WATERSCAPE OF KERALA | 2013

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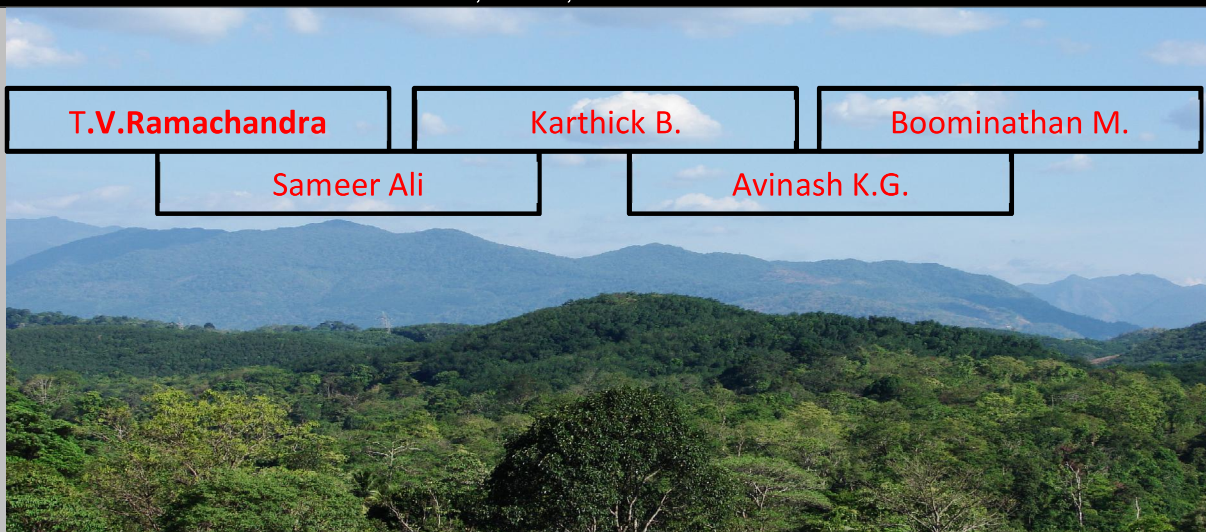

CES Technical Report 133
August 2013

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WATERSCAPE OF KERALA: CHARACTERISATION OF SURFACE, WELL AND TAP WATER IN ALL DISTRICTS

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Executive Summary

Malayala Manorama vide letter dated 16th February 2007 requested Dr. T.V. Ramachandra, Co-ordinator, Energy & Wetlands Research Group, CES, Indian Institute of Science to carryout characterization of surface, well and tap water (based on sampling) in all districts Kerala (Ref: IISc:CP5624/0303/07-3269, 13th March 2007). Assessment of water quality was carried out through representative sampling from all districts (of surface water, wells and tap water – 5 samples each per district). Field sampling was initiated in March 2007 and carried out in two phases, during the last week of March, April and first week of May 2007. Research team consisted of researchers: Karthick B., Boominathan, M., Sameer Ali (all districts) and Avinash K G (Southern Kerala). Mr.Ajith from Malayala Manorama was instrumental in guiding the team to all sampling locations and also successful completion of the field investigations.

The important recommendations covered under different sections of this report are:

1. Water Quality Concerns: Major portion of untreated sewage is let into waterbodies in most localities thus hampering the ecological balance of the system as the quantity of the pollutant entering the waterbody is beyond its neutralising ability. This has lead to the enrichment of nutrients and has resulted in the eutrophication of waterbodies (especially lakes in urban pockets).
2. Pathogens - Presence of coliforms, *E.coli*, indicates faecal contamination; that is, it has come in contact with human or animal faeces. This indicates lack of maintenance of hygiene, which is evident from letting sewage directly into waterbodies (in urban area – towns, etc.) and dumping of solid waste in the catchment of waterbodies or open defecation (in peri-urban and rural area). Due to contamination, most of the waterbodies (both urban and rural) have become a flourished land for the pathogens (disease vectors), evident from frequent episodes of epidemic diseases – malaria, hepatitis, chicken pox, dengue, chikungunya, leptospirosis, dengue, etc.
    a. The situation demands immediate intervention by the state authorities to prevent faecal contamination of waterbodies, through
        i. Decentralised sewage treatment plants for each ward in a city. Decentralised wastewater treatment and recycle systems help in developing reuse programmes without distribution expenses (compared to centralized systems)

ii. Implementation of "polluter pays" principle through "pollution taxes" as per the water act of 1974, 2002 and National water policy, 2002. Government of India.
iii. Reuse and recycling of wastewater. Treated wastewater could be used for gardens and for flushing toilets (in urban areas), industrial use and irrigating crops, groundwater recharge.
iv. Checking leaky distribution networks – due to which contaminants come in contact with the treated water (in tap water distribution network). The government should come up with the measures to minimize such contamination – by changing very old distribution networks.
v. Implementation of Eco-toilets (popularly known as eco-sanitation) in rural area to prevent open defecation, which contaminates streams, rivers and lakes.

To ensure these are adopted, policy interventions required are

- Incentive scheme to encourage reuse and recycling of wastewater
- Support of innovative technologies and capacity building of private sector for design and implementation of water recycling and reusable technologies suitable to Kerala

b. Treatment options: Pathogens - Boiling is the best way to purify water that is unsafe because of the presence of protozoan parasites or bacteria. New technologies such as Ultra Violet sterilization, Ozonation produces satisfactory results.
c. Treatment options: TDS (Total Dissolved Solids): Distillation is the reverse of boiling. To remove impurities from water by distillation, the water is usually boiled in a chamber causing water to vaporize, and the pure (or mostly pure) steam leaves the non volatile contaminants behind. The steam moves to a different part of the unit and is cooled until it condenses back into liquid water. The resulting distillate drips into a storage container. Salts, sediment, metal anything that won't boil or evaporate - remain in the distiller and must be removed. Other techniques are – Ion exchange, membrane separation technologies (ultra filtration, nano filtration, reverse osmosis, etc).
d. Adoption and implementation of integrated solid waste management (ISWM) approaches by segregating the waste at source, treating the organic components of solid waste, reuse and recycle of wastes, implementation and management of

sanitary landfills (which prevents leaching and hence groundwater contamination).

3. Water Quality Concerns - Trace elements contamination: Recharge and withdrawal of water have to be balanced. Fluoride contamination happens naturally, when water withdrawal is higher than the recharge, as in Palghat, Alaphuza, Wayanad, etc. (as the water would have interacted with the geological strata containing these elements). Fluoride contamination also happens, when domestic sewage (urban area), insecticide, pesticide, herbicide (rural area) contaminates ground water aquifer.
4. Abatement and treatment of pollution: Abatement and treatment programmes should include capacity building of farmers for improvement in application of fertilizers and pesticides through better extension of agronomy know-how, which will help in reducing water contamination.
5. Large scale conversions of watershed area of waterbodies have altered the hydrological regime while enhancing the silt movement – lowering water yield in the catchment affecting the ground water recharge.
6. Recharging groundwater aquifer though
    a. Practicing watershed conservation and management practices: Water contamination coupled with scarcity has necessitated to re-look into the current planning and management approaches. Sustainability can only be achieved through conservation of natural resources. Watershed management encompasses the entire system from uplands and headwaters to floodplain wetlands and rivers. Watershed management is an iterative process of integrated decision making considering both terrestrial and aquatic ecosystems (land and water) in a watershed. Human alterations of lands and waters directly affect water yield, sediments and nutrients, and thus fundamentally influence aquatic ecosystems. Buffer zone is to be created and maintained to enhance the water yield and hydrology of the waterbody. 500 to 1000m across waterbody and valley zones are to be declared "no activity zones". There is an urgent need for
        - **Restoring and conserving the actual source of water** - the water cycle and the natural ecosystems that support it - is the basis for sustainable water management;
        - **Environmental degradation is preventing us from reaching goals** of good public health, food security, and better livelihoods world-wide;

- **Improving the human quality of life** can be achieved in ways that also maintain and enhance environmental quality;
- **Reducing greenhouse gases to avoid the dangerous effects of climate change** is an integral part of protecting freshwater resources and ecosystems.

b. Rejuvenate traditional community water harvesting systems: this aids as efficient means of rainwater harvesting at community levels. Apart from recharging arrest groundwater depletion, it also raises the declining water table and can help augment water supply. State should plan for community harvesting structures in each village and in urban ward to minimise problems associated with water scarcity.

c. Measures to prevent contamination of aquifers (domestic sewage, agriculture runoff, etc.).

7. Improving efficiencies and minimizing loss of treated drinking water

Kerala state despite abundant water resources faces acute water scarcity, due to contamination and misuse of resources. This highlights the need for good decntralised governance to ensure efficiency and transparency in decision making processes with respect to the management of natural resources. The year **2007** has been aptly declared the **Water Year for India,** which emphasises the need for everyone to ensure water security and sustainability. The Government has provided adequate policy framework for conservation and sustainable mangement of waterbodies. However, lack of implementation has lead to large scale anthropogenic activities in river and lake catchments, which has altered respective system's ecological integrity in violation of the Indian Fisheries Act – 1857, the Indian Forest Act – 1927, Wildlife (Protection) Act – 1972, Water (Prevention and Control of Pollution) Act – 1974, Water (Prevention and Control of Pollution) Act – 1977, Forest (Conservation Act) – 1980, Environmental (Protection) Act – 1986, Wildlife (Protection) Amendment Act – 1991 and National Conservation Strategy and Policy Statement on Environment and Development – 1992. Despite environmental laws, there is no significant development towards sustaining ecosystems due to the lack of awareness of the values of these ecosystems among the policymakers and implementation agencies. The effective management of waterbodies requires a thorough appraisal of the existing laws, institutions and practices. The involvement of various people from different sectors is essential in the sustainable management of waterbodies. Apart from government regulation, development of better monitoring methods is needed to increase the knowledge of the physical and biological characteristics of each water resources (wetlands, lakes, rivers), and to gain, from this knowledge, a better understanding of system's dynamics and their controlling processes. Discussions based on accurate knowledge and increased awareness of water issues can then begin to develop management strategies (to protect, restore and/or mitigate) that account for the function and value of all water resources in the face of natural and socioeconomic factors, while continuing to satisfy critical resource needs of the human population.

Keywords: Water quality, Rivers, Lakes, Wetlands, Groundwater, Tap water

1.0 INTRODUCTION

Aquatic ecosystems (rivers, lakes, ocean, etc.) contribute to a large proportion of the planet's biotic productivity as about 30 % of the world's primary productivity comes from plants living in the ocean. These ecosystems also include wetlands located at lake shores, river banks, the ocean shoreline, and any habitat where the soil or vegetation is submerged for some duration. When compared to terrestrial communities, aquatic communities are limited abiotically in several different ways (Ramachandra, et al. 2005).

- Organisms in aquatic systems survive partial to total submergence. Water submergence has an effect on the availability of atmospheric oxygen, which is required for respiration, and solar radiation, which is needed in photosynthesis.
- Some organisms in aquatic systems have to deal with dissolved salts in their immediate environment. This condition has caused these forms of life to develop physiological adaptations to deal with this problem.
- Aquatic ecosystems are nutritionally limited by phosphorus and iron, rather than nitrogen and
- These are generally cooler than terrestrial systems which limit metabolic activity.

Aquatic ecosystems have been subjected to various levels of stresses in India, due to unplanned developmental activities in the last century leading to serious environmental degradation. Anthropogenic activities involving changes in land use ultimately affects the receiving water in that drainage. Activities include agriculture –inorganic fertliser, pesticides and herbicides applied to crops, silt washed away because of vegetation removal, or even atmospheric deposition, or disposal of solid and liquid wastes. Thus, aquatic ecosystems are exposed to all local disturbances regardless of where they occur. In addition, waterways have been used for numerous activities other than providing habitat to aquatic organisms. They have been altered for transportation, diverted for agricultural and municipal needs, dammed for energy, used as an industrial coolant, and straightened for convenience. These uses, misuses and exploitation have taken their toll as evidenced by declines in fisheries, floods, droughts, loss of biodiversity and communities trying to deal with finite water supplies. The traits that make aquatic ecosystems particularly vulnerable also make them useful for monitoring environmental quality. Water serves to integrate these impacts by distributing them among the elements within these ecosystems. Although dilution is occurring, subtle changes can be detected in habitats or organisms over a much larger area that may be the result of a single point source. A clean ecosystem with a healthy biological community will be indicative of the condition of the terrestrial habitat in the watershed. Despite few attempts, much needs to be done to effectively manage and conserve aquatic resources. As is evident from the scientific literatures little is known of the national trends in populations, diversity, or biomass of diatoms, algae, and protozoa even though they provide basic functions of photosynthesis, production, and decomposition critical to the normal functioning of aquatic ecosystems. This necessitates detailed scientific investigations and without increased monitoring, some very basic attributes of aquatic systems may be unknowingly lost or severely degraded. Subtle changes such as losses of island habitat and constant water depth or level may lead to drastic declines in productivity or diversity. The loss of some of these vital components of ecosystems may be impossible to restore (Ramachandra, 2006).

Water has a unique place of all the planet's renewable resources. It is essential for sustaining all forms of life, food production, economic development, and for general well being. It is impossible to substitute for most of its uses, difficult to de-pollute, expensive to transport, and it is truly a unique gift to mankind from nature. Water is also one of the most manageable of the natural resources as it is capable of diversion, transport, storage, and recycling. All these properties impart to water its great utility for human beings. The surface water and groundwater resources of the country play a major role in agriculture, hydropower generation, livestock production, industrial activities, forestry, fisheries, navigation, recreational activities, etc. According to National Water Policy in the planning and operation of systems, water allocation priorities are: (i) drinking water, (ii) irrigation, (iii) hydropower, (iv) ecology, (v) agro-industries and non-agricultural industries, and (vi) navigation.

India receives annual precipitation of about 4000 km^3, including snowfall. Out of this, monsoon rainfall is of the order of 3000 km^3. Rainfall in India is dependent on the south-west and north-east monsoons, on shallow cyclonic depressions and disturbances and on local storms. Most of it takes place under the influence of south-west monsoon between June and September except in Tamil Nadu, where it is under the influence of north-east monsoon during October and November. India is gifted with a river system comprising more than 20 major rivers with several tributaries. Many of these rivers are perennial and some of these are seasonal. The rivers like Ganges, Brahmaputra and Indus originate from the Himalayas and carry water throughout the year. The snow and ice melt of the Himalayas and the base flow contribute the flows during the lean season. Lal (2001) mentioned that more than 50% of water resources of India are located in various tributaries of these river systems. Average water yield per unit area of the Himalayan Rivers is almost double that of the south peninsular rivers system, indicating the importance of snow and glacier melt contribution from the high mountains. Apart from the water available in the various rivers of the country, the groundwater is also an important source of water for drinking, irrigation, industrial uses, etc. It accounts for about 80% of domestic water requirement and more than 45% of the total irrigation in the country. As per the international norms, if per-capita water availability is less than 1700 m^3 per year then the country is categorized as water stressed and if it is less than 1000 m^3 per capita per year then the country is classified as water scarce. In India per capita surface water availability in the years 1991 and 2001 were 2309 and 1902 m^3 and these are projected to reduce to 1401 and 1191 m^3 by the years 2025 and 2050 respectively. Hence, there is a need for proper planning, development and management of the greatest assets of the country, viz. water and land resources for raising the standards of living of the millions of people, particularly in the rural areas.

1.1 WATER RESOURCES: Although India occupies only 3.29 million km^2 geographical areas, which forms 2.4% of the world's land area, it supports over 15% of the world's population. The population of India as on 1 March 2001 stood at 1,027,015,247 persons. Thus, India supports about 1/6th of world population, 1/50th of world's land and 1/25th of world's water resources. India also has a livestock population of 500 million, which is about 20% of the world's total livestock population. More than half of these are cattle, forming the backbone of Indian agriculture.

Water resources potential of the country has been assessed from time to time by different agencies. The assessment of 1869 km^3 (or Billion Cubic Metre i.e. BCM) of CentralWater Commission (CWC) carried out in1993 is generally considered as reliable. Within the limitations of physiographic conditions, socio political environment, legal and constitutional constraints and the technology available at hand, the utilizable water resources of the country have been assessed at 1123 km^3, of which 690 km^3 is from surface water and 433 km^3 from ground water sources. The irrigation potential of the country has been estimated at around 139.9 mha without inter-basin sharing of water, and 175 mha with interbasin sharing. The Central Ground Water Board (CGWB) has estimated that it is possible to increase the ground water availability by about 36 km^3, by taking up rainwater harvesting and artificial recharge over an area of 45 mha through non-committed surplus monsoon runoff. Thus the groundwater availability may correspondingly increase.

The annual potential natural groundwater recharge from rainfall in India is about 342.43 km^3, which is 8.56% of total annual rainfall of the country. The annual potential groundwater recharge augmentation from canal irrigation system is about 89.46 km^3. Thus, total replenishable groundwater resource of the country is assessed as 431.89%. After allotting 15% of this quantity for drinking, and 6 km^3 for industrial purposes, the remaining can be utilized for irrigation purposes. Thus, the available groundwater resource for irrigation is 361 km^3, of which utilizable quantity (90%) is 325 km^3. It is estimated that approximately 25% of the annual distribution of rainfall is being utilised at present. Further, the water resources in the country present two contrasting scenario, viz (i) one of harmful plenty in the form of devastating floods in few regions; and (ii) acute scarcity of water resulting in severe drought conditions in some other regions, that has become a recurring feature. The Ministry of Rural Development is particularly concerned with the ground water situation, accounting for 85 percent of the rural water supply in the country. In recent years, the sustainability of the source has emerged as a major issue. Among the various factors responsible, the competing demands from the irrigation sector, using 85 percent of ground water, is a major factor adversely affecting the sustainability of the drinking water source. The situation gets further aggravated in the absence of a well conceived institutional mechanism for regulated development of ground water. In this connection, it may be relevant to mention that all the States have been continuously advised to adopt the Model Bill to regulate and control development of ground water circulated by Ministry of Water Resources. Over exploitation of ground water not only affects sustainability of the resource but also affects the quality, as manifested through arsenic problem in parts of West Bengal, coastal salinity in parts of Tamil Nadu and Gujarat and fluoride problem in a number of States (Kolar in Karnataka, Palghat, Wayanad, etc. in Kerala). The government's concern since independence has been raising the quality of life and the health of the people. Several initiatives were taken at policy formulation level leading to various programmes in this direction.

1.2 National Water Policy: As per Seventh Schedule of the Indian Constitution (as per List-II – State list,), water is a State subject and water resources projects are owned and operated by the State Governments (http://wrmin.nic.in/policy). However, this is subject to the provisions of entry of List-I – Union List, wherein Union Government has been given powers to regulate and develop inter-State rivers and river valleys to the extent such regulation and development under the control of Union is declared by Parliament by Law to be expedient in public interest. Further Economic and Social Planning has been included in List-III – Concurrent List, Item 20. Some salient features of the NWP 2002 are:

- The NWP (http://wrmin.nic.in/policy/nwp2002.pdf)defines water as a prime natural resource, a basic human need and a precious national asset, to be planned, developed, conserved and managed in an integrated and environmentally sound basis, keeping in view the socio-economic aspects and the needs of the States. It recognizes water as a crucial element in developmental planning, to be managed in a sustainable manner and guided by the national perspective. Water as a resource is one and indivisible: rainfall, river waters, surface ponds and lakes and ground water are all part of one system.

- It acknowledges integrated and coordinated development of surface and ground waters and their conjunctive use, the socio-economic, environmental and sustainability issues in water resources development; need for appropriate resettlement and rehabilitation of project affected people; problems of time and cost over runs in project construction; problems of salinity and water logging in some irrigation commands; and issues of equity and social justice in water distribution; and stipulates that all these concerns need to be addressed on basis of common policies and strategies.
- It acknowledges the importance of all types of practices, the traditional practices like rainwater harvesting, preservation of forests; the modern conventional practices like water shed management, soil conservation; and the modern non-conventional methods like inter-basin sharing of water, artificial recharge of ground water and desalination of sea water.
- It emphasizes multi-sect-oral, multi-disciplinary planning with participatory approach, for the entire river basin.
- The water allocation priorities are drinking water, irrigation, hydro-power, ecology, industrial use and navigation, in that order. It specifically stipulates that drinking water requirement shall be first charge on any available water.
- It encourages participation of private sector in planning, development and management of water resources projects with a view to introduce innovative ideas, generate financial resources, and bring in better management practices. All models of private sector participation, *viz.* build, own, operate and transfer, are acceptable.
- It recommends water sharing and distribution amongst States guided by a National perspective with due regards to the availability and needs within a basin.
- It stipulates that there is an urgent need for paradigm shift from creation of new projects to improvement of the performance of existing projects.
- The erosion of land, whether by the sea in coastal areas or by river waters inland, should be minimized by suitable cost-effective measures. The States and Union Territories should also undertake all requisite steps to ensure that indiscriminate occupation and exploitation of coastal strips of land are discouraged and that the location of economic activities in areas adjacent to the sea is regulated.
- Each coastal State should prepare a comprehensive coastal land management plan, keeping in view the environmental and ecological impacts, and regulate the developmental activities accordingly.

1.3 INFLUENCE OF ANTHROPOGENIC ACTIVITIES ON HYDROLOGICAL CYCLE: The hydrological cycle is being modified quantitatively and qualitatively in many river basins of our country due to unplanned developmental activities, which is evident from large scale land cover changes altering the hydrological regime. Human activities affecting the hydrological regime can be classified into four major groups:

(i) activities which affect river runoff by diverting water from rivers, lakes, and reservoirs or by groundwater extraction,

(ii) activities modifying the river channels, e.g. construction of reservoirs and ponds, levees and river training, channel dredging, etc.

(iii) activities due to which runoff and other water balance components are modified due to impacts of basin surface e.g. agricultural practices, drainage of swamps, afforestation or deforestation, urbanization, etc. and

(iv) activities which may induce climate changes at regional or global scale, e.g. modifying the composition of atmosphere by increasing the 'greenhouse' gases or by increased evaporation caused by large scale water projects.

For understanding the effects appropriately, maintaining water quality, regular monitoring of aquatic systems and effective legal framework has to be adopted.

1.4 NEED FOR MAINTAINING QUALITY, LEGAL FRAMEWORK: In view of the existing status of water resources and increasing demands of water for meeting the requirements of the rapidly growing population of the state as well as the problems that are likely to arise in future, a holistic, well planned long-term strategy is needed for sustainable water resources management in India. The water resources management practices may be based on increasing the water supply and managing the water demand under the stressed water availability conditions. Data monitoring, processing, storage, retrieval and dissemination constitute the very important aspects of the water resources management. These data may be utilized not only for management but also for the planning and design of the water resources structures. In addition to these, now a days decision support systems are being developed for providing the necessary inputs to the decision makers for water resources management. Also, knowledge sharing, people's participation, mass communication and capacity building are essential for effective water resources management.

Water-quality monitoring methods can contribute to sustainable development actively and significantly, if they:

- make it possible to identify the economic activities or social behavior causing the pollution (point source or diffuse);

- are chosen for their ability to provide results useful not only as stand-alone data, but also to be aggregated into indexes that are understandable by the various stakeholders with an interest in water quality;
- facilitate the transmission of information, so the results must be quickly and easily accessible;
- are affordable in the economic sense on a long-term basis, while creating quality jobs within the community. The financial resources saved on quality monitoring can afterwards be injected into preservation or rehabilitation activities;
- need as little energy and materials as possible from a life-cycle perspective;
- avoid the use of hazardous substances;
- are socially accepted, in terms of utility and usability, and produce information suitable for end users, such as decision makers.

In addition:

- the data gathered on water bodies and ecosystems must be broad (spatial and temporal coverage, water-quality criteria) and accurate enough to ensure good water quality globally;
- when choosing a given method, one should consider that the data obtained are more likely to be integrated into broader environmental or sustainability-monitoring frameworks, so water-quality indicators should be considered alongside soil, air and effluent indicators, and, possibly even better, social and economic indicators;
- standard methods and equipment should allow for the comparison of the (quantitative) data gathered by the organizations and agencies involved; and,
- the cost and the level of accuracy of the methods employed must be consistent with the kind of information needed and the objectives in place.

2.0 KERALA'S WATERSCAPE – AN OVERVIEW

Kerala State located in the south-western corner of India has a total geographic area of 38,863 km^2 (Figure 1). According to the 2001 census Kerala's population is 31,841,374 persons which included 15,468,614 males and 16,372,760 females (Figure 2.1). Although Kerala accounts for only 1 per cent of the total area of India, it contains about 3 per cent of the country's population. The population density of the state in 2001 is about 819 people per square kilometres (Figure 2.2), three times the national average. By year 2050 the population in Kerala is likely to grow to two times that figure i.e., 64 million.Kerala is one of the densest States in the country and it recorded a decadal population growth of + 9.42% (2,740,101 persons). Figure 3 illustrates district wise percentage share of population. Figure 4, illustrates changes in population during 1901 to 1991. There is bound to be considerable pressure on all natural resources in Kerala. Water resources are no exception. Concerted efforts to formulate proper plans for sustainable development of water resources in Kerala are therefore very important. Kerala State is situated in the humid tropics with unique geomorphology, geology, meteorology, landuse and cropping pattern. These factors considerably influence the water resources and its management. Based on physiography, Kerala can be divided into three zones: (Figure 5) eastern highland (>75m), western lowland (<7.6m) and the central midland (7.5m-75m). The major formations of the State are: (i) crystalline rocks of Archaean age, (ii) sedimentary rocks of Tertiary age, (iii) latentes capping the crystallines and the sedimentary roctcs, and (iv) recent to subrecent sediments forming the low-lying areas and river valleys.

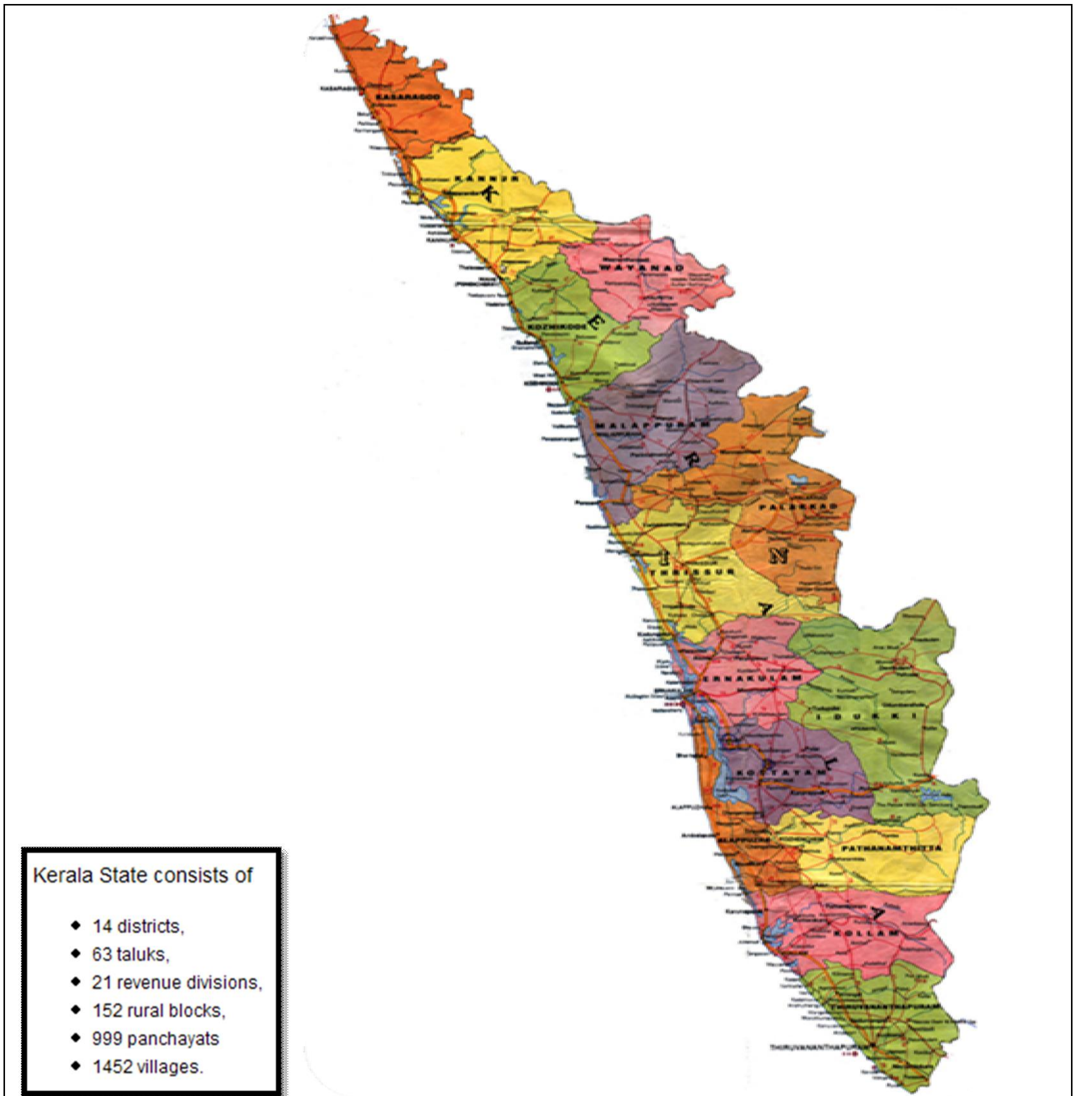
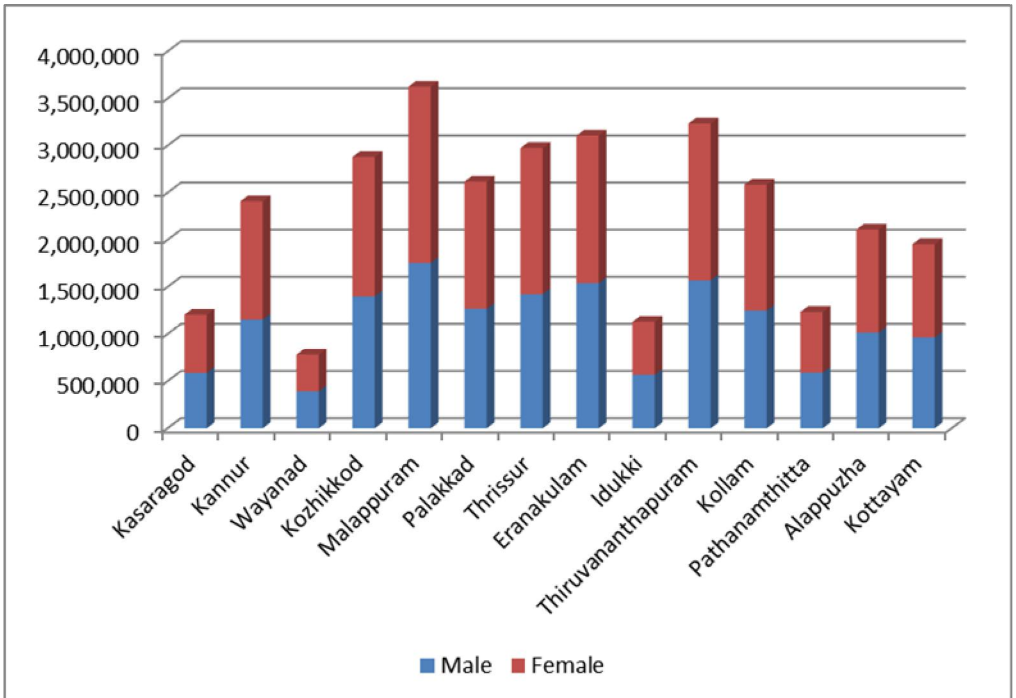


Figure 1: Kerala state (with districts), India – Study area

Figure 2.1: Districtwise population (Male and female), 2001



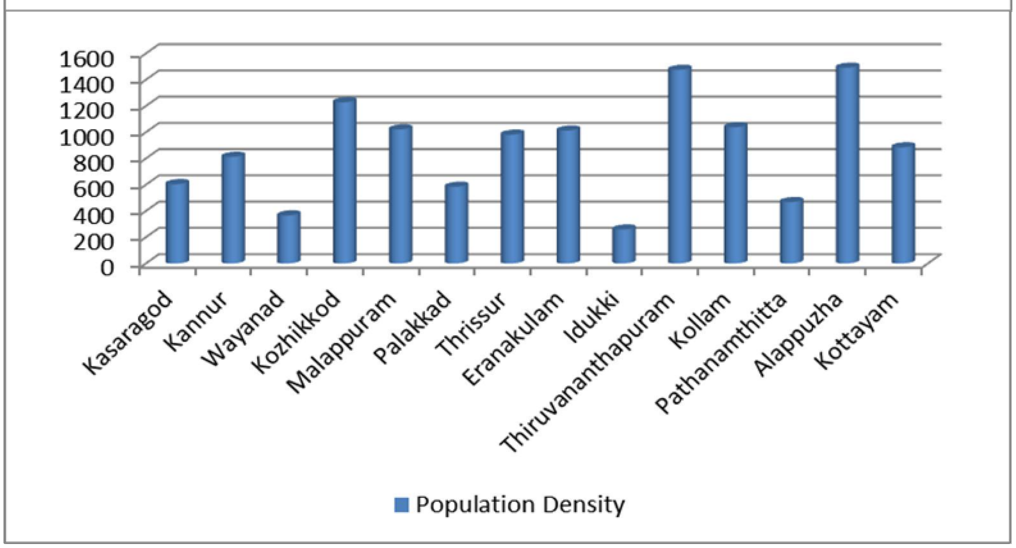


Figure 2.2: District wise population density

Figure 3: District wise population share (%)

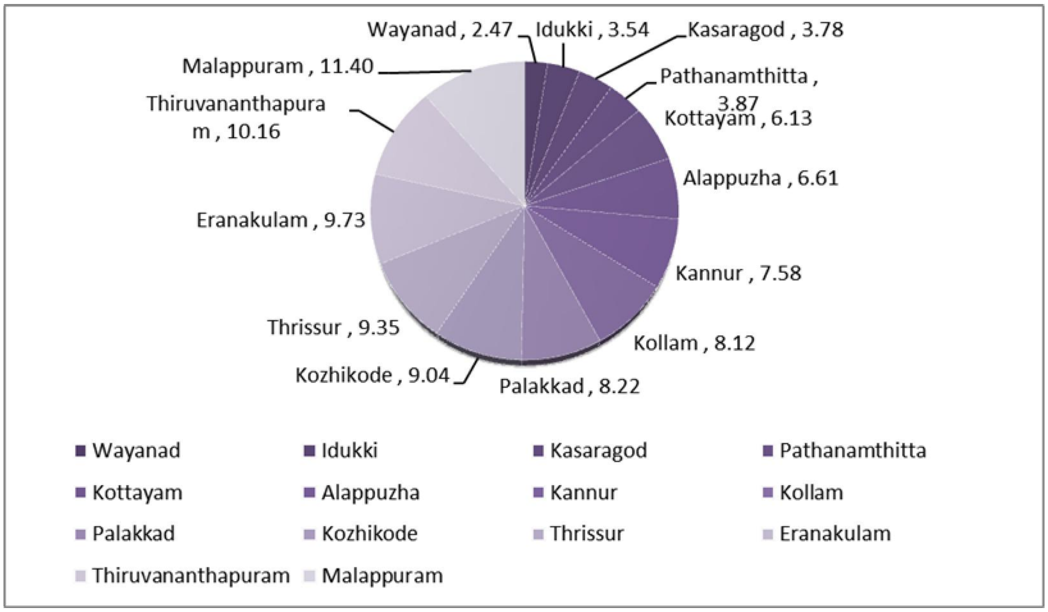
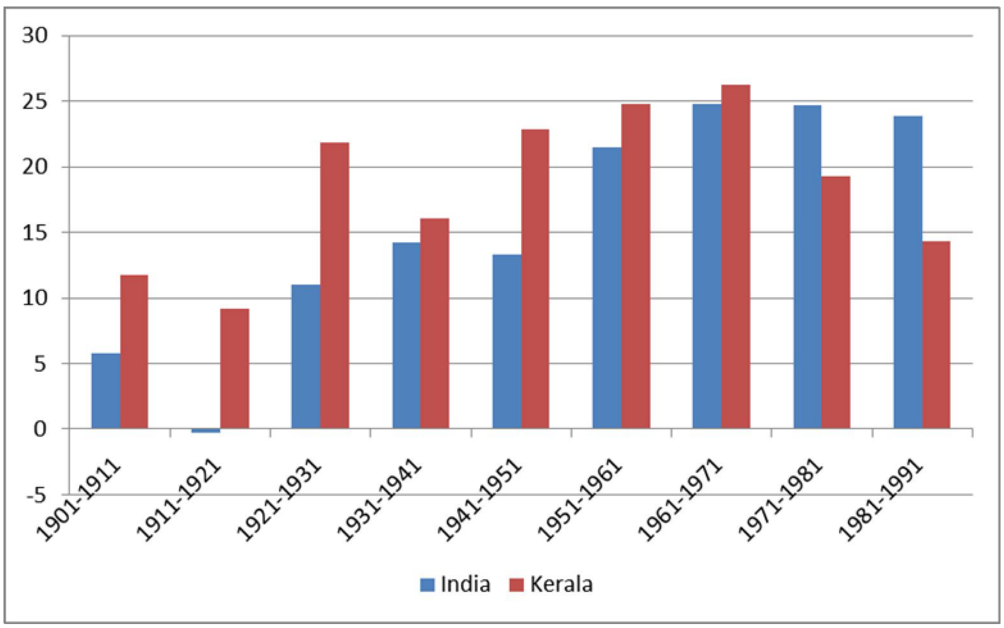


Figure 4: Decadal population changes –India and Kerala



2.1 Physiography: The State is divided into three major physiographic units viz. The coastal plains, the midlands and the hill range (Figure 5). The coastal plains have an elevation of less than 6m. Whereas the elevation of the midland ranges from 6 to 80 m and that of the hill ranges is more than 80 m above mean sea level (amsl). Along the hill ranges two distinct plateau regions are seen, the important being the Wayanad plateau, which covers major part of Wayanad district, the general elevation of which is above 700 m-amsl. The other one is the Munnar plateau, which is seen along the northern part of Idukki district with a general elevation of about 1000 m amsl

2.2 Climatology: Kerala occupies the portion of the subcontinent bounded by latitude 8º- 13ºN and longitude 75º- 77ºE. By physical features Kerala is divided into 3 natural divisions: (i) the low lands consisting of coastal areas, (ii) the middle land and (iii) the high land or the forest area of the Western Ghats on the eastern side. The extreme southern parts of the Ghats run along the eastern boarder of Kerala around 560 km in length. The climate of the state is typical tropical monsoon with seasonally excessive rainfall and hot summer. There are basically 4 seasons (i) March to May the summer or pre-monsoon season, (ii) June to September the south west monsoon season (iii) October to December north east monsoon and (iv) January-February the winter season.

2.3 Rainfall: The annual rainfall in the state varies from 3800 mm in the north to 1800 mm in the extreme south. The annual average rainfall for Kerala is 3070 mm and the departure from this in different years is shown (Table 1). The major rainfall season for Kerala is the south west monsoon period from June to September. The normal date of onset of south west monsoon is 1st June. During this period the average rainfall expected is 2130 mm (Table 1) which constitutes 70% of the annual rainfall. This also varies from north to south, the variation being 85% in the north to 54% in south. The district wise normal rainfall during south west monsoon period is given in the tables (2.21-2.24). The captions in the tables are derived from the names of the district. It can be seen that lowest rainfall during south west monsoon is being received in Thiruvananthapuram (TRV) district while the highest rainfall is in Wayanad (WYD) district. The annual highest average rainfall is in Kozhikode (KZK) district. The heavy falls during south west monsoon is due to the monsoon depressions which form over Bay of Bengal and Arabian Sea. Next to the south west monsoon, the other principal rainy season is the northeast monsoon period which starts from October and ends with December. During this period Kerala receives 16% of its annual rainfall, i.e., 500 mm and there is a reversal in the order of rainfall activity from north to south. When the southern district receives around 600 mm of rain, only 350 mm of rain is received in the northern districts during this period. During the summer period, i.e. March, April and May, Kerala receives 40 cm of rain which is 13% of the annual rainfall. This is mostly due to thuderstorm activity which is purely a local phenomenon. In winter season, i.e., January-February, only 1% of the annual rainfall is received. This amounts to only 3 cm of rain. The state receives an annual rainfall of 307 cm which is much above the average rainfall (110 cm) for the entire country 86% of the total rain is being received during the two monsoon seasons, i.e., June to December. It may be noted that this rain water is the main source for the next 6 months, i.e., January-May for the different kinds of use in various activities. Any failure in the southwest monsoon or northeast monsoon will result in scarcity of water. This will also affect the availability of drinking water, electricity production and agriculture. All efforts should therefore be made to plan and manage the use of water with utmost care so that even when the monsoon fails, water scarcity is not felt. Collection of rain water during the rainy season both for drinking and other purposes would hence be most useful. In terms of water security, it may be that among the 35 Meteorological Sub-divisions in India, Kerala receives the maximum annual rainfall. Considering the area and population, around thirteen thousand liters of water is available per head per day out of which perhaps only one or two percent is sufficient for meeting the daily needs of a person. Thus water security in terms of quantity especially in the high rainfall areas of Kerala, is very good. This state is hence highly suitable for testing DRWH in terms of economic viability and water quality visa-vis other alternatives for at priding water.

Table 4 District wise rainfall of Kerala

	South-west	**North-east**	**Pre-monsoon**	**ANNUAL**
Thiruvananthapuram	96	53	39	192
Kollam	140	62	48	256
Pathanamthitta	178	68	61	313
Alapuzha	179	62	50	296
Kottayam	202	57	49	313
Idukki	232	59	45	338
Ernakulam	222	53	49	327
Thrissur	223	47	41	313
Palakad	162	41	27	233
Malapuram	209	48	33	291
Kozhikode	276	48	41	267
Wyanad	292	35	31	260
Kannur	279	35	32	347
Kasargod	296	32	29	358

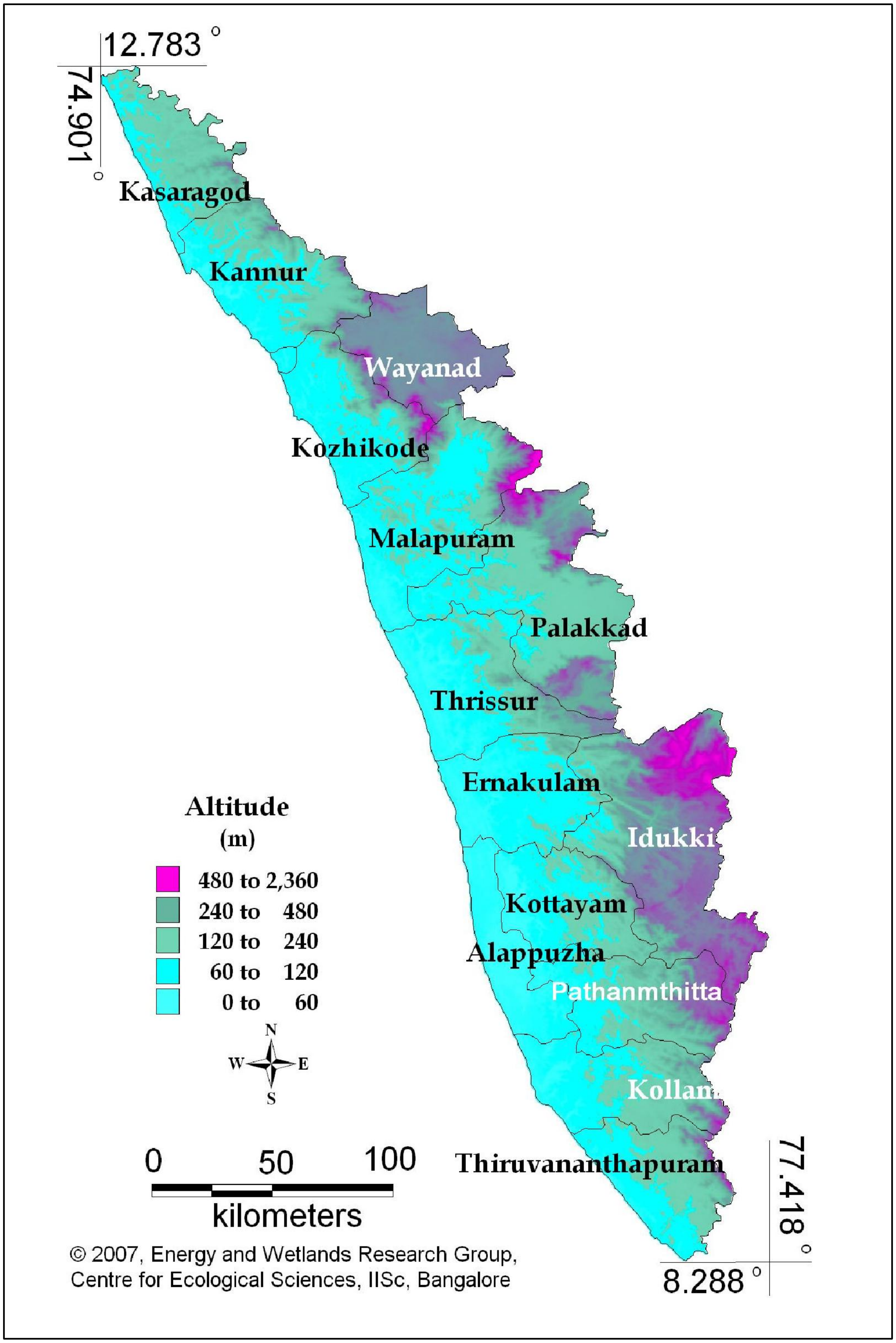


Figure 5: Physiography of Kerala with district

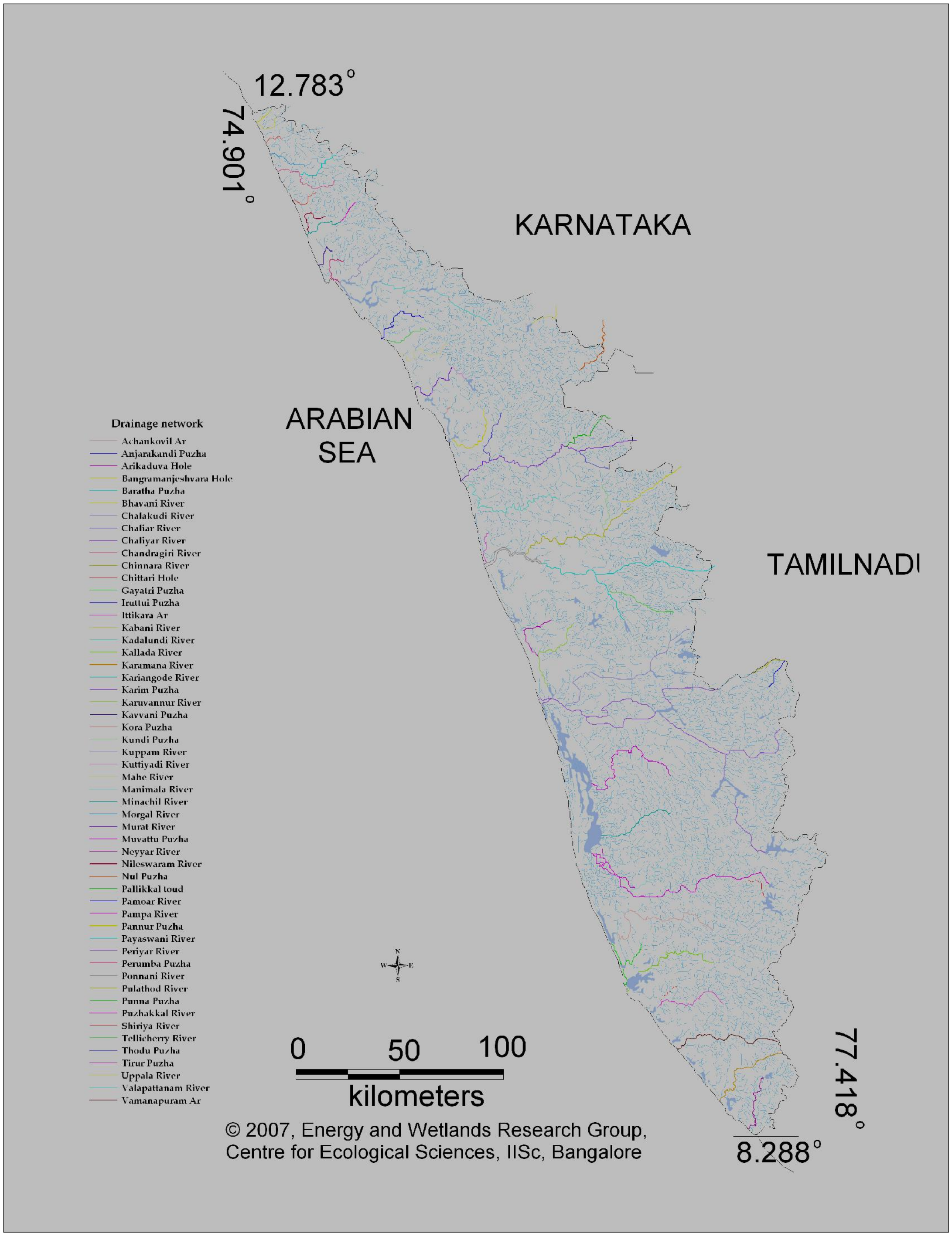


Figure 6: Rivers of Kerala

2.4 Rivers: There are 44 rivers flowing within Kerala, A location map showing the basin boundaries of these 44 rivers is given in Figure 6. Some general information on these 44 river basins in Kerala is given in Table 2. The geographic area of each of the 44 river basins in Kerala is shown in Figure 6. This information indicate that, of the 44 rivers flowing within Kerala, three are east flowing and the remaining 41 are west flowing and 13 river basins have a portion of their basin area falling also outside Kerala in the adjacent States of either Tamp Nadu (6) or Karnataka (7). These 13 river basins can therefore have inter-state water issues to be tackled. The basin area within Kerala in 10 of them are located downstream of the portion outside Kerala. In the case of the remaining three, the basin area within Kerala is upstream of the portion outside Kerala. The remaining 31 river basins fall fully within Kerala. 22 river basins (50 per cent of the total) have a basin area (within Kerala) less than 500 sq km^2, with the smallest river basin (Ramapuram) having a basin area of only 52 sq km^2 Only four river basins have a basin area (within Kerala) greater than 2,000 sq km^{2}with the largest river basin (Periyar) having a basin area of 5,384 sq km^2. Figure 6, gives the geographical distribution of water in Kerala

Table 2: Details of Rivers of Kerala (Source: Rajagopalan, 2002)

Sl.no.	Name of River	Area of River Basin			If a portion of the River Basin falls outside Kerala	
		With in Kerala (in km^2)	Outside Kerala (in km^2)	Total (in km^2)	Which portion is in Kerala	Adjacent State
1	Manjeshwar	95	0	95		
2	Uppala	81	174	255	Downstream	Karnataka
3	Shiriya	305	297	602	Downstream	Karnataka
4	Mogral	140	0	140		
5	Chandragiri	580	836	1416	Downstream	Karnataka
6	Chittari	155	0	155		
7	Nileshwar	205	0	205		
8	Kariangode	429	132	561	Downstream	Karnataka
9	Kawai	143	0	143		
10	Peruvamba	300	0	300		
11	Ramapuram	52	0	52		
12	Kuppam	469	70	539	Downstream	Karnataka
13	Valappatanam	1326	456	1782	Downstream	Karnataka
14	Anjarakkandy	417	0	417		
15	Tellichery	132	0	132		
16	Mahe	404	0	404		
17	Kuttiyadi	593	0	593		
18	Korapuzha	644	0	644		
19	Kallai	96	0	96		

20	Chaliyar	2599	388	2987	Downstream	Tamil Nadu
21	Kadalundi	1162	0	1162		
22	Tirur	117	0	117		
23	Bharathapuzha	4480	1786	6266	Downstream	Tamil Nadu
24	Keecheri	420	0	420		
25	Puzhakkal	244	0	244		
26	Karuvannur	1054	0	1054		
27	Chalakkudy	1455	300	1755	Downstream	Tamil Nadu
28	Periyar	5384	114	5498	Downstream	Tamil Nadu
29	Movathupuzha	1567	0	1567		
30	Meenachil	1302	0	1302		
31	Manimala	887	0	887		
32	Pamba	2328	0	2328		
33	Achenkovil	1519	0	1519		
34	Pallikkal	234	0	234		
35	Kallada	1735	0	1735		
36	Ithikkara	672	0	672		
37	Ayroor	76	0	76		
38	Vamanapuram	717	0	717		
39	Mammom	126	0	126		
40	Karamana	745	0	745		
41	Neyyar	528	0	528		
42	Kabbini	1970	NA	NA	Upstream	Karnataka
43	Bhavani	592	NA	NA	Upstream	Tamil Nadu
44	Pambar	384	NA	NA	Upstream	Tamil Nadu

2.5 Forests: Forests in Kerala cover 24% of geographical area (9,400 km^2) which include tropical wet evergreen and semi-evergreen forests (lower and middle elevations—3,470 km^2), tropical moist and dry deciduous forests (mid-elevations—4,100 km^2 and 100 km^2, respectively), and montane subtropical and temperate (*shola*) forests (highest elevations—100 km^2). Distribution of forests is given in Figure 7. Eastern Kerala's windward mountains shelter tropical moist forests and tropical dry forests, which are common in the Western Ghats. Lake Sasthamkotta and the Vembanad-Kol wetlands—are in Kerala (as well as 1455.4 km^2 of the vast Nilgiri Biosphere Reserve) are two of the world's Ramsar Convention wetlands. Kerala's notable biodiversity is concentrated and protected in the Agasthyamalai Biosphere Reserve in the eastern hills. Almost a fourth of India's 10,000 plant species are found in the state. Among the almost 4,000 flowering plant species (1,272 of which are endemic to Kerala and 159 threatened) are 900 species of highly sought medicinal plants. Table 3 lists plants found in riparian vegetation (listed during March-May 2007, during water quality survey).

Figure 7: Forest cover in Kerala (district wise)

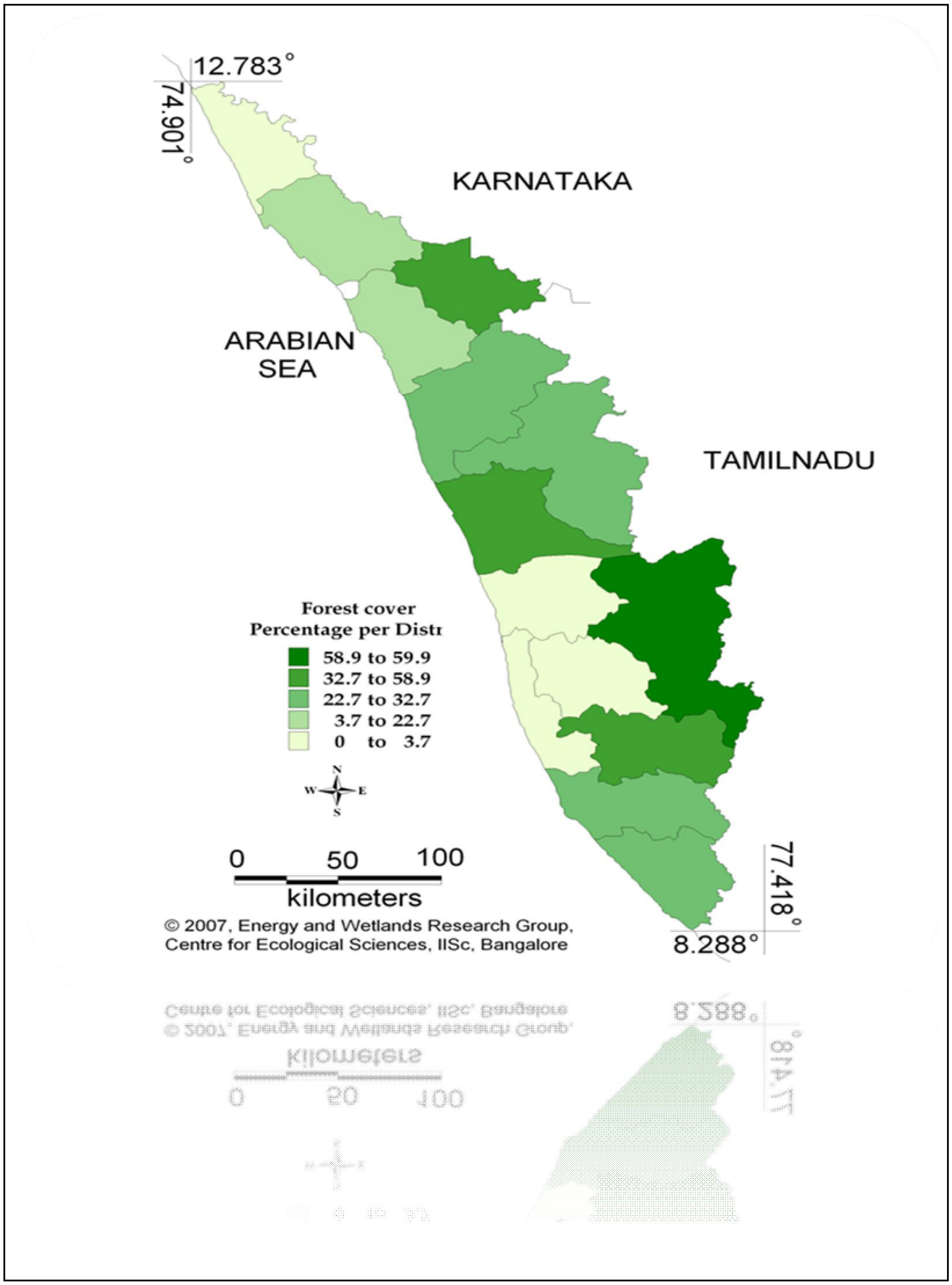


Table 3: List of plants found in the riparian vegetation, Kerala

Sl. No.	Species Name	Family	Distribution
1	*Abrus precatorius*	Fabaceae	Tropics
2	*Acacia auriculiformis*	Fabaceae	Native to Australia, Indonesia and Papua New Guinea
3	*Acacia catechu*	Fabaceae	India, China and Indian Ocean areas
4	*Acacia mangium*	Fabaceae	Native to Asia, Australia
5	*Acacia sinuata*	Fabaceae	Indomalaysia, China
6	*Acacia tora*	Fabaceae	Paleotropics
7	*Acanthephippium bicolor*	Orchidaceae	South W. India
8	*Achyranthus aspera*	Acanthaceae	Pantropical
9	*Acronychia pedunculata*	Rutaceae	Indomalaysia
10	*Acrostichium aureum*	Pteridaceae	Tropical and Sub-tropical coasts
11	*Actinodaphne* sp.	Lauraceae	
12	*Adhotoda zeylanica*	Acanthaceae	Indomalaysia
13	*Aegiceras corniculatus*	Myrsinaceae	South-east Asia and Northern Australia
14	*Aegle marmelos*	Rutaceae	Indomalaysia
15	*Ageratum conyzoides*	Asteraceae	Originally Neotropical, now Pantropical
16	*Aglaia* sp.	Meliaceae	
17	*Ailanthus excelsa*	Simaroubaceae	India, Sri Lanka
18	*Albizia lebbeck*	Fabaceae	Paleotropics
19	*Allophylus cobbe*	Sapindaceae	South W. India, Sri Lanka, Burma
20	*Alstonia scholaris*	Apocynaceae	S. Asia through Malaysia to Australia and Melanesia
21	*Alstonia* sp.	Apocynaceae	
22	*Alternanthera sessilis*	Amaranthaceae	Paleotropics
23	*Alysicarpus vaginalis*	Fabaceae	Paleotropics
24	*Amaranthus spinosus*	Amaranthaceae	Tropics
25	*Amorphophalus bulbifer*	Araceae	India, Burma
26	*Anacardium occidentale*	Anacardiaceae	A Native of America
27	*Ananas comosus*	Bromiliaceae	Native to Brazil and Paraguay
28	*Anogeissus acuminata*	Combretaceae	India, Sri Lanka
29	*Antidesma menasu*	Euphorbiaceae	Western Peninsular India
30	*Aporusa lindleyana*	Euphorbiaceae	Peninsular India, Sri Lanka
31	*Ardisia solanacea*	Myrsinaceae	Peninsular India
32	*Arenga wightii*	Arecaceae	South W. India
33	*Arisaema leschenaultii*	Araceae	South W. India
34	*Artocarpus altilis*	Moraceae	Malay Peninsula and Western Pacific Islands
35	*Artocarpus gomezianus* ssp.*zeylanicus*	Moraceae	South W. India, Sri Lanka
36	*Artocarpus heterophyllus*	Moraceae	Native to South W. India
37	*Artocarpus hirsutus*	Moraceae	South W. India
38	*Asclepias curassavica*	Asclepiadaceae	A Native of Tropical America
39	*Asparagus racemosus* var. *racemosus*	Liliaceae	Paleotropics

40	*Atalantia wightii*	Rutaceae	W. Ghats, Sri Lanka
41	*Averrhoa bilimbi*	Oxalidaceae	Native of Moluccas, distributed in South-east Asian countries
42	*Averrhoa carambola*	Oxalidaceae	Native to Sri Lanka, India and Indonesia
43	*Avicennia marina*	Avicenniaceae	East coast of Africa, Throughout south and south-east Asia,into Australia
44	*Bambusa arundinacea*	Poaceae	Throughout India
45	*Barringtonia racemosa*	Lecythidaceae	Native to Philippines
46	*Bauhinia phoenicea*	Fabaceae	Western Ghats
47	*Bauhinia purpurea*	Fabaceae	Native to South China and Southeastern Asia
48	*Bauhinia racemosa*	Fabaceae	Indomalaysia, China
49	*Bauhinia variegata*	Fabaceae	Southeastern Asia
50	*Biophytum sensitivum*	Oxalidaceae	Western peninsular India, Sri Lanka
51	*Bischofia javanica*	Euphorbiaceae	Indomalaysia
52	*Blyxa octandra*	Hydrocharitaceae	Madagascar, Indomalaysia
53	*Bombax ceiba*	Bombacaceae	Indomalaysia
54	*Borassus flabellifer*	Arecaceae	Southern Asia, Southeast Asia
55	*Boswellia serrata*	Burseraceae	Central & North west India
56	*Breynia* sp.	Euphorbiaceae	
57	*Bridelia crenulata*	Euphorbiaceae	Peninsular India
58	*Buchanania lanzan*	Anacardiaceae	India, Myanmar
59	*Butea monosperma*	Fabaceae	Indomalaya
60	*Calamus* sp.	Arecaceae	
61	*Calamus thwaitesii* var. *canaranus*	Arecaceae	South W. India
62	*Callicarpa tomentosa*	Verbenaceae	South India
63	*Calophyllum apetalum*	Clusiaceae	Western Ghats
64	*Calophyllum tomentosum*	Clusiaceae	Paleoarctic
65	*Calotropis gigantea*	Asclepiadaceae	Throughout mush of Tropical Asia
66	*Calycopteris floribunda*	Combretaceae	Indomalaysia
67	*Camelia sinensis*	Theaceae	South and Southeast Asia
68	*Canarium strictum*	Burseraceae	Western Ghats
69	*Canthium dicoccum var. dicoccum*	Rubiaceae	South India, Myamnar
70	*Capparis spinosa*	Capparaceae	Native to Mediterrenean region
71	*Carallia brachiata*	Rhizophoraceae	Oriental to Australian
72	*Careya arborea*	Lecythidaceae	Himalayas to Sri Lanka
73	*Carissa inermis*	Apocynaceae	Peninsular India
74	*Caryota urens*	Arecaceae	Tropical Asia
75	*Cassia auriculata*	Fabaceae	Indomalaysia
76	*Cassia fistula*	Fabaceae	China, Indomalysia
77	*Cassia occidentalis*	Fabaceae	Tropics
78	*Cassia tora*	Fabaceae	Tropics
79	*Cassine glauca*	Celastraceae	Indomalaysia
80	*Casuarina equisetifolia*	Casuarinaceae	Native to Australia and Islands of

			Pacific
81	*Ceiba pentandra*	Bombacaceae	Mexico, Central America and the Caribbean, Northern south America and to the west Africa
82	*Cerbera odollam*	Apocynaceae	India and other parts of southern Asia
83	*Chasalia* sp.	Rubiaceae	
84	*Cinnamomum macrocarpum*	Lauraceae	Western Ghats
85	*Cinnamomum malabatrum*	Lauraceae	Western Ghats
86	*Cissampelos pareira var. hirsuta*	Menispermaceae	Tropics
87	*Clerodendrum viscosum*	Verbenaceae	Indomalaysia
88	*Cochlospermum religiosum*	Cochlospermaceae	India
89	*Cocos nucifera*	Arecaceae	Polynesia
90	*Colocasia esculenta*	Araceae	Originating in tropical Asia but pantropically cultivated
91	*Corypha umbraculifera*	Arecaceae	Southern India, Sri Lanka
92	*Crateva nurvala*	Capparaceae	S. Asia, Indomalaysia
93	*Crotalaria* sp.	Fabaceae	
94	*Croton bonplandianum*	Euphorbiaceae	Native of South America
95	*Croton* sp.	Euphorbiaceae	
96	*Cullenia exarillata*	Bombacaceae	Western Ghats
97	*Curculigo orchioides*	Liliaceae	India, Java
98	*Curcuma longa*	Zingiberaceae	Tropical South Asia
99	*Curcuma zedoaria*	Zingiberaceae	Western Ghats
100	*Cyathocalyx zeylanica*	Annonaceae	India, Myamnar
101	*Cyclea peltata*	Menispermaceae	Western Ghats
102	*Cyperus* sp.	Cyperaceae	
103	*Dalbergia latifolia*	Fabaceae	Indomalaysia
104	*Dalbergia sisso*	Fabaceae	
105	*Datura metel*	Solanaceae	Paleotropics
106	*Datura stramonium*	Solanaceae	Introduced & naturalized
107	*Delonix regia*	Fabaceae	Tropical & Sub-tropical
108	*Dendrocalamus strictus*	Poaceae	Dry hills of India, Burma
109	*Derris trifoliata*	Fabaceae	Eastern Africa, Madagascar, Mascarene Islands, South and South-East Asia including the whole of Malesia, the Pacific and Australia.
110	*Dilienia indica*	Dilleniaceae	India
111	*Dilienia pentagyna*	Dilleniaceae	China to Indomalaysia
112	*Dimorphocalyx lawianus*	Euphorbiaceae	Western Ghats
113	*Dioscorea oppositifolia*	Dioscoriaceae	India, Sri Lanka
114	*Dioscorea* sp.	Dioscoreaceae	
115	*Diospyros candolleana*	Ebenaceae	Western Ghats
116	*Diospyros crumenata*	Ebenaceae	Western Ghats, Sri Lanka
117	*Diospyros pruriens*	Ebenaceae	Western Ghats
118	*Diospyros* sp. 1	Ebenaceae	

119	*Diospyros* sp. 2	Ebenaceae	
120	*Dipterocarpus indicus*	Dipterocarpaceae	Western Ghats
121	*Dracena terniflora*	Agavaceae	India, S E Asia
122	*Drypetes roxburghii*	Euphorbiaceae	Pantropical
123	*Ecbolium viride*	Acanthaceae	India, Sri Lanka
124	*Eichhornia crassipes*	Pontederiaceae	Native to Tropical America
125	*Elaeocarpus serratus*	Elaeocarpaceae	India
126	*Elaeocarpus* sp.	Elaeocarpaceae	
127	*Elaeocarpus tuberculatus*	Elaeocarpaceae	Indomalaysia
128	*Elettaria cardamomum*	Zingiberaceae	South W. India, Sri Lanka
129	*Emblica officinalis*	Euphorbiaceae	Paleotropics
130	*Emilia sonchifolia*	Asteraceae	Pantropical
131	*Ensete superbum*	Musaceae	South W. India
132	*Entada pursaetha*	Fabaceae	Western India,
133	*Eriocaulon* sp.1	Eriocaulaceae	
134	*Eriocaulon* sp.2	Eriocaulaceae	
135	*Eriocaulon xeranthemum*	Eriocaulaceae	Tropical Africa, Oriental-India
136	*Erythrina stricta*	Fabaceae	South W. India
137	*Eucalyptus* sp.	Myrtaceae	
138	*Euodia lunu-ankenda*	Rutaceae	India to Continental South E. Asia
139	*Euonymus crenulatus*	Celastraceae	Western Ghats
140	*Eupatorium odoratum*	Asteraceae	Neotropic
141	*Euphorbia pulcherrima*	Euphorbiaceae	Pacific coast of Mexico
142	*Euphorbia rosea*	Euphorbiaceae	A Native of Africa
143	*Euphorbia thymifolia*	Euphorbiaceae	Tropics
144	*Excoecaria agallocha*	Euphorbiaceae	Old World Tropics
145	*Ficus arnottiana*	Moraceae	South India, Sri Lanka
146	*Ficus benghalensis*	Moraceae	India, Pakistan
147	*Ficus hispida*	Moraceae	Indomalaysia
148	*Ficus racemosa*	Moraceae	Indomalaysia
149	*Ficus* sp.	Moraceae	
150	*Ficus tsjahela*	Moraceae	South India, Sri Lanka
151	*Fimbristylis* sp.	Cyperaceae	
152	*Flacourtia indica*	Flacourtiaceae	Pantropical
153	*Flacourtia montana*	Flacourtiaceae	Western Ghats
154	*Garcinia indica*	Clusiaceae	W. Ghats, Sri Lanka
155	*Garcinia morella*	Clusiaceae	Indomalaysia
156	*Garcinia* sp.	Clusiaceae	
157	*Gardenia latifolia*	Rubiaceae	India
158	*Glochidion* sp.1	Euphorbiaceae	
159	*Glochidion* sp.2	Euphorbiaceae	
160	*Gloriosa superba*	Liliaceae	Paleotropics
161	*Glycosmis pentaphylla*	Rutaceae	S. India, Sri Lanka
162	*Gmelina arborea*	Verbenaceae	Indomalaysia
163	*Gnetum scandens*	Gnetaceae	South India
164	*Gnidia glauca*	Thymeleaceae	Palaeotropics
165	*Grangea madaraspatna*	Asteraceae	Paleotropics
166	*Grewia microcos*	Tiliaceae	Asia

