Indonesian Journal of Geography Vol. 51, No.1, April 2019 (78- 87)
DOI: http://dx.doi.org/10.22146/ijg.28922

INDONESIAN JOURNAL OF GEOGRAPHY

RESEARCH ARTICLE

An integrated framework for identification of polluted zones: a study from coastal aquifer of India

Kishan Singh Rawat and Sudhir Kumar Singh
Centre for Remote Sensing & Geoinformatics, Sathyabama University, Chennai, India

Received: 2017-10-12
Accapted: 2018-09-20

Keywords:
Hydro-geochemical characteristics; coastal aquifer; inverse distance weighted; polluted zones; saltwater intrusion.

Correspondent email:
ksr.kishan@gmail.com

Abstract In this research work, hydro-geochemical characteristics were determined from twenty groundwater samples and classified into water quality zones on the basis of the World Health Organization (WHO 2006) using inverse distance weighted interpolation technique. Groundwater samples were analyzed with respect to calcium (Ca^{2+}), magnesium (Mg^{2+}), sodium (Na^{+}), HCO_3, total nitrate (NO_2+NO_3^-), chloride (Cl^-), sulphate (SO_4^{2-}), total dissolved solids (TDS), hydrogen ion concentration (pH) and electrical conductivity (EC) were measured form groundwater samples. The water quality indices (WQI_1 and NPI = WQI_2) were used to categorize the water. Water Quality Index (WQI) value suggest that the 65% groundwater samples (excellent + good) are safe for drinking uses and 35% groundwater samples (very poor + poor) needs treatment before consumptive uses from WQI_1. Further, NPI (WQI_2), shows 40% and 60% of groundwater falls under good and poor condition respectively. The findings highlight that the groundwater of few areas requires some degree of treatment before consumptive uses.

1. Introduction

Groundwater is an important source of water supply throughout the world (Singh et al. 2009). It is the major source of drinking water supply for the urban and rural area. The change in land use/land cover (Singh et al. 2010; Amin et al. 2014), urbanization, disposal of untreated wastewater, industrialization and mismanagement has impacts on groundwater of urban and rural areas (Guatam et al. 2013). The irrigation of vegetables with these polluted waters has impacts on human health (Bharose et al. 2013). The conventional method for monitoring of the nonpoint source pollution and analysis is field investigation and sampling analysis, which is subject to human, material, climate and hydrological conditions. The water quality indices, metal pollution indices and statistical methods are commonly used tools to evaluate lake water (Choudhary et al. 2013; Singh et al. 2016), river water and sediment (Gupta et al. 2014; Singh et al. 2017a,b), groundwater (Singh et al. 2013a; Kumar et al. 2015; Singh et al. 2015; Thakur et al. 2015; Jacintha et al. 2016; Rawat et al. 2017a,b; Gautam et al. 2018). The development of satellite remote sensing technology has provided a new approach for nonpoint source pollution research in watershed environments (Gajbhiye et al. 2015; Singh et al. 2016). It is very simple for decision-makers to know about groundwater quality using WQI (Jacintha et al. 2016).

The evaluation of groundwater quality is an important as its quantity since the physical and chemical characteristics of groundwater determine its suitability for agriculture, domestic and industrial uses. For all the above-mentioned usages, the required water should be of the different and specific quality. The quality of water is checked by measuring various parameters like pH, dissolved solids, hardness etc. Risk assessment of groundwater, involves identifying and understanding of the water quality the hazard associated with a particular occurrence, action or circumstance and determination the probability for the occurrence of such hazards (Rawat et al., 2017a; Rawat et al., 2017b; Jacintha et al., 2016; Rawat et al., 2013; Rawat et al., 2012; Smith, 2001). Hence, evaluation of groundwater quantity and quality and establishing database are important for the development of further civilization and for future water resources development strategies.

World Health Organization (WHO) has given criteria for drinking water. But to understand all these standards for common people is difficult. It is also difficult for the authority to make any decision based on these different parameters. Hence a new approach has been developed i.e. Water Quality Index (WQI), which represent the water quality in terms of a numeric value. The WQI is an important tool for decision makers (Rawat et al., 2017a, Rawat et al., 2017b, Anim et al., 2011). It is a mathematical equation used to transform a large number of water quality data into a single number (Saeedi et al., 2010). It is simple and easy to understand for decision makers about quality and possible uses of any water body (Bordalo et al., 2001; Rawat et al., 2013; Rawat et al., 2012). It serves the understanding of water quality issues by integrating complex data and generating a score that describes water quality status.

Geographical Information System (GIS) is commonly used in the field of water quality investigation (Singh et al. 2013a, b; Thakur et al. 2016; Rawat and Singh 2018a; Rawat et al. 2018c) and climate-related studies (Gajbhiye et al. 2016) to prepare the thematic maps. The interpolated maps of WQI gives detailed information to decision makers (Singh et al. 2013b; Rawat et al. 2018; Rawat et al. 2018b; Rawat et al. 2018c; Rawat et al. 2018d).

WQI reflects the composite influence of different water quality parameters and is calculated from the point of view of the suitability of (both surface and groundwater) for human consumption. Furthermore, the WQI is very useful in generating trends, demonstrating the importance of maintaining good water quality and disseminating technical water quality information to the general public. Water quality assessment can be performed using a WQI or statistical approach. However, the classification has some limitations. WQI formulas are not used as absolute measures of the degree of pollution or the actual water quality of groundwater. Although there is no globally accepted composite index of water quality, some countries and regions have used, or are using, aggregated water quality data in the development of water quality indices (Cobbina et al., 2010). Most water quality indices rely on normalizing or standardizing, data parameter by parameter according to expected concentrations and some interpretation of 'good' versus 'bad' concentrations (Jacintha et al., 2016). Parameters are often then weighted according to their perceived importance to overall water quality and the index is calculated as the weighted average of all observations of interest (Avishek et al., 2010; Saeedi et al., 2010). The index is a numerical standardized value of evaluation on a certain matter which is in composite form. Normally, this composite form has a qualitative characteristic. For instance, WQI is a single numeric expression that interprets complex information obtained from any body of water, mostly related to water quality. In this case, the evaluation process is not an easy process since there is no standard value used as a base of comparison of the evaluation. Therefore, the indices are the best way to be introduced to determine that particular standard value. A WQI representing any water ecosystem can be affected by physical and chemical factors. The objective of the study was to evaluate the water quality using indexing approach (WQI1, and WQI2/NPI) for checking the suitability of water and further to categories the water types. These indices serve as a tool to convert a large set of data into a much reduced and informative form.

