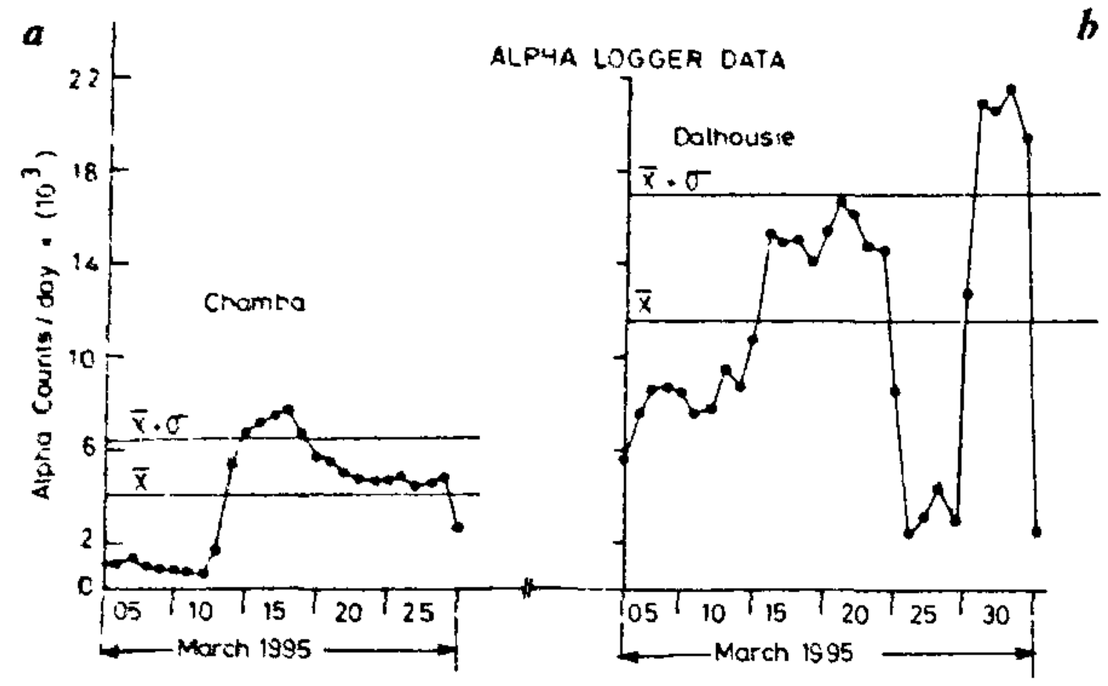

Figure 4. *a*, Alpha-logger radon data recorded at Chamba during March 1995. *b*, Alpha-logger radon data recorded at Dalhousie during March 1995.

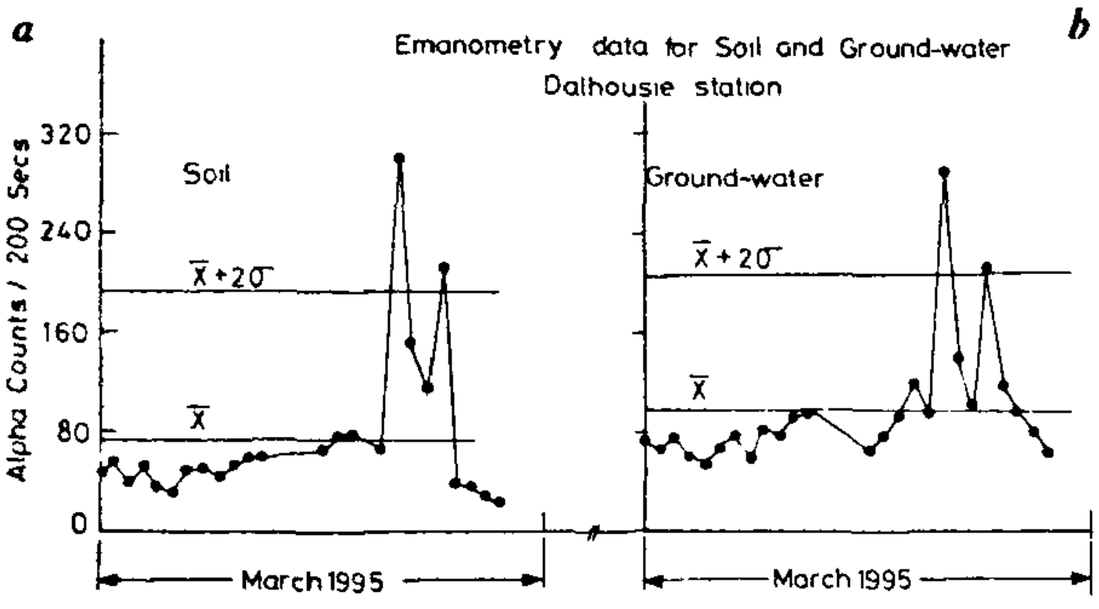

Figure 5. *a*, Radon emanometry data in soil-gas at Dalhousie during March 1995. *b*, Radon emanometry data in groundwater at Dalhousie durnng March 1995.

