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S. I. – CEC FRAMEWORK

Groundwater quality assessment using GIS technology in Kadavanar Watershed, Cauvery River, Tamil Nadu, India

Sekaran Natesan[1] · Vennila Govindaswamy[2] · Suresh Mani[3] · Selvam Sekar[4]

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Abstract
The groundwater quality of Kadavanar watershed, Amaravathy sub-basin, Cauvery river basin, Tamil Nadu, India, was assessed by collecting 147 groundwater samples during April 2016 (pre-monsoon). The Kadavanar watershed area spans for about 2254.66 km^2. The areal extent of the hill and forest is 397.08 km^2 and the plain or the investigation area is 1857.58 km^2. In the study area, sixteen parameters were found to be responsible for the degradation of groundwater quality. The integration of groundwater quality data has been carried out by considering sixteen parameters using GIS technology. The areal extent obtained from the integrated groundwater quality map reveals that nearly 54.02% of the watershed area possesses permissible category (most desirable + maximum allowable) of groundwater. The "most desirable" category of groundwater quality covers 397.08 km^2 of the study area and it is located in the northern part (confluent point) as well as the high lineament and weaker plain of the watershed. The rest of the area (854.19 km^2) is under mixed category of allowable and not permissible zones and extend over the watershed. It is located in central part of the watershed.

Keywords Groundwater quality · Pre-monsoon · Watershed · Integrated · Spatial map · Confluent point

Introduction

The groundwater is the nature's most wonderful gift for human beings and all living organisms such as animals and also plants. Groundwater is widely used for drinking, irrigation to cultivate lands, and other domestic purposes. So, groundwater quality plays an important role in water usage (Srivastava and Ramanathan 2008). Globally, there is a continuous degradation of groundwater quality and depletion of groundwater quantity, in some regions and during some periods, due to land use activities and unsustainable use of water resources. However, the scale of the problem differs in some developing countries and in India, where in the latter case, the threat of unavailability of good quality drinking water is a life-threatening problem (Selvam et al. 2020; Singaraja et al. 2016; Vetrimurugan et al. 2013; Vorosmarty et al. 2000).

Groundwater is a safer source of drinking water than surface water, and moreover, it contains essential substances, which are not provided in surface water. When precipitation infiltrates through the soil zone and unsaturated zone, the water is cleaned through physical, chemical, and biological processes. Moreover, the percolating water makes the soil matrix undergo weathering where these substances are added to the water. The higher quality implies the use of fewer chemicals during treatment for the production of drinking water and thereby leading to lower costs (Gupta et al. 2009). The aquifers also act as protected storage of water, which serves as a buffer against variation in demand and/or supply, i.e., precipitation of surface water for artificial recharge. Other services in addition to drinking water, which are provided from groundwater, are for industrial purposes, irrigation for agriculture and ecological services through discharge into streams and wetlands. Major threats are also due to agriculture, contamination from fertilizers and pesticides, and

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✉ Sekaran Natesan
vasanthamnsekaran@gmail.com

1 Department of Civil Engineering, ErodeSengunthar Engineering College, Perundurai, Erode, Dist. Tamilnadu, India

2 Department of Civil Engineering, K.S. Rangasamy College of Technology, Tiruchengode, Namakkal, Dist. TN, India

3 Department of Civil Engineering, Jayalakshmi Institute of Technology, Thoppur, Dharmapuri, Dist. TN, India

4 Department of Geology, V.O. Chidambaram College, Tuticorin, Tamil Nadu 628008, India

overexploitation of aquifers (Chung et al. 2020; Shivan et al. 2006; Brindha and Elango 2012; Vijay et al. 2011).

Physico-chemical is primarily depending upon various factors such as geological formation, aquifer size, rock water interaction, and dilution due to precipitation (Gautam et al. 2015; Kaur et al. 2017; Abbasnia et al. 2019). Each and every groundwater sample contains various salts in solutions but the kind and amount vary depending upon their source of origin, places of their movement, and the geologic-geomorphic conditions. It is impossible to find absolutely pure water in nature. Water drops just emitting out of the clouds may be considered chemically pure, but as the drops fall down, they absorb some gases and other matters. Suspended impurities are those, which normally remain in suspension. They are microscopic and make the water turbid. Dissolved impurities are not visible, but they are in large amount since water is a good solvent. They cause bad taste, hardness, and alkalinity in water (Appelo and Postma 1993). A number of hydrogeological investigations were carried out in Tamil Nadu, by many researchers (Ramesh et al. 1995; Rajmohan and Elango 2006; Sajil Kumar and James 2013; Srinivasamoorthy et al. 2011), who agreed on a few improvements in groundwater quality.

Study area

The Kadavanar river is one of the watersheds in Amaravathy subbasin of the Cauvery river, Tamil Nadu, India, which has been selected for the study. Dindigul and Karur districts are covered in the study area. The research area is spread between 10° 10′ 57″ to 10° 52′ 49″ degree northern latitude and 77° 37′ 31″ to 78° 13′ 47″ degree of eastern longitude. It is bounded on the north by Namakkal and Erode districts, south by Madurai district, east by Tiruchirappalli district, and west by Tiruppur district. It is an inland district without coastal line. The Kadavanar river originates in the Sirumalai and Kallar hills and runs through the districts of Dindigul and Karur in the western part of the Tamil Nadu. The total length of the Kadavanar river is about 82 km. The total area of the watershed is 2254.66 km^2. The Kadavanar river is one of the important sources of water in surrounding peoples. Thirteen geological variations have occurred in the watershed. But groundwater samples were collected from 8 major distributed geologies only. The following geologies are Pink migmatite, Hornblende-biotite gneiss, Charnockite, Quartzite, Garnet-Silimanite gneiss, Anorthosite, Calc-gneiss/limestone, and Quartz vein. The general trend of this group of rocks in Kadavanar watershed is that they are dipping towards north direction.

Methodology

In the present study, the sample locations have been chosen based on their geological nature. Groundwater samples were collected for pre-monsoon 2016 in 147 locations. Out of them, 83 water samples were from open wells and 64 water samples were from bore wells. The maximum number of water samples was collected from dug wells. One-litter polyethylene container was used for water storage. The collected groundwater samples were analyzed in the TWAD laboratory. Physico-chemical constituents are given below: The major water quality parameters considered for the present study are pH, TDS, TH, Cl^-, Mg^{2+}, Ca^{2+}, SO_4^{2-}, Na^+, K^+, NO_3^-, F^-, EC, HCO_3^-, and CO_3^{2-} (APHA 2005). The concentration of the parameters has been estimated for water samples from all the sampling locations and has been spatially integrated through inverse distance weighted (IDW) interpolation technique (Gong et al. 2014). Three priority classes have been derived with reference to the WHO (2011) standard.

Results and discussion

The quality of groundwater is very essential in the understanding of physical and chemical parameters necessary for different activities, particularly drinking. The quality of groundwater has been tested in different villages in the Kadavanar watershed. In the study, important physical parameters, major cations and anions, and drinking water quality index were also carried out in the study area. Groundwater sample location map and analytical physio-chemical parameters are given in Fig. 1 and Table 1 respectively. In assessing the groundwater quality, each parameter has been divided into 3 categories as per the World Health Organization (WHO 2011) standard. The results are presented in Table 1. These sixteen parameters were found to be responsible for the degradation of groundwater quality in the Kadavanar watershed.

Hydrogen ion concentration pH

pH values indicated the nature of water such as acid and alkaline. pH below 7 refers to acidic nature and above 7 alkaline nature. Table 1 shows that different ranges of pH are observed such as 6.6 to 8.52. This season, the highest pH value is observed at Pachchalakkavundanur (sample no. 41) and the lowest value at Vadakku Manamettuppatti. The pH in groundwater of the research area is well within the desirable limit of the WHO (2011) for drinking uses.

Electrical conductivity and total dissolved solids

Electrical conductance depends on the dissolved and undissolved materials. Potable water contains mostly inorganic mineral matters in dissolved conditions and small amount of organic matter in undissolved conditions. The undissolved matters are usually referred to as "suspended solids." The determination of dissolved and undissolved matters is made with

Table 1 Groundwater quality—physio-chemical constituents statistical data

Parameters	WHO international standard (2004)		Pre-monsoon no. of samples exceeding permissible limits	Minimum	Maximum	Average	Undesirable effect
	Most desirable limits	Maximum allowable limits					
pH	6.5–8.5	9.2	Nil	6.60	8.52	7.47	Taste effects mucus membrane and water supply system
TDS (mg/l)	500	1500	58	182.00	6125.00	1666.82	Gastrointestinal irritation
EC	1500	-	92	260.00	8750.00	2381.18	Gastrointestinal irritation
TH (mg/l)	100	500	55	56.00	1248.00	450.97	(i) Scale formation in boilers (ii) Cardio vascular disease
Na^+ (mg/l)	-	200	83	30.00	1100.00	294.04	-
K^+ (mg/l)	-	12	106	5.00	400.00	31.31	Bitter taste
Ca^{2+} (mg/l)	75	200	10	18.00	344.00	101.14	Scale formation
Mg^{2+} (mg/l)	50	150	Nil	3.00	131.52	47.55	Scale formation
Cl^- (mg/l)	200	600	23	32.00	1620.00	342.10	Salty taste indicates pollution
SO_4^{2-} (mg/l)	200	400	51	25.00	1350.00	358.07	Laxative effective, cause gastrointestinal irritation when Mg and Na sulfate
NO_3^- (mg/l)	45	-	4	5.00	62.00	19.05	Blue baby diseases in children
F^- (mg/l)	-	1.5	7	0.00	2.40	0.59	Fluorosis
HCO_3	300	500	33	57.00	999.51	331.95	Temporary hardness
CO_3	-	-	-				-
Alk	500	-	23	52.00	732.00	318.48	Rice on cooking turns yellow

filtered and unfiltered portions of samples respectively. The extent of electrical conductivity (EC) and total dissolved solids (TDS) is categorized with reference to EC and TDS spatial maps (Figs. 2 and 3) in the watershed and the extent of area covered by each class. The spatial map of EC and TDS reveals that a major portion (1053.81 km^2) of the study area falls under the not permissible category. The most desirable quality of TDS is present in some parts of Thethupatti and Esanatham villages. The lower (northern) part of the Kadavanar watershed comes under the desirable and allowable quality of groundwater. TDS value is in increasing trend in the catchment and middle part of the basin because of heavy rock water interaction and highly weathered subsurface materials (Mohan et al. 2000). Selvam et al. (2020) found high EC in groundwater due to domestic and industrial pollutants.

Total hardness

The main constituents of hardness are Ca, Mg, and CO_3 quantity of suspended elements in the water. Elements are suspended as rock layers and soil as water mobiles in it. The hardness higher values are frequently united by Calc-gneiss/limestone layer (Sawyer and McCarty 1967). Total hardness spatial map (Fig. 4) reveals that the groundwater present in the central part of the watershed belongs to the "not permissible" category due to heavy rock water interaction and deeper water level (Bore well water samples) and coloring and blanching industries they drain the wastewater on the infertile ground, which penetrates under the groundwater and rise up total hardness. The major portion (1141.87 km^2) of the watershed comes under the allowable category. The northern corner, east, and west ends of the watersheds and southern rain feed area fall in the allowable category.

