The Environment and Ground Water

by

C.B. DISSANAYAKE

(Professor of Geology, University of Peradeniya)

Most of Sri Lanka's health problems are deeply rooted in the environment. Deaths caused by water-related diseases have increased rapidly in the past few years. Table 1 shows the number of cases of leading diseases treated at Government hospitals and percentages of total leading diseases in the period 1951-1970. A water-related disease is one which is in some way related to water or to impurities present in the water. One can distinguish between infectious water-related diseases and those related to some chemical property of water such as the association of cardio-vascular diseases with 'soft water' while high nitrate levels are associated with infantile methaemoglobinaemia. In contrast to the industrialized countries, the developing countries particularly in the tropics are beset with infectious, water-related diseases. Faechem et.al. (1978) consider five types of infectious diseases that are related to impure water, lack of water or poor sanitation.

(1) Water-borne diseases, such as typhoid, cholera, dysentery, gastro-enteritis (diarrhoea) and where pollution is exceptionally severe, infective hepatitis. These are spread by drinking or washing food, utensils, hands or face in contaminated water.

(2) Water-washed infections of the skin and eye, such as trachoma,

TABLE I

Number of cases of leading diseases treated at Government hospitals and percentages of total leading diseases in 1951 - 1970

Diagnosis	Cases 1951	% 1951	Cases 1961	% 1961	Cases 1969	% 1970
Diarrhoeal diseases	81802	20.07%	164032	25.99%	180232	22.25%
Tuberculosis	15598	3.83%	12744	2.02%	12841	1.58%
Anaemia & malunutrition	25439	6.25%	67152	10.65%	89017	10.98%
Malignancies	4380	1.08%	5488	0.37%	12115	1.49%
Respiratory infections	189647	46.58%	288956	45.73%	330124	40.74%
Diseases of infancy & immaturity	13853	3.40%	22444	3.56%	4747	0.58%
Heart diseases	16515	4,06%	38911	6.16%	44000	5.43%
Other infectious diseases	59952	14.73%	31437	4.98%	137424	16.95%
TOTAL	407084	100.00%	631164	100.00%	810571	100.00%

Source of data : Economic Review, January 1980 scabies, yaws, leprosy, conjunctivitis, skin sepsis and ulcers.

(3) Water-based diseases where the vector (carrier) is an invertebrate aquatic organism. The most important are Chistosomiasis (or bilharzia, transmitted by snails) and the Guinea worm (transmitted by the microscopic crustacean, cyclops).

(4) Diseases with water-related insect vectors
Mosquitoes (carriers of malaria, filariasis, yellow fever) and blackflies (carriers of river blindness) need water for breeding.

(5) Infections that are primarily caused because of improper sanitation. eg. hookworm.

Table 2 shows 16 different water-related diseases that have been identified. In a recent study by the People's Bank of Sri Lanka (Economic Review, 1980) it was revealed that only between 15-25% of the people in Sri Lanka have access to safe water, or less than 10% have access to piped water. The majority of the people use shallow unprotected wells and in settlement areas, tanks and water channels are the source of drinking water. It has also been found that the proper disposal of human and other waste through sewerage systems and latrines is also limited, less than one-third of the population having satisfactory latrine facilities. These facts illustrate very clearly the close relationship between the quality of the water and community health in Sri Lanka. Whereas the water-related infectious diseases receive a great deal of attention, the non-infectious water diseases have been a neglected field of study in Sri Lanka. The chemical quality of the water is also extremely important and this paper discusses some aspects of the hydrogeochemistry of the potable waters in Sri Lanka. It was apparent that there is a close relationship between the geology, geomorphology, climatology, geochemistry and the presence or absence of mineralization and the

TABLE II

Classification of water-related diseases

Type of disease	Due to water contamination	Due to poor sanitation, lack of health education, inadequacy of water	Due to overcrowding and lack of cleanliness in home, lack of health education	Due to parasitic works	Due to insect vectors
Typhoid	x	x			
Para-typhoid	x	x			
Cholera	x	x			
Bacillar Dysentery	x	x			
Amoebic Dysentery	x	x			
Infective Hepatitis	x	x			
Poliomyelitic	x	x			
Enteritis	x	x			
Hookworm				x	
Whipworm				x	
Thread worm				x	
Round worm				x	
Scabies			x		
Conjunctivitis			x		
Malaria					x
Filaria					x

Source : Ministry of Local Government, Housing and Construction, 1980.

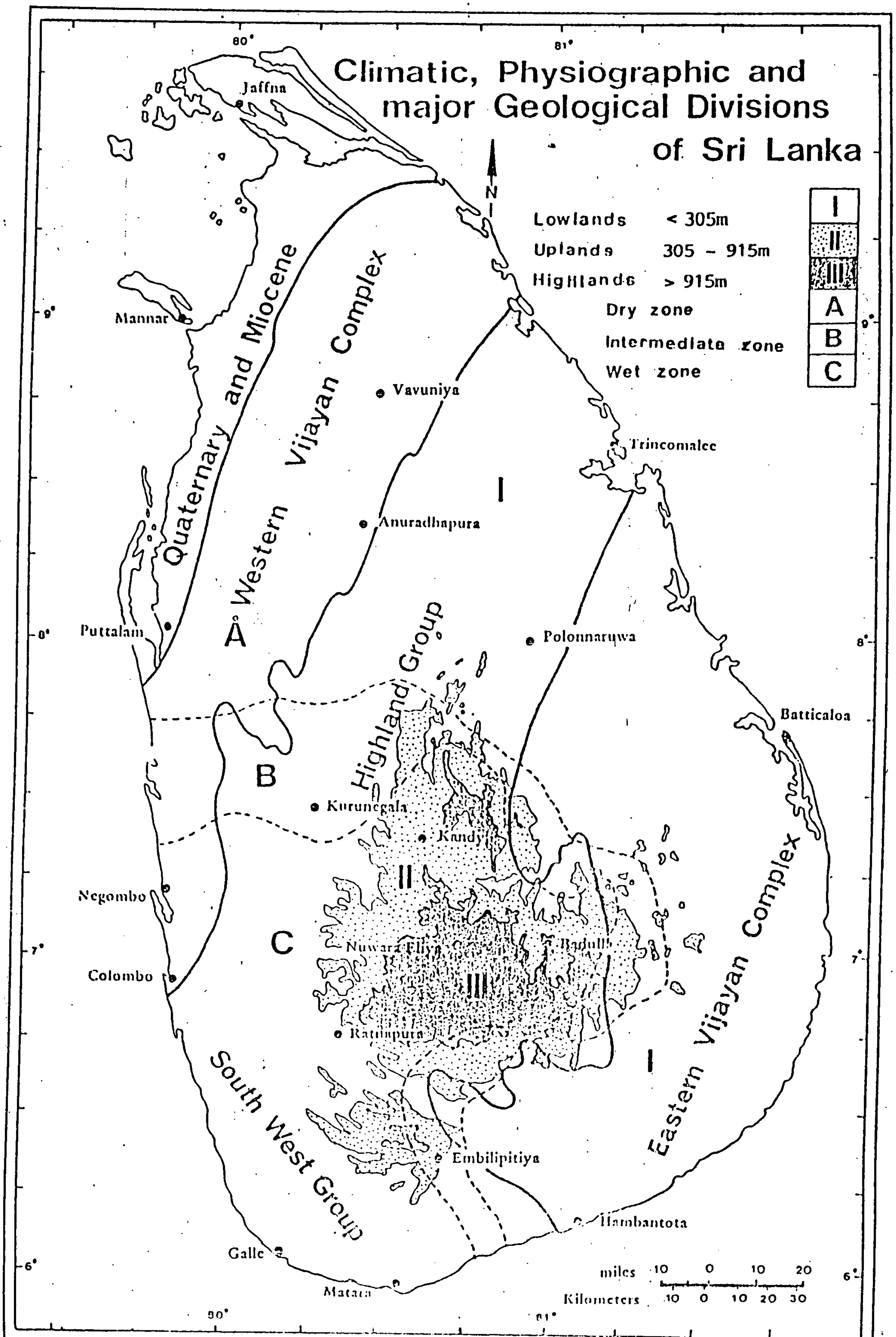
geographical distribution of certain diseases. As such an inter-disciplinary approach is the most appropriate mode of studying epidemiology in Sri Lanka.

