinity hazard. 33% were of low sodium and high salinity hazard, 14% were medium sodium and high salinity hazard, 5% were of medium sodium and very high salinity hazard and 5% were of high sodium and high salinity hazard.24% of the samples collected during May 2019 showed high sodium and very high salinity hazard, 10% were of low sodium and high salinity hazard, 10% were of high sodium and high salinity hazard, high sodium and very high salinity hazard. The samples collected during November 2019 showed 43% of medium sodium and high salinity hazard, 24% showed medium sodium and very high salinity hazard, 14% showed high sodium and high salinity hazard, 5% low sodium and high salinity hazard, and 5% showed very high sodium and very high salinity hazard. Maximum number of samples collected during the four different time period showed medium to high sodium and salinity hazard. This shows that the most of the samples were not of very good quality and also not of very poor quality with respect to sodium and salinity hazard. This indicates that in due course of time the hazard may rise due to pollution and hence it has to be monitored frequently.

Table 5. Statistical summary of ground water quality data in Sathyamangalam. (Season wise)

Season	Description	pH	EC	TDS	TH	TA	Ca^+	Mg^+	K^+	Na^+	NO_3^-	Cl^-	SO_4^{2-}
Pre monsoon (May 2018) n=21	Min	6.64	1125	500	187	97	60	7	5	32	6	96	19
	Max	7.84	4470	3020	878	395	301	32	33	111	18	752	92
	Mean	7.29	2204	1434	355	274	118	14	17	70	9	286	53
	SD	0.30	883	744	167	68	57	8	7	22	4	165	24
Post monsoon (November 2018) n=21	Min	6.89	997	640	150	200	52	5	5	23	6	72	14
	Max	7.83	5030	3560	910	590	282	50	35	123	18	897	80
	Mean	7.16	2210	1494	327	328	107	15	15	67	10	294	49
	SD	0.23	1068	687	144	80	50	10	7	31	4	194	19
Pre monsoon (May 2019) n=21	Min	7.06	854	456	207	97	24	1	8	45	5	100	10
	Max	8.94	4825	3825	878	610	120	34	32	125	17	689	69
	Mean	7.52	2128	1302	357	290	470	14	21	90	10	289	29
	SD	0.55	1036	764	144	102	23	11	7	25	4	145	14
Post monsoon (November 2019) n=21	Min	6.96	1283	805	196	156	21	5	9	56	5	104	10
	Max	7.95	4256	2956	786	406	113	26	28	140	16	738	74
	Mean	7.31	2210	1420	342	296	43	13	16	90	10	279	28
	SD	0.28	793	588	147	61	20	6	5	25	3	156	16

**n = Number of samples collected*

Table 6. Pearson correlation for the hydro chemical parameters of the collected samples

Parameters	pH	EC	Total Alkalinity	Total Hardness	Ca^{2+}	Mg^{2+}	Cl^-	TDS	Na^+	K^+	NO_3^-	SO_4^{2-}
pH	1											
EC	-0.138	1										
Total Alkalinity	-0.070	0.383**	1									
Total Hardness	-0.002	0.546**	0.563**	1								
Ca^{2+}	-0.012	0.557**	0.554**	0.970**	1							
Mg^{2+}	0.030	0.173	0.324**	0.544**	0.334**	1						
Cl^-	-0.181	0.844**	0.286**	0.556**	0.536**	0.290**	1					
TDS	-0.237*	0.882**	0.386**	0.631**	0.616**	0.325**	0.793**	1				
Na^+	0.065	0.462	0.235	0.148	0.171	0.026	0.378	0.415	1			
K^+	0.019	0.463**	0.195	0.392**	0.382**	0.159	0.476**	0.381**	0.040	1		
NO_3^-	0.171	0.287**	-0.041	-0.026	-0.053	0.113	0.224*	0.176	0.139	-0.044	1	
SO_4^{2-}	-0.237*	0.586**	0.097	0.280**	0.299**	0.043	0.705**	0.558**	0.355**	0.199	0.178	1