The study area (Fig. 1) lies between 80° 09' and 80° 21' East longitudes and 13° 15' and 13° 21' North latitudes with a geographical area of 92.182 km2 and it comes under the Survey of India (SOI) topographical map nos. 57C6, 57C7, 57C8, and 57C3. The study area composed of coastal aquifer of Thiruvallur district which is located on the east is the Bay of Bengal, on the north is Araniyar river and south is Kosasthalaiyar river (Table 1). The western boundary is taken as 20 km west from the Bay of Bengal. This coastal aquifer is well known for an arenaceous formation called Coromandel formation (Badrinarayanan, 1978) belongs to Holocene age. The altitude of the study area varies from 1 to 20 m above the mean sea level from east to west respectively. The geological formation of the study area is upper Gondwana consists of gravel, fine to coarse sand, clayey silt, clayey sand. The study area is benefited by two monsoons viz. southwest monsoon season from June to September, northeast monsoon season from October to December.

The climate of the study area is characterized by the subtropical climate with an average temperature of 35 °C. April to June period is generally hot and dry. The annual mean temperature minimum and the maxima are 24.3 and 32.9 °C respectively. The relative humidity ranges from 58 and 84% and sea breeze in the evening hours occur during summer months. The study area gets rain in both monsoons. The north-east monsoon during the months of October, November, and December chiefly contribute to the rainfall in the area. Most of the cyclonic storms form due to depressions in the Bay of Bengal during the north-east monsoon. The south-west monsoon rainfall receives the rain during

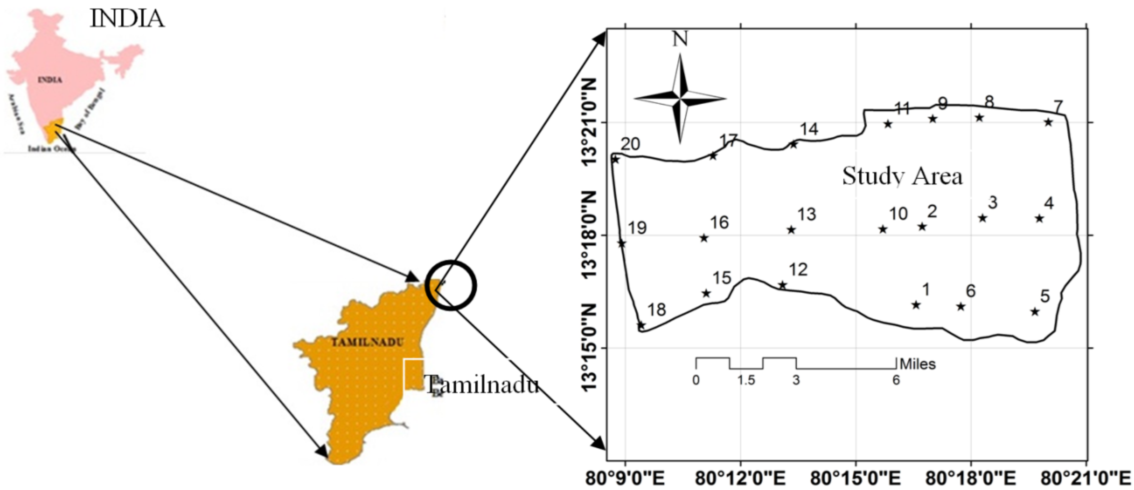


Figure. 1 Study area map showing twenty sampling locations

the months of June to September is highly erratic and summer rains during the month March to May are negligible. The average rainfall as recorded in the nearest rain gauge station at Vallur Anicut is 1260.8 mm.

The elevation ranges from 56 ft above mean sea level (AMSL) in the west to sea level in the east. The study area consists of a complex assemblage of fluvial, estuarine and marine deposits. The major part of the study area is characterized by an undulating topography with innumerable depressions which are used as tanks for storage of rainwater for agriculture. The coastal track is marked by three beach terraces with broad inter–terrace depressions. The coastal plains display a fairly low level or gently rolling surface and only slightly elevated above the local water surfaces (or) rivers. The straight trend of the coastal tract is a result of the development of vast alluvial plain. There is a number of dunes in the coastal tract. The coastal landforms include estuarine, tidal, mud flats or lagoons, salt marsh etc. The study area is mainly drained by Araniyar in north and Korattalayar in the south which is ephemeral in nature and is mostly controlled by structural disturbances along their river courses. The Araniyar, originating in Chittoor district of Andhra Pradesh, flows through the northern part of the study area and finally discharges into Bay of Bengal near Pulicat lake. The Korattalaiyar river originates from the Kaverpakkam tank in Vellore district, flows through the southern part of the study area and finally confluences with the Bay of Bengal near Ennore Backwaters.

Table 1. General information about study area

Coordinates of study area	79° 55' and 80° 25' East
	13° 00' and 13° 35' North
Country	India
State	Tamil Nadu
District	Thiruvallur
Geographical area of Study area	296.173 km^2
River nearby study area	Araniyar river (in North)
	Kosasthalaiyar river (in South)
Part of Coastal	Bay of Bengal.
Elevation range of study area	1 to 20 m
Annual mean Temperature	24.3 (min.) and 32.9 °C (max.)
Rainfall in study area	1260.8 mm (According nearest rain gauge station at Vallur Anicut)
Relative Humidity (RH) ranges	58 and 84%
Soil Type	Red soil, Black soil, Alluvial soil

Soils in the study area have been classified into i) Red soil ii) Black soil iii) Alluvial soil. The major portion of the study area is composed of the Red soil of red sandy/clay loam type. Ferruginous red soils are also seen at some places. It is poor in nitrogen, organic matter and available phosphoric acid and is suitable for cultivation of a large variety of crops. Black soils are a mostly greenish lemon to dark brown, deep to very deep, and generally occur in the depressions adjacent to hilly areas, in the western part of the study area. Black soils are fertile though poor in organic matter. Alluvial soils occur along the river courses and eastern part of the coastal areas. It is enriched with lime potash, magnesium, low in nitrogen content and deficient in phosphate. Sandy coastal alluvium (arenaceous soil) are seen all along the sea coast as a narrow belt. Generally, it is dark brown to yellowish brown in color.