The geology and geomorphology in Sri Lanka

Geologically the greater part (about 92%) of the country consists of rocks of Precambrian age, the island having remained stable over a long period of time. The Precambrian rocks of Sri Lanka are identified as forming two major divisions, namely the Vijayan Complex (Cooray,1978). The Highland Group has a metamorphic subdivision termed the Southwest Group. The Vijayan Complex is geographically separated into the western and eastern Vijayan Complex by the linear arcuate fold belt of the Highland Group (Fig 1).

A suite of metasedimentary and metavolcanic rocks formed under granulite facies conditions comprises the Highland Group. Among the metasediments, quartzites, marbles, quartzo-feldspathic gneisses and metapolites form the major constituents. The Southwest Group consists mainly of Calciphyres, charnockites and cordierite bearing gneisses. The western Vijayan rocks on the other hand consists of basement type leucocratic biotite gneisses, migmatites, pink granite gneisses and granitoids with compositions varying from granitic, syenitic to granodioritic. The granitoids frequently have enclaves of amphibolite and hornblende gneiss. Bodies of metasediments are rare in western Vijayan. The eastern Vijayan is composed of biotite/hornblende genisses, granitic gneisses and scattered bands of metasediments and charnockitic gneisses. Small plutons of granites and acid charnockites also occur close to the east coast (Cooray, 1978). The chemical composition of these rocks has a direct bearing on the geochemistry of the water and as will be shown later on the general health of the community.

Fig. 1



Climatic, Physiographic and major Geological Divisions of Sri Lanka
N
Lowlands < 305m I
Uplands 305 - 915m II
Highlands > 915m III
Dry zone A
Intermediate zone B
Wet zone C
80°
81°
9°
8°
7°
6°
Jaffna
Mannar
Vavuniya
Trincomalee
Anuradhapura
Puttalam
Polonnaruwa
Batticaloa
Kurunegala
Kandy
Negombo
Nuwara Eliya
Badulla
Colombo
Ratnapura
Embilipitiya
Hambantota
Galle
Matara
Quaternary and Miocene
Western Vijayan Complex
Highland Group
Eastern Vijayan Complex
South West Group
A
B
C
I
II
III
miles 10 0 10 20
Kilometers 10 0 10 20 30

Sri Lanka with an area of 69,450 km^2 is primarily a part of the shield area which comprises peninsular India. Geologically and physically, Sri Lanka is a southern continuation of India, only recently separated from the mainland by the shallow sea covering Palk Strait and Gulf of Mannar. On the basis of height and slope characteristics, the island can be divided into three main morphological regions (Vitanage, 1970) Fig. 1 .

I. The coastal lowlands with elevations from sea level to 305 m with a few inselbergs. Slopes are generally flat lying in the narrow marshy belt along the coastal fringe while further inland low 'turtle backs' appear.

II. Uplands with elevations from 305 m to 915 m consisting of ridge and valley topography and highly dissected plateaus with narrow arenas and domes occupying nearly 3/10 of the island.

III. Highlands with a series of well defined high plains and plateaus rimmed with mountain peaks and ridges with elevation from 915 m to 2420 m. Characterize the central part of Sri Lanka. High level topographic discontinuities are common and these form the boundary of a series of high plains, plateaus and structural terraces. Laterites and laterization are common in these places.

Sri Lanka which has a typical humid tropical climate lies in the monsoon region of south-east Asia. The island is characterized by clearly demarcated dry and wet zones as shown in Fig. 1 . The average mean temperature of the wet zone lies between 70-80°F and in the dry zone it is approximately 90°F. Depending on the altitude the mean temperature of the Highlands vary between 58°F and 78°F.

Kayane (1982) investigated the regional differences in water loss by evapotranspiration in Sri Lanka. The annual evapotranspiration was calculated as a residue of annual rainfall minus annual runoff for 70 drainage basins. Kayane (1982) recognized the following values:

(a) 1450-1550 mm/yr. for catchments with evergreen forest in the Wet Zone.

(b) 1000-1200 mm/yr. for catchments in Central Highlands.

(c) Wider range of 1000-1400 mm/yr. in the Dry Zone.

In view of the accumulation of salts in the top soil and hence in the groundwater, evapotranspiration data are of importance in the study of the chemical quality of water.