the media on 21 March, three days before the occurrence of Chamba earthquake and a day before a local event of magnitude 2.0 M, with peak values crossing the $x+2\sigma$ level. There was another peak on 24 March and then a sudden fall in the radon emanation rate after the strain was released. The simultaneous recording of radon peaks in both soil-gas and groundwater at the same site and under similar meteorological conditions before the occurrence of Chamba earthquake on 24 March establishes the efficacy of radon as an earthquake precursor. It also augurs well for setting up radon monitoring networks in N–W, Central and N–E Himalaya for the purpose of earthquake prediction studies and delineation of hidden faults.

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Palaeogeographic evolution of the Akkulam lake and its geotechnical implications in the urban development of Thiruvananthapuram

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The palaeogeographic evolution of the Akkulam lake and its geotechnical significance based on field observations, mapping, lithological core sampling and geotechnical laboratory studies are highlighted. The findings have important implications in the future urban development of Thiruvananthapuram.

FROM a geological perspective all lakes are temporary features in the terrestrial landscape. Lakes originate, evolve and ultimately disappear. They differ from one another mostly in terms of their mode of formation, course of evolution, duration of existence and their ultimate disappearance.

The present investigation is concerned with the palaeogeographic evolution of the Akkulam lake and its geotechnical implications in the future development of the fast-growing urban area of the city of Thiruvananthapuram.

The Akkulam lake is one of the minor lakes located within the coastal plain immediately north of Thiruvananthapuram. The lake presently covers an area of 1.7 km^2 and is intermittently connected with the Lakshadweep

sea through a tidal channel. A temporary transverse sand bar, generally 3 m wide and over 15 m long, cuts off the tidal channel from the sea, preventing direct contact with the latter during most of the year, except during periods of high rainfall. Thus, the lake forms a 'blind' estuary[1]. The manmade inland canal, the Parvathy Puthen Ar, enters this tidal channel. This canal continues further southwest into the coastal plain at a distance of 1.5 km from the coastline, almost parallel to the strandline. The two bridges, one connecting the coastal roads and the other connecting the railway tracks, are constructed across this tidal channel (Figure 1).

The study comprised the following methodology.

1. Geological and geomorphological mapping of the region in and around the Akkulam lake covering an area of 20 km^2 in the scale 1 : 20,000.
2. Drill core sampling, field study of sites of excavations, burrow pits, etc.
3. Lithological study of drill cores, materials of excavations (well cuttings, burrow pits and pits for foundations, etc.).
4. Geotechnical study of the lithological samples.
5. Preparation of a map showing zones of geotechnical hazards.

The field studies conducted in the region surrounding the basin of the lake have indicated that the lake was more extensive in the past, and an arm of the lake appears to have extended up to Kannanmoola for a distance of 6 km from its present margin (Figure 2).

The geomorphological features of the southeastern part of the study area adjoining the lake afford clear evidence of the shrinking of the lake basin to its present size. The landform is characterized by a flat, featureless terrain not exceeding 2.5 m above the water surface of the lake. This low-relief landform resembles that typical of flood plains of aggradation or of valley fills. Data from drill holes, pits and excavations collected from nine selected sites within the valley floors between Akkulam and Kannanmoola afford unmistakable evidence to show that it is genetically a valley flat of aggradational nature where presence of abnormal thickness of sediments has been shown to exist. The sediments forming the infilled portion within the area between the hill-side escarpments and slopes have an aggregate thickness ranging from 11 to 20 m. The width of this zone of aggradation is not uniform, with widths varying from 100 to 500 m. The total area occupied by the sediment infilled zone is estimated to be 11,80,000 m^2. Considerable thickness (ranging in aggregate thickness from 6 to 22 m) of plastic clays alternating with sediments of silty and sandy horizons occupies this tract (Table 1).