Lagoonal sediments intercalated with marine deposits do not crop out but one present along the coast beneath the alluvium. It consists chiefly of grey to black sandy clay, plastic clay, silt, and fine sand. An abundance of marine shells occurs throughout these beds. The youngest formations in the area are the alluvium, which was deposited on the worn-down and eroded surface of Tertiary and Gondwana rocks by the major river. It is noted that the alluvial plains in the eastern part of the study area. The alluvium consists of gravel, fine to coarse sand, clay and sandy clay of various shades of grey and brown. Exploratory drilling shows that the thickness of these deposits increase progressively in an easterly direction towards the coastline east of Minjur,

Table 2.Unit weight of parameters based on the World Health Organization (WHO 2006)

Parameters	Highest Permitted value of Water (Sn)	Unit weightage (Wn)
pH	8.5	0.635
EC	1400	0.004
Ca^{2+}	75	0.072
Mg^{2+}	50	0.108
Na^{+}	200	0.027
Cl^{-}	250	0.022
SO_4^{2-}	400	0.013
HCO_{3-}	1000	0.005
NO_2+-NO_3-	50	0.108
TDS	1000	0.005
	K=5.3997	∑Wn=1

where it is about 50 – 60 m thick. The wind deposited sand, in the form of irregular, low flat dunes ranging in width from less than 0.1km to about a kilometer occur along the coast, except where they are interrupted by the river outlets. The most striking dunes are near Pulicat, where they have grown by wind action into irregular mounds of 12 to 15m high. No indication of crystalline rocks has been recorded over the whole area reaching to Ponneri and Pulicat lake. The granular zones encountered at different depths in the porous formation (Sedimentaries) consist of very fine to coarse sands, silts, and clays in varying proportions and semi-consolidated Gondwana Sandstones. The lithologies show the heterogeneity of the formations. The recent alluvium is deposited over the older formations of the Gondwanas and Archaeans. Eastern and middle part of the study area is Porous formation consisting of Gondwana and recent alluvium which comprise sandstones, clays sands, and shale. The area is underline by alluvium followed by Gondwana sandstone form good aquifers due to good recharge from the overlying permeable zone (alluvium). The depth of dug wells varies from 6.00 to 16.60 m below ground level (BGL) and depth to water level in them varied between 2.20 and 14.15 m BGL. The average yield of the wells is the order of 160m3/day, whereas the yields of boreholes tapping the granular zones of the top alluvium and the weathered Gondwana sediments generally vary from 1 to 3 lps. Quality of water varies from brackish to portable. In the areas pierce the shale, sandstone, and claystone, groundwater occurs under water table to confined conditions. The depth of dug wells varies from 7.00 to 18.00 mbgl and depth to water level in them varied between 3.50 and 11.50mbgl. It is recorded discharges varying from 2 to 3 lps. In the study area, the unconsolidated sediments are represented by fluvial and coastal alluvium. The coastal alluvium is restricted to the eastern part of the study area. The fluvial type

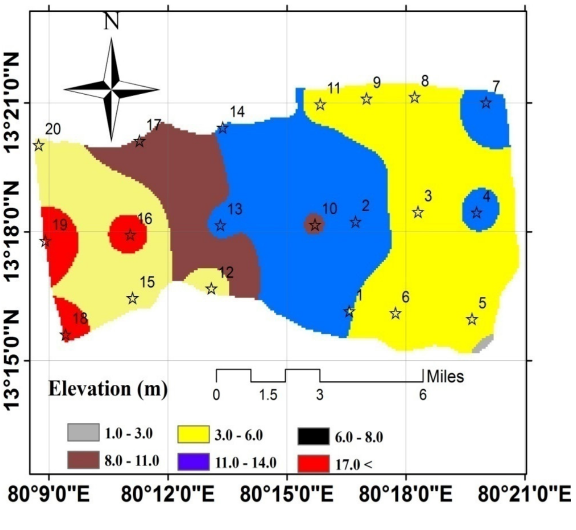


Figure. 2 Elevation map of sampling points

(river) alluvium occurs along the river courses of Araniyar and Korattalaiyar. These consist of fine to coarse-grained sands, gravels, pebbles, and clays.

2.Methods

Collection of data

The groundwater quality data of 20 locations during the post-monsoon season (October-2015) of dug wells bore wells and tube wells were obtained from CGWB. The sampling locations are (P1, P2……..P20) used for collection of groundwater samples at the average depth of 01 m to 17 m. The elevation data were also recorded (Fig. 2). Information related to the date of collection/ sampling, vegetation and cropping system, the location of nearby ponds etc. was also recorded.

Numerical Indices

In this study, the Water Quality Index (WQI) was computed using ten parameters and step for calculating the WQI are as follows: i) to find out descriptive statistic of each parameter, (ii) to calculate WQI using the standards of drinking water quality recommended by the World Health Organization (WHO 2006).

These values were used to calculate WQI using four different modes.

1. The weighted index method was used for the calculation of WQI. Further, quality rating or sub-index (Qn) was calculated using the following expression (1):

$$Q_n = 100 \times \left[(V_n - v_i) / (V_s - v_i) \right]$$

..................................1

Qn = Quality rating for the nth water quality of nth parameter, Vn = Actual value of nth parameter, vi = Ideal value of this parameter and Vs = Standard permissible value of the nth parameter [Consider Vi =0 for all except pH where Vi =7 for pH]

Unit weight was calculated by a value inversely proportional to the recommended standard value Vs of the corresponding parameter using equation (2).

$$W_n = K / V_s$$

$$\text{and } K = \left[1 / \sum_{n=1}^{n} \left(1/V_s \right) \right]$$

..................................2

Wn = unit weight for the nth parameters, K = constant for proportionality, Vs = standard value for the nth parameters, the standard value of the parameter and this weight is given in Table 2.