167	*Grewia* sp.	Tiliaceae	
168	*Grewia tiliifolia*	Tiliaceae	Tropical Africa, Tropical
169	*Helicteres isora*	Sterculiaceae	Indomalaysia
170	*Heliotropium indicum*	Boraginaceae	Pantropical
171	*Hemidesmus indicus*	Asclepiadaceae	India, Sri Lanka
172	*Hevea braziliensis*	Euphorbiaceae	Native to Brazil
173	*Hibiscus rosa-sinensis*	Malvaceae	East Asia
174	*Hibiscus tiliaceus*	Malvaceae	Eastern and Northern Australia, Oceania and South-East Asia
175	*Holigarna arnottiana*	Anacardiaceae	Western Ghats
176	*Holigarna grahamii*	Anacardiaceae	Western Ghats
177	*Homonoia riparia*	Euphorbiaceae	Indomalaysia
178	*Hopea parviflora*	Dipterocarpaceae	Western Ghats
179	*Hopea ponga*	Dipterocarpaceae	Western Ghats
180	*Hydnocarpus pentandra*	Flacourtiaceae	Western Ghats
181	*Hydnocarpus sp.*	Flacourtiaceae	
182	*Hydrilla verticillata*	Hydrocharitaceae	Native to Africa
183	*Hygrophila auriculata*	Acanthaceae	India, Sri Lanka
184	*Ipomaea eriocarpa*	Malvaceae	Paleotropics
185	*Ipomaea* sp.1	Malvaceae	
186	*Ipomoea* sp.2	Convolvulaceae	
187	*Ipsea malabarica*	Orchidaceae	Western Ghats
188	*Ixora brachiata*	Rubiaceae	Western Ghats
189	*Ixora coccinea*	Rubiaceae	W. Ghats, Sri Lanka
190	*Jasminum* sp.	Oleaceae	
191	*Jatropha curcas*	Euphorbiaceae	Native of Tropical America
192	*Jatropha gossypifolia*	Euphorbiaceae	Native of New World Tropics
193	*Knema attenuata*	Myristicaceae	Western Ghats
194	*Kydia calycina*	Malvaceae	India, Burma
195	*Lagenandra* sp.	Araceae	
196	*Lagerstroemia microcarpa*	Lythraceae	Western Ghats
197	*Lagerstroemia parviflora*	Lythraceae	W. Ghats, Myanmar
198	*Lagerstroemia reginae*	Lythraceae	India, Burma, New Guinea
199	*Lannea coromandalica*	Anacardiaceae	India, Sri Lanka
200	*Lantana camara*	Verbenaceae	Introduced from Tropical America
201	*Leea indica*	Leeaceae	India, China to Australia
202	*Leea* sp.	Leeaceae	
203	*Lindernia* sp.	Scrophulariaceae	
204	*Litsea foribunda*	Lauraceae	Western Ghats
205	*Litsea* sp.	Lauraceae	
206	*Lophopetalum wightianum*	Celastraceae	Indomalaysia
207	*Ludwigia perennis*	Onagraceae	East Africa, Iran, Indomalaysia
208	*Ludwigia* sp.	Onagraceae	
209	*Macaranga peltata*	Euphorbiaceae	Peninsular India, Sri Lanka
210	*Madhuca longifolia var. longifolia*	Sapotaceae	India, Myanmar
211	*Madhuca neriifolia*	Sapotaceae	India, Sri Lanka

212	*Mallotus philippensis*	Euphorbiaceae	China, Indomalaysia to Australia
213	*Mallotus* sp.	Euphorbiaceae	
214	*Mangifera indica*	Anacardiaceae	Western Ghats
215	*Manihot glaziovii*	Euphorbiaceae	Native to Brazil
216	*Mastixia arborea ssp. arborea*	Cornaceae	Western Ghats
217	*Meiogyne pannosa*	Annonaceae	South India
218	*Melastoma malabathricum*	Melastomataceae	India
219	*Memecylon* sp.	Melastometaceae	
220	*Memecylon umbellatum*	Melastometaceae	W. Ghats, Sri Lanka
221	*Mesua ferrea*	Clusiaceae	Indomalaysia
222	*Michelia champaca*	Magnoliaceae	South and Southeast Asia
223	*Mimusops elengi*	Sapotaceae	Indomalaysia
224	*Moringa pterygosperma*	Moringaceae	Tropical Asia
225	*Murdannia* sp.	Commelinaceae	
226	*Murraya koenigii*	Rutaceae	India, Sri Lanka
227	*Mussaenda bellila*	Rubiaceae	Peninsular India
228	*Myristica dactyloides*	Myristicaceae	South India, Sri Lanka
229	*Myristica fragrans*	Myristicaceae	Tropical southeast Asia, Australia
230	*Naravelia zeylanica*	Ranunculaceae	Himalayas to Sri Lanka
231	*Naregamia alata*	Meliaceae	India, Angola
232	*Neolamarckia cadamba*	Rubiaceae	India, New Guinea
233	*Nervilia prainiana*	Orchidaceae	India
234	*Nothopegia colebrookeana*	Anacardiaceae	Western Ghats
235	*Nymphea nouchali*	Nymphaeaceae	Tropics
236	*Nymphoides indicum*	Menyanthaceae	Indomalaysia
237	*Ochlandra scriptoria*	Poaceae	South W. India
238	*Oldenlandia* sp.	Rubiaceae	
239	*Olea dioica*	Oleaceae	N E India, S W India
240	*Ophiorrhiza hirsutula*	Rubiaceae	Western Ghats
241	*Palaquium ellipticum*	Sapotaceae	Western Ghats
242	*Pandanus* sp.	Pandanaceae	
243	*Paramignya monophylla*	Rutaceae	India, Burma, Sri Lanka
244	*Parthenium hysterophorus*	Asteraceae	Native to Tropical America
245	*Passiflora foetida*	Passifloraceae	Introduced from Tropical America
246	*Pavetta honenackeri*	Rubiaceae	Western Ghats
247	*Peperomia pellucida*	Piperaceae	South America
248	*Persea macrantha*	Lauraceae	South India, Sri Lanka
249	*Phoenix sylvestris*	Poaceae	Throughout India and Burma
250	*Phyllanthus fraternus*	Euphorbiaceae	Tropics except Australia
251	*Phyllanthus urinaria*	Euphorbiaceae	Tropics
252	*Piper* sp.	Piperaceae	
253	*Pistia stratiotes*	Araceae	Pantropics
254	*Pithecellobium monadelphum*	Fabaceae	South W. India, E. Himalayas
255	*Pittosporum dasycaulon*	Pittosporaceae	South W. India

256	*Polyalthia fragrans*	Annonaceae	Western Ghats
257	*Polyalthia longifolia*	Annonaceae	India, Sri Lanka
258	*Polygonum barbatum*	Polygonaceae	Paleotropics
259	*Polygonum glabrum*	Polygonaceae	Pantropics
260	*Polygonum* sp.	Polygonaceae	
261	*Pongamia pinnata*	Fabaceae	Throughout Asia
262	*Pothos scandens*	Araceae	India, Sri Lanka,
263	*Premna tomentosa*	Verbenaceae	South India, Sri Lanka
264	*Psidium guajava*	Myrtaceae	Native to Brazil
265	*Psychotria curviflora*	Rubiaceae	Western Ghats
266	*Psychotria* sp.	Rubiaceae	
267	*Psychotria truncata*	Rubiaceae	Western Ghats
268	*Pterocarpus marsupium*	Fabaceae	W. Ghats, Sri Lanka
269	*Pterospermum acerifolium*	Sterculiaceae	Indomalaysia
270	*Pterospermum diversifolium*	Sterculiaceae	W. Ghats, Java, Philippines, Malaysia
271	*Quisqualis indica*	Combretaceae	Africa to southeast Asia, Malesia, China and Taiwan
272	*Randia dumetorum*	Rubiaceae	Paleotropics
273	*Rauwolfia serpentina*	Apocynaceae	India, Sri Lanka, Java
274	*Rhaphidophora laciniata*	Araceae	South W. India, Sri Lanka
275	*Ricinus communis*	Euphorbiaceae	Indigenous to Africa, cultivated in Tropics
276	*Rubia cordifolia*	Rubiaceae	Palaeotropics
277	*Rungia pectinata*	Acanthaceae	India, Sri Lanka, Myanmar
278	*Saccharum* sp.	Poaceae	
279	*Salivinia molesta*	Saliviniaceae	Native to South America
280	*Santalum album*	Santalaceae	South India
281	*Saraca asoca*	Fabaceae	Indomalaysia
282	*Schleichera oleosa*	Sapindaceae	Indomalaysia
283	*Schumannianthus virgatus*	Marantaceae	S. India, Sri Lanka
284	*Scoparia dulcis*	Scrophulariaceae	Neotropics
285	*Semecarpus anacardium*	Anacardiaceae	S. Asia, N. Australia
286	*Sida acuta*	Malvaceae	Pantropical
287	*Sida cordifolia*	Malvaceae	Pantropical
288	*Sida rhombifolia*	Malvaceae	Indomalaysia
289	*Solanum* sp.	Solanaceae	
290	*Spathodea companulata*	Bignoniaceae	Native to West Kenya, Uganda
291	*Spermacoce articularis*	Rubiaceae	Indomalaysia
292	*Sphaeranthus indicus*	Asteraceae	Africa to Australia
293	*Spondias pinnata*	Anacardiaceae	Tropical Asia
294	*Stachytarpheta urticifolia*	Verbenaceae	Tropical America
295	*Sterculia guttata*	Sterculiaceae	W. Ghats, Sri Lanka
296	*Steriospermum personatum*	Bignoniaceae	India, Myanmar,
297	*Strychnos nuxvomica*	Loganiaceae	Peninsular India
298	*Swietenia mahogani*	Meliaceae	Neotropics

299	*Symplocos macrocarpa* ssp. *macrocarpa*	Symplocaceae	Western Ghats
300	*Symplocos racemosa*	Symplocaceae	Western Ghats
301	*Syzygium caryophyllatum*	Myrtaceae	W Ghats, Sri Lanka
302	*Syzygium cumini*	Myrtaceae	Indomalaysia
303	*Syzygium hemisphericum*	Myrtaceae	Western Ghats
304	*Syzygium jambos*	Myrtaceae	Southeast Asia
305	*Syzygium lanceolatum*	Myrtaceae	Western Ghats
306	*Syzygium* sp.	Myrtaceae	
307	*Tabernaemontana heyneana*	Apocynaceae	Western Ghats
308	*Tamarindus indica*	Fabaceae	Tropics, Native to Eastern Africa including parts of the Madagascar
309	*Tarenna* sp.	Rubiaceae	
310	*Tectona grandis*	Verbenaceae	Indomalaysia
311	*Terminalia alata*	Combretaceae	India
312	*Terminalia arjuna*	Combretaceae	India, Sri Lanka
313	*Terminalia bellerica*	Combretaceae	Indomalaysia
314	*Terminalia catappa*	Combretaceae	India or Malaya peninsula or New Guinea
315	*Terminalia paniculata*	Combretaceae	South W. India
316	*Themeda tremula*	Poaceae	S. India, Sri Lanka
317	*Themeda triandra*	Poaceae	Pantropics
318	*Thottea siliquosa*	Aristolochiaceae	W. Ghats, Sri Lanka
319	*Toddalia asiatica var. obtusifolia*	Rutaceae	South India
320	*Trema orientalis*	Ulmaceae	Indomalaysia
321	*Trewia nudiflora*	Euphorbiaceae	Indomalaysia
322	*Tridax procumbens*	Asteraceae	From S. America, now Pantropical
323	*Triumfetta rhomboidea*	Tiliaceae	Tropical Africa, Asia
324	*Typhonium* sp.	Araceae	
325	*Urena lobata*	Malvaceae	Pantropical
326	*Uvaria* sp.	Annonaceae	
327	*Vateria indica*	Dipterocarpaceae	South W. India
328	*Vepris bilocularis*	Rutaceae	Western Ghats
329	*Vernonia arborea*	Asteraceae	Paleotropics
330	*Vitex altissima*	Verbenaceae	South India
331	*Vitex leucoxylon*	Verbenaceae	South W. India, Sri Lanka
332	*Vitex negundo*	Verbenaceae	Asia
333	*Wendlandia thyrsoidea*	Rubiaceae	S. India, Sri Lanka
334	*Xylia xylocarpa*	Fabaceae	Indomalaysia
335	*Zanthoxylum rhetsa*	Rutaceae	Indomalaysia
336	*Zingiber roseum*	Zingiberaceae	Western Ghats
337	*Zizyphus oenoplia*	Rhamnaceae	Pantropics
338	*Zizyphus rugosa*	Rhamnaceae	India, Sri Lanka

2.6 **Fauna**: Kerala's fauna are notable for their diversity and high rates of endemism: 102 species of mammals (56 of which are endemic), 476 species of birds, 202 species of freshwater fishes, 169 species of reptiles (139 of them endemic), and 89 species of amphibians (86 endemic). Table 5.1 and 5.2 lists butterflies and birds noticed during the field work. Table 5.3 provides the list of fish species found in hill streams during water quality survey (during March-May 2007)

Table 5.1: Butterflies found in the riparian vegetation, Kerala State.

Family: Papilionidae

Papilionidae: Papilioninae: Troidini

Sl.No.	Species	Common Name
1	*Troides minos* Cramer	Southern Birdwing (WG)
2	*Pachliopta aristolochiae* Fabricius	Common Rose
*3	*Pachliopta hector* L.,	Crimson Rose (PI&SL)

Papilionidae: Papilioninae: Leptocircini

Sl.No.	Species	Common Name
4	*Graphium sarpedon* L.,	Common Bluebottle
5	*Graphium doson* C&R Felder	Common Jay
6	*Graphium agamemnon* L.,	Tailed Jay
7	*Graphium nomius* Esper	Spot Sword Tail
8	*Graphium antiphates* Cramer	Fivebar Swordtail

Papilionidae: Papilioninae: Papilioninii

Sl.No.	Species	Common Name
9	*Papilio clytia* L.,	Common Mime
10	*Papilio demoleus* L.,	Lime Butterfly
11	*Papilio dravidarum* Wood-Mason	Malabar Raven (WG)
12	*Papilio helenus* L.,	Red Helen
13	*Papilio polytes* L.,	Common Mormon
14	*Papilio polymnestor* Cramer	Blue Mormon (PI&SL)

Family: Pieridae

Pieridae: Coliadinae: Coliadini

Sl.No.	Species	Common Name
1	*Catopsilia pomona* Fabricius	Common Emigrant
2	*Eurema brigitta* Cramer	Small Grass Yellow

Pieridae: Pierinae: Pierini

Sl.No.	Species	Common Name
3	*Delias eucharis* Drury	Common Jezebel (PI & SL)
4	*Leptosia nina* Fabricius	Psyche
5	*Cepora nerissa* Fabricius	Common Gull
6	*Appias albina* Boisduval	Common Albatross
7	*Appias lyncida* Cramer	Chocolate Albatross
8	*Ixias pyrene* L.,	Yellow Orange Tip

Pieridae: Pierinae: Euchlocini

Sl.No.	Species	Common Name
9	*Pareronia valeria* Cramer	Common Wanderer
10	*Pareronia ceylanica* C&R Felder	Dark Wanderer (PI&SL)
11	*Hebomoea glaucippe* L.,	Great Orange Tip

Family: Nymphalidae

Nymphalidae: Satyrinae: Melanitini

Sl.No.	Species	Common Name
1	*Melanitis leda* L.,	Common Evening Brown

Nymphalidae: Satyrinae: Elymniini

Sl.No.	Species	Common Name
2	*Elymnias hypermenstra* L.,	Common Palmfly
3	*Lethe europa*	Bamboo Tree Brown
4	*Mycalesis anaxias* Hewitson	White-bar Bushbrown
5	*Mycalesis perseus* Fabricius	Common Bushbrown
6	*Mycalesis patnia* Moore	Glad-eye Bushbrown (PI&SL)
7	*Orsotrioena medus* Fabricius	The Nigger
8	*Zipoetis saitis*	Tamil Catseye (WG)

Nymphalidae: Satyrinae: Satyrini

Sl.No.	Species	Common Name
9	*Ypthima asterope* Klug	Common Three-ring
10	*Ypthima sp.*	Ring

Nymphalidae: Charaxinae: Charaxini

Sl.No.	Species	Common Name
11	*Polyura athamas* Drury	Common Nawab

Nymphalidae: Heliconiinae: Acraeini

Sl.No.	Species	Common Name
12	*Acraea violae* Fabricius	Tawny Coster

Nymphalidae: Heliconiinae: Heliconiini

Sl.No.	Species	Common Name
13	*Cethosia nietneri* C&R Felder	Tamil Lacewing (PI&SL)
14	*Vindula erota* Fabricius	Cruiser

Nymphalidae: Heliconiinae: Argynnini

Sl.No.	Species	Common Name
15	*Cupha erymanthis* Drury	Rustic
16	*Phalanta phalantha* Drury	Common Leopard
17	*Cirrochroa thais* Fabricius	Tamil Yeoman (PI&SL)

Nymphalidae: Limenitinae: Neptini

Sl.No.	Species	Common Name
18	*Neptis hylas* Moore	Common Sailer
19	*Pantoporia hordonia* Stoll	Common Lascar

Nymphalidae: Limenitinae: Limetini

Sl.No.	Species	Common Name
20	*Athyma ranga* Moore	Blackvein Sergeant
21	*Limenitis procris* Cramer	Commander

Nymphalidae: Limenitinae: Parthenini

Sl.No.	Species	Common Name
22	*Parthenos sylvia* Cramer	Clipper

Nymphalidae: Limenitinae: Euthaliinii

Sl.No.	Species	Common Name
23	*Tanaecia lepidea* Butler	Grey Count
24	*Euthalia aconthea* Cramer	Common Baron
25	*Dolpha evelina* Stoll	Red-spot Duke

Nymphalidae: Limenitinae: Biblini

Sl.No.	Species	Common Name
26	*Ariadne merione* Cramer	Common Castor

Nymphalidae: Limenitinae: Marpesiini

Sl.No.	Species	Common Name
27	*Cyrestis thyodamas*	Map

Nymphalidae: Nymphalinae: Nymphalini

Sl.No.	Species	Common Name
28	*Junonia lemonias* L.,	Lemon Pansy
29	*Junonia almana* L.,	Peacock Pansy
30	*Junonia atlites* L.,	Grey Pansy
31	*Junonia iphita* Cramer	Chocolate Pansy
32	*Cynthia cardui* L.,	Painted Lady
33	*Hypolimnas bolina* L.,	Great Eggfly
*34	*Hypolimnas misippus* L.,	Danaid Eggfly (PI&SL)
35	*Kallima horsfieldi* Kollar	South Indian Blue Oak Leaf (WG)

Nymphalidae: Danainae: Danaini

Sl.No.	Species	Common Name
36	*Parantica aglea* Stoll	Glassy Blue Tiger
37	*Tirumala limniace* Cramer	Blue Tiger
38	*Danaus chrysippus* L.,	Plain Tiger

Nymphalidae: Danainae: Euploeini

Sl.No.	Species	Common Name
39	*Euploea core* Cramer	Common Indian Crow
40	*Idea malabarica* Moore	Malabar Tree Nymph (WG)

Family: Lycaenidae

Lycaenidae: Riodininae: Riodinini

Sl.No.	Species	Common Name
1	*Abisara echerius* Stoll	Plum Judy

Lycaenidae: Polymmatinae: Polymmatini

Sl.No.	Species	Common Name
2	*Castalius rosimon* Fabricius	Common Pierrot
3	*Caleta caleta* Hewitson	Angled Pierrot
4	*Everes lacturnus* Godart	Indian Cupid

5	*Actolepis puspa* Horsfield	Common Hedge Blue
6	*Neopithecops zalmora* Butler	Quaker
7	*Pseudozizeeria maha* Kollar	Pale Grass Blue
8	*Zizula hylax* Fabricius	Tiny Grass Blue
9	*Freyeria trochylus* Freyer	Grass Jewel
10	*Lampides boeticus* L.,	Pea Blue
11	*Jamides bochus* Cramer	Dark Cerulean
12	*Jamides celeno* Cramer	Common Cerulean
13	*Nacaduba hermus*	Pale-4 line Blue
14	*Talicada nyseus* Guerin-Meneville	Red Pierrot

Lycaenidae: Theclinae: Arhopalini

Sl.No.	Species	Common Name
15	*Arhopala amantes* Hewitson	Western Centaur Oakblue
16	*Thaduka multicaudata* Moore	Many-tailed Oakblue

Lycaenidae: Theclinae: Loxurini

Sl.No.	Species	Common Name
17	*Loxura atymnus*	Yamfly

Lycaenidae: Theclinae: Horagini

Sl.No.	Species	Common Name
18	*Rathinda amor*	Monkey Puzzle

Lycaenidae: Theclinae: Hypolycaenini

Sl.No.	Species	Common Name
19	*Zeltus amasa*	Fluffy tit

Lycaenidae: Curetinae

Sl.No.	Species	Common Name
20	*Curetis thetis*	Indian Sunbeam (PI&SL)

Family: Hesperiidae

Hesperiidae: Coeliadinae

Sl.No.	Species	Common Name
1	*Hasora chromus* Cramer	Common Banded Awl

Hesperiidae: Pyrginae

Sl.No.	Species	Common Name
2	*Celaenorrhinus leucocera* Kollar	Common Spotted Flat
3	*Tagiades gana* Moore	Immaculate or Suffused Snow Flat
4	*Pseudocoladenia dan* Fabricius	Fulvous Pied Flat
5	*Odontoptilum angulatum* C&R Felder	Chestnut or Banded Angle
6	*Spialia galba* Fabricius	Indian Grizzled Skipper

Hesperiidae: Hesperiinae

Sl.No.	Species	Common Name
7	*Notocrypta paralysos* Wood-Mason & de Niceville	Common Banded Demon
8	*Notocrypta curvifascia* C & R Felder	Restricted Demon
9	*Udaspes folus* Cramer	Grass Demon
10	*Taractrocera maevius* Fabricius	Common Grass Dart
11	*Talicota colon* Fabricius	Pale Palm Dart

Note: * indicates Endangered species (Wildlife Protection Act, 1972)

WG – Western Ghats endemic

PI&SL – Endemic to Peninsular India and Sri Lanka.

Table 5.2: Birds found in the riparian vegetation, Kerala

Sl. No.	Common Name	Scientific Name	River Source
1	Ashy Swallow-Shrike	*Artamus fuscus*	Pamba river (Aratakadavu/Sabarimala)
2	Ashy Wren-Warbler	*Prinia socialis*	Vambanad Lake (Kuppapuram)
3	Asian Koel	*Eudynamys scolopacea*	Neyyar river (Neyyar dam), Karamana river (Tiruvallam, Anekkayathumoola), Achankovil river (Kallarakadavu), Changanassery canal
4	Baya Weaver	*Ploceus philippinus*	Vambanad Lake (Kuppapuram)
5	Black Bird	*Turdus merula*	Hill stream (8th Mile Munnar)
6	Black Drongo	*Dicrurus macrocercus*	Pamba river (Chenkulathakavu), Manimala river (Keecherivalkadavu), Kayamkulam Lake
7	Black-bellied Tern	*Sterna acuticauda*	Penavoorkudithodu (Kuttampuzha)
8	Black-shouldered Kite	*Elanus caeruleus*	Vambanad Lake (Kuppapuram)
9	Blue Rock Pigeon	*Columba livia*	Niramankara, Pallikkal river (Malumelkadavu), Mukkadavu, Pamba river (Athikayam)
10	Blyth's Reed Warbler	*Acrocephalus stentoreus*	Periyar Reservoir (Thekkady)
11	Brahminy Kite	*Haliastur indus*	Ithikara river (Chenkulam), Sasthmkotta Lake, Kayamkulam Lake, Malampuzha dam (Palakkad)
12	Cattle Egret	*Bubulcus ibis*	Neyyar river (Kallikadu), Sasthmkotta Lake, Kallar river (Vadaserikara), Achankovil river (Pandalam), Koodathaipuzha (Koodathai)
13	Chestnut-headed Bee-eater	*Merops leschenaulti*	Neyyar river (Kallikadu), Pamba river (Athikayam), Achankovil river (Pandalam), Manimala river (Vallamkulam)

14	Common Sandpiper	*Acitis hypoleucos*	Kayamkulam Lake
15	Common Swallow	*Hirundo rustica*	Manimala river (Vallamkulam)
16	Creasted Serpent Eagle	*Spilornis cheela*	Azhuta river (Azhuta), Muthappankolli (Muthanga Wildlife Sanctuary), Sairandri (Silent valley National Park)
17	Curlew	*Numenius arquata*	Kappkadavu beach
18	Curlew Sandpiper	*Calidris ferruginea*	Kappkadavu beach
19	Darter	*Anhinga melanogaster*	Kallada river (Pidavoor), Kumarakum wetland, Changanassery canal, Periyar reservoir (Thekkady)
20	Fairy Bluebird	*Irena puella*	Pamba river (Trivani/Sabarimala), Muthirapuzha (Munnar), Hill stream (8th Mile Munnar), Kaliyar aar (Thommankuthu falls)
21	Golden Oriole	*Oriolus oriolus*	Manimala river (Keecherivalkadavu), Bhavani river (Mukkali)
22	Greater Coucal	*Centropus sinensis*	Neyyar river (Neyyattinkara), Chaliyar river (Koolimadu)
23	Grey Heron	*Ardea cinerea*	Kayamkulam Lake
24	Grey Junglefowl	*Gallus sonneratii*	Achankovil river (Naduvathumulikadavu), Periyar reservoir (Thekkady)
25	*Grey-breasted or Jerdon's Laughingthrush	*Garrulax jerdoni*	Hill stream (8th Mile Munnar)
26	Gull-billed Tern	*Gelochelidon nilotica*	Kumarakum wetland, Confluence of Panpa & Achankovil river (Veeyapuram), Kayamkulam Lake
27	Hill Myna	*Gracula indica*	Periyar river (Vallakadavu), Sholayar river (Perumpara estate, Malakkapara)
28	Hoopoe	*Upupa epops*	Nullathanniaar (Nullathanni, Munnar)
29	House Crow	*Corvus splendens*	Neyyar river (Neyyattinkara, Kallikadu, Neyyar dam), Niramankara, Karamana river (Anekkayathumoola)
30	House Martin	*Delichon urbica*	Kallada river (Neduvennorkadavu)
31	House Swift	*Apus affinis*	Neyyar river (Kallikadu), Karamana river (Anekkayathumoola)
32	Indian Myna	*Acridotheres tristis*	Neyyar river (Neyyattinkara), Niramankara, Vamanapuram river (Avanavancheri), Ithikara river (Chenkulam), Azhuta river (Pampa valley), Manimala river (Kulathurmuzhi), Minachil river (Poovathummuddu), Periyar river (Vallakadavu, Thekkady), Nullathanniaar (Nullathanni, Munnar), Malampuzha dam (Palakkad), Muthappankolli (Muthanga Wildlife

			Sanctuary)
33	Indian Robin	*Saxicoloides fulicata*	Hill stream (8th Mile Munnar)
34	Indian Shag	*Phalacrocorax fuscicollis*	Periyar reservoir (Thekkady)
35	Indian Treepie	*Dendrocitta vagabunda*	Achankovil river (Naduvathumulikadavu), Pamba river (Athikayam), Malampuzha dam (Palakkad), Muthappankolli (Muthanga Wildlife Sanctuary)
36	Indina Peafowl	*Pavo cristatus*	Muthappankolli (Muthanga Wildlife Sanctuary)
37	Jungle Babbler	*Turdoides striatus*	Achankovil river (Naduvathumulikadavu)
38	Jungle Crow	*Corvus macrorhynchos*	Manimala river (Kulathurmuzhi)
39	Jungle Owlet	*Glaucidium radiatum*	Achankovil river (Naduvathumulikadavu)
40	Large Cormorant	*Phalacrocorax carbo*	Vambanad Lake (Kuppapuram), Periyar reservoir (Thekkady)
41	Large Pied Wagtail	*Motacilla maderaspatensis*	Mukkadavu, Pamba river (Trivani/Sabarimala)
42	Large Whistling-Duck	*Dendrocygna bicolor*	Penavoorkudithodu (Kuttampuzha)
43	Lesser Golden-backed Woodpecker	*Dinopium benghalense*	Manimala river (Vallamkulam)
44	Little Cormorant	*Phalacrocorax niger*	Pamba river (Trivani/Sabarimala), Manimala river (Vallamkulam, Kulathurmuzhi), Periyar reservoir (Thekkady), Confluence of Panpa & Achankovil river (Veeyapuram), Vambanad Lake (Kuppapuram), Confluence of Thodupuzha & Kaliyar river (Puzhakarakavu), Kcheripuzha (Cherananllur), Bharathapuzha (Naripparambu), Thamarakulam Lake
45	Little Egret	*Egretta garzetta*	Vellayani Lake, Kallada river (Neduvennorkadavu), Changanassery canal, Periyar reservoir (Thekkady), Vambanad Lake (Kuppapuram)
46	Little Grebe	*Tachybaptus ruficollis*	Periyar reservoir (Thekkady)
47	Magpie Robin	*Copsychus saularis*	Ithikara river (Chenkulam), Achankovil river (Kallarakadvu), Manimala river (Keecherivalkadavu), Nullathanniaar (Nullathanni, Munnar), Hill stream (8th Mile Munnar), Vambanad Lake (Kuppapuram)
48	Malabar Pied Hornbill	*Anthracocerous coronatus*	Periyar reservoir (Thekkady)
49	*Malabar Whistling Thrush	*Myiophonus horsfieldii*	Azhuta river (Azhuta), Muthirapuzha (Munnar), Hill stream (8th Mile Munnar), Bhavani river (Mukkali)

50	Median Egret	*Mesophoyx intermedia*	Kumarakum wetland, Periyar reservoir (Thekkady),Confluence of Panpa & Achankovil river (Veeyapuram), Kayamkulam Lake, Vambanad Lake (Kuppapuram)
51	*Nilgiri Flycatcher	*Eumyias albicaudata*	Hill stream (8th Mile Munnar)
52	Orangeheaded Ground Thrush	*Zoothera citrina cyanotus*	Muthirapuzha (Munnar), Sholayar river (Perumpara estate, Malakkapara)
53	Pariah Kite	*Milvus migrans*	Malampuzha dam (Palakkad)
54	Pied Bushchat	*Saxicola caprata*	Nullathanniaar (Nullathanni, Munnar), Hill stream (8th Mile Munnar)
55	Pied Kingfisher	*Ceryle rudis*	Kallada river (Kallummothilkadavu), Kadalundi river (Chamakayam), Chaliyar river (Nilambur)
56	Pond Heron	*Ardeola grayii*	Kallada river (Kallummothilkadavu), Pallikkal river (Malumelkadavu), Pamba river (Trivani/Sabarimala), Achankovil river (Pandalam), Changanassery canal, Periyar river (Vallakadavu), Vambanad Lake (Kuppapuram), Kcheripuzha (Cherananllur)
57	Purple Morhen	*Porphyrio porphyrio*	Kallada river (Kallummothilkadavu), Kayamkulam Lake
58	Purple Sunbird	*Nectarinia asiatica*	Thodupuzha
59	Purplerumped Sunbird	*Nectarinia zeylonica*	Neyyar river (Kallikadu), Ithikara river (Chenkulam), Kazhuthruthyaar (Kazhuthruthy), Pamba river (Athikayam), Minachil river (Poovathummuddu)
60	Racket-tailed Drongo	*Dicrurus paradiseus*	Kallana aar (Chitara estate), Bhavani river (Mukkali), Muthappankolli (Muthanga Wildlife Sanctuary)
61	Red-vented Bulbul	*Pycnonotus cafer*	Periyar river (Vallakadavu), Irritipuzha (Irriti)
62	Red-wattled Lapwing	*Vanellus indicus*	Kallada river (Pidavoor), Muthappankolli (Muthanga Wildlife Sanctuary)
63	Red-whiskered Bubul	*Pycnonotus jocosus*	Karamana river (Anekkayathumoola), Pamba river (Aratakadavu/Sabarimala), Kallar stream (Thannimoodu)
64	River Tern	*Sterna aurantia*	Kallada river (Neduvennorkadavu), Azhuta river (Pampa valley), Achankovil river (Pandalam, Kallarakadavu), Minachil river (Poovathummuddu), Vambanad Lake (Kuppapuram), Chaliyar river (Nilmbur)
65	Rose-ringed Parakeet	*Psittacula krameri*	Karamana river (Anekkayathumoola)

66	Rufous-backed Shrike	*Lanius schach*	Periyar Reservoir (Thekkady)
67	Shikra	*Accipiter badius*	Nedukani
68	Small Blue Kingfisher	*Alcedo atthis*	Kallada river (Kallummothilkadavu, Pidavoor), Pallikkal river (Malumelkadavu), Pamba river (Trivani/Sabarimala), Kallar river (Vadaserikara)
69	Small Green Bee-eater	*Merops orientalis*	Kallana aar (Chitara estate), Kallada river (Pidavoor), Achankovil river (Kallarakadvu), Kayamkulam Lake
70	Spotted Dove	*Sterptopelia chinensis*	Nullathanniaar (Nullathanni)
71	Tailor Bird	*Orthotomus sutorius*	Kallar stream (Thannimoodu), Bhavani river (Mukkali)
72	Thick-billed Flowerpecker	*Dicaeum agile*	Pamba river (Athikayam), Achankovil river (Naduvathumulikadavu)
73	Whiskered Tern	*Childonias hybridus*	Vambanad Lake (Kuppapuram)
74	White Ibis	*Threskiornis melanocephalus*	Kumarakum wetland, Kalapathipuzha (Thondikulam)
75	White-bellied Drongo	*Dicrurus caerulescens*	Kallada river (Kallummothilkadavu)
76	*White-bellied Treepie	*Dendrocitta leucogastra*	Kallana aar (Chitara estate), Valiyakulamthodu (Valiyakulam/Palappilly)
77	Whitebreasted Kingfisher	*Halycon smyrnensis*	Neyyar river (Neyyattinkara, Kallikadu), Ithikara river (Chenkulam), Kallada river (Kallummothilkadavu), Achankovil river (Pandalam), Minachil river (Poovathummuddu), Confluence of Panpa & Achankovil river (Veeyapuram), Vambanad Lake (Kuppapuram), Kadalundi river (Chamakayam), Koodathaipuzha (Koodathai), Thamarakulam Lake
78	White-breasted Waterhen	*Amaurornis phoenicurus*	Pamba river (Trivani/Sabarimala)
79	White-cheeked Barbet	*Megalaima viridis*	Karamana river (Anekkayathumoola), Vamanapuram river (Avanavancheri), Kallana aar (Chitara estate), Pamba river (Athikayam), Kallar stream (Thannimoodu), Confluence of Panpa & Achankovil river (Veeyapuram)
80	White-Eye	*Zosterops palpebrosus*	Kunthipuzha (Sairandri/Silent Valley National Park)
81	White-necked Stork	*Ciconia episcopus*	Periyar Reservoir (Thekkady)
82	Yellow Wagtail	*Motacilla flava*	Azhuta river (Pamba valley), Kallar river (Vadaserikara)
83	Yellow-browed Bulbul	*Iole indica*	Kallar stream, Periyar river (Vallakadavu), Bhavani river (Mukkali)

Note: * indicates Western Ghats endemic

Table 5.3. Fishes found in rivers and hill streams, Kerala

Sl. No.	Species Name	River Source	IUCN Status
1	*Aplocheilus lineatus*	Manjappuzha (Manjappalam), Neyyar river (Kallikadu), Vellayani Lake, Kallana aar (Tributory to Ithikara river), Pampa river (Athikayam), Achankovil river (Naduvathumulikadavu), Changanassery Canal, Cheruthoniaar	LRlc
2	**Barilius bakeri*	Penavoorkudithodu (Kuttampuzha)	LRnt
3	*Barilius bendelisis*	Sholayar river (Perumpara estate, Malakkapara)	LRnt
4	*Barilius sp.*	Kallar stream	
5	*Bhavania australis*	Kadalundi river (Manchalamchola)	LRnt
6	*Danio aequipinnatus*	Manjappuzha (Manjappalam), Theekoiaar (Adukkam), Cheruthoniaar, Thodupuzha	LRlc
7	*Danio malabaricus*	Kunthipuzha (Sairandri, Silent Valley National Park), Hill stream (Bhothokallu/Aralam)	LRlc
8	*Etroplus maculatus*	Confluence of Thodupuzha & Kaliyar river (Puzhakarakavu), Penavoorkudithodu (Kuttampuzha), Chalakudypuzha (Koodupuzha, Karuvannurpuzha), Thodupuzha, Kadamankadavu,	LRlc
9	*Etroplus suratensis*	Thommankuthu falls, Neyyar river (Kallikadu), Pamba river (Athikayam, Chenkulathakavu, Aluva)	LRlc
10	*Garra* sp.1	Hill stream (Kallar), Achankovil river (Naduvathumulikadavu), Theekoiaar (Adukkam), Thodupuzha, Penavoorkudithodu (Kuttampuzha)	
11	*Garra* sp.2	Hill stream (Moonnukalunkutodu), Hill stream (Bhothokallu/Aralam)	
12	*Garra* sp.3	Sholayar river (Perumpara estate, Malakkapara), Kadalundi river (Manchalamchola)	
13	*Glossogobius giuris giuris*	Pampa river (Chenkulathakavu), Confluence of Thodupuzha & Kaliyar river (Puzhakarakavu)	LRlc
14	*Hyporhamphus limbatus*	Minachil river (Poovathummuddu), Muvathupuzha river (Vettikattumukku),	DD
15	*Labeo rohita*	Kalapathipuzha (Thondikulam)	LRlc
16	*Mesonoemacheilus triangularis*	Hill stream (Bhothokallu/Aralam)	LR
17	*Notopterus notopterus*	Chitturpuzha (Mulethara dam, Palakkad)	LRnt
18	*Puntius ampihibius*	Neyyar river (Neyyattinkara), Kadamankadavu, Kallar stream, Ithikara river (Chenkulam), Penavoorkudithodu (Kuttampuzha),	LRlc
19	*Puntius arulius arulius*	Pookote lake & Mananthavady puzha (Wayanad)	EN
20	*Puntius conchonius*	Pamba river (Trivani/Sabarimala)	VU
21	*Puntius fasciatus fasciatus*	Kunthipuzha (Sairandri, Silent Valley National Park), Kadalundi river (Manchalamchola),	EN

		Manjappuzha (Manjappalam), Payaswinipuzha (Jalsoor), Chandragiripuzha (Panathur), Bhothokallu stream (Aralam WLS), Neyyar river (Neyyattinkara, Kallikadu), Karamana river (Anekkayathumoola), Kallar stream,Karamana river (Killiyar), Kallada river (Neduvennorkadavu), Pamba river (Trivani/Sabarimala, Chenkulathakavu), Achankovil river (Naduvathumulikadavu), Theekoiaar (Adukkam), Cheruthoniaar, Penavoorkudithodu (Kuttampuzha), Sholayar river (Perumpara estate, Malakkapara), Chalakudypuzha (Karuvannurpuzha).	
22	**Puntius filamentosus*	Kunthipuzha (Sairandri, Silent Valley National Park), Chandragiripuzha (Panathur), Pamba river (Athikayam), Achankovil river (Pandalam), Muvathupuzha river (Vettikattumukku), Theekoiaar (Adukkam), Confluence of Panpa & Achankovil river (Veeyapuram), Muvathupuzha river (Kakkad), Periyar river (Aluva), Penavoorkudithodu (Kuttampuzha).	LRlc
23	*Puntius parrah*	Penavoorkudithodu (Kuttampuzha)	EN
24	*Puntius sarana sarana*	Cheruthoniaar, Payaswinipuzha (Jalsoor)	VU
25	*Puntius sp.*	Kunthipuzha (Sairandri, Silent Valley National Park)	
26	*Puntius ticto*	Karamana river (Anekkayathumoola), Muvathupuzha river (Vettikattumukku), Chalakudypuzha (Koodupuzha)	LRlc
27	*Puntius vittatus*	Kadamankadavu	VU
28	*Rasbora daniconius*	Manjappuzha (Manjappalam), Karamana river (Anekkayathumoola), Ithikara river (Chenkulam), Pallikkal river (Malumelkadavu), Pamba river (Trivani/Sabarimala), Azhuta river (Pampa valley), Minachil river (Poovathummuddu), Theekoiaar (Adukkam), Cheruthoniaar, Thodupuzha, Confluence of Panpa & Achankovil river (Veeyapuram), Confluence of Thodupuzha & Kaliyar river (Puzhakarakavu), Penavoorkudithodu (Kuttampuzha), Chalakudypuzha (Koodupuzha).	LRnt
29	*Salmostoma boopis*	Bharathapuzha, Payaswinipuzha (Jalsoor)	LRlc
30	*Schistura denisoni denisoni*	Kallada river (Neduvennorkadavu), Pamba river (Athikayam), Theekoiaar (Adukkam)	VU
31	**Schistura nilgiriensis*	Hill stream (Bhothokallu/Aralam)	EN
32	*Schistura sp.*	Kunthipuzha (Sairandri, Silent Valley National Park)	
33	*Schistura sp.*	Kallar stream	
34	*Schistura sp.*	Sholayar river (Perumpara estate, Malakkapara)	
35	**Tetraodon*	Confluence of Panpa & Achankovil river	EN

	travancoricus	(Veeyapuram)	
36	*Tor sp.*	Kallar stream	
37	*Xenentodon cancila*	Penavoorkudithodu (Kuttampuzha), Ithikara river (Chenkulam), Confluence of Panpa & Achankovil river (Veeyapuram).	LRnt

Note: * indicates Western Ghats Endemic; EN – Endangered;VU – Vulnerable;LRnt – Lower Risk near threatened;LRlc – Lower Risk least concern;DD – Data deficient.

3.0 GROUNDWATER

In India, groundwater has played the pivotal role in fulfilling the demands of domestic, industrial and agriculture sectors. At present the groundwater in India contributes more than 58% drinking water, 52% for agriculture production and 50% for urban and industrial sectors. Indiscriminate development and unscientific management of this resource has led to multiple problems of decline in groundwater level, sea water ingress, in- land salinity, groundwater pollution, land subsidence etc. (Ramachandra, 2006b). The measures that need to be adopted in the country to meet the increased water demand in the new millennium would include exploration of deeper aquifers, groundwater recharge, development of aquifers in flood plains, direct use of saline / brackish water, conjunctive use of surface and groundwater in canal command area, creation of groundwater sanctuaries and regulation of groundwater development. During the past five decades, there has been phenomenal increase in growth of groundwater abstraction structures in India. Their number has increased from 4 million in 1951 to about 18 million in 1997-99, while in the same period irrigation potential created from Groundwater has increased from 6 to 30 million hectares.

The word groundwater should be considered as a complex medium composed of ground and water. While both the components are complimentary and interactive they influence in the resulting characteristics of groundwater. Groundwater is an increasingly important resource all over the world. The term groundwater is usually reserved for the subsurface water that occurs beneath the water-table in soils and geologic formation that are fully saturated. Geo-chemically, groundwater is aqueous solution of bicarbonates, chlorides and sulphates of alkaline earth and alkali metals. It supports drinking water supply; livestock needs irrigation, industrial and many commercial activities. While the degree of reliance on groundwater varies significantly, the need of groundwater as a dependable resource of fresh water has been unquestionable. In the overall geo-strategic scenario groundwater has also offered a medium for many environmental solutions. It is key to under standing a wide variety of geologic processes for e.g. the generation of earthquakes, the migration and accumulation of petroleum and the genesis of certain type of ore deposits, soil type and land forms.

Apart from the use of groundwater, which require specific characteristics, the role of groundwater chemistry is important in determining suitability of well.

The chemistry of groundwater has an unusual characteristics in terms of its ability to dissolve a greater range of substances than any other liquid by virtue of its occurrence in different environmental conditions controlled by specific pressure and temperature different from on-land conditions. Chemical process in groundwater zone can influence the strength of geologic materials and in situations where they are not recognized, can cause failure of artificial slopes, dams, mining excavations etc. Geologically 88% of the State is underlain by crystalline rocks of Archaean age comprising schistose formations, charnockites, khondalites and gneisses. All these formations are intruded by dykes of younger age. The sedimentary formations of Tertiary age occurring along the western parts of the State comprise four distinct beds viz. Alleppey, Vaikom, Quilon and Warkali. The crystalline and the Tertiary formations are lateritised along the midland area. Alluvial deposits of recent origin are seen along the coastal plains. The general stratigraphic sequence is given in Table 6.

Table 6: The general stratigraphic sequence of Kerala State

AGE	FORMATION	LITHOLOGY
Recent	Alluvium	Sand, Clay, riverine alluvium etc.
Sub-Recent	Laterite	Derived from crystallines and sedimentaries
Tertiary	Warkali Quilon Vaikom Alleppey	Sand stone, clays with lignite Lime stone, marl and clay Sandstone with pebbles, clay and lignite Carbonaceous clay and fine sand
Undated	Intrusives	Dolerite, Gabbro, Granites, Quartzofeldspathic Veins
Archaean	Wayanad group Charnockites Khondalites	Granitic gneiss, Schists etc. Charnockites and associated rocks Khondalite suite of rocks and its associates

Ground water occurs under phreatic, semi-confined and confined conditions in the above formations. The weathered crystallines, laterites and the alluvial formations form the major phreatic aquifers, whereas the deep fractures in the crystallines and the granular zones in the Tertiary sedimentary formations form the potential confined to semi-confined aquifers.

Different Geological forms and ground water of Kerala

<u>The Crystalline aquifers:</u> The shallow aquifers of the crystalline rocks are made up of the highly decomposed weathered zone or partly weathered and fractured rock. Thick weathered zone is seen along the midland area either beneath the laterites or exposed. In the hill ranges, thin weathered zone is seen along topographic lows, area with lesser elevation and gentle slope. In areas along the hill ranges generally rock exposures are seen. The depth to water level in this aquifer varies from 2 to 16 metres below ground level (mbgl) and the yield of the well ranges between 2 to 10 m^3 per day. The exploratory drilling carried out by Central Ground Water Board in the State in the crystalline formations has indicated that the potential fractures are encountered at depths ranging between 60 to 175 mbgl. With yield varying from less than 1 to as much as 35 litres per second (lps). In Charnockites, more than 40% of the wells have yielded more than 10 lps or above.

<u>The Tertiary aquifers:</u> Ground water occurs under phreatic condition in the shallow zone and under semi-confined to confined conditions in the deeper aquifers. The Tertiary formation of Kerala coast is divided into four distinct beds viz. Alleppey, Vaikom, Quilon and Warkali. These formations except the Alleppey beds are seen as outcrops and lateritised wherever they are exposed. The maximum thickness of Tertiary sediments is found between Karunagapally and Kattoor and all the four beds are encountered in this area. Ground water is commonly developed through dug wells tapping the sandy zones at shallow depth in the Tertiary sediments. The depth to water level in this shallow zone ranges from 3.0 to 27 mbgl and the yield of the well ranges from 500 lpd to 10 m^3 per day.

The Vaikom and Warkali beds form the most potential aquifers in the Tertiary group. The Alleppey beds have been encountered at deeper levels in the bore holes drilled in the coastal tract of Alleppey district and the formation water is found to be saline and hence, no tube well has been constructed by tapping this formation. In the Vaikom aquifers, the piezometeric level is between 2 m and 20 m above msl. The yield of the tube wells constructed in this formations ranges from 1 to 57 lps. This bed forms 'auto flow' zones along the coast between Karunagapally in Quilon district and Nattika in Trichur district.

Warkali aquifers are the most developed aquifer system among the Tertiary group. The urban and rural water supply in the coastal area between Quilon and Shertalai is mostly dependent on this. The piezometric head is about 3 m. above msl along the eastern part of the sedimentary basin whereas it is 10 m. below msl in and around Alleppey. The yield of the wells tapping this formation ranges from 3 to 14 lps. The hydrogeological information on the Quilon beds is very limited. The formation is considered to be a poor aquifer compared to Vaikom and Warkali beds.

Laterites: Laterites are the most widely distributed lithological unit in the State and the thickness of this formation varies from a few meters to about 30m. The depth to water level in the formation ranges from less than a meter to 25 mbgl. Laterite forms potential aquifers along valleys and can sustain medium duty irrigation wells with the yields in the range of 0.5 - 6 m^3 per day. The occurrence and movement of ground water in the laterites are mainly controlled by the topography. Laterite is a highly porous rock formation, which can form potential aquifers along topographic lows. However, due to this same porous nature, groundwater is drained from elevated places and slopes at shortest duration after monsoon due to which scarcity is experienced in the elevated places and slopes. This is the most extensive hydrogeologic unit in the State. The thickness varies generally from less than a meter to above 20m and thicker zones are seen along Malappuram and other northern districts.

Alluvium: The alluvium forms potential aquifer along the coastal plains and ground water occurs under phreatic and semi-confined conditions in this aquifer. The thickness of this formation varies from few meters to above 100 m. and the depth to water level ranges from less than a meter to 6 mbgl. Filter point wells are feasible wherever the saturated thickness exceeds 5 m. This potential aquifer is extensively developed by dug wells and filter point wells throughout the state and the yield ranges from 5 to 35 m^3 per day.

In the state groundwater occurs in all the geological formations from Archaean crystalline to recent alluvium. Groundwater occurs in phreatic condition in the laterite, alluvium and in weathered crystallines. It is in semi-confined to confined condition in the deeper fractured rocks. However, in the eastern part of Palghat District (study area), both the phreatic and deeper aquifers tap only the crystallines. The phreatic zone comprises weathered to partly weathered crystallines, and the deeper aquifer is formed by the fractured crystallines. laterization is limited and alluvium is restricted to river beds and no dug well taps these zones. Moreover, this area has been subjected to a high degree of deformation, which has given rise to network/intersection fractures; this can be traced surficially. This intersecting nature of lineaments suggests that the water-yielding zones for phreatic and deeper aquifers are interconnected in hydraulic continuity. Thus the mechanism of fluoride release for both the aquifers is the same since the aquifer is one and the same, i.e. country rock, hornblende biotite gneiss. In this area the depth of the well ranges from 6 to 18 mbgl. The diameter ranges from 1 to 5 m and water level ranges from 3 to 15.0 mbgl.

4.0 TAP WATER

Drinking water system in Kerala can be broadly classified into two categories. The first one is the schemes owned and operated by the state government through the Kerala Water Authority and local governments. Second one is family managed drinking water supply which includes individual families creating their own drinking water resources by constructing wells on their house compounds and managing the water supply source by themselves (SEUF 2000). Family managed drinking water supply system in Kerala has a substantial role in the water supply scenario especially in rural areas. The provision of piped water supply in rural areas is the responsibility of the state government and funds have been provided in the state budgets right from the commencement of first five year plan. National Water Supply and Sanitation programme was introduced in social welfare sector in 1954. The states gradually build up the Public Health Engineering Departments to address the problems of water supply and sanitation. In 1972 - 73, Government of India introduced Accelerated Rural Water Supply Programme to assist the states and union territories with 100 percent grants in aid to implement schemes in problem villages. As a part of it, in 1970s, more than 450 piped rural systems were launched in Kerala. During 1980s, as part of the drinking Water supply and Sanitation Decade Programme, several projects were launched with the support of bilateral and multilateral agencies. The history of organized piped water supply in rural Kerala dates back to the beginning of twentieth century. Over the years, the organisational set up for the implementation and management of water supply schemes had undergone several changes. Kerala Water Authority (KWA) came into existence on 1st April 1984 in the place of the erstwhile Public Health Engineering Department of the Government of Kerala.

Kerala Water Authority (KWA) is one of the main agencies for the design, construction, operation and maintenance of water supply and sewerage schemes in the whole state. KWA has been implementing piped water supply schemes based on surface and groundwater sources. It also executes multilateral and bilateral funded projects and accelerated rural water supply schemes on behalf of the government of India. As per Economic Review, 2003 KWA was operating 63 urban and 1700 rural water supply schemes. Among the rural water supply schemes, 607 were multi-panchayat and 1093 were single panchayat schemes. Two hundred and twenty four urban and rural water supply schemes were under different stages of implementation, of these, 182 were rural and 42 were urban water supply schemes (State Planning Board 2002).

The public sector experience over the last two decades revealed that the efforts of one agency alone would not be sufficient to meet the drinking water needs of the state especially in the rural areas within a definite time-frame. The new democratic initiatives in the state, 'peoples plan campaign' along with the constitution's 73rd and 74th Amendments provided a firm footing for the decentralized planning process in the state. The State government devolved powers to local governments to initiate new water supply schemes. Following the structural adjustment programme in the national economy and implementation of neo liberal policies, public investment in necessary services has declined. The new policy approach comprises decentralized administration and collaboration between state, NGOs and Civil Society movements provided far reaching consequences in the state regulated economic approaches. As part of these initiatives Kerala Rural Water Supply and sanitation Agency, NGOs, Community organizations, etc., have subsequently entered into the water and sanitation sector.

A survey conducted by Rajiv Gandhi National Drinking Water Mission revealed that in Kerala, out of 9763 drinking water habitats, 21.5 per cent have been fully covered with piped water and 70.5 per cent are partially covered by January 2003. 8.01 per cent habitats are Non-covered. In Kerala piped water is provided to 204 lakh people, who constitute around 64 per cent of the total population as on July 2003. It shows that 59 per cent of the rural population and 79 per cent of the urban population are covered under the piped drinking water. Among the water supply connections in Kerala domestic users are more compared to non-domestic and industrial users. NSSO report on Drinking water (1999) shows that population covered under piped water supply is merely 11.5 per cent, which is much lower than the Kerala water authority estimates. If tap, tube well and hand pumps are considered as the only potable source, following the norms of government of India, drinking water coverage in Kerala is very inadequate.

NSSO report shows that the position of Kerala is far below than the other Indian states in the case of piped water supply. Percentage of the household having sufficient drinking water throughout the year is also low in Kerala compared to all India and other major Indian states. If sufficiency of drinking water throughout the year also takes into consideration, the coverage of piped water supply in Kerala is merely 8.78 per cent. But, a majority of the household in Kerala traditionally depended on open wells for their household water supply needs. NSS data show that, over 85 percent of the households in Kerala depended on well water for their domestic needs. However, among the people depending on well as principal source nearly 59 per cent are getting sufficient water through out the year. It is in Kerala highest percentage (30.4) of household reported for insufficiency of drinking water in some part of the year. These 30.4 percent households had to find alternative sources of water supply for their domestic water needs. This seasonality in water availability was an important dimension of water supply problem in Kerala. Besides, among the dependants of well around 51 percent households were obtaining water at their household premises. Hence, people were forced to spend considerable time in fetching water.

Wastage of water produced and distributed by Kerala water authority ranges around 40 percent. The quantity of water produced and water sold in rural and urban area and per capita supply of piped water is given in Table 7. CAS study (2000) revealed that wastage in water production was very high in Kerala compared to other cities.

Table 7: Production and distribution of water by Kerala water authority in 2001

	Quantity of water produced (million liter per year)	Quantity of water sold (million liter per year)
Urban	1,45,080	86,509
Rural	2,43534	1,46731
Total	3,88,614	2,33,240

Source: Crisil Advisory Service 2002

Alternative forms of water supply schemes existing in the state were community managed. Community management in drinking water supply recently emerged as an alternative to the prevailing institutional set up. All the community managed schemes in the state are funded by either central government or external agencies. External agencies include World Bank and Royal Netherlands Embassy. Jalanidhi is the community water supply schemes initiated in the state with the help of World Bank. In 1999, for implementing the World Bank assisted Rural Water Supply project, the Government has set up the Kerala Rural Water & Sanitation Agency (KRWSA). As per data collected on 2004, KRWSA covered 80 panchayats in the four northern contiguous districts of Kozhikode, Malappuram, Thrissur and Palakkad. The project is covering the areas drained by the Bharathapuzha and the following smaller basins: Chaliyar, Kadalundi, Keecheri, Puzhakkal, Kuttiadi, Korapuzha, Kallai, Tirur and Karuvannur. The main feature of 17 the World Bank assisted program is that the community meets a part of the project cost, implements the project and becomes the owner of the water supply scheme.

5.0 LITERATURE REVIEW

The lakes are either freshwater or marine, major lakes found in the Kerala are, Vambanad, Ashtamudi, Vellayani Sasthamkotta and Pookot lake. Among the fresh water lakes of Kerala, Pookot lake is the one which has been well studied, The water quality characteristics of Pookot lake is optimum for a productive lake, which is being used for fish culture and recreational purposes The physico-chemical parameters are within the standards recommended for domestic use. Electrical conductivity was found to be in the range26.7-63.1 micromhos/cm. Total hardness varied between 12 mg/L and 33.3 mg/L. Nitrate and nitrite varies in the range 0.01mg/l-0.5mg/L and 0.001-0.004 mg/L. Seasonal variations of trace metals like aluminum, magnesium, calcium, potassium, sodium, iron and copper showed that their levels are below the permissible limit for potable and agricultural waters (CWRDM Report 1988).

Meteorological, physical and chemical parameters of Vellayani Lake, Kerala, India, have been analysed for twelve months (August 1980 to July 1981), the topography of the lake is described, and correlation coefficients were calculated between meteorological and hydrographical parameters. The results indicate that the lake can be converted into a productive aquafarm by means of slight manuring (Jayachandran and Joseph, 2007). Hydrographical features and prawn fauna of the Veli-Aukulam Lake. The ranges of various hydrographical features recorded were: Water temperature -27.25 degree (January and July) to 32.10 degree C (April) oxygen content -4.0 (September) to 7.49 mg/l (October); pH - 6.68 (January) to 7.98 (October); Salinity - 0.18 (August) to 4.37% (September); Phosphate phosphorus -2.95 (October) to 8.45 mu g at./l (August); Silicate silicon - 12.2 (September) to 19.65 mu g at./l (February); Nitriate nitrogen - 0.71 (February) to 20.60 mu g at./l (November); Nitrite nitrogen - 0.45 (March) to 5.55 mu g at./l (June). The prawn fauna recorded were *Macrobrachium idella idella*; *M. idae*; *M. equidens*; *M. scabriculum*; *M. veliense* (Jayachandran and Joseph, 1985), *M. josephi* (Jayachandran, 1989); *Palaemon concinnus* (Dana, 1852); *Penaeus indicus* (H. Milne Edwards, 1837); *Metapenaeus affinis*; *M. dobsoni*.

Prakasam, V.R and Joseph, M.L., (2000) studied the water characteristics of Sasthamcotta Lake, Kerala on the basis of primary productivity. The lake water was clear, soft and acidic. All the physico-chemical characteristics were stable throughout the period of study. The primary productivity of the lake was quite low and it is classified as oligotrophic type. The effects of soap-detergent-fertilizer discharges, as revealed by indicator parameters, were not at dangerous levels. Microbial analysis of fecal coliforms indicated that the water was contaminated with human excreta.

Soman, K and Chattopadhyay, M., (2004) studied catchment characteristics, physical setting including elucidation of geology and geomorphology, landuse, landuse change, water budgeting in GIS environment and water quality the two south Kerala freshwater lakes, namely, Sasthamkotta and Vellayani. Sasthamkotta lake has a projected storage capacity of 30 MCM water at +4 m level, whereas in the case of the Vellayani lake, the maximum possible storage capacity would be just over 5 MCM at a bund height of +1.65 to 1.70 m. Temporal analysis of landuse indicate that changes in landuse pattern in the peripheral areas of the lakes have been enormous over the years. Preservation of adjacent wetlands has been suggested to enhance infiltration into the lakes. Slope protection measures have been suggested to avoid siltation of the lakes, which will be conducive to maintain sustained storage capacity of the lakes.

Devi, et al., 1996, studied the Ashtamudi Estuary. Siltation and decay of organic wastes were the major causes for loss of depth and the decline in transparency values. Lower DO and pH values suggested the extent of pollution contributed by the industrial establishments located on the bank of the estuary. The study highlights the impact of human intervention which has resulted in the deterioration of water quality and the inhibition of various estuarine processes.

Gopakumar., et al., 2007, assess the flood storage capacity of the Vembanad wetland using GIS. Hydrologic analysis indicates that the flooding in the wetland area result from extensive storms covering the associated river basins. Since the water level in the Vembanad Lake is determined by the river flows and tidal conditions downstream, storage effects are also important in the formation of extreme floods in the wetlands. At the same time, the flood storage capacity of the wetland is closely related to the land use pattern.

Water quality status of the rivers of Kerala: The analyses of the Mavattnpuzha river water samples from upstream indicated that the river is very clean with values of pH 6 5-6.7; suspended solid 6-9 4mg/l; BOD within lmg/1, COD 4.1-4,7mg/l; colour 15-19 FT-Co units; chlorides 4.5 - 4.7 mg/1 ; sodium 3,91-4 14aig/l and SAR 0..39-0.52. At the downstream of the effluent discharge point, the increase in the concentration of solids, BQD,COD are reported. BOD is reported to have increased to 4.6-6..3mg/l, CQD to 17-20 mg/1 At the upstream station the coliform count varies from 700-1205 MPN/l00 ml, In the downstream me density of coliform is reported to vary from 517 to 1825 MPN/ 100ml indicating the impact of sewage discharge on the left bank of the river.

In Chlthrapodia river, the concentrations of TDS, Chloide, nitrate, sulphate, fluoride, calcium and lead were found to be high. Presence of heavy metals such as copper, Zinc, nickel, iron, manganese and chromium were detected in the water samples. The residual analysis of animal and plant tissues showed lead concentration as high as 68 mg/kg and 76.4 mg/kg in fish and prawn tissues respectively (CWRDM Report 1997).

The water quality of river Bharatapuzha indicated the presence of mineral oil and a high concentration iron (0.69mg/T) in the water samples. Organo chlorine pesticides like hexachlorohexane (14 ng/1) was also detected in the water samples collected.

Maya, et al., (2007) addresses the water quality and nutrient flux of two tropical rivers and discusses the impact of urbanization and industrialization on Periyar and Chalakudy river-water quality. Nutrients in the two rivers reveal marked seasonal and regional concentration variations. The Periyar river shows higher average concentrations of dissolved inorganic nitrogen (DIN) (monsoon 801 g/l and non-monsoon 292 g/l) than Chalakudy river (monsoon 478 g/l and non-monsoon 130 g/l). Dissolved inorganic phosphorus (DIP) has lower average values in the monsoon season (Periyar River, 38 g/l; Chalakudy River, 42 g/l) than dissolved organic phosphorus (DOP) values (Periyar River, 107 g/l; Chalakudy, 62 g/l). The discharge of dissolved silicon (DSi), into the Periyar river (40 193 t/y) is nearly five times higher than that in the Chalakudy river (8275 t y-1). The discharges of dissolved Fe (DFe) through the Periyar and Chalakudy rivers are 257 t/y and 36.7 t/y, respectively.

Sahib, 2004 studied the physicochemical characteristics of the water and phytoplankton in the Kallada River. Out of the 35 species of phytoplankton recorded, Chlorophyceae represented the bulk of the phytoplankton throughout the entire study period. Results indicate decrease in dissolved oxygen and increase in CO_2 during rainy season due to the retarded photosynthetic activity of the phytoplankton or to decreased concentration of oxygen being consumed by the organic matter in turbid state of water during low phytoplankton density.

Nair, N.B, et al., 1989, investigations in the Neyyar river, Kerala, India show that riparian vegetation along the stream side in the watersheds from the headwater has much impact on the channel structure such as shading, retention of allochthonous organic matter etc., and the changes in the biological analogue with regard to the organic substance are evident in the stream river network.

The water quality survey of Punnurpuzha-a river situated near Kozhikode revealed that the water of the river is rather soft and is suitable for all the three major uses-drinking, irrigation, and industry. The total dissolved solid, hardness, and bicarbonate contents of the river water go up during the post-monsoon months (Abbasi, et al., 1996). Water quality of forty two randomly selected open wells along Malappuram Coast (Kozhikode, India) reveal that portability of the majority of the wells (90.6%) is below permissible levels as per the ICMR and WHO standards (Abbasi and Nipaney, 1995).

The south central parts of Kerala State exhibit changes in land use from agriculture fields (1974-75) to built-up environment. Flood water transports alluvial sediments and nourishes soil fertility. During summer the acidity of the soil is neutralized by saline water intrusions. Certain recently introduced environmental modifications to control flood water and to regulate salt water entry, with a view to increasing rice production, have largely resulted in deteriorating ecological balance. The consequent results are analysed in the light of irrational water resource management having irrevocable effects on life, life-supporting systems and development of the region. The present status of the above areas calls for greater caution and well planned programs in handling water conservation projects and praticising resource management which have a close bearing on the delicate ecosystems and prevailing environment (Balchand., 1983).

Study was undertaken in the estuarine part of south-western part of Kerala which is bound by three important rivers namely Periyar in the north, Pumba in south and Muvattu puzha in the east, to evaluate the water pollution caused by existing industries in parts of Cochin (Khurshid, 1998). Chemical nature of the surface water bodies from Eloor to Cochin harbour has been made with a view to assess the extent of pollution of various trace elements. The study revealed that the concentration of trace elements around Eloor industrial belt is higher than the Vembanad Lake, which may be attributed to steady discharge of effluents in Eloor region. In most of the samples, concentration of trace elements exceeds the maximum permissible limit prescribed by W.H.O. (1984).

Chalakudy river basin in Kerala was studied (Chattopadhyay, et al., 2005) based on an analysis of 27 water samples spread over five landuse types and monitored during four seasons, substantiated linkages between landuse pattern and water quality. Change in landuse practices, particularly urbanization and intensive agriculture lead to water quality deterioration.. Samples under urban landuse showed poor water quality throughout the year. Correlation analysis of various parameters indicated seasonality in physico-chemical characteristics of river water, which was linked to fluctuations of drainage discharge and changes in landuse pattern.

Unnikrishnan, P and Nair, S. M., (2004) studied the concentrations of dissolved and particulate trace metals (Ni, Pb, Zn and Mn) and their partitioning behaviour between the dissolved and particulate phases in a typical backwater system of Kerala, the southern upstream part of Cochin

Estuarine System (South India). They have discussed spatial and temporal variations of trace metals in the dissolved and particulate phases with special reference to pH, dissolved oxygen, salinity and suspended particulate matter. The distribution and partitioning behaviour of trace metals in the water column were found influenced by the presence of a salinity barrier across the backwater system and also by the massive use of pesticides and chemical fertilizers in the vast area of agricultural land near the backwater system. Lack of proper flushing of the backwaters, which receive large amount of trace metals through the application of pesticides and agro-chemicals, due to the presence of the salinity barrier has significantly affected the water quality of the area.

Hydrogeochemistry of groundwater in upland sub-watersheds of Meenachil river, parts of Western Ghats, Kottayam, Kerala, India was used to assess the quality of groundwater for determining its suitability for drinking and agricultural purposes (Vijith, H and Satheesh, R., 2005). The study area is dominated by rocks of Archaean age, and Charnonckite is dominated over other rocks. Rubber plantation dominated over other types of the vegetation in the area. Though the study area receives heavy rainfall, it frequently faces water scarcity as well as water quality problems. Hence, a Geographical Information System (GIS) based assessment of spatiotemporal behaviour of groundwater quality has been carried out in the region. Twenty-eight water samples were collected from different wells and analysed for major chemical constituents both in monsoon and postmonsoon seasons to determine the quality variation. Physical and chemical parameters of groundwater such as pH, dissolved oxygen (DO), total hardness (TH), chloride (Cl), nitrate (NO3) and phosphate (PO4) were determined. A surface map was prepared in the Arc-GIS 8.3 (spatial analyst module) to assess the quality in terms of spatial variation, and it showed that the high and low regions of water quality varied spatially during the study period. The influence of lithology over the quality of groundwater is negligible in this region because majority of the area comes under single lithology, i.e. charnockite, and it was found that the extensive use of fertilizers and pesticides in the rubber, tea and other agricultural practices influenced the groundwater quality of the region. According to the overall assessment of the basin, all the parameters analysed are below the desirable limits of WHO and Indian standards for drinking water. Hence, considering the pH, the groundwater in the study area is not suitable for drinking but can be used for irrigation, industrial and domestic purposes. The spatial analysis of groundwater quality patterns of the study area shows seasonal fluctuations and these spatial patterns of physical and chemical constituents are useful in deciding water use strategies for various purposes.

Rahiman, et al., (2003) examined the bacteriological quality of water from wells at Ponnani, a fishermen dominated coastal region of rural Kerala, India. The quality was assessed in terms of total coliform (TC), faecal coliforms (FC), and faecal streptococci (FS). TC ranged from 0.4 to 110 mL-1, with a mean value of 39.4 mL-1. Mean values of FC and FS were 36.4 and 17.1 mL-1 respectively. FC: FS ratio revealed that most of the samples had human faecal pollution. All the strains of Escherichia coli encountered in the samples showed multiple antibiotic resistance.

5.1 Need for the Study

The rivers of Kerala are monsoon-fed and fast-flowing. According to an estimate (PWD, 1974), the total runoff of the rivers of the state amounts to about 77,900 mm^3 , of which 70,200 mm^3 is from Kerala catchments and the remaining 7700 mm^3 is from Karnataka and Tamil Nadu catchments. The available per capita fresh water resource in Kerala is less than the national average; hence it's important to conserve the aquatic ecosystems of the state. Aquatic ecosystem conservation and management requires collaborated research involving natural, social, and inter-disciplinary study aimed at understanding various components, such as monitoring of water quality, biodiversity and other activities, as an indispensable tool for formulating long term conservation strategies. In order to get the current status of these threatened ecosystems a state level water quality programme was developed.

Findings of this study address a wide range of water-quality issues related to potential effects on human health and aquatic ecosystems, for example, on

i.) The quality of water in streams, public-supply and domestic wells;
ii.) The role of hydrology and contaminant transport on water quality, drinking water, and ecosystem health;
iii.) Effects of agriculture and urbanization on aquatic health, nutrient enrichment, and stream ecosystems;
iv.) Changes in selected contaminants in streams and ground water over time;

6.0 OBJECTIVES

Water quality monitoring is an important exercise, which helps in evaluating the nature and extent of pollution control required, and effectiveness of pollution control measures already in existence. It also helps in drawing the water quality trends and prioritising pollution control efforts. To ensure that the water quality is being maintained or restored at desired level. The water quality monitoring is performed with following objectives:

- To assess physcio-chemical and biological nature of water from various sources like surface water (rivers, streams, lakes, etc.), wells and taps water.
- To assess the fitness of water for drinking and other purposes
- Prioritize geographic areas, basins, and aquifers in which water resources and aquatic ecosystems are most vulnerable to

contamination and where improved treatment or management can have the greatest benefits

7.0 MATERIAL AND METHODS

7.1 Sampling Methods: Water samples from a range of sources such as surface, ground and tap were collected from the taluk head quarters of 14 districts in Kerala to study its physical, chemical and biological charactersistics. The water samples were collected in the two and half-liter polythene cans for laboratory analysis (chemical and biological). Some of the chemical parameters such as pH, Salinity, Dissolved oxygen and Nitrate and physical parameters such as Water Temperature, Total Dissolved Solids and Electrical Conductivity were analysed in the sampling spots. The methods adopted for water quality analysis are given in table 8. Details of sampling locations of surface water, wells and tap water are listed in tables 9.1, 9.2 and 9.3 respectively and presented spatially in Figure 8.