Distribution of nitrates in the potable waters of Sri Lanka

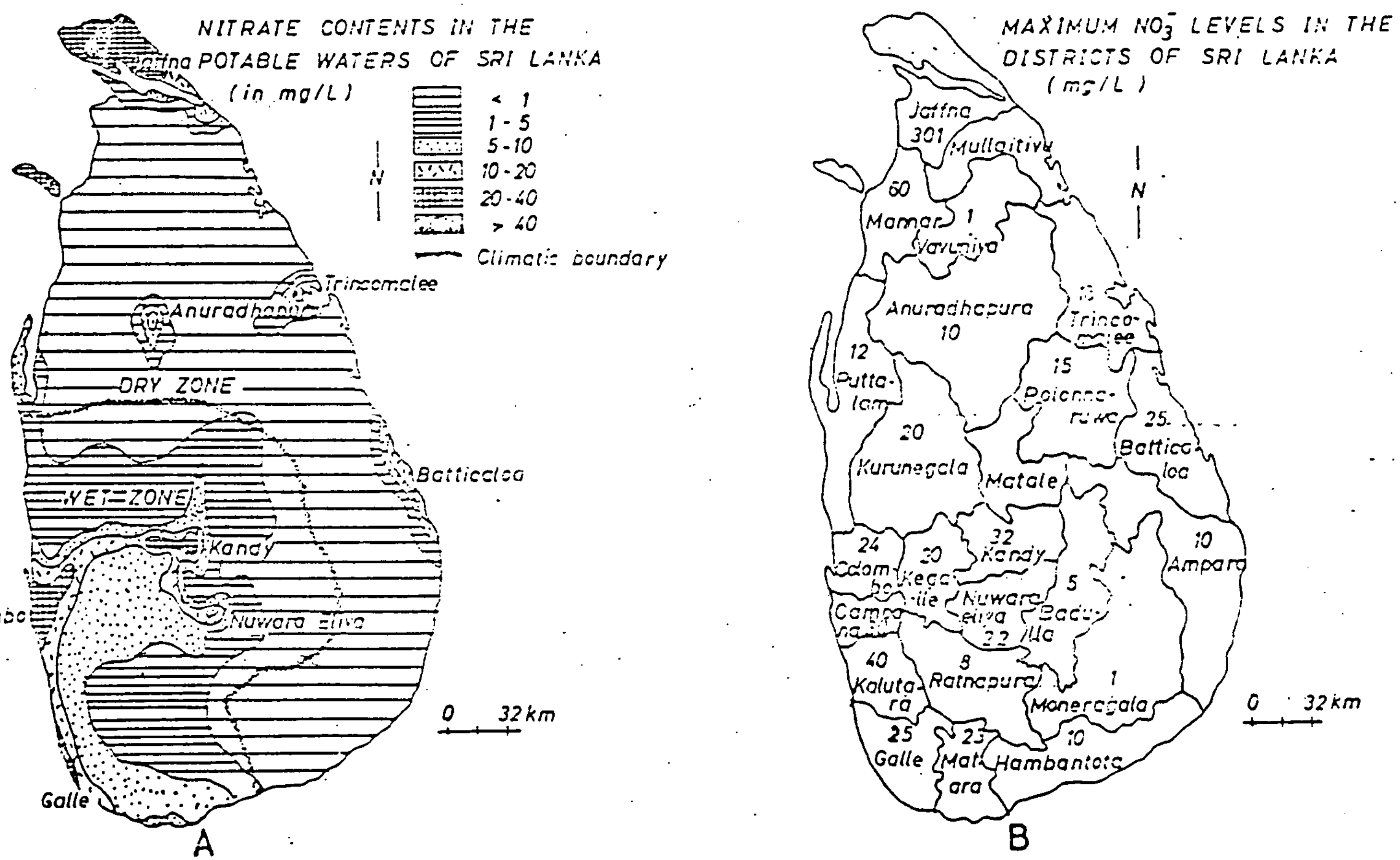
The study of nitrates in groundwater and potable water systems has recently assumed extreme importance. The potential health implications of the contamination of drinking water by nitrates have attracted scientific attention since 1945, primarily in connection with methaemoglobinaemia (Comly, 1945; Weart, 1948; Waring, 1949; Mc Letchie and Robertson, 1949; Walton, 1951). As pointed by Brooks and Cech (1979), attention is at present sharply focussed on the problem of the intake of excessive nitrates, as these compounds on reduction yield nitrite and secondary amines known to be carcinogenic (Magee and Barnes, 1967; Bogovski, 1972). The impact of nitrates, nitrites and nitrosoamines on human health therefore remains a question in the forefront of scientific research priorities. This is particularly so in developing countries in view of the extreme contamination of water that can be caused by poor sanitation, improper location of pit latrines near drinking water wells and use of nitrogeneous fertilzier. Therefore, an interdisciplinary approach is clearly evident in an island wide survey of nitrates in the potable waters. Fig. 2 shows the distribution of nitrates in the potable waters of Sri Lanka. In general the average nitrate levels are below the danger levels of 50 mg/l specified by the World Health Organization. In Jaffna, however, these levels are exceeded and will be discussed in a later section. It is seen from Fig. 2 that higher nitrate contents are found in and around the main cities of Sri Lanka, indicating a dependence on the population density. Fig. 3 illustrates the population density per square mile and it is apparent that there is a striking similarity with Fig. 2 showing the nitrate distribution. This clearly indicates the effect of human influence on the input and distribution of nitrogeneous species into the groundwater regime.

The influence of the climate on the levels of nitrates in the groundwater in Sri Lanka is marked. As shown in Fig. 2, most of the wet zone of Sri Lanka has greater nitrate concentrations than in the dry zone. The rainfall influences the distribution of nitrates through the soil. In the dry zone of Sri Lanka the water table is deep and inspite of a high fertilizer input into the soil, the groundwater contains very low nitrates mainly due to the problems associated with hte migration of the nitrogeneous species deep into the water table. In the wet zone on the other hand, the water table as expected is shallow and hence easy migration of the nitrates from the top soil into the relatively shallow water table resulting in a high nitrate content in the waters of the wet zone.

The factors controlling the severity of nitrate contamination in groundwater bodies have been outlined by Lewis et.al. (1980). It is known that nitrates, once they enter a groundwater body, remain there for a very long period. The overall factors controlling the severity of nitrate contamination are:

(a) efficiency of the nitrogen removal processes beneath

Fig. 2 The distribution of nitrates in the groundwater of Sri Lanka



inputs such as pit latrines. This will depend on many factors, such as the soils, hydraulic conductivity, the hydraulic loading of the input, whether anaerobic conditions favourable for denitrification are established and the clay/organic content of the sub soil.

(b) the population using on - site sanitation systems and the density of the units.

(c) Dilution by local recharge and regional aquifer through flow, where this has a lower nitrate concentration.

(d) denitrification in the saturated zone. However, groundwater conditions giving rise to denitrification may well be associated with other problems such as high concentration of the Mn and other metals. Although not a serious health hazard, this may impart an objectionable taste, and hence cause people to use alternative surface water sources.

Lewis et al. (1980) estimate human wastes to contain about 5 kg. N/ha/ annum in the form of ammonium and complex organic compounds, both of which can readily be converted to highly mobile nitrate under aerobic conditions. All of this nitrogen however, will not reach the groundwater table since a certain amount of denitrification is bound to occur. Further, urine accounts for some 80% of the nitrogen execreted.

Oakes and Young (1981) state that during the period 1975-1980 research in U.K. has produced a large and possibly unique body of data on the distribution of solutes derived from agricultural land in the major British aquifers. Unsaturated zone pure-water quality profiles demonstrated a clear relationship between teh concentration of solutes,