For computing the WQI1, the SI (sub-indices) is first to determine for each chemical parameter, which is then used to determine the WQI1 as per the following equation (3)

$$WQI_1 = \sum Q_n W_n \Big/ \sum W_n \quad \text{..3}$$

On the basis of the calculated Water Quality Index (WQI1) the assumptions made regarding water quality is given in Table 2.

2. Numerous Pollution Index (NPI or WQI2) is a simplified pollution index (Mohan et al., 2007) which is also known as Raw's Pollution Index. It is given as equation (4):

$$NPI\,(WQI_2) = V_n \Big/ V_s \quad \text{..4}$$

Vn = Actual value or observed concentration of the nth parameter, Vs = permissible limit of the nth parameter.

3. Results and Discussions

Hydrogeochemistry of water

Table 3 presents descriptive statistics of groundwater. The result showed that pH has the mean value of 7.65 (Fig. 3a), which is less than 4.34 percent less from WHO 2006 permissible value of pH (Table 3). Maximum pH was noted at P13 and P19 these sampling locations are away from the coastal region with an elevation of 5.18 m and 16.15 m respectively with distances 6307 m and 19603.9 m respectively. From Table 3 EC is having highest SD of 1058.08 (µS/cm) among ten groundwater variables. EC also has the highest mean (1868.25 µS/cm; Fig. 3b) and max (5000 µS/cm; Fig. 3b) at P15 with distances (12931.7 m) from the coastal area and at this point elevation is 8.53 m. Ca2+ recorded as the third lowest SE and SD of 8.68 and 38.81mg/l, respectively. Ca2+ have a mean and maximum value of 60.25 and it is 19.67 percent less from WHO 2006 permissible value of Ca2+ (Fig 3c, Table 3) and 150 mg/l at P10 respectively. Table 3, Mg2+ has a mean value of 52.95 mg/l (Fig. 3d) which is 5.9 percent more from WHO (2006) value (50 mg/l; Table 3) for Mg2+. At site P15 it was found maximum value as 197 mg/l with 8.53 m elevation from mean sea level. Magnesium in groundwater may be attributed to the chemistry of the geological composition of the rock beneath of earth. Similarly mean value of Na+ (238.85 mg/l) cross the WHO (2006) standard value of 200 mg/l (Table 3) with maximum value (589 mg/l) at P15 for Na+ (Fig. 3e). Whereas distance of P19 from coastal was 19603.9 m with a high elevation of 16.15 m which revealed that low impact of seawater on groundwater or fewer intrusions seawater in the area. Mean value (402.50mg/l; Fig. 3f) of Cl- was found 28.92 percent of maximum (1392 mg/l), at P15, with low elevation of 8.53 m which reveal that Cl- contamination may arise as a result of various soluble salts from the sea (Ayeni et al., 2011; Ojosipe, 2007). Due to the impact of the sea, it is maximum at a distance of 12931.7 m from the coastal value of Cl- in the study area. Maximum and minimum value of SO42- was found as 456 at P6 with the lowest elevation of study area 4.88 m (Fig. 3g) and 55 mg/l with mean value of 151.10 (Fig. 3g), which was 37.78 percent of permissible limit of SO42- according WHO (2006) mg/l. From Table 3, mean value of HCO3- is 28.14 percent of WHO (2006) recommended value as 1000 mg/l, while highest value (484 mg/l) of HCO3- was found at P6 with lowest elevation value of 4.88 m. Total nitrate (NO2+NO3-) has the highest value of 25 mg/l at P18 while the mean value of total nitrate was 23.32 percent (5.83 mg/l) of maximum total nitrate. The total nitrate concentration in groundwater sources may be attributed to the leaching of the watershed in relation to agricultural activities, sewage disposal at Kosalaiyar river and leached wastewaters generated industrially, domestically or municipally (Olajire and Imeokparia, 2000). According to Table 3, the maximum TDS of the study area was 2674 mg/l, it is 1.5 times more from WHO (2006) for TDS. TDS indicates the general nature of water quality or salinity. Water containing more than 500 mg/l is considered undesirable for domestic uses.

Water quality index

Table 4a, b presents the classification of groundwater quality of study area based on WQI1 (Brown et al., 1970) and WQI2 (Mohan et al., 2007). Table 5 is representing descriptive statistics of WQI1 and WQI2. According to Table 5 mean value of WQI1 and WQI2 were 47.85 and 1.13 respectively, which comes under the category of good (25 to 50, Table 4a) and poor (1 < , Table 4b) according to Brown et al. (1970) and Mohan et al. (2007) respectively. The minimum value of WQI1 (19.75) and WQI2 (0.80) both are showing the excellent category of water quality for the study area during the study period. On the pattern of relative variation (Fig. 5a), result of coefficient of variation (CV%=SD*100/M, CV%WQI1= 11.72 and CV%WQI2=6.04) showed that all the points are heterogeneous according to WQI1 and WQI2 (Fig. 5a), but variability of classes wise WQI1 heterogeneity clearly plotted (Fig. 5b). In case of WQI2 heterogeneity cannot be plotted as classes because, according to Mohan et al. (2007), only two classes are available in WQI2 method/scheme (Fig. 5c). The proposed WQI (WQI1 and WQI2) equations are more technically sound compared to the existing equations because these are developed and formulated based on the questionnaire survey of the water quality experts, limits for the parameters considered in the WQI define by WHO (2006).