Total alkalinity

The total alkalinity spatial map (Fig. 5) shows the status of the groundwater quality with reference to total alkalinity in the watershed. The map stresses that the desirable quality of groundwater occupies almost the whole area of the watershed by accommodating 1793.08 km^2. The "not permissible" zones are spread over the upper and middle portions of the watershed covering an area of 64.50 km^2 because of heavy rock water interaction (Rajesh et al. 2012).

Cations such as Ca, Mg, Na, and K

Calcium

The spatial map (Fig. 6) of calcium shows that desirable and allowable ranges were occupied almost throughout the watershed. Only a small portion (12.18 km^2) of the middle part comes under the category of "not permissible." As per the WHO (2011) classification based on calcium, 4.76% of wells comes under very high concentration (> 200 mg/l). The high concentration of calcium may be due to the presence of highly weathered feldspar rocks (Rajesh et al. 2012).

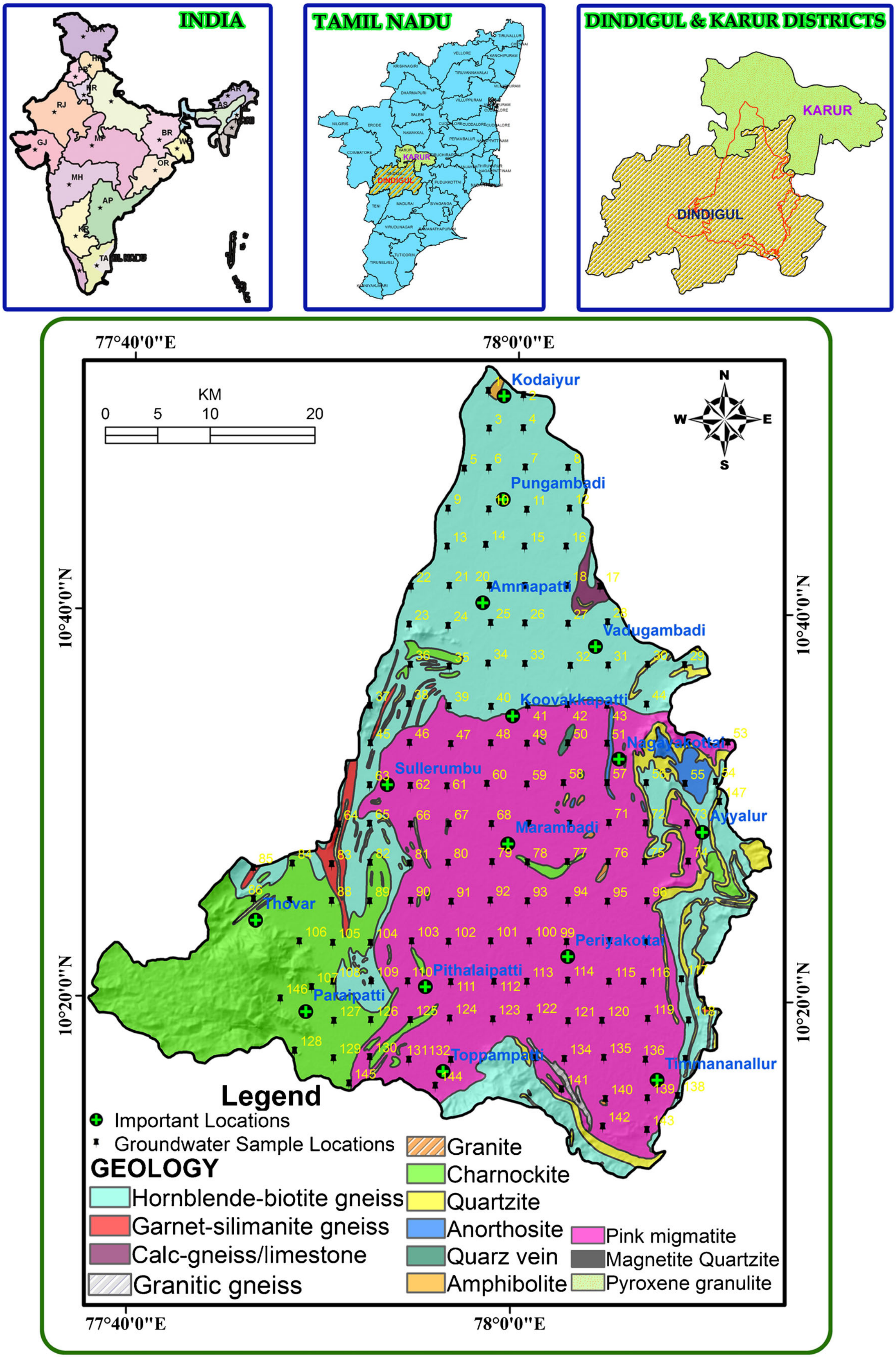

Fig. 1 Location map of the study area along with groundwater sampling sites

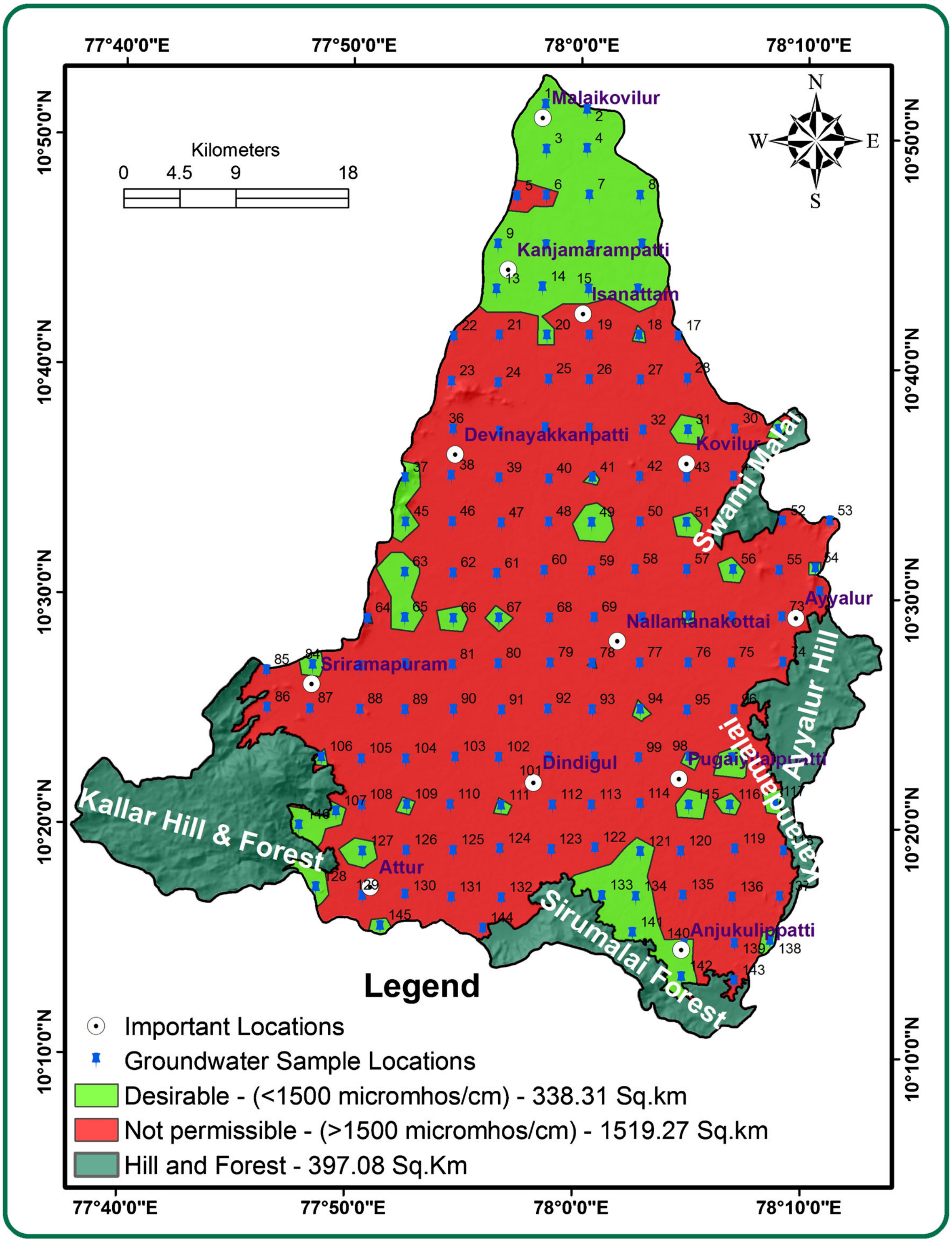

Fig. 2 Spatial distribution map of EC

Magnesium

Magnesium is the 7th most plentiful constituent on the earth. The hydrochemistry of magnesium is quite related to that of calcium. The solvent of magnesium carbonate is also controlled by the availability of CO_2 (Rajesh et al. 2012). The spatial map of magnesium is shown in Fig. 7. The study shows that the magnesium concentration in the watershed area is not greater than 150 mg/l. Allowable groundwater quality zone (50 mg/l) as per the World Health Organization (WHO 2011) standard is noticed in migmatite rock intergrowth of other younger rocks. This portion of the groundwater quality is classified as "desirable" for drinking purposes.