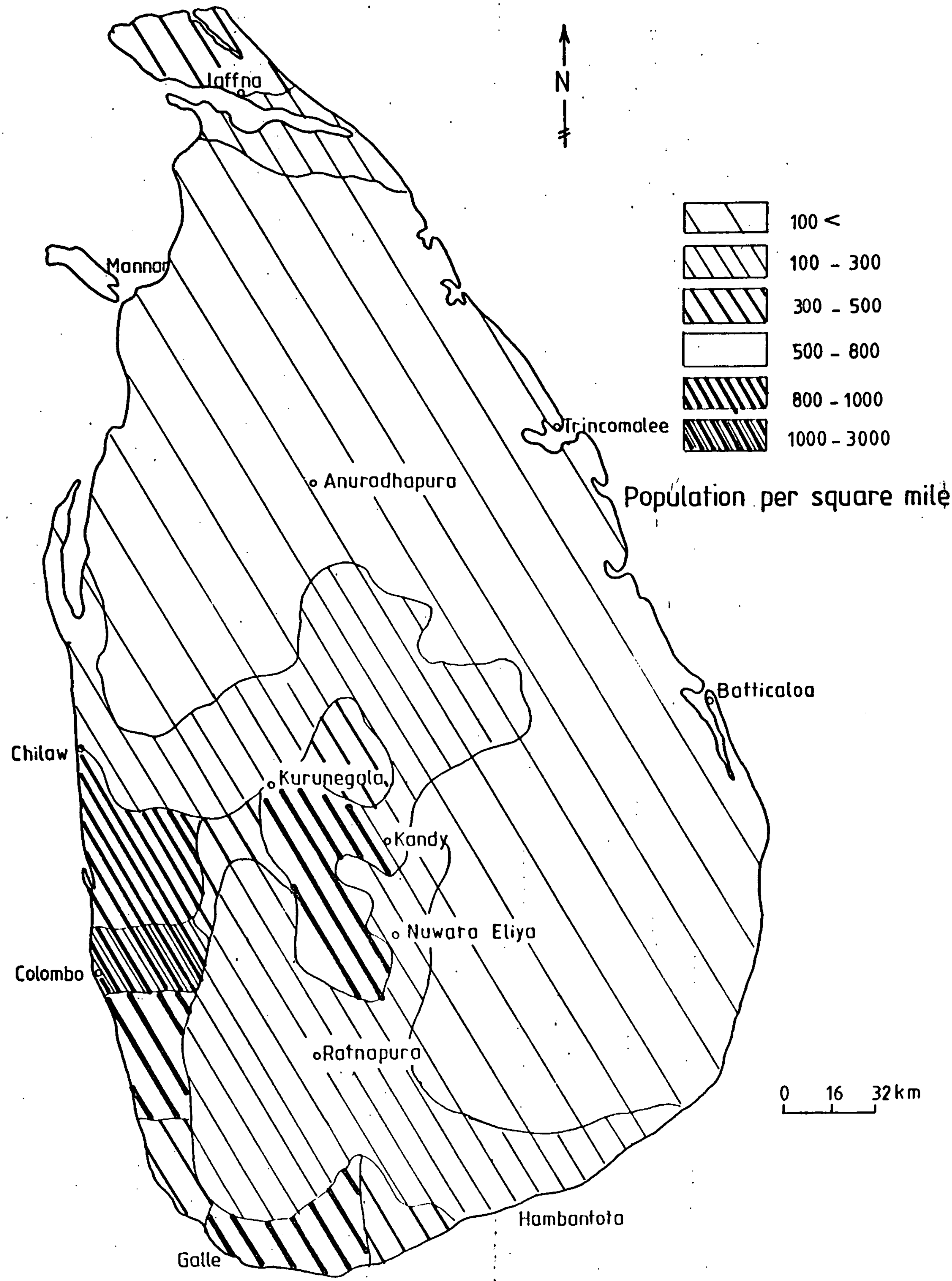


Fig. 3 The population density of Sri Lanka

especially nitrates and farming practice. High concentration of nitrates, often in excess of World Health Organization recommended limits are characteristic of areas of arable farming whilst low concentrations are generally found beneath permanent grass woodland.

In Sri Lanka, highly nitrogenous fertilizer such as urea used in abundance in farming practice and agriculture influence the abundance of nitrates in water. Paddy cultivation is the major agricultural practice in Sri Lanka and most fertilizer is used in the rice fields. In Fig. 4 is shown the variation of the infant mortality rate in Sri Lanka with the nitrate levels of drinking water. Even though high nitrate levels are not the sole cause of infant mortality, a correlation does nevertheless exist. A feature worthy of note is the high mortality rate in the wet zones particularly in the highlands, as opposed to the dry zone lowlands. The importance of the influence of climate and topography in geomedical studies of endemic diseases in tropical terrains is clearly illustrated here.

<u>Nitrates in the Jaffna Peninsula - A special case</u>

As shown in Fig. 2, the Jaffna peninsula has the highest nitrate contents in the ground water of Sri Lanka and warrants further investigation. Geologically, the Jaffna peninsula is underlain by highly fractured and kartstified limestone of Miocene age. There is a thin soil mantle of the red/yellow latosol type and in the southern part of the peninsula are 10-20 meters of fine sand which lie over the limestone formation.

According to Gunasekaram (1983), 80% of the groundwater of the Jaffna peninsula is being extracted from the limestone aquifer and utilized for drinking, domestic, agricultural and industrial purposes, the rest being obtained from the sand aquifer. The water table in the Jaffna peninsula is very shallow on account of the surface aquifers.

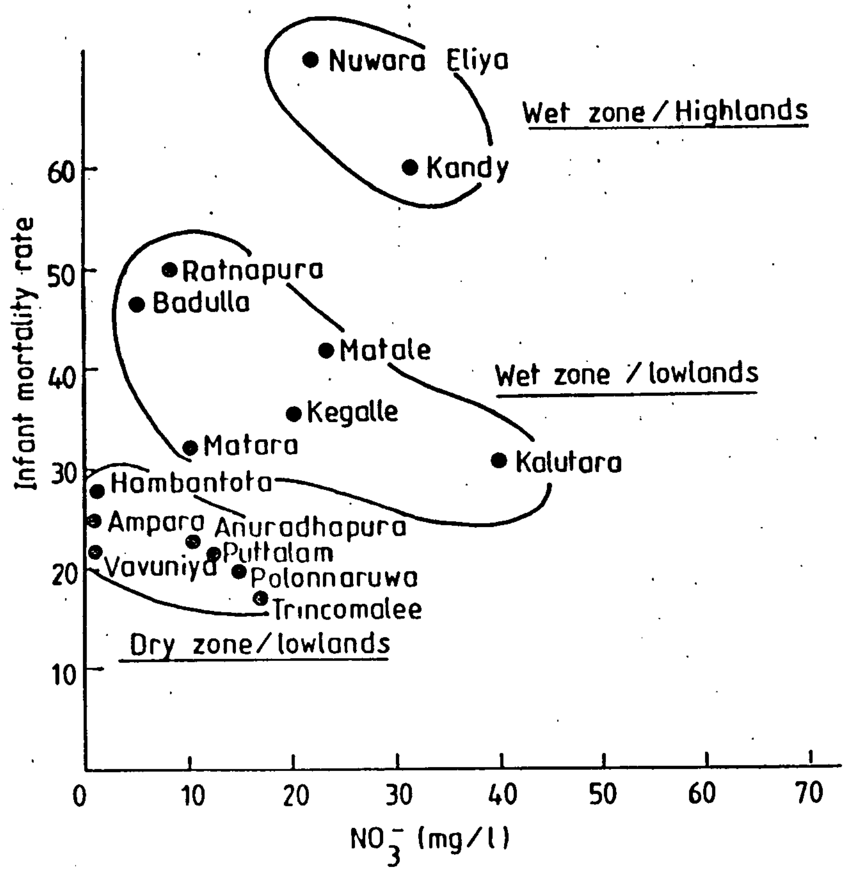


Fig 4. Variation of the infant mortality rate with the nitrate levels of groundwater

Gunasekeram (1983) in his detailed study of the groundwater contamination and case studies in the Jaffna peninsula found that 80% of the water wells yielded water of unacceptable bacteriological quality contaminated with faecal coliform. Among the major factors responsible for the poor water quality in the Jaffna peninsula are:

