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Hydrogeochemistry and spatio-temporal changes of a tropical coastal wetland system: Veli-Akkulam Lake, Thiruvananthapuram, India

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Abstract The backwater of Veli-Akkulam, adjoining the Arabian Sea in the south-west part of Indian Peninsula, is a coastal wetland system and forms an integral part of the local ecosystem. In addition to the usual marine interactions, this water body is subjected to anthropogenic interference due to their proximity to the Thiruvananthapuram City urban agglomeration. This paper showcases how an urban agglomeration alters wetland system located within a tropical monsoonal environment. Water samples from this lake together with different feeder streams reveal that the lake is under the threat to eutrophication. A spatio-temporal analysis has shown that the lake and adjacent wetlands are shrinking in a fast pace. Over a period of about seven decades, the lake has shrunk by 28.05 % and the wetlands by 37.81 %. And hence, there is a pressing requirement of eco-management practices to be adopted to protect this lake.

Keywords Veli-Akkulam Lake · Hydrogeochemistry · Spatio-temporal variation · Eutrophication

Introduction

Brackish water lakes of Kerala, called 'kayals' (in native 'Malayalam' language) or backwaters or coastal lagoons, and its associated flood plains form the coastal wetland system of Kerala. The total estimated wetland area is 127,930 ha comprising 34,200 ha of 'inland wetlands' and 93,730 ha 'coastal wetlands' (Nair 2007). It is generally believed that these coastal wetlands have evolved through gradual regression of the sea after the Holocene marine transgression (Bruckner 1989; Ravindrakumar et al. 1990; Thrivikramji et al. 2007; Nair 2007; Nair et al. 2010; Padmalal et al. 2010). Among the various states in India, Kerala stands first in having the largest area of wetlands (Nayar and Nayar 1997). Physiographically, all the brackish lakes are located in the coastal tract, whereas the freshwater lakes occupy the mid-land portion. The low-relief coastal plain topography of Kerala is renowned for the presence of several backwaters of very special forms in plan view and unique orientation with respect to the modern shoreline (Sabu and Thrivikramji 2002). Backwaters play an important role in the field of transportation, fishing, navigation, irrigation and drinking water schemes in Kerala (Muraleedharan and Muraleedharan 2002). They also play a vital role in shaping the socio-economic and climatic condition of the state.

Many studies have been carried out on the Veli-Akkulam Lake which includes soil study (Slimmings 1997), an integrated environmental assessment (Muraleedharan Nair et al. 1998), methane emission and diurnal pattern (Divya 2007), heavy metal pollution monitoring using lichens (Salini 2007), lake morphology and water quality (Sheela et al. 2011), heavy metal (Swarnalatha et al. Swarnalatha et al. 2012) and extent of sea-level rise (Sheela et al. 2013). The studies, on a whole, indicate that the heavy metal content of Veli-Akkulam Lake is high and that the water quality depends on the morphometric features like mean depth, surface area, volume. These studies further show that the dilution capacity is very low for the Veli-Akkulam Lake and also that the nitrate and phosphate content of the lake is high.

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The present study mainly focuses on the hydrogeochemistry of this coastal wetland system as well as the streams feeding this lake. This study on the hydrogeochemistry will be of immense help in updating the existing ecological and environmental geochemical database of the lake. This lake is slowly dying due to eutrophication induced by the continuous inflow of effluents from the streams draining the urban agglomerate, and any addition to the knowledge base on the health of the lake is of immense importance in nurturing the lake back to health and also to prevent any further deterioration. As the lake is situated in between Thiruvananthapuram City and the nearby fast-developing information technology hub—Kazhakkuttam—where numerous skyscrapers have emerged and related constructional activities have resulted in filling up of various wetlands, a study on the spatio-temporal changes in the natural environment of the area is also a pressing requirement.

Study area

The Veli-Akkulam Lake, a famous tourist destination, is located about 8 km north of Thiruvananthapuram and fringes the Arabian Sea in the western coast of India (Fig. 1). It is situated between 8°31′14″ and 8°31′52″ north latitudes and 76°53′12″ and 76°54′06″ east longitudes and is covered by the Survey of India topographic sheet 58D/14/SE (on 1:25,000 scale). The total area of study is 135 km^2 of which the lake occupies an area of 1.16 km^2.

The Travancore–Shornanur (TS) Canal or Parvathy Puthanar (the erstwhile navigation canal connecting north and south Kerala) connects this lake with two estuaries—Kadinamkulam to the north and Thiruvallam to the south. Veli-Akkulam Lake is fed by Kannammoola stream, Kulathur stream, Amaizhanchan stream and Sreekaryam stream. These streams together with their tributaries drain the urban precincts of Thiruvananthapuram and finally debouch to the Veli-Akkulam Lake. Numerous dwellings and slums are situated all along these rivers. Sewage waste from the dwellings, domestic waste and other industrial waste have resulted in polluting these drainages as well as Veli-Akkulam Lake.

Geologically, the area forms a part of Kerala Khondalite Belt (KKB) characterized by the presence of khondalites and charnockites. Usually, these Precambrian rocks are overlain by Tertiary sediments (Soman 2002). Veli-Akkulam Lake and adjacent areas also expose Quaternary sediments
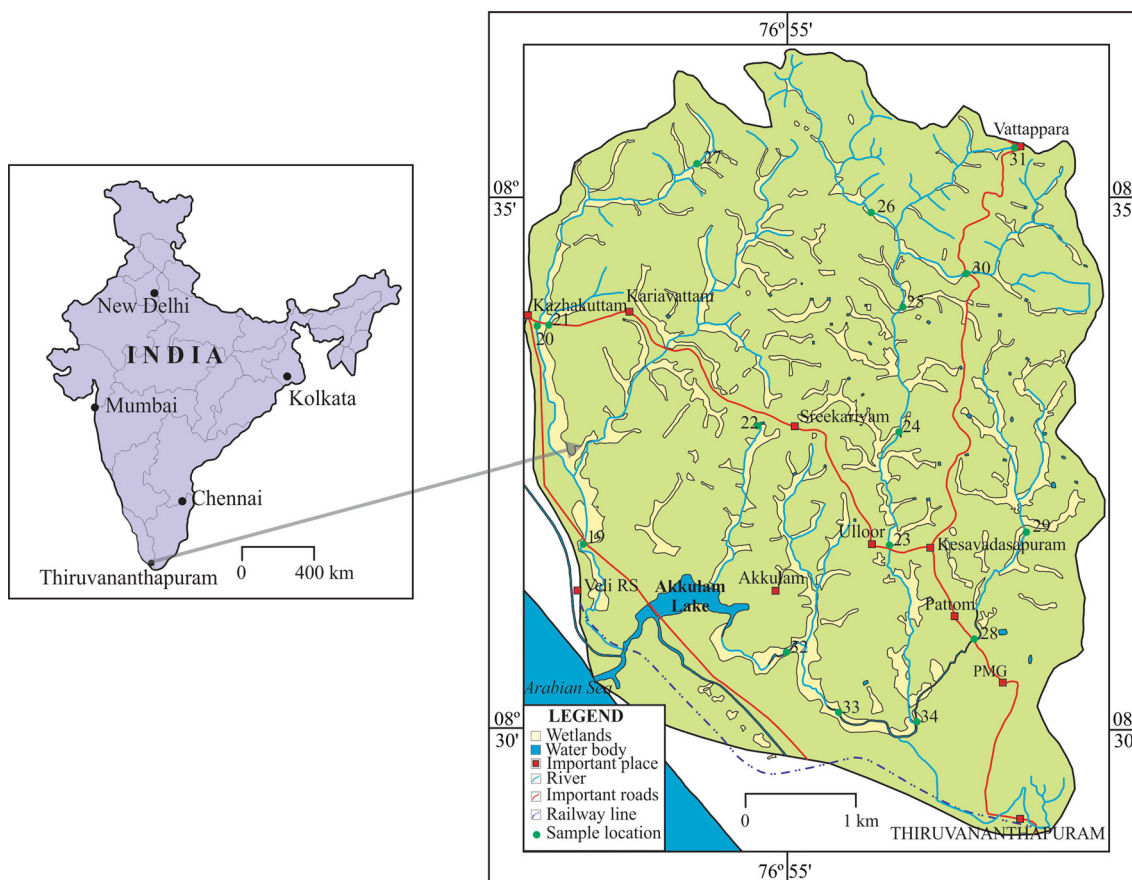