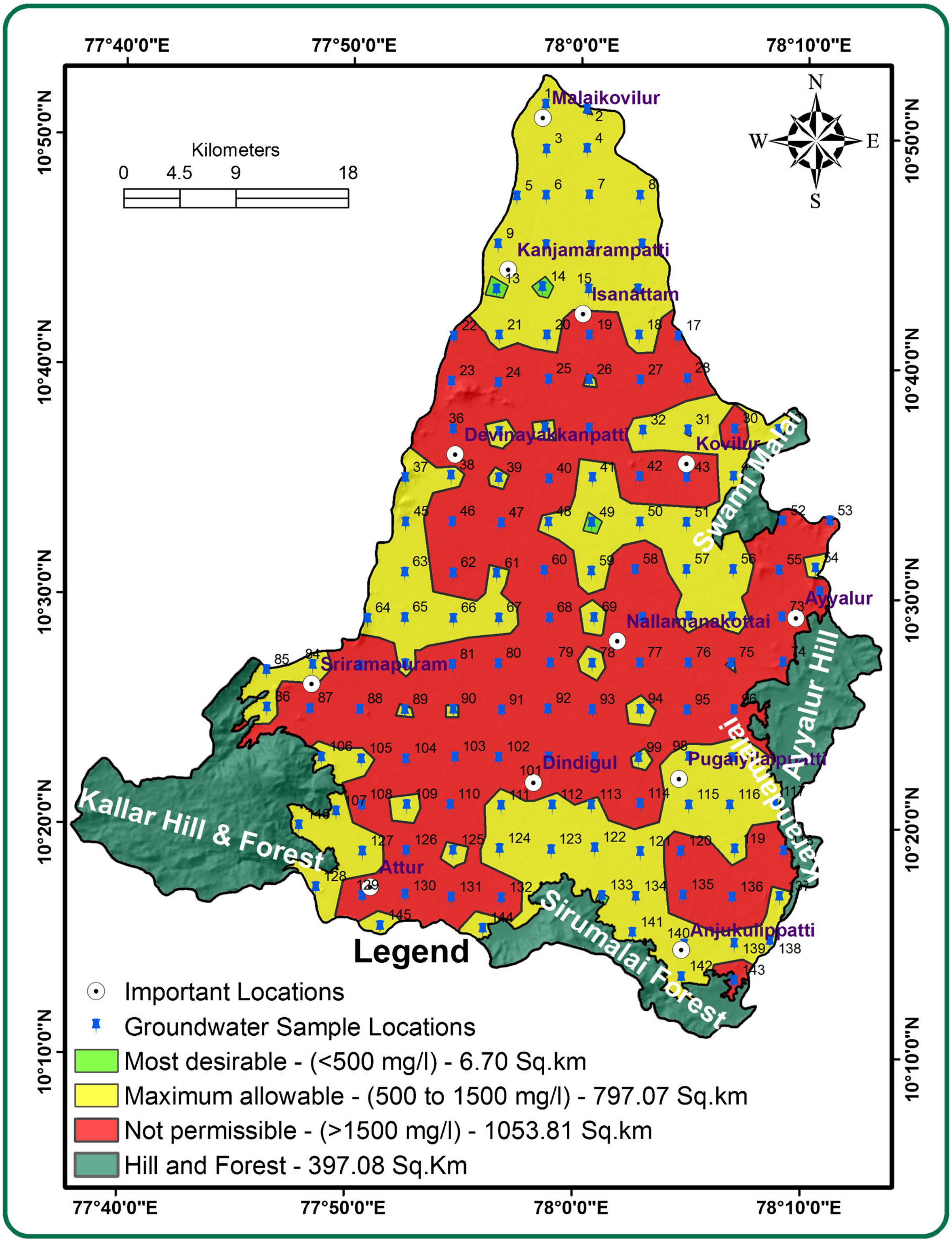

Fig. 3 Spatial distribution map of TDS

Sodium and potassium

Sodium is a dominating cation of the study area. Sodium spatial map (Fig. 8) shows that the "desirable" groundwater quality zone is present in the lower part and foothill area. In terms of sodium ion concentration, a major portion of the watershed (76%) is classified as the "not permissible" groundwater quality zone. The abnormally high concentration of sodium is reported at some locations during observations. Domestic discharges contribute to an increase in sodium contents through leaching (Parker et al. 2008). This may be due to the high weathering of feldspar minerals (Stallard and Edmond 1983).

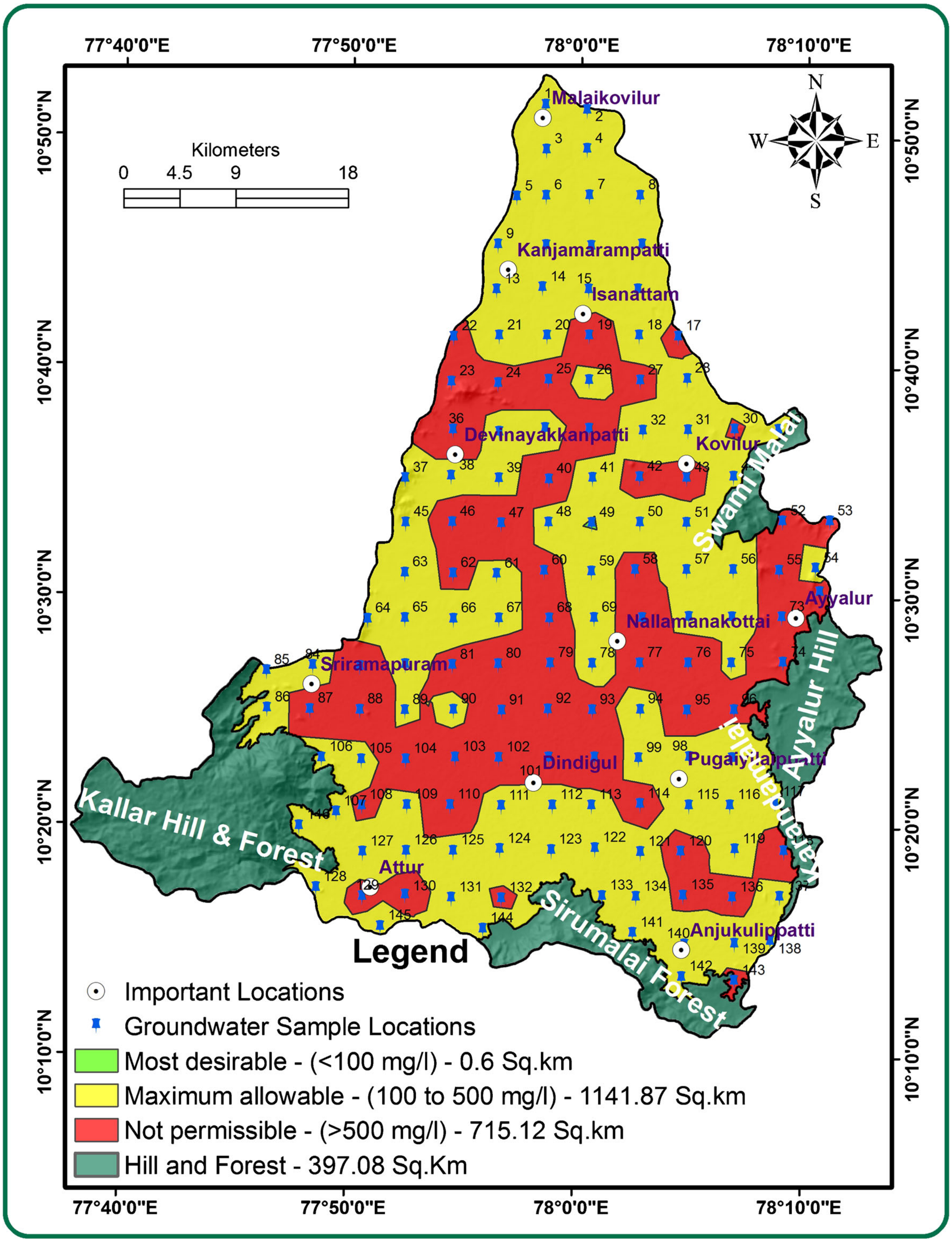

Fig. 4 Spatial distribution map of TH

Potassium is the least present cation in the study area. But, it is more dangerous for drinking and irrigational purposes. Potassium spatial map (Fig. 9) shows that almost all the watershed is occupied by "not permissible" groundwater quality for drinking purposes. It is present in very high concentration (> 12 mg/l) because of the high weathering of feldspar minerals and the secondary cause for this is agricultural activities. The Kadavanar watershed mixed with the Amaravathy river portion is within the permissible limit for drinking uses. At some locations, the occurrence of higher values of potassium is attributed principally to the agricultural activities taking place in the surrounding areas (Brindha et al. 2016).

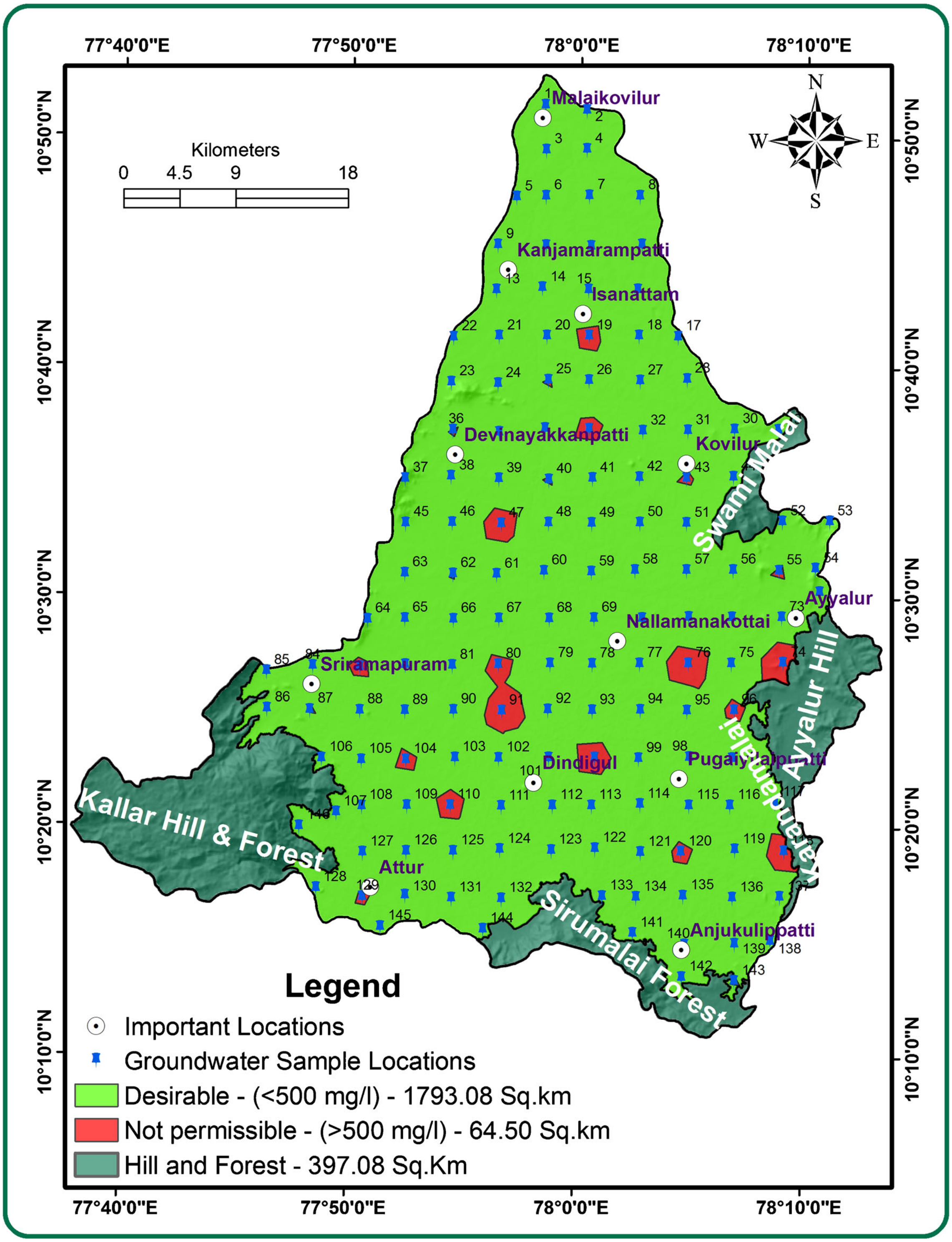

Fig. 5 Spatial distribution map of Total Alkalinity

Anions such as Cl, SO_4, CO_3, HCO_3, NO_3, and F

Chloride

Sodalite and apatite are the only familiar minerals in primary and tertiary units with Cl as an important component. Nevertheless, Cl is a little portion of the earth, which is a mainly suspended component in the majority of normal waters. Liquid intrusion in minerals and litho-units is an additional supply of chloride from primary rocks. Cl concentration is a sign of water quality monitoring. Chlorides reflect as a "mobile" element in groundwater because factors other than