A narrow channel of 15 m width occupies the central portion of the sediment-infilled portion of the lake. While the net flow of water in this channel is seaward, the direction of flow is reversed once or twice daily according to the tidal regime. Tidal influence is experienced in this channel up to just north of Vempalavattom and perceptible effects are recorded during some months in this channel as far as Kannanmoola, when the sand bar of the estuarine mouth is breached. Marshy tracts and paddy fields occupy both sides of the sediment-filled portion of the Akkulam basin, extending laterally up to the terraced bluffs flanking the valley-side escarpments, where extensive coconut cultivation prevails. In the neighbourhood of Kannanmoola the sediment infilled part of the Akkulam basin supports extensive marshy tracts almost throughout the year, where enormous thickness of plastic clays highly enriched in organic matter is known to attain an aggregate thickness of over 20 m.

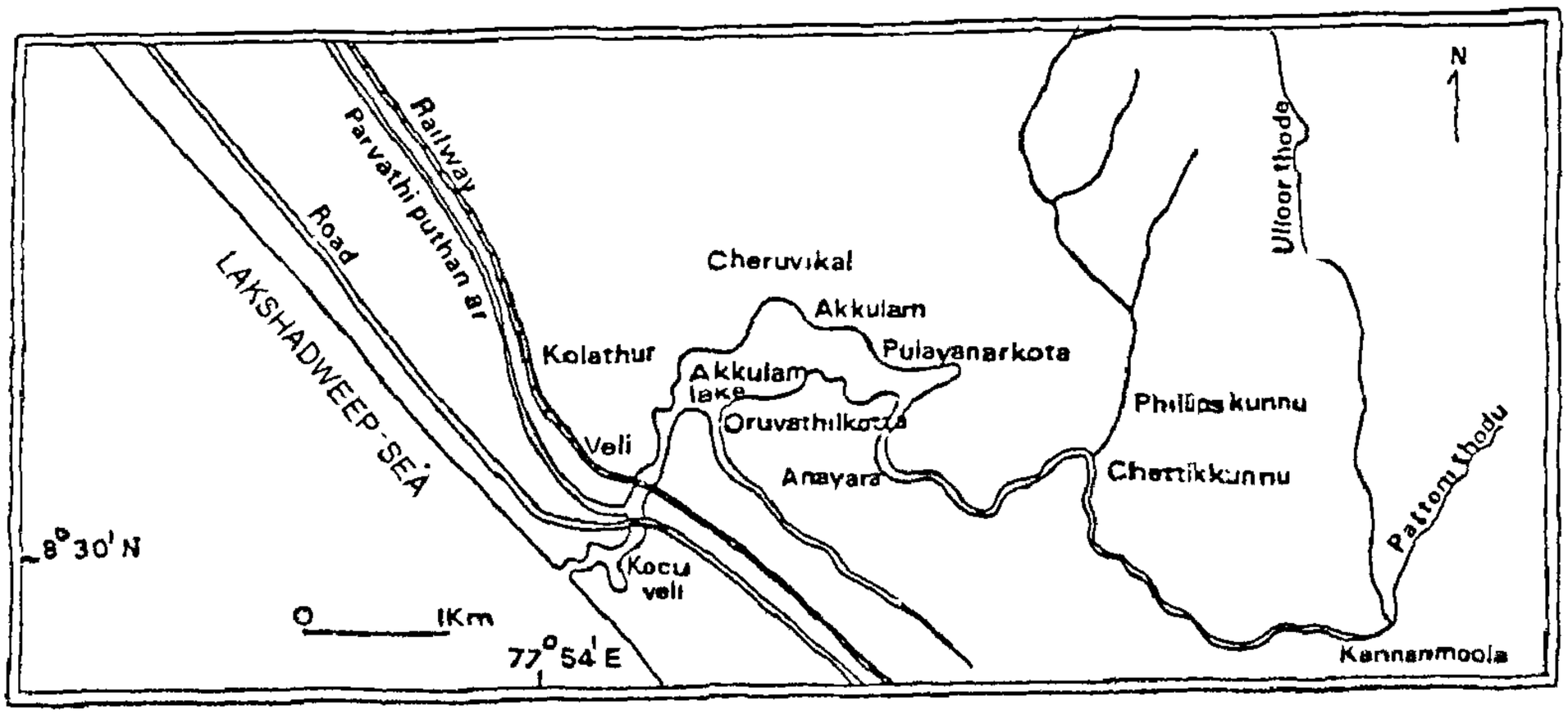

Figure 1. Geological map of the region around the Akkulam lake covering an area of 20 km^2.