Table 8: Methods for physicochemical and biological analysis

Parameters	Methods (APHA, 1985.)
pH	Electrode Probe
Water Temperature (ºC)	
Salinity	
TDS	
EC (µS)	
DO	Azide Modification Iodometric (421 A)
Alkalinity	Acid Titrimetric (403)
Chlorides	Argentometric (407 A)
Hardness	Ethelenediaminetetraacitic acid (314 B)
Calcium Hardness	Ethelenediaminetetraacitic acid (311 C)
Magnesium Hardness	Magnesium by Calculation (318 C)

Phosphates	Stannous Chloride (424 E)
Sulphates	Turbidimetric method (426 C)
Sodium	Flame Photometric (325 B)
Potassium	Flame Photometric (322 B)
Nitrate	Electrode screening (418 B)
Fluoride	SPADNS (413 C)
Faecal Coliform Bacteria	Standard Total Coliform Multiple Tube Tests (908 A, D)

Table 9.1: Sampling Locations of Surface Water Samples (Streams, Rivers and Lakes)

Sampling Sites	Latitude	Longitude	Altitude
Achankoil River	9.17906	76.92349	24
Adukkam	9.7189	76.8278	75
Alathur	10.65322	76.54832	60
Aluva	10.1125	76.36039	6
Annakkayathumoola	8.61994	77.10592	63
Aranmula Sathrakadavu	9.32811	76.68442	17
Athikayam	9.38655	76.84254	36
Avananvancherri	8.70442	76.86275	21
Azhuta River	9.42102	76.93607	86
Azhuta River-Idukki	9.57684	76.99231	961
Bavikara-Chandragiripuzha	12.49257	75.10047	7
Bhoothokallu	11.94053	75.84644	84
Changanacherry	9.44389	76.52631	14
Chatakadavu-Mananthavadi	11.79976	75.99759	723
Chenkulam	8.87615	76.74738	4
Chenkulathukavu	9.36969	76.51566	10
Cherananllur	10.64068	76.12003	16
Cheruthoni	9.85179	76.9683	594
Edayur	10.07679	76.30839	15
Ellukachi-Karike	12.45642	75.39298	110
Ezhuvathruthy-Nariooarambu	10.82764	75.96434	3
Irriti	11.99244	75.67612	26
Jalsoor	12.57818	75.32279	66
Kakkad	9.90115	76.48202	20
Kaladi	10.16509	76.44273	8

Kalar River	9.33883	76.82664	18
Kalikadu	8.53364	77.13578	61
Kallada river	8.92718	77.06522	115
Kallana aru	8.84465	76.97749	59
Kallarakadvu	9.25813	76.78977	20
Kallummoottilkadavu	9.00173	76.61032	14
Kandiyoor	9.2572	76.53653	18
Karimbam-Taliparamba	12.04258	75.39082	13
Karuvannurpuzha	10.40987	76.20329	9
Kattupara	10.91448	76.21259	21
Kavalam-Kuttanadu	9.47625	76.45487	
Kazhuthruthy	8.97102	77.10452	177
Kochindajetty	9.17042	76.45709	0
Koodathi	11.40111	75.95237	11
Koolimadu	11.27066	75.97395	17
Kothamangalam-Kozhipalli	10.05961	76.6332	26
Kudapuzha	10.31211	76.35033	14
Kulathurmozhi	9.4557	76.71108	15
Kundamankadavu	8.50843	77.00367	11
Kuppapuram	9.5016	76.36753	
Kuttampuzha	10.15237	76.74187	49
Lekkidi-Vythri	11.52768	76.01849	771
Malampuzha	10.83515	76.68035	113
Malapuram-Chamakayam	11.04455	76.04608	29
Malumelkadavu	9.075	76.58654	9
Mananchira lake -Calicut	11.25534	75.77929	2
Manchalamchola	11.13943	76.39558	338
Manjappalam	11.45854	75.81873	29
Mannarkad-Kunthipuzha	10.98952	76.44289	54
Marakadavu	11.87042	76.18027	690
Moonnukalunkutodu	10.06532	76.80698	239
Mukkadavu	9.03853	76.92401	26
Mundakkal	8.86739	76.60349	8
Munddari	11.46651	76.22898	79
Munnar - Marayyr Rd	10.13738	77.05874	1640
Muthanga	11.67077	76.36673	849
Muthappankolli	11.63642	76.4172	944
Muthirapuzha - Munnar	10.08199	77.06228	1468
Muvathupuzha	9.98549	76.58339	9
Nallathanni	10.09509	77.03646	1536
Nedumangadu	8.60401	76.99679	48
Neyyar	8.4028	77.0887	10
Nilambur	11.28413	76.23007	20
Ottapalam	10.7689	76.37764	24
Pallipadi	10.86734	75.9958	14

Pamba-Aratukadavu	9.41586	77.06709	170
Pambala-lower Periyar	9.96042	76.95818	256
Pamba-Njunungar	9.41666	77.06711	168
Panathur	12.45922	75.34491	81
Pandalam	9.23258	76.6732	19
Pazhasii Dam	11.97866	75.60975	38
Pazhayidam	9.50592	76.77889	28
Peechi Dam	10.53091	76.36993	57
Perumpara Estate	10.28748	76.84742	816
Pidavoor	9.07869	76.85696	19
Pookod Lake	11.54076	76.08286	772
Poovathummuddu	9.63129	76.56625	14
Punnamada Lake	9.50139	76.35256	8
Puthalam	11.22541	76.05727	16
Puzhapalam - Chitturpuzha	10.68915	76.71836	106
Sabrimala-Pamba	9.41401	77.07128	170
Sairandri	11.0966	76.44605	887
Sasthamkotta Lake	9.03996	76.62919	8
Thamarakulam lake - Calicut	11.2892	75.76309	8
Thannimoodu - Kallar stream	9.82906	77.17097	837
Thirthala	10.80447	76.1276	17
Thodupuzha	9.89682	76.72219	67
Thommankuthu-Kaliyar	9.95579	76.83437	67
Tirunelli	11.91556	75.99445	980
Urukkuzhi	11.54585	75.92441	726
Vadakara-Koorangottukatavu	11.62657	75.74831	18
Valikulam-Palapilly	10.4376	76.42337	24
Vallakadavu	9.52781	77.11297	829
Veeyapuram	9.32502	76.46415	8
Vellayani	8.42576	76.99421	12
Vettikattumukku	9.80531	76.45244	12
Wadakancheery	10.66453	76.24577	29

Table 9.2: Sampling Locations of Well Water Samples

Sampling Sites	Latitude	Longitude	Altitude
Aaviyal	12.3029	75.0886	35
Adhur	12.5514	75.1833	94
Adukkam	9.71874	76.8275	69
Alathoor -WYD	11.825	76.1817	789
Alathur	10.6509	76.5481	65
Aluva	10.1069	76.3587	34
Athikayam	9.38509	76.8435	33
Attathodu East	9.40303	77.024	308
Avananvancherri	8.70404	76.8335	3
Balusserry - Vaikundam	11.4472	75.8264	14
Bengathadka	12.563	75.1655	186
Boundermukku	8.62209	77.0982	104
Bovikanam	12.5063	75.095	104
Chalakudy	10.3119	76.3497	20
Chatakadavu	11.8001	75.997	726
Chavakkad	10.582	76.0225	13
Chemnad	12.4998	75.002	12
Chenkulathukavu	9.36956	76.5148	8
Cherananllur	10.6398	76.1204	16
Chitara Estate	8.82995	76.977	150
Fort Cochin	9.96433	76.2434	16
Guruvayoor	10.5943	76.0442	15
Guruvayoor1	10.5963	76.0392	26
Hosabettu - Manjeshwar	12.725	74.8929	25
Irriti	11.9874	75.6761	47
Kaladi	10.1651	76.4425	42
Kalikulam Junction	9.68621	76.353	
Kallarakadvu	9.25893	76.7904	26
Kallely Check Post	9.20065	76.8933	49
Kallummoottilkadavu	9.00203	76.6108	11
Kalpetta - Rattakoli	11.6029	76.09	760
Kandiyoor	9.25668	76.5372	12
Kanhangad	12.3029	75.0886	35
Kannimari	10.6468	76.812	195
Kannur	11.8721	75.3765	14
Karimbam-Taliparamba	12.0462	75.3796	38
Karingalmanna	11.4014	75.9513	25
Kattachal	8.87392	76.7382	26
Kayamkulam	9.17485	76.5114	10
Kochupilammood	8.87694	76.5922	16

Kollengode	10.6129	76.7006	116
Koodungalur	10.2258	76.2032	8
Kothamangalam	10.0596	76.6332	26
Kottooli	11.2593	75.7969	11
Koyilandy	11.4547	75.6843	9
Koyilandy	11.4407	75.6942	29
Koyilandy-Kothamangalam	11.4403	75.7002	25
Kulasekaram	8.52549	77.0051	43
Kulathurmozhi	9.45532	76.7117	18
Mahe	11.7029	75.5348	20
Malappuram-Kottakunne	11.045	76.0831	115
Malumelkadavu	9.07438	76.5873	20
Manjeri	11.1239	76.1229	54
Mannarkkad	10.9886	76.4433	71
Mattancherry	9.96088	76.2492	17
Mullackal-Azhapuzha	9.49908	76.3442	5
Muvathupuzha	9.98426	76.5829	21
Nedumangadu	8.60334	76.9972	65
Neyyar Dam	8.53222	77.1484	95
Neyyathinkara	8.4028	77.0887	10
Nilambur	11.2769	76.2251	38
Old Munnar	10.0737	77.0641	1455
Onakkoor-Piravam	9.88267	76.505	64
Ottapalam	10.7629	76.4045	76
Pampa Valley	9.42206	76.9349	84
Panathur	12.4572	75.3546	102
Pandalam	9.23219	76.6745	32
Payyanoor	12.1082	75.2097	13
Payyanoor	12.1059	75.211	11
Pazhayidam	9.50385	76.7769	36
Peeramedu	9.57362	76.9937	953
Perinthalmanna	10.9663	76.2281	93
Pidavoor	9.07782	76.8575	29
Placimada	10.6453	76.8177	200
Ponnani	10.7803	75.9189	4
Poorot	12.7167	74.9006	14
Poovathummuddu	9.63196	76.5658	21
Puzhapalam	10.6885	76.7169	110
Sulthan Bathery	11.6603	76.25	915
Thalassery	11.7486	75.4873	0
Thannimoodu	9.83008	77.1111	840
Thiruvallam	8.44126	76.9557	10

Thodupuzha	9.89827	76.7161	50
Thondikulam Agraharam	10.7652	76.6398	86
Thrissur	10.5518	76.2345	7
Thuruthelpalam	9.44445	76.5273	13
Tirur	10.9085	75.9159	14
Vadakara	11.5959	75.5948	20
Vadaserikara	9.33982	76.8275	30
Vaithiri	11.5548	76.0389	730
Vallakadavu	9.52803	77.1143	830
Veeyapuram	9.32455	76.4622	8
Vettakkal Junction	9.72687	76.3006	10
Vettikattumukku	9.80562	76.452	16
Wadakancheery	10.6661	76.2544	41

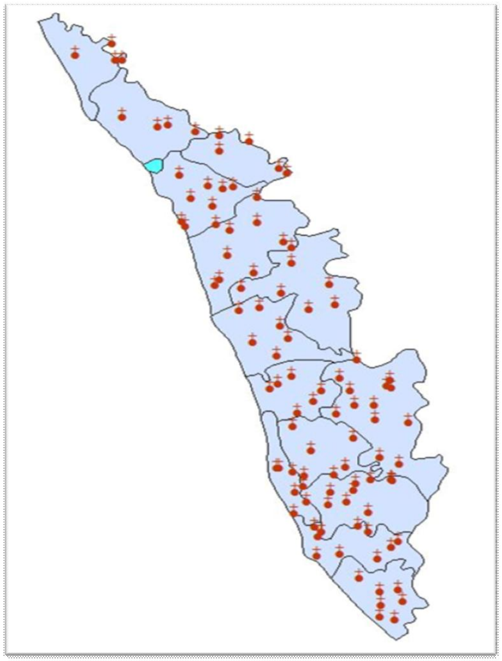
Table 9.3: Sampling Locations of Tap Water Samples

Sampling Sites	Latitude	Longitude	Altitude
Adithippuzha	9.36521	76.83722	37
Akathethara	10.81184	76.64952	91
Alathoor -WYD	11.82125	76.18068	791
Alathur	10.65086	76.54813	65
Aluva	10.10833	76.35866	18
Avananvancherri	8.70404	76.8335	3
Balusserry - Vaikundam	11.44667	75.82616	17
Boundermukku	8.62254	77.09835	80
Chalakudy	10.31211	76.35033	14
Chavakkad	10.58199	76.02254	13
Chenkulathukavu	9.36645	76.51418	4
Cherananllur	10.63976	76.12035	16
Chirakadavu	9.52936	76.78501	59
Chitara Estate	8.82877	76.9769	16
Chittur	10.69899	76.75312	133
Cholomkunnu	10.96094	76.22856	81
Fort Cochin	9.96433	76.24344	16
Guruvayoor	10.59549	76.04137	26
Irriti	11.9918	75.676	37
Kakkad	9.88463	76.48805	16
Kakki Junction	9.57814	77.09715	810
Kaladi	10.16742	76.44032	15
Kalikadu	8.53364	77.13578	61
Kalikulam Junction	9.6852	76.35192	14
Kallarakadvu	9.25923	76.79111	27
Kallely	9.20512	76.88363	50
Kallummoottilkadavu	9.00173	76.61032	14
Kalpetta - Rattakoli	11.6029	76.09004	760

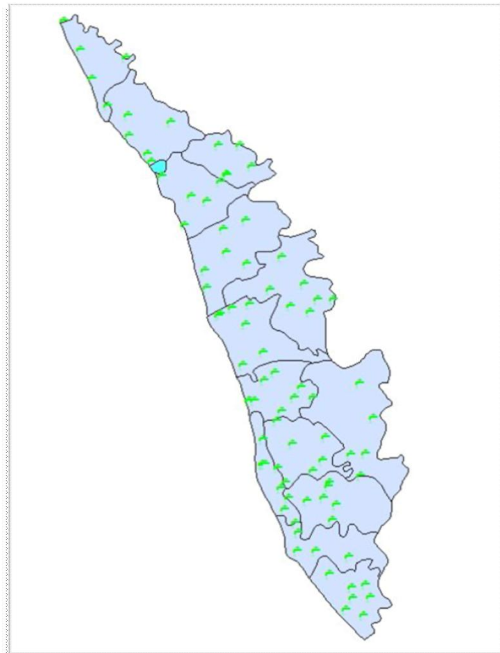
Kalpetta	11.6115	76.08286	743
Kandiyoor	9.2572	76.53653	18
Kanhangod	12.30675	75.09766	58
Kasargod	12.51618	75.01061	103
Kavalam-Kuttanadu	9.47719	76.45628	
Kayamkulam	9.17573	76.51106	9
Kilikkallungal	11.21257	76.06111	64
Kollam Beach	8.86977	76.59952	1
Kollengode-Vellanara	10.60589	76.69493	123
Kondayangadi-Mananthavadi	11.82333	76.0216	792
Koodungalur	10.22577	76.2032	8
Kothamangalam	10.05961	76.6332	26
Kulasekaram	8.52549	77.00512	43
Kulathurmozhi	9.45129	76.7122	24
Kummallor	8.87094	76.73517	36
Kuppapuram	9.49961	76.36706	
Mahe	11.69975	75.53562	36
Malappuram-Kottakunne	11.0447	76.08256	106
Malumelkadavu	9.07434	76.58594	9
Moonkilmada	10.69758	76.86153	221
Munnar Town	10.08837	77.06033	1476
Muvathupuzha	9.98725	76.57779	21
Nedumangadu	8.60334	76.99717	65
Nedumkandam	9.8374	77.15971	870
Neyyathinkara	8.4028	77.0887	10
Nilambur	11.2765	76.22709	25
Ottapalam	10.76757	76.40224	76
Pallikunnu - Kannur	11.89182	75.3692	40
Pamba-Triveni	9.41558	77.0673	168
Pandalam	9.239	76.67467	33
Parayilkaling	9.81488	76.4511	
Pathanapuram pump house	9.09568	76.85452	18
Payyanoor	12.10556	75.21015	13
Pazhavangadi Jn-Aazhapuzha	9.49845	76.34445	10
Peeramedu	9.57362	76.99367	953
Peramanur-ERKM	9.96479	76.28603	11
Perror	9.65036	76.56855	23
Pokki-Manjeshwar	12.72322	74.89179	14
Ponathur	12.45954	75.34963	114
Ponnani	10.78245	75.93809	14
Shastiparambu	9.96088	76.24923	17
South Beach - Calicut	11.2425	75.77393	0
Sultan Battery	11.66704	76.26344	915
Talipparamba	12.0374	75.36081	53
Thalassery	11.75606	75.50279	6

Thamarassery	11.41226	75.93623	49
Thathampally	9.5013	76.35223	8
Theekoy	9.69759	76.8056	69
Thenkara	11.0112	76.49055	113
Thiruvallam	8.44105	76.95443	12
Thodupuzha	9.98793	76.71574	41
Thrissur	10.5185	76.2216	45
Tirur	10.91157	75.92276	14
Vadakara	11.59655	75.60885	35
Vadaserikara	9.34019	76.82858	32
Vaithiri	11.55584	76.039	730
Veeyapuram	9.32416	76.48288	10
Wadakancheery	10.66612	76.25443	41

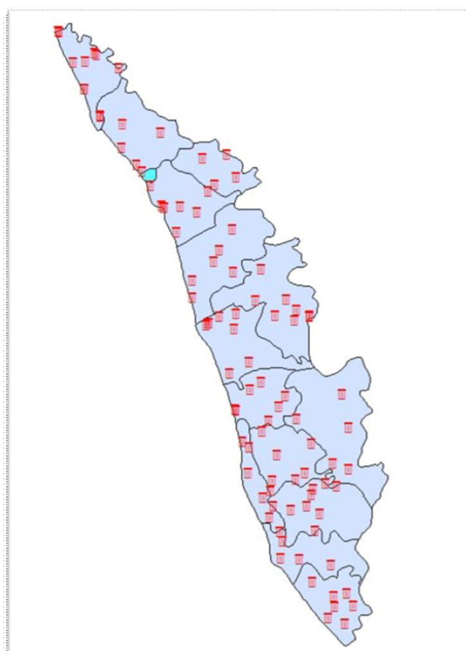
Figure 8 : Sampling locations of Surface water, Tap water and Well water



Surface water sampling locations



Tap water sampling locations



Well water sampling locations

8.0 WATER QUALITY PARAMETERS:

8.1 WATER TEMPERATURE: The water temperature parameter is important for its effects on the chemistry, and biological reactions in the organisms in water. A rise in temperature of the water leads to the speeding up of the chemical reactions in water, reduces the solubility of gases and amplifies the tastes and odours. At higher temperatures with less dissolved gases, the water becomes tasteless. At elevated temperatures metabolic activity of organism's increases, requiring more oxygen but at the same time the solubility of oxygen decreases. The disease resistance in the fishes also decreases with rise in temperature. The temperature of drinking water has an influence on its taste (Trivedy and Goel., 1984)

Procedure

Clean the pH-TDS-EC probe with distilled water and fill the container with water sample. Then check the water temperature of the sample by dipping the pH-TDS-EC probe into sample and express in degrees Celsius (°C).

8.2 CONDUCTIVITY: Conductivity is a numerical expression of the ability of an aqueous solution to carry an electrical current. This ability depends on the presence of ions, their total concentration, mobility, valence, relative concentration and on the temperature of measurement (APHA, 1985). Solution of most inorganic acids, bases and salts are relatively good conductors. Conversely molecules of organic compounds that do not dissociate in aqueous solution conduct a current very poorly, if at all. Conductivity in water is affected by the presence of inorganic dissolved solids such as chloride, nitrate, sulfate, and phosphate anions (ions that carry a negative charge) or sodium, magnesium, calcium, iron, and aluminum cations (ions that carry a positive charge). Organic compounds like oil, phenol, alcohol, and sugar do not conduct electrical current very well and therefore have a low conductivity when in water. Conductivity is also affected by temperature: the warmer the water, the higher the conductivity. For this reason, conductivity is reported as conductivity at 25° C.

Normally the physical measurement of conductivity is done through determination of resistance, measured in ohms or megohms. The resistance of a conductor is inversely proportional to its length. The magnitude of the resistance measured in an aqueous solution therefore depends on the characteristics of the conductivity cell used; it is not meaningful without this knowledge.

Using this method, a low-voltage alternating current is applied across the electrodes. The resistance of the electrodes is measured and is converted to conductivity according to the following,

$$K = L/AR$$

Where K is the conductivity, L is the distance between the electrodes (cm), A the surface area of the electrode (cm^2), and R the resistance [ohm = Siemens $(S)^{-1}$] Siemens is the S.I unit of the electrical conductivity (Roger Reeve, 2002).

The cell is calibrated by using solutions of known conductivity. Conductivity is highly temperature dependent and so care has to be taken that calibration solutions and the unknown sample are at the same temperature. A standard temperature of 25° C is often used. The relationship between conductivity and total salt content is not simple. All ions having the same charge have approximately the same conductivity, but unfortunately most environmental waters contain ions with different charges in varying concentrations.

The substance dissociates positive and negative ions and imparts conductivity in a solution. Those with poor solubility in water are called weak electrolytes and those with high solubility, the strong electrolytes. Thus higher the concentration of electrolytes in water the more is its electrical conductivity. i.e. lesser the resistance. The conductance of distilled water ranges from 1 to 5 µmho (µS).

The amount of current that can flow through a solution is proportional to the concentration of dissolved ionic species in the solution. The rough guide to the conversion between µS/cm to mg/l for natural waters is the conductivity in µS/cm is about 110-115 % of the dissolved solids in mg/l.

Conductivity in streams and rivers is affected primarily by the geology of the area through which the water flows (which is a natural process). Streams that run through areas with granite bedrock tend to have lower conductivity because granite is composed of more inert materials that do not ionize (dissolve into ionic components) when washed into the water. On the other hand, streams that run through areas with clay soils tend to have higher conductivity because of the presence of materials that ionize when washed into the water. Ground water inflows can have the same effects depending on the bedrock they flow through. (Chapman, 1996)

Procedure

Clean the pH-TDS-EC probe with distilled water and fill the container with water sample. Then the electrical conductivity of the sample is determined by dipping the conductivity probe into sample and express in µS/cm.

8.3 SOLIDS: The general term solids refer to matter is suspended (insoluble solids) or dissolved (soluble solids) in water. Solids can affect the water quality in several ways. Drinking water with high dissolved solids may not taste good and may have a laxative effect. Boiler water with high dissolved solids requires pre-treatment to prevent scale formation. Water high in suspended solids may harm aquatic life by causing abrasion damage, clogging of fish gills, harming spawning beds, and reducing photosynthesis by blocking sunlight penetration, among other consequences.

8.4 Total Dissolved Solids (Non-Filterable Solids): The substances that would pass through the filter paper but will remain as residue when the water evaporates which includes dissolved minerals and salts, humic, tannin and pyrogens. A constant level of minerals in the water is necessary for aquatic life. Changes in the amounts of dissolved solids can be harmful because the density of total dissolved solids determines the flow of water in and out of an organism's cells. Many of these dissolved solids contain chemicals, such as nitrogen, phosphorous, and sulfur, which are the building blocks of molecules for life. Concentration of total dissolved solids that are too high or too low may limit the growth and may lead to the death of many aquatic organisms. High concentrations of total dissolved solids may reduce water clarity, which contributes to a decrease in photosynthesis and lead to an increase in water temperature. Many aquatic organisms cannot survive in high temperatures (Ramteke and Moghe, 1988).

The conductivity in water is affected by the presence of inorganic dissolved solids such as chloride, nitrate, sulfate, and phosphate anions or sodium, magnesium, calcium, iron, and aluminum cations. These particles contribute the dissolved solids of the water.

Procedure

Clean the pH-TDS-EC probe with distilled water and fill the container with water sample. Then the total dissolved solids is determined by dipping the pH-TDS-EC probe into sample and express in parts per million (ppm).

8.5 pH: pH is one of the most important parameter in water chemistry and it indicates the acid/ alkaline or neutral status. pH of 7 is considered to be neutral. When the pH is less than 7, it is acidic; a pH greater than 7 is basic. A pH value between 7.0 and 8.0 are optimal for supporting diverse aquatic ecosystem. A pH range between 6.5 and 8.5 is generally suitable. Acidity or alkalinity are the acid and base neutralizing capacities of a water and usually expressed as milligrams $CaCO_3$/L. pH is given by –log[H^+], it is the intensity factor of acidity (Sorenson, 1909). At a given temperature the intensity of the acidic or basic character of a solution is indicated by pH or H^+ activity.

pH = -log[H]$^+$ As H^+ increases, pH decreases. Since pH is on a log scale based on 10, the pH changes by 1 for every power of 10 changes in [H] (APHA, 1985). Pure water is very slightly ionized and at equilibrium the ion product is

At a given temperature, pH indicates the intensity of the acidic or basic character of a solution and is controlled by the dissolved chemical compounds and biochemical processes in the solution. In unpolluted waters, pH is principally controlled by the balance between the CO_2, carbonates and bicarbonate ions as well as the other natural compounds such as humic and fulvic acids (Chapman, 1996). The level of acidity of the water is important to the plant and animal life there. Most animals are adapted to living in neutral conditions. Changes in pH endanger the lives the organisms in the water.

The level of acidity can be changed by human's actions. Acid rain, a result of air pollution and matter emitted from tailpipes and smokestacks affect the pH. When these things combine with water in the atmosphere, they form sulfuric and nitric acids, then fall to the earth as acid rain, snow, hail, and fog. This precipitation mixes with water already on the earth, in creeks, rivers and wetlands. Other pollutants carried by runoff from the land, also change the acidity of the water (Chapman, 1996).

Procedure

Clean the pH-TDS-EC probe with distilled water and fill the container with water sample. Then pH of the sample is determined by dipping the pH probe into sample.

8.6 SALINITY: Salinity is defined as the total solids in water after all carbonates have been converted to oxides, all bromide and iodide have been replaced by chloride, and all organic matter has been oxidized. It is numerically smaller than the total dissolved solids (APHA, 1985).

Procedure

Clean the pH-TDS-EC probe with distilled water and fill the container with water sample. Then determine the salinity of the sample by dipping the pH-TDS-EC probe into sample and express in parts per million (ppm).

8.7 HARDNESS: The hardness of natural water depends on the presence of calcium and magnesium salts. The total content of this hardness is total hardness or general hardness. The total hardness is further classified in to carbonate and non-carbonate hardness. Carbonate hardness determined by the concentration of the calcium and magnesium hydro carbonates and non-carbonate hardness is determined by calcium and magnesium salts of strong acids. Hydro carbonates are transformed during the boiling of water into carbonates, which usually precipitates, so the carbonates hardness is also called as temporary hardness. On the other hand the hardness remaining in the water after boiling is called constant hardness or permanent hardness (Chapman, 1996).

In total hardness the calcium hardness is usually prevalent (up to 70%) although in some cases magnesium hardness can reach up to 50-60%. Water hardness is the ability of water to precipitate soap. It is roughly measured by the amount of soap required for adequate lathering and also the rate of scale formation in the hot water boilers.

Hardness has some similarities with alkalinity. Like alkalinity, hardness is also not attributed to a single constituent, so some convention must be adopted to express hardness quantitatively as a concentration. As with alkalinity hardness is usually expressed as an equivalent concentration of CaCO3. Hardness is the property of cations (Ca^{2+} and Mg^{2+}) and alkalinity is the property of anions (HCO^{3-} AND $CO3^{2-}$) (Weiner, 2000)

Hardness is sometimes useful as an indicator proportionate the total dissolved solids, because Ca^{2+}. Mg^{2+} and HCO^{3-} often represent the larger portions of TDS. There is no report relating hardness with the human health except some inverse effect with the cardiovascular disorders. The high level of the hardness may inhibit the growth of fish, but low level of hardness increases the sensitivity of the fish towards the toxic metals, so the higher hardness is beneficial by reducing the toxicity to fish. The soft water is readily dissolvable than the hard water, so it brings metal ions from the plumbing network. Lime stones, which are percolated by rainwater, are the natural source and artificial sources such as mine discharge, industrial and domestic effluents also contribute hardness.

EDTA titrimetry for hardness

Ethylene diamine tetra acetic acid (EDTA) forms a chelated complex when it is added to a solution containing metal cations. The dye Erichrome Black-T forms a complex with cations in the solution at pH of 10.0 ± 1.0 and turns to wine red colour. When the EDTA is added as a titrant it gets complexed with the existing cations. When all the magnesium and calcium gets complexed, the indicator comes back to its original blue colour.

METAL + INDICATOR ⟶ METAL-INDICATOR COMPLEX (Wine red colour)

METAL-INDICATOR COMPLEX + EDTA ⟶ METAL-EDTA COMPLEX + INDICATOR (Blue colour)

Reagents

1. Standard EDTA indicator: (0. 01 M) Weigh 3.723 g of EDTA and dissolve in 1000 ml of distilled water and standardise against standard calcium solution.
2. EBT Indicator: The powdery form of the Erichrome Black-T can be used for this purpose.

Procedure

Select the sample volume requires less than 15 ml of EDTA titrant in a conical flask and complete titrant within 5 minutes after addition of the buffer. Take 25 ml of the sample (dilute it with distilled water if required) and add 1-2 ml of the buffer solution and 1-2 g of EBT indicator. Then titrate against the EDTA, with continuous stirring; until the last reddish tinge disappears. At the end point the solution gives blue colour.

Calculation

$$\text{Hardness (EDTA) as mg } CaCO_3/L = \frac{A*B*1000}{\text{ml of sample}} * \text{Dilution factor (If diluted)}$$

Where A= ml titrant required and B= mg $CaCO_3$ equivalent to 1 ml EDTA titrant

Degree of hardness	$Mg.CaCO_3/L$	Effects
Soft	< 75	May increase toxicity of dissolved metals. No scale deposition
Moderately hard	75-120	Not objectionable for most purposes. Requires more soap Slightly scale formation
Hard	120-200	Considerable scale formation and staining
Very hard	>200	Requires softening for household and commercial use.

8.8 CALCIUM HARDNESS: The presence of calcium (fifth most abundant) in water results from passage through or over deposits of limestone, dolomite, gypsum and such other calcium bearing rocks. Calcium is present in all waters as Ca^{2+} and is readily dissolved from rocks rich in calcium minerals, particularly as carbonates and sulphates. The salts of calcium, together with those of magnesium are responsible for hardness of water (Chapman, 1996). Calcium is an important element for all organisms and is incorporated in to the shells of many aquatic invertebrates, as well as the bones of vertebrates. Calcium concentrations in natural waters are typically <15 mg/l. For water associated with carbonate rich rocks concentrations may reach 30-100 mg/l. Salt waters have concentrations of several hundred milligrams per litre or more.

Ethylene diamine tetra acetic acid (EDTA) Titrimetric Method

The simplicity and rapidity of the EDTA titration procedure make it the method of choice for general use. When EDTA is added to water containing both calcium and magnesium, it combines first with the calcium, because during the increase of pH magnesium is largely precipitated as the hydroxide and the murexide indicator combines only with calcium.

Reagents

1. Sodium hydroxide: (NaOH) 1Normality.
2. Indicator: Murexide (Ammonium purpurate)
3. Standard EDTA indicator: (0. 01 M) Weigh 3.723 g of EDTA and dissolve in 1000 ml of distilled water and standardise against standard calcium solution.

Procedure

Sample preparation: Start titration as soon as the addition of the alkali and indicator, because high pH is required for this reaction .Use 50 ml sample or a smaller portion diluted to 50 ml, so that the calcium content is about 5-10 mg. Analyse hard waters with alkalinity higher than 300 mg $CaCO_3$/l by taking the smaller portion and diluting to 50ml, or by neutralizing the alkalinity with acid, boiling 1 min and cooling before beginning the titration.

Titration: Add 2 ml NaOH solution per volume sufficient to produce the pH 12-13. Stir well and add a pinch of indicator. Add EDTA titrant slowly with continuous stirring to the proper end point [pink to purple]. Run the blank along with the sample.

Calculation

$$\text{Calcium hardness as CaCO3} = \frac{A*B*1000}{\text{ml of sample taken}} * \text{Dilution factor (If diluted)}$$

Where A = ml titrant for sample and B = mg Caco3 equivalent to 1.0 ml EDTA titrant.

8.9 MAGNESIUM HARDNESS: Magnesium arises principally from the weathering of rocks containing Ferro magnesium minerals and from the carbonate minerals, ranking eighth in abundance among the elements. It is found in all natural waters and its source lies in rocks, generally present in lower concentration than calcium. It is also an important element contributing to hardness and an essential element for photosynthetic pigment chlorophyll. Its concentration greater than 125 mg/L can influence cathartic and diuretic actions. Magnesium hardness can be calculated from the estimated total hardness and calcium hardness.

Calculation

Magnesium = (A - B) as mg/L

where, A = Total hardness mg\L (as $CaCO_3$) and B = Calcium hardness mg\L (as $CaCO_3$)

8.10 SODIUM AND POTASSIUM: Sodium ranks sixth among the elements in order of abundance and is present in most natural waters. The high solubility of sodium confirms its presence in the all the natural water. Sodium available in Na^+ (ionic form) in plant and animal. The increased concentration of the sodium in surface water is due to industrial effluent, agricultural activities and seawater intrusion in coastal area. Sodium is commonly measured where the water is used for the drinking and agricultural purposes. The elevated sodium level in certain soil types result in the degradation of soil fertility and it also results in restriction of water movement, which leads to affects the plant growth. The high concentration of sodium in water bodies limits the biological diversity due to the osmotic pressure. Soil permeability can be harmed by high calcium ratio. (Weiner, 2000)

Potassium ranks seventh among the elements in order of abundance. Potassium (as K^+) is found in low concentrations in natural water, because the rocks containing potassium is resistance to weathering. But potassium from industrial waste and agricultural run off contributes its level in natural freshwater bodies. Potassium usually found in the ionic form and it is easily soluble. It is readily incorporated into mineral structure and accumulated by aquatic biota, as it is an essential nutritional element. The normal concentration of potassium in natural waters is usually less than 10 mg/L, whereas concentrations as high as 100-25000 mg/L can occur in hot springs and brines (Weiner, 2000).

The estimation of sodium and potassium on the emission spectroscopy deals with the excitation of electrons from ground state to higher energy state and come back to original position with emission of light. The trace amount of sodium and potassium can be determined by flame photometry method. The sample is sprayed in to a gas flame; the excitation takes place in controlled condition. The desired spectral line is isolated by appropriate silt arrangement in light dispersing device. The intensity of the light is measured by phototube potentiometer. The intensity of light at appropriate wavelength is approximately proportional to the concentration of the element.

INSTRUMENT: Systronics Flame Photometer 128 with a compressor and a gas supply.

Reagents

1. Stock sodium solution: Dissolve 2.542g of Sodium chloride of dried (at 140^o C) was in 1000ml-distilled water (1ml = 1mg of sodium).
2. Intermediate sodium solution: Dilute 10 ml of the stock sodium solution to 100 ml of water. (1 ml = 100µg Na)
3. Stock potassium solution: Dissolve1.907g of dried Potassium chloride, in 1000ml of distilled water. (1ml = 1mg of potassium)
4. Intermediate potassium solution: Dilute 10 ml of the stock potassium solution to 100 ml of water. (1 ml = 100µg K)

5. Standard sodium and potassium solution: Prepare the standard solution as per the required concentration, from intermediate solution.

Procedure

Follow the instructions given by the manufacturers of flame photometry. Start the electrical supply and compressor, stabilise the air supply to appropriate level. Switch on the gas fuel and adjust the cone-shaped blue coloured flame by aspirating distilled water. Calibrate the instrument with standard solutions and follow it with sample analysis.

Calculation

Mg/L of sodium = Test absorbance * Slope * D

$$\text{Where, Slope} = \frac{\text{Sum of concentration of standards}}{\text{Sum of absorbance of standards}}$$

Mg/L of Potassium = Test absorbance * Slope * D

$$\text{Where, Slope} = \frac{\text{Sum of concentration of Standards}}{\text{Sum of absorbance of Standards}}$$

$$\text{D = Dilution ratio} = \frac{\text{ml sample + ml distilled water}}{\text{ml sample}}$$

8.11 ALKALINITY: In natural water, that are not highly polluted alkalinity is more commonly found than acidity. Alkalinity is the good indicator of presence of dissolved inorganic carbon (Bicarbonates and carbonate anions). Some of the minor contributions to alkalinity are come from ammonia, phosphates, borates, silicates and other basic substances.

Alkalinity is beneficial to aquatic animals and plants, because it buffers the both natural and human induced pH changes. Water with high alkalinity generally has a high concentration of dissolved inorganic carbon (in the form of HCO_3^- and CO_3^{2-}), which can be converted to biomass by photosynthesis (Kegley and Andrews, 1998)

Titrating a basic water sample with acid to pH 8.3 measures phenolphthalein alkalinity. Phenolphthalein alkalinity primarily measures the amount of carbonate ion (CO_3^{2-}) present in the sample. Titrating with acid to pH 3.7

measures methyl orange alkalinity or total alkalinity. Total alkalinity measures the neutralizing effects of all the bases present.

Reagents

1. Standard sulphuric acid (0.02N): Dilute 200 ml of 0.1N H_2SO_4 with distilled water to 1000ml to obtain standard 0.02N H_2SO_4.
2. Phenolphthalein indicator: Dissolve 0.5g phenolphthalein in 1:1 95 % ethanol and distilled water. Add 0.05 N CO_2 free NaOH solution drop wise until faint pink colour appears.
3. Methyl orange indicator: Dissolve 0.5 g of methyl orange in 1000ml CO_2 free distilled water.

Procedure

Measure a suitable volume of sample in 250 ml conical flask. Add 2-3 drops of phenolphthalein indicator. If the pink colour develops titrate against 0.02 N H_2SO_4, till the colour disappears, which is the characteristic of pH 8.3.Note down the volume of H_2SO_4 consumed. Add 2-3 drops of methyl orange and continue titration with H_2SO_4 till the yellow colour changes to orange, which is the characteristic of pH 4.5. Note down the additional amount of H_2SO_4 required. In case pink colour does not appear after addition of phenolphthalein continue with addition of methyl orange.

Calculation

Calculate total phenolphthalein and methyl orange alkalinity as follows and express in mg/L as $CaCO_3$,

$$\text{P Alkalinity m mg/L as } CaCO_3 = \frac{A*1000}{\text{ml sample}}$$

$$\text{T Alkalinity m mg/L as } CaCO_3 = \frac{B*1000}{\text{ml sample}}$$

Where, A= ml of H_2SO4 required to raise pH up to 8.3
B= ml of H_2SO4 required to raise pH up to 4.5

8.12 CHLORIDES: Chloride (Cl^-) enters surface waters by the atmospheric deposition of oceanic aerosols with the weathering of some sedimentary rocks (mostly rock salt deposits), industrial effluents and agricultural run-off. High concentrations of chloride can make waters unpalatable and therefore unfit for drinking or livestock watering. Chloride is abundant anions found in the wastewater and is a good indicator of pollution sources. Chloride gives water a salty taste detectable at a level of 250 ppm with sodium as cation, but with Ca and Mg cations, the salty taste is not detectable until the chloride concentration reaches up to 1000 ppm (Weiner, 2000).

All chlorides salts are very soluble expect for chloride salts of lead ($PbCl_2$), silver ($AgCl_2$) and mercuric (Hg_2Cl_2, $HgCl_2$). Chloride is not absorbed by soils and little part moves with water and there is no retardation. Consequently, it eventually moves to closed basins (as Great salt lake in Utah) or to the ocean. (Kegley and Andrews, 1998)

Estimation of chloride by argentometric method

In a neutral or slightly alkaline solution, potassium chromate can indicate the endpoint of the silver nitrate titration of chloride. Silver chloride is quantitatively precipitated before red silver chromate is formed.

1) $Ag^{+}+Cl^{-} \longrightarrow AgCl$ (White precipitate)
2) $2Ag^{+}+CrO^{-}4 \longrightarrow AgCrO4$ (Red precipitate)

Reagents

1. Potassium chromate indicator: Add 50g K_2CrO_4 in little amount of water and dilute to 1000ml.
2. Standard Silver nitrate (0.0141N): Dilute 70.5 mL of 0.1N $AgNO_3$ in distilled water to 500ml. (1ml=0.5mg Cl=500µg Cl)
3. Standard Sodium Chloride (0.0141N): Dissolve 824.0mg NaCl (dried at 140^{o}C) and dilute to 1000ml. (1ml= 0.5mg Cl=500µg Cl)

Procedure

Use a 100ml of sample or a suitable portion diluted to 50ml. Directly titrate samples in the pH range 7-10.Adjust sample pH to 7 to 10 with H_2SO_4 or NaOH if it is not in this range. Add 10 ml of K_2CrO_4 indicator solution. Titrate with standard $AgNO_3$ titrant to a pinkish yellow colour end point. Standardize $AgNO_3$ against standard NaCl. For better accuracy titrate distilled water (50ml) in the same way to establish reagent blank.

Calculation

$$\text{Chlorides mg/L} = \frac{(A-B)*N*35.45*1000}{\text{ml sample}}$$

Where, A = ml Ag NO3 required for sample.
B = ml Ag NO3 required for blank.
N = Normality of AgNO3 used.

8.13 NITRATES: Nitrate ion (NO_3^-) is the common form of combined nitrogen found in natural waters. It may be bio chemically reduced to nitrite (NO_2^-) by denitrification processes, usually under anaerobic conditions. The nitrite ion is rapidly oxidized to nitrate. Natural sources of nitrate to surface water include igneous rocks, land drainage and plant growth and decay. The natural concentration of nitrate is 0.1mg/L; it may be enhanced by sewage, industrial effluents and nitrate fertilizers (Chapman, 1996)

Ammonia and other nitrogenous material in natural waters tend to be oxidized by aerobic bacteria first to nitrite and then nitrates. So all organic compounds containing nitrogen are potential source of nitrates. In oxygenated to nitrite (NO_2^-) is rapidly oxidized to nitrate (NO_3^-) so normally the amount of nitrite is very low. High concentrations (>1-2 mg/L) of nitrate or nitrite in surface or ground water generally indicate agricultural contamination from fertilizers and manure.

NITRIFICATION

$$\text{Ammonia} \xleftrightarrow[\text{ADB}]{\text{(O)}} \text{Nitrite} \xleftrightarrow[\text{FAB}]{\text{(R)}} \text{Nitrates}$$

ADB = Aerobic Denitrifying Bacteria. Ex: Nitrosomes
FAB = Facultative Anaerobic Denitrifying Bacteria. Ex: Pseudomonas

Estimation of nitrates by electrode screening method

Principle: The NO_3^- ions electrode is a selective sensor that develops a potential across a thin, porous, inert membrane that holds in a place a water-immiscible liquid ion exchanger. The electrode responds only to NO_3^- ion activity between about 10^{-5} and 10^{-1} M (0.14 to 1400 mg NO_3^- -N/L). The lower limit of detection is determined by the small but finite solubility of the liquid ion exchanger.

Apparatus: Nitrate ion electrode

Reagents

1. Nitrate free water: Use distilled or deionized water of highest purity to prepare all solutions and dilutions.
2. Stock nitrate solution: Dry potassium nitrate in an oven at 105°C for 24 h. dissolve 0.7218 g in water and dilute to 1000 mL. Preserve with 2 mL $CHCl_3$/L; 1.00 mL = 100 µg NO_3^- -N.

3. Standard nitrate solution: Dilute 1.0, 10 and 50 mL stock nitrate solution to 100 mL with water to obtain standard solutions of 1.0, 10 and 50 mg NO_3^- -N/L, respectively.
4. Buffer solution: Dissolve 6.66 g $Al_2(SO_4)_3.18H_2O$, 3.12 g Ag_2SO_4, 1.24 g H_3BO_3, and 1.94 g sulfamic acid (H_2NSO_3H), in about 400 mL water. Adjust to pH 3.0 by slowly adding 0.10N NaOH. Dilute to 1000 mL.
5. Sodiun hydroxide, NaOH, 0.1N.

Procedure

Prepare calibration curve by transfer 10 mL of 1 mg NO_3^- -N standard to a 50 mL beaker, add 10 mL 10 mL buffer solution, and stir for a constant time (2 or 3 min.). Immerse electrode tips and record millivolt reading after 1 min. Remove electrodes, rinse, and blot dry. Repeat for 10 mg NO_3^- -N/L and 50 mg NO_3^- -N/L standards and plot a graph.

Measurement of sample: Transfer 10 mL sample to a 50 mL beaker, add 10 mL buffer solution, and stir for a constant time (2 or 3 min.). Immerse electrode tips in sample and record potential reading after 1 min. Read concentration from calibration curve.

8.14 PHOSPHATES: Phosphates are an essential nutrient for living organisms and exist in water bodies on both forms as dissolved and particulate species. Phosphorus concentration is limiting factor for algae growth. Artificial increase in phosphorous concentration in aquatic system results in eutropication. In natural water and wastewater phosphorous occurs as orthophosphates, polyphosphates and organically bound phosphates (Chapman, 1996)

Orthophosphates applied to agricultural land as a fertilizer, it find its way to surface water by runoff. The condensed phosphate like pyrophosphates and polyphosphates are comes to environment from the heavy-duty detergents (Sodium tri polyphosphate $Na_5P_3O_{10}$). Biological processes are the only source for organic phosphates, such as weathering of rock and decomposition of organic matter.

Estimation of phosphorous by stannous chloride Method

In the acidic condition, orthophosphates reacts with ammonium molybdate to form molybdophosphoric acid. It is further reduced to intensely coloured molybdenum blue colour by adding the reducing agent stannous chloride. The intensity of the coloured complex is measured at 690nm, which is directly proportional to the concentration of phosphates present in the sample.

$$PO_4+12(NH_4)_2MoO_4+24H^+ \longrightarrow (NH_4)PO_4.12MoO_3+21NH_4^++12H_2O$$

$$(NH_4)_3PO_4.12\,MoO_3+Sn^{2+} \longrightarrow \text{Molybdenum blue} + Sn^{4+}$$

Reagents

1) Standard phosphate solution: Dissolve 219.5 mg of anhydrous KH_2PO_4 in 1000ml of water (1 ml = 0.5 mg PO_4).
2) Ammonium molybdate solution:
   a) Dissolve 25 g ammonium molybdate in 175 ml distilled water.
   b) Add cautiously 280 ml concentrated sulphuric acid to 400ml water and cool.
   Mix two solutions (a) and (b) and make up to 1000ml.
3) Stannous Chloride: Dissolve 2.5 g $SnCl_2$. 2 H_2O in the 100ml glycerol. Heat in water bath to ensure complete dissolution. Prepare stannous chloride freshly.

Procedure

Take the appropriate aliquot of sample (as per the expected concentration of phosphates) in the Nessler tube. Add 2ml of ammonium molybdate and mix well. Add 0.5 ml of stannous chloride and make up to the mark with distilled water. Prepare the blank using the distilled water instead of sample. Measure the intensity of light path at 690 nm.

Calculation

Mg/L of phosphates = Test absorbance * Slope * Dilution factor

$$\text{Where, Slope} = \frac{\text{Sum of concentration of Standards}}{\text{Sum of absorbance of Standards}}$$

$$\text{D = Dilution ratio} = \frac{\text{ml sample + ml distilled water}}{\text{ml sample}}$$

8.15 SULPHATES: Sulphate is naturally present in surface water as SO_4^{2-}. It arises from atmospheric deposition of oceanic aerosols and leaching of sulphur compounds, either sulphate minerals such as gypsum or sulphide minerals such as pyrite from sedimentary rocks. Under anaerobic condition, sulphates serve as an oxygen source for bacteria that reduce dissolved sulphate to sulphide, which is then volatilised to the atmosphere as H_2S. This process is common in anaerobic regions of wetlands and lakes fed by surface and ground waters with high sulphate levels (Chapman, 1996).

Industrial discharge and air emission of sulphur-di-oxide and sulphur-tri-oxide are the sources of sulphate in surface water. Mine drainage contributes large amount of sulphate. Sulphate concentration normally varies between 10-80 mg/L in most of the surface waters, although they may reach up to thousands of milligram per litre near industrial effluent. High sulphate content is present in well water and surface water in arid zone, because of sulphate minerals.

Estimation of sulphates by barium chloride precipitation method

Sulphate ions in the sample are precipitated as barium sulphate $BaSO_4$ in acidic media (HCl) with barium chloride. The absorption of light by this precipitated suspension is measured by spectrophotometer at 420nm.

$$Ba^{++} + SO_4^{2-} \longrightarrow BaSO_4 \text{ (White precipitate)}$$

Reagents

1) Conditioning reagent: Mix 50 ml glycerol with a solution containing 30ml concentrated hydrochloric acid, 300ml of distilled water, 100ml 95% ethyl alcohol or isopropyl alcohol and 75 g Nacl.
2) Barium chloride: Barium chloride crystals of 20-30 meshes.
3) Standard sulphate solution: Dissolve 147.9 mg anhydrous Na_2SO_4 and dilute to 1000ml. (1ml=100 mg SO_4).

Procedure

Take suitable volume of sample in nessler tube. Add 5ml of conditioning reagent and mix well. Stir the content with help of a stirrer. Add a spatula of barium chloride and continue the stirring for one or more minutes. Note down the absorbance at 420 nm after 2 minutes. Prepare the standard graph with standard sulphate solution of 0-40mg/L ranges.

Calculation

Mg/L of nitrate = Test absorbance * Slope * Dilution factor

$$\text{Where, Slope} = \frac{\text{Sum of concentration of Standards}}{\text{Sum of absorbance of Standards}}$$

$$\text{D = Dilution ratio} = \frac{\text{ml sample + ml distilled water}}{\text{ml sample}}$$

8.16 FLUORIDE: Fluoride may occur naturally in water, in rare instances the naturally occurring fluoride concentration may approach 10 mg/L; such waters should be defluoridated. Accurate determination of fluoride has increased in importance with the growth of the practice of fluoridation of water supplies as a public health measure. Maintenance of an optimal fluoride concentration is essential in maintaining effectiveness and safety of the fluoridation procedure (APHA, 1985).

Fluorides have dual significance in water supplies. High concentration causes dental fluorosis and lower concentration (<0.8 mg/L) causes dental caries. A fluoride concentration of approximately 1mg/L in drinking water is recommended. They are frequently found in certain industrial processes resulting in fluoride rich wastewaters. Significant sources of fluoride are found in coke, glass and ceramic, electronics, pesticide and fertiliser manufacturing, steel and aluminium processing and electroplating industries. It is calculated by SPADNS method (http://wgbis.ces.iisc.ernet.in/energy/monograph1/Frames.html).

Principle

The colorimetric method of estimating fluoride is based on the reaction of fluorides (HF) with zirconium SPADNS solution and the 'lake' (colour of SPADNS reagent), which is greatly influenced by the acidity of the reaction mixture. Fluoride reacts with the dye ‘lake’, dissociating (bleaching) the dye into a colourless complex anion (ZrF_6^{2-}). As the amount of fluoride increases, the colour produced becomes progressively higher or of different hue.

Apparatus required: Spectrophotometer and lab glassware.

Reagents

1. Standard fluoride solution:
    a. Stock: 221.0mg of AR grade sodium fluoride was dissolved in distilled water and made up to 1000ml to give 1ml = 100 m g of F^-
    b. Working Standard: 100ml of the stock fluoride was diluted to 1000ml to give 1ml = 10 mg of fluoride.
2. SPADNS solution: Dissolve 958 mg SPADNS, sodium 2-(parasulfophenylazo)-1,8-dihydroxy-3,6-napthalene disulfonate, also called 4,5-dihydroxy-3-(parasulfophenylazo)-2,7-napthalenedisulfonic acid trisodium salt, in distilled water and dilute to 500 mL.
3. Zirconyl-acid reagent: Dissolve 133 mg zirconyl chloride octahydrate, $ZrOCl_2.8H_2O$, in about 25 mL distilled water. Add 350 mL concentrated HCl and dilute to 500 mL with distilled water.
4. Sodium arsenite solution: Dissolve 5.0 g $NaAsO_2$ and dilute to 1 L with distilled water. (Toxic)

Procedure

Take suitable volume (50 mL) of sample in nessler tube. If the sample contains residual chlorine, remove it by adding 1 drop (0.05 mL) $NaAsO_2$ solution. Add 5ml each of SPADNS solution and Zirconyl-acid reagent mix well. Note down the absorbance at 570 nm. Prepare the standard graph with standard fluoride solution of 0 - 1.40 mg F^-/L ranges.

Calculation

When the prepared 0 mg F^-/L standard is used to set the photometer, alternatively calculate fluoride concentrations as follows:

$$mg\ F^-/L = \frac{A_0 - A_x}{A_0 - A_1}$$

Where:
A_0 = absorbance of the prepared 0 mg F^-/L standard,
A_1 = absorbance of the prepared 1.0 mg F^-/L standard, and
A_x = absorbance of the prepared sample.

8.17 Dissolved Oxygen

Oxygen is essential to all forms of aquatic life, including those organisms responsible for the self-purification processes in natural waters. DO depend upon the physical, chemical and biochemical activities in the water body. The analysis for DO is a key test in water pollution and waste treatment control. Low levels of DO frequently indicate a high concentration of decaying organic matter in the water. As bacteria digest organic matter, they use up oxygen, leaving little for the other aquatic creatures. The factors affecting the DO are (1) temperature, as temperature increases, the amount of oxygen (or any gas) dissolved in water decreases. (2) Partial pressure of O_2 in contact with water, at high altitudes, less oxygen is dissolved in water because the partial pressure of oxygen in the atmospheric is low (3) Salinity the solubility of gases O_2, CO_2 decreases with increasing salinity (Weiner, 2000).

D.O (mg/L)	Water quality
Above 8.0	Good
6.5-8.0	Slightly polluted
4.5-6.5	Moderately polluted
4.0-4.5	Heavily polluted
Below 4.0	Severely polluted

Estimation of dissolved oxygen by Winkler's iodometric method

When manganous sulphate is added to the sample containing alkaline potassium iodide, manganous hydroxide is formed, which is oxidized by the dissolved oxygen in the sample to basic manganic oxide. The basic manganic oxide liberates iodine equivalent to that of dissolved oxygen originally present in the sample. The liberated iodine is titrated with standard solution of sodium thiosulphate using starch as the indicator.

REAGENTS

Manganous sulphate solution: Dissolved 100 g of manganous sulphate in 200ml of distilled water and heated to dissolve salt and filtered after cooling.

1) Alkaline potassium iodide solution: Dissolved 100 g of KOH and 50 g of KI in 200ml of preboiled distilled water.
2) Sodium thiosulphate 0.025 N: Dilute 62.50 ml of 0.1N sodium thiosulphate in a preboiled distilled water and made up to the volume of 250ml.
3) Starch indicator solution: Dissolved 1 g of starch in 100ml of distilled water and warmed for complete dissolution.
4) Concentrated sulphuric acid.

Procedure

The sample was collected in 125ml BOD bottle carefully without allowing air bubbles. Added 1ml of manganous sulphate and 1ml of alkali iodide – azide reagent. A brown precipitate of basic manganic oxide formed was allowed to settle. Added 1ml of concentrated sulphuric acid and mixed well until the precipitate dissolved. About 25ml of the solution was taken and titrated against sodium thiosulphate until a straw yellow colour appeared. Few drops of starch indicator was added and titrated again until the blue colour disappeared (Manivasakam, 1997).

CALCULATION

$$\text{Dissolved oxygen, mg/L} = \frac{(\text{ml*N}) \text{ of sodium thiosulphate} * 8 * 1000}{V_2 \left[(V_1 - V)/V_1\right]}$$

Where,

V_1 = Volume of sample bottle

V_2 = Volume of contents titrated

V = Volume of $MnSO_4$ and KI added (2ml)

8.18 Biological Analysis

8.18.1 Faecal Coliform Bacteria: In general, coliform bacteria can be divided into a fecal and a non-fecal group. Fecal coliform bacteria occur normally in the intestines of humans and other warm-blooded animals. They are discharged in great numbers in human and animal wastes. Their absence from water is thus a good indication that the water is bacteriologically safe for human consumption.

Standard Total Coliform Multiple Tube Tests

The total coliform bacteria test includes both Escherichia and Aerobacter coliform bacteria groups. Aerobacter and some Escherichia can grow in soil. Therefore, not all coliforms found in the total coliform test come from human wastes. Escherichia coli (E. coli) apparently are all of fecal origin. The Coliform bacteria that ferment lactose with gas formation with in 48 h at 35°C (APHA, 1985)

Medium composition

Peptone, Dipotassium hydrogen phosphate, Ferric ammonium citrate, sodium thiosulphate, 1ml Teepol and 50 ml distilled water.

Procedure

The medium was taken in to three set of test tubes 10, 1.0 and 0.1 mL respectively, each set had 5 test tubes. The tubes are then sterilized and incubated at 35 ± 0.5° C for 24 to 48 hours. The water sample was added to each set of test tubes 40, 9 and 1 mL respectively. Each of which contains lactose broth or lauryl tryptose broth and an inverted tube. The tubes are then incubated at 35 ± 0.5° C and each test tube were examined for growth, gas or acidic reaction after 24 and 48 hours. Production of gas in the test tubes within 48 ± 3 h constitutes a positive reaction. The numbers of positive results for each set of proportion were noted down. Then the density of organisms were determined from the MPN index (908: V) given in the APHA standard methods.

9.0 RESULTS AND DISCUSSION:

Faecal Coliform Bacteria

Coliform bacteria include a wide range of aerobic and facultative anaerobic, Gram-negative, non-spore-forming bacilli capable of growing in the presence of relatively high concentrations of bile salts with the fermentation of lactose and production of acid or aldehyde within 24 h at 35–37 °C. *Escherichia coli* and thermotolerant coliforms are a subset of the total coliform group that can ferment lactose at higher temperatures. As part of lactose fermentation, total coliforms produce the enzyme b-galactosidase. Traditionally, coliform bacteria were regarded as belonging to the genera *Escherichia, Citrobacter, Klebsiella* and *Enterobacter*, but the group is more heterogeneous and includes a wider range of genera, such as *Serratia* and *Hafnia*. The total coliform group includes both Faecal and environmental species.

By testing for coliforms, especially the well known *E.coli*, which is a thermotolerant coliform, one can determine if the water has probably been exposed to faecal contamination; that is, whether it has come in contact with human or animal faeces. It is important to know this because many disease-causing organisms are transferred from human and animal faeces to water, from where they can be ingested by people and infect them.

Effects on Environment and Human Health

Total coliforms should be absent immediately after disinfection, and the presence of these organisms indicates inadequate treatment. The presence of total coliforms in distribution systems and stored water supplies reveal regrowth and possible biofilm formation or contamination through ingress of foreign material, including soil or plants.
Large quantities of Faecal coliform bacteria in water may indicate a higher risk of pathogens being present in the water. Some waterborne pathogenic diseases include ear infections, dysentery, typhoid fever, viral and bacterial gastroenteritis, and hepatitis A. The presence of faecal coliform tends to affect humans more than it does aquatic creatures, though not exclusively.

Remedial Measures

Faecal coliform, like other bacteria, can usually be killed by boiling water or by treating with chlorine. Washing thoroughly with soap after contact with contaminated water can also help prevent infections. Municipalities that maintain a public water supply should monitor and treat for Faecal coliforms.

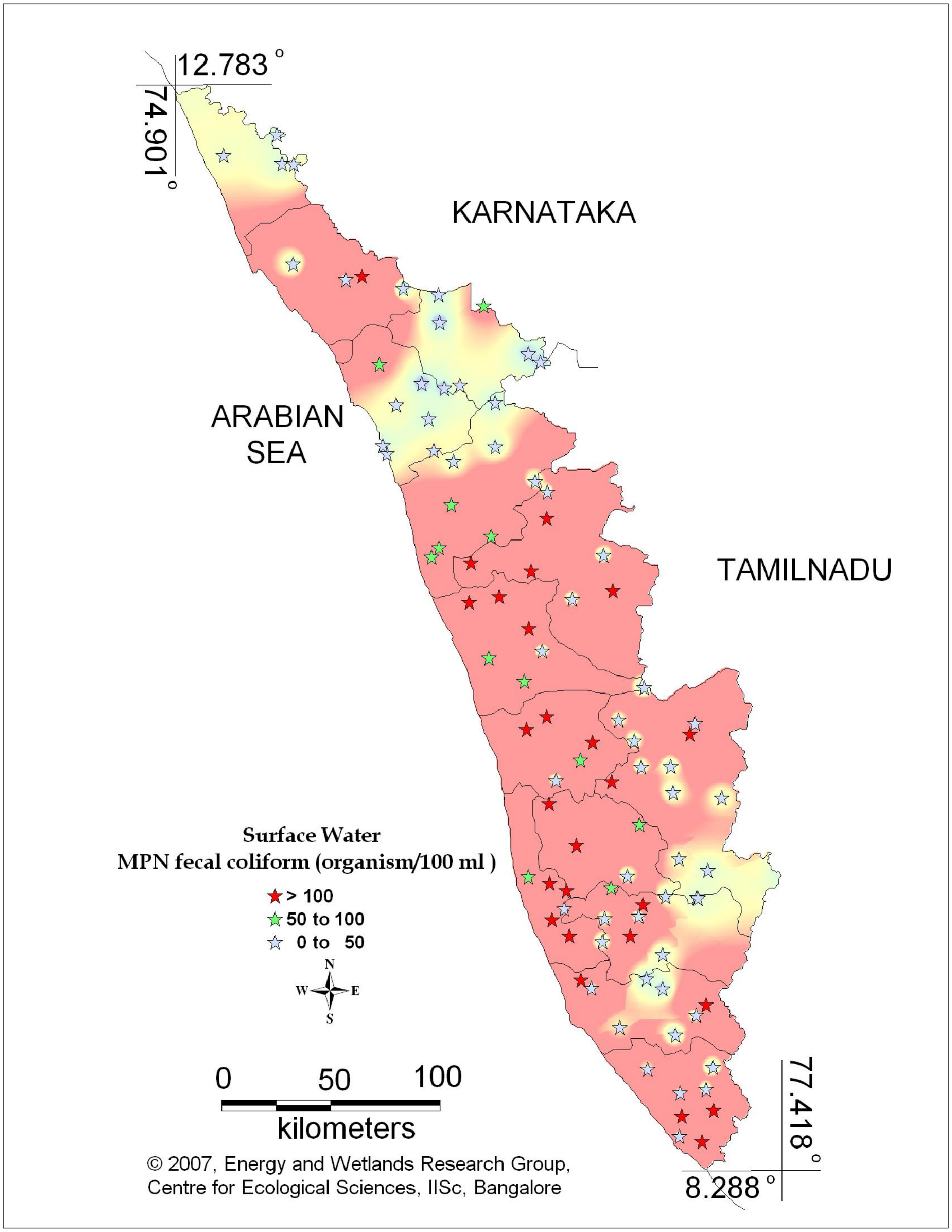


Figure 9.1: Spatial distribution of Faecal Coliform Bacteria in Kerala surface water

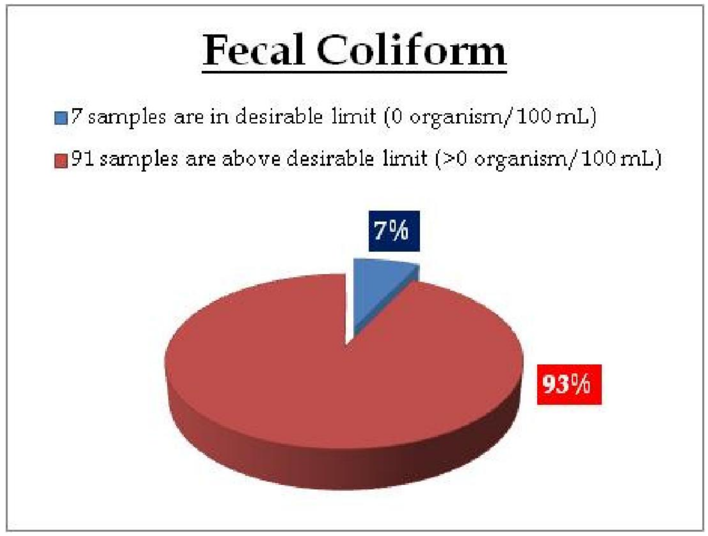
Surface water – Faecal Coliform

For water entering a distribution system

- ❖ Coliform count in any sample of 100 ml should be zero (0).

For water in a distribution system –

- ❖ *E coli* count in 100 ml of any sample must be zero (0).
- ❖ Coliform organisms should not be more than 10 per 100 ml in any sample.
- ❖ Coliform organisms should not be present in 100 ml of any two consecutive samples or more than 5% of the samples collected for the year.



Remarks

Sampling sites above desirable limit (organism/100ml) are listed ditrictwise in Table 10.1 and the same is shown spatially in Figure 9.1

Table 10.1: Locations of Faecal Coliform Bacteria above desirable limit

Location	Value	District
Kallana aru	2	Kollam
Lekkidi-Vythri	2	Wayanad
Mukkadavu	2	Kollam
Munnar (8th mile)	2	Idukki
Perumpara Estate	2	Thirssur
Pidavoor	2	Kollam
Tirunelli	2	Wayanad
Vellayan	2	Tiruvanthapuram
Annakkayathumoola	4	Tiruvanthapuram
Kalar River	4	Kollam
Muthanga	4	Wayanad
Muthappankolli	4	Wayanad
Neduvannor Kadavu	4	Kollam
Pandalam	4	Pathinamthita
Thamarakulam lake	4	Kozhikode
Thommankuthu-Kaliyar	4	Idukki

Valikulam-Palapilly	4	Thirssur
Malampuzha	6	Palakkad
Moonnukalunkutodu	6	Idukki
Munddari	6	Malappuram
Pazhayidam	6	Kollam
Pambala-lower Periyar	7	Idukki
Azhuta River	8	Kottayam
Pamba-Aratukadavu	8	Pathinamthita
Chenkulathukavu	9	Kottayam
Koodathi	9	Kozhikode
Alathur	11	Palakkad
Nilambur-Chaliyar	11	Malappuram
Panathur	11	Kasarkod
Aranmula Sathrakadavu	12	Pathinamthita
Cheruthoni	12	Idukki
Jalsoor	12	Kasarkod
Kakkad	12	Ernakulam
Vallakadavu	12	Idukki
Achankoil River	14	Pathinamthita
Karimbam-Taliparamba	17	Kannur
Kuttampuzha	17	Idukki
Pamba-Njunungar	17	Pathinamthita
Puthalam	17	Malapuram
Sabrimala-Pamba	21	Pathinamthita
Thannimoodu - Kallar	21	Idukki
Mananchira lake	22	Kozhikode
Bavikara-Chandragiripuzha	23	Kasarkod
Ellukachi-Karike	26	Kasarkod
Pookod Lake	26	Wayanad
Azhuta River-Idukki	27	Idukki
Manjappalam	27	Kozhikode
Avananvancherri	33	Tiruvanthapuram
Chenkulam	33	Kollam
Nedumangadu	33	Thiruvananthapuram
Sasthamkotta Lake	33	Kollam
Koolimadu	34	Kozhikode
Ezhuvathruthy-Nariooarambu	50	Malappuram
Muvathupuzha	50	Ernakulam
Pallipadi	50	Malapuram
Karuvannurpuzha	60	Malappuram
Kudapuzha	60	Thirssur
Kulathurmozhi	60	Kottayam
Kuppapuram	60	Alapuzha
Malapuram-Chamakayam	60	Malapuram

Marakadavu	60	Wyanad
Vadakara-Koorangottukatavu	60	Kozhikode
Kattupara	80	Malapuram
Adukkam	90	Kottayam
Cherananllur	110	Thirssur
Kavalam-Kuttanadu	110	Alapuzha
Nallathanni	110	Idukki
Vettikattumukku	110	Kottayam
Wadakancheery	110	Thirssur
Kallarakadvu	140	Pathinamthita
Kandiyoor	140	Alappuzha
Malumelkadavu	140	Kollam
Veeyapuram	140	Alappuzha
Athikayam	170	Pathinamthita
Kaladi	170	Ernakulam
Kalikadu	170	Tiruvanthapuram
Kothamangalam-Kozhipalli	170	Ernakulam
Kundamankadavu	170	Thiruvananthapuram
Ottapalam	280	Palakkad
Thirthala	280	Palakkad
Peechi Dam	300	Thirssur
Kazhuthruthy	350	Kollam
Poovathummuddu	350	Kottayam
Puzhapalam - Chitturpuzha	350	Palakkad
Thodupuzha	500	Idukki
Changanacherry	900	Kottayam
Irriti	900	Kannur
Mannarkad-Kunthipuzha	900	Palakkad
Munnar - Marayyr Rd	900	Idukki
Aluva	1600	Ernakulam
Neyyar	1600	Thiruvananthapuram

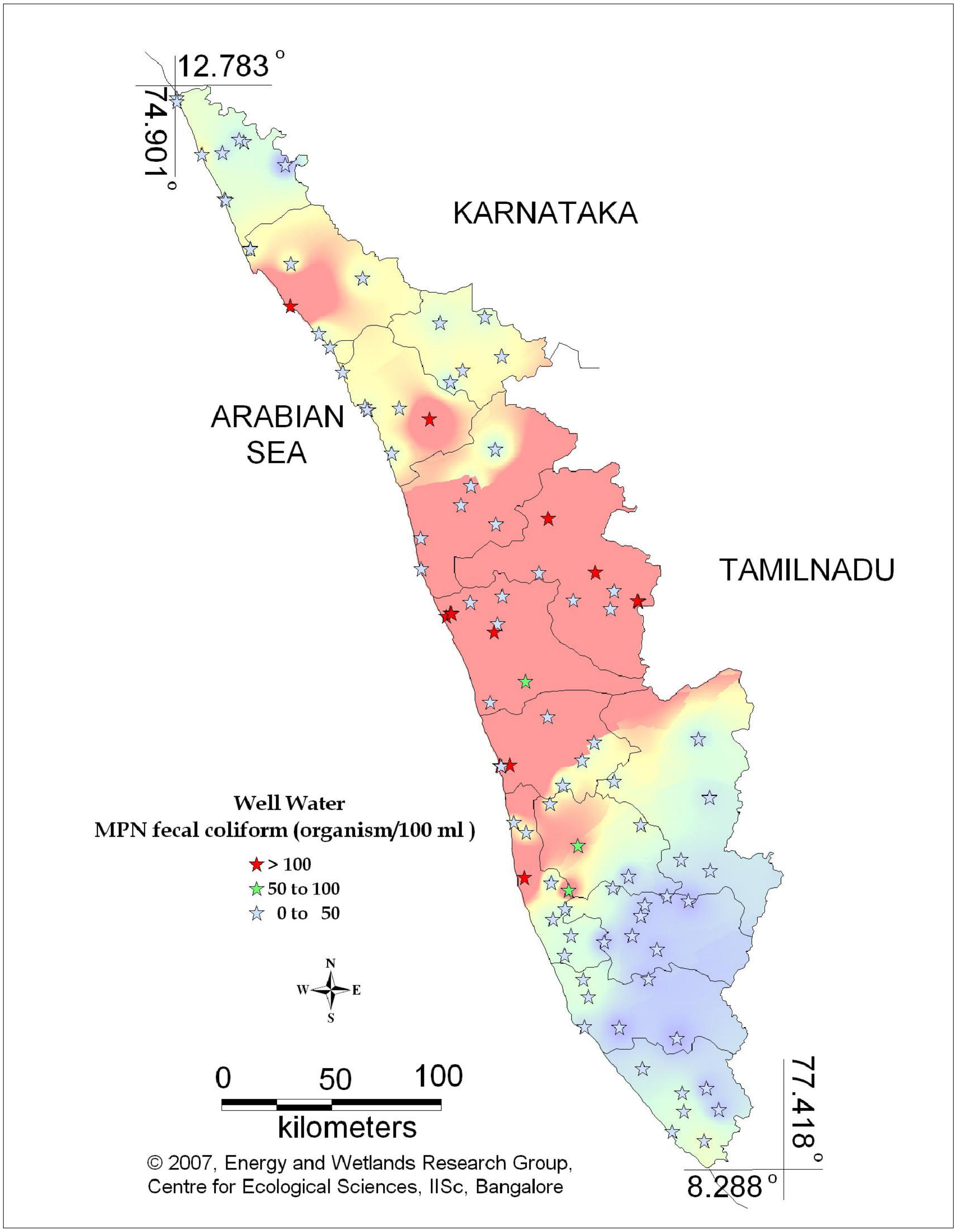


Figure 9.2: Spatial distribution of Faecal Coliform Bacteria in Kerala well water

Well water – Coliform (MPN)

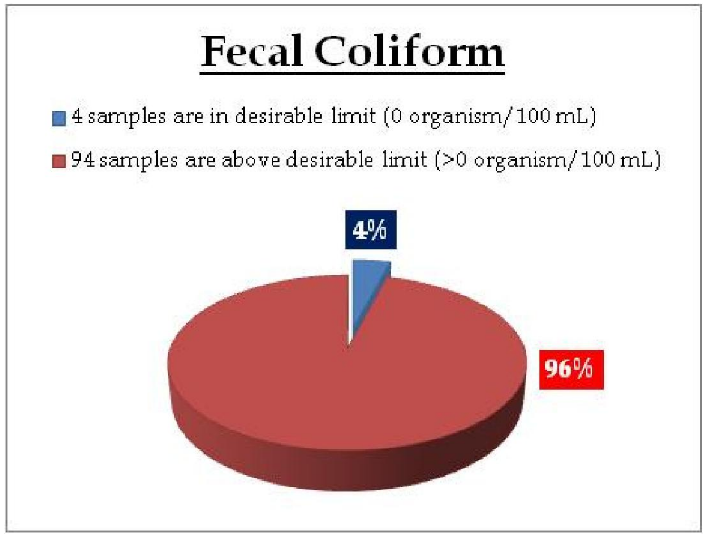
For water entering a distribution system

- Coliform count in any sample of 100 ml should be zero (0).