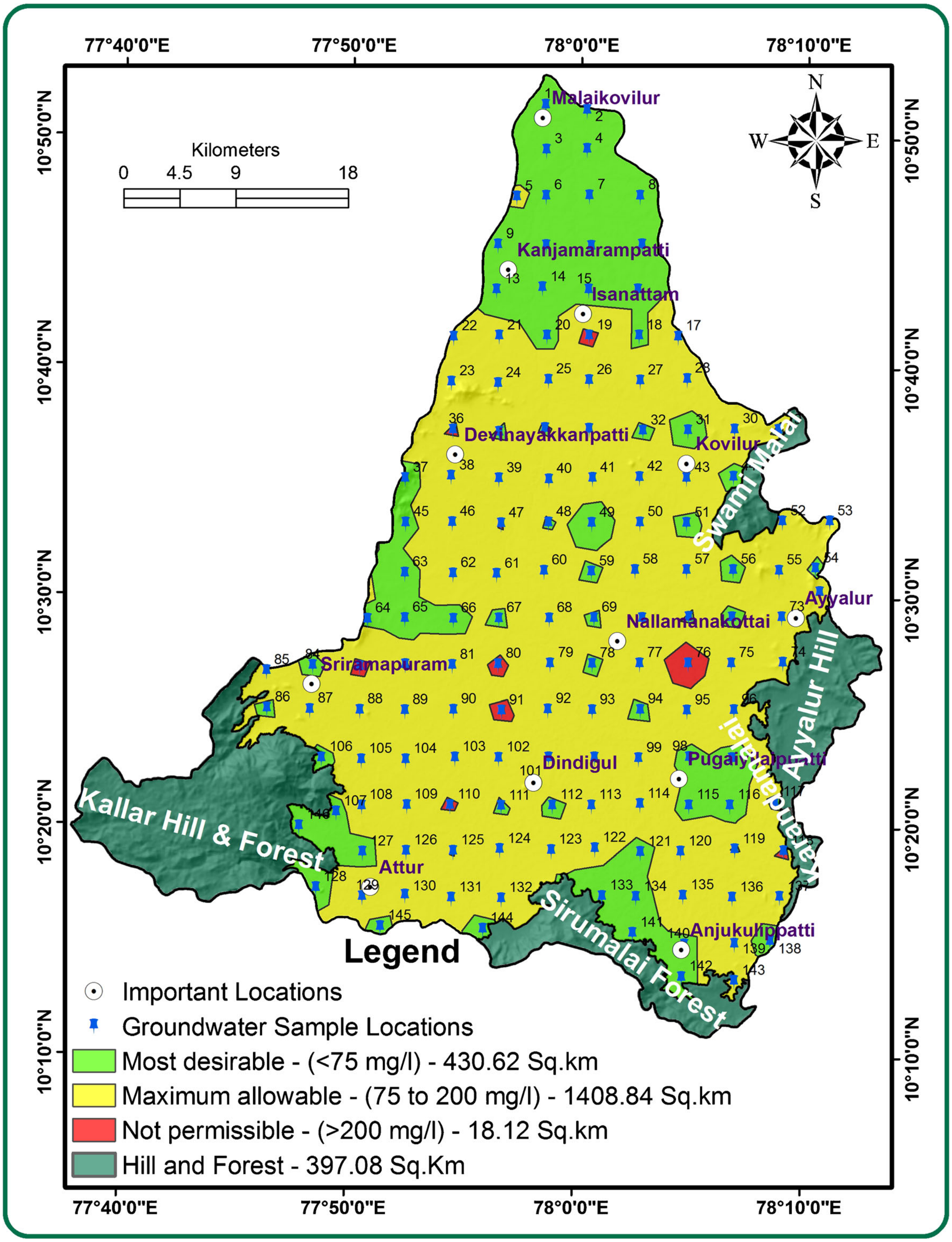

Fig. 6 Spatial distribution map of Ca

internal-fluid reactions determine their concentration. Some of the groundwater samples have a higher concentration of Cl; it represents percolating as the topmost strata due to the manufacturers and household activities and arid weather. Such factors include the presence of Cl as a boost to the groundwater system, the addition of Cl to the groundwater by mixing with higher chloride water from the nearby formation, and Cl leached from fluid inclusion or intergranular salts.

Chloride-limiting value is 600 mg/l as per the WHO (2011) standard. Generally, the excess amount of chloride affects various parts of the human body such as the heart and kidneys (Kumar et al. 2014; Vertrimurugan et al. 2013). Chloride

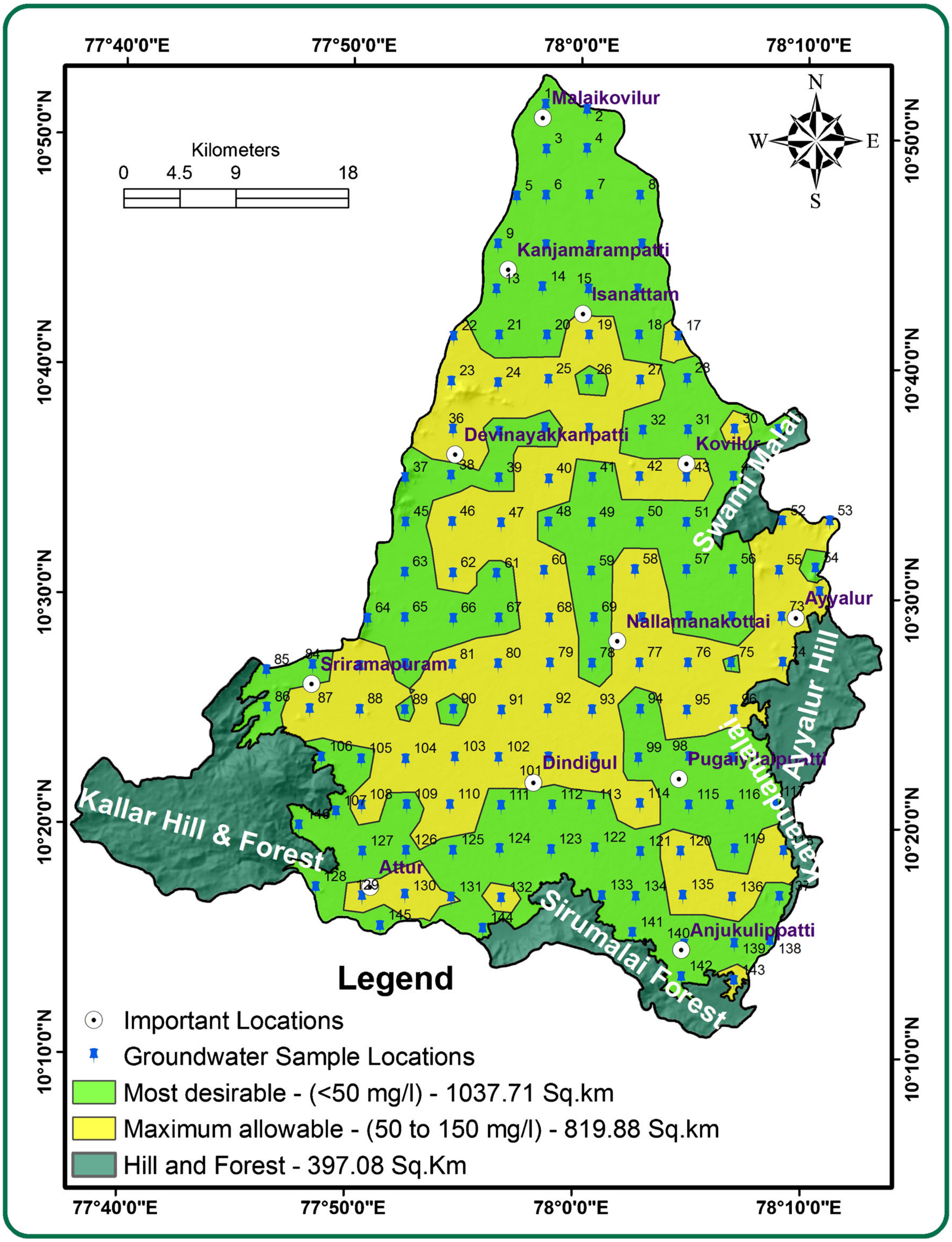

Fig. 7 Spatial distribution map of Mg

spatial map (Fig. 10) shows that the groundwater quality with reference to chloride in the watershed indicates that the allowable quality of groundwater occupies almost 75% of the watershed by accommodating 1394.58 km^2. The northern (lower) part of the watershed is classified under the desirable zone of water quality for drinking purposes.