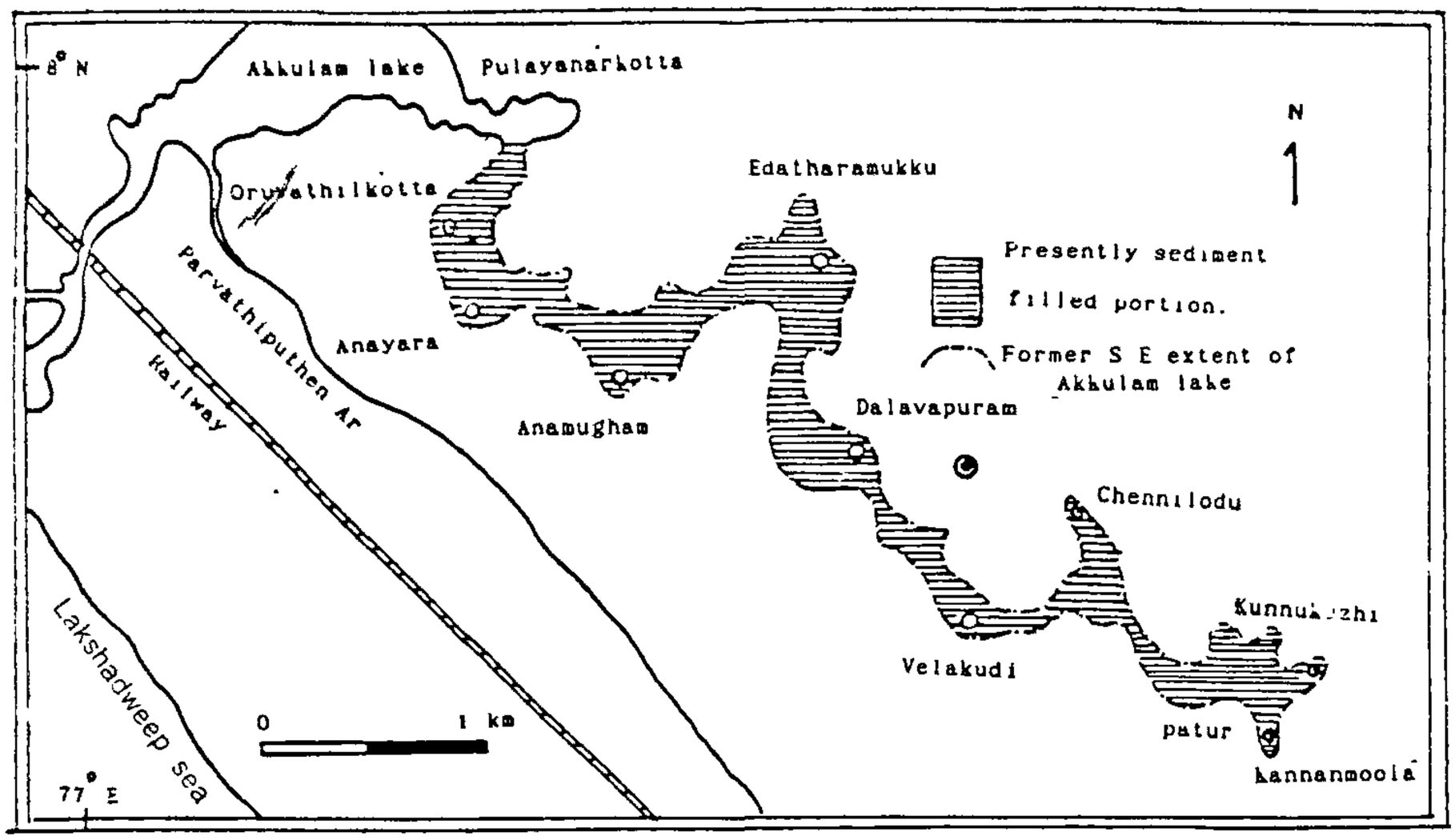

Figure 2. Geomorphological map of the region around the Akkulam lake covering an area of 20 km^2.

This locality is situated 5 km inland from the present coastline and occupies almost the central part of the city of Thiruvananthapuram.

The drill core samples collected from the sediment-filled portions of the Akkulam basin from Kannanmoola comprise occasional horizons containing skeletal fragments and complete shells of molluscs, and other invertebrates characteristic of brackish water environments. Thus, the palaeontological observations afford another strong evidence for the prevalence of brackish water condition up to Kannanmoola somewhere in the recent past.