Fig. 1 Location map of the study area. Samples locations are also shown (samples 1–18 are collected from both the banks of the lake and are not shown here due to the scale limitations)

Table 1 Physical parameters of water samples

Sample no	Colour	Odour	Taste	Turbidity	Temperature (°C)
1	Grey colour	Odourless	Brackish	Turbidity	27.75
2	Slightly grey	Odourless	Bitter	Slightly turbid	30
3	Slightly clear	Odourless	Saline	Slightly turbid	31
4	Slightly grey	Odourless	Bitter	Turbid	30.5
5	Slightly clear	Odourless	Brackish	Turbid	32.5
6	Slightly grey	Odourless	Brackish	Slightly turbid	28.5
7	Grey colour	Odourless	Brackish	Slightly turbid	29
8	Grey colour	Odourless	Brackish	Slightly turbid	30
9	Slightly grey	Odourless	Saline	Turbid	30.5
10	Slightly clear	Odourless	Bitter	Slightly turbid	30
11	Slightly clear	Odourless	Brackish	Slightly turbid	31
12	Grey colour	Odourless	Brackish	Slightly turbid	30
13	Grey colour	Odourless	Brackish	Turbid	32.5
14	Slightly clear	Odourless	Saline	Slightly turbid	30
15	Slightly clear	Odourless	Saline	Slightly turbid	32
16	Slightly clear	Odourless	Brackish	Slightly turbid	32
17	Slightly clear	Odourless	Saline	Slightly turbid	32.5
18	Slightly clear	Odourless	Saline	Slightly turbid	32
Kulathur					
19	Grey colour	Pungent		Turbid	26.5
20	Black	Pungent		Highly turbid	28.5
21	Black	Pungent		Highly turbid	29
27	Clear	Odourless	Good	Slightly turbid	31
Amaizhanchan					
23	Light black	Slightly Pungent		Slightly turbid	28.5
24	Clear	Odourless	Good	Clear	28
25	Clear	Odourless	Good	Clear	29
26	Clear	Odourless	Good	Clear	28.5
30	Clear	Odourless	Good	Slightly turbid	28.5
31	Clear	Odourless	Good	Slightly turbid	30.5
Kannanmoola					
28	Black colour	Pungent		Turbid	32
29	Clear	Odourless	Bitter	Slightly turbid	31
Amaizhanchan–Kannanmoola confluence					
32	Grey colour	Pungent		Turbid	31
33	Light black	Slightly Pungent		Turbid	30
34	Clear	Odourless	Brackish	Turbid	31
Sreekariyam Thodu					
22	Clear	Slightly Pungent		Turbid	28

belonging to Viyyam Formation formed by laccustrine processes. Geomorphologically, these areas are influenced by coastal and marine activities. A bar separates this lake from the Arabian Sea which is usually opened during monsoon to prevent upstream flooding and inundation, and a new bar is naturally created by the long-shore currents after the monsoon. Marine ingressions are common.

Methodology

Thirty-four surface water samples (as shown in Fig. 1) were collected, which includes lake samples (18 nos) and samples from the streams (16 nos) that feed the lake, in order to understand the hydrogeochemistry of this wetland system. The physical parameters of water like colour,

Table 2 Mean and range values of hydrogeochemical parameters

Parameter	Range		Mean	BIS	
	Max	Min		Highest desirable	No relaxation
pH	7.62	6.37	6.99	6.5–8.5	No relaxation
EC (μS/cm)	4380	46.2	745.59	–	–
TDS (ppm)	3900	34.4	552.81	500	2000
Salinity (ppt)	2.57	0.034	0.414	–	–
Total Hardness (ppm)	505	50	163.97	300	600
K^+ (ppm)	30	2	10.97	–	–
Ca^{2+} (ppm)	114.22	10.02	32.29	75	200
Mg^{2+} (ppm)	89.86	3.60	15.69	30	100
Na^+ (ppm)	930	18	113.64	–	200
HCO_3^- (ppm)	375	20	113.97	–	–
Cl^- (ppm)	1583.3	49.7	191.81	250	1000
NO_3^- (ppm)	8.68	0	1.051	45	100
SO_4^{2-} (ppm)	143.41	8.12	39.67	200	400
PO_4^{3-} (ppm)	9.95	0	1.503	–	–

odour, taste, turbidity and temperature were calculated in the field, immediately after sample collection. These water samples were analysed through various analytical methods like titration, spectrophotometer (Perkin Elmer Lambda 25 UV–Visible Spectrophotometer) and flame photometer (ESCIO Digital Clinical Flame Photometer) for quantifying the hydrogeochemistry at the Department of Geology, University of Kerala, using the standard techniques like APHA (1989). Further, the results are graphically represented in standard diagrams like Hill Piper (Piper 1953), US salinity (1954) and Wilcox (1955) for understanding the suitability of water for various uses.

Spatio-temporal changes of Veli-Akkulam Lake and land-use/land-cover changes were studied using Survey of India topographic sheets 58D/14 for the years 1942 (on 1:63,500 scale), 1990 (on 1:25,000) and the Google Earth Imagery of 2013. All the temporal data were analysed in a GIS environment using MapInfo Professional 10.5.