Sulfate

Sulfate is generally abundant in groundwater. The main sources of sulfate in groundwater are rainwater, solution of sulfate minerals in sedimentary rocks, sulfides of heavy metals, surface water used for irrigation, oxidation of sulfate

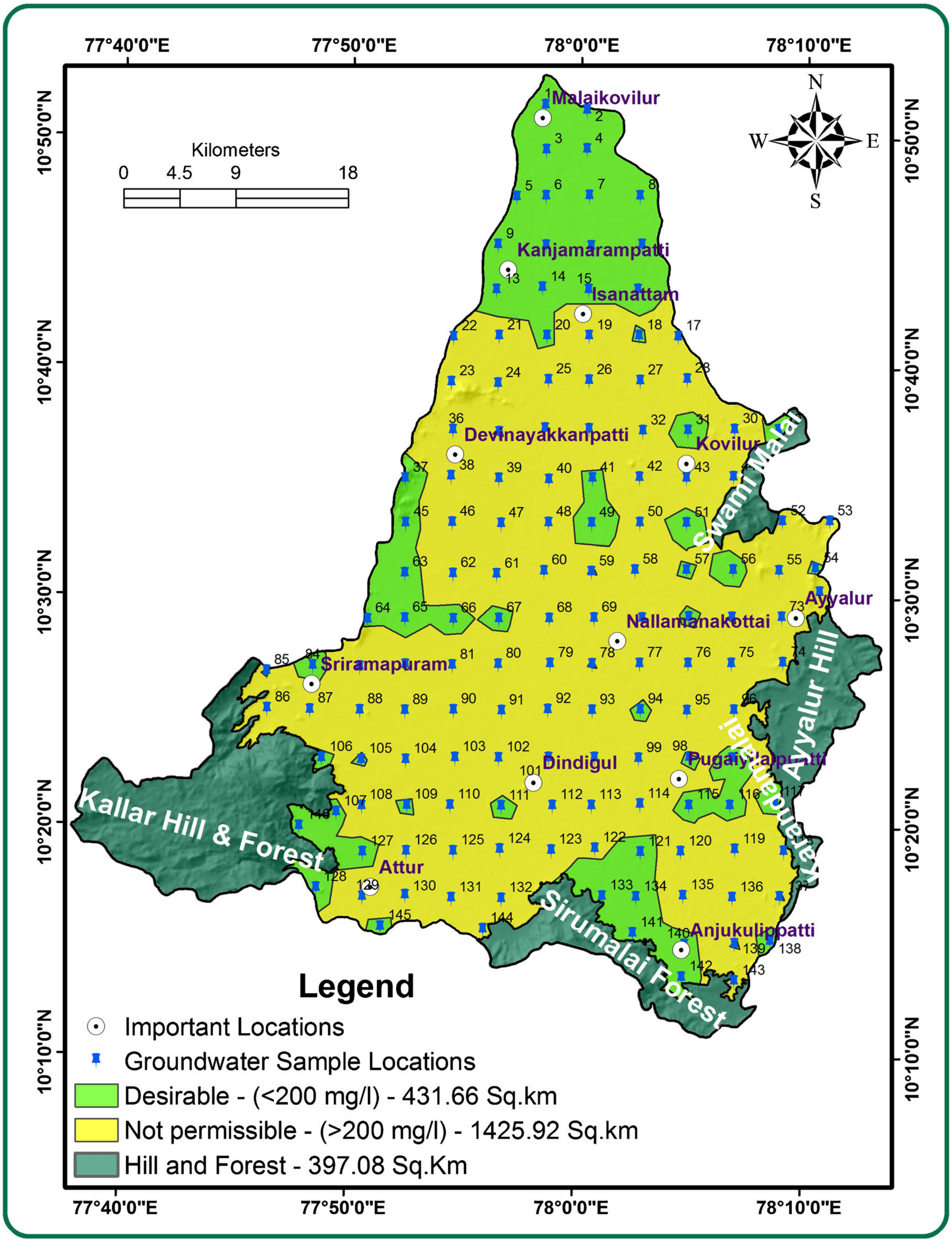

Fig. 8 Spatial distribution map of Na

minerals from igneous rocks, burning of coal and oil, etc. Fertilizers also put in a small amount of sulfate in the groundwater. The application of gypsum and pyrite also adds sulfate content into the groundwater. Industrial discharges and atmospheric precipitation can add considerable amounts of sulfate to the groundwater (Chapman 1992).

Sulfate spatial map (Fig. 11) shows the groundwater quality with reference to sulfate based on the World Health Organization (WHO 2011) standard. Not permissible water quality is extended up to 688.92 km^2 in the central part of the watershed. The northern (lower) part of the watershed shows the desirable water quality zone

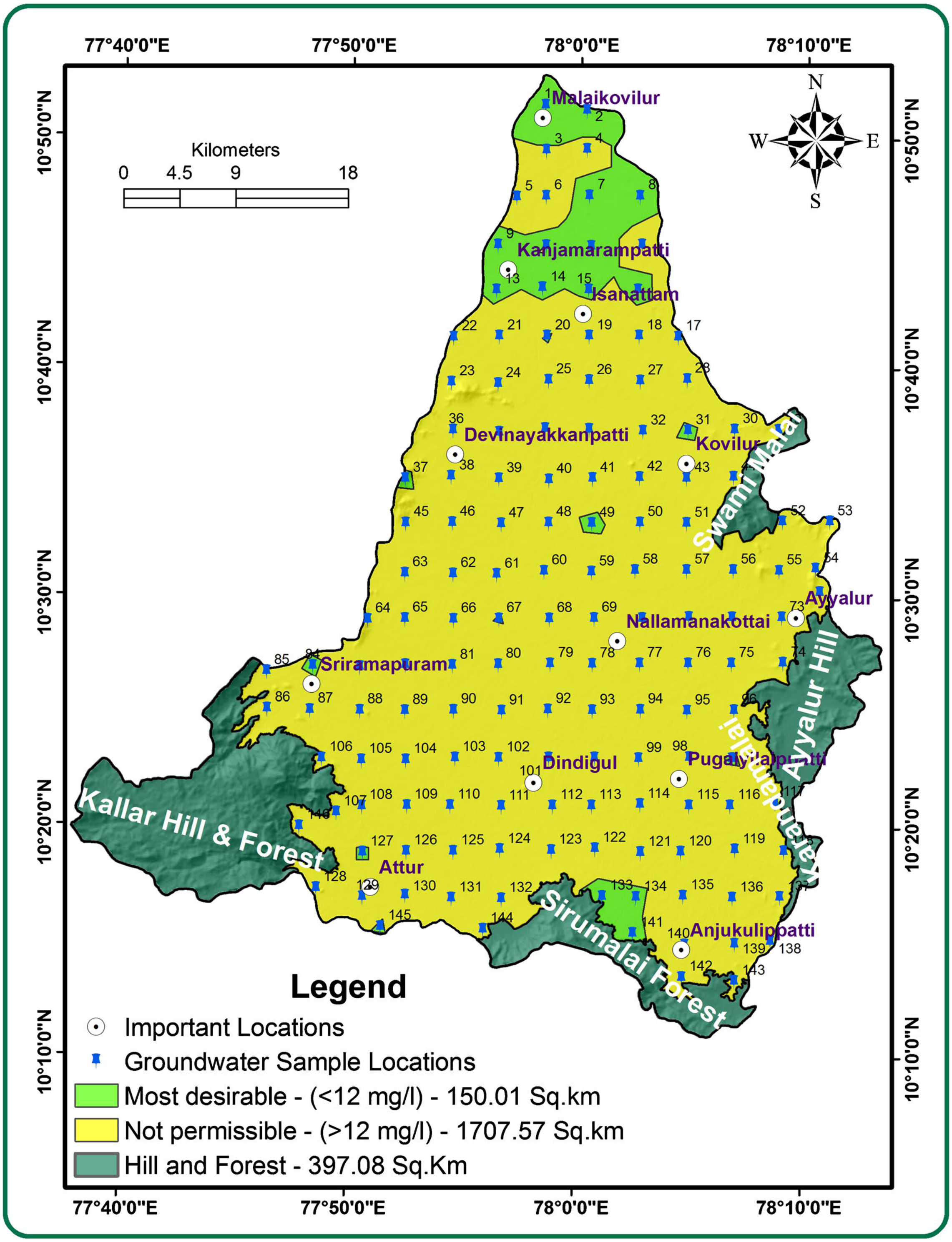

Fig. 9 Spatial dstribution map of K

for drinking purposes. Sulfate concentration is in increasing trend in the catchment and middle part of the basin because of heavy rock water interaction and highly weathered subsurface materials (Srinivasamoorthy et al. 2008).

Bicarbonate

Bicarbonate content in groundwater is one of the best indicators of hardness. Bicarbonate indicates the principal total alkalinity. Alkalines in water are the determination of its competence of

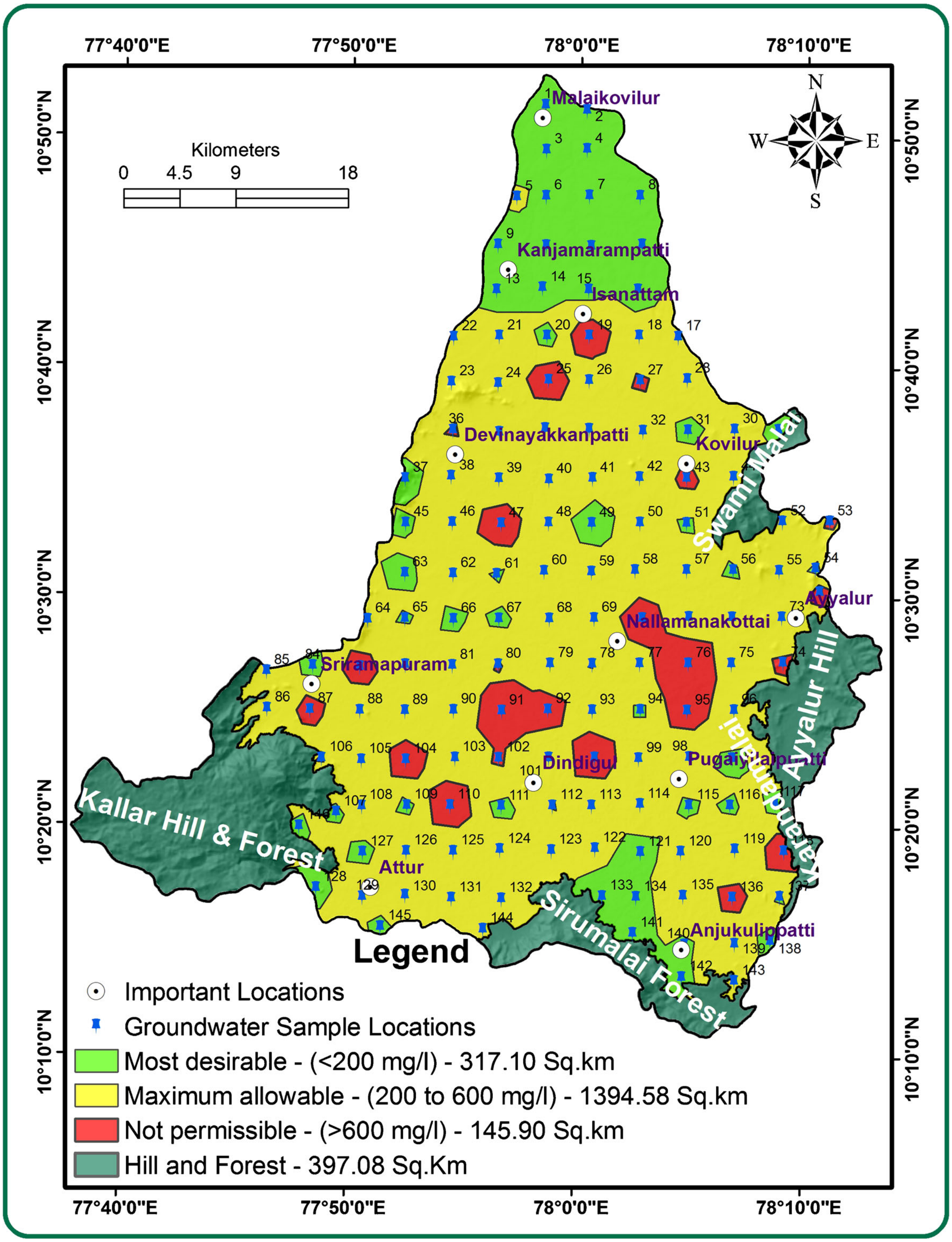

Fig. 10 Spatial distribution map of Cl

neutralities. It is shaped mostly by the act of atmospheric CO_2 and CO_2 freed as of natural decay (Bhardwaj and Singh 2011). The spatial map (Fig. 12) shows that the northern part of the region falls under most desirable zone and the rest of the watershed area is a mixed zone of all three categories.