For water in a distribution system –

- *E coli* count in 100 ml of any sample must be zero (0).
- Coliform organisms should not be more than 10 per 100 ml in any sample.

Coliform organisms should not be present in 100 ml of any two consecutive samples or more than 5% of the samples collected for the year.



Remarks

Sampling sites above desirable are listed districtwise in Table 10.2

Table 10.2: Locations of Faecal Coliform Bacteria above desirable limit

Location	Value	District
Athikayam	2	Pathinamthita
Boundermukku	2	Thiruvananthapuram
Kallarakadvu	2	Pathinamthita
Kallely Check Post	2	Pathinamthita
Neyyar Dam	2	Thiruvananthapuram
Pampa Valley	2	Pathinamthita
Pazhayidam	2	Kottayam
Pidavoor	2	Kollam
Vadaserikara	2	Pathinamthita
Vaithiri	2	Wayanad
Bengathadka	4	Kasaragod
Bovikanam	4	Kasaragod
Chenkulathukavu	4	Kottayam
Manjeri	4	Malappuram
Nilambur	4	Malappuram
Onakkoor-Piravam	4	Ernakulam
Kattachal	6	Kollam

Kochupilammood	6	Kollam
Kulathurmozhi	6	Kottayam
Old Munnar	6	Idukki
Vallakadavu	6	Idukki
Avananvancherri	7	Thiruvananthapuram
Peeramedu	7	Idukki
Thannimoodu	7	Idukki
Kandiyoor	9	Alapuzha
Kayamkulam	9	Alapuzha
Nedumangadu	9	Thiruvananthapuram
Veeyapuram	9	Alapuzha
Thiruvallam	11	Thiruvananthapuram
Adhur	12	Kasaragod
Kallummoottilkadavu	12	Kollam
Kanhangad	12	Kasaragod
Kothamangalam	12	Ernakulam
Mattancherry	12	Ernakulam
Muvathupuzha	12	Ernakulam
Payyanoor	12	Kannur
Thalassery	12	Kannur
Chatakadavu	13	Wayanad
Alathoor -WYD	14	Wayanad
Alathur	14	palakkad
Kulasekaram	14	Thiruvananthapuram
Malumelkadavu	14	Kollam
Tirur	14	Malappuram
Aaviyal	17	Kasaragod
Hosabettu - Manjeshwar	17	Kasaragod
Kottooli	17	Kozhikode
Koyilandy- Kothamangalam	17	Kozhikode
Thodupuzha	17	Idukki
Adukkam	22	Kottayam
Irriti	22	Kannur
Mahe	22	Puduchery
Neyyathinkara	22	Thiruvananthapuram
Poorot	22	Kasaragod
Karimbam-Taliparamba	23	Kasaragod
Ponnani	23	Malappuram
Kalikulam Junction	26	Alapuzha
Kavalam	26	Alapuzha
Kollengode	26	palakkad
Koodungalur	26	Thrissur
Koyilandy	26	Kozhikode

Puzhapalam	26	palakkad
Sulthan Bathery	26	Wayanad
Thrissur	26	Thrissur
Vettakkal Junction	26	Alapuzha
Wadakancheery	26	Thrissur
Koyilandy	27	Kozhikode
Vettikattumukku	27	Kottayam
Balusserry - Vaikundam	30	Kozhikode
Kaladi	30	Ernakulam
Malappuram-Kottakunne	30	Malappuram
Vadakara	30	Kozhikode
Chemnad	33	Kasaragod
Cherananllur	33	Thrissur
Kalpetta - Rattakoli	33	Wayanad
Ottapalam	34	palakkad
Perinthalmanna	34	Malappuram
Payyanoor	40	Kasaragod
Chalakudy	50	Thrissur
Poovathummuddu	50	Kottayam
Thuruthelpalam	80	Kottayam
Guruvayoor	110	Thrissur
Kannimari	110	palakkad
Karingalmanna	110	Kozhikode
Placimada	110	palakkad
Mullackal-Azhapuzha	140	Alapuzha
Guruvayoor1	240	Thrissur
Kannur	280	Kannur
Chavakkad	300	Thissur
Thondikulam Agraharam	350	palakkad
Ernakulam	500	Ernakulam
Fort Cochin	500	Ernakulam
Mannarkkad	500	palakkad
Aluva	900	Ernakulam
Thrissur	>1600	Thrissur

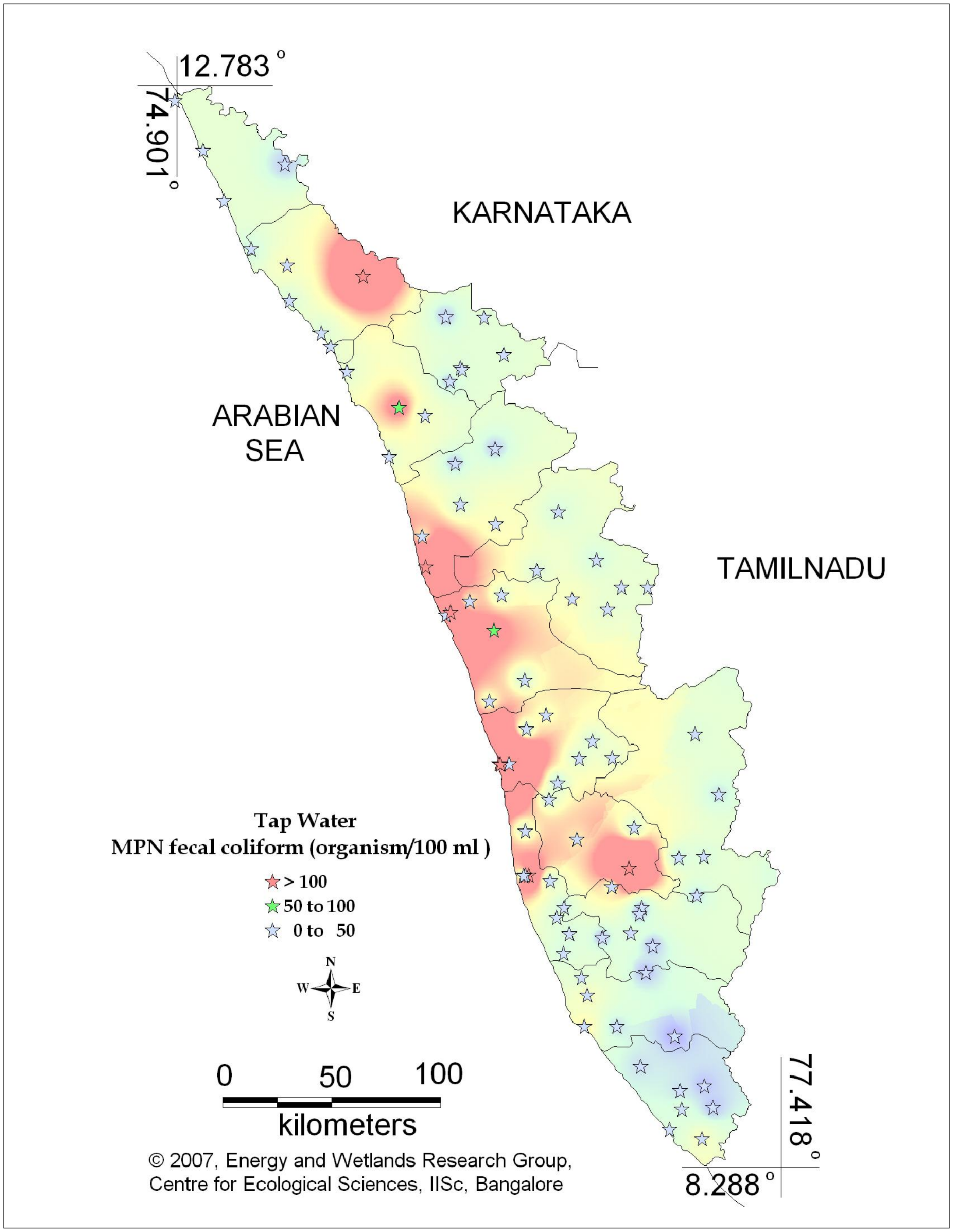


Figure 9.3: Spatial distribution of Faecal Coliform Bacteria in Kerala tap water

Tap water –Coliform (MPN)

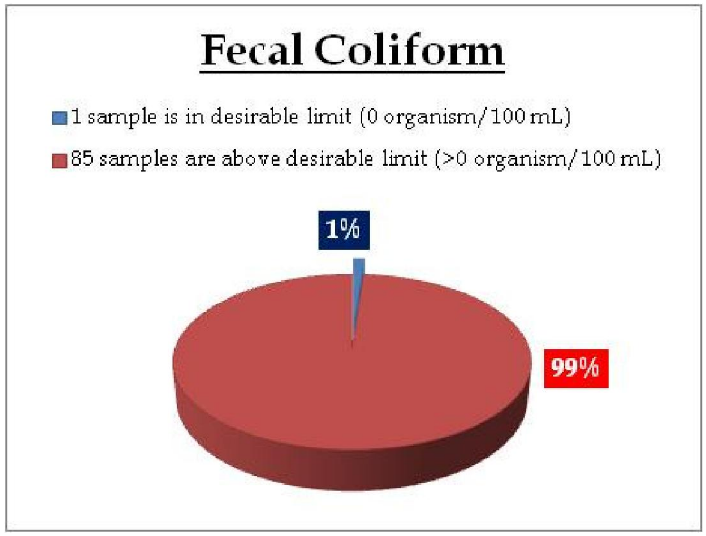
For water entering a distribution system

- ❖ Coliform count in any sample of 100 ml should be zero (0).

For water in a distribution system –

- ❖ *E coli* count in 100 ml of any sample must be zero (0).
- ❖ Coliform organisms should not be more than 10 per 100 ml in any sample.

Coliform organisms should not be present in 100 ml of any two consecutive samples or more than 5% of the samples collected for the year.



Remarks

Sampling sites above desirable limit (organism/100ml) are listed districtwise in Table 10.3

Table 10.3: Locations of Faecal Coliform Bacteria above desirable limit

Location	Value	District
Adithippuzha	2	Pathinamthita
Boundermukku	2	Thiruvananthapuram
Kalikadu	2	Thiruvananthapuram
Kallely	2	Pathinamthita
Pandalam	2	Kasaragod
Pathanapuram pump house	2	Kottayam
Vadaserikara	2	Pathinamthita
Kakkad	4	Ernakulam
Kilikkallungal	4	Malapuram
Kondayangadi-Mananthavadi	4	Wayanad
Nilambur	4	Malapuram
Ponathur	4	Kasaragod
Vaithiri	4	Wayanad
Avananvancherri	6	Thiruvananthapuram
Chenkulathukavu	6	Kottayam
Kavalam-Kuttanadu	6	Alappuzha
Kummallor	6	Kollam
Nedumangadu	6	Thiruvananthapuram

Pamba-Triveni	6	Pathinamthita
Pazhavangadi Jn-Aazhapuzha	6	Kannur
Nedumkandam	7	Thiruvananthapuram
Peeramedu	7	Alappuzha
Akathethara	9	Palakkad
Kandiyoor	9	Alappuzha
Kayamkulam	9	Alappuzha
Payyanoor	9	Pathinamthita
Thathampally	9	Alapuzhala
Kakki Junction	11	Alappuzha
Kallarakadvu	11	Pathinamthita
Kulasekaram	11	Thiruvananthapuram
Parayilkaling	11	Pathinamthita
Thenkara	11	palakkad
Aluva	12	Ernakulam
Chalakudy	12	Thrissur
Kothamangalam	12	Ernakulam
Muvathupuzha	12	Ernakulam
Pallikunnu - Kannur	12	Kannur
Thalassery	12	Kannur
Theekoy	12	Kottayam
Thiruvallam	12	Thiruvananthapuram
Veeyapuram	12	Alapuzhala
Munnar Town	13	Idukki
Alathoor -WYD	14	Wayanad
Kalpetta - Rattakoli	14	Wayanad
Kalpetta	14	Wayanad
Malappuram-Kottakunne	14	Malapuram
Malumelkadavu	14	Kollam
Ottapalam	14	Palakkad
Sultan Battery	14	Wayanad
Chittur	17	Palakkad
Kalikulam Junction	17	Alappuzha
Kanhangod	17	Kasaragod
Kasargod	17	Kasaragod
Kollengode-Vellanara	17	Palakkad
Mahe	17	Puducherry
Moonkilmada	17	Palakkad
Pokki-Manjeshwar	17	Kottayam
South Beach - Calicut	17	Kozhikode
Thodupuzha	17	Idukki
Vadakara	17	Kozhikode
Wadakancheery	17	Thrissur
Thamarassery	21	Kozhikode

Alathur	26	Palakkad
Cholomkunnu	26	Malapuram
Kaladi	26	Ernakulam
Kallummoottilkadavu	26	Kollam
Koodungalur	26	Thrissur
Neyyathinkara	26	Thiruvananthapuram
Talipparamba	26	Kannur
Kulathurmozhi	27	Kottayam
Chavakkad	33	Thirssur
Cherananllur	33	Thirssur
Ernakulam	33	Ernakulam
Kollam Beach	34	Kollam
Perror	34	Idukki
Tirur	34	Malapuram
Balusserry - Vaikundam	60	Kozhikode
Thrissur	60	Thrissur
Guruvayoor	110	Thrissur
Irriti	140	Kannur
Kuppapuram	170	Alappuzha
Ponnani	240	Malapuram
Chirakadavu	280	Kottayam
Fort Cochin	300	Ernakulam
Shastiparambu	350	Ernakulam

NITRATE

Nitrate and nitrite are naturally occurring ions that are part of the nitrogen cycle. Nitrate is used mainly in inorganic fertilizers, and sodium nitrite is used as a food preservative, especially in cured meats. Nitrates may occur in both shallow and deep well supplies, but they are most common in water from shallow wells. Nitrate nitrogen can result from the seepage of water through soil containing nitrate-bearing minerals. The nitrate concentration in groundwater and surface water is normally low but can reach high levels as a result of leaching or runoff from agricultural land or contamination from human or animal wastes as a consequence of the oxidation of ammonia and similar sources. Anaerobic conditions may result in the formation and persistence of nitrite. Chlorination may give rise to the formation of nitrite within the distribution system if the formation of chloramine is not sufficiently controlled. The formation of nitrite is as a consequence of microbial activity and may be intermittent. Nitrification in distribution systems can increase nitrite levels, usually by 0.2–1.5 mg/litre.

Effects on Environment and Human Health

The primary health concern regarding nitrate and nitrite is the formation of methaemoglobinaemia, which is also known as "blue-baby syndrome." Nitrate is reduced to nitrite in the stomach of infants, and nitrite is able to oxidize haemoglobin (Hb) to methaemoglobin (metHb), which is unable to transport oxygen around the body. The reduced oxygen transport becomes clinically manifest when metHb concentrations reach 10% or more of normal Hb concentrations; the condition, called methaemoglobinaemia, causes cyanosis and, at higher concentrations, asphyxia. The normal metHb level in infants under 3 months of age is less than 3%. The Hb of young infants is more susceptible to metHb formation than that of older children and adults.

Remedial Measures

The best method for treatment of large nitrate nitrogen concentrations due to human or animal wastes is prevention. Wells should be properly located and constructed in order to prevent sewage contamination. Nitrates can be removed through distillation, deionization, or reverse osmosis. Even though only 95% of ionic nitrates can be removed by reverse osmosis, non-ionic forms of nitrogen will not pass through the membrane.

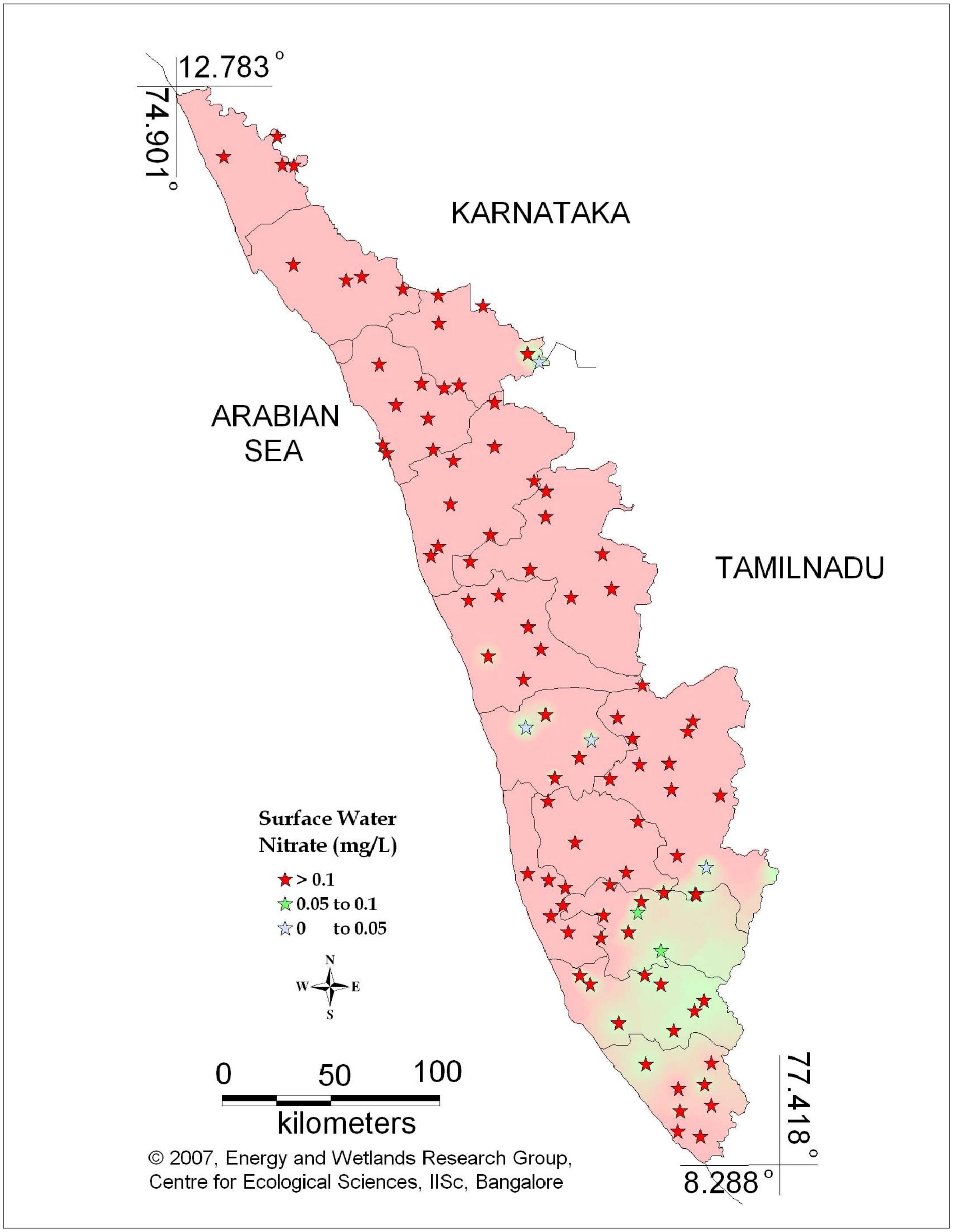
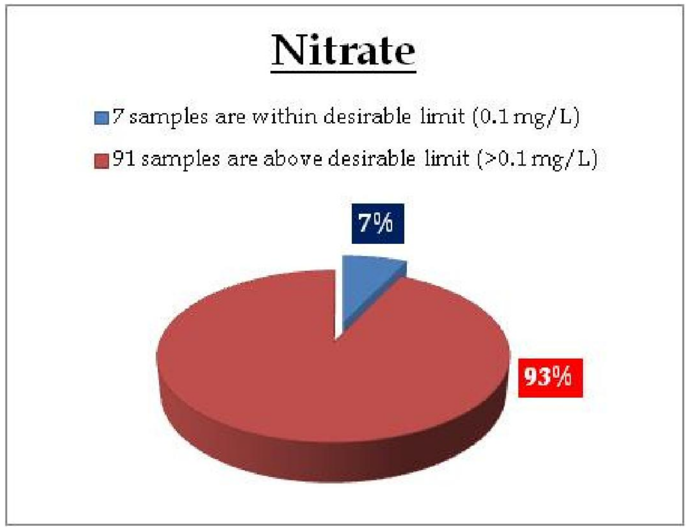


Figure 10.1 : Spatial variation of Nitrate in Kerala surface water

Surface water - Nitrate

Tolerance limit for inland surface waters subject to pollution

Desirable Limit: 0.1 mg/L



Remarks
Sampling sites above desirable limit are listed in Table 11.1

Table 11.1: Locations above desirable limits of Nitrate

Location	Value	District
Aranmula Sathrakadavu	0.11	Pathinamthita
Muthanga	0.11	Wyanad
Athikayam	0.11	Pathinamthita
Azhuta River	0.11	Kottayam
Pidavoor	0.12	Kollam
Kulathurmozhi	0.12	Kottayam
Kazhuthruthy	0.13	Kollam
Pandalam	0.13	Pathinamthita
Avananvancherri	0.14	Thiruvananthapuram
Sasthamkotta Lake	0.14	Kollam
Kallarakadvu	0.15	Pathinamthita
Malumelkadavu	0.16	Kollam
Pamba-Aratukadavu	0.17	Pathinamthita
Neduvannor Kadavu	0.18	Kollam
Chenkulam	0.20	Kollam
Kakkad	0.20	Ernakulam
Kallana aru	0.20	Kollam
Mukkadavu	0.21	Kollam

Pamba-Njunungar	0.23	Pathinamthita
Annakkayathumoola	0.28	Thiruvananthapuram
Kaladi	0.36	Ernakulam
Moonnukalunkutodu	0.37	Idukki
Muvathupuzha	0.37	Ernakulam
Karuvannurpuzha	0.43	Thirssur
Kundamankadavu	0.54	Thiruvananthapuram
Cherananllur	0.61	Thirssur
Kuttampuzha	0.63	Idukki
Kalikadu	0.68	Thiruvananthapuram
Kallar	0.71	Kollam
Chenkulathukavu	0.76	Kottayam
Valikulam-Palapilly	0.76	Thirssur
Peechi Dam	0.81	Thirssur
Perumpara Estate	0.87	Thirssur
Kudapuzha	0.89	Thirssur
Neyyar	0.90	Thiruvananthapuram
Nedumangadu	0.91	Thiruvananthapuram
Sairandri	0.92	Palakkad
Bhoothokallu	0.95	Kannur
Wadakancheery	1.04	Thirssur
Lekkidi-Vythri	1.05	Wyanad
Urukkuzhi	1.07	Kozhikode
Mannarkad-Kunthipuzha	1.27	Palakkad
Tirunelli	1.28	Wyanad
Vellayani	1.34	Thiruvananthapuram
Vettikattumukku	1.50	Kottayam
Changanacherry	1.63	Kottayam
Puthalam	1.65	Malapuram
Manchalmchola	1.72	Malapuram
Azhuta River-Idukki	1.76	Idukki
Koolimadu	1.79	Kozhikode
Koodathi	1.96	Kozhikode
Alathur	2.00	Palakkad
Pazhasii Dam	2.32	Kannur
Kattupara	2.35	Malapuram
Ezhuvathruthy-Nariooarambu	2.35	Malapuram
Ottapalam	2.37	Palakkad
Malampuzha	2.52	Palakkad
Adukkam	2.63	Kottayam
Thamarakulam lake	2.77	Kozhikode
Manjappalam	2.79	Kozhikode
Thirthala	2.98	Palakkad
Cheruthoni	3.61	Idukki

Malapuram-Chamakayam	3.72	Malapuram
Marakadavu	3.72	Wyanad
Mananthavadi	3.73	Wyanad
Pallipadi	3.79	Malapuram
Irriti	4.00	Kannur
Pambala-lower Periyar	4.05	Idukki
Munddari	4.31	Malapuram
Mananchira lake -Calicut	4.37	Kozhikode
Pazhayidam	4.39	Kottayam
Pookod Lake	4.58	Wyanad
Nilambur-Chaliyar	4.65	Malapuram
Vadakara-Koorangottukatavu	4.72	Kozhikode
Karimbam-Taliparamba	4.73	Kannur
Munnar (8th mile)	4.74	Idukki
Panathur	4.75	Kasarkod
Ellukachi-Karike	4.75	Kasarkod
Thannimoodu - Kallar stream	4.80	Idukki
Poovathummuddu	5.23	Kottayam
Thodupuzha	5.23	Idukki
Nallathanni	5.91	Idukki
Bavikara-Chandragiripuzha	6.72	Kasarkod
Puzhapalam - Chitturpuzha	6.79	Palakkad
Veeyapuram	7.22	Alapuzha
Jalsoor	8.21	Kasarkod
Thommankuthu-Kaliyar	9.07	Idukki
Kavalam-Kuttanadu	9.14	Alapuzha
Munnar - Marayyr Rd	9.22	Idukki
Kandiyoor	11.30	Alapuzha
Kuppapuram	20.40	Alapuzha

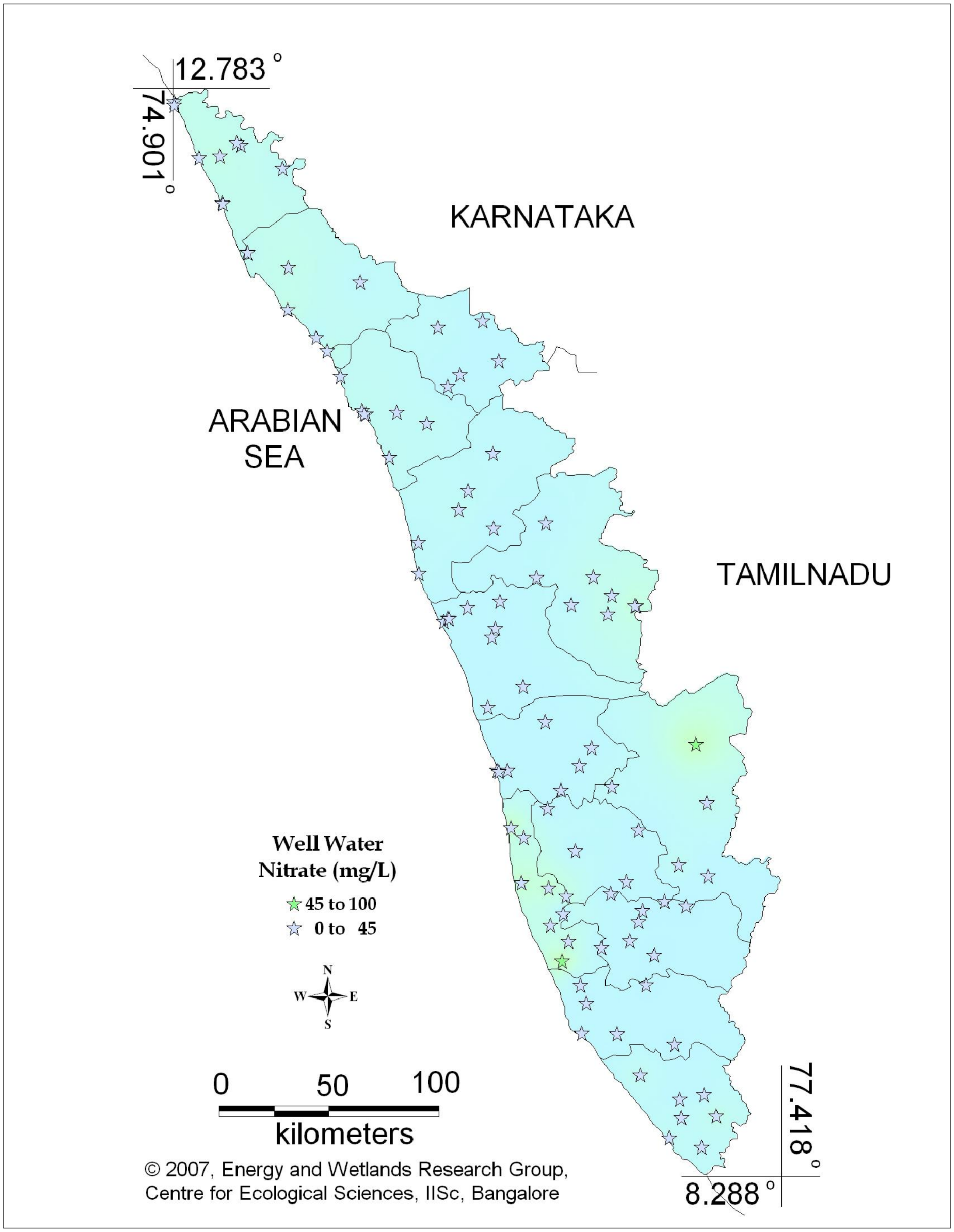
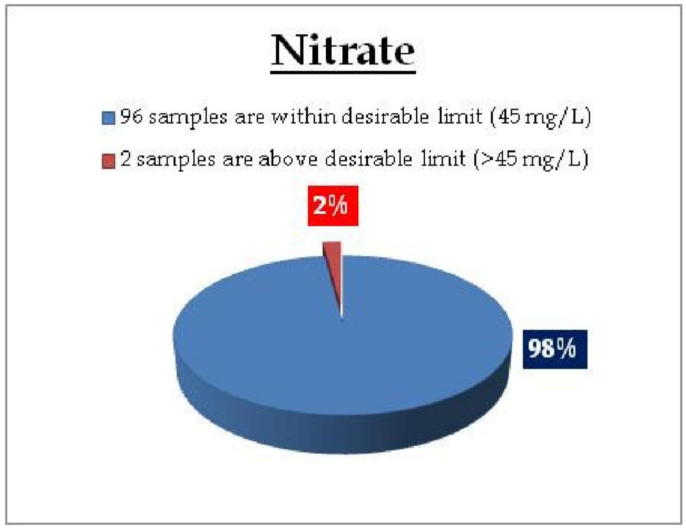


Figure 10.2: Spatial variation of Nitrate in Kerala well water

Growth of Algae due to high amount of Nitrates

Well water - Nitrate

Standard for Drinking Water (BIS 105000)
Desirable Limit: 45 mg/L
Permissible limit in the absence of an alternative source: 100mg/L



Remarks
Sampling sites above desirable limit are given in Table 11.2

Table 11.2: Locations above desirable limits of Nitrate

Location	**Value**	**District**
Old Munnar	45.30	Idukki
Kayamkulam	50.00	Alappuzha

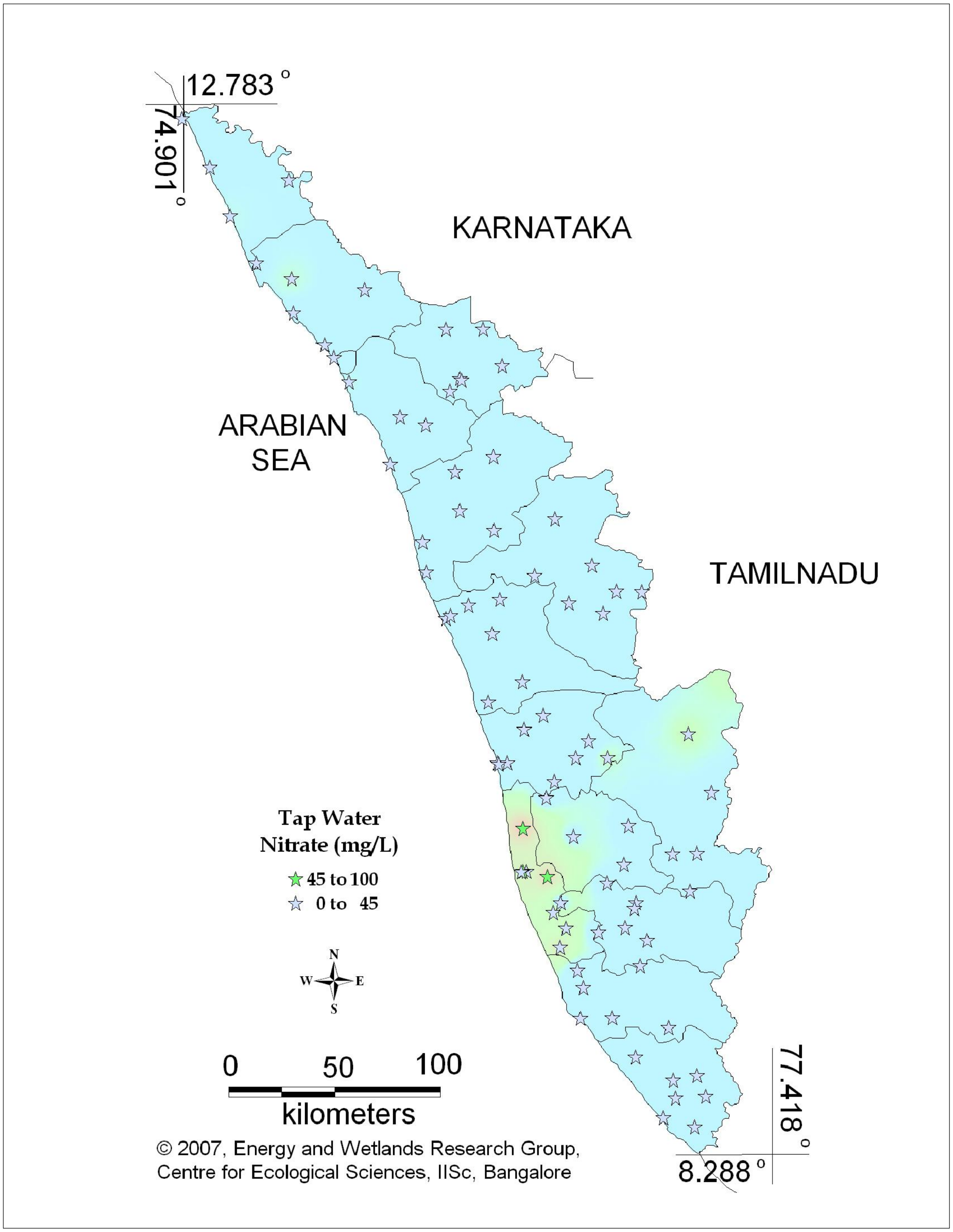
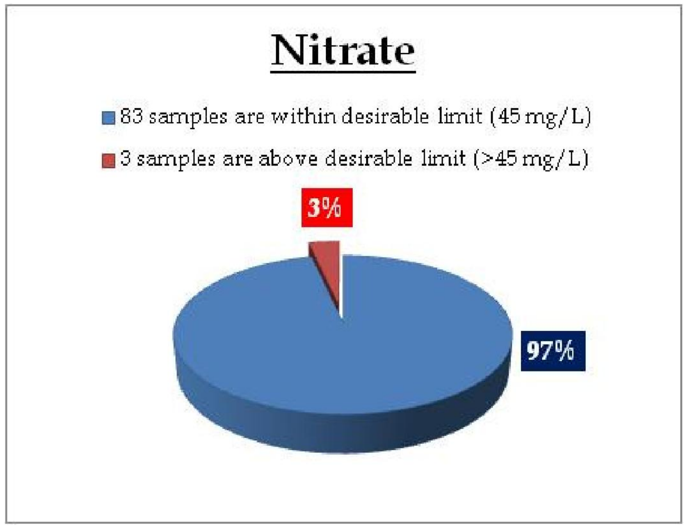


Figure 10.3: Spatial variation of Nitrate in Kerala tap water

Tap water - Nitrate

Standard for Drinking Water (BIS 105000)
Desirable Limit: 45 mg/L
Permissible limit in the absence of an alternative source: <45 mg/L



Remarks

Sampling sites above desirable limit of Nitrate are listed in Table 11.3

Table 11.3: Sampling sites above desirable limits of Nitrate

Location	Value	District
Kavalam-Kuttanadu	46.10	Alappuzha
Thathampally	50.00	Alappuzha
Kalikulam Junction	54.90	Alappuzha

Fluoride

Fluoride accounts for about 0.3 g/kg of the Earth's crust and exists in the form of fluorides in a number of minerals. The most important source of fluoride in drinking water is when water comes in contact with geological strata rich in fluorides. Inorganic fluoride-containing minerals are used widely in industry for a wide range of purposes, including aluminium production. Fluorides can be released to the environment from the phosphate-containing rock used to produce phosphate fertilizers; these phosphate deposits contain about 4% fluorine. Fluorosilicic acid, sodium hexafluorosilicate and sodium fluoride are used in municipal water fluoridation schemes. Daily exposure to fluoride depends mainly on the geographical area.

Effects on Environment and Human Health

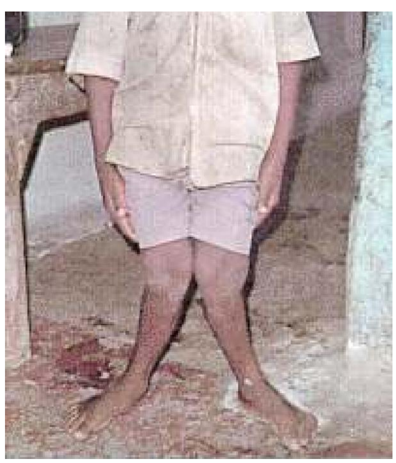
Fluoride ions maybe present either naturally or artificially in drinking water and are absorbed to some degree in the bone structure of the body and tooth enamel. Fluoride at extremely high levels can cause mottling (discoloration) of the teeth. Some fluoride compounds may also cause corrosion of piping and other water treatment equipment. Natural fluorides occur in rocks in some areas. Another source of fluorides in streams and reservoirs is releases from sewage treatment plants, since most public water supplies add fluoride to drinking water to reduce dental decay. Fluoride has beneficial effects on teeth at low concentrations in drinking water, but excessive exposure to fluoride in drinking water, or in combination with exposure to fluoride from other sources, can give rise to a number of adverse effects. High level of fluoride will also leads to soft tissue fluorosis, gastrointestinal manifestations, neurological manifestations, urinary tract manifestations, hormonal disorders, etc.

Remedial Measures

Most people are aware that there is a controversy surrounding public fluoridation of drinking water. There are few ways to obtain drinking water without fluoride like,

- Reverse Osmosis Filtration: Reverse osmosis systems at community level would be feasible.
- Distillation Filtration: There are household distillations filters can be used to remove fluoride from water.

Fluorosis due to high amount of Fluoride



Skeletal Fluorosis due to high amount of Nitrates

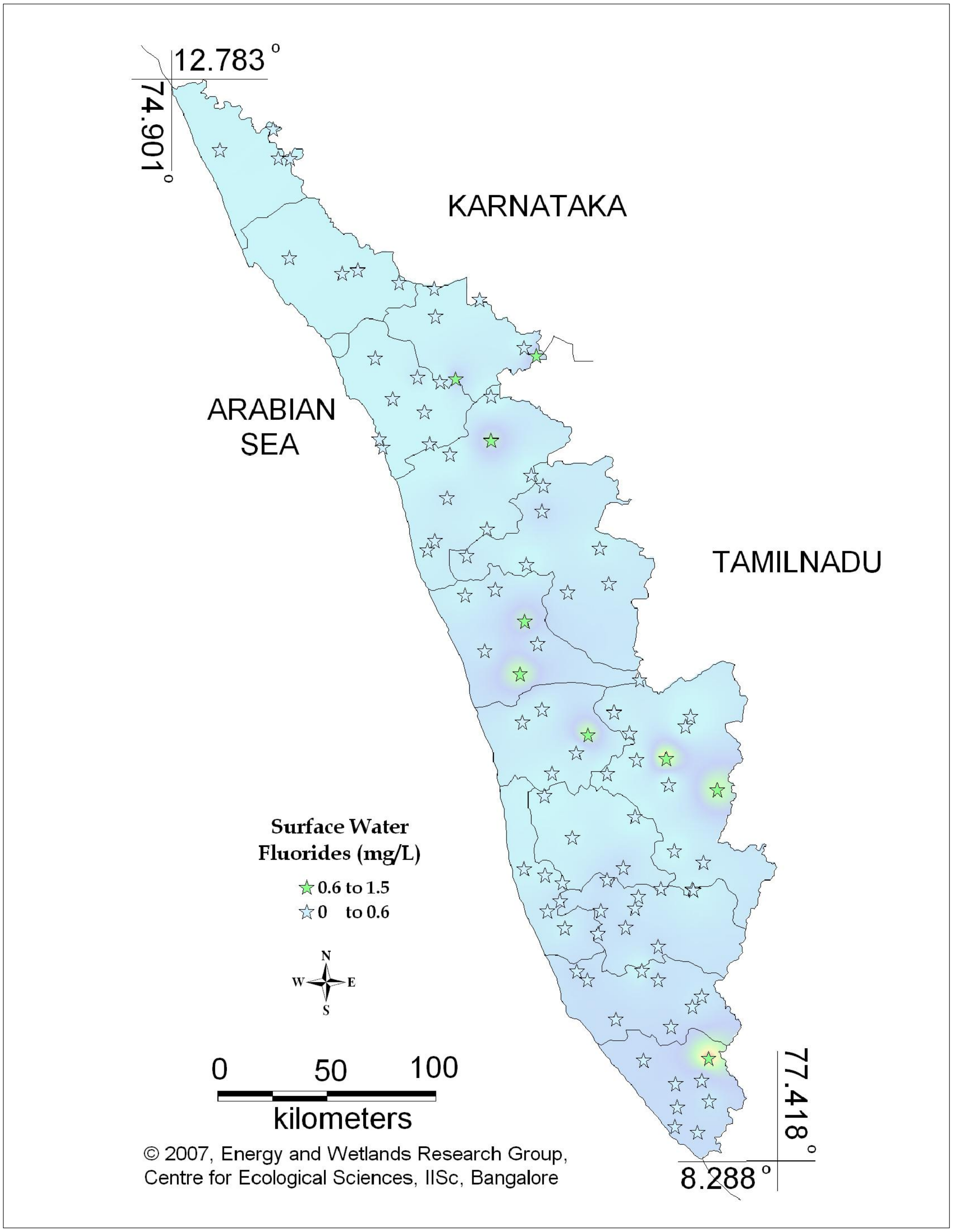
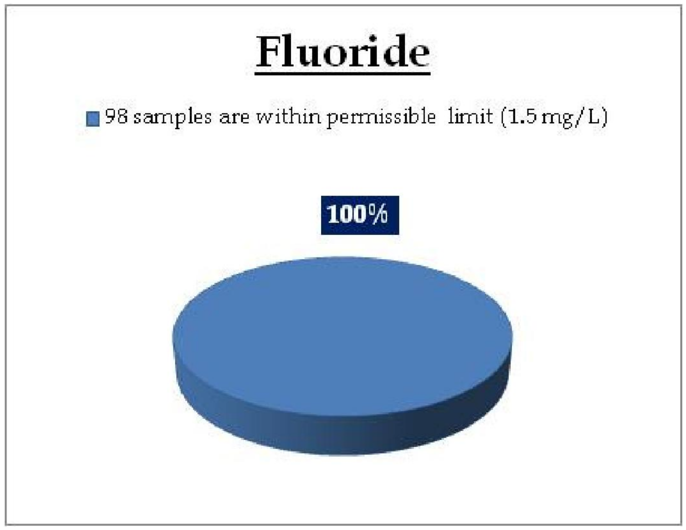


Figure 11.1: Spatial variation of fluoride in surface water

Surface water - Fluoride

Tolerance limit for inland surface waters subject to pollution

Permissible Limit: 1.5 mg/L



Remarks
All the 98 surface water samples collected from rivers, streams and lakes spread over in Kerala are under the inland surface water standard.

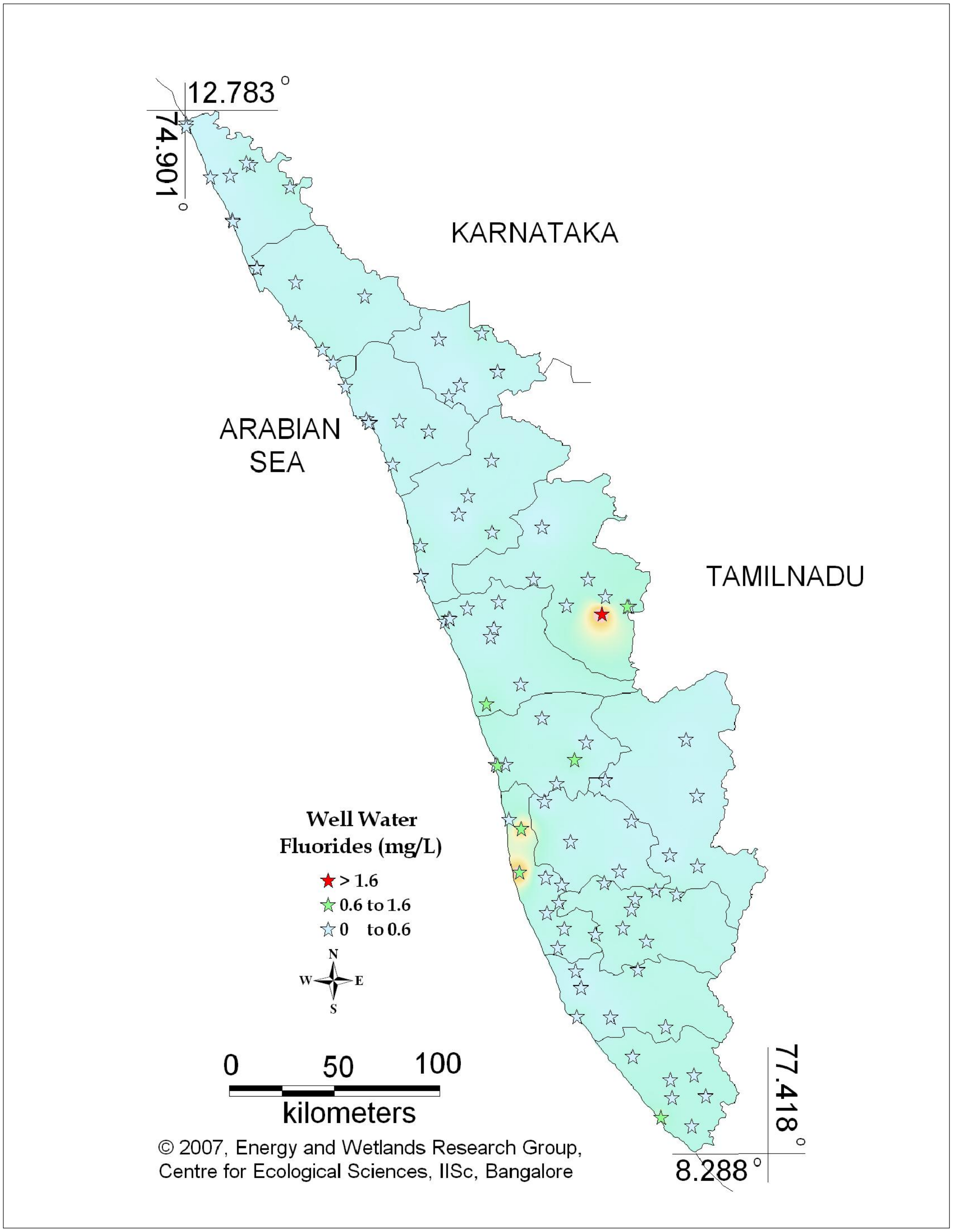
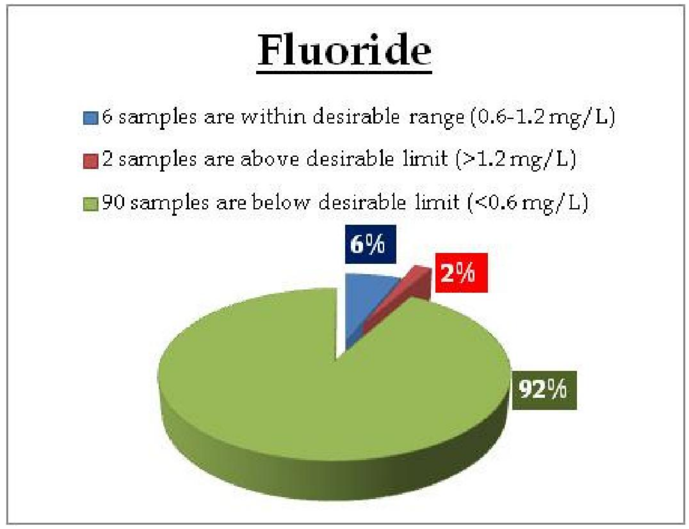


Figure 11.2: Spatial variation of fluoride in well water

Well water - Fluoride

Standard for Drinking Water (BIS 105000)
Desirable Limit: 0.6 – 1.2 mg/L

Values below and above the standard limit cause bone related diseases.



Remarks

Sampling sites above desirable limit and below desirable limits are listed in Tables 12.1 and 12.2 respectively

Table 12.1: Locations of wells - fluorides above desirable limits

Location	Value	District
Mullackal	1.4	Alappuzha
Kollengode	1.6	Palakkad

Table 12.2: Sampling sites below desirable limit of flouorides

Location	Value	District
Kallummoottilkadavu	0.2	Kollam
Pazhayidam	0.2	Kottayam
Vettikattumukku	0.2	Kottayam
Peeramedu	0.2	Idukki
Mannarkkad	0.2	Palakkad
Malappuram-Kottakunne	0.2	Malapuram
Kalpetta - Rattakoli	0.2	Wayanad
Poorot	0.2	Kasarkod
Bovikanam	0.2	Kasarkod
Koyilandy	0.2	Kozhikode
Koyilandy-Kothamangalam	0.2	Kozhikode
Kattachal	0.3	Kollam

Malumelkadavu	0.3	Kollam
Thuruthelpalam	0.3	Kottayam
Poovathummuddu	0.3	Kottayam
Adukkam	0.3	Kottayam
Thannimoodu	0.3	Idukki
Old Munnar	0.3	Idukki
Thodupuzha	0.3	Idukki
Kavalam	0.3	Alappuzha
Kothamangalam	0.3	Ernakulam
Thrissur	0.3	Thrissur
Ponnani	0.3	Palakkad
Vaithiri	0.3	Wayanad
Chatakadavu	0.3	Wayanad
Chemnad	0.3	Kasarkod
Kanhangad	0.3	Kasarkod
Payyanoor	0.3	Kannur
Vallakadavu	0.4	Idukki
Veeyapuram	0.4	Alappuzha
Kayamkulam	0.4	Alappuzha
Onakkoor-Piravam	0.4	Ernakulam
Ernakulam	0.4	Ernakulam
Kaladi	0.4	Ernakulam
Chalakudy	0.4	Thrisuur
Guruvayoor	0.4	Thrissur
Guruvayoor	0.4	Thrissur
Cherananllur	0.4	Thrissur
Wadakancheery	0.4	Thrissur
Thrissur	0.4	Thrissur
Puzhapalam	0.4	Palakkad
Ottapalam	0.4	Palakkad
Nilambur	0.4	Malapuram
Manjeri	0.4	Malapuram
Karingalmanna	0.4	Kozhikode
Balusserry - Vaikundam	0.4	Kozhikode
Kottooli	0.4	Kozhikode
Sulthan Bathery	0.4	Wayanad
Hosabettu - Manjeshwar	0.4	Kasarkod
Adhur	0.4	Kasarkod
Payyanoor	0.4	Kannur
Karimbam-Taliparamba	0.4	Kasarkod
Kannur	0.4	Kannur
Irriti	0.4	Kannur
Mahe	0.4	Puduchery
Vadakara	0.4	Kozhikode

Koyilandy	0.4	Kozhikode
Chitara Estate	0.5	Kollam
Pidavoor	0.5	Kollam
Athikayam	0.5	Pathinamthita
Attathodu East	0.5	Pathinamthita
Pampa Valley	0.5	Pathinamthita
Vadaserikara	0.5	Pathinamthita
Kallely Check Post	0.5	Pathinamthita
Pandalam	0.5	Pathinamthita
Kallarakadvu	0.5	Pathinamthita
Chenkulathukavu	0.5	Kottayam
Kulathurmozhi	0.5	Kottyam
Neyyathinkara	0.5	Tiruvanthapuram
Neyyar Dam	0.5	Tiruvanthapuram
Kulasekaram	0.5	Tiruvanthapuram
Boundermukku	0.5	Tiruvanthapuram
Nedumangadu	0.5	Tiruvanthapuram
Avananvancherri	0.5	Tiruvanthapuram
Kochupilammood	0.5	Kollam
Kandiyoor	0.5	Alappuzha
Vettakkal Junction	0.5	Alappuzha
Fort Cochin	0.5	Ernakulam
Aluva	0.5	Ernakulam
Chavakkad	0.5	Thrissur
Thondikulam Agraharam	0.5	Palakkad
Placimada	0.5	Palakkad
Alathur	0.5	Palakkad
Tirur	0.5	Malappuram
Perinthalmanna	0.5	Malappuram
Alathoor -WYD	0.5	Wyanad
Bengathadka	0.5	Kasarkod
Panathur	0.5	Kasarkod
Aaviyal	0.5	Kasarkod
Thalassery	0.5	Kannur

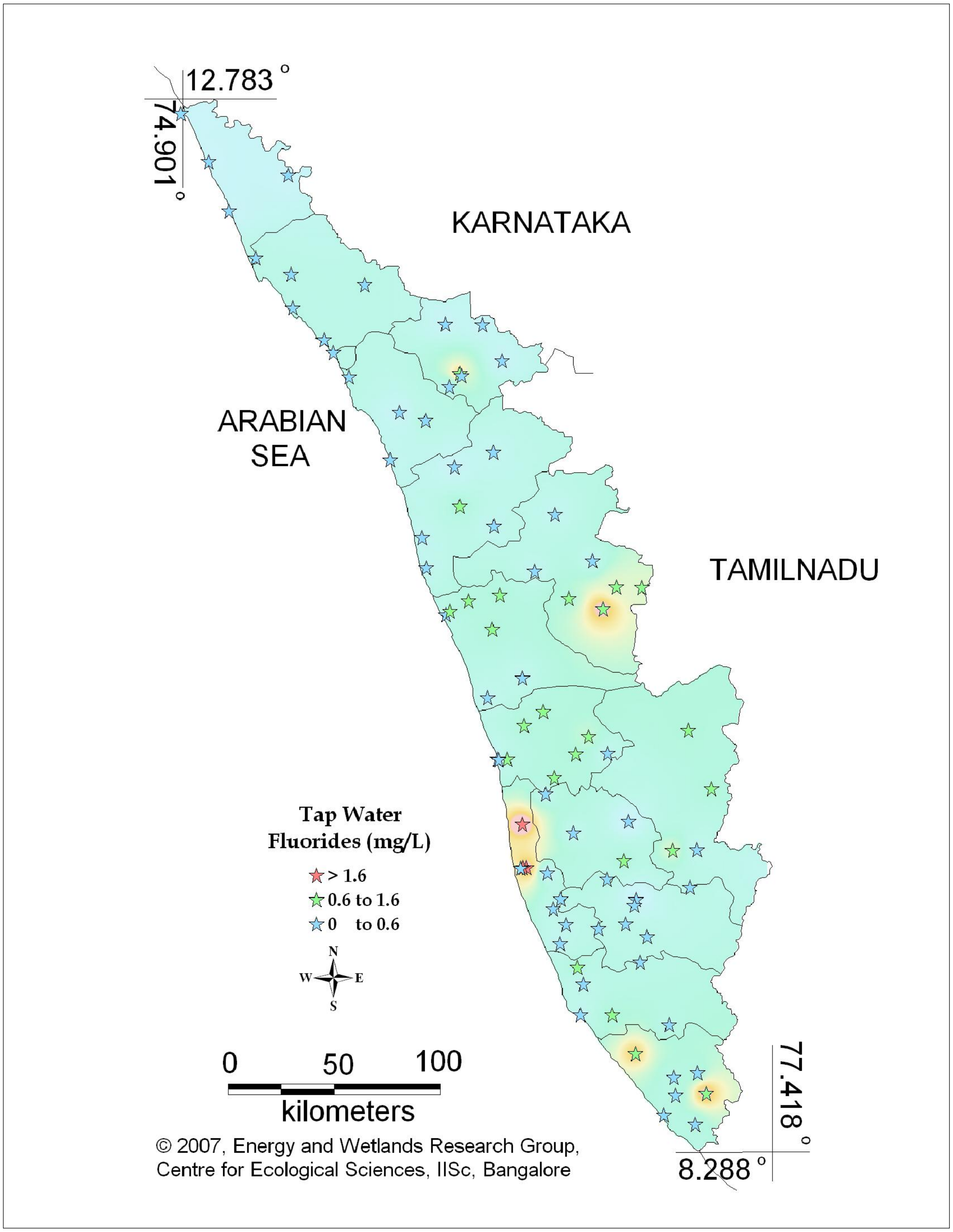
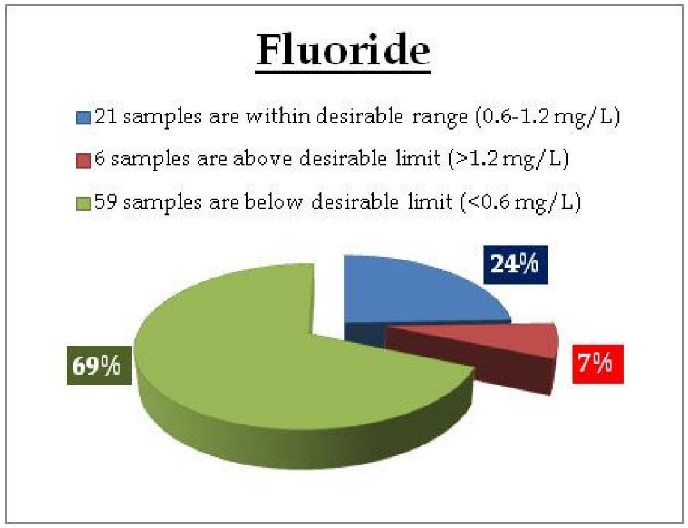


Figure 11.3: Spatial variation of fluoride in tap water

Tap water - Fluoride

Standard for Drinking Water (BIS 105000)
Desirable Limit: 0.6 – 1.2 mg/L

Values below and above the standard limit cause bone related diseases.



Remarks
Sampling sites above desirable limit and below desirable limit are listed in Table 12.3 and Table 12.4 respectively.

Table 12.3: Tap waters with fluoride above desirable limit

Location	Value	District
Kalikadu	1.4	Thiruvanathapuram
Kollengode-Vellanara	1.4	Palakkad
Kalpetta	1.4	Wayanad
Thathampally	1.6	Alappuzha
Kuppapuram	1.6	Alappuzha
Kalikulam Junction	1.6	Alappuzha

Table 12.4: Tap waters with fluoride below desirable limit

Location	Value	District
Adithippuzha	0	Pathinamthita
Fort Cochin	0.2	Ernakulam
Kavalam-Kuttanadu	0.2	Alappuzha
Theekoy	0.2	Kottayam
Alathoor -WYD	0.3	Wayanad
Balusserry - Vaikundam	0.3	Kozhikode
Kanhangod	0.3	Kasaragod
Kasargod	0.3	Kasaragod

Kilikkallungal	0.3	Malapuram
Kondayangadi-Mananthavadi	0.3	Wayanad
Pokki-Manjeshwar	0.3	Kasaragod
Ponathur	0.3	Kasaragod
Sultan Battery	0.3	Wayanad
Akathethara	0.4	palakkad
Chalakudy	0.4	Thrissur
Chavakkad	0.4	Thirssur
Cholomkunnu	0.4	Malapuram
Kakki Junction	0.4	Alapuzhala
Kallummoottilkadavu	0.4	Kollam
Kalpetta - Rattakoli	0.4	Wayanad
Kandiyoor	0.4	Alapuzha
Kayamkulam	0.4	Alappuzha
Kollam Beach	0.4	Kollam
Koodungalur	0.4	Thrissur
Nilambur	0.4	Malapuram
Ottapalam	0.4	palakkad
Parayilkaling	0.4	Kottayam
Pazhavangadi Jn-Aazhapuzha	0.4	Alappuzha
Perror	0.4	Kottayam
Ponnani	0.4	Malapuram
Shastiparambu	0.4	Ernakulam
South Beach - Calicut	0.4	Kozhikode
Thenkara	0.4	palakkad
Thodupuzha	0.4	Idukki
Tirur	0.4	Malapuram
Vaithiri	0.4	Wayanad
Veeyapuram	0.4	Alapuzhala
Boundermukku	0.5	Thiruvananthapuram
Chenkulathukavu	0.5	Kottayam
Chitara Estate	0.5	Thirssur
Irriti	0.5	Kannur
Kallarakadvu	0.5	Pathinamthita
Kallely	0.5	Pathinamthita
Kulasekaram	0.5	Thiruvananthapuram
Kulathurmozhi	0.5	Kottayam
Mahe	0.5	Puducherry
Nedumangadu	0.5	Thiruvananthapuram
Neyyathinkara	0.5	Thiruvananthapuram
Pallikunnu - Kannur	0.5	Kannur
Pamba-Triveni	0.5	Pathinamthita

Pandalam	0.5	Pathinamthita
Pathanapuram pump house	0.5	Pathinamthita
Payyanoor	0.5	Kannur
Talipparamba	0.5	Kannur
Thalassery	0.5	Kannur
Thamarassery	0.5	Kozhikode
Thiruvallam	0.5	Thiruvananthapuram
Vadakara	0.5	Kozhikode
Vadaserikara	0.5	Pathinamthita

Chlorides

Chlorides are salts resulting from the combination of the gas chlorine with a metal. Some common chlorides include sodium chloride (NaCl) and magnesium chloride ($MgCl_2$). Chlorine alone as Cl_2 is highly toxic and it is often used as a disinfectant. In combination with a metal such as sodium it becomes essential for life. Small amounts of chlorides are required for normal cell functions in plant and animal life.

Effects on environment and human health:

Chlorides are not usually harmful to people; however, the sodium part of table salt has been linked to heart and kidney disease. Sodium chloride may impart a salty taste at 250 mg/L; however, calcium or magnesium chlorides are not usually detected by taste until levels of 1000 mg/L are reached.

Chlorides may get into surface water from several sources including: 1) rocks containing chlorides; 2) agricultural runoff; 3) wastewater from industries; and 4) effluent wastewater from wastewater treatment plants.

Chlorides can corrode metals and affect the taste of food products. Therefore, water that is used in industry or processed for any use has a recommended maximum chloride level. Chlorides can contaminate fresh water streams and lakes. Fish and aquatic communities cannot survive in high levels of chlorides.

Remedial measures

Chlorides can be removed from water by reverse osmosis. Deionization (demineralization) or distillation will also remove chlorides from water, but these methods are less suitable for household use than reverse osmosis.

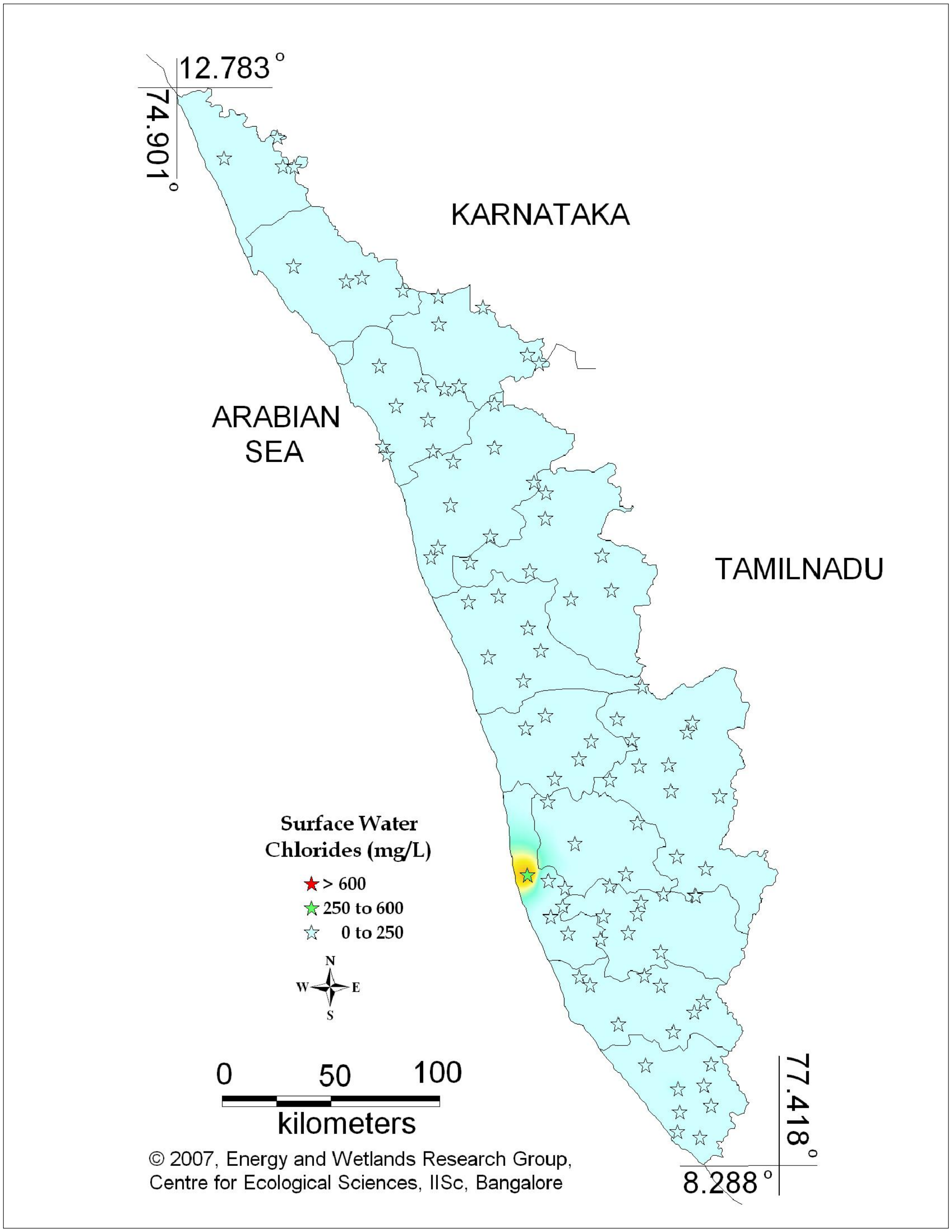
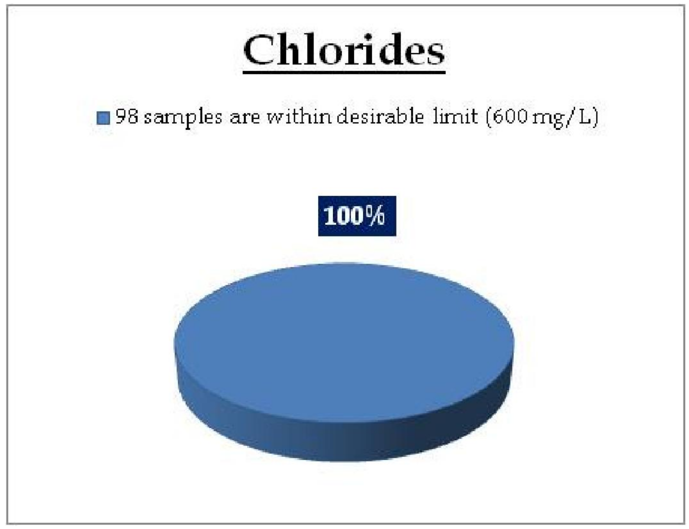


Figure 12.1: Spatial variation of Chlorides in surface water

Surface water - Chlorides

<table>
<tr><td>Tolerance limit for inland surface waters subject to pollution

Desirable Limit: 250 mg/L
Permissible Limit: 1000 mg/L</td><td>
</td></tr>
<tr><td colspan="2">Remarks

All the 98 surface water samples collected from rivers, streams and lakes spread over in Kerala are under the inland surface water standard.</td></tr>
</table>

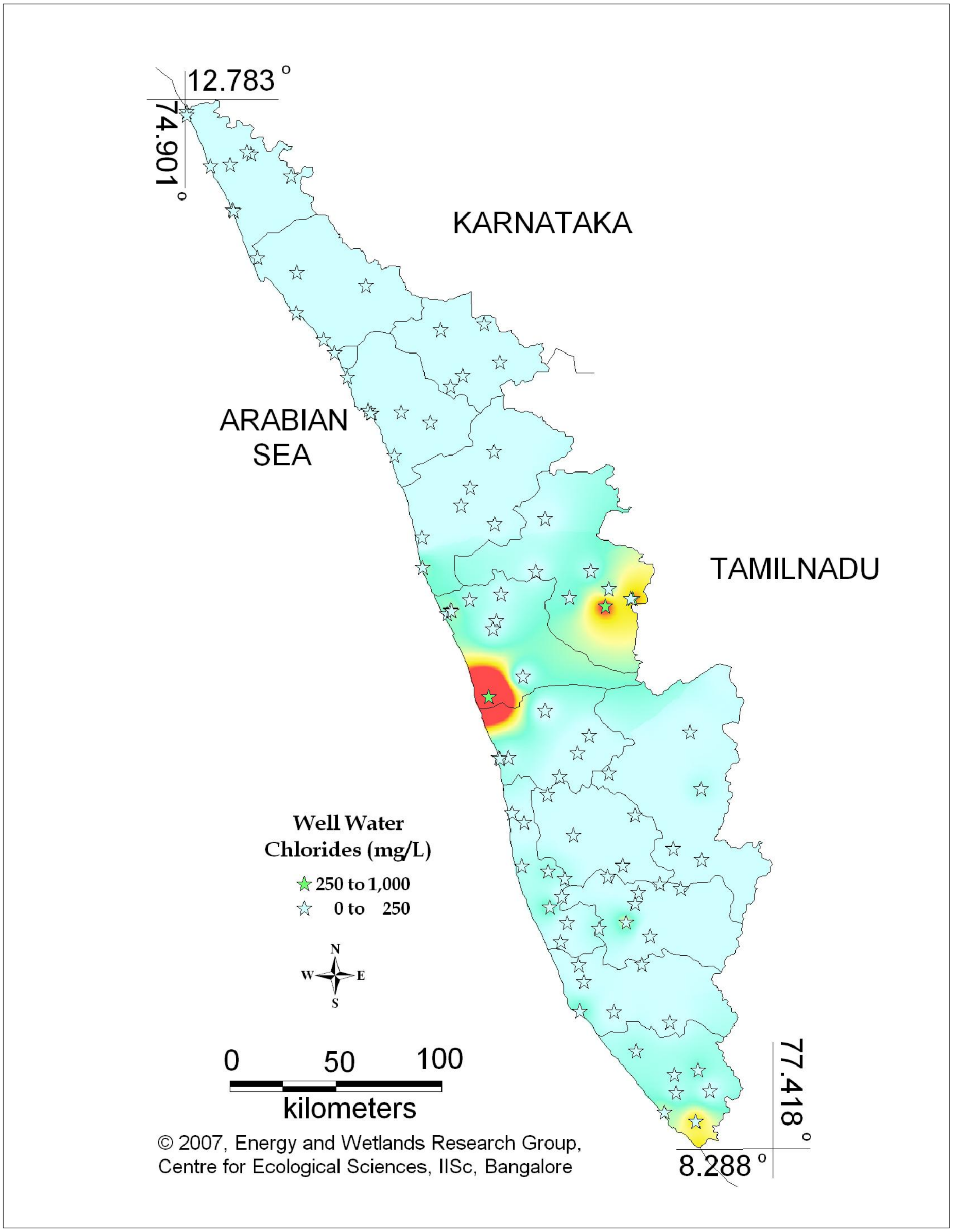
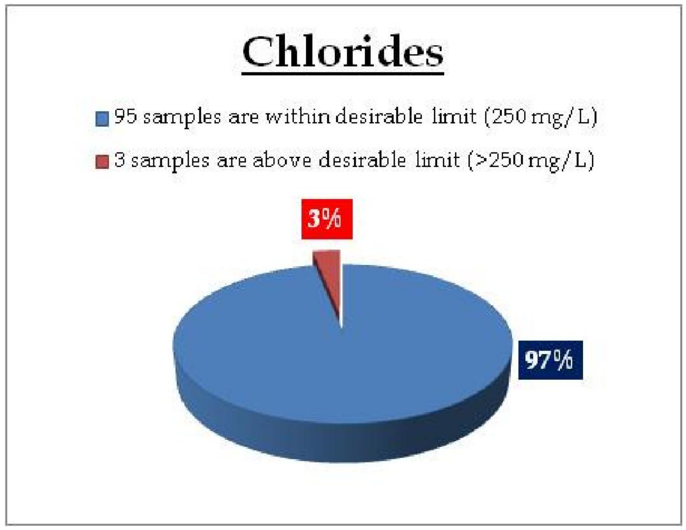


Figure 12.2: Spatial variation of chlorides in well water

Well water- Chlorides

Standard for Drinking Water (BIS 105000)
Desirable Limit: 250 mg/L
Permissible limit in the absence of an alternative source: 1000mg/L

Beyond this limit taste, corrosion and palatability are affected.