Water quality mapping

Descriptive statistics of WQI of groundwater samples are given in table 5. Groundwater quality classes are useful for summarizing information in order to obtain a regional and national perspective. In this study hydro-chemical parameters have been tested in the process of proposing an appropriate WQI

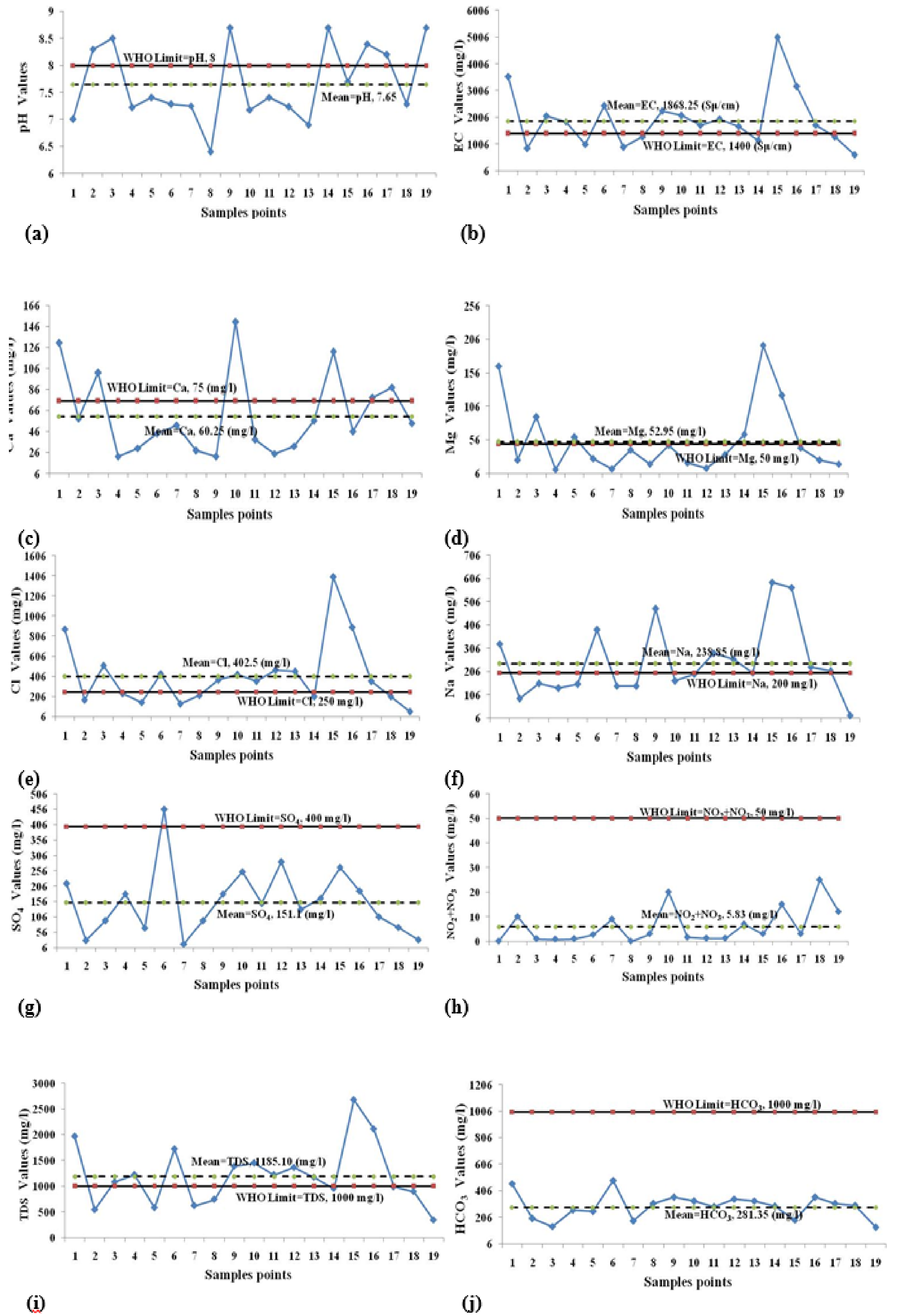


Figure. 3 (a-j) Concentration of each groundwater quality parameters versus WHO 2006 standard

Table 3. Descriptive statistics of hydrochemical data of groundwater samples at the study are

	pH	EC	Ca^{2+}	Mg^{2+}	Na^{+}	Cl^{-}	SO_4^{2-}	HCO_3^{2-}	NO_2+NO_{3-}	TDS
SV	8.5	1400	75	50	200	250	400	1000	50	1000
M	7.65	1868.25	60.25	52.95	238.85	402.50	151.10	281.35	5.83	1185.10
SE	0.15	236.59	8.68	11.71	35.15	72.26	24.25	21.84	1.61	131.23
Me	7.35	1716	49	31	197	357.5	140	290.5	2.82	1124.5
Mo	8.7	N/A	22	12	N/A	N/A	180	307	3	1220
SD	0.69	1058.08	38.81	52.38	157.21	323.16	108.45	97.67	7.20	586.88
SV	0.48	1119542	1506	2743	24716	104432	11762	9540	51	344428
K	-1.07	2.98	0.18	2.55	0.50	3.77	1.83	-0.18	1.58	0.80
SK	0.31	1.55	1.11	1.79	1.07	1.84	1.14	0.27	1.52	0.93
R	2.3	4400	128	185	573	1337	438	354	25	2336
Min	6.4	600	22	12	16	55	18	130	0	338
Max	8.7	5000	150	197	589	1392	456	484	25	2674

SV, Standard Value (according to WHO 2006) ; M, Mean; SE, Standard Error; Me, Median; Mo, Mode; SD, Standard Deviation; SV, Sample Variance; K, Kurtosis; SK, Skewness; R, Range; Min, Minimum; Max, Maximum

Table 4a. Classification of water quality on the basis of WQ

WQI_1	Suitability
0 to 25	Excellent
25 to 50	Good
50 to 75	Poor
75 to 100	Very poor
100 and above	Unsuitable for drinking

Source: Brown et al. (1970)