Nitrate

The major source of nitrate is agricultural fertilizers and the influence of irrigational activities. Nitrate spatial map (Fig. 13) shows that the study area has been

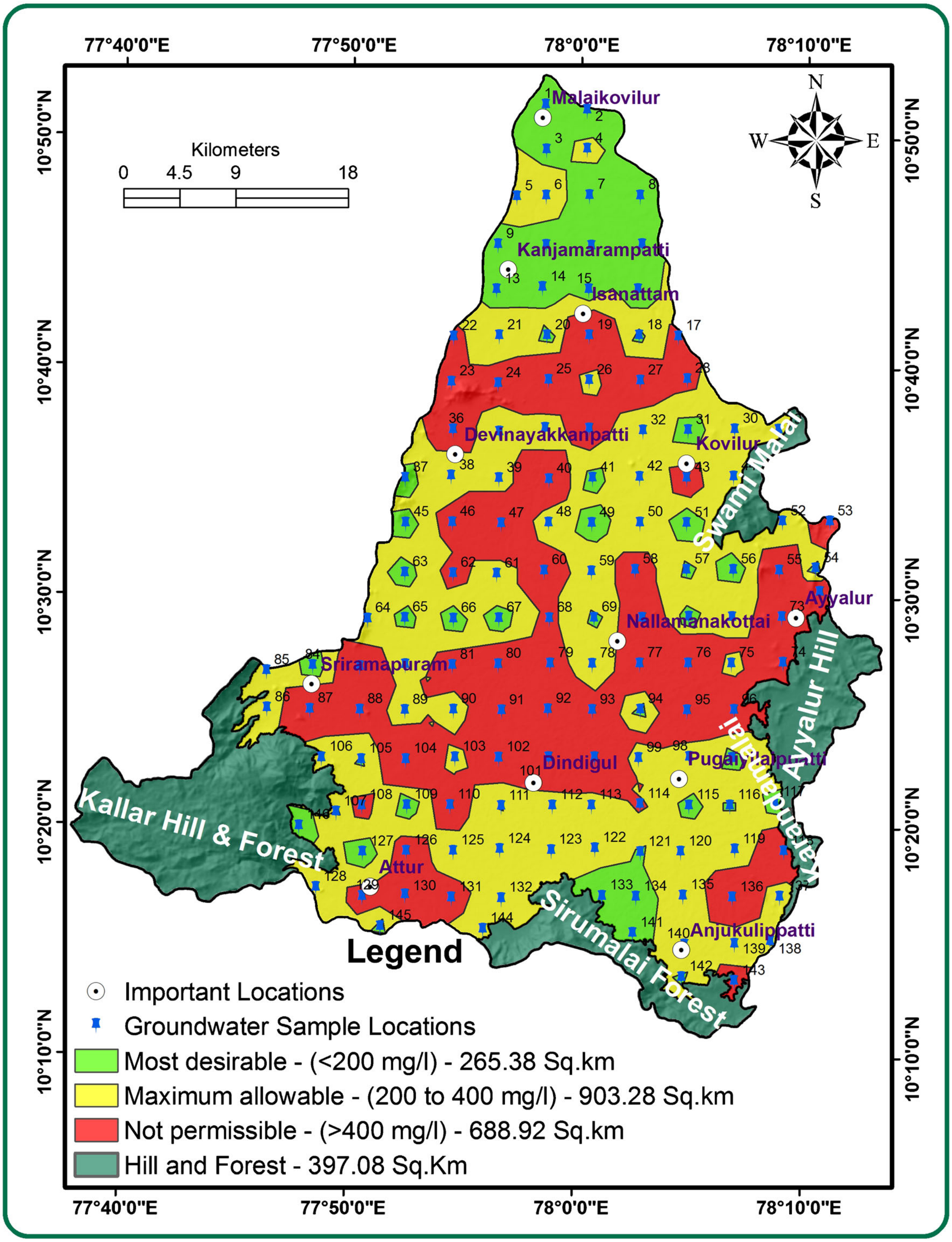

Fig. 11 Spatial distribution map of SO_4

divided into two classes according to the World Health Organization (WHO 2011) standard. The desirable quality of groundwater occupied almost the entire study area by covering 1849.56 km^2 of the watershed. The "not permissible" quality of groundwater is observed in the Ammapattai, Morepatti, and Velvankottai villages in an area of 8.02 km^2. The source of nitrates is from various ways such as leaching fertilizers and domestic and industries wastewater (Gilli et al. 1984).

Fluoride

Fluoride is generally inversely related to the dissolved Ca and Mg. The negative correlation is due to the low solubility of

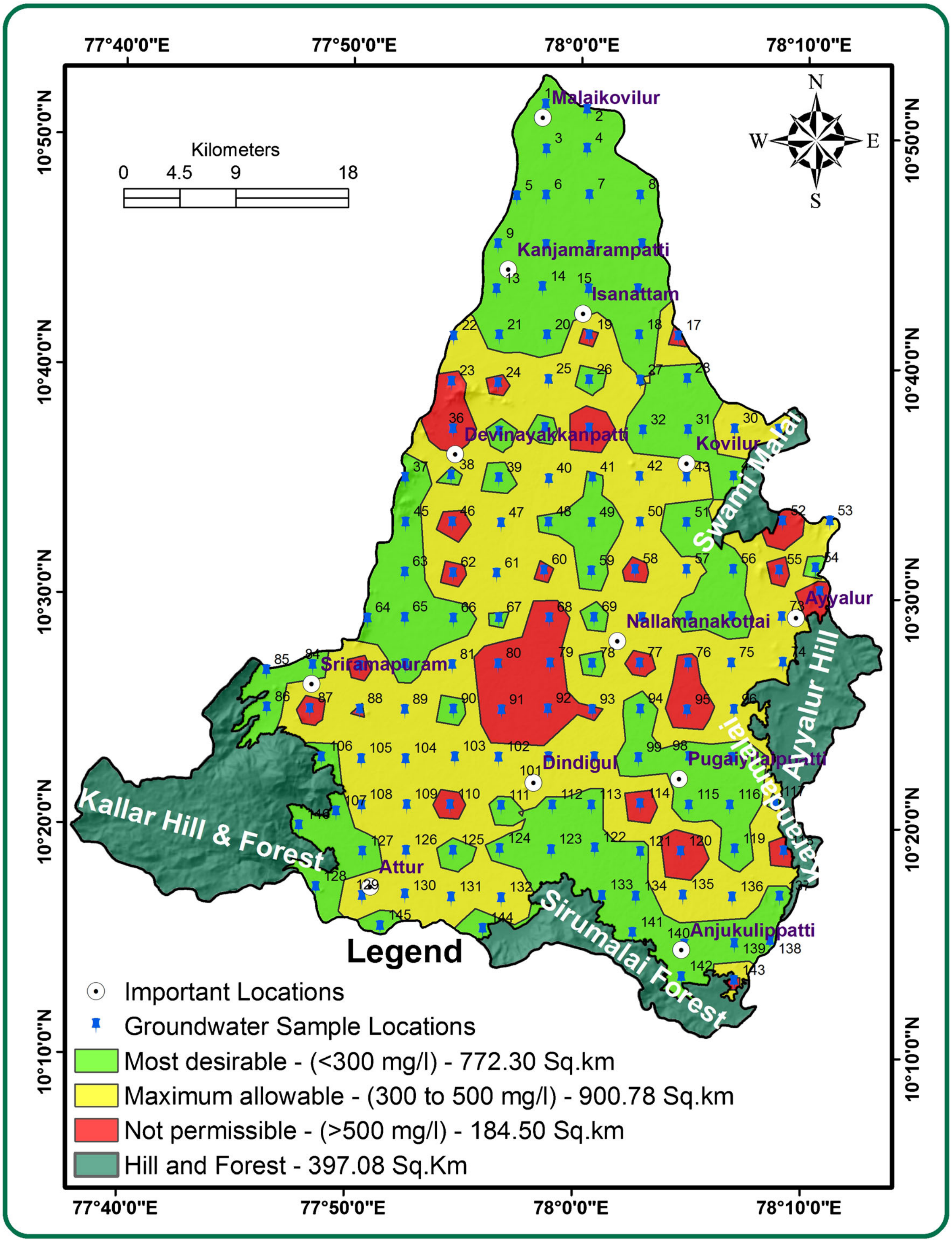

Fig. 12 Spatial distribution map of HCO_3

fluoride to these ions (Hem 1991). Fluoride is the least anion present in the study region. Fluoride is useful in the human body, as it reacts with the bone (calcium) and preserves bone joints and teeth. Major health problems of humans due to fluorides are dental fluorosis and skeletal fluorosis. If fluoride concentration is greater than 1.5 mg/l, it causes dental fluorosis (Keller 1979). Dental fluorosis is not only a cosmetic problem but is also known to cause social problems. More than 2 mg/l of fluorides in the groundwater causes skeletal fluorosis. Fluoride spatial map