Remarks
Sampling sites above desirable limit are listed in Table 13

Table 13: Sampling locations of well water containing chlorides above desirable limit

Location	**Value**	**District**
Kollengode	268.29	Palakkad
Placimada	314.35	Palakkad
Koodungalur	921.01	Thrissur

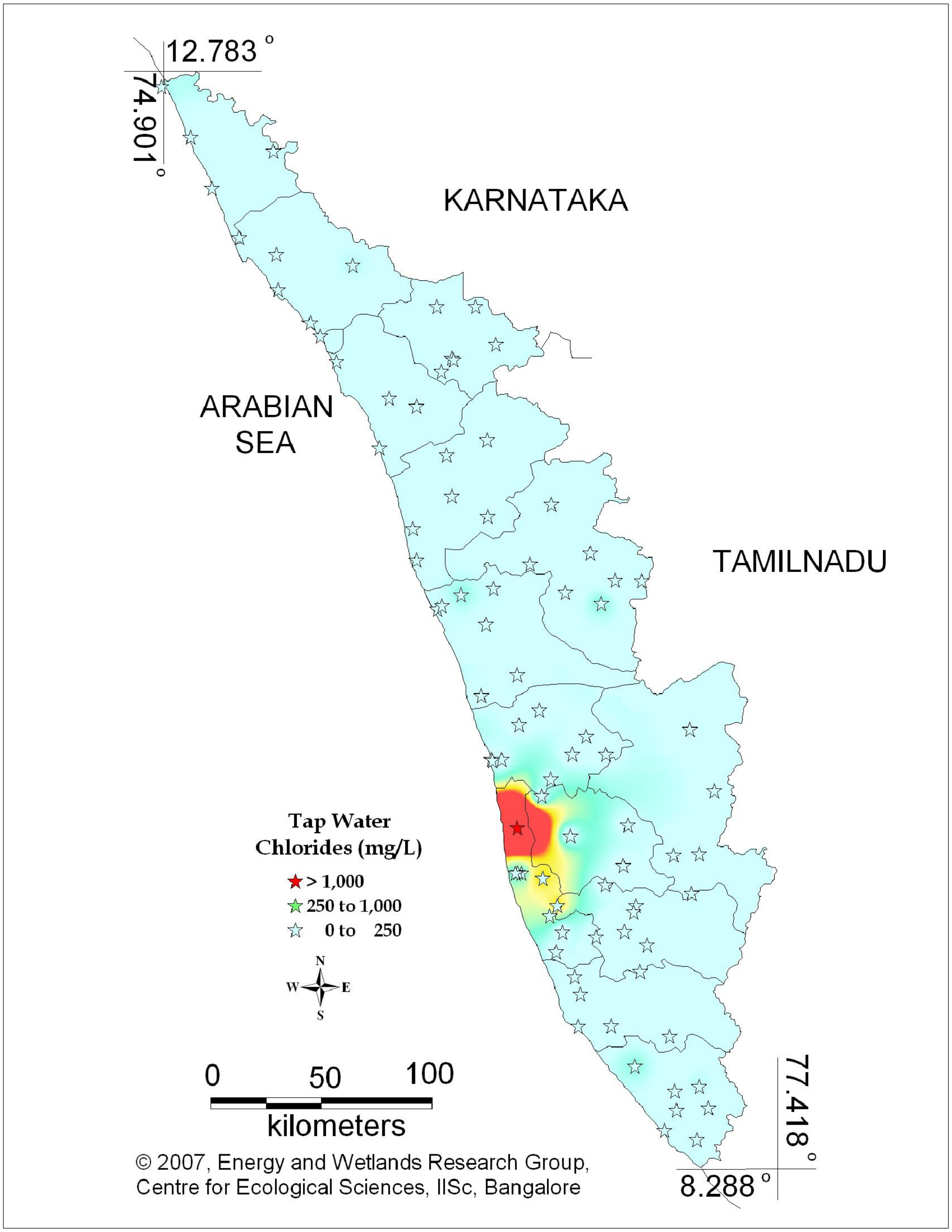
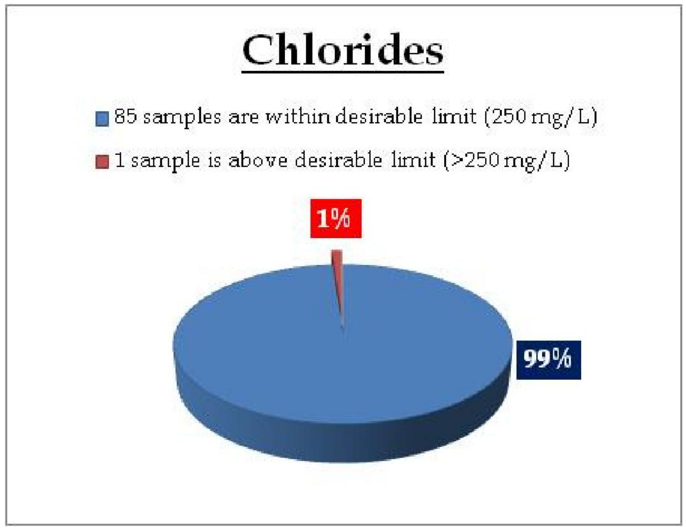


Figure 12.3: Spatial variation of chlorides in tap water

Tap water- Chlorides

Standard for Drinking Water (BIS 105000)
Desirable Limit: 250 mg/L
Permissible limit in the absence of an alternative source: 1000mg/L

Beyond this limit taste, corrosion and palatability are affected.



Remarks
Sampling site above desirable limit is listed in Table 13.2

Table 13.2: Sampling locations of tap water containing chlorides above desirable limit

Location	Value	District
Kalikulam Junction	1751.93	Alappuzha

Phosphates

Phosphates are chemical compounds containing phosphorus. Phosphorus is a non-metallic element which is necessary for life and is found in rock as inorganic phosphates. As water runs over and through rocks it carries off small amounts of minerals such as calcium, magnesium, and phosphates. Inorganic phosphates are a plant nutrient and are taken in by plants with water and incorporated into organic phosphate compounds. Animals obtain their essential phosphorus from phosphates in water and plant material. Natural waters have a phosphorus concentration of approximately 0.02 mg/L which is a limiting factor for plant growth. On the other hand, large concentrations of this nutrient can accelerate plant growth.

Effects on Environment and Human Health

Phosphates enter waterways through manmade sources also. The addition of large quantities of phosphates to waterways accelerates algae and plant growth in natural waters; enhancing eutrophication and depleting the water body of oxygen. This can lead to fish kills and the degradation of habitat with loss of species. Large mats of algae can form and in severe cases can completely cover small lakes. As a result, water can become putrid from decaying organic matter. When the concentration of phosphates rises above 100 mg/liter the coagulation processes in drinking water treatment plants may be adversely affected. Manmade sources of phosphate include human sewage, agricultural run-off from crops, sewage from animal feedlots, pulp and paper industry, vegetable and fruit processing, chemical and fertilizer manufacturing, and detergents.

Remedial Measures

The precipitation of phosphates from wastewater can occur during different phases within the wastewater treatment process. Pre-precipitation, where the chemicals are added to raw wastewater in primary sedimentation facilities, removes the precipitated phosphates with the primary sludge. In co-precipitation, the chemicals are added during secondary treatment to the effluent from the primary sedimentation facilities; to the mixed liquor in the activated-sludge process; or to the effluent from a biological treatment process before secondary sedimentation. They are removed with the waste biological sludge. In post-precipitation, the chemicals are added to the effluent from secondary sedimentation facilities and are removed in separate sedimentation facilities or in effluent filters. An alternative, biotechnological, approach is that of 'Enhanced Biological Phosphate Removal' ('EBPR') which utilises the ability of some microorganisms to accumulate phosphate (as polyphosphate) in excess of their normal metabolic requirements.

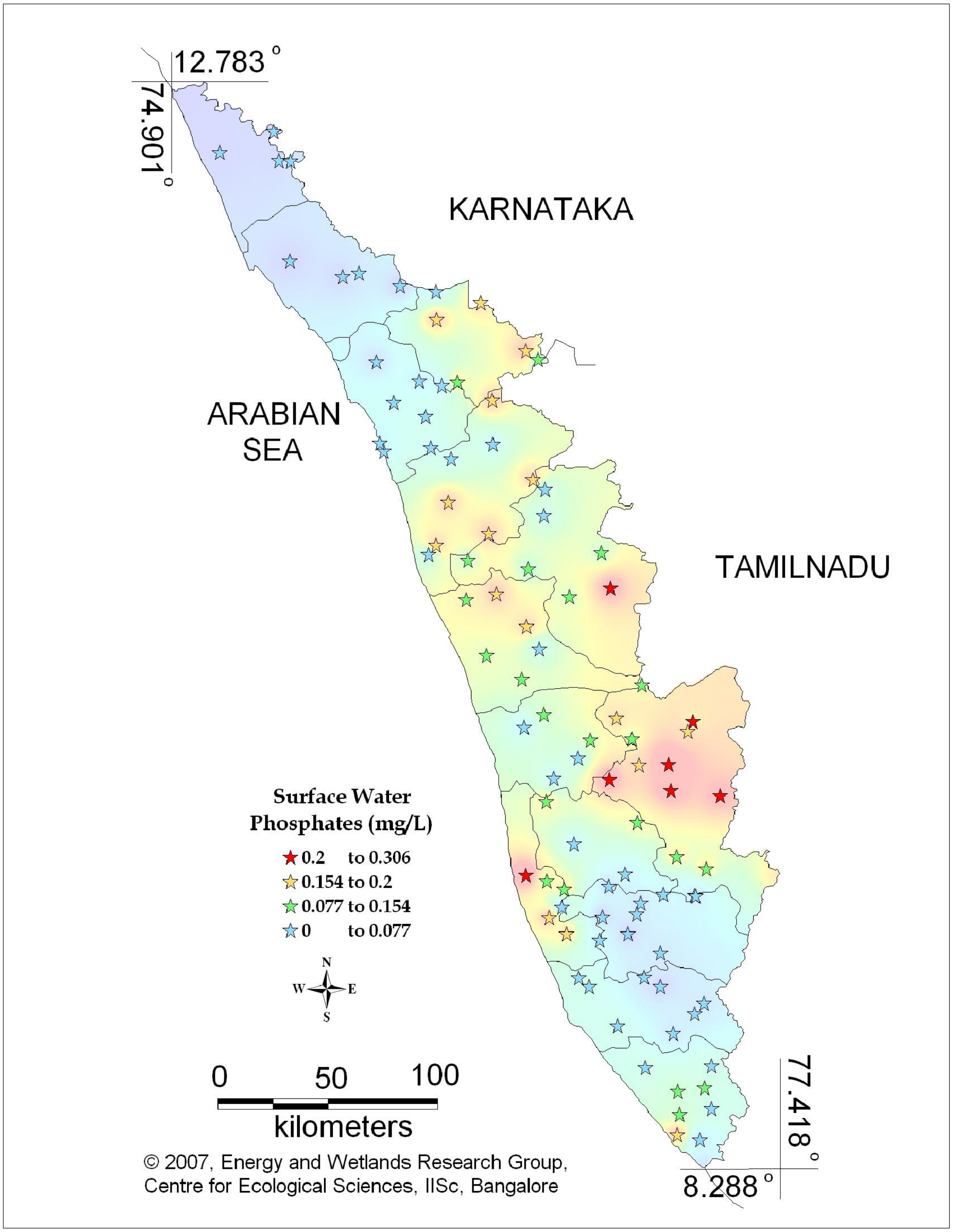
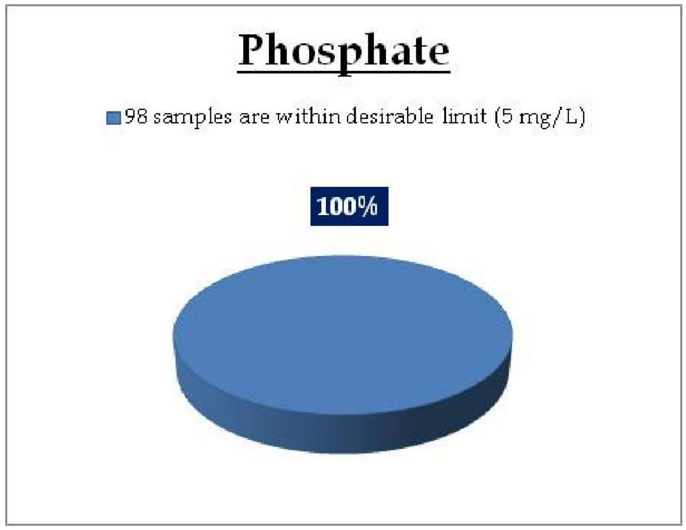


Figure 13.1:Spatial variation of phosphates in Kerala's surface water

Surface water - Phosphates

Tolerance limit for inland surface waters subject to pollution Permissible Limit: 5 mg/L	

Remarks

All the 98 surface water samples collected from rivers, streams and lakes spread over in Kerala are under the inland surface water standard.

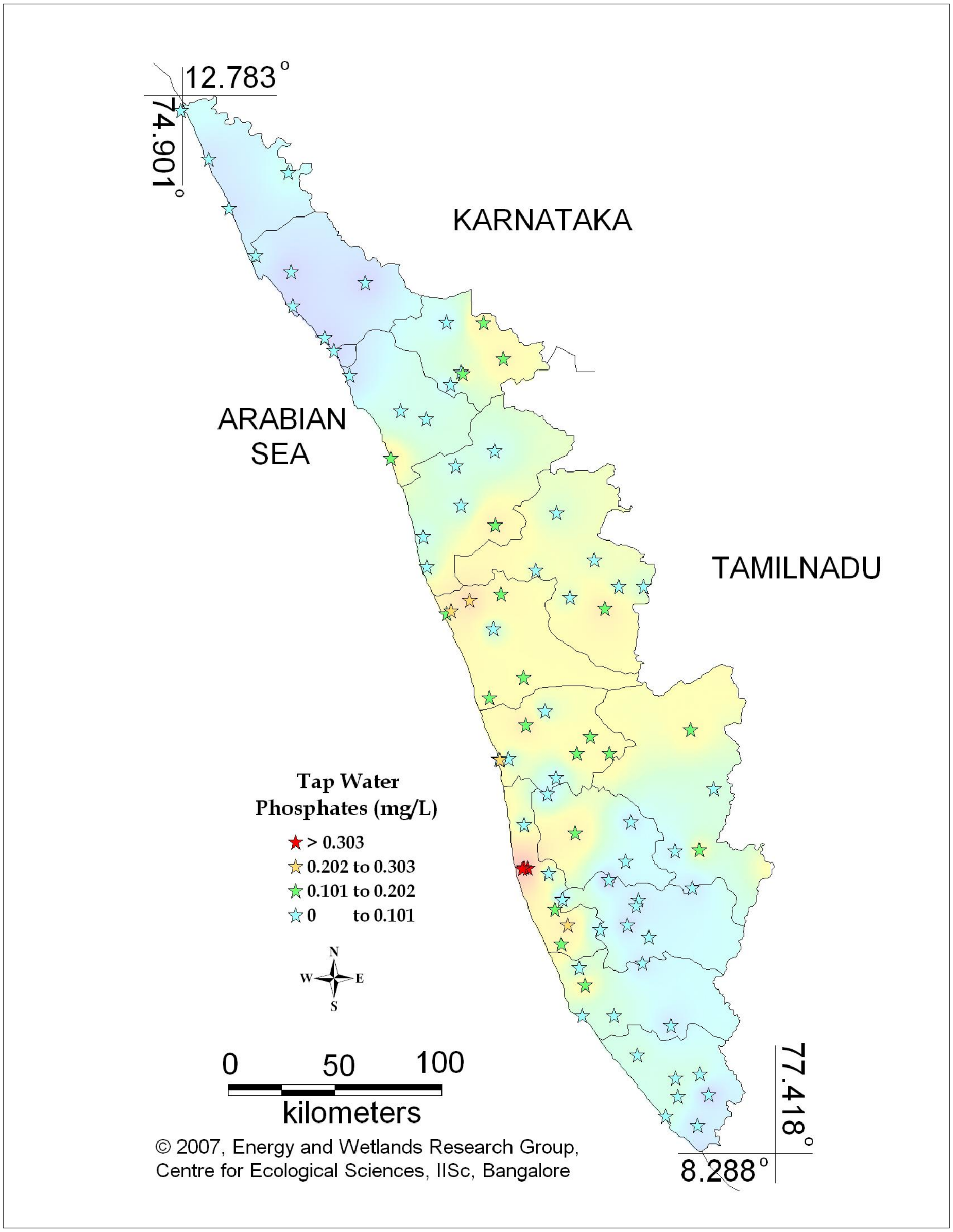


Figure 13.3: Spatial variation of phosphates in Kerala's tap water

Sulphate

Two forms of sulphur are commonly found in drinking water: sulphate and hydrogen sulphide. Both forms are nuisances and usually do not pose a health risk at the concentrations found in domestic wells.

Sulphate is a combination of Sulphur and oxygen, part of naturally occurring minerals in some soil and rock. The mineral dissolves over time and is released into ground water. Hydrogen sulfide is produced by Sulphur-reducing bacteria, which use sulphur as an energy source. The bacteria chemically change natural sulfate in water to hydrogen sulfide. Hydrogen sulfide gas also occurs naturally in some ground water. It is found in deep or shallow wells.

Effects on Environment and Human Health

Sulphur a secondary water contaminant, with no direct threat to human health. Sulphate gives water a bitter taste and can have a laxative effect that may lead to dehydration. Hydrogen sulphide gives water a "rotten egg" odor and taste, and can cause nausea. Both forms of sulphur damages water distribution system. Sulphate causes scale buildup in pipes, producing a dark slime that can clog plumbing and stain clothing. Hydrogen sulphate is corrosive to metals such as iron, steel, copper and brass. It can tarnish silverware and discolor copper and brass utensils. Hydrogen sulphide also can cause yellow or black stains on kitchen and bathroom fixtures.

Coffee, tea and other beverages made with water containing hydrogen sulfide may be discolored and the appearance and taste of cooked foods can be affected. High concentrations of dissolved hydrogen sulfide also can foul the resin bed of an ion exchange water softener.

Remedial Measures

Sulphate can be partially removed by reverse osmosis.

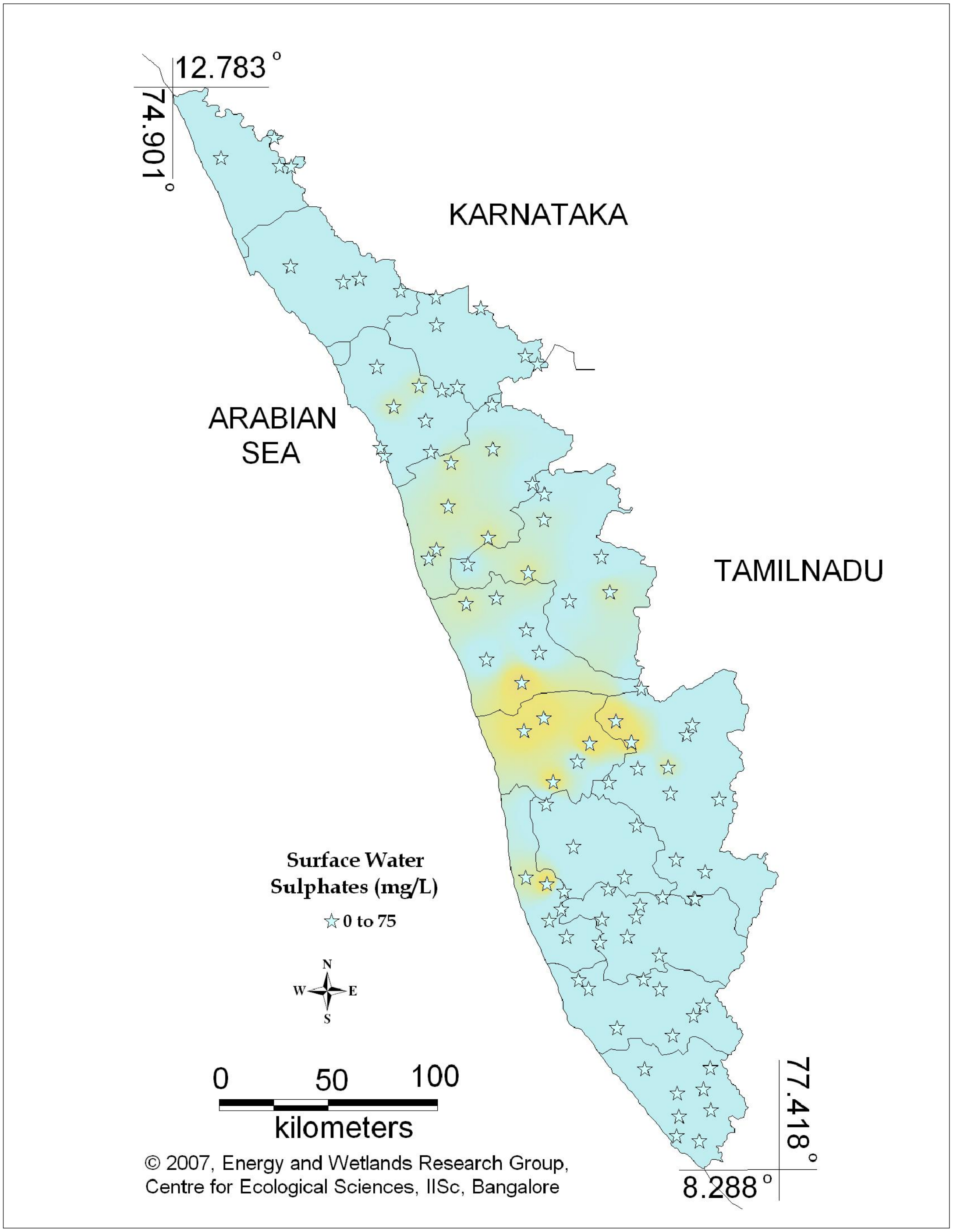
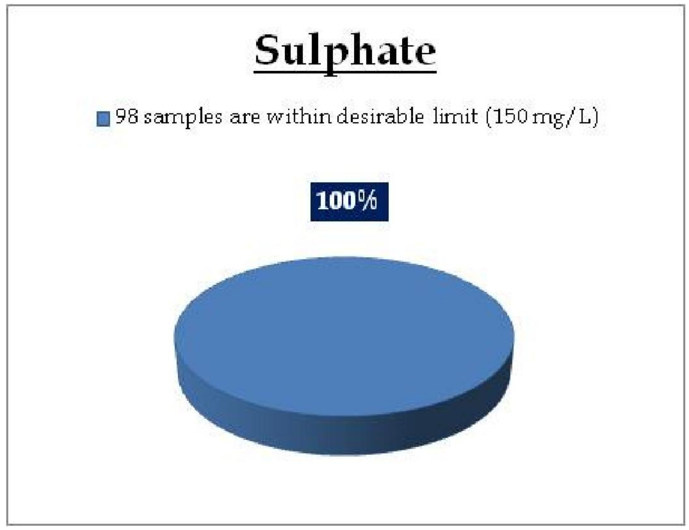


Figure 14.1: Spatial variation of sulphate in Kerala's surface water

Surface water - Sulphate

Standard for Drinking Water (BIS 105000)
Desirable Limit: 150 mg/L
Permissible limit in the absence of an alternative source: 400mg/L

Beyond this cause gastrointestinal irritation when magnesium or sodium is present



REMARKS
All the 98 surface water samples collected from rivers, streams and lakes spread over in Kerala are under the inland surface water standard.

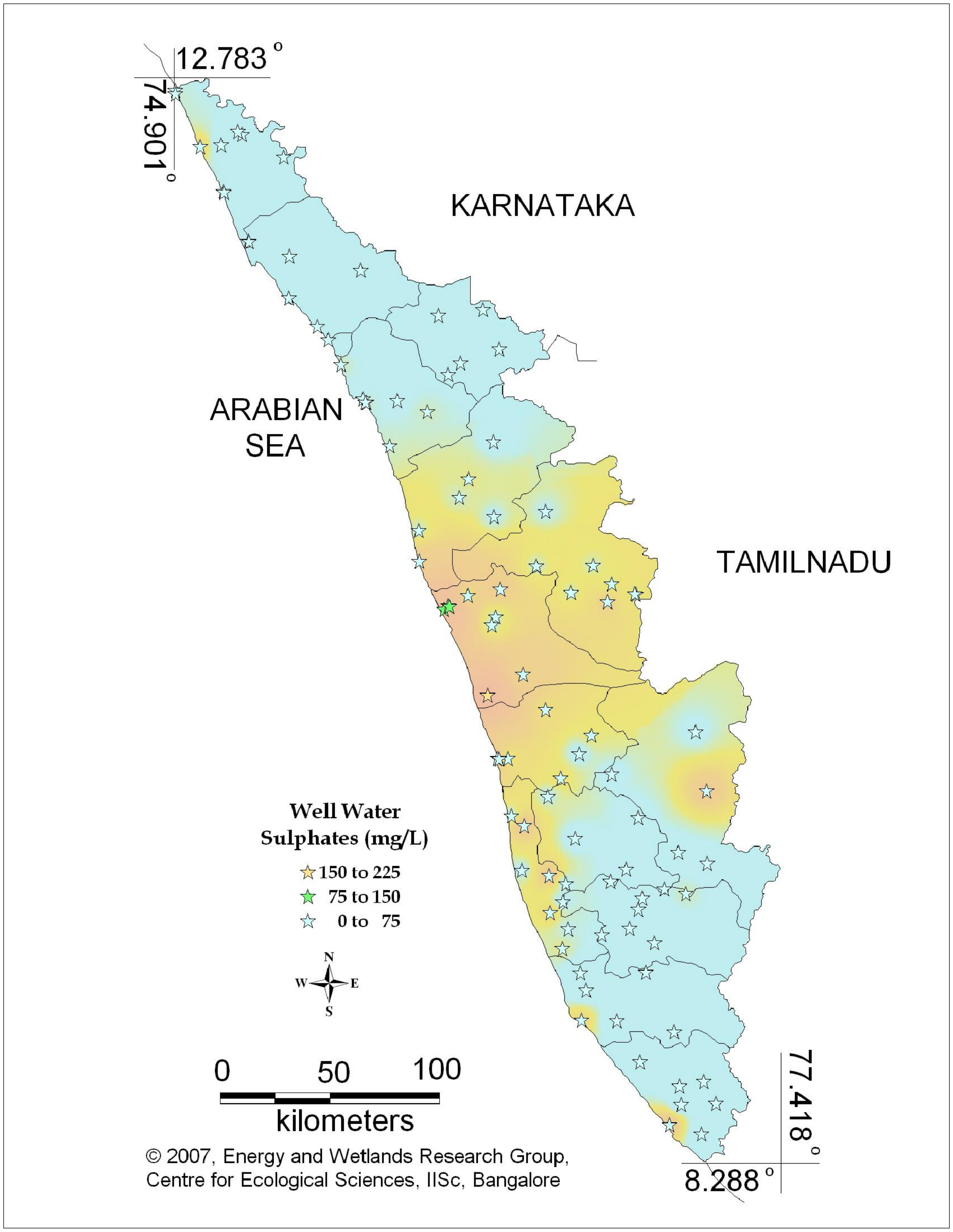
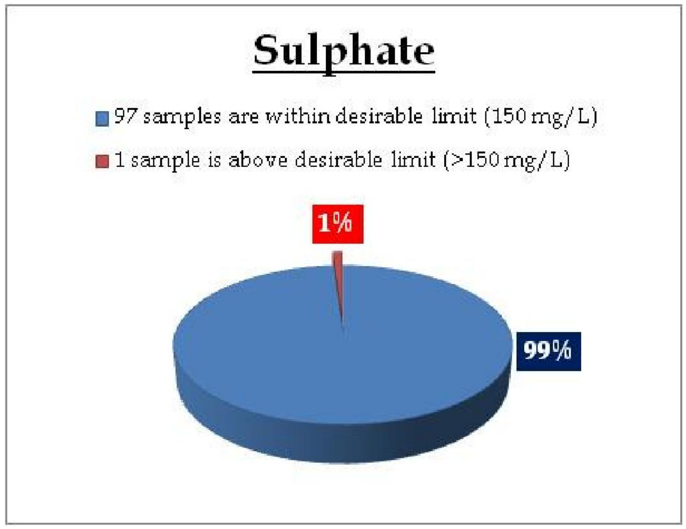


Figure 14.2: Spatial variation of sulphate in Kerala's well water

Well water - Sulphate

Standard for Drinking Water (BIS 105000)
Desirable Limit: 150 mg/L
Permissible limit in the absence of an alternative source: 400mg/L

Beyond this cause gastrointestinal irritation when magnesium or sodium is present



Remarks
Sampling sites above desirable limit, value (mg/L) and district is listed below:

Location	**Value**	**District**
Koodungalur	200.7	Thrissur

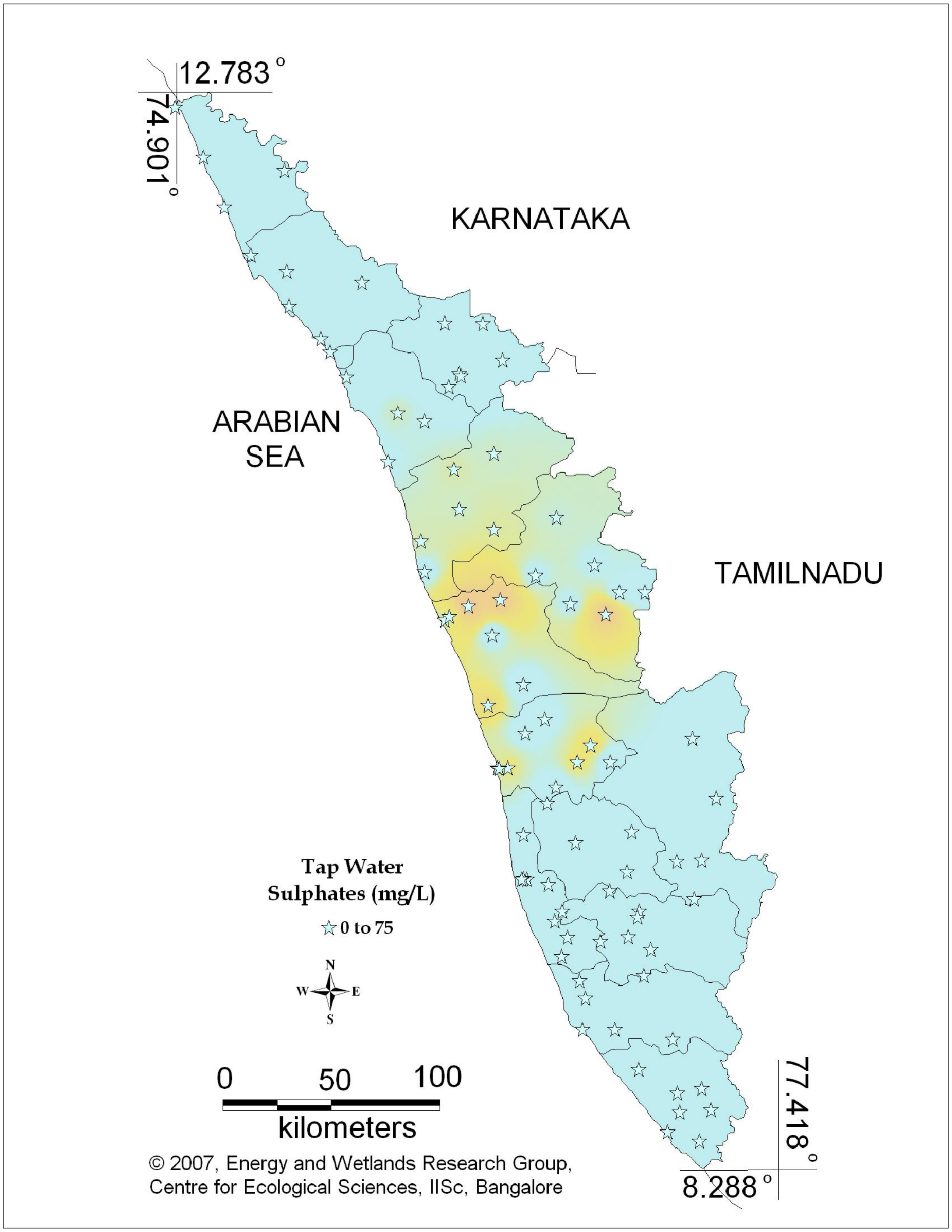
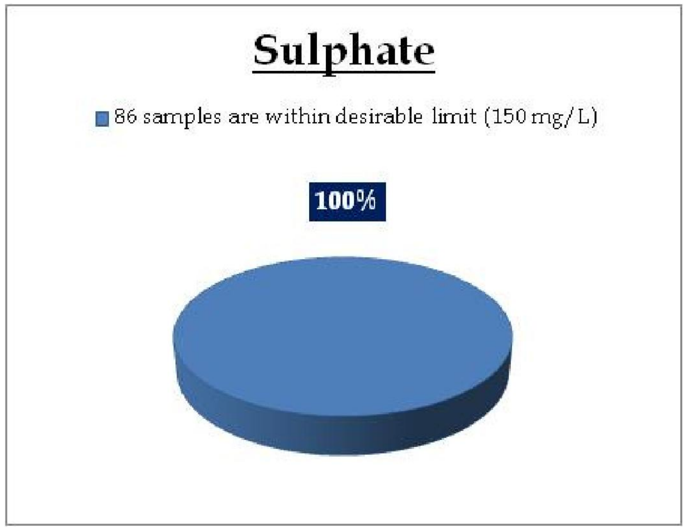


Figure 14.3: Spatial variation of sulphate in Kerala's tap water

Tap water - Sulphate

<table>
<tr>
<td>Standard for Drinking Water (BIS 105000)
Desirable Limit: 150 mg/L
Permissible limit in the absence of an alternative source: 400mg/L

Beyond this cause gastrointestinal irritation when magnesium or sodium is present</td>
<td>
</td>
</tr>
</table>

Remarks

All the 98 surface water samples collected from rivers, streams and lakes spread over in Kerala are under the inland surface water standard.

Hardness

Hard water is high in dissolved minerals, both calcium and magnesium. As water moves through soil and rock, it dissolves small amounts of these naturally-occurring minerals and carries them into the ground water zone. Water is a great solvent for calcium and magnesium, so if the minerals are present in the soil around well and its water supply, we end up with hard water. Hard water interferes with almost every cleaning task, from doing the laundry to washing dishes to taking a shower. Clothes can look dingy and feel rough and scratchy. Dishes and glasses get spotted and a film may build up on shower doors, bathtubs, sinks and faucets. Washing hair in hard water may leave it feeling sticky and dull. Finally, hard water can cause a residue to build-up in pipes that can lower water pressure throughout the house.

Effects on Environment and Human Health

Hardness does not pose a serious health risk and is not regulated. In fact, calcium and magnesium in drinking water can help ensure to get the average daily requirements for these minerals in our diet.
However, hard water can be a nuisance due to the mineral buildup on plumbing fixtures and poor soap and detergent performance. It often causes aesthetic problems, such as an alkali taste to the water that makes coffee taste bitter; build-up of scale on pipes and fixtures than can lead to lower water pressure; build-up of deposits on dishes, utensils and laundry basins; difficulty in getting soap and detergent to foam; and lowered efficiency of electric water heaters.

Remedial Measures

Water softeners operate on the ion exchange process (specifically a cation exchange process where ions are exchanged). In this process, water passes through a media bed, usually sulfonated polystyrene beads. The beads are supersaturated with sodium (a positive ion). The ion exchange process takes place as hard water passes through the softening material. The hardness minerals (positively charged Calcium and Magnesium ions) attach themselves to the resin beads while sodium on the resin beads is released simultaneously into the water. When the resin becomes saturated with calcium and magnesium, it must be recharged. The recharging is done by passing a concentrated salt solution through the resin. The concentrated sodium replaces the trapped calcium and magnesium ions which are discharged in the waste water. Softened water is not recommended for watering plants, lawns, and gardens due to its elevated sodium content.

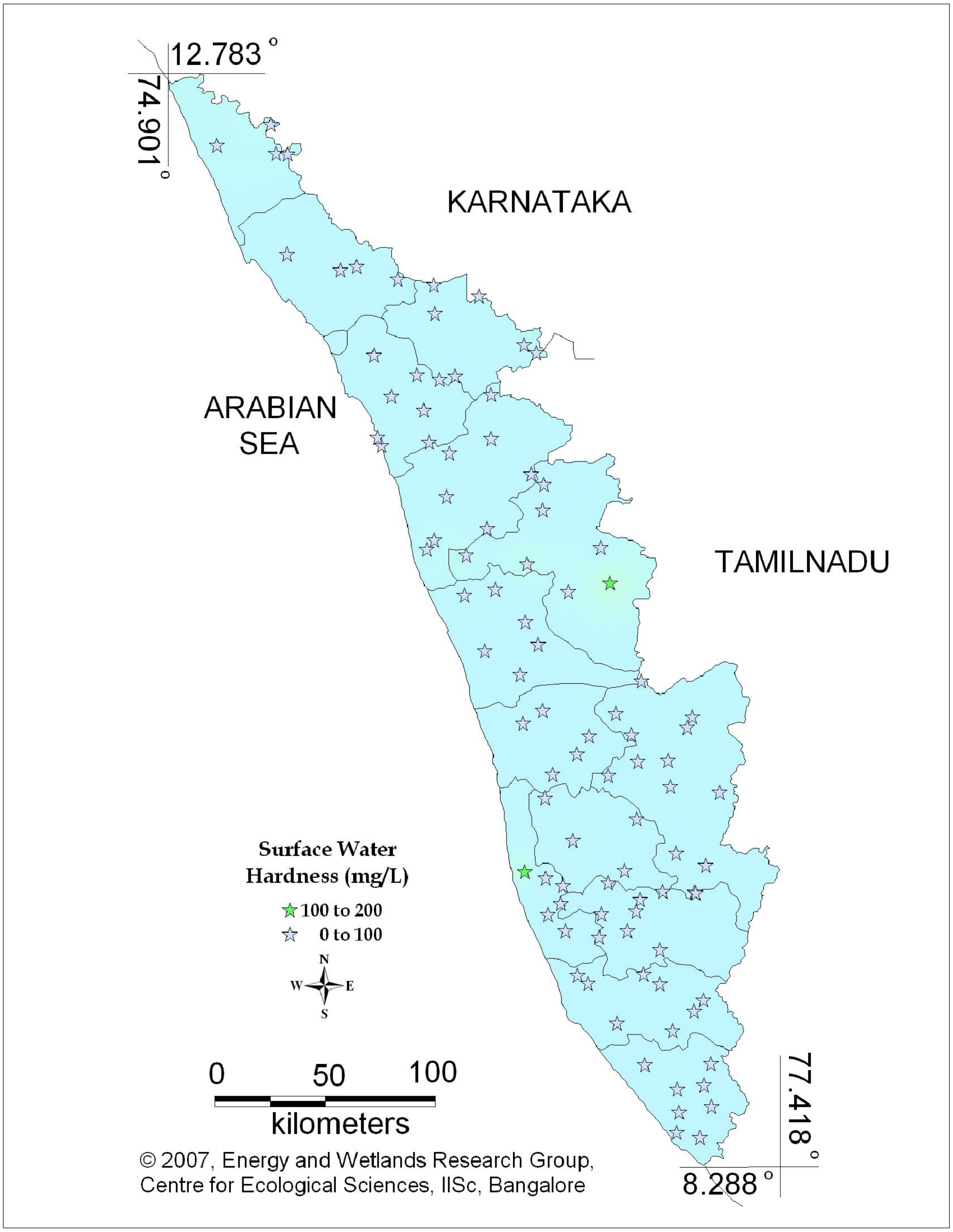
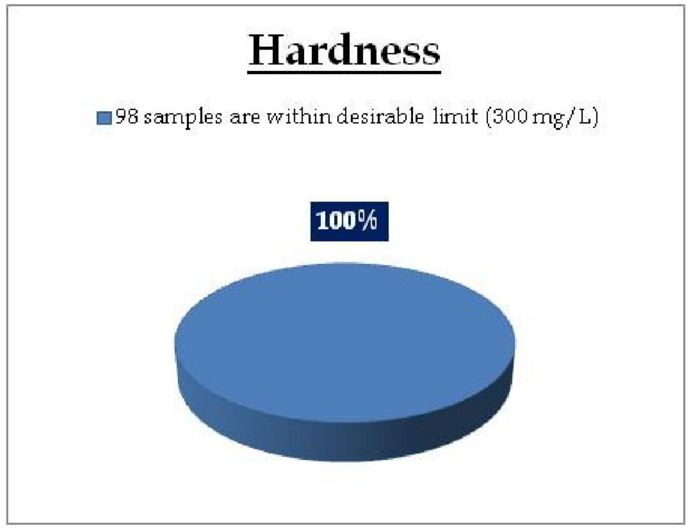


Figure 15.1: Spatial variation of Hardness in Kerala's surface water

Surface water - Hardness

Tolerance limit for inland surface waters subject to pollution Desirable Limit: 300 mg/L Permissible Limit: 600 mg/L	

Remarks

All the 98 surface water samples collected from rivers, streams and lakes spread over in Kerala are under the inland surface water standard.

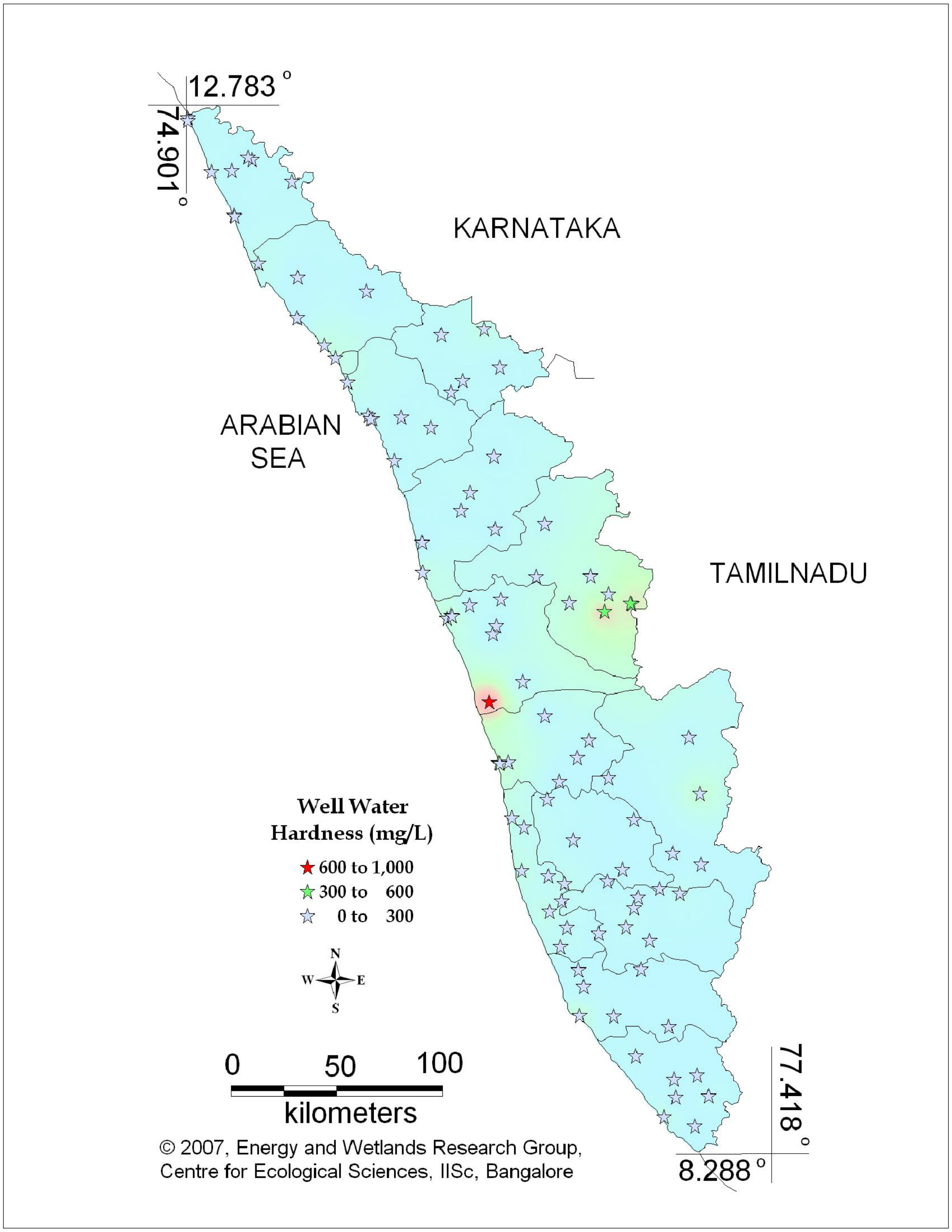
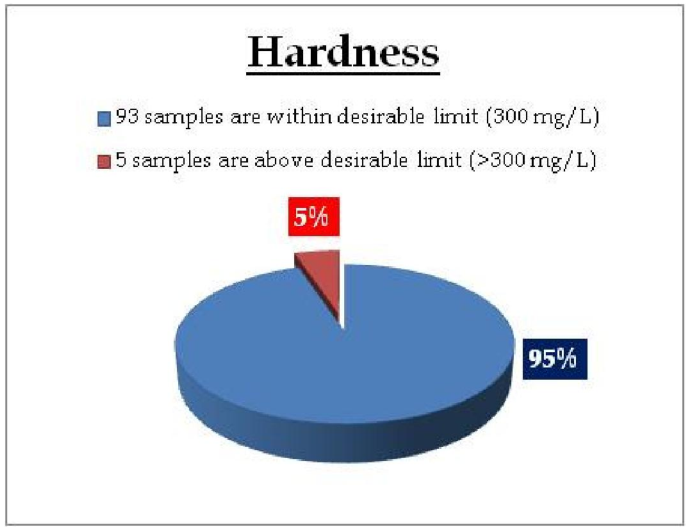


Figure 15.2: Spatial variation of Hardness in Kerala's well water

Well water - Hardness

Standard for Drinking Water (BIS 105000)
Desirable Limit: 300 mg/L
Permissible limit in the absence of an alternative source: 600mg/L



Remarks
Wells at following sampling sites have hardness above desirable limit

Location	Value	District
Kannimari	320.00	Palakkad
Fort Cochin	392.00	Ernakulam
Placimada	512.00	Palakkad
Kollengode	520.00	Palakkad
Koodungalur	700.00	Thrissur

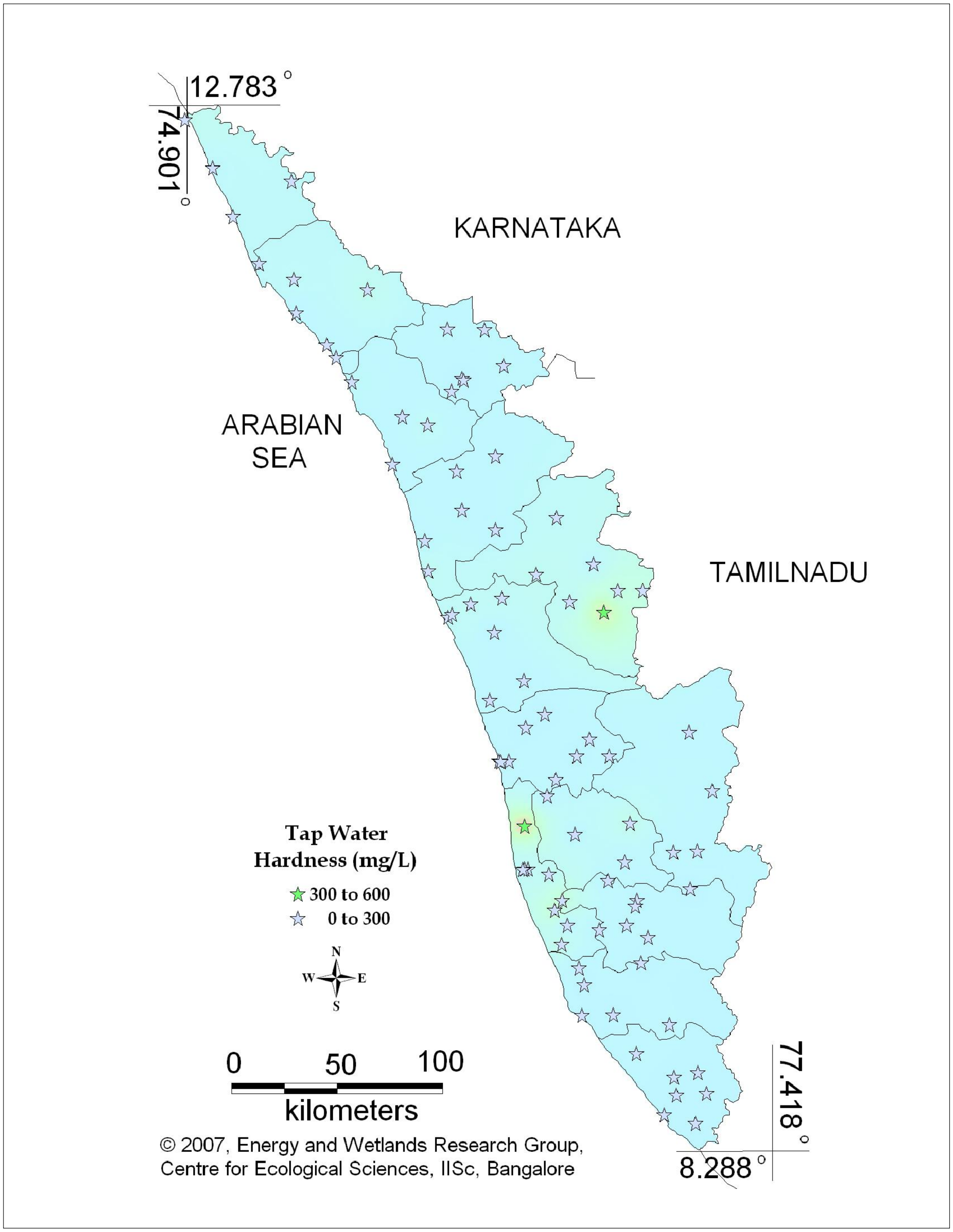
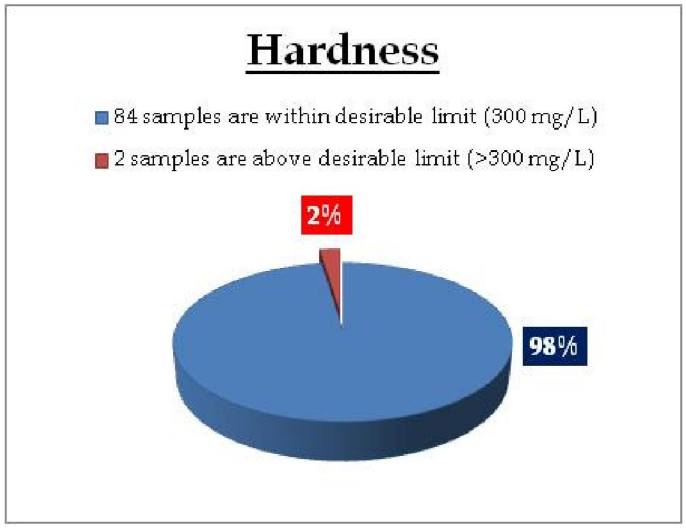


Figure 15.3: Spatial variation of hardness in Kerala's tap water

Tap water - Hardness

Standard for Drinking Water (BIS 105000)
Desirable Limit: 300 mg/L
Permissible limit in the absence of an alternative source: 600mg/L



Remarks
Tap water at following sampling sites have hardness above desirable limit

Location	Value	District
Kollengode-Vellanara	424.00	Palakkad
Kalikulam Junction	500.00	Alappuzha

Calcium

Calcium salts and calcium ions are among the most commonly occurring in nature. They may result from the leaching of soil and other natural sources or may come from man-made sources such as sewage and some industrial wastes. Calcium is usually one of the most important contributors to hardness. Human body requires approximately 0.7 to 2.0 grams of calcium per day as a food element, excessive amounts can lead to the formation of kidney or gallbladder stones. High concentrations of calcium can also be detrimental to some industrial processes. Thus, both domestic and industrial water users have to consider calcium concentrations. Calcium (Ca) is the major mineral causing hardness in water. When groundwater saturated with dissolved carbon dioxide is pumped to the surface, any subsequent rise in temperature and/or reduction in pressure causes degassing of carbon dioxide and precipitation (settling) of calcium salts forming encrustation deposits.

Effects on Environment and Human Health

Calcium also serves an important role in the health of bodies of water. In natural water it is known to reduce the toxicity of many chemical compounds on fish and other aquatic life.

Remedial measures

In case of higher amount of calcium, it can be removed by reverse osmosis or deionization methods. These techniques will remove the entire calcium content, which may affect human health due to lack of calcium.

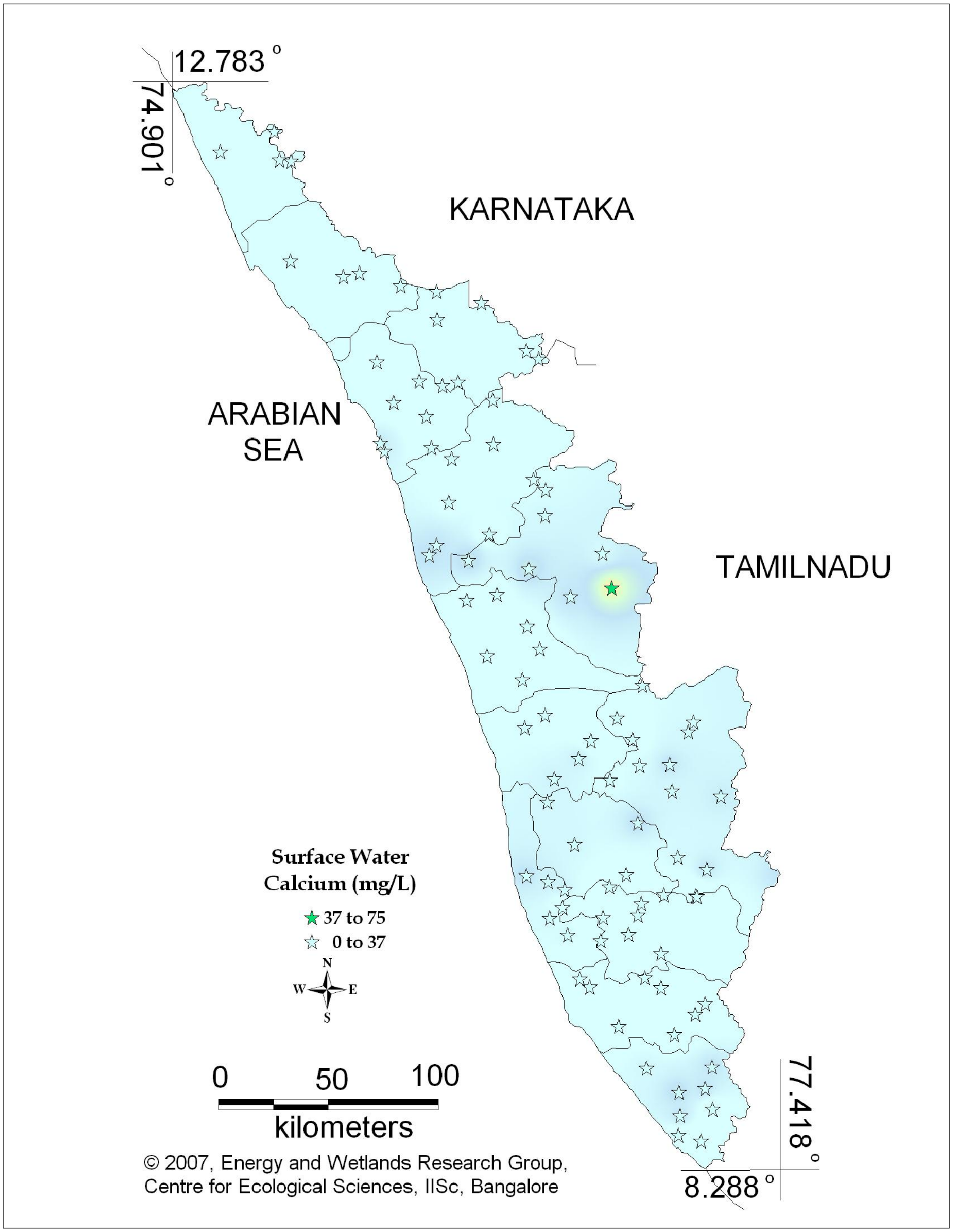
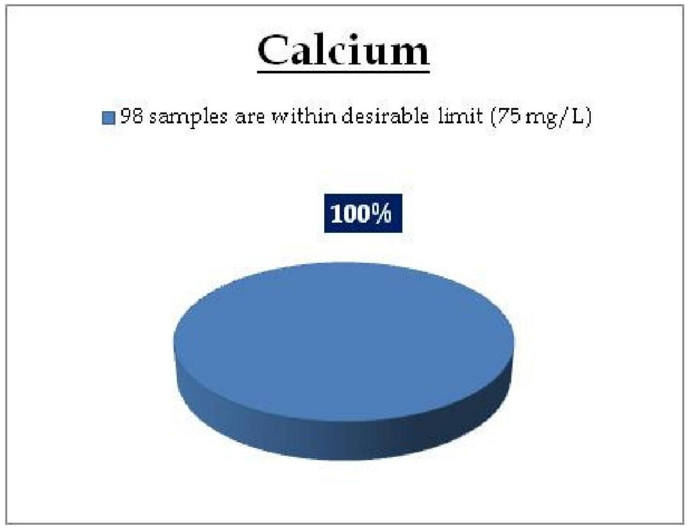


Figure 16.1: Spatial variation of calcium in Kerala's surface water

Surface water - Calcium

<table>
<tr><td>Tolerance limit for inland surface waters subject to pollution

Desirable Limit: 75 mg/L
Permissible Limit: 200 mg/L</td><td>
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<tr><td colspan="2">Remarks
All the 98 surface water samples collected from rivers, streams and lakes spread over in Kerala are under the inland surface water standard.</td></tr>
</table>

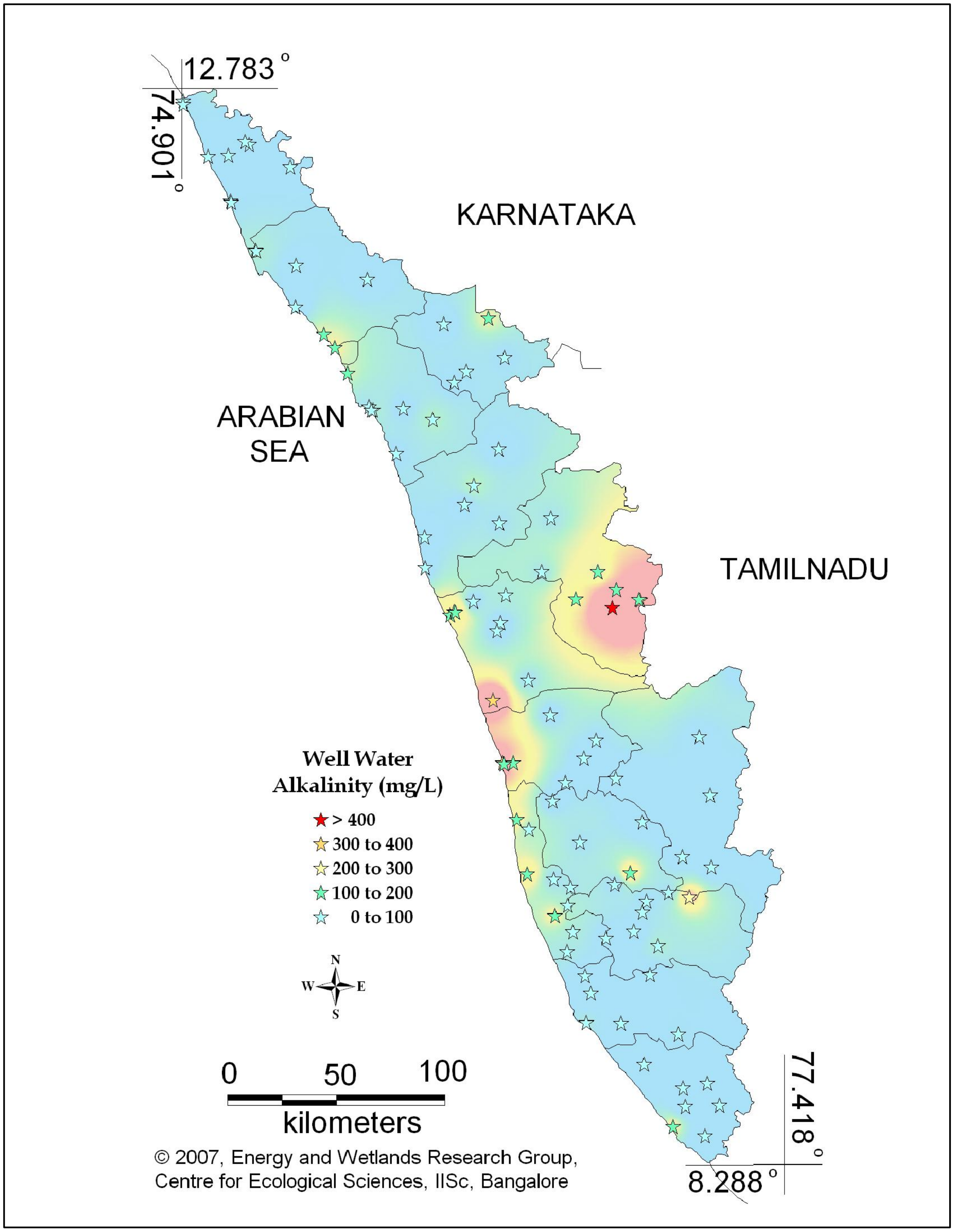
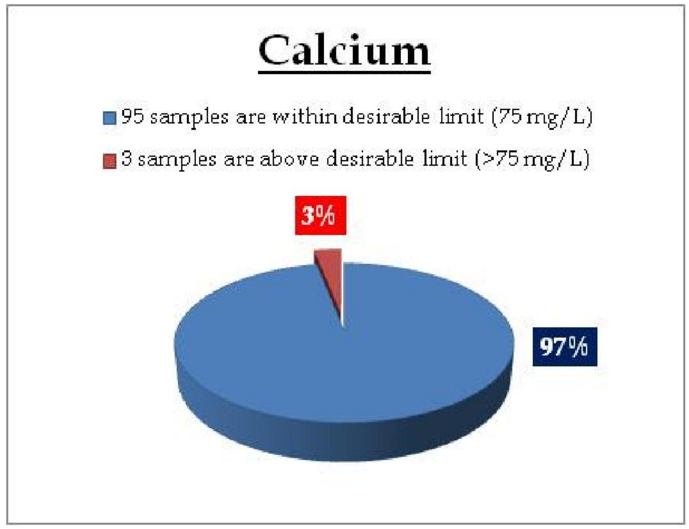


Figure 16.2: Spatial variation of calcium in Kerala's Well water

Well water - Calcium

Standard for Drinking Water (BIS 105000)

Desirable Limit: 75 mg/L
Permissible limit in the absence of an alternative source: 200mg/L



Remarks
Well water at following sites have calcium above desirable limit

Location	**Value**	**District**
Ponnani	109.02	Malappuram
Koodungalur	120.24	Thirssur
Fort Cochin	157.11	Ernakulam

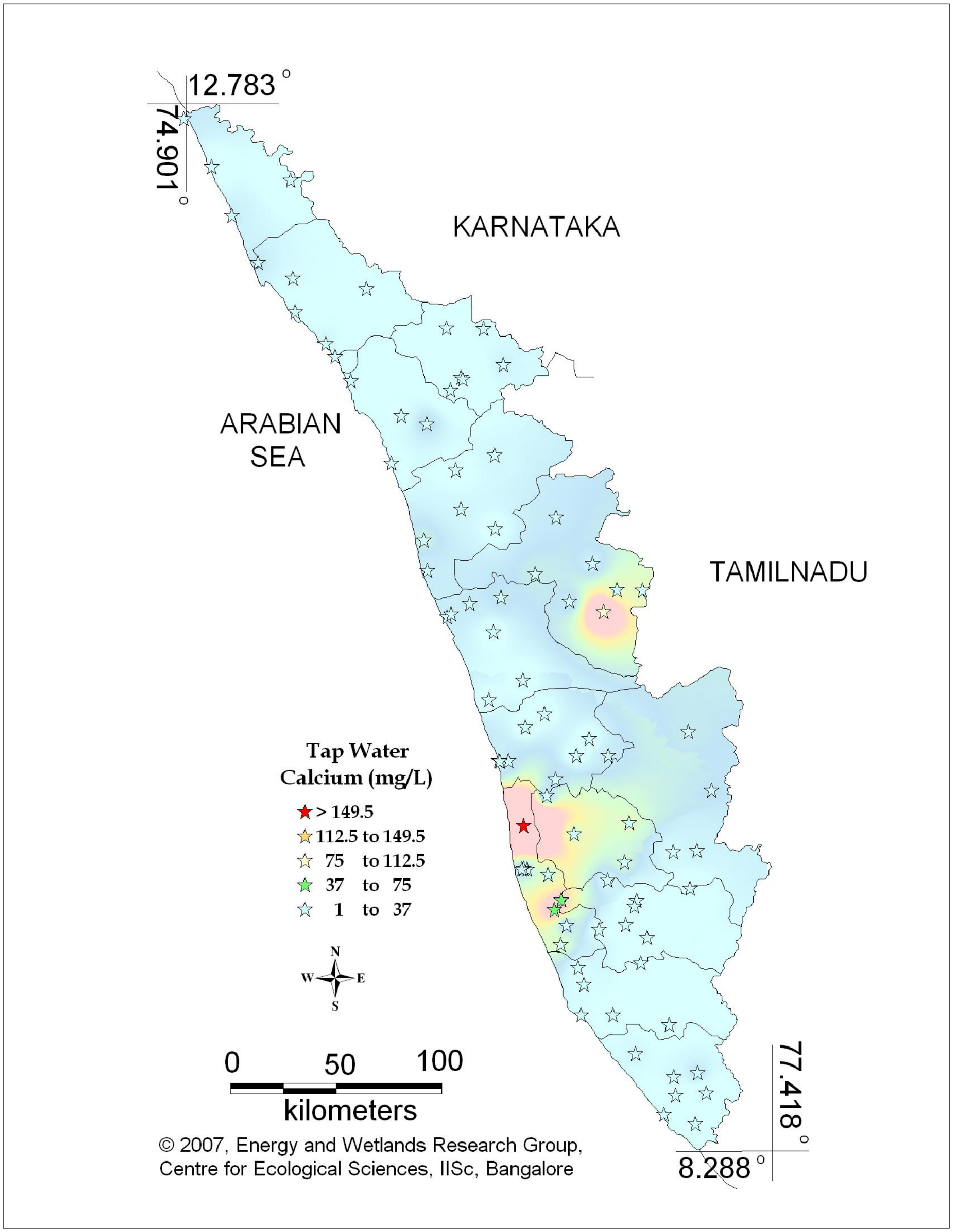


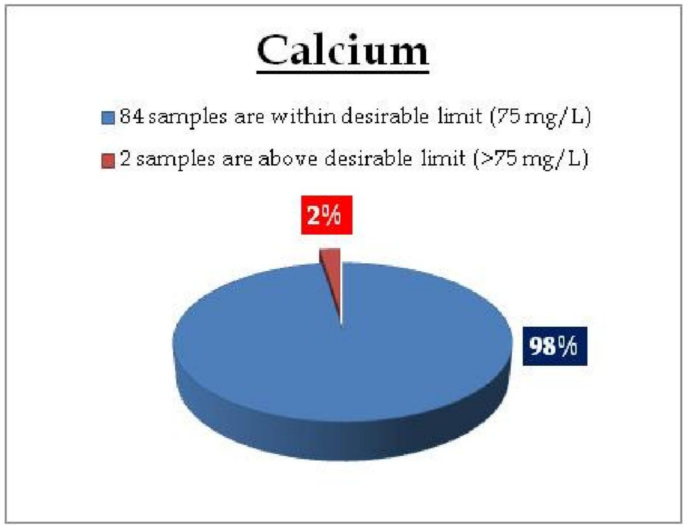
Figure 16.3: Spatial variation of calcium in Kerala's Tap water

Tap water- Calcium

Tolerance limit for inland surface waters subject to pollution

Desirable Limit: 75 mg/L
Permissible Limit: 200 mg/L

Encrustation in water supply structure and adverse effect on domestic use



Remarks
Tap water at following sampling sites have calcium above desirable limit

Location	Value	District
Kollengode-Vellanara	92.99	Palakkad
Kalikulam Junction	440.88	Alappuzha

Magnesium

A large number of minerals contains magnesium, for example dolomite (calcium magnesium carbonate; $CaMg(CO_3)_2$) and magnesite (magnesium carbonate; $MgCO_3$). Magnesium is washed from rocks and subsequently ends up in water. Magnesium has many different purposes and consequently may end up in water in many different ways. Chemical industries add magnesium to plastics and other materials as a fire protection measure or as filler. It also ends up in the environment from fertilizer application and from cattle feed. Magnesium sulphate is applied in breweries and magnesium hydroxide is applied as a flocculent in wastewater treatment plants. Magnesium is also a mild laxative.

Effects on Environment and Human Health

The studies found an inverse (protective) association between cardiovascular disease mortality and increased water hardness (measured by calcium carbonate or another hardness parameter and/or the calcium and magnesium content of water). The associations were reported in numerous studies, While magnesium is one of the elements that supports life, many studies have been performed regarding physiological functions as well as correlation with diseases.
Environmental problems indirectly caused by magnesium in water are caused by applying softeners. Calcium and magnesium ions (particularly calcium) negatively influence cleansing power of detergents, because these form nearly insoluble salts with soap.

Remedial Measures

Magnesium compounds can be removed from water by means of water softening.