Table 4b. Suitability of groundwater based on NPI/ WQI2 Index

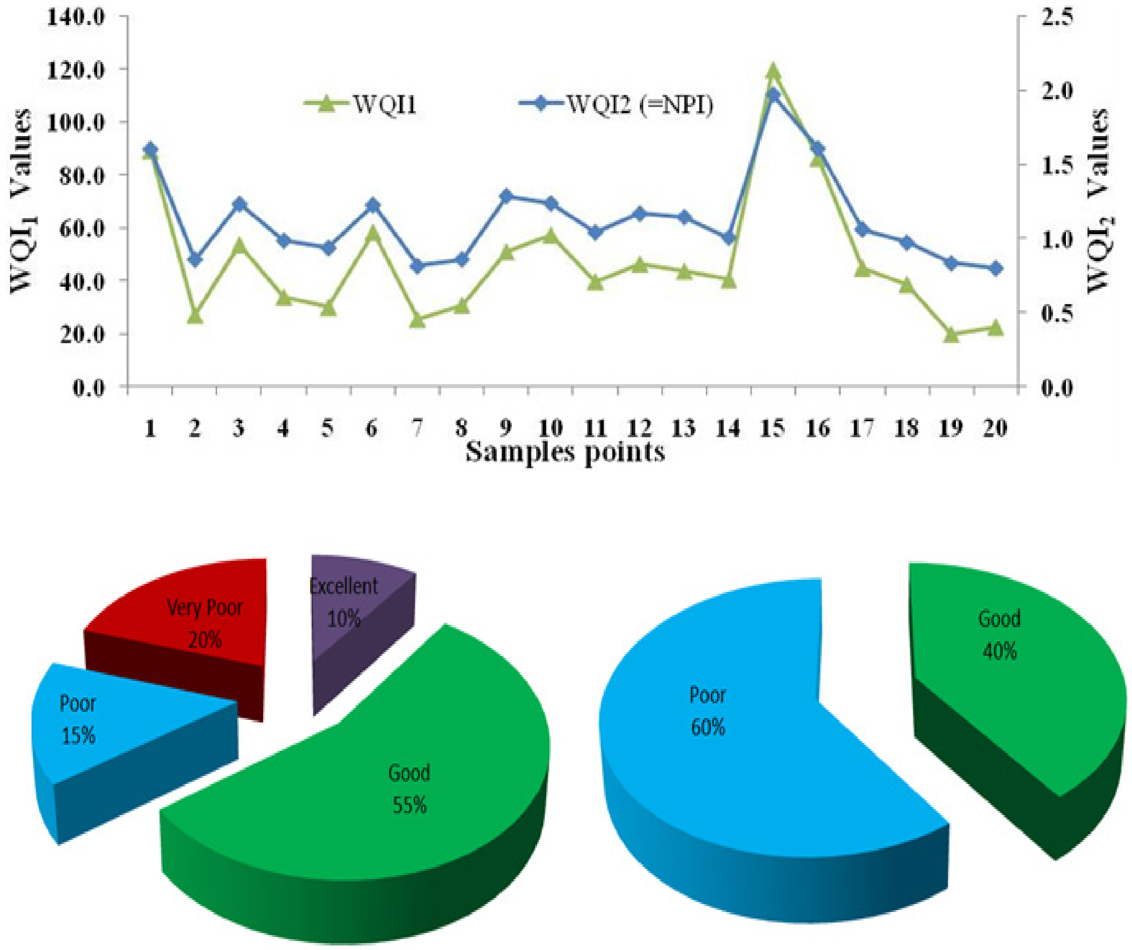
NPI	Status
< 1	Excellent
1 <	Poor

Source: Mohan et al. (2007)

Table 5. Descriptive statistics of WQI of groundwater samples at study area

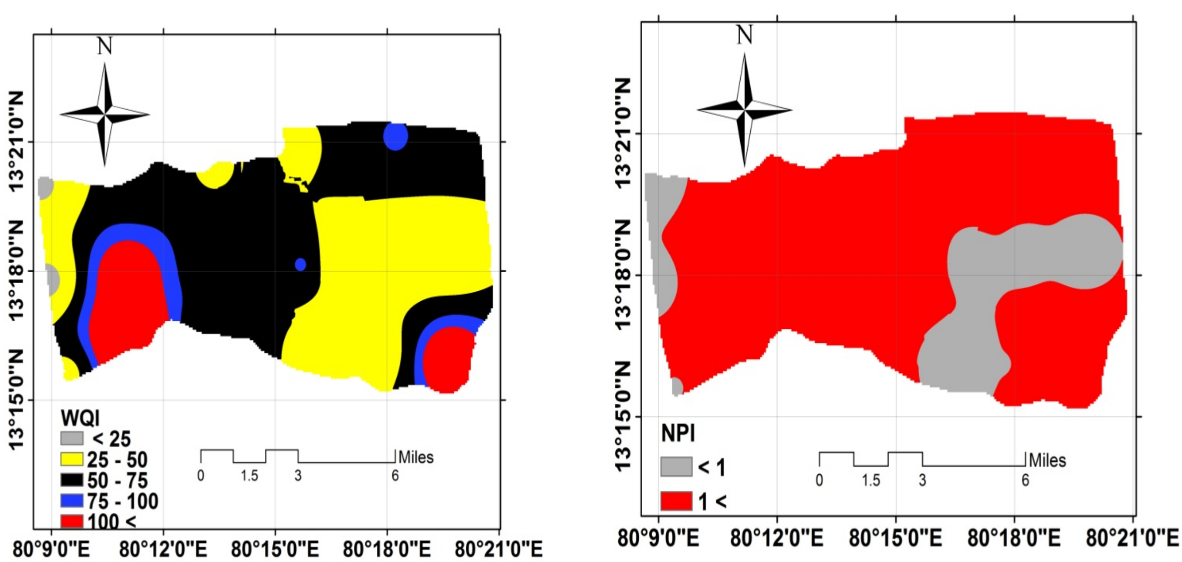
	WQI1	WQI2 =(NPI)
M	47.85	1.13
SE	5.61	0.07
Me	41.92	1.05
Mo	N/A	N/A
SD	25.08	0.31
SV	628.81	0.09
K	2.52	1.79
SK	1.57	1.34
R	99.82	1.17
Min	19.75	0.80
Max	119.57	1.97