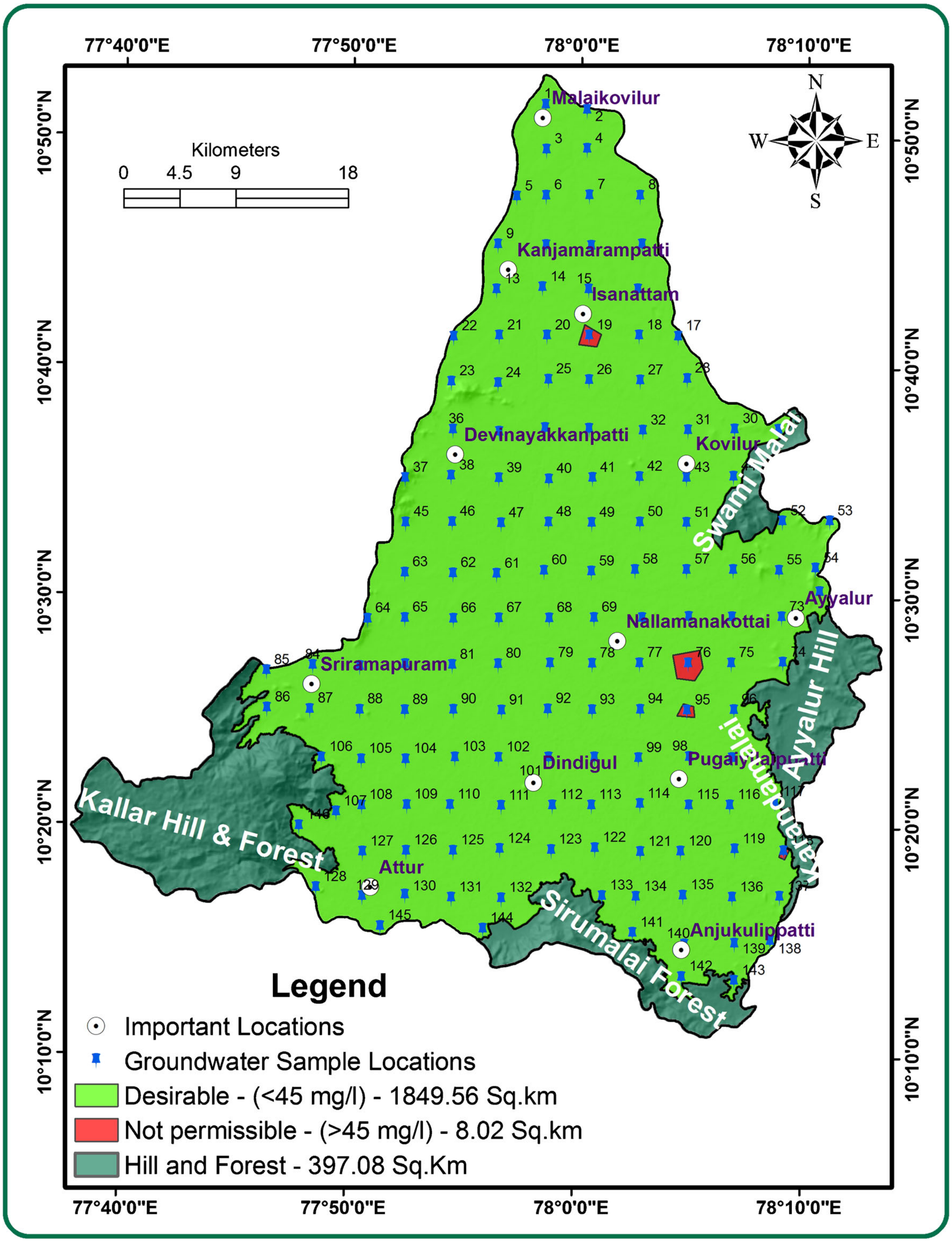

Fig. 13 Spatial distribution map of NO_3

(Fig. 14) reveals that a high concentration of fluoride occurs in small patches over the upper part of the watershed.

The fluoride supplies in subsurface water in the study area are due to the existence of various fluoride accomplish elements. At the time of their contact with water, it suspends fluoride ion. Familiar fluoride posture minerals are fluorite, rock phosphate, phosphatic nodules, and phosphates like wagnesite, apatite, and amblygonite. Agarwal et al. (1997) has reported a fluoride concentration of groundwater due to fluoride minerals and rock.

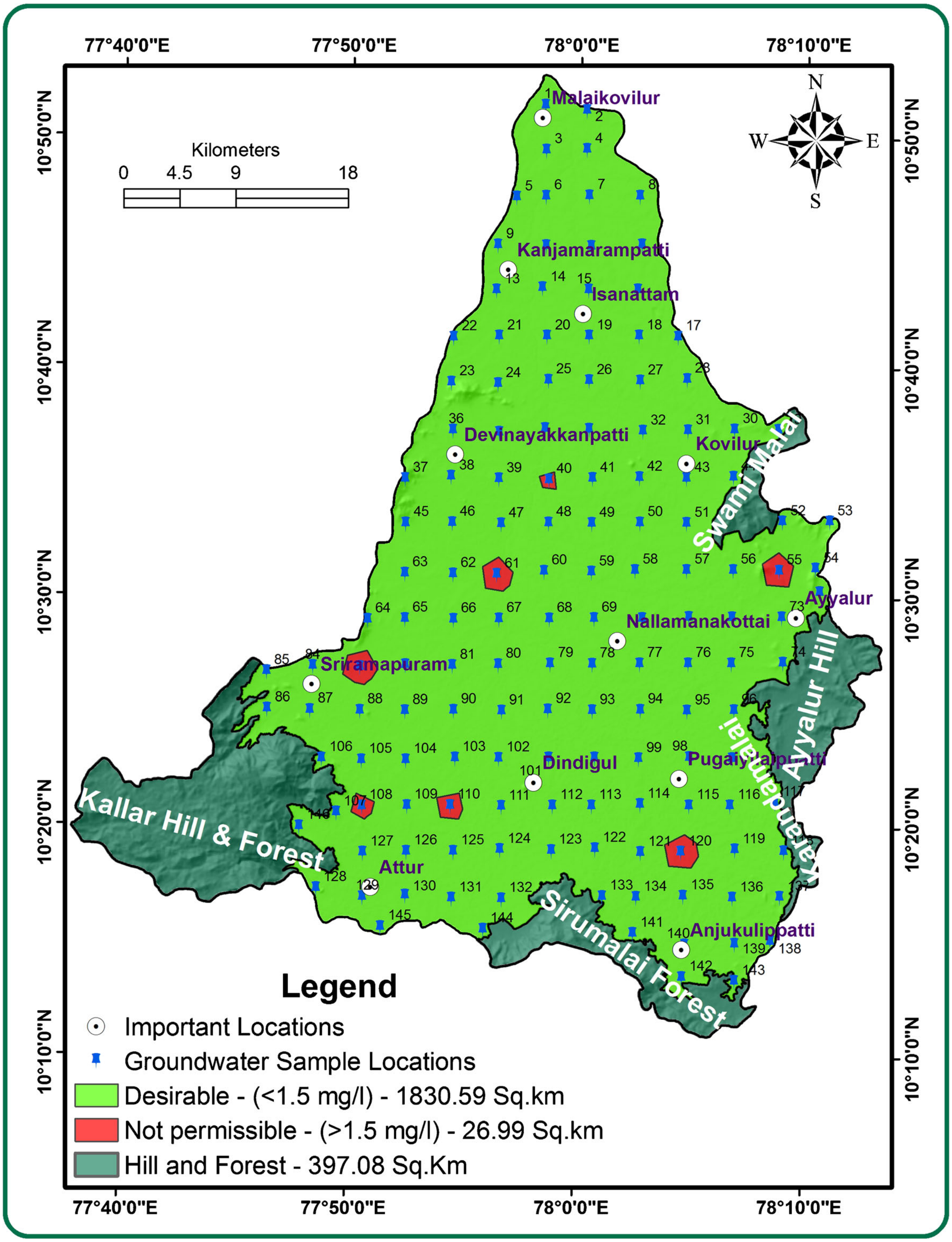

Fig. 14 Spatial distribution map of F

Spatial data integration using GIS

For the integration of groundwater quality data, sixteen parameters were taken into consideration, which plays a dominant role in groundwater quality in the Kadavanar watershed. Since the concentrations of parameters like pH, carbonate, and magnesium were within the permissible limit in all the locations in the watershed, these parameters were not considered. After integration, the map showing the groundwater quality (Fig. 15) provides an idea about the most desirable, maximum allowable, and not permissible quality in the Kadavanar region.

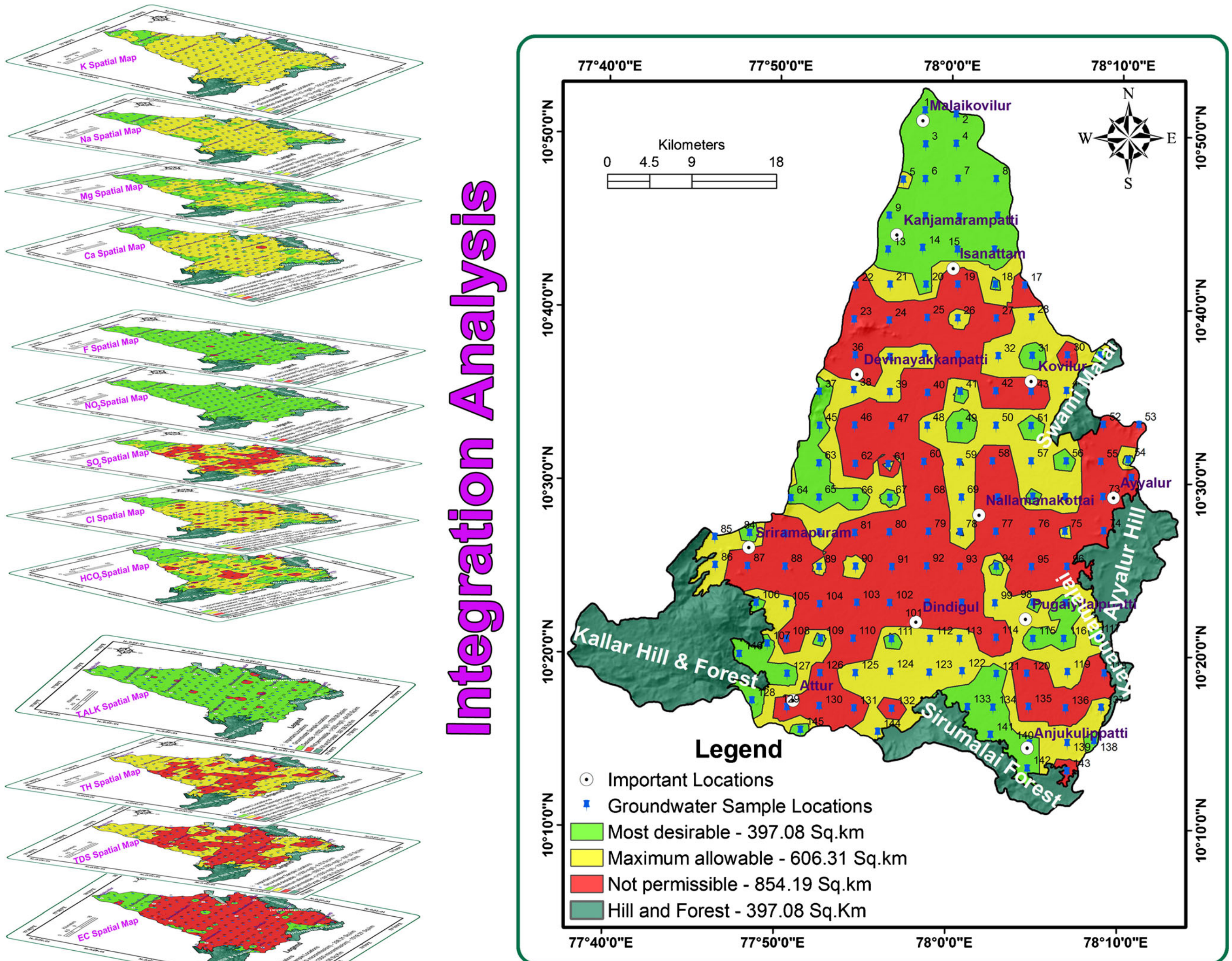

Fig. 15 Spatial integration map based on groundwater quality

The final integration map presents the details about the areas of most desirable, maximum allowable, and not permissible groundwater quality of the overlaying maps of each parameter. The integrated groundwater quality spatial map indicates that the "most desirable" category is present over 397.08 km^2 of the study area which is located in the northern part (confluent point) as well as the high lineament and weaker plain of the watershed. The rest of the area is of a mixed category of allowable and not permissible zones. The not permissible area is 854.19 km^2 in the watershed and it is due to heavy rock water interaction and deeper water level (Bore well water samples) and leaching fertilizers and domestic and industries waste (Rajendran et al. 2016).