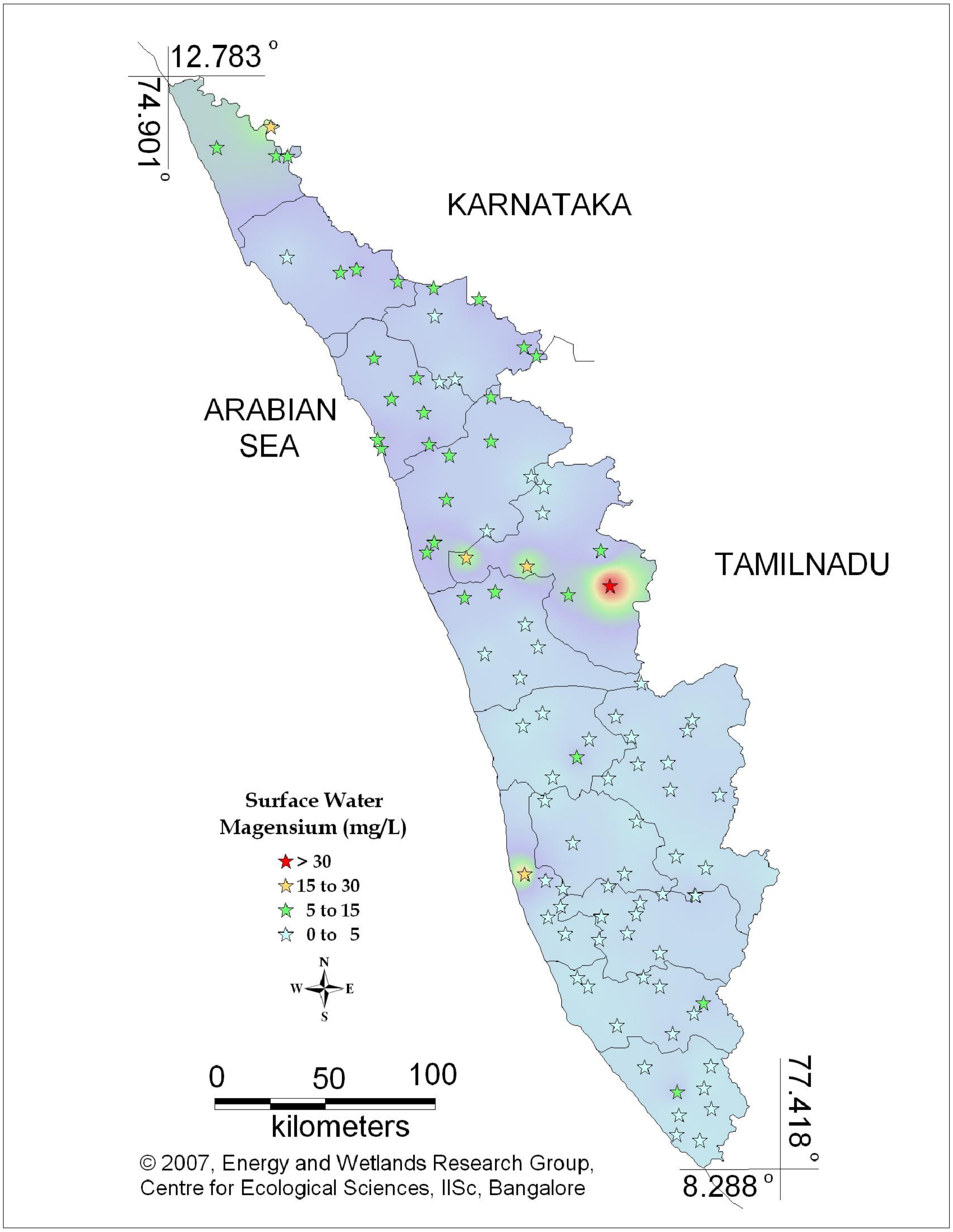


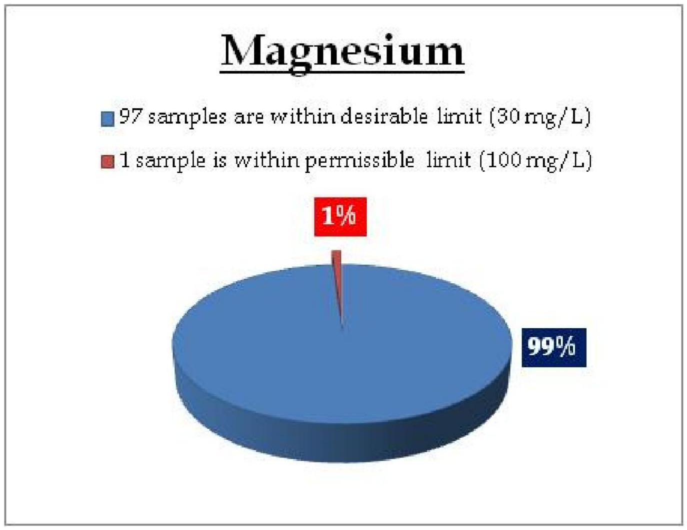
Figure 17.1: Spatial variation of Magnesium in Kerala's surface water

Surface water - Magnesium

Tolerance limit for inland surface waters subject to pollution

Desirable Limit: 30 mg/L*
Permissible Limit: 100 mg/L*

*Standard for Drinking Water (BIS 105000)



Remarks
Sampling site above desirable limit of Magnesium is:

Location	Value	District
Puzhapalam	31.60	Palakkad

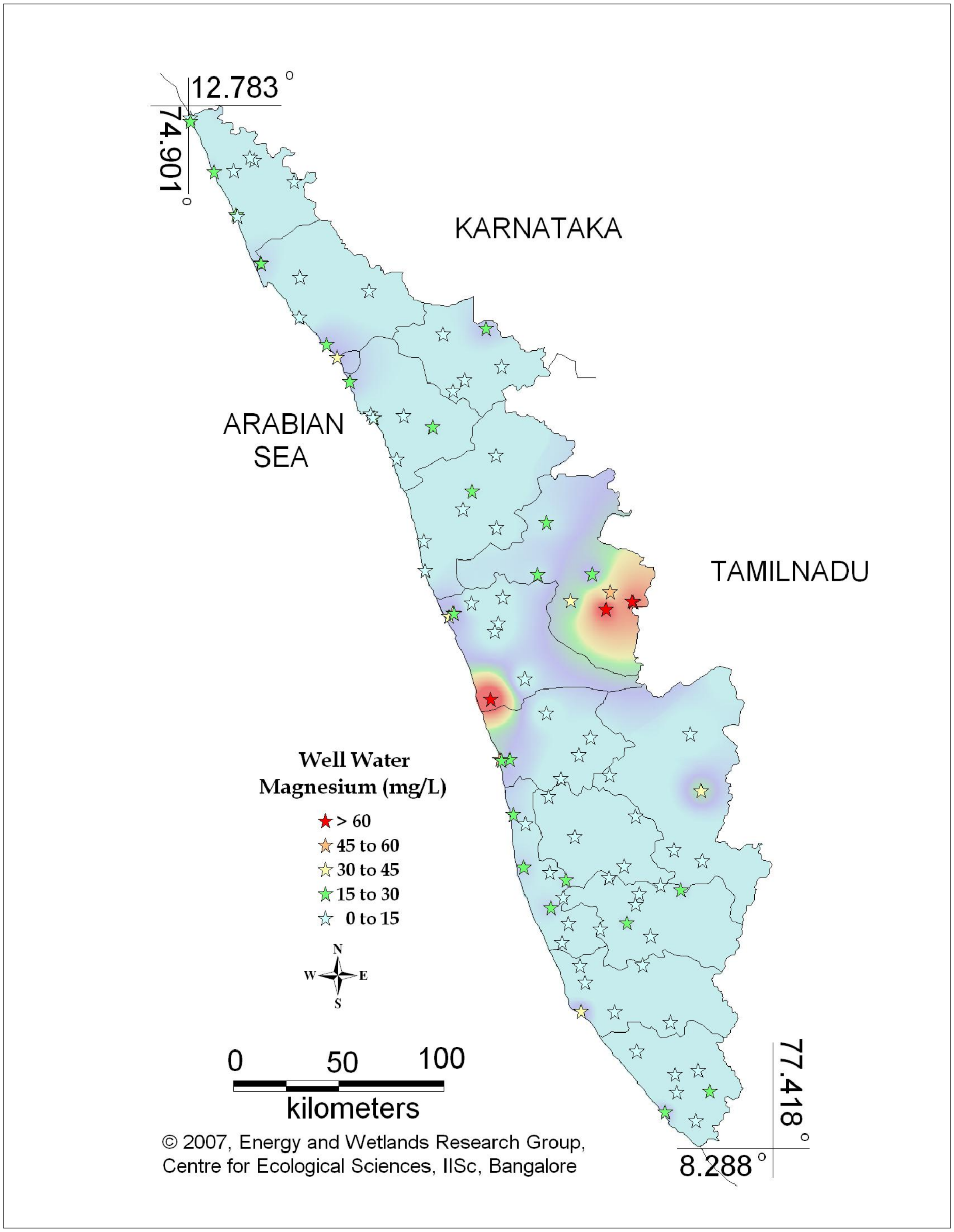
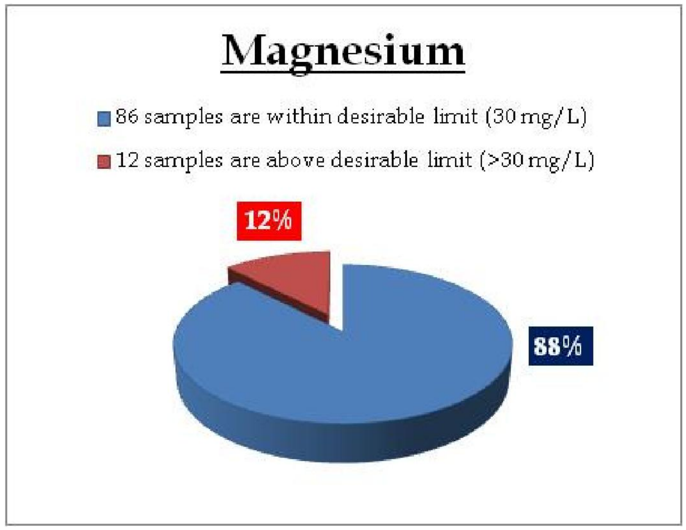


Figure 17.2: Spatial variation of Magnesium in Kerala's well water

Well water - Magnesium

Standard for Drinking Water (BIS 105000)
Desirable Limit: 30 mg/L
Permissible limit in the absence of an alternative source:100 mg/L



Remarks
Sampling sites where Magnesium is above desirable limit

Location	Value	District
Chavakkad	30.81	Thrissur
Mahe	31.99	Mahe - Puducheery
Kochupilammood	35.10	Kollam
Alathur	36.69	Palakkad
Guruvayoor	41.95	Thrissur
Thannimoodu	42.14	Idukki
Puzhapalam	46.24	Palakkad
Fort Cochin	57.31	Ernakulam
Kannimari	69.47	Palakkad
Placimada	109.67	Palakkad
Kollengode	118.67	Palakkad
Koodungalur	141.46	Thrissur

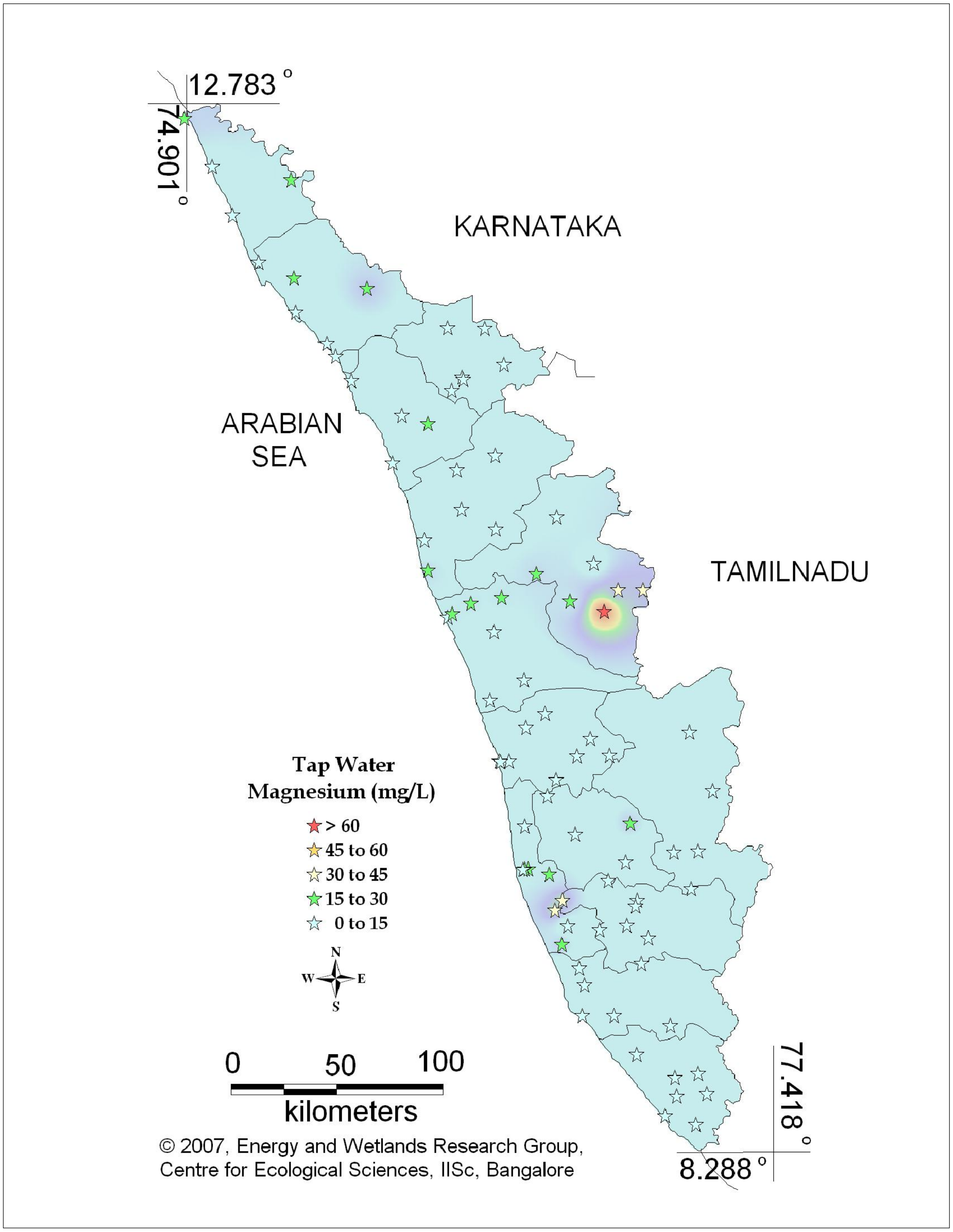
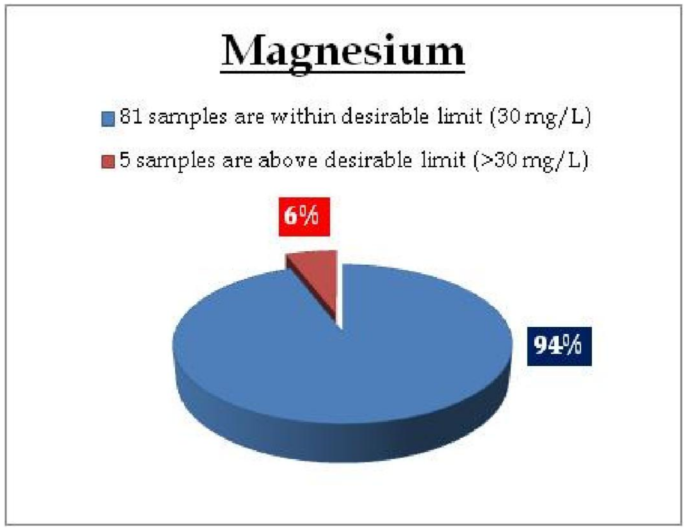


Figure 17.3: Spatial variation of Magnesium in Kerala's tap water

Tap water - Magnesium

Standard for Drinking Water (BIS 105000)
Desirable Limit: 30 mg/L
Permissible limit in the absence of an alternative source:100 mg/L



Remarks

Sampling sites where Magnesium is above desirable limit

Location	Value	District
Moonkilmada	31.80	Palakkad
Chittur	32.19	Palakkad
Veeyapuram	39.98	Alappuzha
Chenkulathukavu	40.58	Kottayam
Kollengode-Vellanara	80.77	Palakkad

Sodium

Sodium is the sixth most abundant element on the Earth and is widely distributed in soils, plants, water and foods. Most parts of the world has significant deposits of sodium-containing minerals, most notably sodium chloride (salt). Sodium dissolves easily in water and is always present at some level. If well water is treated for hardness, that process usually involves sodium and can lead to higher levels of sodium in the water. (Some water softeners use potassium and are not a threat). Other sources of sodium are natural occurrences and runoff.

Effects on Environment and Human Health

Sodium is a normal component of the body and adequate levels of sodium are required for good health. Food is the main source of daily human exposure to sodium. Less than one percent of daily intake of sodium comes from water. The people with high blood pressure are sensitive to sodium and can reduce blood pressure by reducing sodium. Although some people can consume excessive levels of sodium without increased blood pressure, many cannot. Other risk factors for high blood pressure include excess weight, alcohol consumption, and a family history of high blood pressure. High levels of sodium may aggravate existing high blood pressure. Factors to help reduce high blood pressure include a low sodium diet, increased fruit and vegetable consumption, exercise, weight control, and medication if necessary. Sodium in drinking water may be an issue for someone with heart disease, hypertension, kidney disease, circulatory illness or on a sodium-controlled diet.

Remedial Measures

Reverse osmosis will reduce the amount of sodium in drinking water a significant amount.

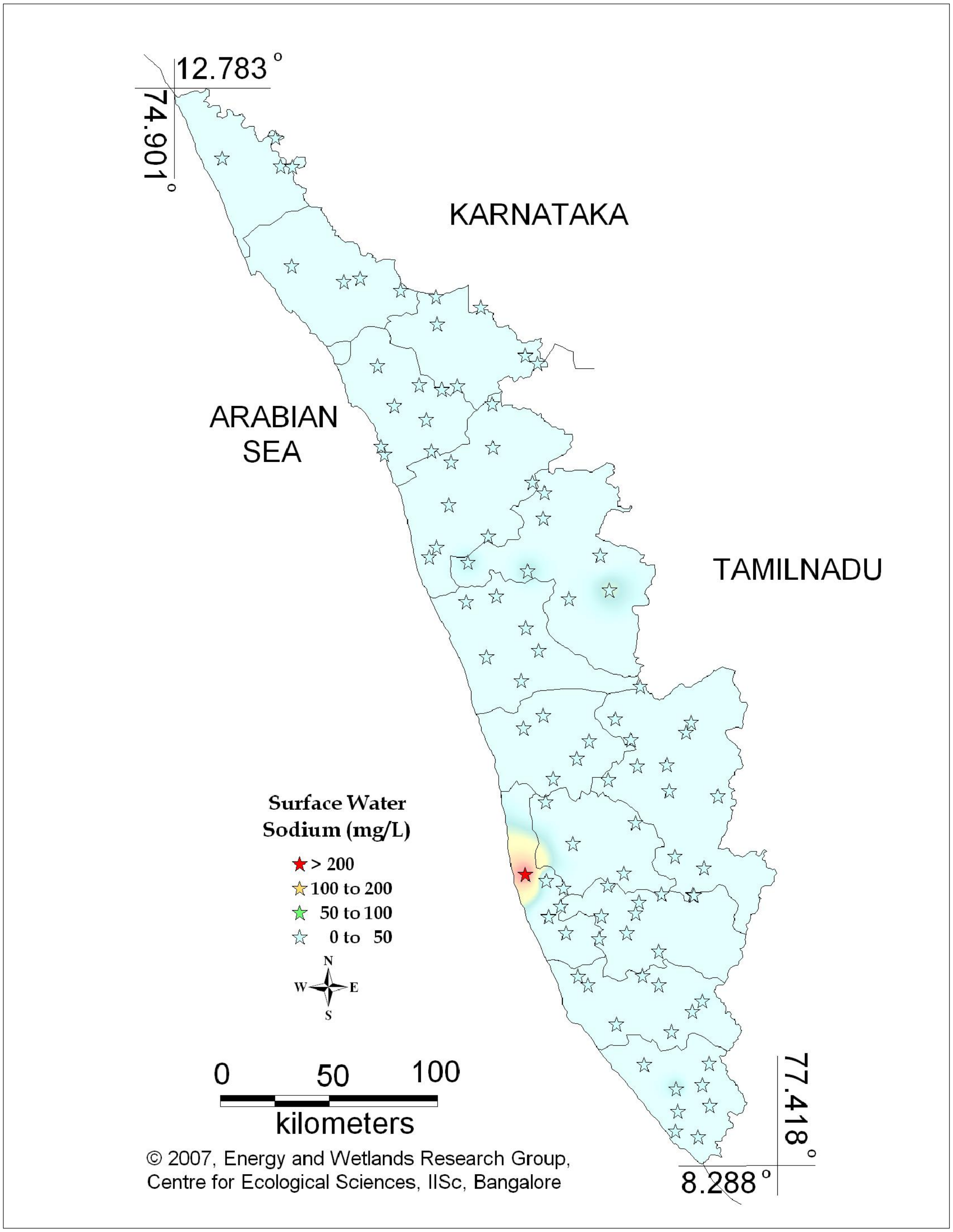
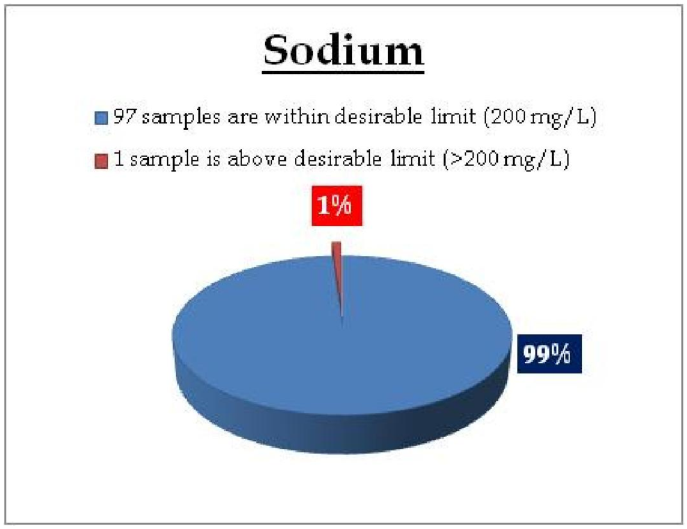


Figure 18.1: Spatial variation of sodium in Kerala's surface water

Surface water - Sodium

Standard for Drinking Water (WHO)

Desirable Limit: 200mg/L



Remarks
Sampling site having Sodium above desirable limit

Location	Value	District
Kuppapuram	279.18	Alappuzha

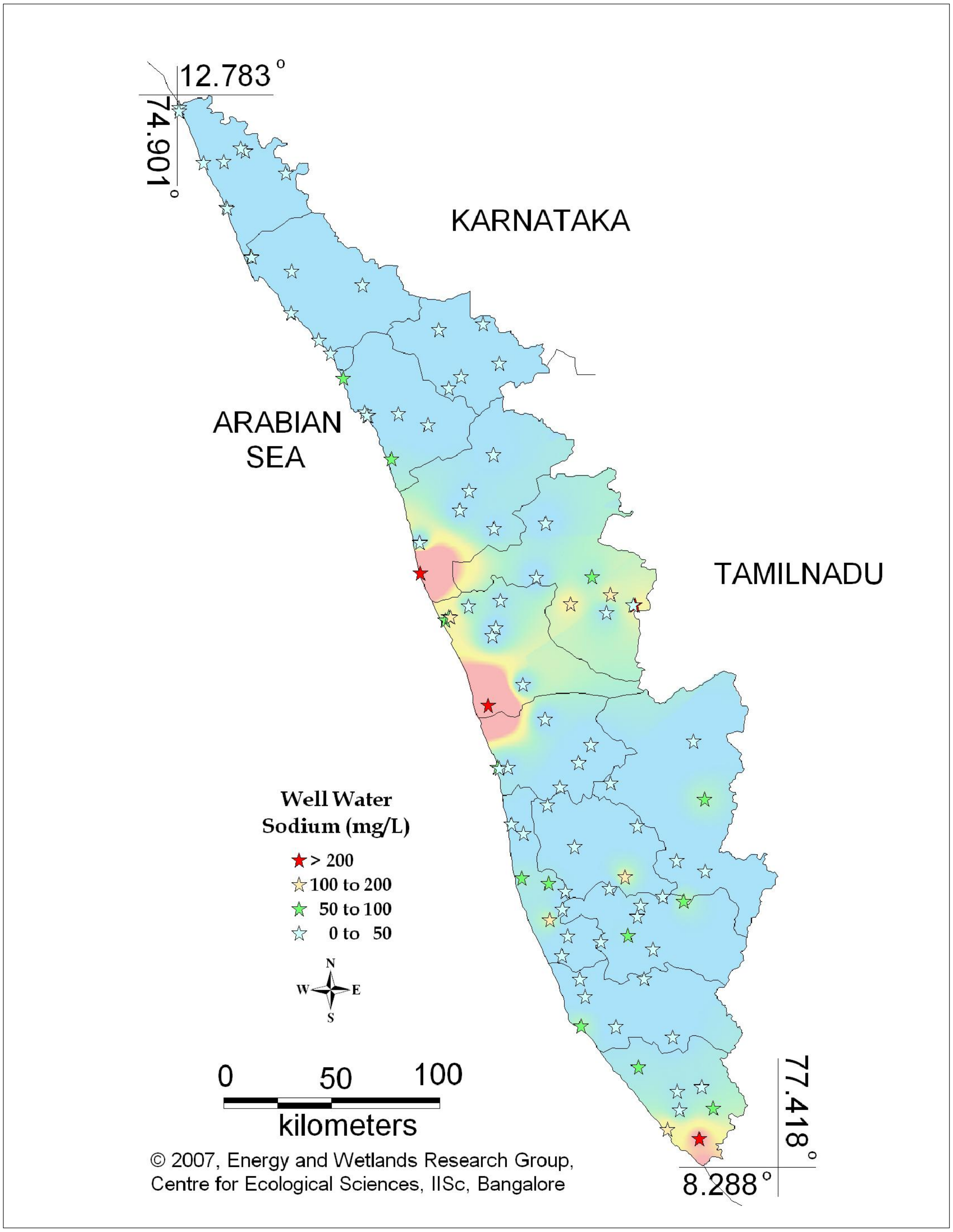
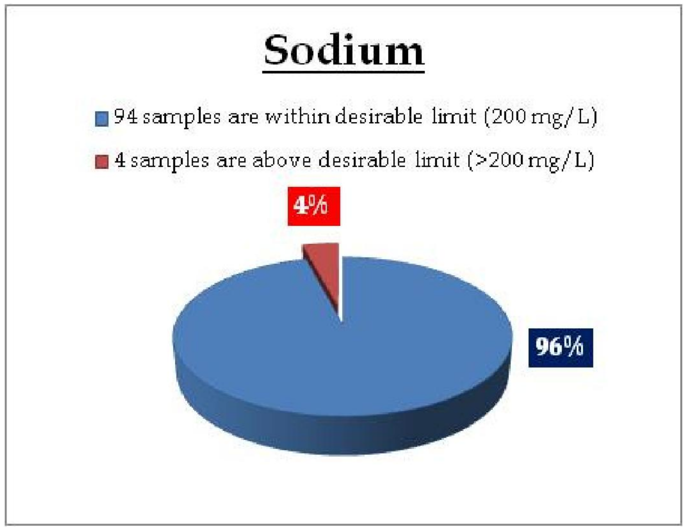


Figure 18.2: Spatial variation of sodium in Kerala's well water

Well Water - Sodium

Standard for Drinking Water (WHO)

Desirable Limit: 200mg/L



Remarks
Sampling sites above desirable limit of Sodium:

Location	Value	District
Neyyathinkara	216.20	Tiruvanthapuram
Placimada	229.32	Palakkad
Ponnani	1120.14	Palakkad
Koodungalur	1203.20	Thrissur

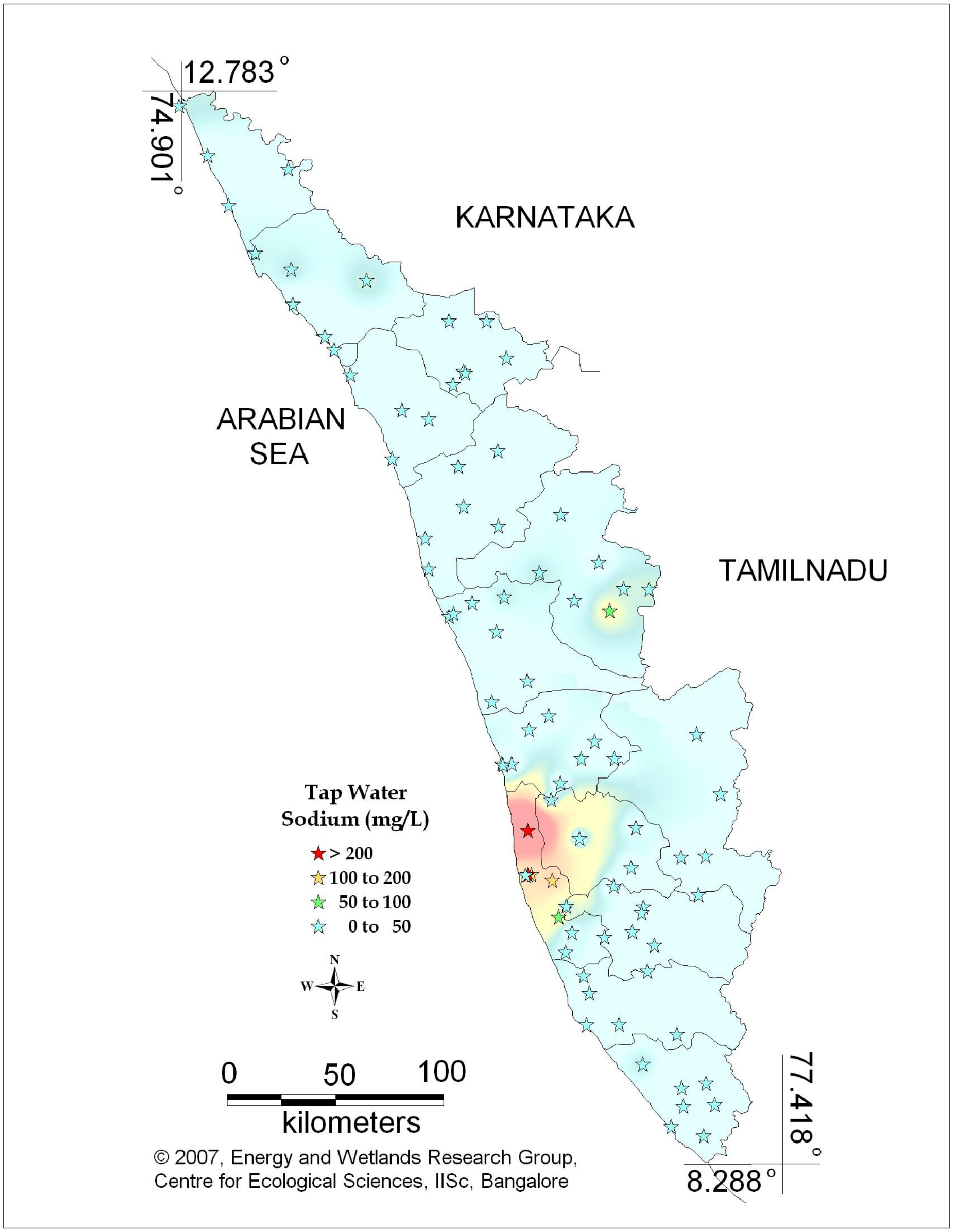
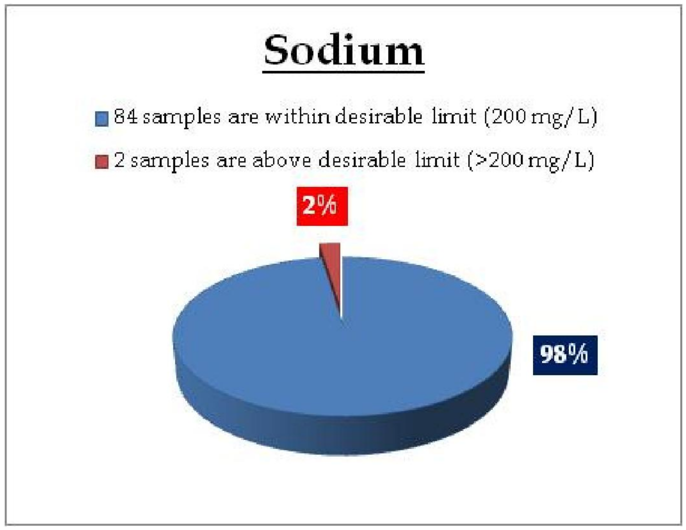


Figure 18.3: Spatial variation of sodium in Kerala's tap water

Tap water - Sodium

Standard for Drinking Water (WHO)

Desirable Limit: 200mg/L



Remarks

Sampling sites above desirable limit of Sodium are:

Location	Value	District
Thathampally	257.56	Alappuzha
Kalikulam Junction	1259.60	Alappuzha

Potassium

Hard water is indicative of the presence of higher levels of magnesium. The need for magnesium increases with age as well as level of stress. Magnesium controls muscle contraction, protein metabolism, blood coagulation, and energy production, among other vital tasks. Failure to take in enough magnesium over time leads to high blood pressure and osteoporosis.

Magnesium aids in body functions; it can also help prevent disease. Studies show that magnesium in drinking water protects against the deaths of patients with diabetes mellitus, and prevents the development of cerebrovascular disease. Magnesium also lowers the risk of fatality from acute myocardial infarction (heart disease), particularly in females. In high-risk patients, magnesium is recommended to protect against gastric cancer

Effects on Environment and Human Health

There is currently no background document or summary statement for potassium in the Guidelines for Drinking-water Quality. Potassium water softeners are being used as an alternative to sodium water softeners, in response to a perception that potassium is better for health. However, some people with specific diseases or on certain medications are susceptible to hyperkalaemia, and some mention of this needs to be made in WHO guidance.

Remedial Measures

Magnesium can be removed by reverse osmosis, along with other total dissolved solids.
Other removal methods like distillation and deionization

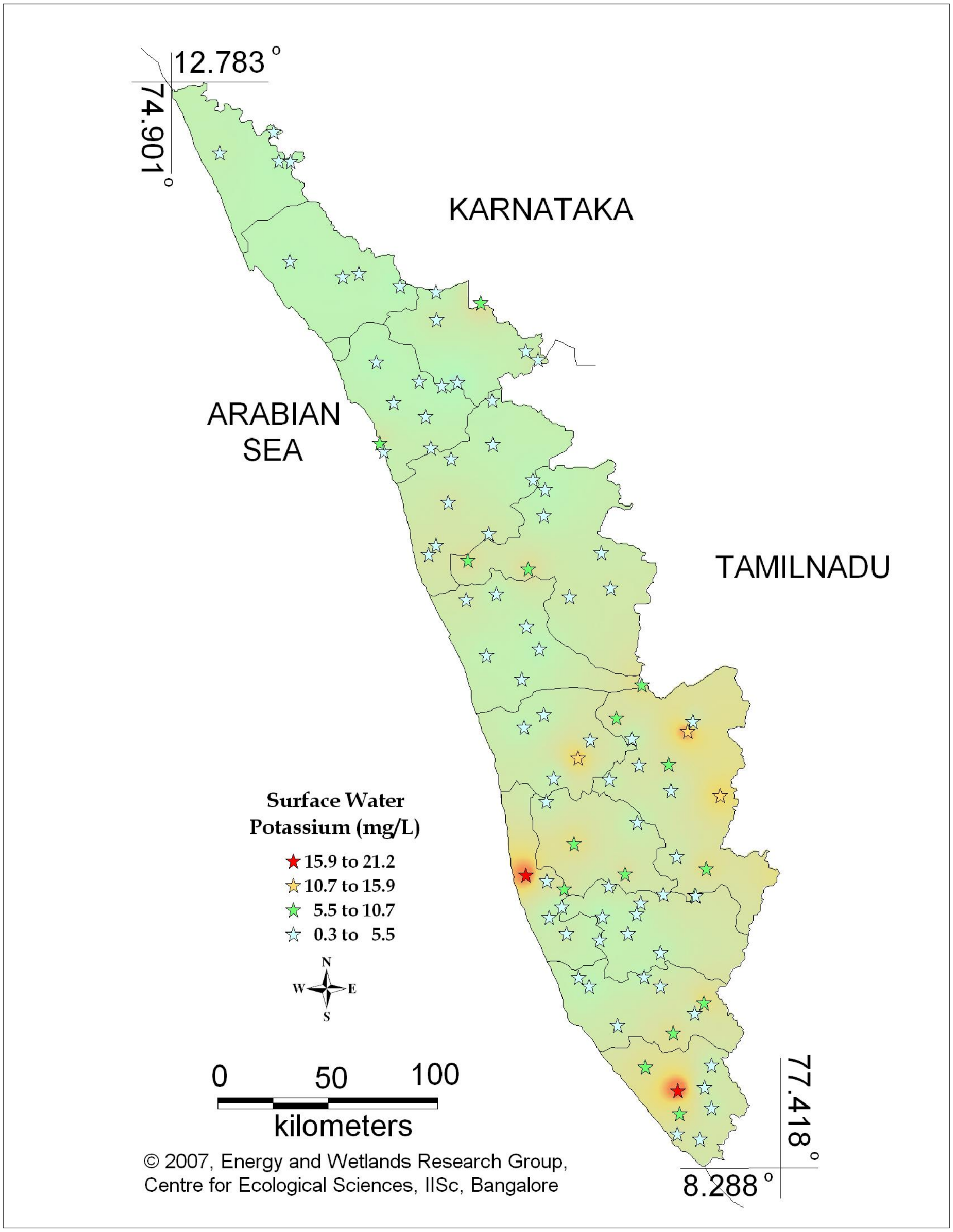


Figure 19.1: Spatial variation of potassium in Kerala's surface water

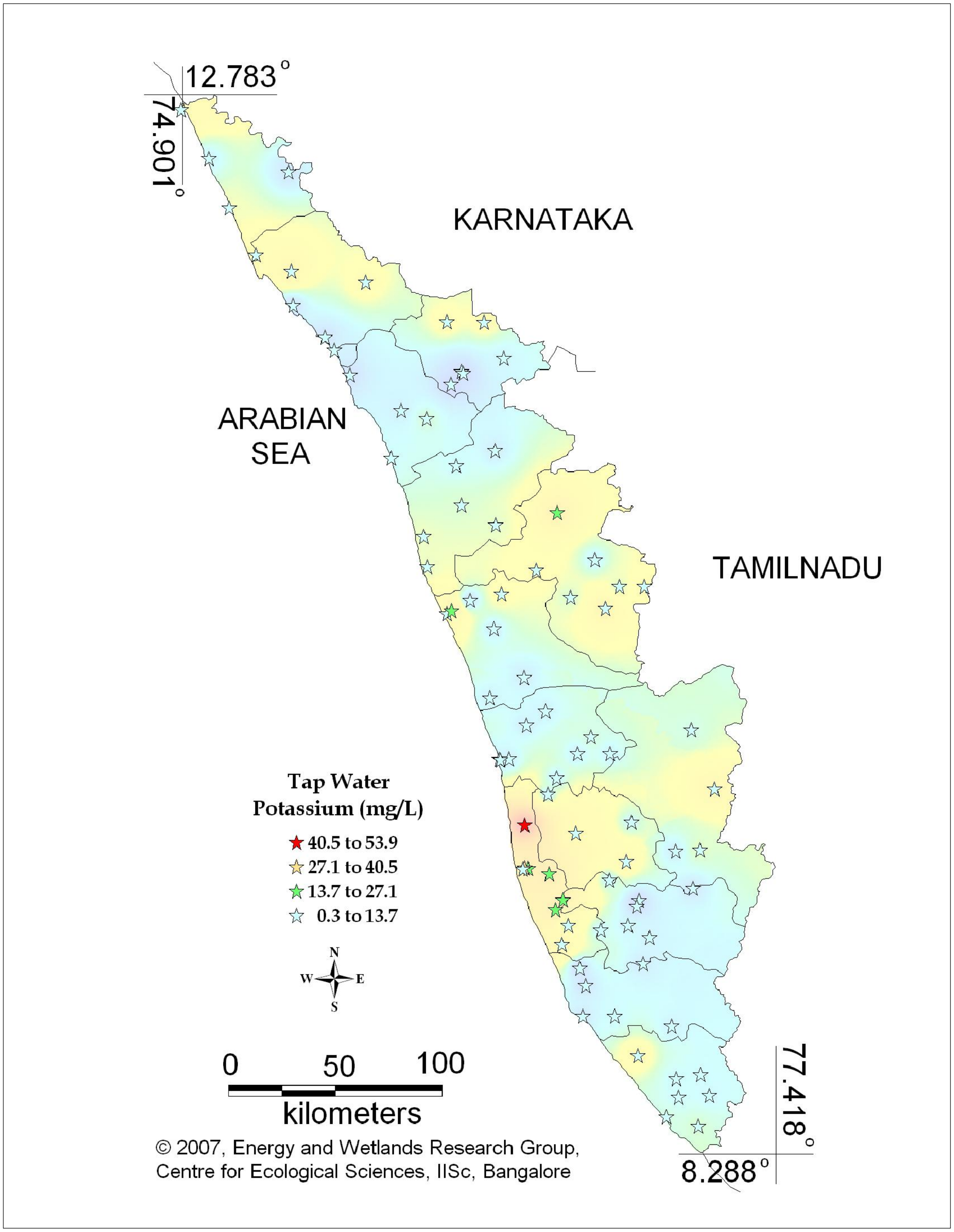


Figure 19.2: Map showing spatial variation of potassium in Kerala's tap water

Alkalinity

Alkalinity refers to the capability of water to neutralize acid. This is really an expression of buffering capacity. A buffer is a solution to which an acid can be added without changing the concentration of available H^+ ions (without changing the pH) appreciably. It essentially absorbs the excess H^+ ions and protects the water body from fluctuations in pH. Alkalinity is often related to hardness because the main source of alkalinity is usually from carbonate rocks (limestone) which are mostly $CaCO_3$. If $CaCO_3$ actually accounts for most of the alkalinity, hardness in $CaCO_3$ is equal to alkalinity. Since hard water contains metal carbonates (mostly $CaCO_3$), it is high in alkalinity. Conversely, unless carbonate is associated with sodium or potassium which don't contribute to hardness, soft water usually has low alkalinity and little buffering capacity. So, generally, soft water is much more susceptible to fluctuations in pH from acid rains or acid contamination.

Effects on Environment and Human Health

Alkalinity is important for fish and aquatic life because it protects or buffers against rapid pH changes. Living organisms, especially aquatic life, function best in a pH range of 6.0 to 9.0. Alkalinity is a measure of how much acid can be added to a liquid without causing a large change in pH. Higher alkalinity levels in surface waters will buffer acid rain and other acid wastes and prevent pH changes that are harmful to aquatic life.

Remedial Measures

Alkalinity can be removed by reverse osmosis, along with other total dissolved solids. Other removal methods like distillation and deionization remove total dissolved solids and alkalinity, but they are less suitable for household use than reverse osmosis, but can be used at community level.

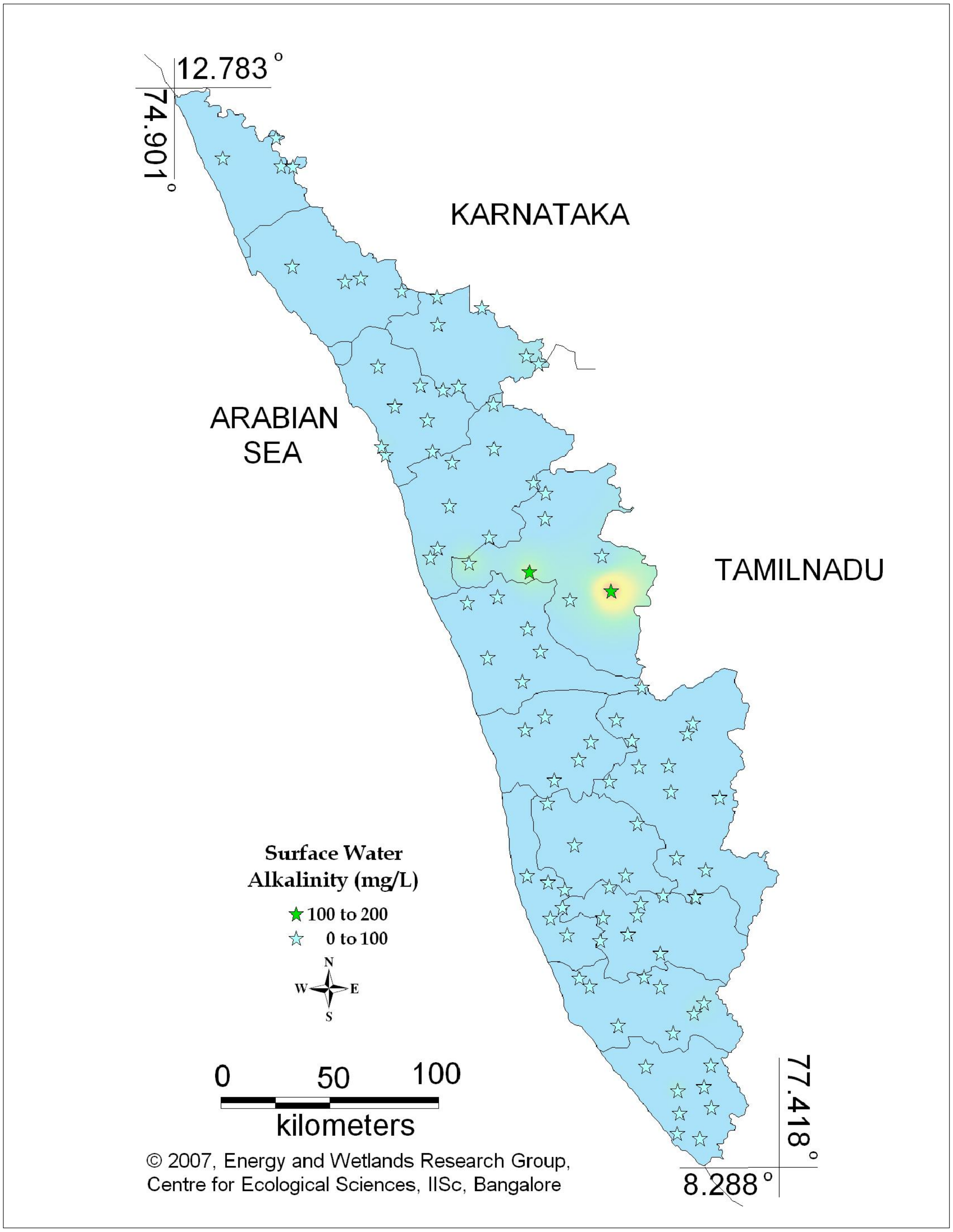
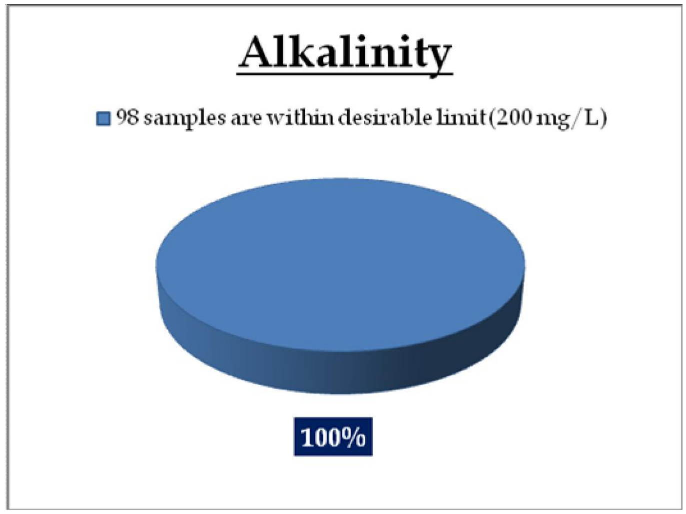


Figure 20.1: Spatial variation of alkalinity in Kerala's surface water

Surface water - Alkalinity

Tolerance limit for inland surface waters subject to pollution Desirable Limit: 200 mg/L Permissible Limit: 600 mg/L	

Remarks

All the 98 surface water samples collected from rivers, streams and lakes spread over in Kerala are under the inland surface water standard.

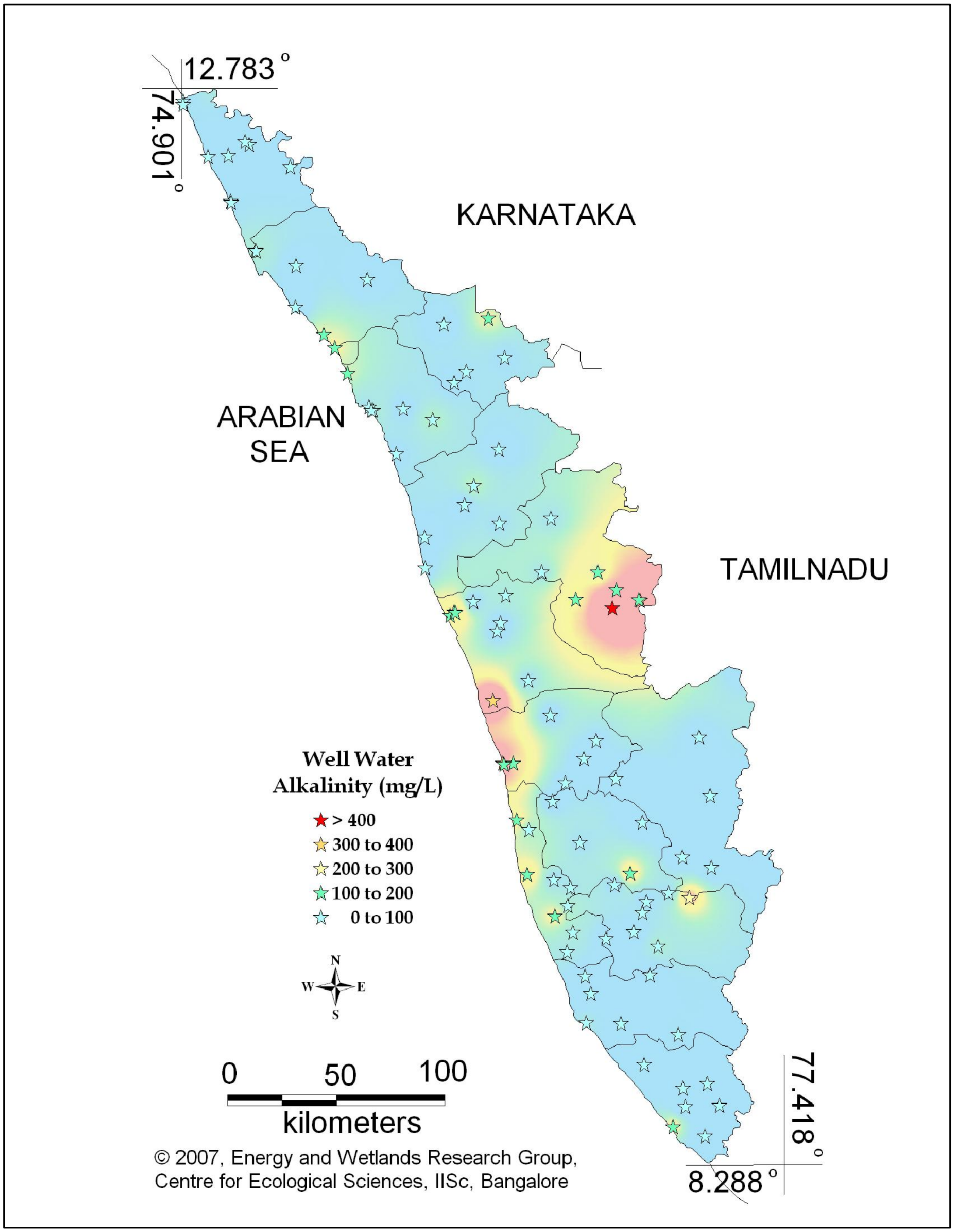
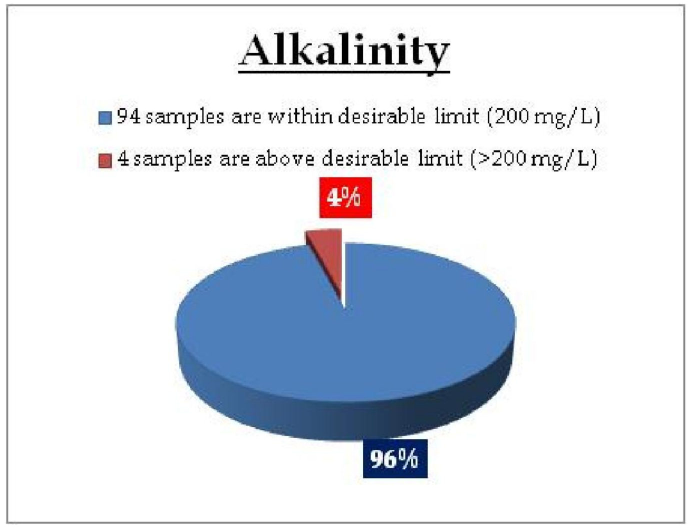


Figure 20.2: Spatial variation of alkalinity in Kerala's well water

Well water - Alkalinity

Standard for Drinking Water (BIS 105000)
Desirable Limit: 200 mg/L
Permissible limit in the absence of an alternative source: 600mg/L

Beyond this limit taste becomes unpleasant.



Remarks

Sampling sites above desirable limit of Alkalinity are:

Location	Value	District
Attathodu East	200.00	Pathanamthitta
Koodungalur	304.00	Thrissur
Placimada	340.00	Palakkad
Fort Cochin	352.00	Ernakulam
Kollengode	408.00	Palakkad

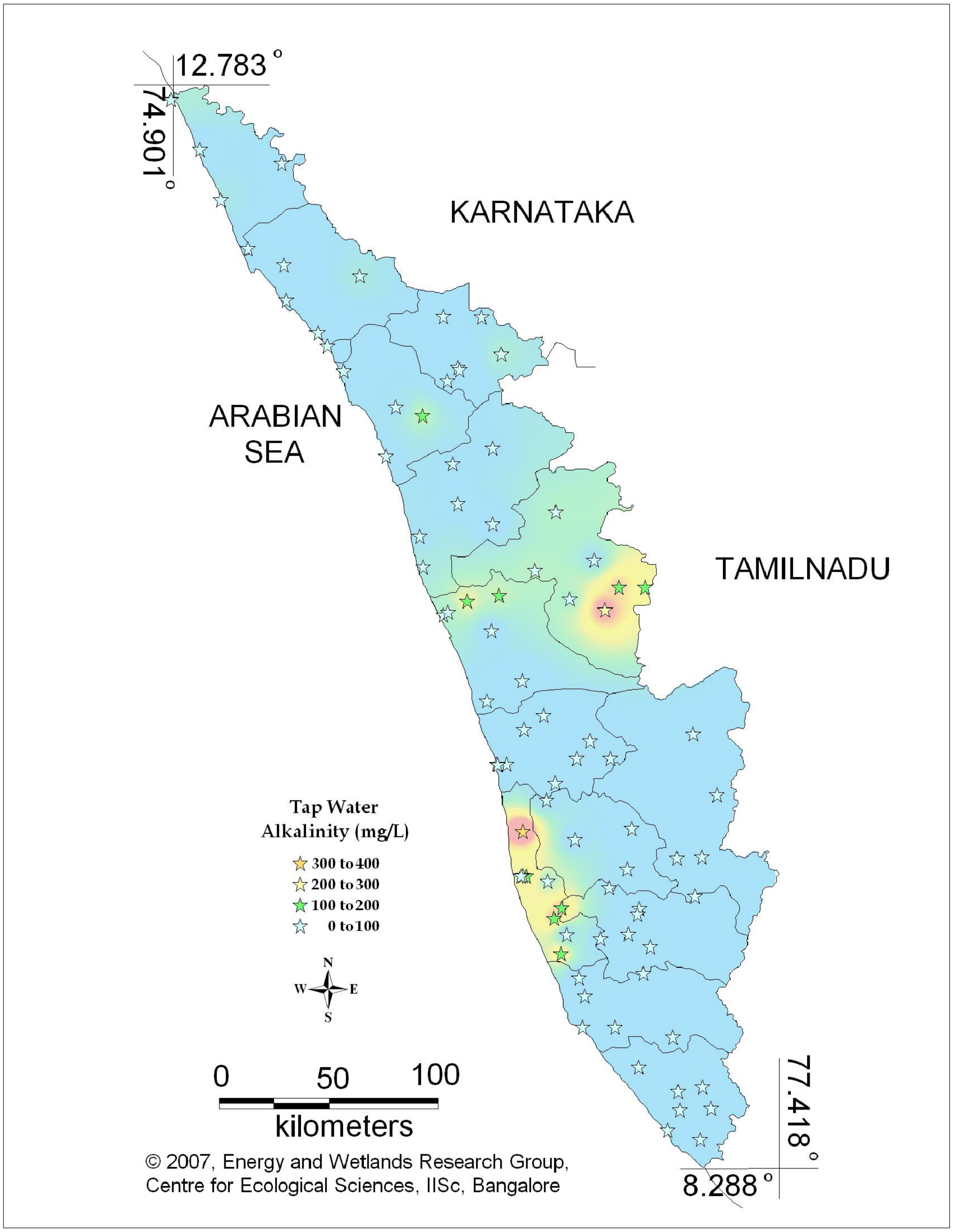
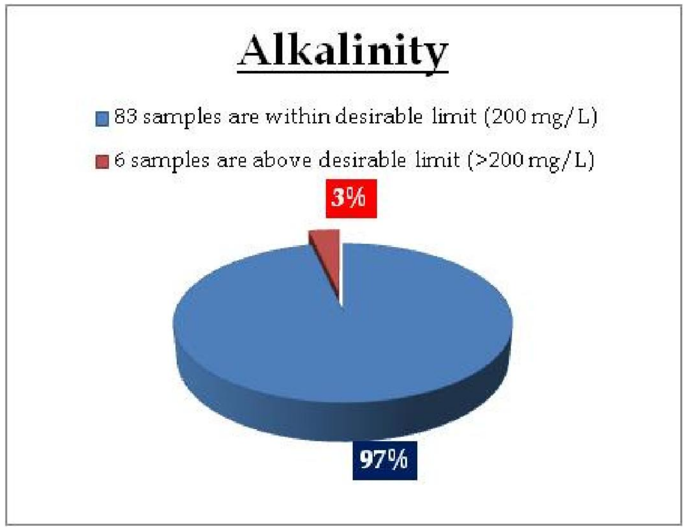


Figure 20.3: Spatial variation of Alkalinity in Kerala tap water

Tap water - Alkalinity

Standard for Drinking Water (BIS 105000)
Desirable Limit: 200 mg/L
Permissible limit in the absence of an alternative source: 600mg/L

Beyond this limit taste becomes unpleasant.



Remarks
Sampling sites above desirable limit of Alkalinity are:

Location	Value	District
Kollengode-Vellanara	228.00	Palakkad
Thathampally	232.00	Alappuzha
Kalikulam Junction	304.00	Alappuzha

Total Dissolved Solids

The expression, "total dissolved solids" (TDS), refers to the total amount of all inorganic and organic substances – including minerals, salts, metals, cations or anions – that are dispersed within a volume of water. By definition, the solids must be small enough to be filtered through a sieve measuring 2 micrometers. TDS concentrations are used to evaluate the quality of freshwater systems. TDS concentrations are equal to the sum of positively charged ions (cations) and negatively charged ions (anions) in the water. Sources for TDS include agricultural run-off, urban run-off, industrial wastewater, sewage, and natural sources such as leaves, silt, and rocks. Piping or plumbing may also release metals into the water.

Effects on Environment and Human Health

TDS is not considered primarily as pollutant, high TDS levels typically indicate hard water and may lead to scale buildup in pipes, reduced efficiency of water filters, hot water heaters, etc., and aesthetic problems such as a bitter or salty taste. Water with a high TDS concentration may indicate elevated levels of ions that do pose a health concern, such as aluminum, arsenic, copper, lead, nitrate and others.

Remedial Measures

TDS can be removed by reverse osmosis and other removal methods like distillation and deionization.

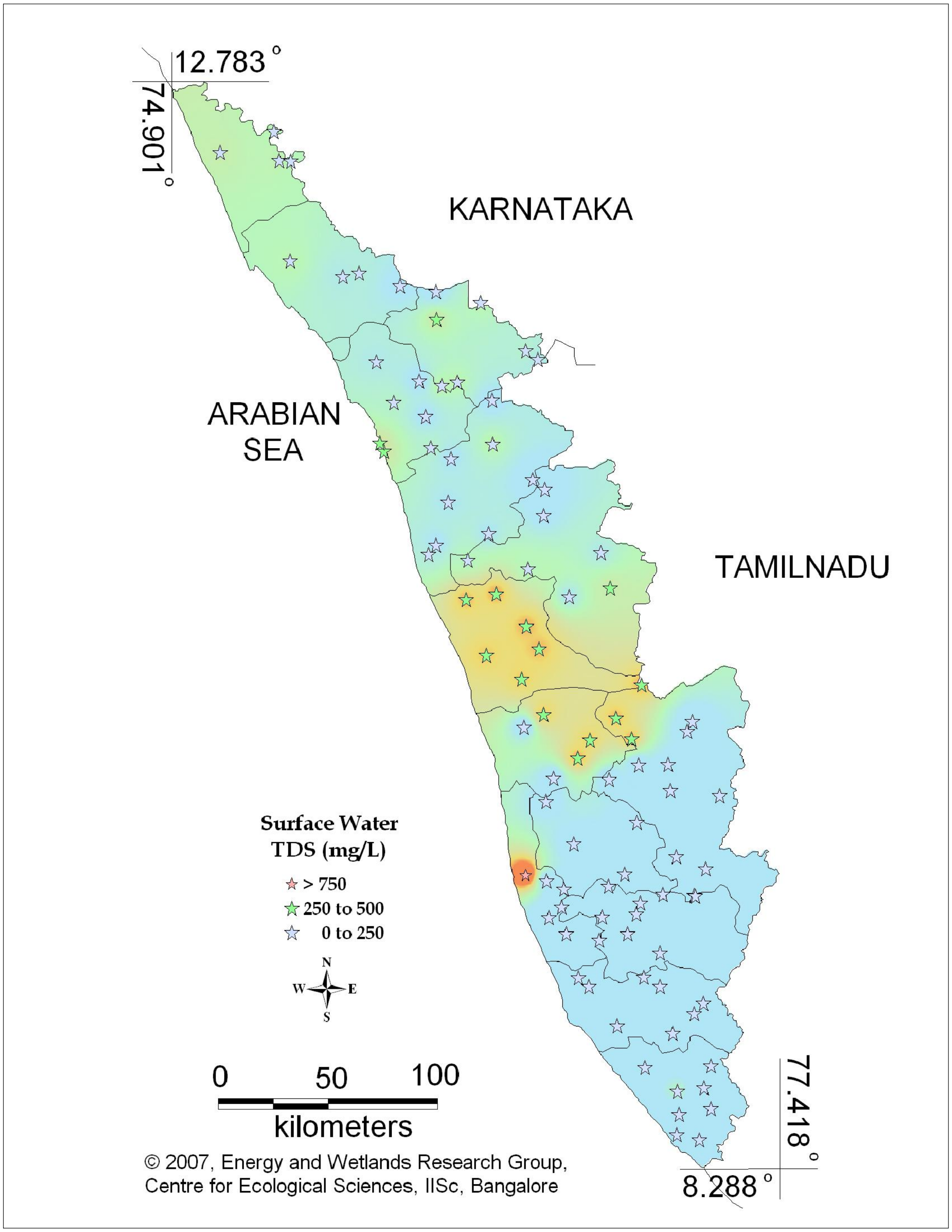
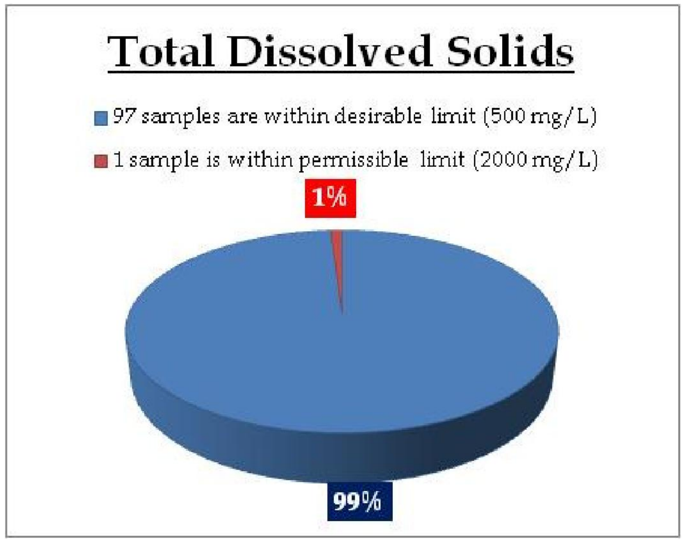


Figure 21.1: Spatial variation of TDS in Kerala's surface water

Surface water – Total Dissolved Solids

Tolerance limit for inland surface waters subject to pollution

Desirable Limit: 500 mg/L
Permissible Limit: 2000 mg/L



REMARKS

Sampling site above desirable limit of TDS is:

Location	Value	District
Kuppapuram	786.00	Alappuzha

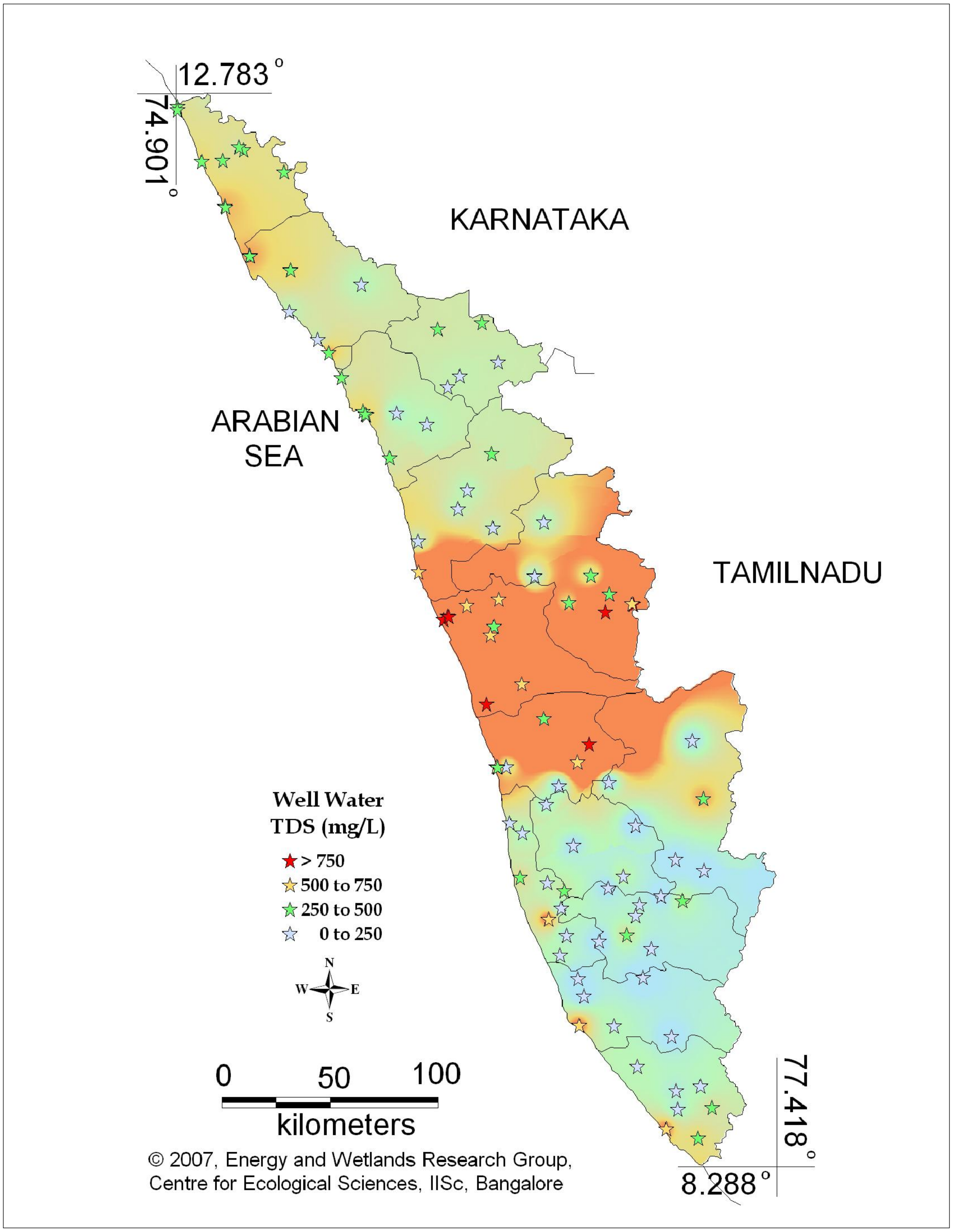
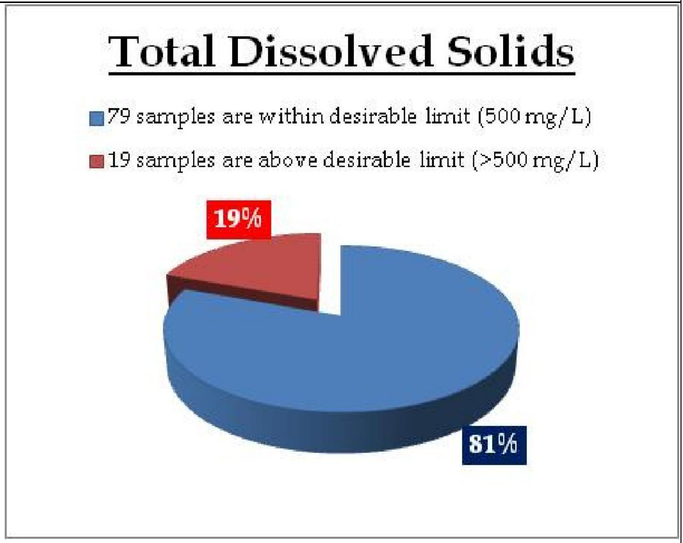


Figure 21.2: Spatial variation of TDS in Kerala's well water

Well water – Total Dissolved Solids

Tolerance limit for inland surface waters subject to pollution

Desirable Limit: 500 mg/L
Permissible Limit: 2000 mg/L



REMARKS

Sampling sites above desirable limit of TDS are:

LOCATION	VALUE	DISTRICT
Thiruvallam	514.00	Tiruvanthapuram
Chalakudy	518.00	Thrissur
Kochupilammood	527.00	Kollam
Thrissur	531.00	Thrissur
Kannimari	539.34	Palakkad
Cherananllur	548.00	Thrissur
Veeyapuram	554.00	Alappuzha
Muvathupuzha	566.00	Kottayam
Wadakancheery	583.00	Thrissur
Fort Cochin	633.00	Ernakulam
Ponnani	644.33	Palakkad
Guruvayoor1	828.00	Thrissur
Chavakkad	870.00	Thrissur
Kollengode	995.92	Palakkad
Placimada	1190.55	Palakkad
Aluva	4060.00	Ernakulam
Kothamangalam	4220.00	Ernakulam
Guruvayoor	4480.00	Thrissur
Koodungalur	6060.00	Thrissur

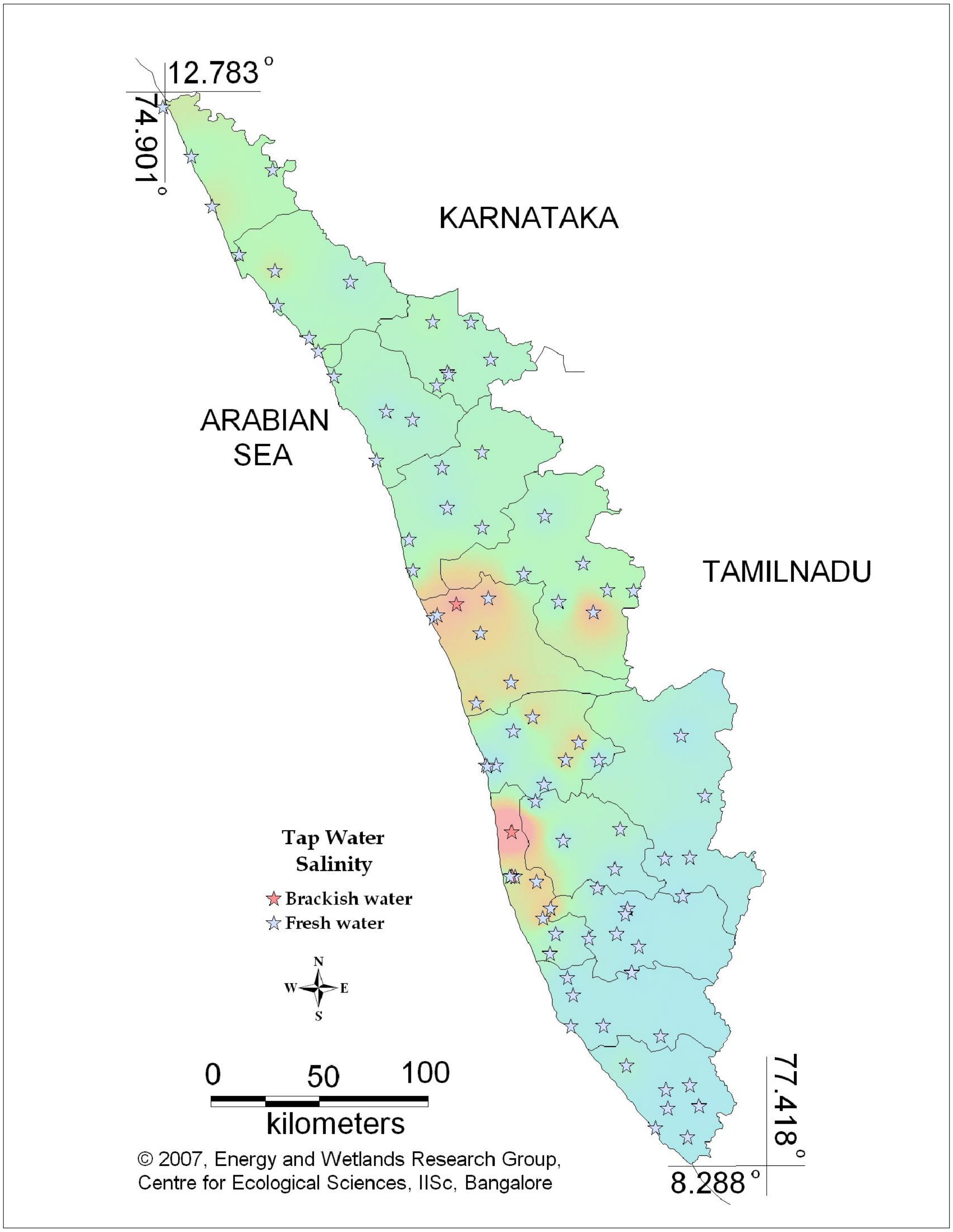
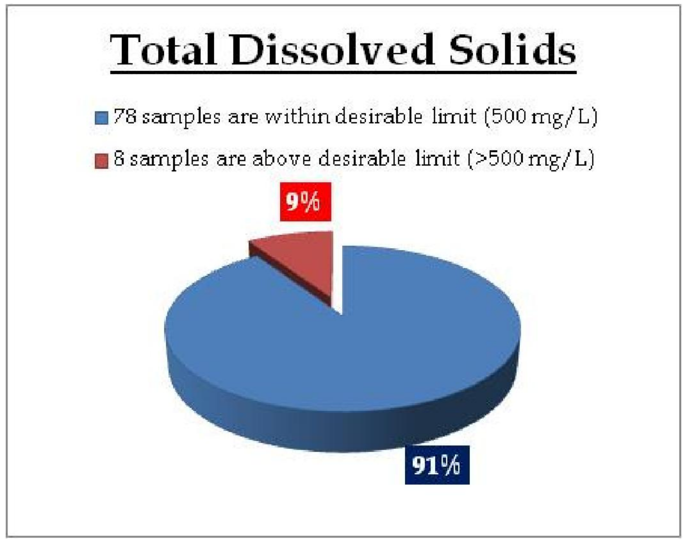


Figure 21.3: Spatial variation of TDS in Kerala's tap water

Tap water – Total Dissolved Solids

Tolerance limit for inland surface waters subject to pollution

Desirable Limit: 500 mg/L
Permissible Limit: 2000 mg/L



Remarks
Sampling sites above desirable limit of TDS are:

Location	Value	District
Chenkulathukavu	517.00	Kottayam
Chavakkad	560.00	Thrissur
Guruvayoor	566.00	Thrissur
Wadakancheery	597.00	Thrissur
Kollengode-Vellanara	611.40	Palakkad
Thathampally	695.00	Alappuzha
Cherananllur	702.00	Thrissur
Kalikulam Junction	1920.00	Alappuzha

Salinity

Salinity is an indication of the concentration of dissolved salts in a body of water. The ions responsible for salinity include the major cations (calcium, Ca^{2+}; magnesium, Mg^{2+}; sodium, Na-; and potassium, K-) and the major anions (carbonates, CO_3^{2-} and HCO_3^{2-}; sulphate, SO_4^{2-}; and chloride, Cl^-). The level of salinity in aquatic systems is important to aquatic plants and animals as species can survive only within certain salinity range. Although some species are well-adapted to surviving in saline environments, growth and reproduction of many species can be hindered by increases in salinity. There are two kinds of salinity – dryland and irrigation salinity. Both involve water management and the need to maintain the right balance or equilibrium.