in industrial cum agricultural area and especially in among activities. WQI for 20 samples ranges from 19.75 to 119.57 and >1 to 1 < for WQI1 and WQI2 respectively. About 55% and 70%, of groundwater of study area, fall under the poor category of quality according to WQI1 and WQI2 respectively (Fig. 6a and b). On the basis of WQI1, a major area of study was found to be poor (50 to 75, black color patches in Fig. 6a) and good (25 to 50 yellow color patches in Fig. 6a) category as per WQI1. Whereas very poor and unsuitable for drinking purposes areas are covered by very less area with blue and red color, respectively. Figure 6, revealed that the area of point P16, P15 and P5 are more contaminated because it contains blue (very poor category) and red (unsuitable for drinking category) color patches. This may be due to intrusions of seawater to groundwater. The WQI2 mapping (Fig. 6b) is also showing spatial destitution of groundwater quality within the study area of the study period 2015. Fig. 6b explain study area into only two categories, it is both advantage and disadvantage of WQI2, because it is very easy to understand the category of groundwater quality excellent (if, < 1) and very poor (if, 1<). The disadvantage is only two class is not capable to show heterogeneity/variability of water quality, this is also revealed in Fig. 5a (graphical representation show variation in WQI2) and 6b (pictorial representation show only two classes of WQI2).



(b) (c)

Figure 5a. Water quality index values; (b-c) percentage of categorise of groundwater samples of study area based on WQI1 and WQI2



(a) (b)

Figure 6. Spatial destitution of water quality index (a) WQI1 and (b) NPI/WQI2

4.Conclusion

WQI in this study has been found useful in assessing the overall quality of water and to get rid of judgment on the quality of the water nearby of the bay of Bengal coastal area of Thiruvallur district of Tamil Nadu (India). This method appears to be more systematic and gives a comparative evaluation of the water quality. It is also helpful for the public to understand the quality of water as well as being a useful tool in many ways in the field of water quality management. The use of the WQI in the determination of the water quality on the study area corresponds to the present tendencies within the field of water resources management; thus, it is attempted at a more important scale to assign chemical importance to the classical parameters related to the chemical quality. The advantages of WQI includes more variables in only one number, brings to the same measuring unit more parameters related to the water quality, offers the possibility to compare in temporal and spatial terms the quality of more water bodies or that of a single one and offers an image of the water usage degree in various fields/purposes. Further, the calculated WQI revealed that the most parts the groundwater quality in is suitable for human use. We concluded that the limited extraction of groundwater for municipal water supply in the study area is suitable for drinking and also used for irrigation. However, there is a need for routine monitoring of the various human activities within the basin especially at the upstream to check the occurrence of high salinity.

Acknowledgments

The authors are grateful to K. Santhanam [Former Joint Director (Geology), Water Resources Division, P.W.D, Chennai] for providing water quality datasets for present study and thank Dr. Anil Kumar Mishra (Principal Scientists, Water Technology Centre, IARI, New Delhi) for his critical input and suggestions on the manuscript.

References

Amin A, Fazal S, Mujtaba A & Singh SK. (2014). Effects of land transformation on water quality of Dal lake, Srinagar, India. J Indian Soc Remote Sens. 42:119–128.

Anim AK, Duodu GO & Ahialey EK. (2011). Assessment of surface water quality: The perspectives of the Weija dam, Ghana. International Journal of Chemistry, 3(2): 32-39

APHA. (1998). The standard method for the examination of water and wastewater (20th Edition). American Public Health Association, Washington, USA

Avishek K., Pathak G., Nathawat M. S., Jha U., & Kumari N., (2010), Water-quality assessment of Majhiaon block of Garwa district in Jharkhand with a special focus on fluoride analysis, Environmental Monitoring Assessment, 167, pp 617–623.

Bharose R, Singh SK & Srivastava PK. (2013). Heavy metals pollution in soil-water-vegetation continuum irrigated with groundwater and untreated sewage. Bull Environ Sci Res. 2:1–8.

Bordalo, A.A., W. Nilsumranchit & K. Chalermwat (2001). Water quality and uses of the Bangpakong river (Eastern Thailand). Water Research, 35(15): 3635-3642.

Brown, R. M., McClelland, N. I., Deininger, R. A & Tozer, R. (1970). A Water Quality Index -Do we Dare?. Water and Sewage Works, October.

Chaudhary MP, Uddin S, Singh SK & Singh P. (2013). Statistical analysis for presence of chloride in water at different locations of upper lake in Madhaya Pradesh state of India. Int J Math Arch. 4:35–37.

Cobbina S. J., Anyidoho L. Y., Nyame F. & Hodgson I. O. A., (2010), Water quality status of dugouts from five districts in Northern Ghana: implications for sustainable water resources management in a water-stressed tropical savannah environment, Environmental Monitoring Assessment, 167, pp 405–416.

Gajbhiye S, Singh SK & Sharma SK. (2015). Assessing the Effects of Different Land Use on Water Qualify using Multi-temporal Landsat Data in edited book Resource Management and Development Strategies: A Geographical Perspective. Edited by Siddiqui AR and Singh PK. Pravalika Publication, Allahabad, Uttar Pradesh, India. pp. 337 - 348 ISBN : 91 8-93-84292-21 -8

Gajbhiye S, Meshram C, Singh SK, Srivastava PK & Islam T. (2016). Precipitation trend analysis of Sindh River basin, India, from 102-year record (1901-2002). Atmos Sci Lett. 17:71–77.

Gautam SK, Tziritis E, Singh SK, Tripathi JK & Singh AK. (2018). Environmental monitoring of water resources with the use of PoS index: a case study from Subarnarekha River basin, India. Environmental Earth Sciences. 77:70. https://doi.org/10.1007/s12665-018-7245-5

Gupta LN, Avtar R, Kumar P, Gupta GS, Verma RL, Sahu N, Sil S, Jayaraman A, Roychowdhury K, Mutisya E & Singh SK. (2014). A multivariate approach for water quality assessment of river Mandakini in Chitrakoot, India. J Water Resour Hydraul Eng. 3:22–29.