Results and discussion

Hydrogeochemistry of the coastal wetland system

This area offers an excellent example to study the spatial variation of geochemistry of a lake and its feeding streams within a small geographical area of about 135 km^2. The results of the analysis of the 34 different water samples collected from both the lake and the stream are given in Tables 1, 2 and 3. Table 1 provides the physical parameters of the water samples. Since the lake is situated in the fringe of an urban area, the physical parameters reflect the influence of urbanization in surface water. There is a

deterioration of quality of water as it travels down through the agglomeration. Most astonishing feature noticed in the water samples collected from feeder stream is that the odour and colour varies from odourless (mainly Amaizhanchan stream) to slightly pungent to pungent (mainly Kulathur stream) and clear to black towards the confluence. But the lake water samples are odourless and slightly clear to grey in colour.

The minimum, maximum and mean values of all hydrogeochemical constituents are tabulated and compared with Bureau of Indian Standards (BIS, 1991) and are given in Table 2. The comparison shows that only two locations (from Kulathur stream) show high variation from the BIS values. In the rest of the streams, all the constituents are within the permissible limit.

Table 3 provides the values of chemical constituents of all the samples of the feeder streams and lake in the study area. The physico-chemical constituents of the samples show wide variations, even within the lake as well as between different feeder streams. Of the different feeder streams, Kulathur stream (sample nos 20 and 21) shows the maximum values for majority of the constituents, whereas Kulathur stream (sample no 27) shows the minimum value. Such a major variation in the geochemistry of a watershed within an urbanized environment can be easily attributed to anthropogenic interferences. Dumping of waste materials in the streams is a common phenomenon in majority of the urban areas in developing nations, and the study area is no exception. The uniqueness of this city is the absence of a centralized waste collection or disposal as its only solid waste incinerator located at Vilapilsala (8°32′20″N; 77°02′19.5″E) is shut down due to local agitation. Hence, domestic wastes and sewerages together with industrial

Table 3 Hydrochemical data of water samples collected from the study area

Sample no.	pH	Salinity (ppt)	EC (µs/cm)	TDS (ppm)	Total hardness (ppm)	Na$^+$ (ppm)	K$^+$ (ppm)	Ca^{2+} (ppm)	Mg^{2+} (ppm)	Cl$^-$ (ppm)	HCO$_3^-$ (ppm)	SO$_4^{2-}$ (ppm)	NO$_3^-$ (ppm)	PO$_4^{3-}$ (ppm)
1	6.94	0.336	620	442	185	71	14	38.07	21.82	159.75	105	18.56	0	1.18
2	7.24	0.271	501	357	145	65	12	28.05	18.19	106.5	110	34.04	0	2.45
3	7.16	0.287	541	385	135	64	14	30.06	14.54	127.8	90	20.69	0.058	1.82
4	7.27	0.292	545	386	155	62	15	36.07	15.75	127.8	165	20.76	3.684	1.26
5	7.37	0.312	583	415	145	77	11	28.05	18.19	138.45	95	30.96	1.067	1.10
6	7.22	0.477	883	623	200	115	13	66.13	8.42	213	110	105.05	1.082	2.2
7	7.26	0.462	853	606	180	109	13	18.03	32.78	237.85	115	52.58	0.731	2.05
8	7.42	0.366	684	484	165	90	12	36.07	18.18	152.65	95	46.16	8.68	2.15
9	7.32	0.282	527	374	135	69	12	34.06	12.10	113.6	90	20.65	0.065	1.60
10	7.45	0.502	919	659	260	118	6	46.09	34.17	216.55	200	12.26	0	0
11	7.23	0.443	819	579	180	105	12	36.07	21.82	209.45	115	59.41	0.898	1.80
12	7.22	0.357	634	467	160	100	12	36.07	16.92	230.75	90	53.69	1.293	2.55
13	7.35	0.434	802	569	170	105	12	38.07	18.17	117.5	105	51.66	0.911	3.10
14	7.02	0.356	663	470	155	86	11	26.05	21.83	159.75	95	85.52	1.600	1.97
15	7.45	0.420	790	552	210	101	12	36.07	29.11	198.8	105	69.01	1.712	2.25
16	7.43	0.416	775	549	170	99	12	38.07	18.17	191.7	95	54.21	0.200	0
17	7.48	0. 342	634	451	175	80	11	36.07	20.61	131.35	100	47.10	0.671	0
18	7.14	0.433	806	571	185	99	12	36.07	23.04	170.4	95	75.65	1.323	2.65
Max	7.48	0.502	919	659	260	118	15	66.13	34.17	237.85	200	105.05	8.68	3.1
Min	6.94	0.271	501	357	135	62	6	18.03	8.42	106.5	90	12.26	0	0
Mean	7.28	0.38	698.83	496.61	172.78	89.72	12.00	35.73	20.21	166.87	109.72	47.66	1.33	1.67
Kulathur														
19	7.44	0.343	640	452	160	73	14	36.07	16.96	138.45	125	20.24	1.685	0
20	7.38	2.57	4380	3100	505	930	30	114.22	53.32	809.4	375	136.15	5.643	9.95
21	7.36	2.56	4340	3900	460	840	30	36.07	89.86	1583.3	340	143.41	0	0.179
27	7.24	0.062	109.1	77.3	50	20	2	10.02	6.06	60.35	30	13.54	0	0
Max	7.4	2.6	4380.0	3900.0	505.0	930.0	30.0	114.2	89.9	1583.3	375.0	143.4	5.6	10.0
Min	7.2	0.1	109.1	77.3	50.0	20.0	2.0	10.0	6.1	60.4	30.0	13.5	0.0	0.0
Mean	7.4	1.4	2367.3	1882.3	293.8	465.8	19.0	49.1	41.6	647.9	217.5	78.3	1.8	2.5
Amaizhanchan														
23	7.4	0.148	275	196	125	34	6	20.04	18.2	49.7	80	14.06	1.289	0
24	7.34	0.086	156.4	111	50	18	5	12.02	4.85	56.8	50	11.76	0	0
25	7.38	0.099	182.5	130	75	21	5	16.03	8.48	49.7	55	11.28	0	0
26	7.5	0.115	212	150	100	25	5	16.03	14.56	49.7	60	12.39	0	0
30	7.45	0.113	210	149	105	25	3	20.04	13.34	53.25	50	10.15	0.085	0
31	7.26	0.124	229	163	90	26	5	22.04	8.47	56.8	225	8.12	0.494	0
Max	7.5	0.1	275.0	196.0	125.0	34.0	6.0	22.0	18.2	56.8	225.0	14.1	1.3	0.0
Min	7.3	0.1	156.4	111.0	50.0	18.0	3.0	12.0	4.9	49.7	50.0	8.1	0.0	0.0
Mean	7.4	0.1	210.8	149.8	90.8	24.8	4.8	17.7	11.3	52.7	86.7	11.3	0.3	0.0
Kannanmoola														
28	7.06	0.034	46.2	34.4	100	26	9	20.04	12.12	56.8	140	11.51	0	4.69
29	7.46	0.109	205	144	125	23	4	20.04	18.2	56.8	20	9.92	0	0
Max	7.46	0.109	205	144	125	26	9	20.04	18.2	56.8	140	11.51	0	4.69
Min	7.06	0.034	46.2	34.4	100	23	4	20.04	12.12	56.8	20	9.92	0	0
Mean	7.26	0.0715	125.6	89.2	112.5	24.5	6.5	20.04	15.16	56.8	80	10.715	0	2.345