**Correlation is significant at the 0.05 level (2 –tailed) ** Correlation is significant at the 0.01 level (2 –tailed)*

The samples collected during all the four different periods are of excellent to good quality for irrigation purpose as shown in Figures 7 (a-d). The SAR values computed for the study area varied from a minimum of 0.45 to a maximum of 16.94. Sodium Absorption ratio with a mean of 9.60 ± 2.87 standard deviation. Of the samples collected during May 2018, 43% are excellent and 57% were good to be used for irrigation. 95% of the samples collected during November 2019 were good for irrigation and only 5% were unsuitable. 72% of the samples collected during May 2019 were good for irrigation use and only 28 % were unsuitable for irrigation. 62% of the samples collected during November 2019 were good for irrigation purpose and 38% were not suitable for irrigation. It is inferred that the quality of the water samples collected with respect to SAR was highly suitable for agricultural use.

5.4. Statistical analysis

To identify the significant differences of water quality parameters among the different seasons, one-way analysis of variance (ANOVA) with Tukey post-hoc multiple comparison was performed using SPSS statistics 20.0 software (Ghulam Shabir Solangi *et al.*, 2019; Anjali Malan and Hardeep Rai Sharma *et al.*, 2018). The Pearson correlation between the physic chemical parameters is indicated in Table 6. The results shown in the table indicate high positive correlation only between EC, TDS (r = 0.882) and Cl^- (r = 0.844) (p<0.01), TH and Ca^{2+}(r = 0.970) (p < 0.01). Table 6 shows the Pearson correlation table for the water quality parameters.

6. Conclusions

This study is mainly focused on assessing the water quality for drinking as well as irrigation purpose in and around the open dump site area at Sathyamangalam town. From the analysis, the following observations and conclusions may be drawn.

1. The water samples collected in and around the open dumpsite during four different periods showed varying WQI. Irrespective of the seasons collected and their location with respect to the open dump site, majority of the samples are of poor quality with respect to drinking water standards.
2. With respect to different parameters such as Wilcox diagram, Kelly' Ratio, Sodium Absorption ratio most of the water samples are suitable for irrigation. The salinity and sodium hazard ranges from moderate to high for most of the samples.
3. In due course of time, the poor quality samples may still become poorer and at one stage they may be unfit for domestic and agricultural use. Hence it is necessary to identify the source of pollution in order to reduce the impact on the underground water quality parameters. Frequent monitoring is necessary to identify the quality of water and predict its suitability for drinking and agriculture.
4. In the open dumpsites, if the wet / organic wastes are not separated and dumped along with other wastes, there is a possibility of leachate formation resulting in the pollution of soil as well as the underground water sources. Hence it is the need of the hour to switch over from open dump sites to sanitary landfills to reduce the impact on the environment and promote sustainable development.
5. The wastes can be segregated as wet and dry waste. The wet waste can be made into compost using Effective microbes (EM) solution and windrow composting. The dry waste shall be further segregated and the plastics which are recyclable can be sent to the recycling centers and non-recyclable can be used as feed for boilers in cement factories. Other types of wastes such as thermocole, paper cardboard can be sent to recycling centers or can be used as energy recovery materials.

7. Further Study

Groundwater samples shall be collected on a monthly basis for a period of one – two years and shall be analyzed for all the physic chemical parameters. The variation in the concentration with respect to different months shall be studied and can be compared with the results obtained from other dumpsites in the district/ state/country. The reason for contamination can be identified and suitable remedial measures in terms of recycling, treatment of solid waste etc., shall be suggested to promote sustainable development.

Statements and declarations

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Competing interests

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Author contributions

All authors contributed to the study, conception of the research work. Guidelines for selection of water sample location, collection method were contributed by Authors B and C. Material preparation, data collection and analysis were performed by Author A with guidelines from Authors B and C. The first draft of the manuscript was written by Author A. Authors B and C commented on the previous versions of the manuscript. All authors read and approved the final manuscript.

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Data availability

The datasets generated during and/or analyzed during the current study are available from the corresponding author on reasonable request.

Compliance with ethical standards

Conflict of interest *The authors declare that they have no conflict of interest.*

Ethics approval *Not Applicable*

Consent to participate *Not Applicable.*

Consent to publish *Not applicable.*

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