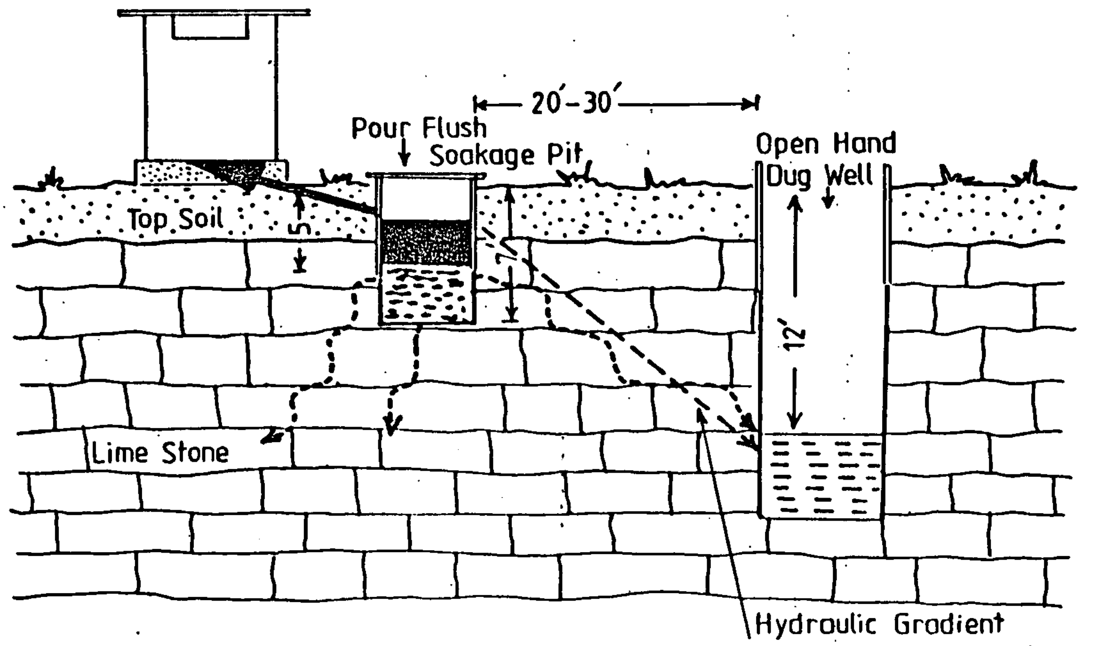
(1) Discharge of human excreta in the form of soakage pit/ septic tank effluents directly underground within densely populated urban areas. In some cases due to limitations of available land the distance between soakage pit and water well is only 3 meters.

(2) Abundant use of agricultural fertilizers, mainly urea which contains 46% N. Excessive use of urea on crops such as chillies and onions is prevalent. In addition cattle manure is commonly used.

(3) The easy solubility of urea enables it to reach the very shallow groundwater table and under normal conditions about 75% of the nitrates applied reach the groundwater periolates.

Fig. 5 illustrates the typical soakage pit and water well layout in Jaffna. The fact that Jaffna has nitrate levels exceeding the W.H.O. limits by 100-150% is thus mainly due to the abundant nitrogeneous input reaching the shallow groundwater table aided by the surface limestone aquifer. The geological conditions are therefore extremely conducive for the excessive accumulation of nitrates. The poor sanitary conditions are mainly caused by improper planning of soaking pits and latrines and this aids in the serious contamination of the groundwater by nitrates.

The dangers associated with drinking water wells being placed very close to the septic tanks have been highlighted in many



(modified after Gunasekaram, 1983)

Fig. 5 The soakage pit layout in Jaffna

many case studies from other countries. Hutton and Lewis (1980) in their study of nitrate pollution of groundwater in Botawana found nitrate levels as high as 603 mg/l. in several water supplies providing drinking water to many villages. A lithium chloride tracer injected into a pit latrine was detected in the supply borehole 25 m away after only four hours. The steep hydraulic gradient between the latrine and the borehole had obviously induced the rapid movement of nitrates occurring in open fissures.

The situation in Jaffna can even be worse, bearing in mind the very short distance of 6 m from the pit latrine to the water well as observed in some cases.

<u>The distribution of fluoride in water and the incidence of dental diseases in Sri Lanka</u>

The importance of trace elements in human health and nutrition is well known and there appears to be geographical patterns in the incidence of certain diseases. Well established relationships with the geochemical environment include iodine deficiency with goitre, fluoride deficiency with dental caries and fluoride excess with fluorosis. Webb (1975) points out that there are numerous and controversial correlations with no proven causal relationship, and these include water hardness and cardio-vascular diseases, Pb and multiple celerosis, Cd and hypertension and atherosclerosis, a range of trace elements with cancer. The delineation of areas of different trace element concentrations thus helps in the initial demarcation of geographical areas liable to be affected by the disease concerned. Dissanayake (1979) and Dissanayake and Senaratne (1982) carried out research on the incidence of dental diseases in relation to the geographical distribution of fluoride in water in Sri Lanka.

Fig. 6 illustrates the geographical distribution of fluoride in drinking water in Sri Lanka. It can be seen that the central hill country and the south-west coastal region are relatively free of fluoride. The lowland dry zone contains a higher amount of fluoride in water with areas around Eppawela in the North Central Province and Uda Walawe in the Southern Province showing anomalously high fluoride concentrations.

The effect of the fluoride concentrations in well water on the dental health of the people in the areas can be seen in Table 3 where details for 3 areas are given. It is clearly seen that the areas of high fluoride content have higher dental fluorosis whereas those in the low fluoride regions suffer from dental caries. The marked difference in the fluoride concentration in well water in the dry zone and the wet zone is put into proper perspective in Fig. 7 and 8, where the variation of the fluoride concentration with rainfall and altitude characteristics is shown. The marked decrease in fluoride can be attributed to the continuous leaching of fluoride from fluoride-bearing rocks and minerals, the physiography of the region playing an important role in the process of leaching. While the intensity of rainfall is a major factor in the geographical distribution of fluoride in well water, the natural geological factors are also significant.

Among the areas containing the highest fluoride concentrations in well water the region around Eppawela and Anuradhapura is the largest. Senewiratne and Senewiratne (1975) reported fluoride concentrations as high as 9.0 ppm in this region. The abundance of fluoride which caused severe dental fluorosis among people of this area can be attributed to an abundance of fluoride in the rocks. It is significant that in this area there occurs an economically exploitable deposit of apatite (fluoro-hydroxy phosphate), classified as a carbonatite, and is known to contain