Table 3 continued

Sample no.	pH	Salinity (ppt)	EC (μs/cm)	TDS (ppm)	Total hardness (ppm)	Na⁺ (ppm)	K⁺ (ppm)	Ca²⁺ (ppm)	Mg²⁺ (ppm)	Cl⁻ (ppm)	HCO₃⁻ (ppm)	SO₄²⁻ (ppm)	NO₃⁻ (ppm)	PO₄³⁻ (ppm)
Amaizhanchan–Kannanmoola confluence														
32	6.94	0.33	614	438	160	58	14	38.07	15.74	106.5	105	18.53	0	4.9
33	7.62	0.312	586	415	150	71	10	28.05	19.4	152.65	110	28.47	2.516	0.29
34	7	0.144	271	193	90	25	6	30.06	3.6	49.7	80	15.32	0	0.979
Max	7.62	0.33	614	438	160	71	14	38.07	19.4	152.65	110	28.47	2.516	4.9
Min	6.94	0.144	271	193	90	25	6	28.05	3.6	49.7	80	15.32	0	0.29
Mean	7.187	0.262	490.333	348.667	133.333	51.333	10	32.06	12.913	102.95	98.333	20.773	0.839	2.056
Sreekariyam Thodu														
22	6.37	0.153	315	204	120	34	9	16.03	19.42	188.15	55	23.93	0	0

Fig. 2 **a** Stream flowing through Kannanmoola. Note the contamination, **b** stream flowing through Plamoodu. Note the contamination, **c** water stagnation near Kuzhikattukonam, **d** water stagnation near Maruthur
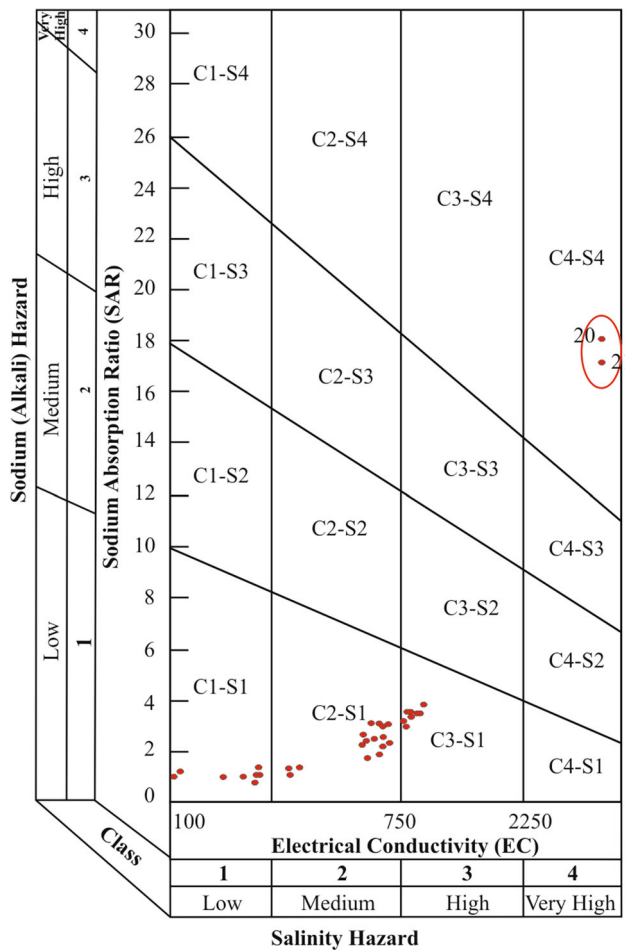
Fig. 3 US salinity diagram: samples are in low-sodium category and in different salinity category. Samples 20 and 21 show exception which are collected from the upcoming urban agglomerate

effluents find its final destination in the streams which ultimately debouch into the Veli-Akkulam Lake. The high content of solid and liquid waste material will change the water's natural colour, odour, taste, turbidity and temperature. Hence, these waters cannot be used for drinking and domestic purposes. This polluted water on entering the lake will also lead to eutrophication.

Figure 2a–d shows four different streams that drain to the Veli-Akkulam Lake. Figure 2a shows the stream which flows through Kannanmoola. Water from this stream is highly polluted with waste materials and has a pungent smell and is light black in colour. Sample no 34 represents this stream. The water is turbid and slightly hard in nature. It is not suitable for drinking and domestic purposes. Most of the solid waste materials are dumped into the stream,

thereby polluting its water. Figure 2b shows the stream which flows through Plamoodu, and sample no 28 represents this. The water from this stream shows pungent smell and is black in colour. It is slightly turbid and hard in nature. Figure 2c, d (represented by sample nos 25 and 30, respectively) depicts water scarcity. The excess quantity of waste dumped has resulted in stagnation of water, and its free flow of water has been hampered. This results in water scarcity in the further downward traverse of some streams. This stagnation also promotes breeding of mosquitoes.

Variations in other physical parameters are also mainly attributed to anthropogenic activities. The larger variation in EC (from 46.2 in sample 28 to 4380 μs/cm in sample 20) is mainly attributed to anthropogenic activities as well as to the geochemical processes prevailing in this region. Hardness of the water samples also varies among moderately hard, hard and very hard (from 50 in sample 27 to 505 sample 20) precluding the use of the water for drinking, domestic or irrigation purpose. Samples 20 and 21 are the most polluted ones. These samples were collected from two adjacent streams at Kazhakuttom. These streams are sites of poultry and live stock waste disposal, in addition to the usual wastes. To find out the suitability of water for domestic, drinking and irrigation purposes, the data have been plotted on US Salinity Laboratory (Fig. 3), Wilcox (Fig. 4) and Hill Piper (Fig. 5) diagrams, and this shows that most of the water samples in the study area are unfit for various purposes. In the US salinity diagram, except samples 20 and 21, all the samples fall in low-sodium hazard area. Similarly in Wilcox diagram, except the same samples 20 and 21, rest of the samples fall in very good to good fields. The ionic distribution present in the water sample can be determined by using Hill Piper diagram. Based on this diagram, it is recognized that most samples are under the sodium chloride type.