Jacintha TGA, Rawat KS, Mishra A & Singh SK. (2016). Hydrogeochemical characterization of groundwater of peninsular Indian region using multivariate statistical techniques. Appl Water Sci.7(6):3001–3013. doi/10.1007/s13201-016-0400-9

Kumar RP, Ranjan RK, Ramanathan AL, Singh SK & Srivastava PK. (2015). Geochemical modeling to evaluate the mangrove forest water. Arab J Geosci. 8:4687–4702.

Mohan, A., Singh, R. K., Panday, K., Kumar V. & Jain. V. (2007). Indian Journal of Environmental Protection, 27(11), 1031.

Rawat K.S. Mishra A.K. & Sehgal V.K. (2012). Spatial Variability of Ground Water Quality in Mathura District (Uttar Pradesh, India) with Geostatistical Method. International Journal of Remote sensing Application, 2(1), 1-9.

Rawat K.S. Mishra A.K. & Sehgal V.K. (2013). Identification of Geospatial Variability of Fluoride contamination in Ground Water of Mathura District, Uttar Pradesh, India. Journal of Applied and Natural Science, 4(1), 117-122.

Rawat K.S. Tripathi V.K & Singh S.K. (2017b). Groundwater Quality Evaluation using Numerical Indices: a case study (Delhi, India), Sustainable Water Resources Management, DOI10.1007/s40899-017-0181-9

Rawat KS, Tripathi VK & Singh SK. (2017a). Groundwater quality evaluation using numerical indices: a case study (Delhi, India). Sustain. Water Resour. Manag. https://doi.org/10.1007/s40899-017-0181-9

Rawat K.S., Mishra A.K. & Singh S.K. (2017a). Mapping of Groundwater Quality Using Normalized Difference Dispersal Index of Dwarka Sub-city at Delhi National Capital of India, ISH Journal of Hydraulic Engineering, 10.1080/09715010.2016.1277795.

Rawat KS, Mishra AK & Singh SK. (2017b). Mapping of groundwater quality using Normalized Difference Dispersal Index of Dwarka sub-city at Delhi National

Capital of India. ISH J Hydraul Eng. 5010:1–12.Saeedi, M., O. Abessi, F. Sharifi and H. Meraji, 2010. Development of groundwater quality index. Environmental Monitoring Assessment, 163: 327-335.

Rawat KS, Jeyakumar L, Singh SK & Tripathi VK. (2018a). Appraisal of groundwater with special reference to nitrate using statistical index approach. Groundwater for Sustainable Development. https://doi.org/10.1016/j.gsd.2018.07.006

Rawat KS, Jacintha TGA & Singh SK. (2018b). Hydro-chemical Survey and Quantifying Spatial Variations in Groundwater Quality in Coastal Region of Chennai, Tamilnadu, India – a case study. Indonesian Journal of Geography. 50 (1): 57 – 69. http://dx.doi.org/10.22146/ijg.27443

Rawat KS & Singh SK. (2018c). Water Quality Indices and GIS-based evaluation of a decadal groundwater quality. Geology, Ecology, and Landscapes. 1-12. https://doi.org/10.1080/24749508.2018.1452462

Rawat KS, Singh SK, Jacintha TGA, Nemcˇic´-Jurec J & Tripathi VK. (2018d). Appraisal of long term groundwater quality of peninsular India using water quality index and fractal dimension. J. Earth Syst. Sci. https://doi.org/10.1007/s12040-017-0895-y

Singh S, Singh C, Kumar K, Gupta R & Mukherjee S. (2009). Spatial-temporal monitoring of groundwater using multivariate statistical techniques in Bareilly district of Uttar Pradesh, India. J Hydrol Hydromechanics. 57:45–54.

Singh SK, Singh CK & Mukherjee S. (2010). Impact of land-use and land-cover change on groundwater quality in the Lower Shiwalik hills: a remote sensing and GIS based approach. Cent Eur J Geosci. 2:124–131

Singh SK, Srivastava PK, Pandey AC & Gautam SK. (2013a). Integrated assessment of groundwater influenced by a confluence river system: concurrence with Remote Sensing and Geochemical Modelling. Water Resour Manag. 27 (12):4291–4313. https://doi.org/10.1007/s11269-013-0408-y

Singh SK, Srivastava PK & Pandey AC. (2013b). Fluoride contamination mapping of groundwater in Northern India integrated with geochemical indicators and GIS. Water Sci Technol Water Supply. 13:1513–1523.

Singh SK, Srivastava PK, Singh D, Han D, Gautam SK & Pandey AC. (2015). Modeling groundwater quality over a humid subtropical region using numerical indices, earth observation datasets, and X-ray diffraction technique: a case study of Allahabad district, India. Environ Geochem Health. 37 (1):157–180. https://doi.org/10.1007/s10653-014-9638-z

Singh SK, Prafull Singh & Gautam SK. (2016). Appraisal of urban lake water quality through numerical index, multivariate statistics and earth observation data sets. Int J Environ Sci Technol. 13:445–456.

Singh H, Pandey R, Singh SK & Shukla DN. (2017a). Assessment of heavy metal contamination in the sediment of the River Ghaghara, a major tributary of the River Ganga in Northern India. Applied Water Science.7(7):4 133-4149

Singh H, Singh D, Singh SK & Shukla DN. (2017b). Assessment of river water quality and ecological diversity through multivariate statistical techniques, and earth observation dataset of rivers Ghaghara and Gandak, India. Int J River Basin Manag. 15(3): 347-360. https://doi.org/10.1080/15715124.2017.1300159Smith, K., 2001. Environment hazards: Assessing risk and reducing disaster (3 ed., pp: 324). London: Routlege.

Thakur JK, Diwakar J & Singh SK. (2015). Hydrogeochemical evaluation of groundwater of Bhaktapur Municipality, Nepal. Environ Earth Sci. 74:4973–4988.

Thakur JK, Singh SK & Ekanthalu VS. (2016). Integrating remote sensing, geographic information systems and global positioning system techniques with hydrological modeling. Appl Water Sci.:1–14.

World Health Organization (2006).Guidelines for drinking-water quality. Recommendations, vol 1, 3rd edn. World Health Organization, Geneva.