Water quality index

The water quality index is a key factor for the validation of groundwater chemistry (Gupta et al. 2015). The following parameters considered for the present study are pH, TDS, TH, Cl^-, Mg^{2+}, Ca^{2+}, SO_4^{2-}, Na^+, EC, and the calculated water quality index (WQI). The WQI results are presented in Table 2. The WQI value is a minimum of 7.66 (excellent) to 263.34 (worst) classes. Sixty-three (43%) of the samples come under the "excellent" class, 46 (31%) of the sites fall under the "good" class, "poor," and "very poor" classes; the following 25 (17.01%), 10 (6.80%), and 3 (2%) of the samples come under the "worst" class. During the year 2016 pre-monsoon, the water quality index of groundwater of Kadavanar watershed is classified as "excellent," "good," "poor," and "very poor." The water quality index spatial map (Fig. 16) shows that the "good" quality of groundwater occupies almost 60.22% of the watershed by accommodating 1118.56 km^2. The northern (lower) part of the watershed is classified under the "excellent" zone of water quality for drinking purposes. The WQI spatial map indicates that the "excellent" category is present over 424.21 km^2 of the study area which is located in the northern part (confluent point) and food hill of the catchment area. It is located as high lineament and weaker plain of

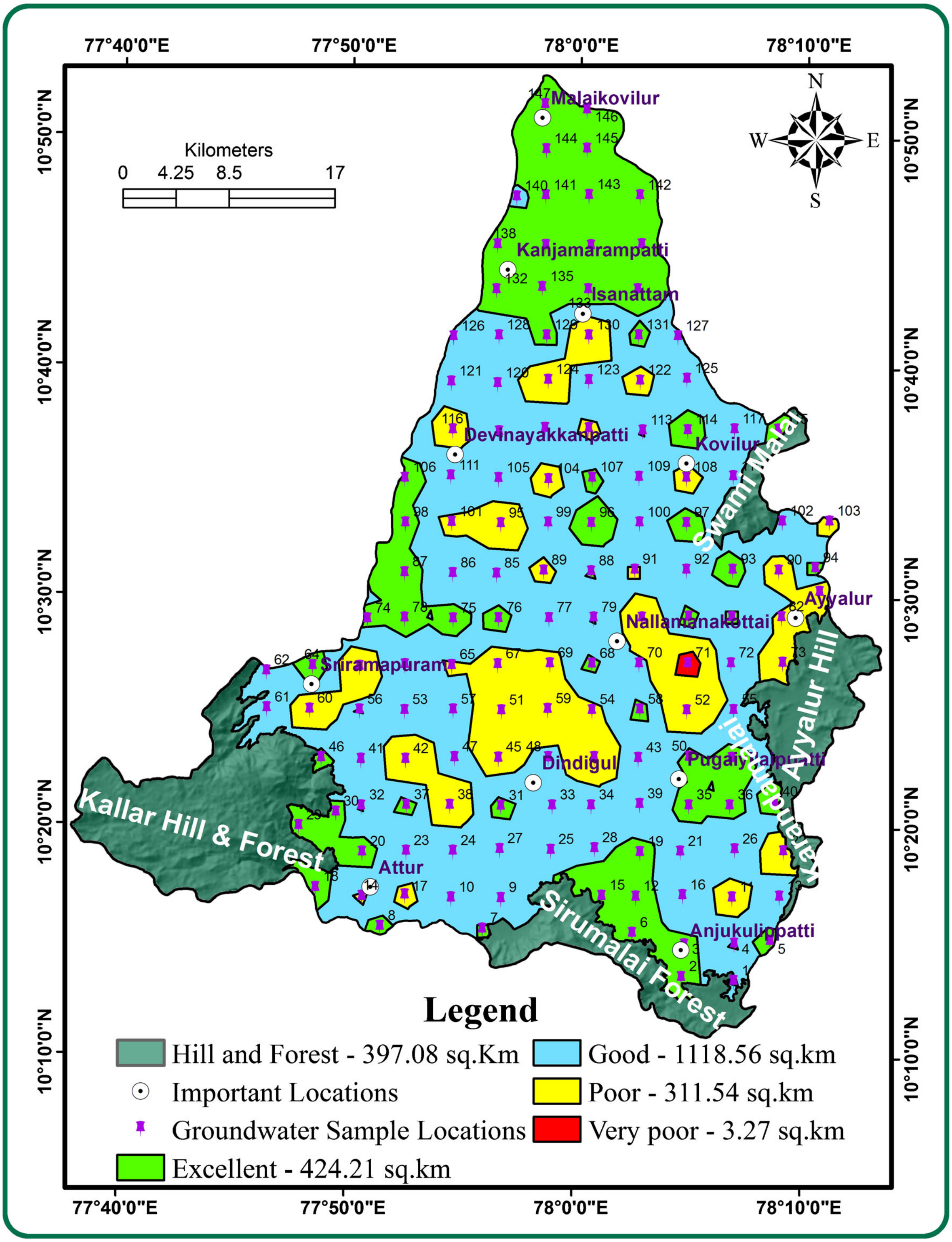

Fig. 16 Water quality index map of the study area

the watershed. The rest of the area is of the mixed category of poor (311.54 km^2) and very poor (3.27 km^2) zones. "Poor" and "very poor" groundwater quality zones are in the watershed. It is due to heavy rock water interaction and leaching fertilizers and domestic and industrial waste (Kalaivanan et al. 2017).

Conclusion

The present study concludes that many of the groundwater quality parameters namely pH, TDS, TH, Cl^-, Mg^{2+}, Ca^{2+}, SO_4^{2-}, Na^+, K^+, NO_3^-, F^-, EC, HCO_3^-, and CO_3^{2-} exhibit a direct influence with reference to the groundwater quality of

Table 2 Results of groundwater quality index

Sl. no.	WQI values	WQI class
1	29.19	Excellent
2	22.15	Excellent
3	34.37	Excellent
4	40.04	Excellent
5	55.87	Good
6	49.25	Excellent
7	34.25	Excellent
8	28.33	Excellent
9	28.26	Excellent
10	27.43	Excellent
11	27.05	Excellent
12	37.23	Excellent
13	15.53	Excellent
14	15.31	Excellent
15	25.98	Excellent
16	19.00	Excellent
17	97.01	Good
18	37.79	Excellent
19	202.60	Worst
20	27.38	Excellent
21	59.60	Good
22	91.90	Good
23	90.65	Good
24	92.24	Good
25	168.61	Very poor
26	59.56	Good
27	118.32	Poor
28	69.72	Good
29	41.83	Excellent
30	71.38	Good
31	20.36	Excellent
32	48.99	Excellent
33	107.24	Poor
34	52.79	Good
35	49.08	Excellent
36	133.09	Poor
37	21.32	Excellent
38	57.06	Good
39	56.97	Good
40	129.22	Poor
41	42.75	Excellent
42	87.96	Good
43	127.93	Poor
44	54.79	Good
45	37.68	Excellent
46	113.01	Poor
47	177.53	Very poor
48	53.29	Good
49	7.66	Excellent
50	59.74	Good
51	30.75	Excellent
52	65.44	Good
53	115.51	Poor
54	32.86	Excellent
55	132.19	Poor
56	35.08	Excellent
57	51.20	Good
58	105.63	Poor
59	48.37	Excellent
60	114.06	Poor
61	54.66	Good
62	99.22	Good
63	30.66	Excellent
64	44.14	Excellent
65	33.25	Excellent

Table 2 (continued)

Sl. no.	WQI values	WQI class
66	28.45	Excellent
67	27.90	Excellent
68	95.97	Good
69	48.44	Excellent
70	149.23	Poor
71	35.62	Excellent
72	44.15	Excellent
73	102.51	Poor
74	129.87	Poor
75	59.73	Good
76	263.34	Worst
77	96.34	Good
78	40.99	Excellent
79	107.42	Poor
80	143.07	Poor
81	106.14	Poor
82	59.74	Good
83	169.22	Very poor
84	21.52	Excellent
85	52.80	Good
86	56.73	Good
87	160.60	Very poor
88	100.20	Poor
89	59.61	Good
90	57.84	Good
91	174.94	Very poor
92	152.22	Very poor
93	102.61	Poor
94	29.57	Excellent
95	172.85	Very poor
96	94.99	Good
97	30.19	Excellent
98	39.41	Excellent
99	58.01	Good
100	204.27	Worst
101	83.10	Good
102	114.98	Poor
103	80.88	Good
104	175.28	Very poor
105	48.81	Excellent
106	39.17	Excellent
107	32.87	Excellent
108	102.74	Poor
109	34.05	Excellent
110	167.27	Very poor
111	37.23	Excellent
112	50.54	Good
113	58.39	Good
114	93.38	Good
115	34.67	Excellent
116	42.04	Excellent
117	34.94	Excellent
118	179.94	Very poor
119	52.74	Good
120	88.47	Good
121	34.32	Excellent
122	53.95	Good
123	57.39	Good
124	56.36	Good
125	57.04	Good
126	84.13	Good
127	26.09	Excellent
128	34.41	Excellent
129	105.37	Poor
130	114.97	Poor

Table 2 (continued)

Sl. no.	WQI values	WQI class
131	81.13	Good
132	78.62	Good
133	20.28	Excellent
134	25.53	Excellent
135	89.09	Good
136	144.95	Poor
137	50.92	Good
138	32.37	Excellent
139	49.11	Excellent
140	41.56	Excellent
141	22.24	Excellent
142	32.43	Excellent
143	103.04	Poor
144	47.21	Excellent
145	30.83	Excellent
146	35.69	Excellent
147	141.81	Poor

the study area. Since the parameters like pH, carbonate, and magnesium were within the permissible limit in all the locations in the watershed, these parameters were not considered for integrating the water quality of the study area. The areal extent obtained from the integrated groundwater quality map reveals that nearly 54.02% of the watershed area possesses permissible category of (most desirable + maximum allowable) groundwater quality.

The final groundwater quality spatial map shows that the "most desirable" area is 397.08 km^2 and it is located in the northern part (confluent point) as well as the high lineament and weaker plain of the watershed. The rest of the area is mixed allowable and not permissible zones. Not permissible area (854.19 km^2) extends over the watershed. The water quality index study was evaluated in the present study. It is 90% of positive correlation of the final groundwater spatial map. The reason behind the not permissible groundwater quality is due to heavy rock water interaction and deeper water level (bore well water samples) and leaching fertilizers and domestic and industries waste.

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