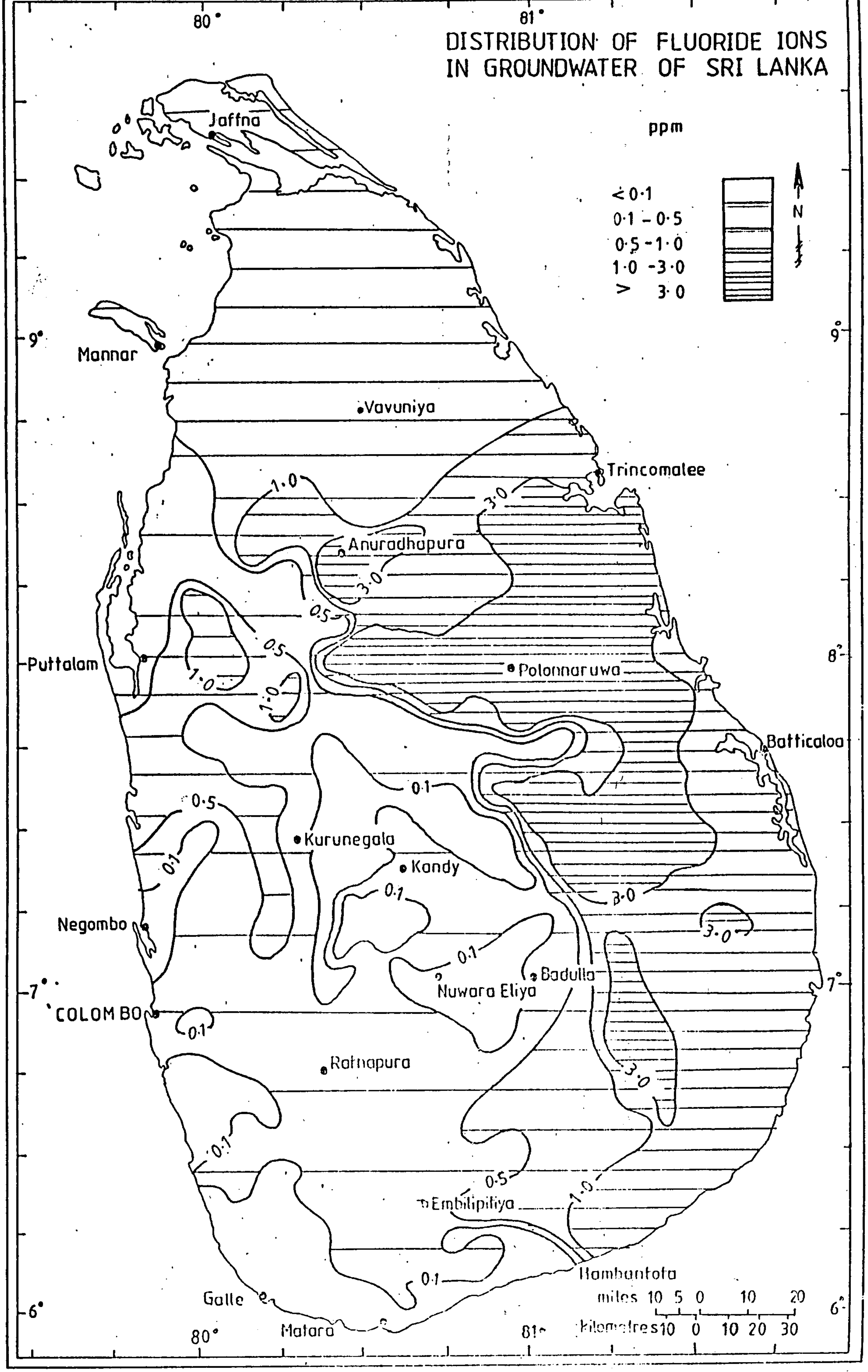


Fig. 6 Distribution of fluoride in the groundwater of Sri Lanka

TABLE III

Fluoride concentrations and the incidence of the dental fluorosis and dental caries in three areas of Sri Lanka

	Anuradhapura	Polonnaruwa	Kandy
Dental fluorosis	77.5%	56.2%	13.0%
Dental caries	26.2%	26.5%	95.9%
Fluoride concentration	0.34 - 3.75 ppm	0.26 - 4.25 ppm	less than 0.2 ppm

Note : The maximum fluoride concentration in the Anuradhapura area was 9.0 ppm; 5.8 ppm in Maha Oya and 4.8 ppm in Uda Walawe (see figure 8 for localities) reserves pf 23 million tons. The apatite deposit is now being mined and analysis shows it to contain a fluoride concentration of 1.5 - 2.4%.

It is a well established fact that the fluoride ion can take the place of the hydroxyl ion and that an equilibrium could be maintained. The substitution of fluoride for hydroxyl is to expected from similarity of ionic radii and charges. Extensive research has been carried out on the fluoride-hydroxyl exchange in geological materials. The presence of higher concentrations of fluoride in water in this area bearing fluorine-rich rocks is therefore explained on the basis of $F^- \rightleftharpoons OH^-$ interchange between mineral and water. Apart from apatite, micas which are present in abundance in this area are also known to exhibit this interchange of fluoride and hydroxyl.

The area in the South-east of Sri Lanka around Uda Walawe (Fig. 6) which contains high concentrations of fluoride, comprises different geological formations compared to the region around Anuradhapura. It has been recently discovered that the area around Uda Walawe consists of large deposits of serpentinites (Dissanayake and Van Riel, 1978; Dissanayake, 1982). These occur as long and narrow belts and a number of such deposits occur to the north and south of Uda Walawe. Serpentine, an iron-magnesium hydroxy silicate also possesses the property of exchanging the fluoride ion for the hydroxyl ion; it exhibits the property of taking up the fluoride ion into its structure from an aqueous solution and also the release of fluoride into an aqueous medium. Serpentine generally contains 1000-2000 ppm of fluoride and this is quite sufficient for an enrichment of fluoride in water in the vicinity, bearing in mind the many deposits present in the area.

The third high fluoride zone lies around Maha Oya in the eastern part of Sri Lanka and also lies in an area of geological and geochemical significance. Around Maha Oya, a number of hot water springs, considered to be derived from thermally heated circulating ground water and gaseous emanations are present. Apart from the many dissolved ions, gases are also seen to bubble through the hot water. The abundance of flouride among these gases in such terrains is well known. Further to the north and to the south of Maha Oya, there are other hot springs indicating a much larger area of thermally heated waters.

These observations on the incidence of dental diseases in Sri Lanka clearly illustrates the need for an interdisciplinary approach towards the study of health problems in Sri Lanka.

Geochemistry of well water and cardiovascular diseases in Sri Lanka

Kobayashi (1975) first demonstrated a statistical association between drinking water quality and mortality rates in Japanese communities. This was followed by other works which aimed at establishing similar relationships in other parts of the world (U.S. National Committee for Geochemistry, 1979; Roberts, 1978; Barker and Rose, 1976; Keil (1979). A number of these studies have known statistically significant negative correlation between death rates from cardiovascular diseases and water hardness. A negative correlation indicates that death rates tend to be lower in the harder water areas. This conclusion has however, not been universal.