Yet another evidence supporting the palaeogeographic change of the Akkulam lake basin is afforded by the drainage pattern of the existing fluvial system physically associated with the present lake basin. A number of stream systems extending over an aggregate area of about 30 km debouch their discharges into the Akkulam lake. Among these, the southerly flowing Ulloor Thode and southwesterly flowing Pattom Thode are the prominent ones. In addition, a few smaller streamlets enter the lake from its northern side traversing Kolathur, Cheruvickal and neighbouring localities. The Ulloor Thode and the Pattom Thode combine together at the centre of the marshy tract of Kannanmoola – the locality, as already noted, represents probably the former southeastern extremity of the present Akkulam lake. The sediment accumulation process in the portion of the lake basin from Kannanmoola up to Akkulam left only a narrow channel up to its present margin to drain away the discharges received from Ulloor Thode and Pattom Thode. A close study of the drainage pattern of the region reveals an abrupt northwestward diversion of the downstream portion of the stream channel beyond the point of confluence of Pattom Thode and Ulloor Thode. This unusual stream pattern indicates perhaps that in the past the streams had their termination near Kannanmoola up to where the southeast-trending arm of the Akkulam lake extended and subsequent infilling of this portion of the lake basin forced the stream channel to extend gradually up to Akkulam – the lake's present margin.

The urban area of Thiruvananthapuram is growing at an accelerated rate and the urban–suburban boundary is expanding at different rates along different directions. The scarcity of land for building construction has forced increasing reclamation of most of the paddy fields that occupied a substantial portion of the urban area. The building construction activity has already reached the infilled southeastern portion of the Akkulam basin. This tract being a geotechnically hazardous zone, special precautionary measures should be taken for foundation treatment while planning construction of buildings, especially high-rise constructions. Field studies have indicated serious damages of various sorts even in newly constructed buildings in this tract due to foundation problems. The enormous thickness of plastic clays in the sedimentary succession of this tract, extending up to Kannanmoola should be taken into consideration in planning future urban development of the infilled portion of the Akkulam basin.

The clay-enriched sedimentary succession has a significant influence upon its geotechnical properties. The moisture content and the energy with which this moisture

Table 1. A representative lithological borehole log at Velakudi

	Lithology	Gravel %	Sand %	Silt %	Clay %
A	Clayey and sandy silt	–	12	42	46
B	Stiff lateritic clay	8	30	52	10
C	Soft grey clay with peaty matter	–	4	6	90
D	Carbonaceous plastic clay	–	–	8	92
E	Sandy and silty clay	–	12	18	70
F	Carbonaceous plastic clay with occasional peaty horizons	–	3	11	86
G	Sandy clay	–	18	20	62
H	Silty clay with shell fragments	–	2	30	68
I	Medium sand with shell fragments	–	42	26	32
J	Disintegrated rock	16	52	32	–
K	Hard rock (Khondalite)				

is held are the important factors to be taken into account while planning high-rise buildings in such areas, since these determine the consistency, strength and volume changes resulting from swelling, shrinkage and consolidation, which are also related to permeability and migration of moisture. Volume changes can occur as a result of loading consequent to consolidation and heave, due to reduction in void ratio. Because of their low permeability, the rate of consolidation will be a relatively slow process but the net effect will be considerable over a long span of time. The sensitivity of the clays of the region, i.e. the ratio of the undisturbed to the remoulded strength at the same moisture content ranges from about 3 to 6. Because of the high content of moisture of the clays, any fluctuation in the moisture content may increase the sensitivity of these clays. However, the ultimate bearing capacity of foundations on clay-enriched successions is influenced by its shear strength, which, in turn, depends on its consistency as well as the shape and depth at which the structure is placed. There are unmistakable evidences of severe foundation problems in the sediment-infilled portion of the Akkulam basin in the form of collapse of bridges due to tilting of foundations at localities such as Anamughom, near Edatharamukku and Nelliazhi. The shear strength of the clays determined for samples obtained from deep excavations and drill cores gave values ranging from 20–60 kN/m^2.

The study revealed that the Akkulam lake initially extended from its present margin up to Kannanmoola in southeast. Geomorphological, geological and palaeontological evidences support this view. This infilled arm of the lake contains considerable thickness of plastic clays and thus constitutes a geotechnically hazardous zone. This fact should be taken into consideration while planning major civil engineering constructions for the future urban development programmes.

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