Salinity (dry land) - Dryland salinity occurs when salt stored in the soil profile over thousands of years is brought to the surface or close to the surface by rising groundwater levels. Dryland salinity is classified as either primary or secondary. Primary salting occurs naturally while secondary salting is induced by human activities such as agriculture. The ultimate outcome of dryland salinity is the discharge of saline water to streams and soils, commonly occurring when saline groundwater rises to within two metres of the ground surface. Salinity (irrigation) - Irrigation salinity resembles dryland salinity, except that groundwater accession is induced through irrigation water rather than rainfall alone. Irrigation salinity refers to an accumulation of salt in the plant root zone or on the soil surface, commonly as a result of saline groundwater rising within two metres of the ground surface. Salt sources are consistent with those that occur in the process of dryland salinity and include cyclic salts, salts derived from old marine sediments or from the weathering and breakdown of rocks in soil formation.

Effects on Environment and Human Health

An elevated Salinity is not a health hazard. The Salinity concentration is a secondary drinking water standard and therefore is regulated because it is more of an aesthetic rather than a health hazard.

Remedial Measures

Salinity can be removed by reverse osmosis, along with other total dissolved solids. Other removal methods like distillation and deionization can also remove salinity.

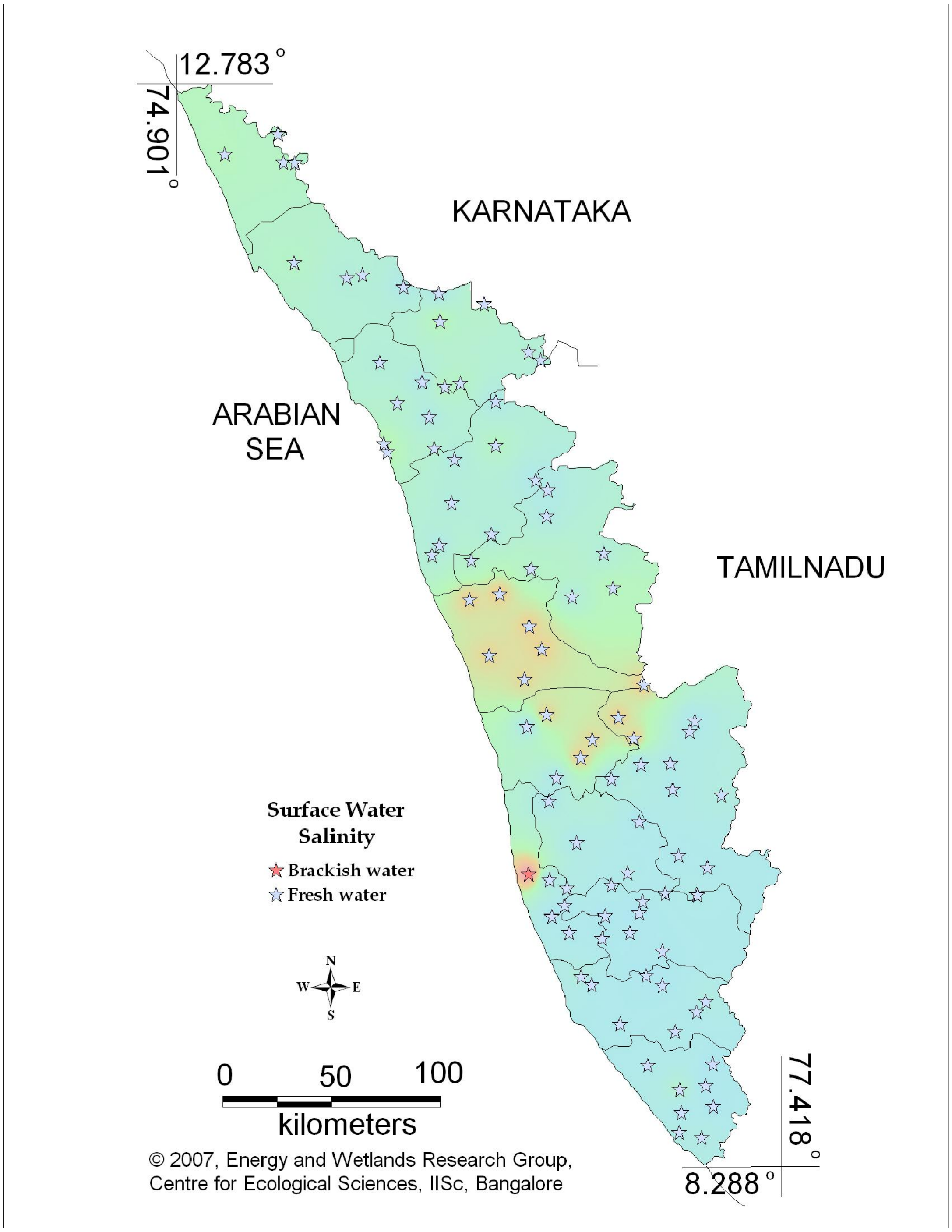
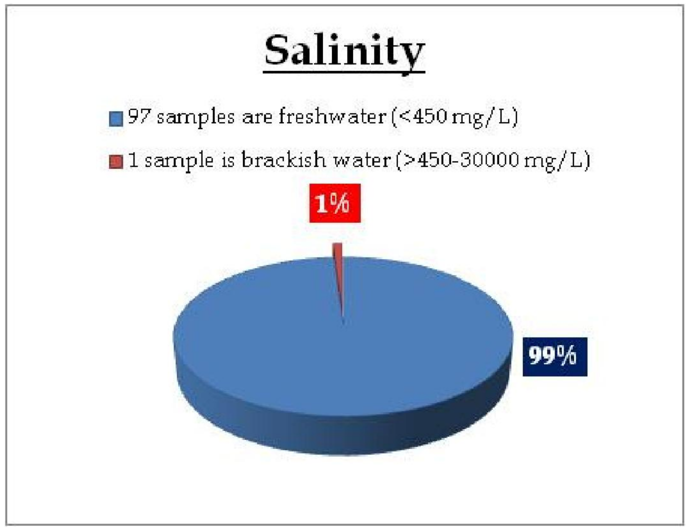


Figure 22.1: Spatial variation of Salinity in Kerala's surface water

Surface water – Salinity

Water Classification according to Salinity
0-450mg/L = Freshwater
450 - 30 000 mg/L = Brackish water
30 000 - 50 000 mg/L = Saline water



Remarks
Sampling site in brackish water condition is:

Location	Value	District
Kuppapuram	561.00	Alappuzha

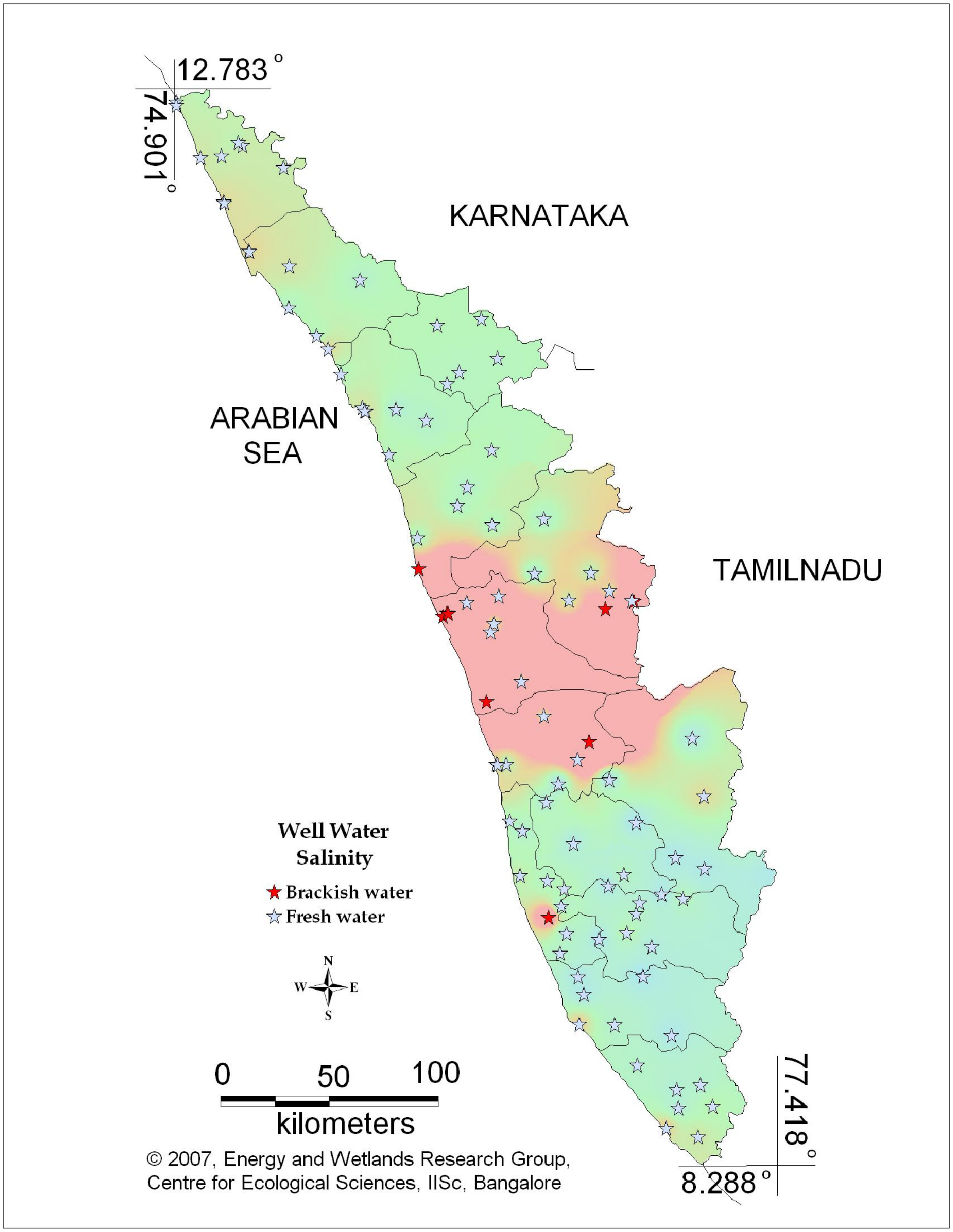


Figure 22.2: Spatial variation of Salinity in Kerala's well water

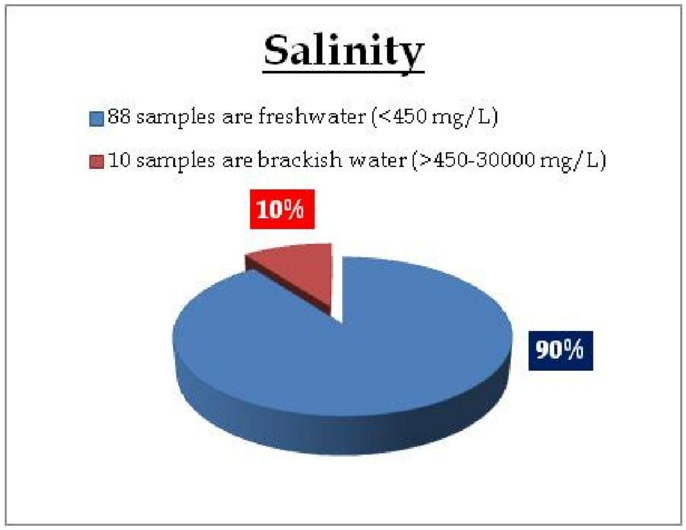
Well water – Salinity

Water Classification according to Salinity

0-450mg/L = Freshwater

450 - 30 000 mg/L = Brackish water

30 000 - 50 000 mg/L = Saline water



Remarks

Sampling sites in brackish water condition are:

Location	Value	District
Ponnani	461.62	Palakkad
Guruvayoor	590.00	Thrissur
Chavakkad	618.00	Thrissur
Kollengode	712.46	Palakkad
Veeyapuram	795.00	Alapuzha
Placimada	851.32	Palakkad
Aluva	2900.00	Ernakkualm
Kothamangalam	3000.00	Ernakkualm
Guruvayoor 1	3180.00	Thrissur
Koodungalur	4310.00	Thrissur

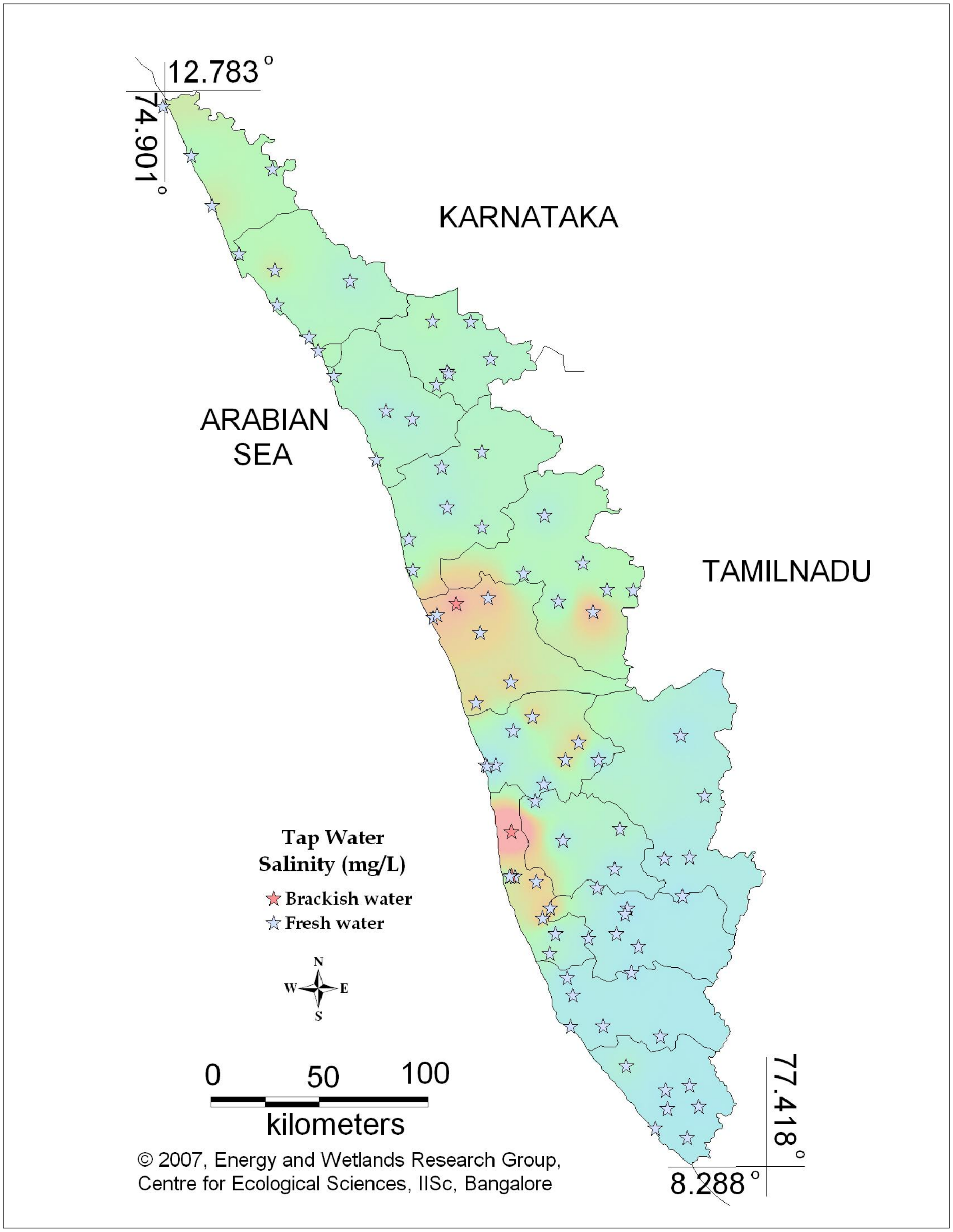
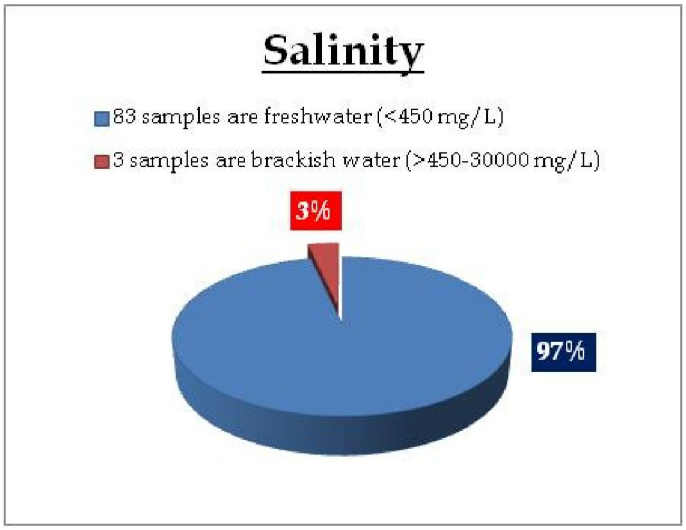


Figure 22.3: Spatial variation of Salinity in Kerala's tap water

Tap water – Salinity

Water Classification according to Salinity
0-450mg/L = Freshwater
450 - 30 000 mg/L = Brackish water
30 000 - 50 000 mg/L = Saline water



Remarks
Sampling sites in brackish water condition are:

Location	**Value**	**District**
Thathampally	495.00	Alappuzha
Cherananllur	500.00	Thrissur
Kalikulam Junction	1380.00	Alappuzha

Conductivity

Conductivity is a measurement of the ability of an aqueous solution to carry an electrical current. An ion is an atom of an element that has gained or lost an electron which will create a negative or positive state. For example, sodium chloride (table salt) consists of sodium ions (Na^+) and chloride ions (Cl^-) held together in a crystal. In water it breaks apart into an aqueous solution of sodium and chloride ions.

Effects on Environment and Human Health

Conductivity is a measurement used to determine a number of applications related to water quality. These are as follows:

[1] Determining mineralization: this is commonly called total dissolved solids. Total dissolved solids information is used to determine the overall ionic effect in a water source. Certain physiological effects on plants and animals are often affected by the number of available ions in the water.

[2] noting variation or changes in natural water and wastewaters quickly;

[3] estimating the sample size necessary for other chemical analyses; and

[4] Determining amounts of chemical reagents or treatment chemicals to be added to water sample.

Elevated dissolved solids can cause "mineral tastes" in drinking water. Corrosion or encrustation of metallic surfaces by waters high in dissolved solids causes problems with industrial equipment and boilers as well as domestic plumbing, hot water heaters, toilet flushing mechanisms, faucets, and washing machines and dishwashers.

Indirect effects of excess dissolved solids are primarily the elimination of desirable food plants and habitat-forming plant species. Agricultural uses of water for livestock watering are limited by excessive dissolved solids and high dissolved solids can be a problem in water used for irrigation.

Remedial Measures

Conductivity can be removed by reverse osmosis desalination or electrodialysis.

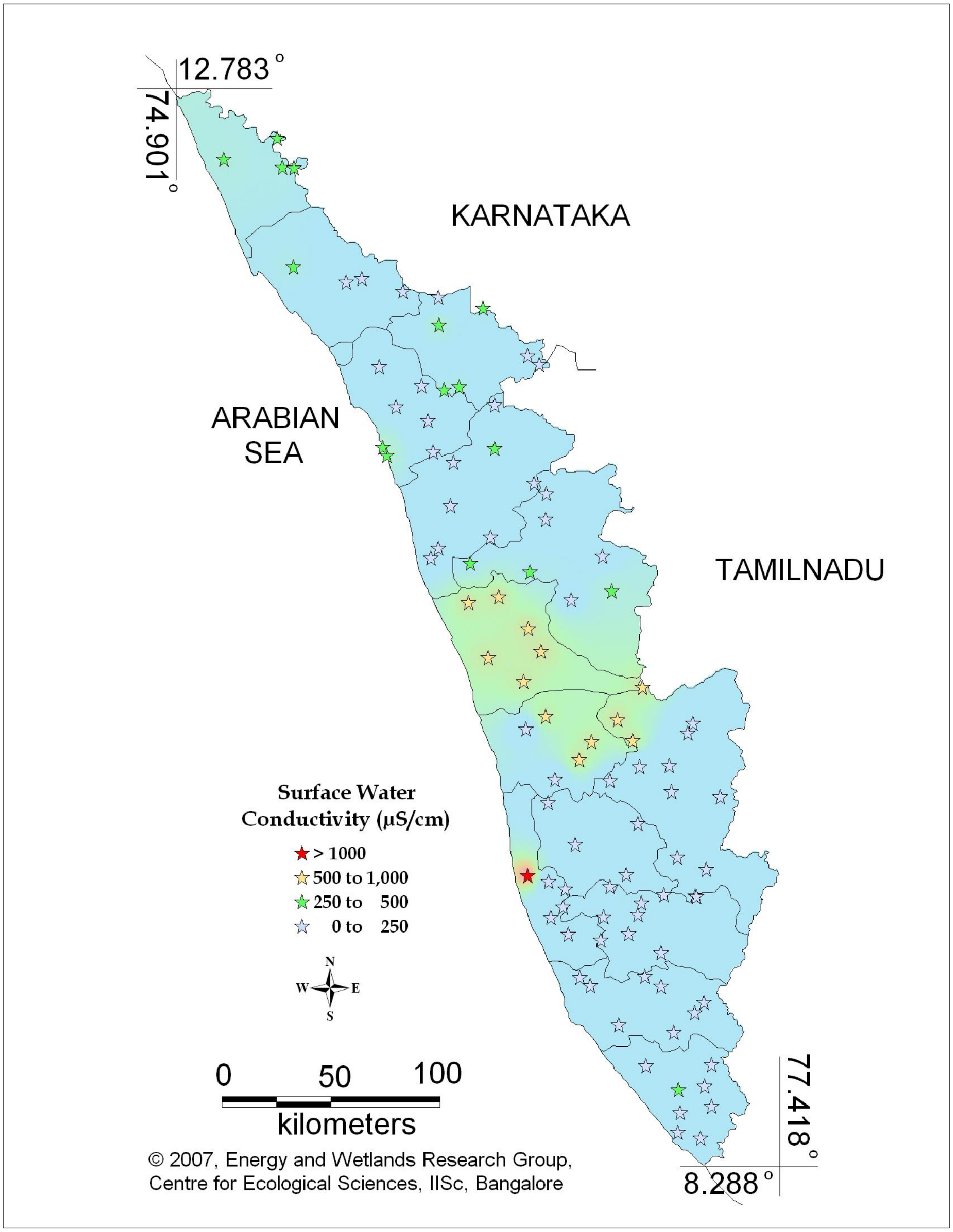
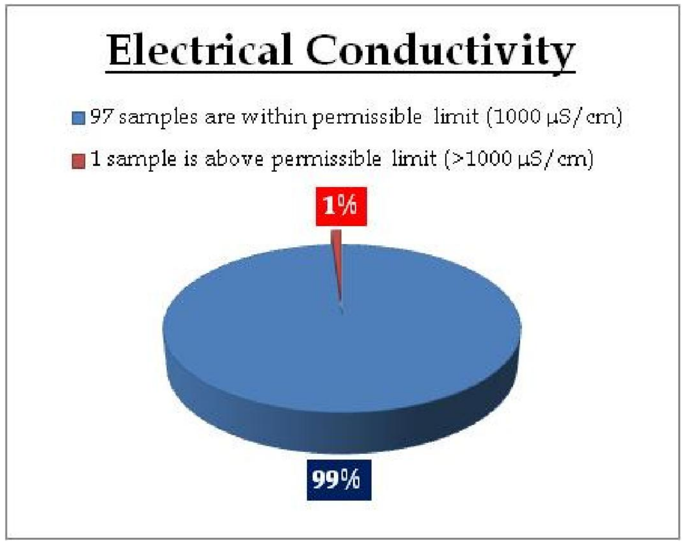


Figure 23.1: Spatial variation of conductivity in Kerala's surface water

Surface water- Conductivity

Tolerance limit for inland surface waters subject to pollution

Permissible Limit: 1000 µS/cm



Remarks
Sampling site above permissible limit of conductivity is:

Location	Value	District
Kuppapuram	1126.00	Alappuzha

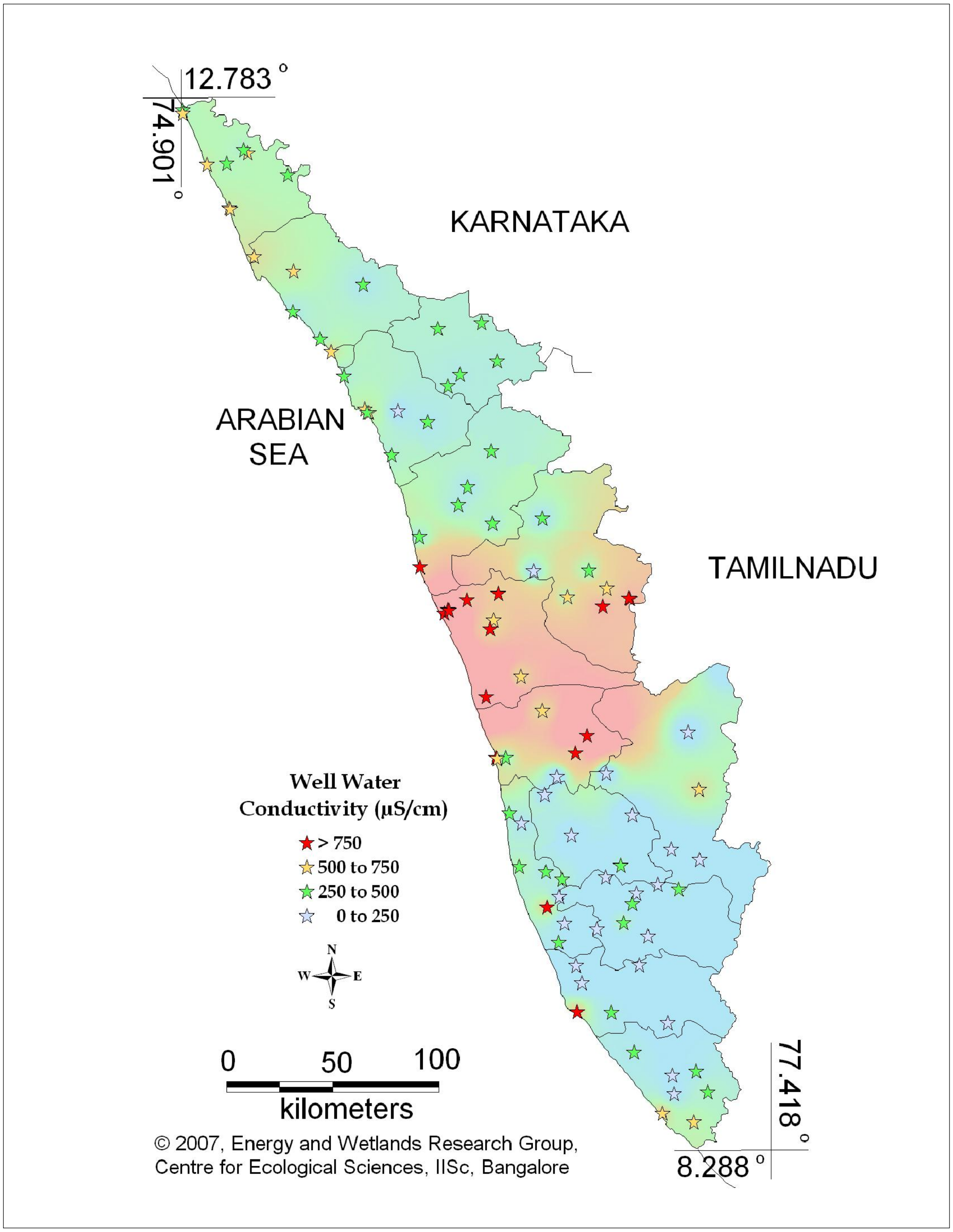


Figure 23.2: Spatial variation of conductivity in Kerala's Well water

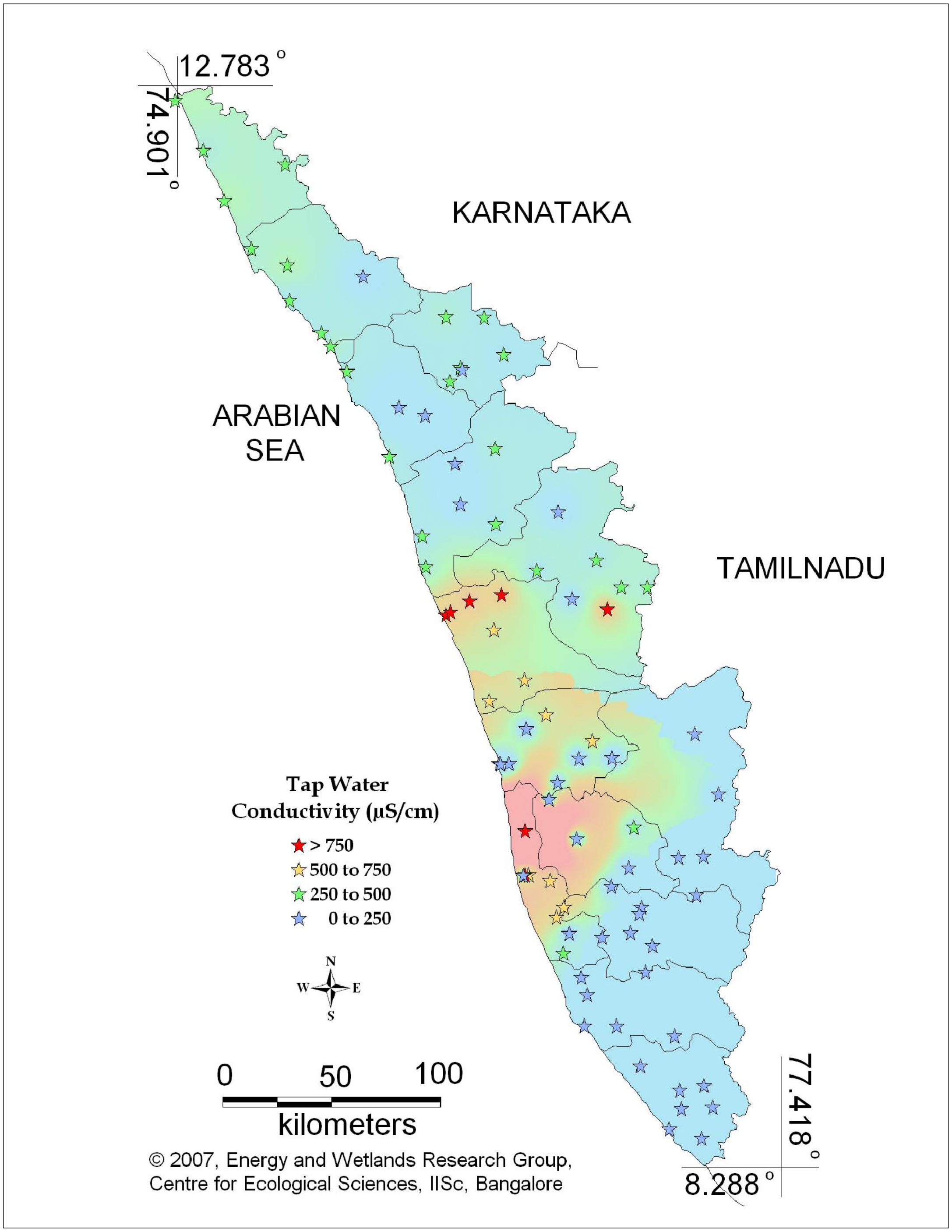


Figure 23.3: Map showing spatial variation of conductivity in Kerala's tap water

pH

The pH level of drinking water reflects how acidic or alkaline it is. pH stands for "potential hydrogen," referring to the amount of hydrogen mixed with the water. pH is measured on a scale that runs from 0-14. Seven is neutral, indicating there is no acid or alkalinity present. A measurement below 7 indicates acid is present and a measurement above 7 indicates alkalinity.

The normal range for pH in ground water lies between 6 and 8.5.

Effects on Environment and Human Health

The pH is of major importance in determining the corrosivity of water. In general, the lower the pH, the higher the level of corrosion. However, pH is only one of a variety of factors affecting corrosion.
Exposure to extreme pH values results in irritation to the eyes, skin, and mucous membranes. Eye irritation and exacerbation of skin disorders have been associated with pH values greater than 11. In addition, solutions of pH 10–12.5 have been reported to cause hair fibres to swell. In sensitive individuals, gastrointestinal irritation may also occur. Exposure to low pH values can also result in similar effects. Below pH 4, redness and irritation of the eyes have been reported, the severity of which increases with decreasing pH. Below pH 2.5, damage to the epithelium is irreversible and extensive (10). In addition, because pH can affect the degree of corrosion of metals as well as disinfection efficiency, it may have an indirect effect on health.

Remedial Measure

Treat the problem of acidic, low pH drinking water with a neutralizer. The neutralizer feeds a solution, typically using soda ash, into the water to prevent the water from reacting with the house plumbing or contributing to corrosion, which can leach metals into the water. Note: neutralizing with soda ash increases the sodium content of the water, which may pose additional health concerns for your household. Treat hard water with a high pH with an ion-exchange system or the addition of a lime-soda ash mixture. These processes also can increase the sodium content of the water.
Although pH usually has no direct impact on water consumers, it is one of the most important operational water-quality parameters. Careful attention to pH control is necessary at all stages of water treatment to ensure satisfactory water clarification and disinfection. For effective disinfection with chlorine, the pH should preferably be less than 8. The pH of the water entering the distribution system must be controlled to minimize the corrosion of water mains and pipes in household water systems. Failure to do so can result in the contamination of drinking-water and in adverse effects on its taste, odour, and appearance.

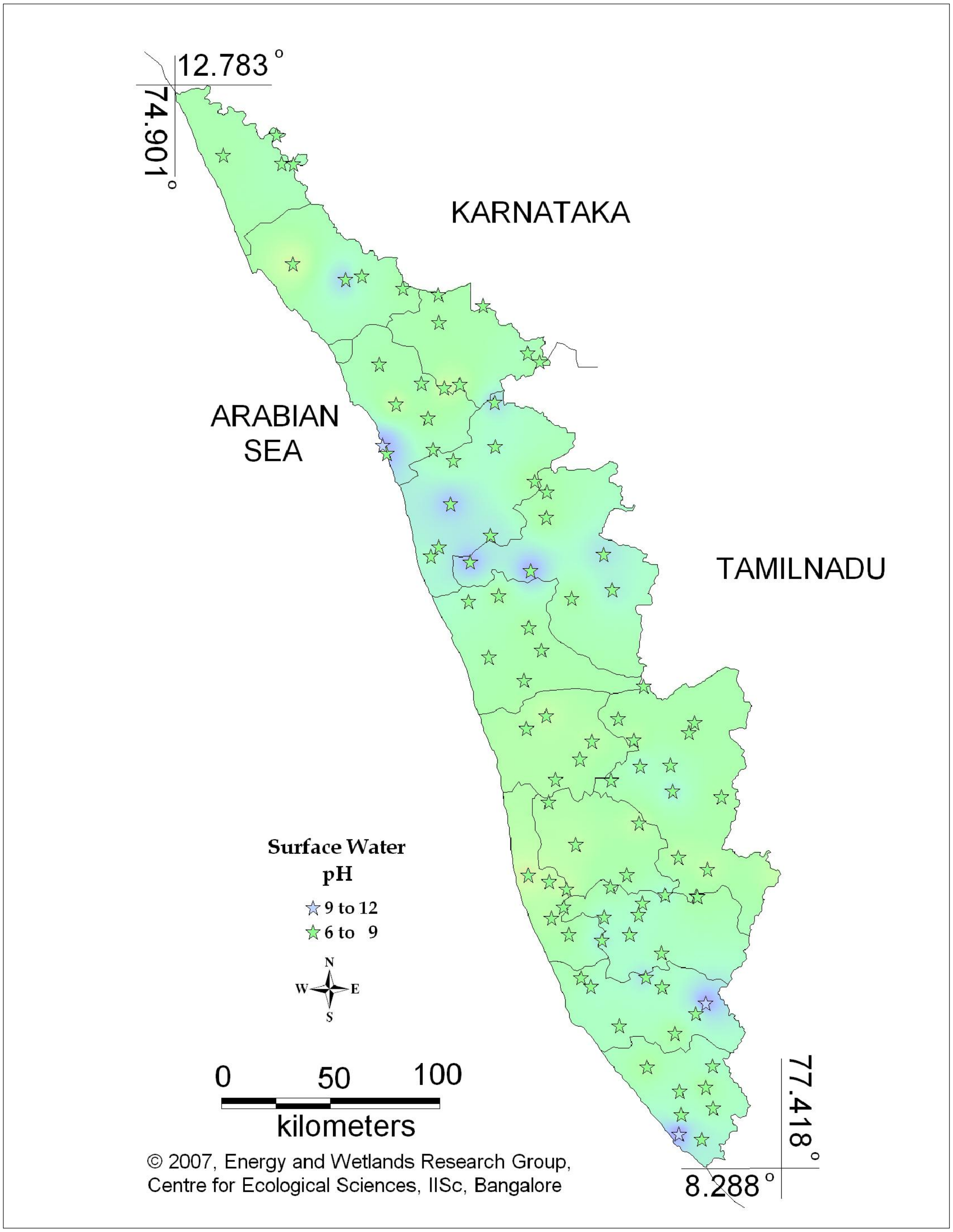
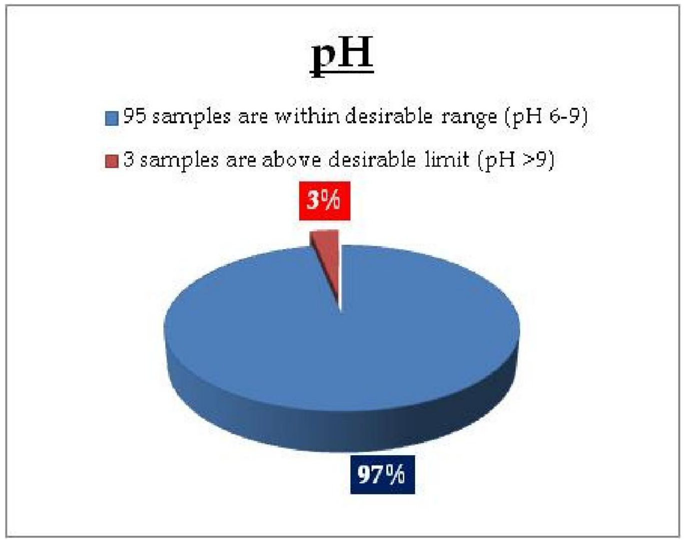


Figure 24.1: Spatial variation of pH in Kerala's surface water

Surface water - pH

Tolerance limit for inland surface waters subject to pollution

Desirable range: 6 - 9



Remarks

Sampling sites above desirable limit of pH are:

Location	Value	District
Thamarakulam lake	9.08	Kozhikode
Kazhuthruthy	9.11	Kollam
Vellayani lake	9.18	Tiruvanthapuram

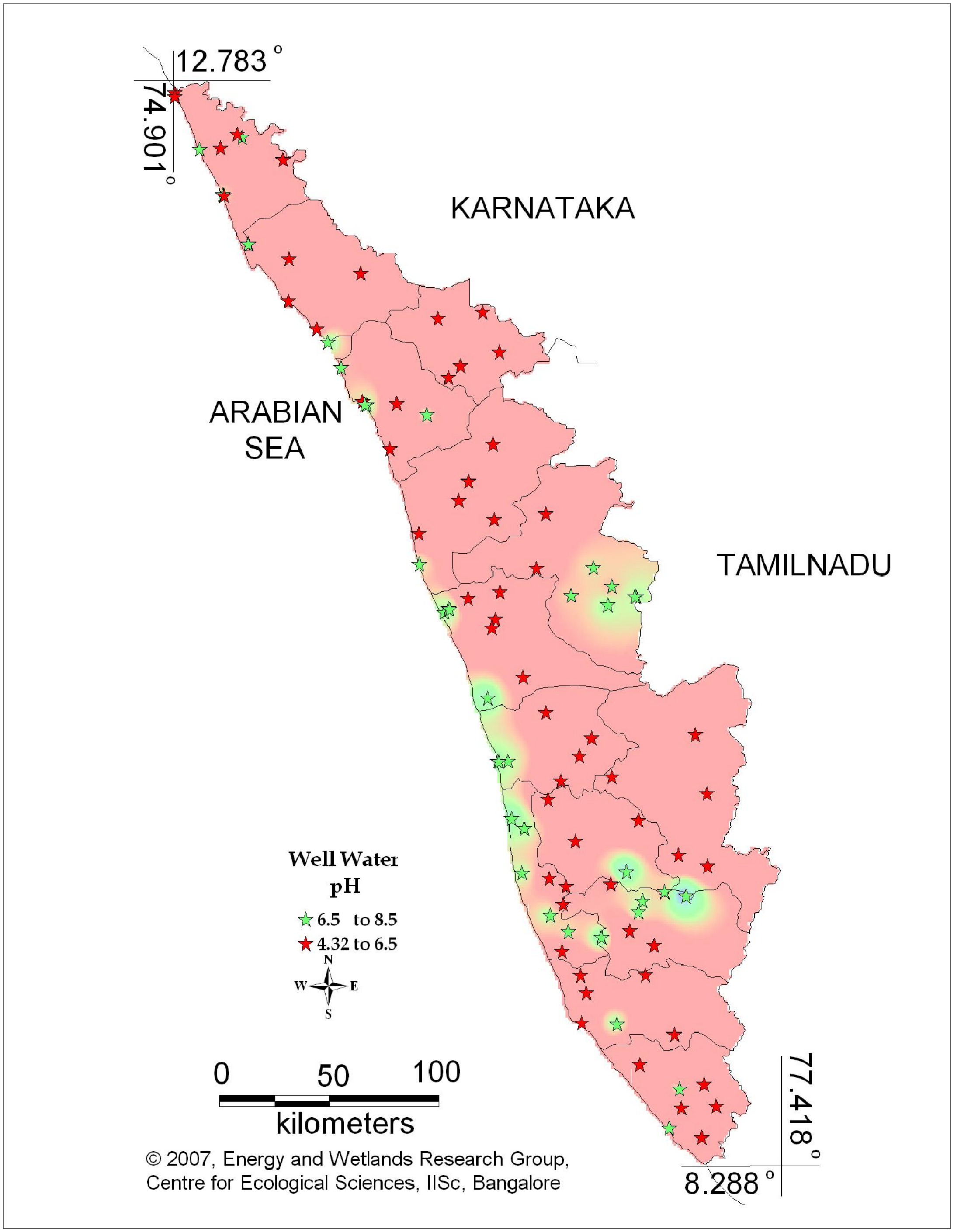
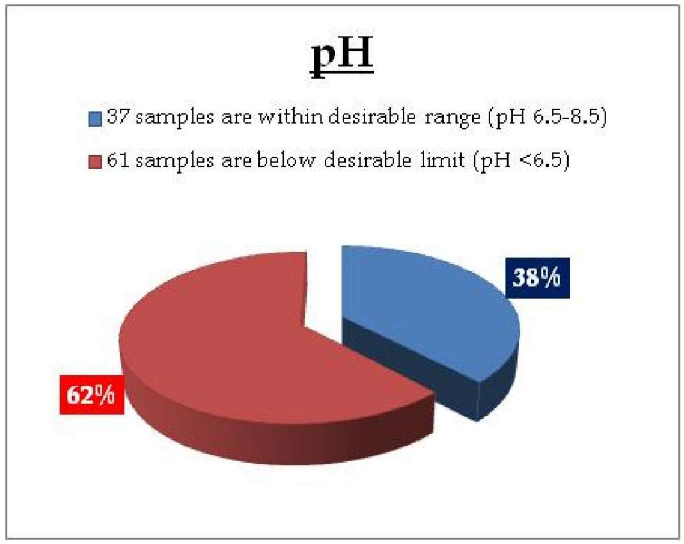


Figure 24.2: Spatial variation of pH in Kerala's well water

Well water - pH

Standard for Drinking Water (BIS 105000)
Desirable range: 6.5 - 8.5



Remarks
Sampling sites above desirable limit of pH are:

Location	**Value**	**District**
Neyyathinkara	4.32	Tiruvanthapuram
Kannur	4.87	Kannur
Bovikanam	4.93	Kasarkod
Kulasekaram	5.14	Tiruvanathapuram
Kallarakadvu	5.15	Pathinamthitta
Adukkam	5.15	Kottayam
Malumelkadavu	5.24	Kollam
Aluva	5.26	Ernakulam
Kottooli	5.26	Kozhikode
Thrissur	5.28	Thrissur
Irriti	5.30	Kannur
Avananvancherri	5.36	Tiruvanthanpuram
Balusserry - Vaikundam	5.42	Kozhikode
Vaithiri	5.47	Wayanad
Cherananllur	5.48	Thrissur
Peeramedu	5.49	Idukki
Thodupuzha	5.64	Idukki
Chatakadavu	5.65	Wayanad
Hosabettu - Manjeshwar	5.66	Kasarkod

Onakkoor-Piravam	5.70	Ernakulam
Malappuram-Kottakunne	5.71	Malapuram
Sulthan Bathery	5.72	Wayanad
Pidavoor	5.79	Kollam
Nilambur	5.80	Malapuram
Tirur	5.81	Malapuram
Kaladi	5.87	Ernakulam
Boundermukku	5.88	Tiruvanthapuram
Vettikattumukku	5.88	Kottayam
Chitara Estate	5.92	Kollam
Kothamangalam	5.92	Ernakulam
Poovathummuddu	5.94	Kottayam
Kallummoottilkadavu	6.01	Kollam
Vallakadavu	6.07	Idukki
Muvathupuzha	6.07	Ernakulam
Thrissur	6.07	Thrissur
Thannimoodu	6.08	Idukki
Mannarkkad	6.11	Palakkad
Perinthalmanna	6.11	Malapuram
Payyanoor	6.12	Kannur
Kallely Check Post	6.13	Pathinamthita
Bengathadka	6.15	Kasarkod
Panathur	6.16	Kasarkod
Karimbam-Taliparamba	6.16	Kannur
Ottapalam	6.19	Palakkad
Kavalam	6.20	Alappuzha
Kayamkulam	6.23	Alappuzha
Wadakancheery	6.23	Kozhikode
Neyyar Dam	6.25	Tiruvanthapuram
Kochupilammood	6.25	Kollam
Old Munnar	6.25	Idukki
Kalpetta - Rattakoli	6.25	Wayanad
Alathoor	6.25	Palakkad
Poorot	6.28	Kasarkod
Thalassery	6.30	Kannur
Thuruthelpalam	6.34	Kottayam
Manjeri	6.34	Malapuram
Kanhangad	6.37	Kasarkod
Chalakudy	6.38	Thirssur
Kulathurmozhi	6.40	Kottayam
Koyilandy	6.40	Kozhikode
Chenkulathukavu	6.46	Kottayam

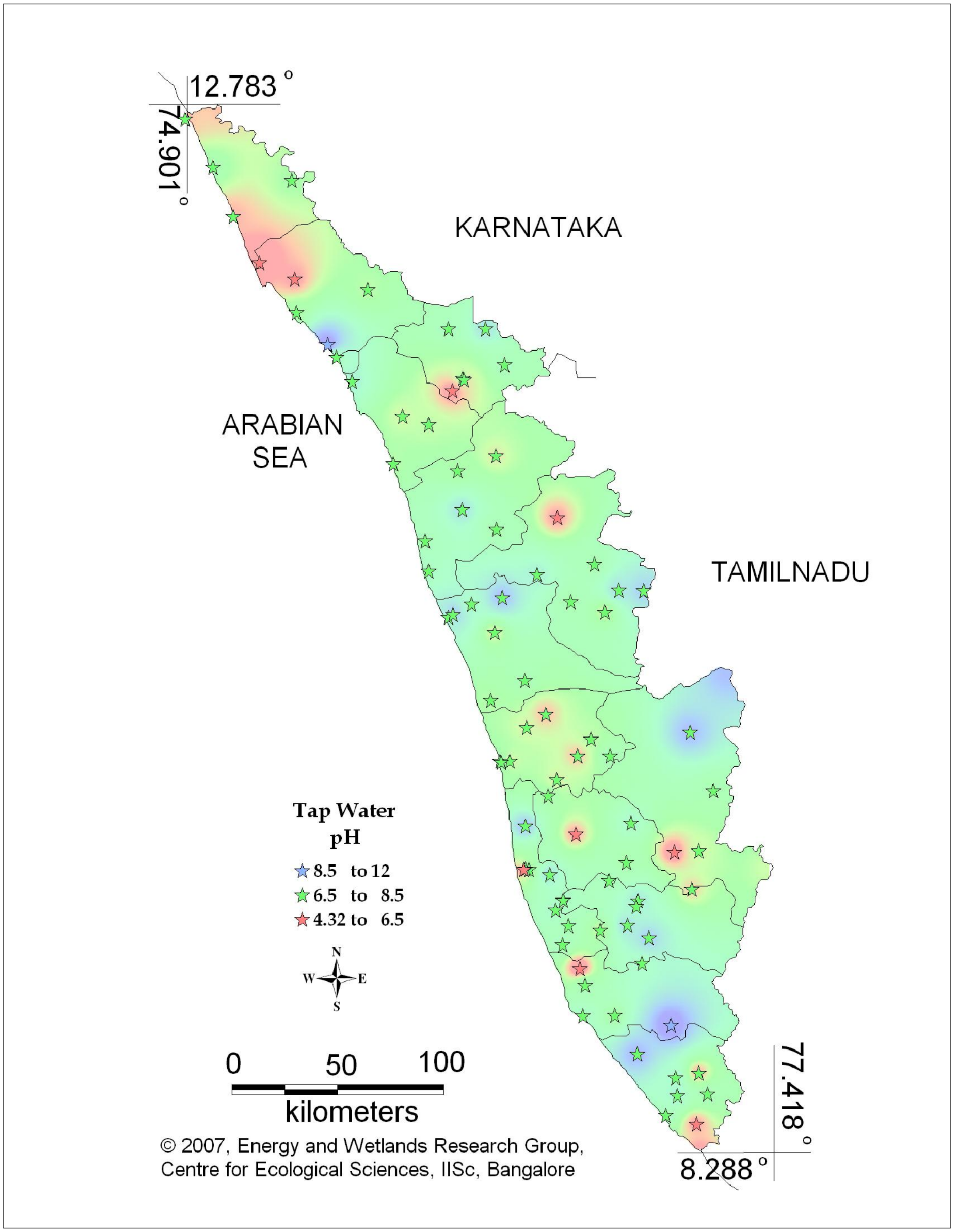
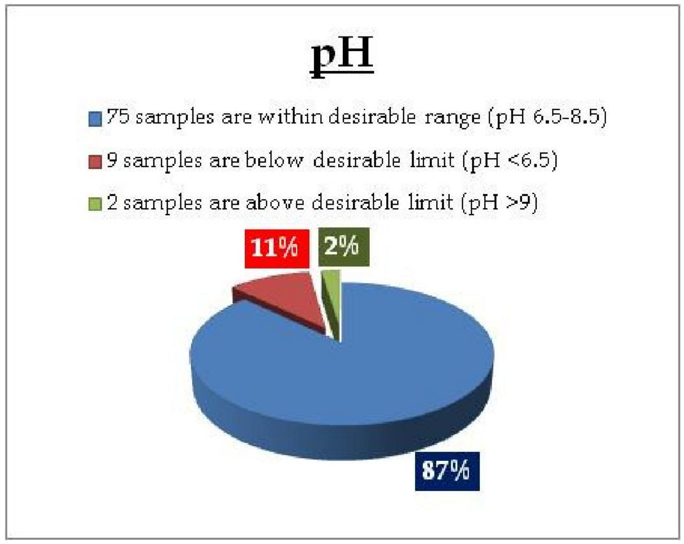


Figure 24.3: Spatial variation of pH in Kerala's tap water

Tap water - pH

Standard for Drinking Water (BIS 105000)
Desirable range: 6.5 - 8.5



Remarks

Sampling sites below desirable limit of pH are:

Location	Value	District
Pazhavangadi Jn	5.93	Alappuzha
Payyanoor	6.03	Kasarkod
Malumelkadavu	6.13	Kollam
Peeramedu	6.27	Idukki
Vaithiri	6.28	Wayanad
Talipparamba	6.44	Kannur
Neyyathinkara	6.45	Tiruvanthapuram
Thenkara	6.45	Palakkad
Perror	6.49	Kottayam

Sampling sites above desirable limit of pH are:

Thalassery	8.89	Kannur
Chitara Estate	9.06	Kollam

Dissolved oxygen

Dissolved oxygen analysis measures the amount of gaseous oxygen (O_2) dissolved in an aqueous solution. Dissolved oxygen is one of the most important parameters in aquatic systems. This gas is an absolute requirement for the metabolism of aerobic organisms and also influences inorganic chemical reactions. Therefore, knowledge of the solubility and dynamics of oxygen distribution is essential to interpreting both biological and chemical processes within water bodies. Oxygen gets into water by diffusion from the surrounding air, by aeration (rapid movement) and as a waste product of photosynthesis. The amount of dissolved oxygen gas is highly dependent on temperature. Atmospheric pressure also has an effect on dissolved oxygen. The amount of oxygen (or any gas) that can dissolve in pure water (saturation point) is inversely proportional to the temperature of water. The warmer the water, the less dissolved oxygen.

Effects on Environment Health

In a nutrient-rich water body the dissolved oxygen is quite high in the surface water due to increased photosynthesis by the large quantities of algae. However, dissolved oxygen tends to be depleted in deeper waters because photosynthesis is reduced due to poor light penetration and due to the fact that dead phytoplankton (algae) falls toward the bottom using up the oxygen as it decomposes. In a nutrient-poor water body there is usually less difference in dissolved oxygen from surface to bottom. This difference between surface and bottom waters is exaggerated in the summer in reservoirs, stream-pools, and embayment when thermal layering occurs which prevents mixing. The surface may become supersaturated with oxygen (>100%) and the bottom anoxic (virtually no oxygen). Shallower reservoirs and actively flowing shallow streams generally are kept mixed due to wind action in the shallow reservoirs and physical turbulence created by rocks in the stream beds.

Adequate dissolved oxygen is needed and necessary for good water quality. Oxygen is a necessary element to all forms of life. Adequate oxygen levels are necessary to provide for aerobic life forms which carry on natural stream purification processes. As dissolved oxygen levels in water drop below 5.0 mg/L, aquatic life is put under stress. The lower the concentration, the greater the stress. Oxygen levels that remain below 1-2 mg/L for a few hours can result in large fish kills. Total dissolved oxygen concentrations in water should not exceed 110 percent. Concentrations above this level can be harmful to aquatic life. Fish in waters containing excessive dissolved gases may suffer from "gas bubble disease"; however, this is a very rare occurrence. The bubbles or emboli block the flow of blood through blood vessels causing death. Aquatic invertebrates are also affected by gas bubble disease but at levels higher than those lethal to fish.

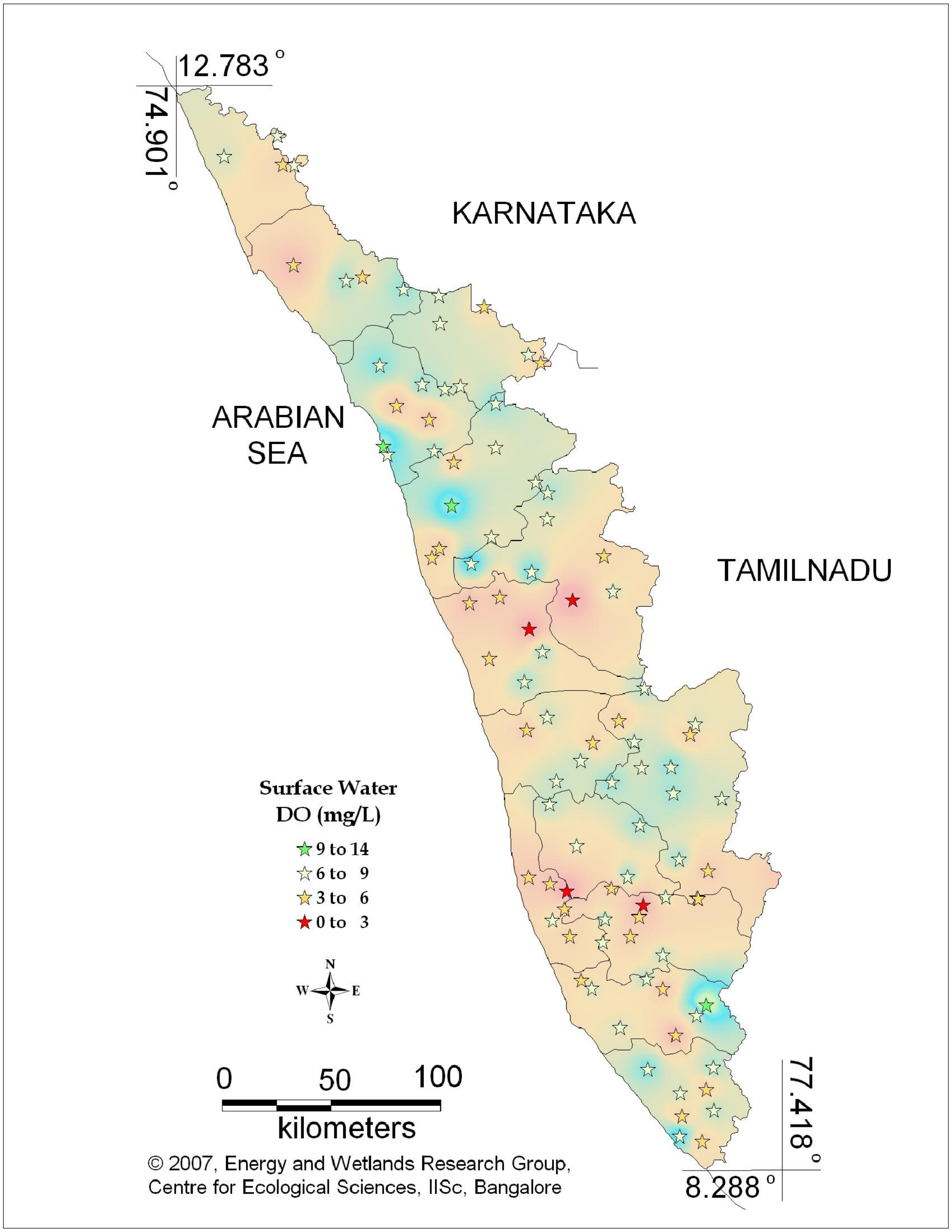
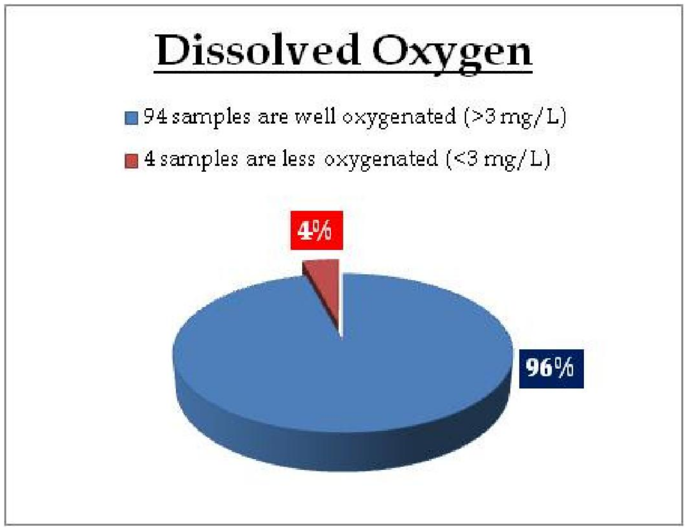


Figure 25.1: Spatial variation of dissolved oxygen in Kerala 's surface water

Surface water – Dissolved Oxygen

Tolerance limit for inland surface waters subject to pollution

Desirable Limit: 3 mg/L



Remarks

Sampling sites not in the desirable limit of DO are:

Location	**Value**	**District**
Changanacherry	0.89	Kottayam
Alathur	1.73	Palakkad
Athikayam	2.08	Pathinamthitta
Peechi Dam	2.24	Thrissur

Aquatic weeds growth in waterways, which affects the oxygen mixing in water

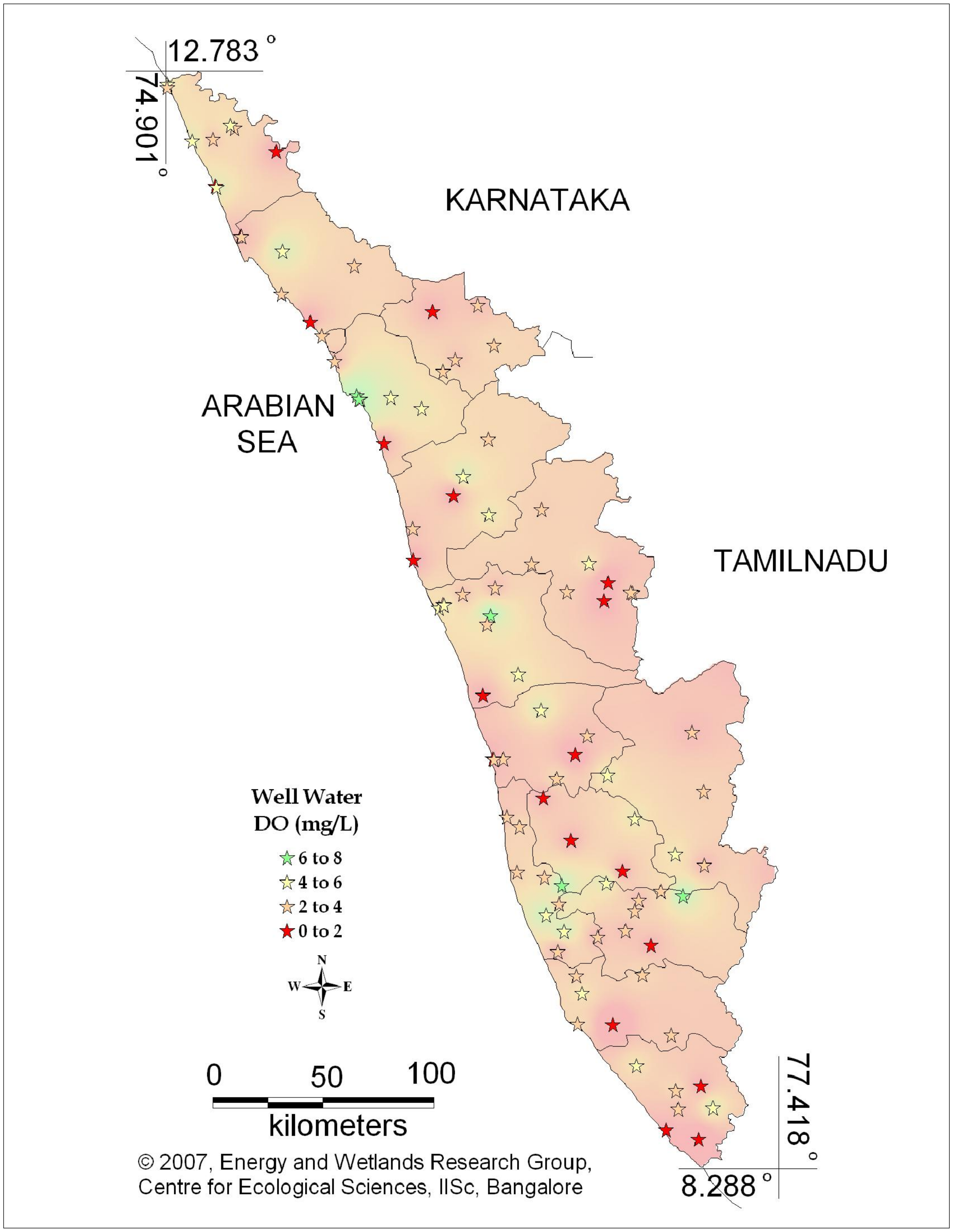


Figure 25.2: Spatial variation of Dissolved Oxygen in Kerala's well water

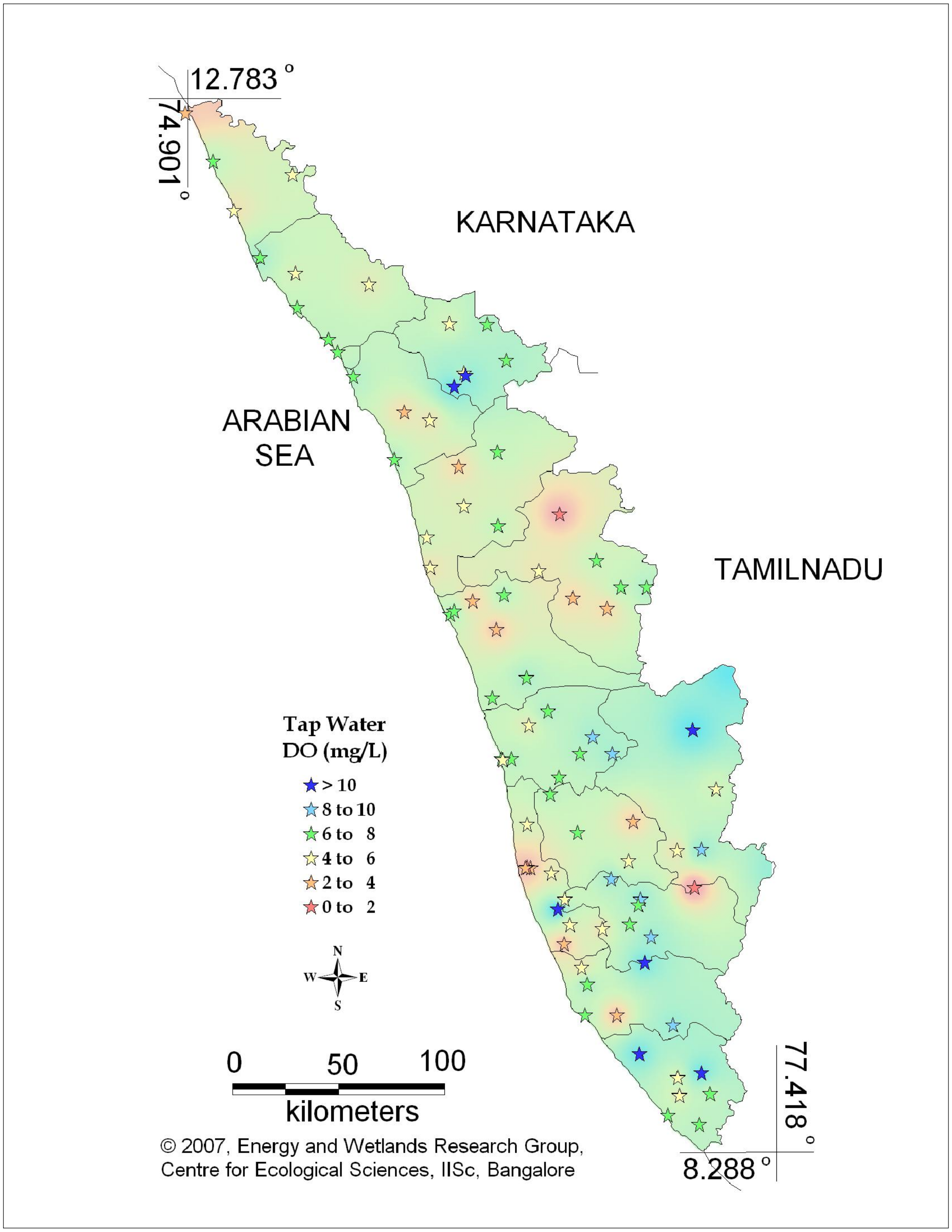


Figure 25.3: Spatial variation of dissolved oxygen in Kerala's tap water

10.0 KERALA WATER RESOURCE - THREATS AND MANAGEMENT ISSUES

Deforestation - Land use changes: Conversion of watershed area has altered the hydrological regime while enhancing the silt movement – lowering water yield in the catchment affecting the groundwater recharge. Large-scale deforestation in the Western Ghats and introduction of plantation crops in highlands replacing the natural vegetation reduced the storage capacity of soil and resulted in surface soil erosion in watersheds and sedimentation in rivers. This has affected summer flow in rivers and some perennial rivers and rivulets have became seasonal in the last few decades due to large scale land cover changes.