In Sri Lanka some preliminary work on the incidence of cardio-vascular diseases in relation to water hardness has been carried out by Dissanayake et.al. (1982). Fig. 9 and 10 illustrate respectively the variation of death rate due to cardio-vascular diseases and hypertensive diseases in Sri Lanka. It can be seen that there is a wide variation in the incidence of the cardio-vascular diseases in Sri Lanka and

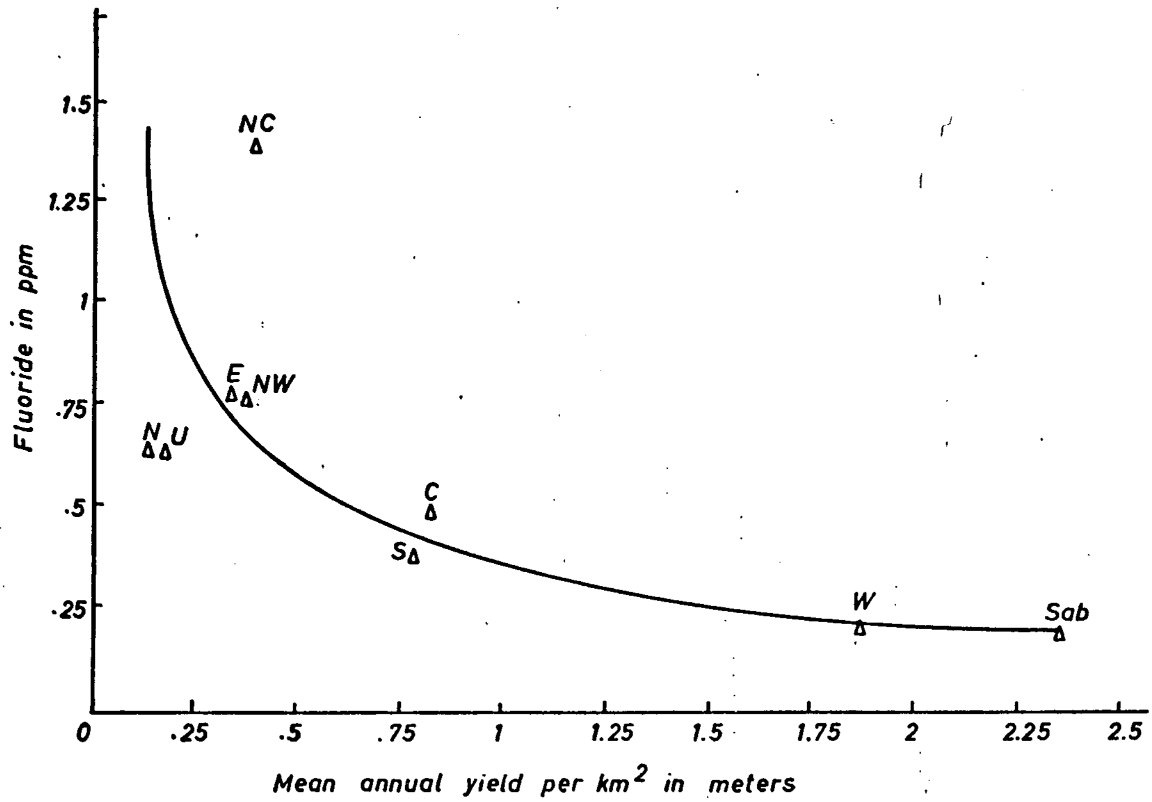


Fig. 7 Variation of fluoride concentration in well water with rainfall

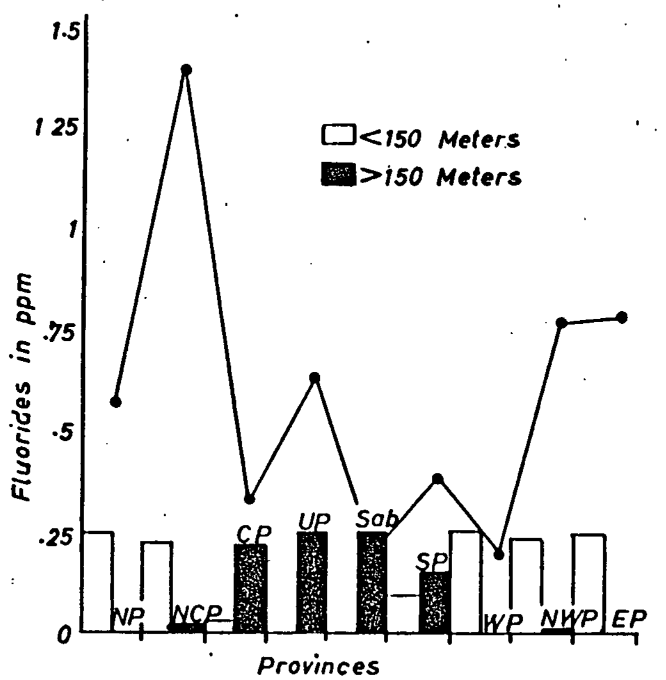


Fig. 8 Variation of fluoride in well water with respect to the elevation

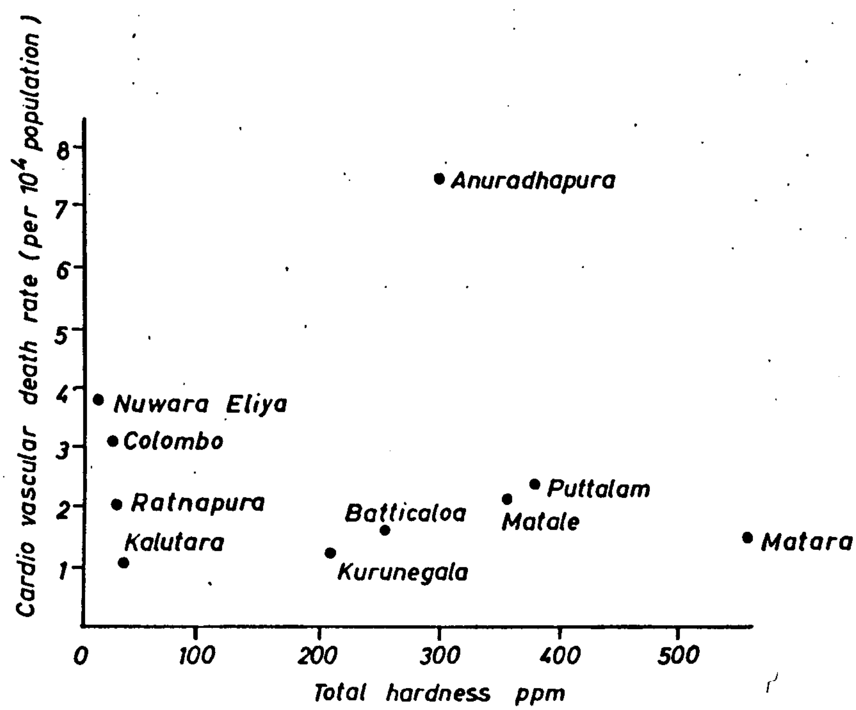


Fig. 9 Variation of the incidence of cardiovascular death rate with the total hardness of water