Spatio-temporal changes of Veli-Akkulam Lake

The spatio-temporal changes of Veli-Akkulam Lake and changes in the land-use/land-cover pattern of adjacent areas, over a period of 61 years, were extracted from the Survey of India topographic sheets and Google Earth Imagery (Fig. 6). Table 4 shows the variation in the areal extent of this lake over time. The lake shows a small change in the areal extent from 1942 to 1990. But there was a contrasting change in the areal extent of the lake between 1990 and 2013 which is a real matter of concern. Comparative studies point out that the shrinkage of area is more than 28 % during this short period owing to the real boom of urbanization and increase in population (Table 5). It was

Fig. 4 Wilcox diagram: samples are in very good to good category except samples 20 and 21
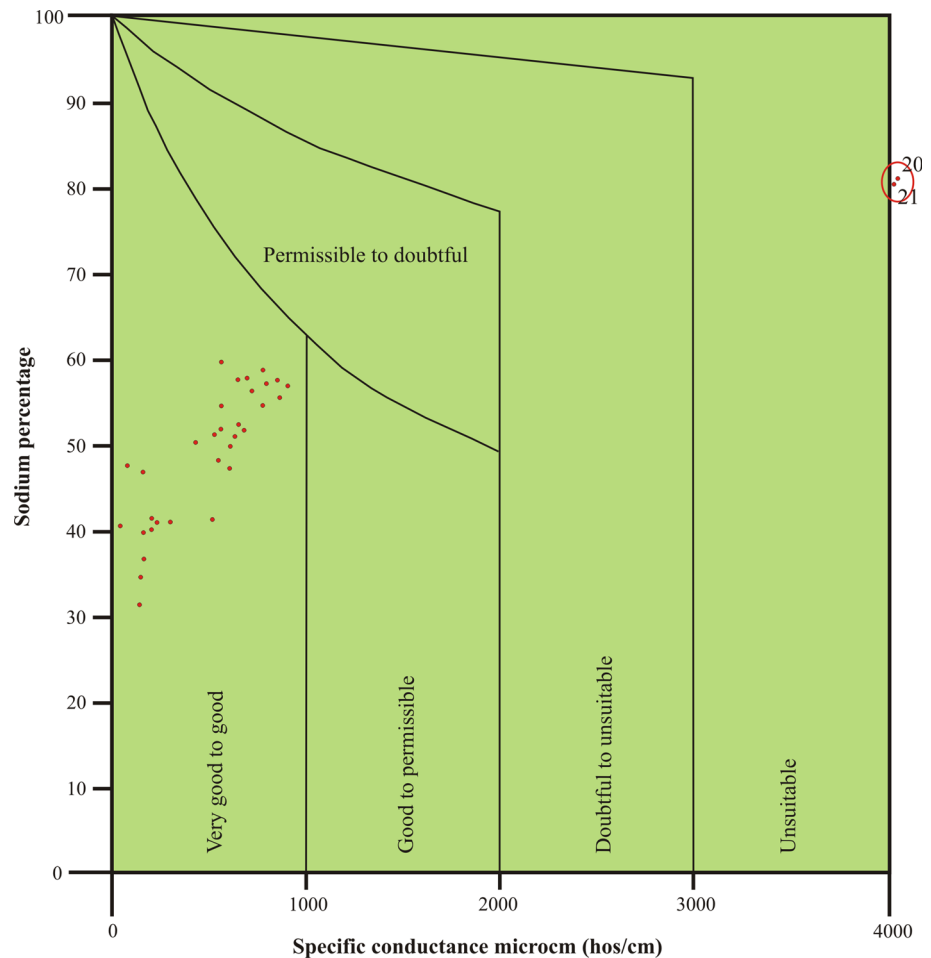
during this period the real boom of urbanization occurred. The most striking intervention is the conversion of flood plains of the lake into large and small settlements. The wetland areas have witnessed reclamation (Fig. 7a). Numerous multi-storied buildings started mushrooming in the wetlands during this period (Fig. 7b). As a result only a few stretches of wetlands are seen today. Beyond the geological phenomena of the shrinking of lakes, the aggravated human interference played a major role in shrinking the lake and its flood plains. Due to the lack of bathymetric data, the changes in the depth were not analysed. The reclamation activity in the lake areas has resulted in the reduction in the original capacity or areal extent of the lake.

Land-use changes in and around Veli-Akkulam Lake

Spatio-temporal changes in land-use and land-cover are common in any urbanized region. An analysis of different temporal data will give an idea about these changes.

Figure 8 and Table 6 show the change in the areal extent of different land-use/land-cover classes between 1942 and 2013. The study reveals that coastal alluvium, wetlands and mixed cultivation with settlements were the major land-cover during earlier days. Moreover, the earlier maps show that roads were fewer and most of the land was covered by mixed cultivation with settlements. The major cultivation of these areas was coconut, mango, jackfruit and cashew plants. The coastal tract was completely occupied by coconut trees.

Now, the entire coastal alluvium, present very close to the lake, has been converted into settlement with mixed cultivation. Residential establishments increased exponentially. Widening and construction of new roads took place. The Thiruvananthapuram City by-pass road from Kazhakkuttam to Kovalam has led to the bifurcation of certain water bodies and marshes and truncated many lower-order streams, thereby reducing water infiltration, increasing water-logging condition along a few stretches (Muraleedharan and Muraleedharan 2002) as well as blocking the coast perpendicular drainage systems which

Fig. 5 Hill Piper diagram: Samples spread in almost all types with sodium chloride type dominating

LEGEND

Calcium chloride type (Permanent hardness)

Sodium chloride type (Saline)

Calcium bicarbonate type (Temporary hardness)

Mixed type

Sodium bicarbonate type (Alkali carbonate)
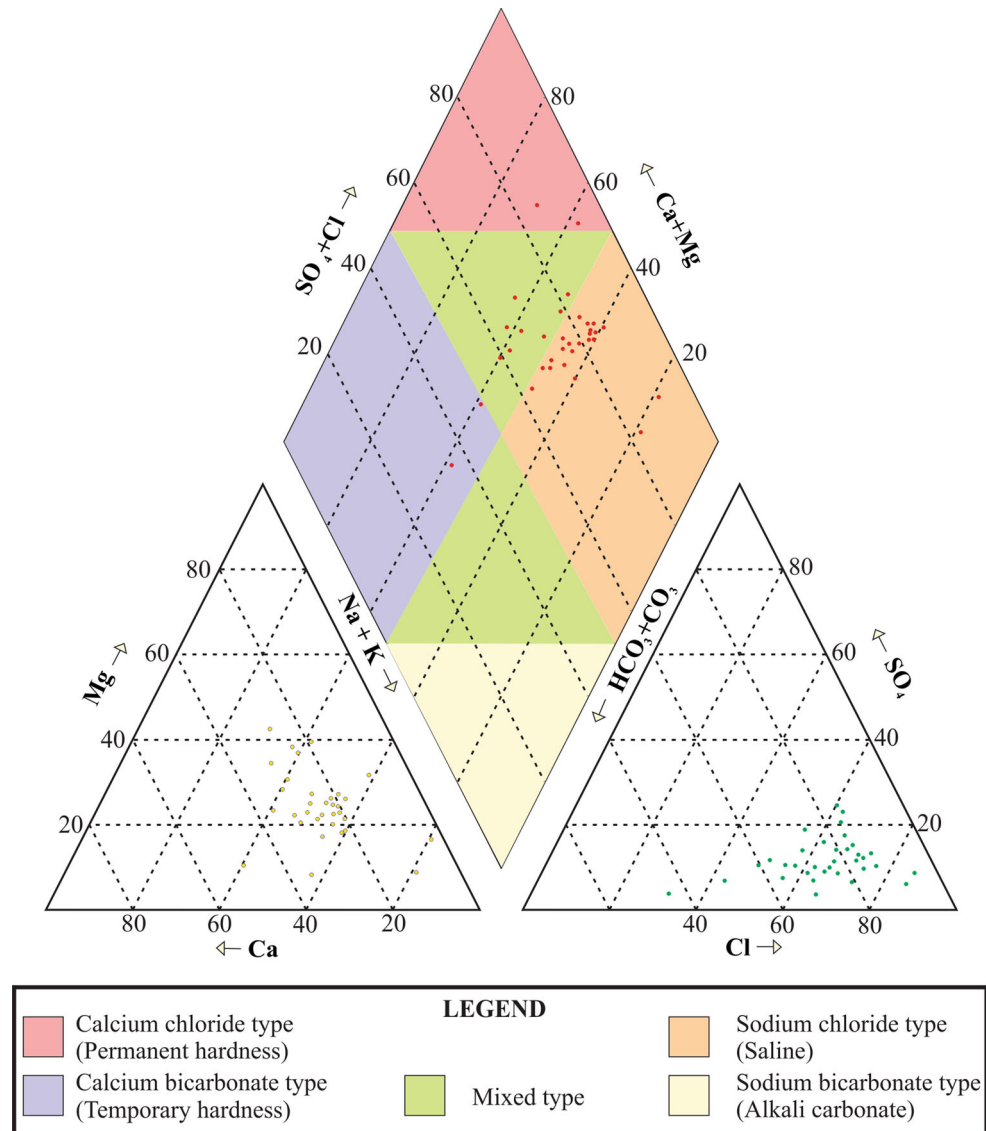
are generally natural pathways for excess surface water to get drained off during heavy monsoon. Many of the multistoried buildings, industrial establishments such as Technopark, Vikram Sarabhai Space Centre (VSSC), factories, air force academy and boat club are situated in the area. These offices and industries have created a lot of employment opportunities, and hence, people from nearby suburban and rural areas have migrated and settled down in the urban areas. This increase in population might be the main reason for the change in the land-use pattern. Moreover, factories and industries have also played some role in the formation of barren or waste land in their adjoining areas. Agricultural land has been replaced to a large extent by either settlements or industrial establishments. Increase in various types of human activities has resulted in increase in waste dumping. Large-scale construction of apartments

and flats are quite common now days, so sewages are directly opened to the surface water system, which in turn contaminate the lake.

Conclusions

The hydrogeochemistry of the lake and its feeding system were studied by the analyses of water samples by various analytical methods and comparison with the BIS standards. Based on the hydrogeochemistry, it is revealed that most of the stream water samples contain normal content of cations and anions in the upstream portion and gradually there is a gradual deterioration in the quality as it flows through the agglomeration. This is pictorially shown in Fig. 9. Thus, the main natural channels draining into the lake have been

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Fig. 6 Spatio-temporal changes of Veli-Akkulam Lake
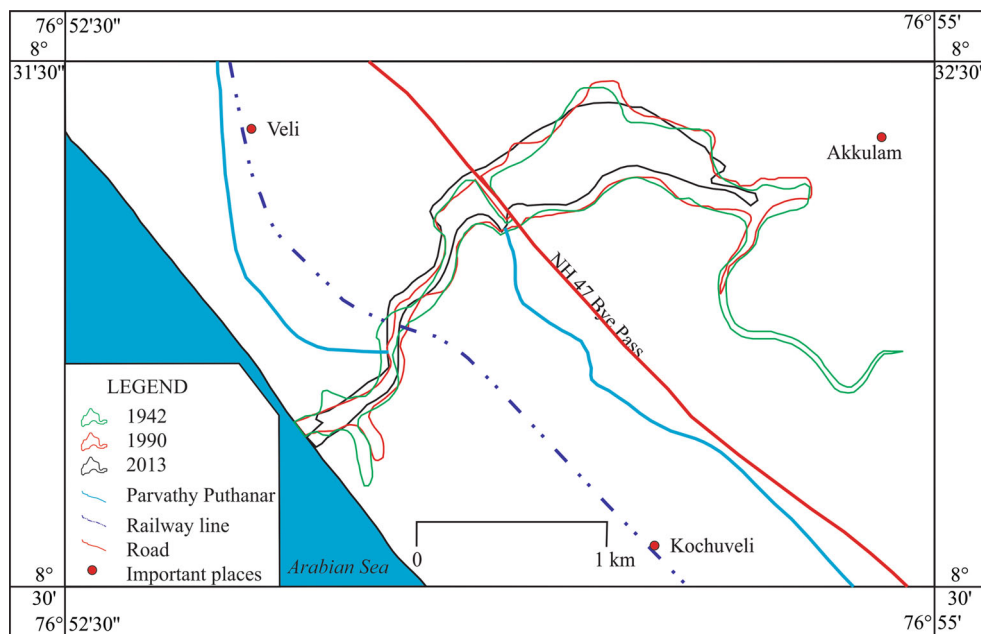
Table 4 Spatio-temporal changes of Akkulam Lake with respect to the year 1942

Year	Area (sq.km)	% change with respect to 1942
1942	1.608	–
1990	1.576	2.00
2013	1.157	28.05

Table 5 Population of Thiruvananthapuram municipal corporation

	1981[a]	1991[b]	2001[c]	2011[c]
Thiruvananthapuram corporation	4,83,086	6,46,372	8,89,635	10,48,283

Source: Census of India (1981, 1991, 2001, 2011)

[a] Area was 141.74 sq.km

[b] Area was 177.77 sq.km

[c] Area was 216.36 sq.km

changed into a major source of pollutants. These streams contain sewage wastes, poultry wastes and waste from households. These streams together with other streams have resulted in the high concentration of ions in the lake water. In some portions of the lake, high amount of the algal contents are seen giving an indication of a minor eutrophication.