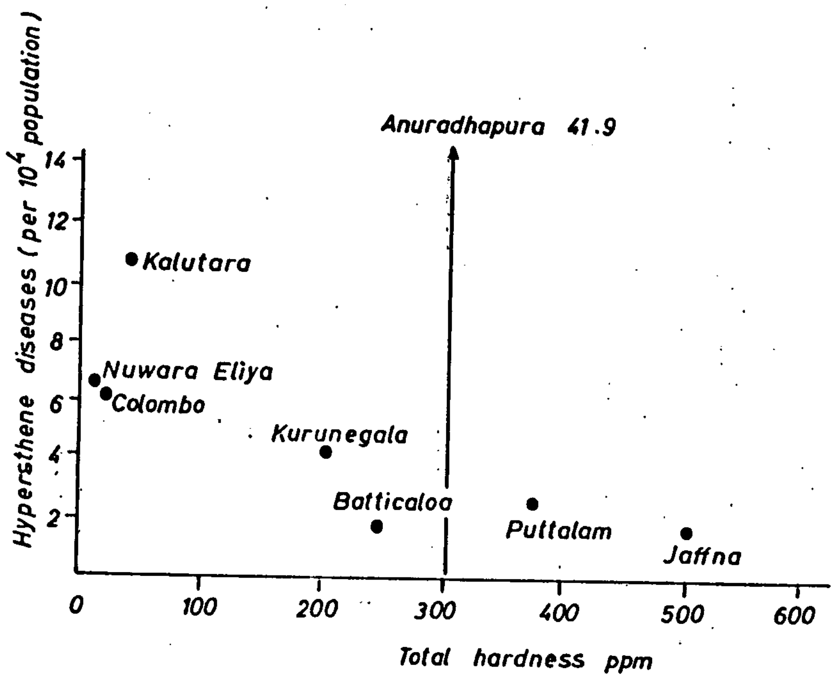


Fig. 10 Variation of the incidence of the hypertensive diseases with the total hardness of water

this can be put in perspective when the relationship with water hardness is shown. Figs. 11 and 12 illustrate the variations of some cardio-vascular diseases in certain areas in relation to water hardness. It is apparent from these figures that there is a broad correlation indicating a low incidence of cardio-vascular diseases when the hardness of water reaches appreciable values. However, a clear-cut association between the hardness of drinking water and cardio-vascular mortality cannot be expected, since other factors also appear to be involved. A case in point are the high hypertensive diseases and death rates in the North Central Province, even though the water hardness is high enough to prevent such a high incidence. It is of interest to note that Keil (1979) in his study on the incidence of cardio-vascular diseases in relation to water hardness in West Germany noted that in spite of some doubt concerning the "water story", it seems likely that there is a factor which is closely associated with the drinking water and which has a damaging influence on the health of the population.

The U.S. National Committee for Geochemistry of the National Academy of Sciences through its Sub-committee on the Geochemical-Environment in relation to Health and Disease recently convened a Panel on Geochemistry of Water in Relation to Cardiovascular Disease. One striking conclusion emerged from the detailed study, namely that the relation was clearly equivocal. It was obvious that additional studies with considerably more scientific rigour are required if the issue of a relation between water hardness and cardio-vascular diseases is to be resolved satisfactorily.

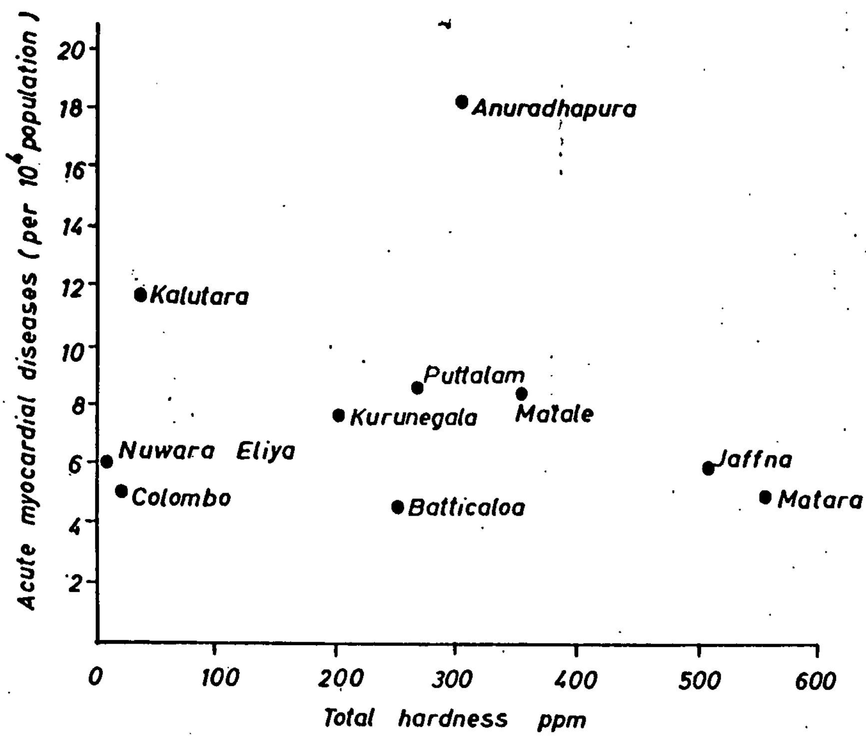


Fig. 11 Variation of the incidence of acute myocardial diseases with total hardness of water

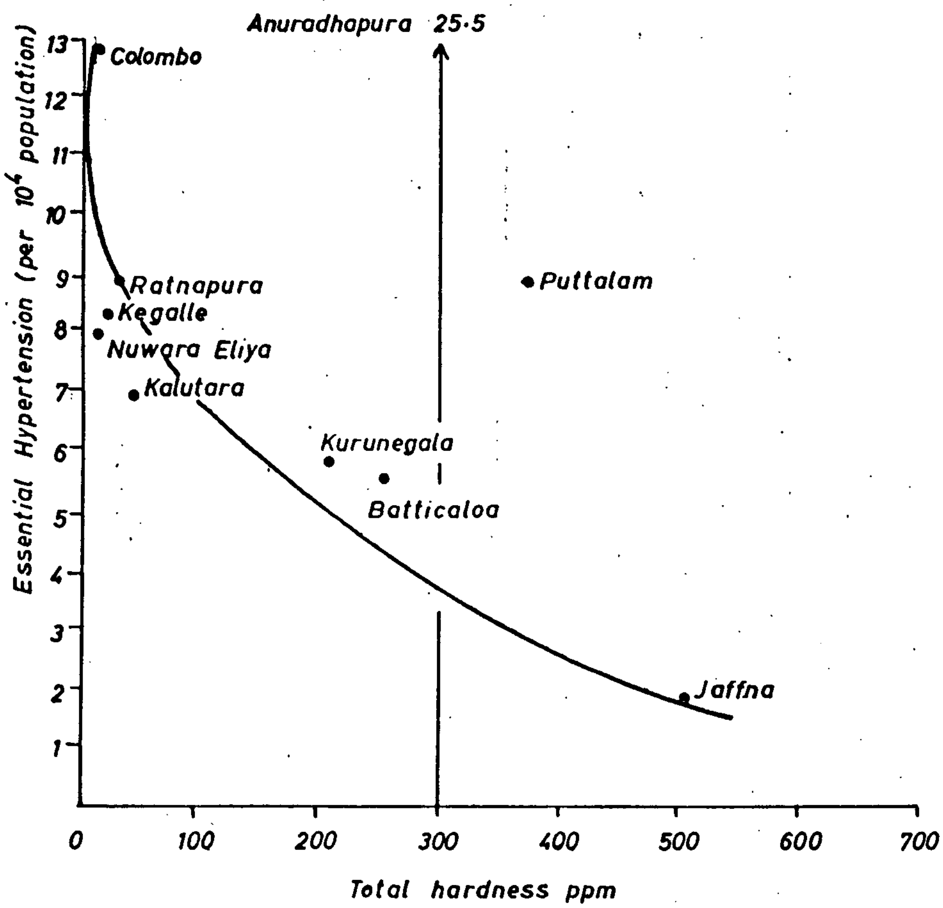


Fig. 12 Variation of the incidence of essential hypertension with the total hardness of water