Spatio-temporal study of lake and its land-use/land-cover shows that the pressure of the population has resulted in the shrinkage and alteration of this wetland system

(Fig. 10). It is identified that most of the coastal alluvium is gradually being occupied by small- and large-scale buildings. Wetlands have also changed due to reclamation activities. As the years pass, a lot of adverse changes are happening in the land-use and land-cover pattern in and around Veli-Akkulam Lake. Agricultural land has been replaced to a large extent by either settlements or industrial establishments. The reclamation activity in the lake area has resulted in the reduction in the original basin capacity.

Since the lake and the adjacent wetland system are under a threat of eutrophication, a few measures are suggested to prevent the lake from further eutrophication.

1. Awareness to people that the lake is under the threat of unfettered pollution and this will affect their lives also.
2. Streams should be freed from being sites of waste dumping.
3. Remove all waste material from the water by using technical and chemical methods.
4. Keep the lake's drainages clean and neat, and this will increase the storage capacity and quality of the water in the lake.
5. Sediments that enter into the lake can be reduced by greening and afforestation in the hinterland, and the status quo of the basin capacity maintained by periodic dredging.
6. Quality monitoring of water needs to be done periodically in months or every year.
7. Improper land-use in and around the lake must be curtailed, thereby preserving the current areal extent of the lake.
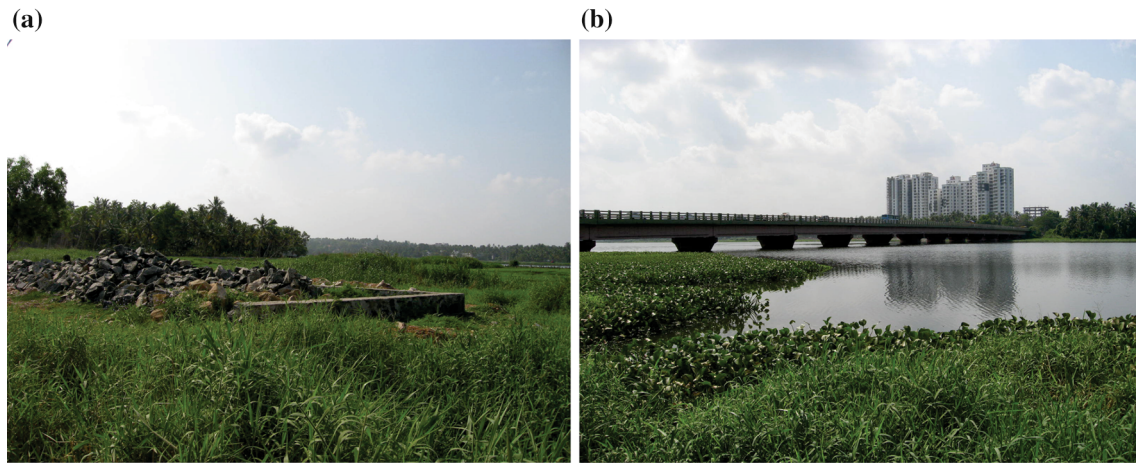
Fig. 7 **a** Reclamation of wetlands in progress, **b** skyscrapers occupying the wetlands
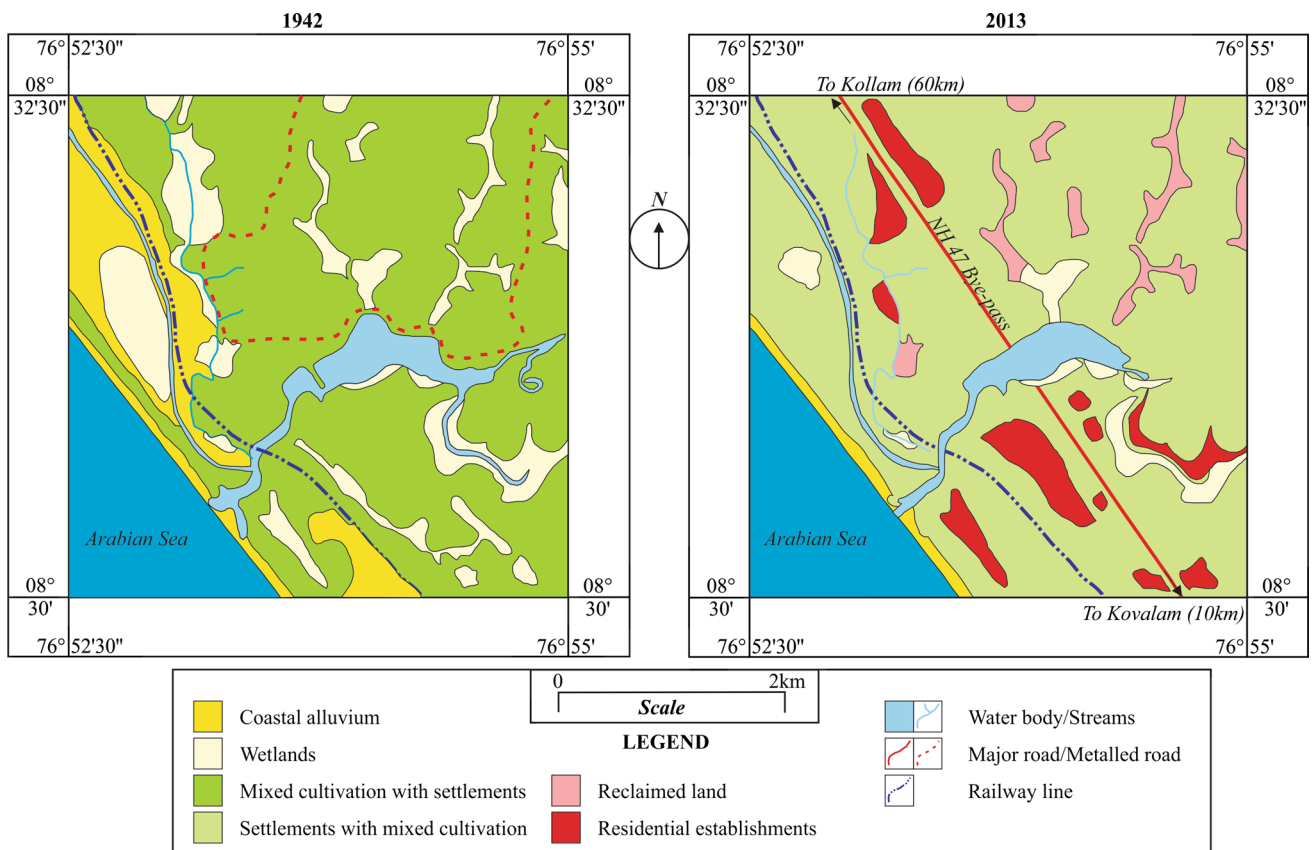

Fig. 8 Land-use/land-cover changes in and around Akkulam Lake (1947–2013)

Proper management of waste and land-use and land-cover in and around Veli-Akkulam Lake will prevent water pollution to a great extent. This will help retain the areal extent of the lake. Reduced waste material entering into the lake will also reduce the dissolved solids and ionic content of the water. This in turn will prevent the possible eutrophication of the lake also. This will increase the irrigation and domestic quality of the water. So the lake water can be used for irrigation while it is free from pollution, and also it can be used for domestic and drinking purposes. Using the simple pollution prevention steps is an economical way to tackle the deterioration of this once pristine backwater. Effective management must ensure that the best use is made of available supplies, including

Table 6 Change in land-use/land-cover between 1947 and 2013

Land-use/land-cover	1942 (area in sq.km)	2013 (area in sq.km)	Change in land-use/land-cover (%)
Coastal alluvium	2.186	0.308	14.10
Wetlands	2.969	1.125	37.81
Mixed cultivation with settlements	13.136		100
Reclaimed land		1.448	
Settlements with mixed cultivation		15.761	
Total area (sq.km)	18.291	18.742	

Increase in area from 1942 to 2013 is due to the shrinkage of lake

Fig. 9 Pictorial representation of changes of ions throughout the traverse of feeder streams
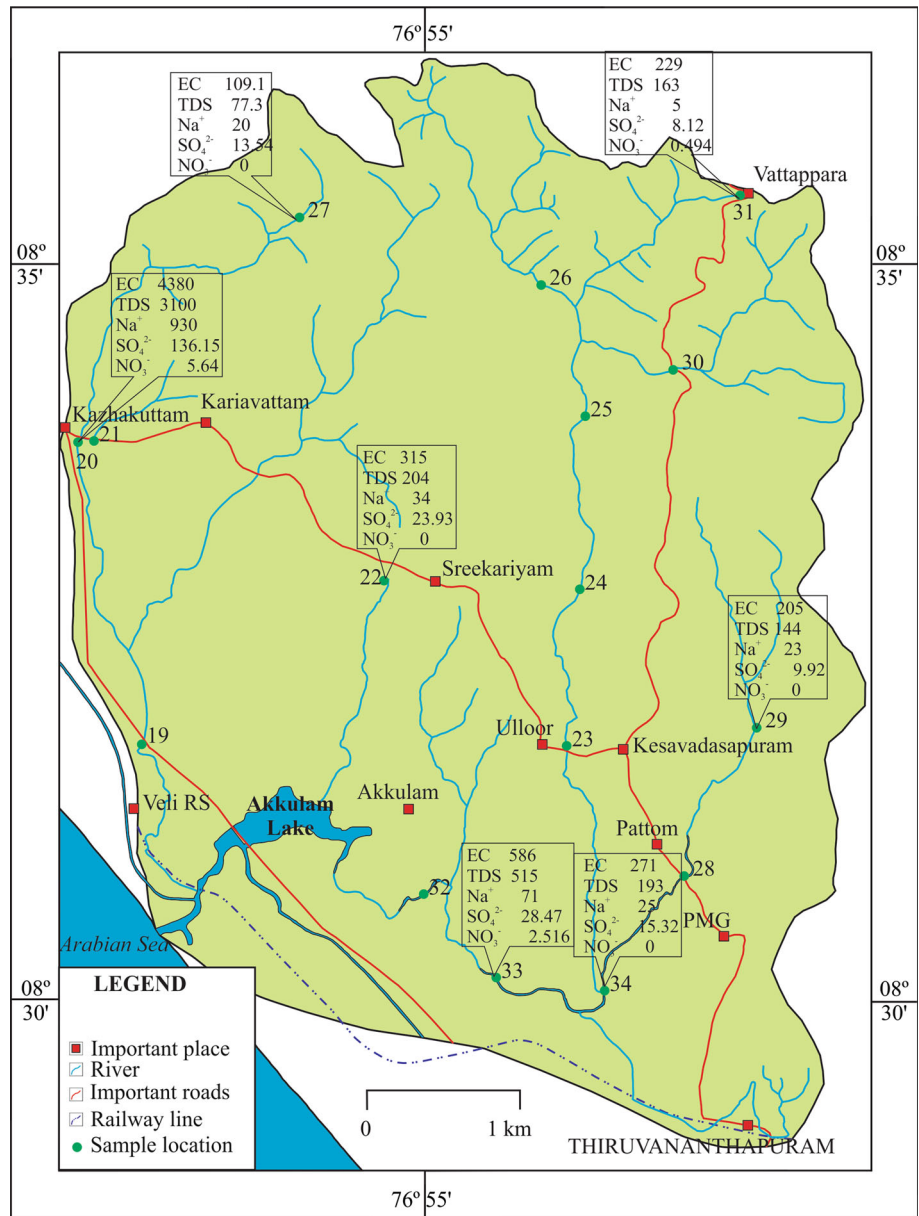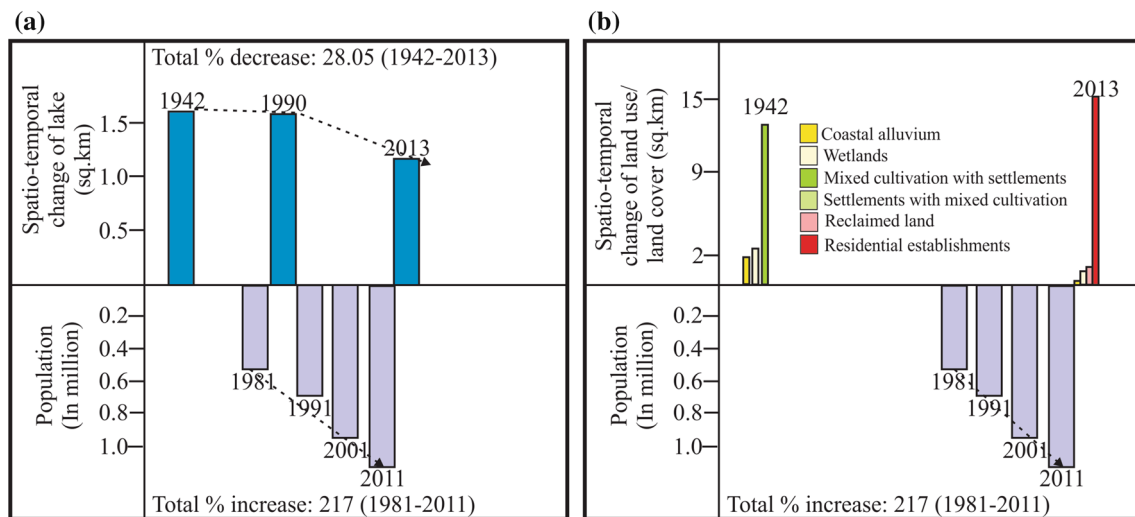
Fig. 10 Spatio-temporal change of lake vis-à-vis increase in population

protection from pollution, and should seek to limit conflicts over access to freshwater. This calls for the establishment of clearly defined policies and strategies as well as the development of enforceable mechanisms and tools for water pollution control.

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