Sand Quarrying and River Bank Agriculture

Sand quarrying in rivers and watersheds are killing the rivers. Such activities lead to bank erosion, lowering of water table and create several environmental problems. Ground water level in some of the watersheds has gone down by nearly one meter in the last two decades. Agricultural practices in the riverbanks (and also inside the dry riverbeds) during non-rainy months also add to bank erosion and sedimentation in rivers.

Prevalent illegal sand mining in rivers and streams

Degradation of Water Resources

All 44 rivers in Kerala are highly polluted due to inflow of untreated domestic, industrial wastes and agriculture runoff. Most of the industries are near the thickly populated riversides, often near cities and towns. There is no efficient water treatment system in industries and city municipalities. Pollution level in some of the sites is far above permissible limits.

Oil spill: Water contamination

Land Reclamation and Construction: Sand filling of ponds, farmlands, wetlands and other water bodies affects natural water flow and groundwater recharge. Construction of new roads and buildings has blocked many canals, which were important for navigation and freshwater. Vast areas of wetlands and paddy fields have been converted into settlement and industrial areas in the recent times.

Land reclamation

Bacteriological Contamination in Drinking Water Source

Wide spread bacteriological contamination of fecal origin in sources of public drinking water supplies, viz. traditional open dug wells, bore wells and surface sources. This is confirned by the findings and public concerns expressed during site visits. Theses concerns for ground and surface water contamination relate to

- Close proximity of increasing numbers of leach pit latrines under varying soil conditions, laterite (midland) and sandy soils (coastal area);
- Non point sources of pollution in the catchment area including possible agricultural and surface run off, especially during the rainy season;
- Washing, bathing and other domestic activities around the open dug well sources, especially among the low income communities;
- Inadequate and irregular disinfection of drinking water supplies, including chlorination under KWA schemes;
- Inadequate testing and irregular monitoring of drinking water quality.

Leaky water distribution network: Source of contamination of treated water

Solid waste dumping in a river catchment

MANAGEMENT WATER QUALITY ASPECTS

Effective and continuous disinfection of all drinking water supplies so as to maintain minimum residual chlorine of 0.5 mg/l. The experimental results show that the quality of drinking water supplies in the state clearly indicates high level of bacterial contamination. This poses a serious risk to public health. This is confirmed by the high incidence of acute diarrhoeal diseases and other water borne infections among the people especially the poor sections of the community. This brings out the need for a system of continuous disinfection of the water supplies. The traditional wells used as a drinking water sources are reported to be disinfected only

GROUNDWATER PROTECTION

Contamination of Groundwater is more complex than surface water pollution mainly because of difficulty in its timely detection and slow movement. In addition the complex geo-chemical reactions taking place in the subsurface between myriad contaminants and earth materials are not always well-understood. Ideally speaking contamination should be prevented from occurring. After a contaminant or several contaminants are found in groundwater, a decision must be made on whether to rehabilitate the aquifer or find alternative groundwater resources.

Responsible Factor	Most Probable Response
Groundwater pollution originating on land surface	
Infiltration of contaminated surface water	Contamination of stream side aquifer due to polluted stream
Land disposal of waste	Contamination due to direct disposal of waste
Stock piles (ore) tailings (over burden dumps	Release of mineralized leachate
Disposal of Sewage/Sludge	Release of Biological mineralized leachate
Salt spreading on road	Pollution due to winter time road salting
Animals feed lots	Biological waste
Fertilizer and Pesticides	Run-off resulting from indiscriminate use of such items
Accidental spills	Spill of in-transit chemicals and contamination due to spray water used during such mishap.
Air borne source	Acid/alkali rain particulates as fall out from smoke/ flue dust automobile pollutants

Groundwater pollution originating above the groundwater table	
Septic tanks Cess pools	Biological contamination of groundwater
Surface impoundment	Leachate from lagoons for storage/treatment of sewage industrial wastewater oil field brines spent acids etc.
Underground storage tanks/pipelines	Corrosion and /or leakage
Artificial Recharge	In case of improper operation the recharge may lead to increased concentration of nitrates, metals, bacteria, viruses, detergents etc.
Groundwater pollution originating below the groundwater table	
Waste disposal in wet excavations	Contamination through abandoned mines
Agriculture drainage wells	Drainage of agricultural residues from marshes /ponds
Well disposal of waste	Contamination due to direct injection of waste
Secondary recovery of petroleum	Migration and ingress of hydrocarbons
Mines	Percolation of mine water
Exploratory wells and test holes	Inter-linking of aquifers leading to dissemination of pollutants
Abandoned wells	Direct migration of mineralized fluids
Water supply wells	Contamination by surface run-off
Excessive groundwater development	Salt water ingress

Classification	Transmission	Examples	Preventive strategies
Water-borne (water-borne diseases can also be water washed	Disease is transmitted by ingestion	• Diarrhoeas (e.g. cholera) • Enteric fevers (e.g. typhoid) • Hepatitis A	• Improve quality of drinking water • Prevent casual use of other unimproved sources • Improve sanitation
Water-washed (water scarce)	Transmission is reduced with an increase in	Diarrhea (e.g. amoebic dysentery)	Increase water quantity Improve accessibility

	water quantity: • Infections of the intestinal tract • Skin or eye infections • Infections caused by lice or mites	Trachoma Scabies	and reliability of domestic water supply Improve hygiene Improve sanitation
Water-based	The pathogen spends part of its life cycle in an animal which is water-based. The pathogen is transmitted by ingestion or by penetration of the skin.	Guinea worm Schistosomiasis	Decrease need for contact with infected water Control vector host populations Improve quality of the water (for some types) Improve sanitation (for some types)

Insect-vector	Spread by insects that breed or bite near water	Malaria River blindness	Improve surface-water management Destroy insects' breeding sites Decrease need to visit breeding sites of insects Use mosquito netting Use insecticides

Bathing in contaminated water leads to water borne skin disease

Watershed-Based Approach to Aquatic Resource Management

isease

Each river system - from its headwaters to its mouth - is an integrated system and must be treated as such. The focus of water resource management is on wise and efficient use of water resources for such purposes as energy production, navigation, flood control, irrigation, and drinking water (Rajinikanth, R. and Ramachandra, T.V. 2001). It also places emphasis on improving ambient water quality. Watershed approach can provide benefits to individual citizens, the public sector, and the private sector. Individual citizens benefit when watershed protection improves the environment and the livability of an area. The watershed- wide participation of local citizens and organizations ensures that those who are most familiar with a watershed, its problems and possible solutions, play a major role in watershed stewardship. The private sector can benefit because the burden of water resource protection is distributed more equitably among pollution sources.

A comprehensive approach to water resource management is needed to address the myriad water quality problems that exist today from non-point and point sources as well as from habitat degradation. Watershed based planning and resource management is a strategy for more effective protection and restoration of aquatic ecosystems and for protection of human health. The watershed approach emphasizes all aspects of water quality, including chemical water quality (e.g., toxins and conventional pollutants), physical water quality (e.g., temperature, flow, and circulation), habitat quality (e.g., stream channel morphology, substrate composition, and riparian zone characteristics),and biological health and biodiversity (e.g., species abundance, diversity, and range).

To deal with non-point source pollution in an effective manner, a smaller and more comprehensive scale of analysis and management is required. While point source pollution control programs encourage identifying isolated polluters, non-point source strategies recognize that small sources of pollution are widely dispersed on the landscape and that the cumulative impacts of these pollutants on water quality and habitat are great. A whole basin approach to protecting water quality has proved most effective because it recognizes connected sub-basins (Ramachandra T.V., 2006b). This includes

- Addressing issues of water quantity, protection of riparian areas, control of aquatic non-native species, and protection of water quality.
- Protecting the integrity of permanent and intermittent seeps, streams, rivers, wetlands, riparian areas, etc.
- Prioritising watersheds for protection and restoration and focus available resources on highest priorities. Also, identify subwatersheds in which to emphasize high water quality.
- Not implementing any timber management in riparian areas without proof that these activities actually increase coarse woody debris above natural levels and the benefits outweigh the risks (sedimentation, oil and fuel runoff, etc).
- Conducting a comprehensive all seasons water quality monitoring.
- Eliminating commercial logging and unrestrained recreation in municipal watersheds

3.2 Watershed Management Practices

Non-point source pollution poses a serious threat to the health of watersheds. It results from an accumulation of many small actions, and, although the individual impacts may seem minor, the combined cumulative effects are significant. Control measures and best management practices (BMPs) exist that can be utilized for improved watershed health (Ramachandra, T.V. 2006b). The effectiveness of the measures varies, depending on the specific pollutants addressed; the watershed hydrology and characteristics, such as soils, slopes, type of vegetative cover, and the nature and extent of area development; the waterbodies in the watershed; and the sources of the pollution. Effectiveness also depends on correct application of the control measure or practice. All types of land uses have the potential to create non-point source pollution. Most of this pollution results from changes and disturbances on the land. Some key sources include residential areas, agricultural activities and forest practices.

Residential problems stem from neighbourhoods containing typical single- or multi-family dwelling units. The problems arise from impervious surfaces that increase the flow and volume of runoff causing stream channel erosion and flooding, and from sedimentation from eroded lawns and gardens. Runoff can become contaminated by household chemicals such as fertilizers, pesticides and herbicides, paints, solvents, and street/auto contaminates like oil. The most effective control measures to address residential non-point source pollution include:

- public education
- use of vegetated swales and wetlands for contaminate filtration before runoff enters receiving streams
- sediment traps in stormwater systems
- stormwater retention (e.g. detached downspouts)
- landscape design for erosion control
- recycling and proper disposal of household chemicals and wastes
- proper maintenance of on site septic systems to reduce nutrient loading
- combined sewer overflow management
- vegetative planting and riparian enhancement of neighborhood streams
- street sweeping to reduce suspended solid loading and decrease heavy metals and phosphorus contamination to receiving streams
- planned development on steep slopes
- limited amount of impervious surface
- increased use of cluster developments
- utilization of erosion control ordinances, especially on construction sites

Agricultural Activities include land uses such as orchards, nurseries, crop production, feedlots, and grazing. Most non-point source pollution from agricultural practices comes from erosion or chemical contamination of receiving waters. The most effective control measures to address agriculture-related non-point source pollution include:

- riparian area protection and enhancement
- revised management practices for livestock grazing and manure handling

Forestry practices generally lead to nonpoint source pollution problems of soil erosion and chemical contamination. The most effective control measures to address these problems include:

- technical assistance to landowners
- limits on road building and management

- use of erosion control standards
- chemical application controls (pesticides and herbicides)
- riparian area protection and enhancement

This accentuates the need for healthier watersheds. Healthier watersheds would slow the runoff, increase percolation into underground aquifers, decrease siltation of waterways, and lengthen the flow period for the rivers.

Watershed management has worked for over a century in Tinelvelli, where watershed recovered resulting in improved stream flow in less than five years when cattle grazing and fuelwood harvest were removed. The Palni Hills Conservation Council (PHCC) found that the watersheds of the Karavakurichi Reserve Forest improved in mere two years when fuelwood harvesters were given alternate employment in tree nurseries. Similar success stories are reported from dry arid districts like Ananthpur.

Aquatic Ecosystem: Conservation Strategy

While rivers, lakes, and wetlands contain a mere 0.01% of the Earth's water, these ecosystems support a disproportionately large part of global biodiversity. Freshwater fishes alone account for approximately one quarter of all living vertebrate species and It is estimated that there are 44,000 scientifically named species of freshwater biota. Tallies of endangered species indicate that freshwater biodiversity is generally more threatened than terrestrial biodiversity. For example, of those species considered in The World Conservation Union's (IUCN) Red List for 2000, 20% of amphibians and 30% of fishes (mostly freshwater) were considered threatened. Freshwater biodiversity faces a broad range of threats. These include the direct impacts of dams, exotic species, overfishing, pollution, stream channelisation, water withdrawals, and diversions, as well as the indirect consequences of terrestrial activities such as logging, agriculture, industry, housing development, and mining (Prasad, et al. 2002). Conservation strategies need to be evolved and implemented to protect freshwater biodiversity. The Aquatic Conservation Strategy focus on conservation and maintaining the ecological health of watersheds and aquatic ecosystems so as to (Ramachandra, T.V. et al. 2002):

- Maintain and conserve the distribution, diversity, and complexity of watershed and landscape-scale features to ensure protection of the aquatic systems to which species, populations, and communities are uniquely adapted.
- Maintain and conserve spatial and temporal connectivity within and between watersheds. Lateral, longitudinal, and drainage network connections include flood plains, wetlands, up slope areas and headwater tributaries. These lineages must provide chemically and

physically unobstructed routes to areas critical for fulfilling life history requirements of aquatic and riparian-dependent species.

- Maintain and restore the physical integrity of the aquatic system, including shorelines, banks, and bottom configurations.
- Maintain and preserve water quality necessary to support healthy riparian, aquatic, and wetland ecosystems. Water quality must remain in the range that maintains the biological, physical, and chemical integrity of the system and benefits survival, growth, reproduction, and migration of individuals composing aquatic and riparian communities.
- Maintain the sediment regime under which an aquatic ecosystem evolved. Elements of the sediment regime include the timing, volume, rate, and character of sediment input, storage, and transport.
- Maintain in stream flows sufficient to create and sustain riparian, aquatic, and wetland habitats and to retain patterns of sediment, nutrient, and wood routing (i.e., movement of woody debris through the aquatic system). The timing, magnitude, duration, and spatial distribution of peak, high, and low flows must be protected.
- Maintain the timing, variability, and duration of flood plain inundation and water table elevation in meadows and wetlands.
- Maintain and conserve the species composition and structural diversity of plant communities in riparian zones and wetlands to provide adequate summer and winter thermal regulation, nutrient filtering, appropriate rates of surface erosion, bank erosion, and channel migration, and to supply amounts and distributions of coarse woody debris sufficient to sustain physical complexity and stability.
- Maintain and conserve habitat to support well-distributed populations of native plant, invertebrate, and vertebrate riparian-dependent species.
- Aquatic ecosystem conservation and management require collaborated research involving natural, social, and inter-disciplinary study aimed at understanding the various components, such as monitoring of water quality, socio-economic dependency, biodiversity, and other activities, as an indispensable tool for formulating long term conservation strategies (Ramachandra, 2005). This requires multidisciplinary-trained professionals who can spread the understanding of ecosystem's importance at local schools, colleges, and research institutions by initiating educational programs aimed at raising the levels of public awareness and comprehension of aquatic ecosystem restoration, goals, and methods.
- Actively participating schools and colleges in the vicinity of the waterbodies may value the opportunity to provide hands-on environmental education which could entail setting up laboratory facilities at the site. Regular monitoring of waterbodies (with

permanent laboratory facilities) would provide vital inputs for conservation and management.

Watershed restoration should be an integral part of the conservation program to aid recovery of habitat, riparian habitat, and water quality. The most important components of a aquatic restoration program are control and prevention of pollution and sediment production, restoration of the condition of riparian vegetation, and restoration of in-stream habitat complexity (Ahalya, N. and Ramachandra, T.V. 2001).

Restoration of Aquatic Ecosystems

Due to various anthropogenic activities to cater the needs of growing population, the degradation of freshwater ecosystems by a variety of stressors has increased logarithmically. As a result, many aquatic ecosystems are in need of some drastic corrective measures / restoration. Restoration is the "return of an ecosystem to a close approximation of its condition prior to disturbance" or the reestablishment of predisturbance aquatic functions and related physical, chemical and biological characteristics. It is a holistic process not achieved through the isolated manipulation of individual elements. The objective is to emulate a natural, self-regulating system that is integrated ecologically with the landscape in which it occurs. Often, restoration requires one or more of the following processes: reconstruction of antecedent physical conditions, chemical adjustment of the soil and water; and biological manipulation, including the reintroduction of absent native flora and fauna. These principles focus on scientific and technical issues, but as in all environmental management activities, the importance of community perspectives and values is to be considered. Coordination with the local people and organizations that may be affected by the project can help build the support needed to get the project moving and ensure long-term protection of the restored area. In addition, partnership with all stakeholders can also add useful resources, ranging from finance and technical expertise to volunteer help with implementation and monitoring (Ramachandra T.V. 2001). Restoration principles are

- **Preserve and protect aquatic resources:** Existing, relatively intact ecosystems are the keystone for conserving biodiversity, and provide the biota and other natural materials needed for the recovery of impaired systems.
- **Restore ecological integrity:** Ecological integrity refers to the condition of an ecosystem -- particularly the structure, composition, and natural processes of its biotic communities and physical environment.
- **Restore natural structure:** Many aquatic resources in need of restoration have problems that originated with harmful alteration of

channel form or other physical characteristics, which in turn may have led to problems such as habitat degradation, changes in flow regimes, and siltation.

- **Restore natural function:** Structure and function are closely linked in river corridors, lakes, wetlands, estuaries and other aquatic resources. Reestablishing the appropriate natural structure can bring back beneficial functions.
- **Work within the watershed and broader landscape context:** Restoration requires a design based on the entire watershed, not just the part of the waterbody that may be the most degraded site. Activities throughout the watershed can have adverse effects on the aquatic resource that is being restored. By considering the watershed context in this case, restoration planners may be able to design a project for the desired benefits of restoration, while also withstanding or even helping to remediate the effects of adjacent land uses on runoff and non-point source pollution.
- **Understand the natural potential of the watershed:** Restoration planning should take into account any irreversible changes in the watershed that may affect the system being restored, and focus on restoring its remaining natural potential.
- **Address ongoing causes of degradation:** Identify the causes of degradation and eliminate or remediate ongoing stresses wherever possible.
- **Develop clear, achievable, and measurable goals:** Goals direct implementation and provide the standards for measuring success. The chosen goals should be achievable ecologically, given the natural potential of the area, and socio-economically, given the available resources and the extent of community support for the project.
- **Focus on feasibility** taking into account scientific, financial, social and other considerations.
- **Anticipate future changes:** As the environment and our communities are both dynamic, many foreseeable ecological and societal changes can and should be factored into restoration design.
- **Involve the skills and insights of a multi-disciplinary team:** Universities, government agencies, and private organizations may be able to provide useful information and expertise to help ensure that restoration projects are based on well-balanced and thorough plans.
- **Design for self-sustainability:** Ensure the long-term viability of a restored area by minimizing the need for continuous maintenance of the site. In addition to limiting the need for maintenance, designing for self-sustainability also involves favoring ecological integrity, as an ecosystem in good condition is more likely to have the ability to adapt to changes.

- **Use passive restoration, when appropriate:** Simply reducing or eliminating the sources of degradation and allowing recovery time will allow the site to naturally regenerate. For some rivers and streams, passive restoration can reestablish stable channels and floodplains, regrow riparian vegetation, and improve in-stream habitats without a specific restoration project. Passive restoration relies mainly on natural processes and it is still necessary to analyze the site's recovery needs and determine whether time and natural processes can meet them.
- **Restore native species and avoid non-native species:** Many invasive species outcompete natives because they are expert colonizers of disturbed areas and lack natural controls.
- **Use natural fixes and bioengineering techniques, where possible:** Bioengineering is a method of construction combining live plants with dead plants or inorganic materials, to produce living, functioning systems to prevent erosion, control sediment and other pollutants, and provide habitat. These techniques would be successful for erosion control and bank stabilisation, flood mitigation, and even water treatment.
- **Monitor and adapt where changes are necessary:** Monitoring before and during the project is crucial for finding out whether goals are being achieved. If they are not, "mid-course" adjustments in the project should be undertaken. Post-project monitoring will help determine whether additional actions or adjustments are needed and can provide useful information for future restoration efforts. This process of monitoring and adjustment is known as adaptive management. Monitoring plans should be feasible in terms of costs and technology, and should always provide information relevant to meeting the project goals.

These principles focus on scientific and technical issues, but as in all environmental management activities, the importance of community perspectives and values should not be overlooked. The presence or absence of public support for a restoration project can be the difference between positive results and failure. Coordination with the people and organizations that may be affected by the project can help build the support needed to get the project moving and ensure long-term protection of the restored area (Ramachandra, T.V. et al. 2002). Thus, a sustainable water system encompass issues such as:

- Environment: watershed protection, ecosystem balance, waste-water and bio-solids
- Community: sufficient and reliable water supply, participation in planning and recreational use to water.
- Economy: Evolution and diversification, Sustainable and long-term growth.

Within this overall vision, water management system will require, among other steps, the following action to be taken:

- Through strategic partnerships among national agencies, provincial agencies and local/city departments
- Developing alternate water sources - reclaimed/treated water, desalination, rainwater and water reuse.
- Implementing new technologies for water fees/metering, leak detection and water auditing systems
- Engage the community through education, local and regional planning processes and outreach to cultural and community groups.
- Scientific investigations involving aquifer monitoring, coastal marine environment study, supply-demand forecasting and pollution prevention.

The principal components of water management system include:

- **Supply optimization**, including assessments of surface and groundwater supplies, water balances, wastewater reuse, and environmental impacts of distribution and use options.
- **Demand management**, including cost-recovery policies, water use efficiency technologies, and decentralized water management authority.
- **Equitable access** to water resources through participatory and transparent management, including support for effective water users association, involvement of marginalized groups, and consideration of gender issues.
- **Improved policy, regulatory and institutional frameworks**, such as the implementation of the polluter-pays principle, water quality norms and standards, and market-based regulatory mechanisms.
- **Intersectoral approach** to decision-making, combining authority with responsibility for managing the water resource.

Water quality and quantity are becoming increasingly critical factors of socioeconomic development in many parts of the world. One of the milestones in managing international and transnational water resources and boundaries was the meeting and agreement on transboundary water management signed in Helsinki in the 1966 (ILC Helsinki 1966).

Helsinki rule evolved by the International law association in 1966 (see Annexure I) are:

i) the geography of the basin including, in particular, the extent of the drainage area in the territory of each basin state;

ii) the hydrology of the basin including, in particular, the contribution of water by each basin state;
iii) the climate affecting the basin;
iv) the past utilization of the waters of the basin, including in particular, existing utilization;
v) the economic and social needs of each basin state;
vi) the population dependent on the waters of the basin of each state;
vii) the comparative costs of alternative means of satisfying the economic and social needs of each basin state;
viii) the availability of other resources;
ix) the avoidance of unnecessary waste in the utilization of the waters of the basin;
x) the practicability of the compensation to one or more of the co-basin states as a means of adjusting conflicts among users; and
xi) the degree to which the needs of a basin state may be satisfied without causing substantial injury to a co-basin state.

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12.0 Reponses to queries

HOW THE SURVEY WAS DONE?

- **Selection of location**
  - The surface, tap and well water samples are collected from the district head quarters, taluk head quarters and places of tourist importance in 14 districts in Kerala

- **Time of the survey**
  - The sampling was done during the pre-monsoon season of 2007
  - The samples were collected in three phases
    - Phase I (2nd April 2007 to 8th April)
    - Phase II (21st April to 3rd May 2007)
    - Phase III (13th May 27th May)
- **Method of sampling**
  - The water samples were collected in the two and half-liter polythene cans for laboratory analysis.

Parameters	Methods (APHA Section no.)
pH*	Electrode Probe
Water Temperature (°C) *	
Salinity*	
TDS*	
EC (µS) *	
DO*	Azide Modification Iodometric (421 A)
Alkalinity	Acid Titrimetric (403)
Chlorides	Argentometric (407 A)
Hardness	Ethelenediaminetetraacitic acid (314 B)
Calcium Hardness	Ethelenediaminetetraacitic acid (311 C)
Magnesium Hardness	Magnesium by Calculation (318 C)

Phosphates	Stannous Chloride (424 E)
Sulphates	Turbidimetric method (426 C)
Sodium	Flame Photometric (325 B)
Potassium	Flame Photometric (322 B)
Nitrate*	Electrode screening (418 B)
Fluoride	SPADNS (413 C)
Faecal Coliform Bacteria	Standard Total Coliform Multiple Tube Tests (908 A, D)

* Analysis carried on site

Why water sources are polluted in Kerala?

Most polluted surface water stretches

Name of the River System	Reasons
Kuppapuram & Vembanad Lake complex	• High amount of Total dissolved solids, electrical conductivity, sodium, phosphates, potassium, hardness, salinity, and Nitrate • Infestation of water hyacinth • Waste water from boats • Confluence of major rivers
Periyar river (Aluva stretch)	• High amount of coliform, Total dissolved solids, electrical conductivity, Sodium and salinity • Industrial effluents • Alteration of river bed by sand mining • Physical appearance of water body a) abnormal colouration like greenish brown
Gayathripuzha (Alathur stretch)	• High amount of Total dissolved solids, conductivity, sodium and nitrate • Low level of dissolved oxygen • Infestation of water hyacinth
Karamana river (Nedumangad stretch)	• High amount of Total dissolved solids, conductivity, sodium,
Pamaba river (Athikayam stretch)	• High amount of Total dissolved solids, conductivity and sodium.

	• Low level of dissolved oxygen
Tamarakulam lake (Kozhikode)	• High amount of pH, Total dissolved solids, conductivity and sodium • Eutrophication
Neyyar river (Neyyattinkara stretch)	• High amount of coliform, Total dissolved solids, conductivity and sodium. • Sewage and hospital waste mixing with river

Most polluted well water sources

Name of the Site	Reasons
Koodungalur (Thrissur)	High amount of Total dissolved solids, electrical conductivity, sodium, chlorides, hardness, salinity, calcium, alkalinity, sulphates and nitrate
Thrissur town (Thrissur)	High amount of Total dissolved solids, electrical conductivity, sodium, hardness, salinity, and nitrate VERY HIGH AMOUNT OF COLIFORM
Fort Cochin (Ernakulam)	High amount of Magnesium, alkalinity, calcium
Aluva (Ernakulam)	VERY HIGH AMOUNT OF COLIFORM
Plachimada (Palakkad)	High amount of Sodium, magnesium, alkalinity, salinity
Ponnani (Palakkad)	High amount of sodium, alkalinity, calcium, salinity
Old Munnar (Idukki)	High amount of Nitrate

Most polluted tap water sources

Name of the Site	Reasons
Kallikulam Junction (Alappuzha)	• High amount of salinity, calcium, alkalinity, sodium, chlorides, fluorides, Total dissolved solids, nitrates, hardness and coliform • Salt water intrusion
Thathampally (Alappuzha)	• High amount of salinity, alkalinity, sodium, chlorides, fluorides, Total dissolved solids and nitrates

	• Salt water intrusion
Cheranellur (Thrissur)	• High amount of salinity, Total dissolved solids and coliform • Water supply from groundwater
Kollengode (Palakkad)	• High amount of calcium, alkalinity, alkalinity, fluorides, Total dissolved solids, hardness and coliform
Kavalam (Alappuzha)	• High amount of nitrates and coliform • Salt water intrusion
Guruvayoor (Thrissur)	• High amount of Total dissolved solids and coliform

What are the reasons for fluoride and nitrate contamination?

Fluoride and Nitrate menace in Kerala

- Fluoride contamination is high in well and tap waters of Alappuzha and Palakkad dist. and tap waters of Thiruvanathapuram (Kalikadu), Wayanad (Kalpetta) districts.
    - Fluoride contamination in drinking water can causes fluorosis, a mottling of the surface of the teeth, osteoporosis and arthritis, hip fractures, cancer, infertility, brain damage, etc.
- Nitrate is high in the tap and well waters of Alapuzha and one well water sample of Idukki dist. (Old Munnar). Most of the surface water samples are having nitrate value above desirable limit (0.1 mg/L).
    - Nitrate in drinking water can cause blue baby syndrome in infants under six months old. Blue baby syndrome or methemoglobinemia are common symptoms of nitrate contamination. Nitrate contamination in drinking water may also increase cancer risk, because nitrate is endogenously reduced to nitrite and subsequent nitrosation reaction give rise to N- nitroso compounds; these compounds are highly carcinogenic and can act systematically

River	Grade of the river
Achenkovil	A
Chaliyar	B
Chandragiri	B
Ithikkara	B
Kabbini	B
Kadalundi	B

Kallada	B
Kuttiyadi	B
Manimala	B
Manjeshwar	B
Meenachil	B
Movathupuzha	B
Pallikkal	B
Vamanapuram	B
Bharathapuzha	C
Chalakkudy	C
Karamana	C
Keecheri	C
Neyyar	D
Pamba	D
Periyar	D

Note: Based on sampling at 3 or more locations (results at sampling locality)

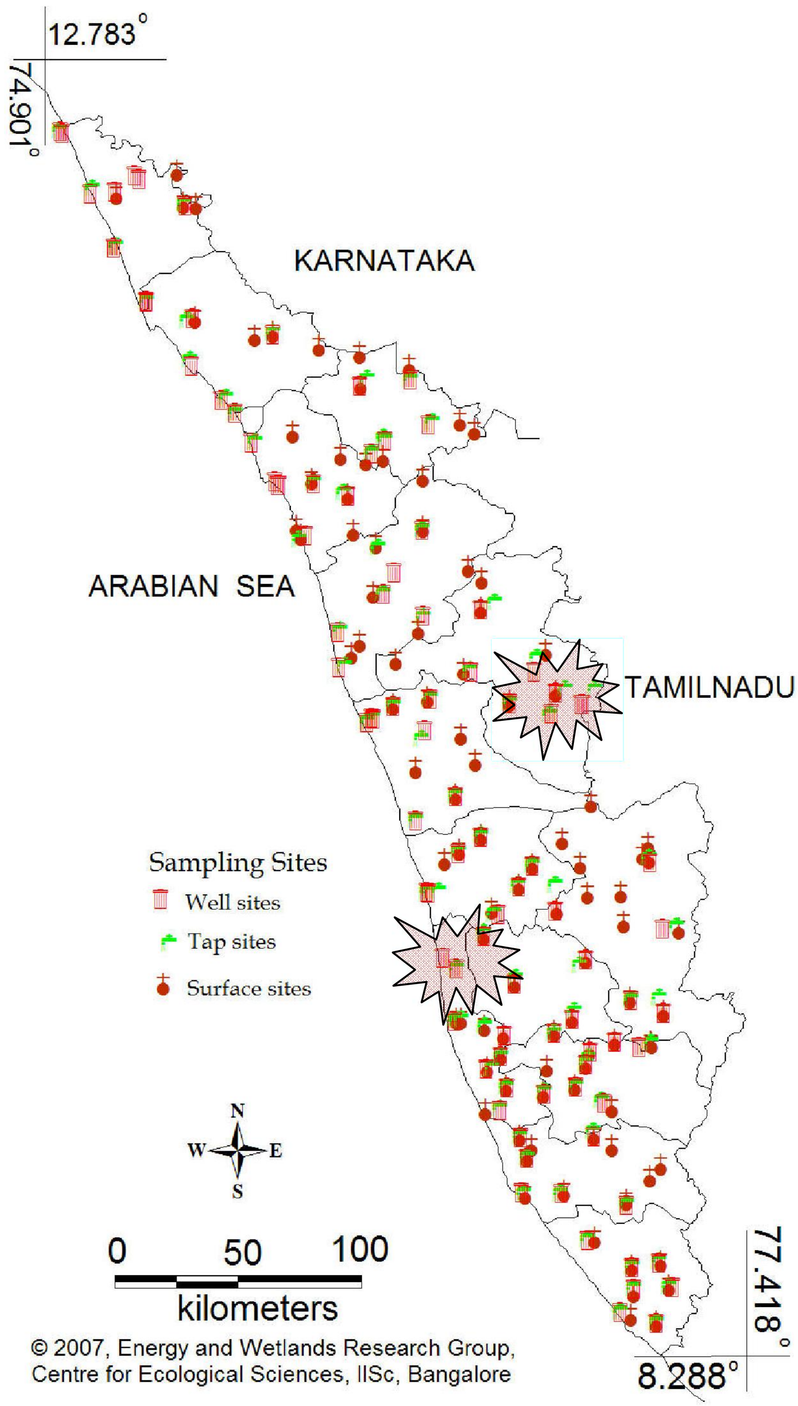
A = Total Coliforms Organism MPN/100ml: 50 or less
pH between 6.5 and 8.5
Dissolved Oxygen 7mg/L or more

B = Total Coliforms Organism MPN/100ml: 500 or less
pH between 6.5 and 8.5
Nitrate more than 0.1 mg/L
Dissolved Oxygen 5 – 6 mg/L

C= Total Coliforms Organism MPN/100ml > 500
pH not in neutral range
Nitrate more than 0.1 mg/L
Dissolved Oxygen < 5mg/L

D = Total Coliforms Organism MPN/100ml > 750
Nitrate more than 0.1 mg/L
Mixing of sewage/industrial effluents
Alteration of river bed/flow (sand mining, check dam, etc.)

Sampling sites with affected regions



Vol. V No. 1 February 2012

The IUP Journal of
Soil and Water Sciences

The Icfai University Press
www.iupindia.in

Spatial Assessment of Groundwater Quality in Kerala, India

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Groundwater is located in soil pore spaces and in the fractures of lithologic formations under subsurface. Pollutants leached to the ground make their way down into groundwater and contaminate an aquifer. The study focuses on the physicochemical and biological quality of groundwater spatially in Kerala to assess its suitability for drinking and understand the type of hydrochemicals and spatial distribution of major ions. Groundwater samples from 98 locations covering all districts in Kerala state, India were collected and analyzed, as per standard protocol. The results revealed that fecal coliform bacteria and pH were exceeding in many places. Nitrates exceeded permissible limits in two samples which contained 45.3 mg/L and 50 mg/L at Kayamkulam (Alappuzha) and Old Munnar (Idukki). Fluorides exceeded the desirable limit (1 mg/L) at Mullackal (1.4 mg/L) and Kalikulam Junction (1.2 mg/L) in Alappuzha district and Kollengode (1.6 mg/L) in Palakkad district. Hydrochemical types, relationship among the physicochemical parameters, characterization of sampling sites according to the physicochemical and biological characters and the spatial distribution of major ions are also discussed.

Keywords: Groundwater, Water quality, BIS standards, Piper diagram, Geostiff diagram, Spatial analysis

Introduction

Fresh water quality has gained substantial attention in recent years throughout the world (Chang, 2004). Groundwater (0.06% of Earth's available water) is a key source of drinking water among freshwater resources. This relatively small volume is critically important as it represents 98% of the freshwater readily available to humans (Zaporozec and Miller, 2000). India, diverse in terms of population (70% rural and 30% urban) depends on groundwater for drinking and domestic purposes (Reddy *et al.*, 1996 and Jaiswal *et al.*, 2003). Groundwater meets the drinking water requirement of over 50% of Kerala's population (Kerala Water Authority, 1991; Pillai and Ouseph, 2000; and Roy, 2004).

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The physicochemical and biological characteristics of groundwater in a given area are determined by the natural-geological formations (Subramani *et al.*, 2005), weathering, dissolution, precipitation, ion exchange and biological processes (Jeevanandam *et al.*, 2007) as well as anthropogenic activities. Often groundwater is contaminated by non-point sources (agricultural, urban runoff) and point sources (sewage, industrial effluents disposal) in many developing countries including India (Jeevanandam, 2007; and Jain *et al.*, 2010). In the recent years, the unplanned urbanization has influenced the quality as well as quantity of the water, evident from declining groundwater table, higher levels of contamination (Ramachandra and Uttam Kumar, 2008). These factors have necessitated the understanding of groundwater quality in the recent years (Yanggen and Born, 1990).

In Kerala, prevalence of water-borne diseases like diseases of gastrointestinal system (Panikar and Soman, 1984), diarrhea, dysentery, typhoid, worm infestations and infectious hepatitis (Aravindan, 1989; and Kunhikannan and Aravindan, 2000) are attributed to groundwater contamination, especially fecal coliform contamination (Kerala Water Authority, 1991; Radhakrishnan *et al.*, 1996; Calvert and Andersson, 2000; Panicker *et al.*, 2000; Rahiman *et al.*, 2003; Laluraj *et al.*, 2005; Laluraj *et al.*, 2006; Babu *et al.*, 2007; Harikumar and Kokkal, 2009; Rejith *et al.*, 2009; and Varghese and Jaya, 2009). Low pH was reported from many places (Gopinath and Seralathan, 2006; Laluraj and Gopinath, 2006; Vijith and Satheesh, 2007; Harikumar and Kokkal, 2009; and Rejith *et al.*, 2009). Harikumar and Kokkal (2009) have also reported high amount of alkalinity, magnesium, hardness, chloride, calcium and TDS. The contamination of groundwater by chloride, TDS and fluoride were reported by Harikumar *et al.* (2000); Laluraj *et al.* (2005); George and Prakasam (2008); and Shaji *et al.* (2007 and 2009).

Most of these reports are fragmented and were restricted to a particular panchayat or river basin or district. A comprehensive study covering the entire region would aid the decision-making process to implement the effective strategies to minimize or mitigate contamination of drinking water sources. This study focuses on the physicochemical and biological quality of groundwater throughout Kerala to assess its suitability for drinking as per standards (Bureau of Indian Standards - BIS, 1991) and to see the types of hydrochemicals and spatial distribution of major ions.

Materials and Methods

Study Area

Kerala, a coastal state in the southwest of peninsular India is situated between 8° 15′N-12° 50′N latitude and 74° 50′E-7° 30′E longitude. It receives rainfall from southwest monsoon (June-September) and northeast monsoon (October-November). According to the 2001 census, Kerala's population is 31,841,374 persons, with population density being 819 people per square kilometer (http://censusindia.gov.in). Kerala has a

Table 1: Physicochemical and Biological Parameters and the Methods

Parameters	Units	Methods	Section No. APHA, 1995
pH	-	Electrode Method	4500-H^+ B
WT	°C		2550 B
Salinity	ppm		2520 B
TDS	ppm		2540 B
EC	µS		2510 B
DO	mg/L	Iodometric method	4500-O B
Alkalinity	mg/L	HCl Titrimetric Method	2320 B
Cl^-	mg/L	Argentometric Method	4500-Cl^- B
Hardness	mg/L	EDTA Titrimetric Method	2340 C
Ca^{2+}	mg/L	EDTA Titrimetric Method	3500-Ca B
Mg^{2+}	mg/L	Calculation Method	3500-Mg B
Na^+	mg/L	Flame Emission Photometric Method	3500-Na B
K^+	mg/L	Flame Emission Photometric Method	3500-K B
F^-	mg/L	SPADNS method	4500-F^- D
NO_3^-	mg/L	Nitrate Electrode method	4500-NO_3^- D
SO_4^{2-}	mg/L	Turbidimetric method	4500-SO_4^{2-} E
PO_4^{3-}	mg/L	Stannous Chloride Method	4500-P D
Fecal coliform	MPN/100 mL	Multiple Tube Fermentation Technique	9221 B

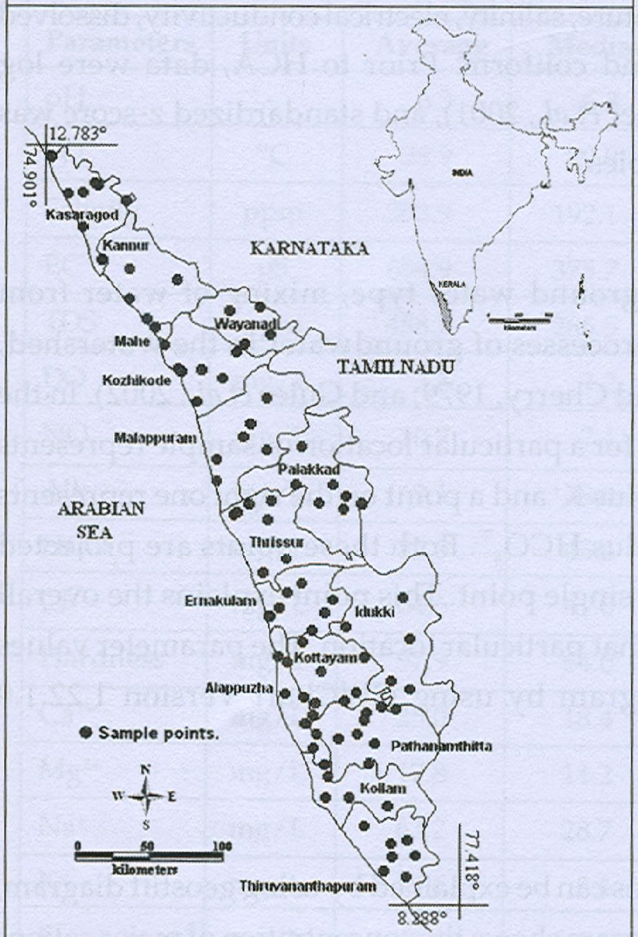
Note: WT - Water Temperature; TDS - Total Dissolved Solids; EC - Electrical Conductivity; and DO - Dissolved Oxygen.

geographical area of 38,863 sq km (http://www.kerala.gov.in) with a diverse topography; from the lowlands adjoining the sea on the west, the landscape ascends steadily towards the east to the midlands and further on to the highlands sloping from the Western Ghats.

Sample Collection

Stratified random sampling was adopted to collect groundwater samples from 98 wells covering all districts (Figure 1) during the summer period (April-May 2007). Summer season was chosen for water quality analysis as the water situation in most parts of Kerala is acute during that period. A minimum of four samples and maximum of 11 samples were collected from each district of Kerala. Samples were collected in disinfected 2.5 liter plastic containers. After collection, the samples were labeled with sample number, date of collection, latitude and longitude (retrieved from Garmin GPS).

Figure 1: Locations for Groundwater Sampling



Physical, Chemical and Biological Analysis

In situ measurements of pH, water temperature, salinity, total dissolved solids and electrical conductivity were recorded with EXTECH COMBO electrode (EC500) and nitrates by using Orion Ion Selective Electrode. Alkalinity, chloride, hardness, calcium, magnesium, sodium, potassium, fluoride, sulphate, phosphates and coliform bacteria were analyzed at Environment Chemistry Laboratory, Center for Ecological Sciences, as per the standard procedure given in APHA (1995). Bicarbonate and carbonate were calculated by using the formula given by Russell (2006). Coliform bacteria were estimated by using standard Multiple Tube Fermentation Technique (MTFT), nine multiple tube dilution technique using double and single strength Bromo-Cresol Purple, MacConkey medium and Membrane filter techniques by using M-EC test agar, and MPN Index was calculated from MPN table (APHA, 1995). Indian standard specifications for drinking water IS: 10500, 1992 (Reaffirmed 1993) were adopted in this study.

Data Analysis

Correlation

Correlations among variables were determined using Pearson product movement coefficient through RLPlot version 1.4. The value of correlation coefficient greater than or equal to -0.50 or +0.50 is statistically significant at 95% confidence level (Einax *et al.*, 1997).

Cluster Analysis

Hierarchical Cluster Analysis (HCA) was carried out using R version 2.7.1 (R Development Core Team, 2008). This has been done in Q mode (classification of samples according to their parameters) to cluster the samples into groups, using Euclidean distance with Ward's method. HCA helped to group the samples with similar characteristics (Guler *et al.*, 2002). Twenty variables were used in this analysis, viz., Ca^{2+}, Mg^{2+}, Na^{+}, K^{+}, CO_3^{2-}, HCO_3^{-}, SO_4^{2-}, PO_4^{3-}, NO_3^{-}, TDS, pH, water temperature, salinity, electrical conductivity, dissolved oxygen, alkalinity, hardness, fluoride and coliform. Prior to HCA, data were log transformed in PAST version 1.98 (Hammer *et al.*, 2001), and standardized z-score was computed to give equal weight to all variables.

Piper Diagram

To understand geochemical evolution, ground water type, mixing of water from different sources and physicochemical processes of groundwater in the watershed, Piper (1944) diagram was used (Freeze and Cherry, 1979; and Guler *et al.*, 2002). In the diagram, a point on the left triangular part for a particular location or sample represents the major cations like Ca^{2+}, Mg^{2+} and Na^{+} plus K^{+} and a point on the right one represents the major anions like SO_4^{2-}, Cl^{-}, CO_3^{2-} plus HCO_3^{-}. Both these points are projected together in the diamond shaped part as a single point. This point explains the overall chemical character of the groundwater of that particular location. The parameter values were plotted as mg/L in the Piper diagram by using GWChart Version 1.22.1.0 (Winston, 2000).

Spatial Distribution

The spatial distribution pattern of major ions can be explained by using geostiff diagram, that is georeferenced stiff diagram. Stiff diagram shows the concentration of major cations (left side) and anions (right side) of a particular place in a single diagram. Geostiff diagram allows to plot one or more stiff diagrams spatially in a single diagram. The major cations and anions used to prepare geostiff diagram were Ca^{2+}, Mg^{2+}, K^{+}, Na^{+}, CO_3^{2-}, HCO_3^{-}, Cl^{-} and SO_4^{2-} along with TDS in mg/L. The geostiff diagram was prepared in the shape file format by using geostiff version 1.0. Then the shape file was imported in QGIS version 1.4.0-Enceladus and the final image format was prepared using MapInfo version 6.0.

Results and Discussion

Drinking Water Quality

The summary of descriptive analytical results of the 98(n) well samples for various physicochemical and biological parameters is presented in Table 2. Among 98 samples, physicochemical and biological parameters of only nine samples, Attathodu, Pampa Valley, Athikayam, Vadaserikara, Pandalam (Pathinamthita district), Kandiyoor (Alappuzha), Kattachal (Kollam), Pazhayidam (Kottayam) and Nedumangadu (Thiruvananthapuram), were within the desirable limit as per BIS.

Table 2: Summary of Physical, Chemical and Biological Properties of Groundwater						
Parameters	Units	Average	Median	Minimum	Maximum	SD
pH	–	6.3	6.3	4.3	8.2	0.7
WT	°C	29.9	29.9	23.2	36.2	2.1
Salinity	ppm	352.9	192.1	14.8	4310.0	651.3
EC	µS	694.9	375.7	2.5	8640.0	1307.0
TDS	ppm	488.7	266.5	22.2	6060.0	913.6
DO	mg/L	3.3	3.2	0.0	7.5	1.5
NO_3^-	mg/L	10.7	7.4	0.1	50.0	10.5
Alk	mg/L	69.1	38.0	4.0	408.0	78.4
HCO_3^-	mg/L	83.0	45.6	4.8	489.6	94.1
Cl^-	mg/L	64.6	41.0	17.0	921.0	99.5
Hardness	mg/L	97.9	64.0	12.0	700.0	111.1
Ca^{2+}	mg/L	25.0	18.4	1.6	157.1	25.7
Mg^{2+}	mg/L	17.8	11.2	0.2	141.5	22.8
Na^+	mg/L	63.2	28.7	2.6	1203.2	165.2
K^+	mg/L	13.6	5.4	0.6	160.7	24.1
F^-	mg/L	0.4	0.4	0.2	1.6	0.2
SO_4^{2-}	mg/L	18.8	9.2	0.0	200.7	30.4
PO_4^{3-}	mg/L	0.1	0.1	0.0	1.3	0.2
Fecal coliform	MPN/ 100 mL	72.79	17	0	1600	204.48

Note: WT - Water Temperature, TDS - Total Dissolved Solids, EC - Electrical Conductivity, DO - Dissolved Oxygen; and SD - Standard Deviation.

The places having many parameters out of desirable limit are Fort Cochin (Ernakulam district), Placimada and Kollengode (Palakkad) and Koodungalur (Thrissur). The parameters exceeding the desirable limit in each district are given in Table 3. Among the parameters analyzed, MPN and pH were out of the desirable limit in many samples via 66 and 61 samples respectively. Overall, 89 samples were affected by one or more parameters, thereby causing the 90.82% of groundwater in the study area unsuitable for drinking.

The physicochemical parameters analyzed to characterize the water based on BIS standards are:

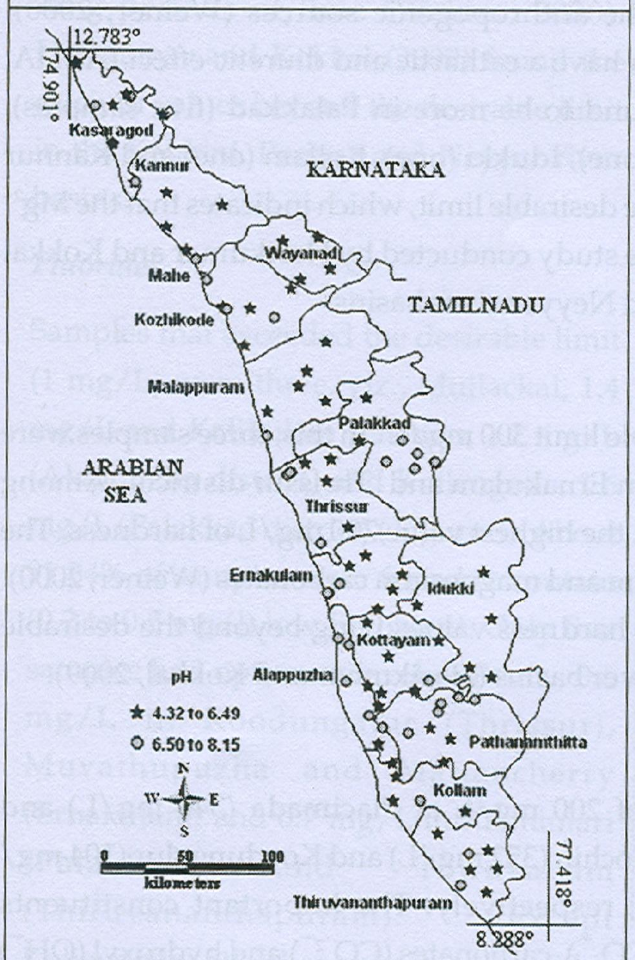
Table 3: Number of Parameters Exceeding the Desirable Limit Per District			
District	No. of Samples Analyzed	No. of Samples Exceeding the DL with One or More Parameters	Parameters Exceeding the DL
Alappuzha	7	6	pH, NO_3^-, F^-, TDS, Sal, MPN
Ernakulam	8	8	pH, Alk, Har, Ca^{2+}, Mg^{2+}, TDS, Sal, MPN
Idukki	5	5	pH, NO_3^-, Mg^{2+}, MPN
Kannur	5	5	pH, Mg^{2+}, MPN
Kasargod	11	11	pH, MPN
Kollam	6	5	pH, Mg^{2+}, TDS, MPN
Kottayam	7	6	pH, MPN
Kozhikode	7	7	pH, MPN
Malappuram	6	6	pH, Ca^{2+}, TDS, MPN
Palakkad	8	8	pH, Alk, Cl^-, Har, Mg^{2+}, F^-, TDS, Sal, MPN
Pathanamthitta	7	2	pH
Thiruvananthapuram	7	6	pH, TDS, MPN
Thrissur	9	9	pH, Alk, Cl^-, Har, Ca^{2+}, Mg^{2+}, SO_4^{2-}, TDS, Sal, MPN
Wayanad	5	5	pH, MPN

Note: Sal - Salinity; TDS - Total Dissolved Solids; Alk - Alkalinity; Har - Hardness; and DL - Desirable Limit.

pH

Most of the groundwater samples n = 86 were acidic in nature, and the remaining 12 samples were alkaline. Among 86 samples, 61 were found to have pH 4.32-6.46, less than the desirable limit 6.5-8.5. It is shown spatially in Figure 2. The low pH of groundwater may be the result of sulphide oxidation (Weiner, 2000), acidic nature of the soil or due to aquifer origin (Harikumar and Kokkal 2009). This can be curbed by adding clam or oyster shells to drinking water in the wide-mouthed barrels (Bordalo and Savva-Bordalo, 2007). Low pH was observed in Idukki (Rejith *et al.*, 2009), Kottayam (Vijith and Satheesh, 2007), Muvattupuzha (Gopinath and Seralathan, 2006; and Laluraj and Gopinath, 2006) districts and Kabbini, Periyar and Neyyar river basins (Harikumar and Kokkal, 2009).

Figure 2: Spatial Variation of pH



Salinity

Most of the samples (89 out of 98) were lying within the fresh water salinity range (< 500 ppm). Salinity was found to be higher in Aluva (2900 ppm) and Kothamangalam (3000 ppm) of Ernakulam district and in Guruvayoor (3180 ppm) municipal well and Koodungalur (4310 ppm) in Thrissur district. This may be due to the addition of more chlorides in municipal well for disinfection purpose or sea water intrusion. Comparatively, another sample from Guruvayoor near a pilgrimage site had very less salinity (590 ppm) than that of Guruvayoor municipal well. Other samples having more salinity were from Palakkad (Kollengode and Placimada), Thrissur (Chavakkad and Koodungalur) and Alappuzha (Veeyapuram) districts, which had salinity between 600 and 900 ppm.

TDS

The TDS range was 22.2 to 6060 ppm. The highest value 6060 ppm was found in Koodungalur (Thrissur district). The TDS was more than the desirable limit of 500 ppm in Thrissur (eight samples), Ernakulam (four), Palakkad (three), Malappuram (one), Alappuzha (one), Kollam (one) and Thiruvananthapuram (one) districts. Evaporation, groundwater movement through solute mineral containing rocks, untreated sewage, waste deposits and agrochemicals are the main contributors to high TDS value. The difference in the taste of non-potable and potable water is often due to the presence of high TDS level in water addition to certain metals, particularly iron, copper, manganese and zinc (Weiner, 2000). The high TDS values were observed by Shaji *et al.* (2009) in Chavara, Quilon district and Harikumar and Kokkal (2009) from Kabbini, Periyar and Neyyar river basins.

Magnesium

Magnesium was more than the desirable limit of 30 mg/L in many places at Palakkad and the highest value was found at Koodungalur (Thrissur) 141.46 mg/L. Magnesium mainly comes from the ferromagnesium minerals in igneous rocks and magnesium carbonates in sedimentary rocks than the anthropogenic sources (Weiner, 2000). Concentrations greater than 125 mg/L can have a cathartic and diuretic effect (APHA, 1995). Magnesium contamination was found to be more in Palakkad (five samples), followed by Thrissur (three), Ernakulam (one), Idukki (one), Kollam (one) and Kannur (one). A majority of samples were within the desirable limit, which indicates that the Mg^{2+} is contributed by the natural processes. The study conducted by Harikumar and Kokkal (2009) also found high value in Periyar and Neyyar river basins.

Hardness

Five out of 98 samples exceeded the desirable limit 300 mg/L . In this, three samples were from Palakkad and rest of the samples from Ernakulam and Thrissur districts. Among these districts, Thrissur (Kodungallur) had the highest value 700 mg/L of hardness. The principal sources of hard water were calcium and magnesium carbonates (Weiner, 2000). Harikumar and Kokkal (2009) also found hardness values lying beyond the desirable limit in the Kabbini, Periyar and Neyyar river basins (Harikumar and Kokkal, 2009).

Alkalinity

Alkalinity exceeded the desirable limit of 200 mg/L at Placimada (340 mg/L) and Kollengode (408 mg/L) in Palakkad, Fort Cochin (352 mg/L) and Koodungalur (304 mg/L) in Ernakulam and Thrissur districts, respectively. The important constituents contributing alkalinity are bicarbonate (HCO_3^-), carbonates (CO_3^{2-}) and hydroxyl (OH^-) anions (Weiner, 2000). The highest value of alkalinity was observed by Harikumar and Kokkal (2009) in the Neyyar river basin.

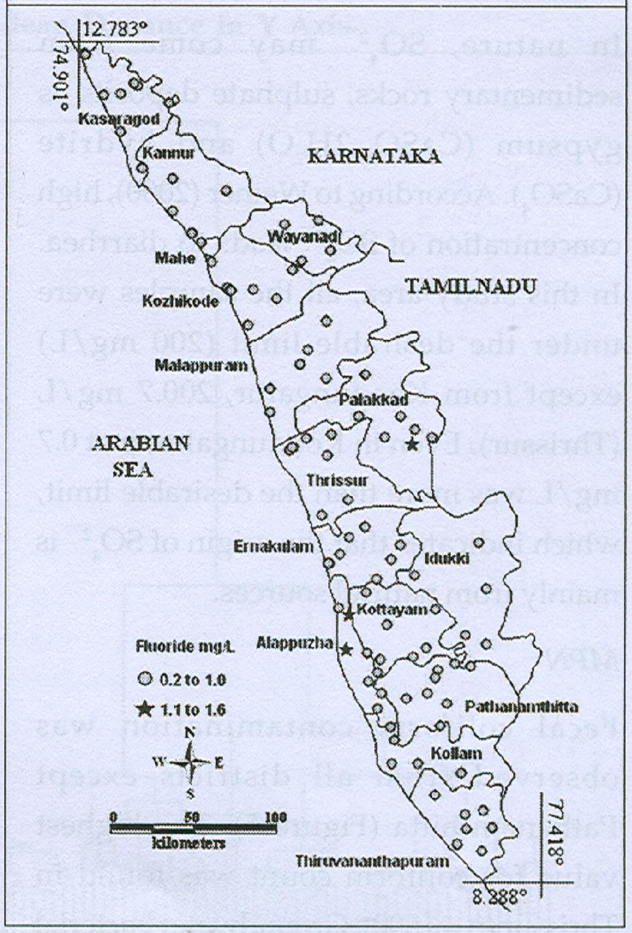
Chlorides

Chlorides exceeded the desirable limit of 250 mg/L at Placimada 314.35 mg/L , Kollengode 268.29 mg/L in Palakkad district and Koodungalur 921.01 mg/L in Thrissur district. All other samples (n = 9 5) were within the desirable limit. In natural waters, chloride comes from weathering of chloride minerals. People having heart and kidney problems have high risk when exposed to high amount of chlorides (Weiner, 2000). Laluraj *et al.* (2005), in the coastal zone of Central Kerala, and Harikumar and Kokkal (2009), in the Kabbini and Neyyar river basins, have found the chloride values beyond the desirable limit.

Calcium

Three places out of 98 places sampled, exceeded the desirable limit of 75 mg/L. They were Fort Cochin (157.11 mg/L), Ponnani (109.02 mg/L) and Koodungalur (120.24 mg/L) in Ernakulam, Malappuram and Thrissur districts, respectively. Calcium in groundwater is mainly due to the dissolution of minerals. High concentration of calcium may increase the risk of kidney stones when exposed for long periods of time (Weiner, 2000). Harikumar and Kokkal (2009) found the calcium values beyond the desirable limit in the Kabbini, Periyar and Neyyar river basins.

Figure 3: Spatial Variation of Fluoride



Fluorides

Samples that exceeded the desirable limit (1 mg/L) were three, viz., Mullackal, 1.4 mg/L and Kalikulam Junction, 1.2 mg/L (Alappuzha district) and Kollengode, 1.6 mg/L (Palakkad district) (Figure 3). About 91.84% of samples were found to contain (0.2 to 0.5 mg/l) low F^- content. Only five samples had optimum level of F^- viz., 0.6 mg/L in Koodungalur (Thrissur), Muvathupuzha and Mattancherry (Ernakulam) and 0.7 mg/L in Kannimari (Palakkad) and Thiruvallam (Thiruvananthapuram). Except Kollengode, all other values were within WHO (World Health Organization) (2008) guideline value (1.5). Fluoride comes from weathering of minerals like fluorite (CaF_2), cryolite (Na_3AlF_6), and fluorapatite ($Ca_5F(PO_4)_3$) (Weiner, 2000). Low F^- content (< 0.60 mg/L) causes dental caries, whereas high (>1.20 mg/L) fluoride levels cause fluorosis (ISI, 1983). Fluoride contamination was observed by George and Prakasam (2008) in the Edamulackkal Grama Panchayat, Kollam District, Harikumar *et al.* (2000) from the Thrissur, Palakkad, and Alappuzha Districts, and Shaji *et al.* (2007) in Palghat District.

Nitrates

Except two samples which contained 45.3 mg/L and 50 mg/L in Kayamkulam (Alappuzha) Old Munnar (Idukki), all samples were within the desirable limit of 45 mg/L (Figure 4). According to WHO (2008), all samples were within the guideline value (50 mg/L). This indicates that the anthropogenic influence is minimal in ground water. Fertilizers, animal waste and human sewage are the main sources for nitrates. High concentration (>1-2 mg/L) of nitrate in groundwater may be the result of manure seepage and fertilizers through agricultural activities (Weiner, 2000). High nitrate content causes gastric carcinomas and blue baby diseases/methemoglobinemia in the case of children (Comly 1945; and Gilly *et al.*, 1984).

Sulphates

In nature, SO_4^{2-} may come from sedimentary rocks, sulphate deposits as gypsum ($CaSO_4.2H_2O$) and hydrite ($CaSO_4$). According to Weiner (2000), high concentration of SO_4^{2-} leads to diarrhea. In this study area, all the samples were under the desirable limit (200 mg/L) except from Koodungalur, 200.7 mg/L (Thrissur). Even in Koodungalur, just 0.7 mg/L was more than the desirable limit, which indicates that the origin of SO_4^{2-} is mainly from natural sources.

MPN

Fecal coliform contamination was observed from all districts except Pathanamthitta (Figure 5). The highest value for coliform count was found in Thrissur (n = 1600). Groundwater bacterial contamination may be due to improper disposal of organic garbage or leachates from the tanks or pits (Harikumar and Kokkal, 2009). The groundwater bacterial contamination will cause typhoid, diarrhea, cramps, nausea and headaches (http://www.epa.gov; Barrell *et al.*, 2000). A coliform study was conducted in coastal Kerala (Calvert and Andersson, 2000; and Laluraj *et al.*, 2005); Kottayam (Panicker *et al.*, 2000) and Thiruvananthapuram (Varghese and Jaya, 2009) districts; Chalakudy basin (Babu *et al.*, 2007), Kabbini, Periyar and Neyyar river basins (Harikumar and Kokkal, 2009) also recorded the presence of fecal coliform contamination.

Figure 4: Spatial Distribution of Nitrate in Kerala

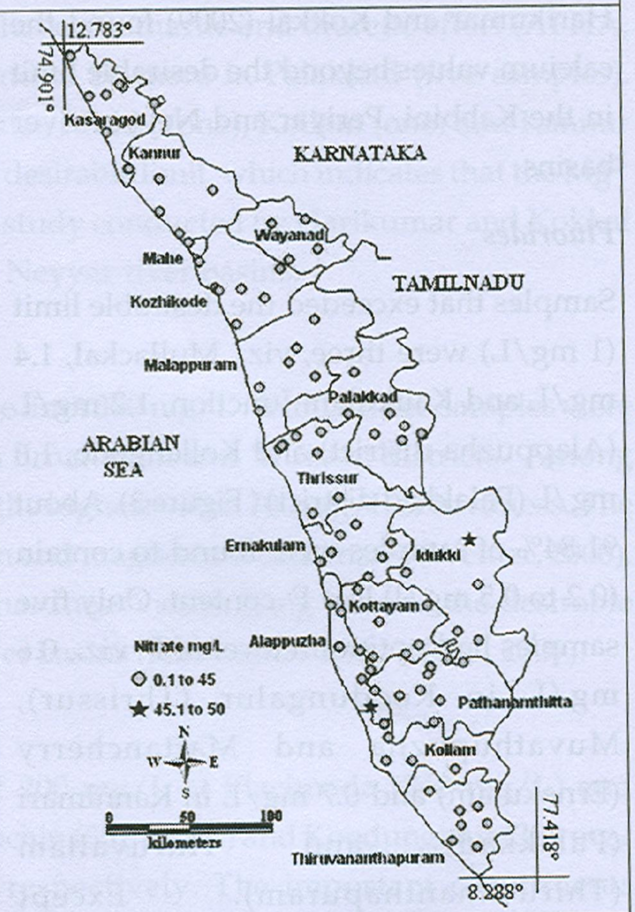


Figure 5: Spatial Variation of MPN

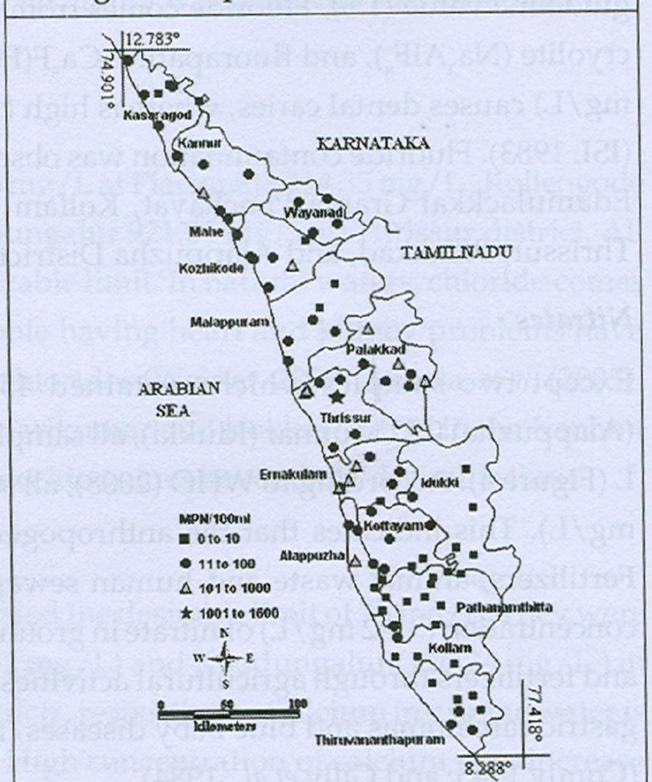
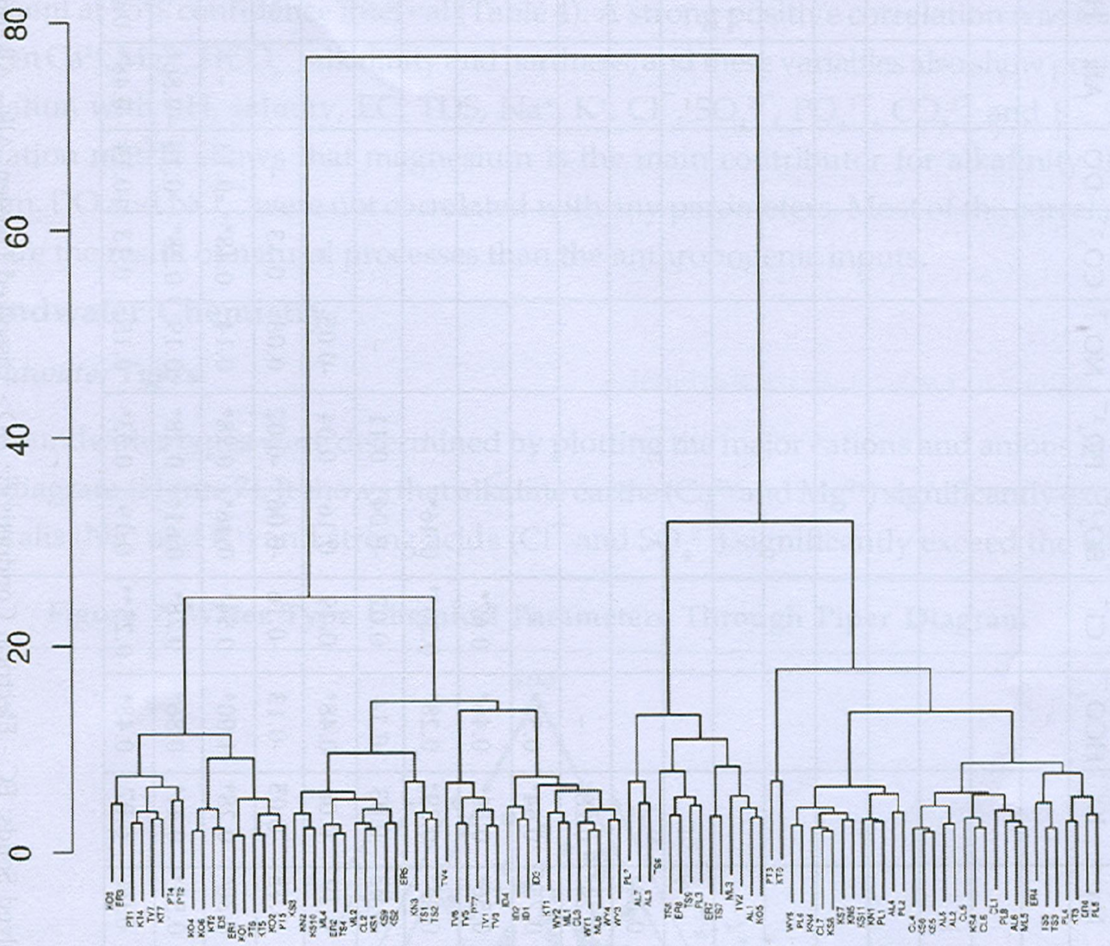


Figure 6: Hierarchical Cluster Analysis in Q Mode Using Ward's Method Showing Euclidean Distance in Y Axis



Note: AL-Alappuzha, CL-Kozhikode, ER-Ernakulam, ID-Idukki, KN-Kannur, KO-Kollam, KS-Kasaragod, KT-Kottayam, ML-Malappuram, PL-Palakkad, PT-Pathanamthitta, TS-Thrissur, TV-Thiruvananthapuram, WY-Wayanad; and Number 1 to 11 indicates that the place.

Cluster Analysis

Dendrogram of Hierarchical Cluster Analysis (HCA) have four clusters at Euclidean distance 20 (Figure 6). Cluster I samples were characterized by unpolluted sites and sites slightly exceeding the desirable limit of BIS (1993) by one or more parameters like pH, fecal coliform and TDS. Cluster II samples were mostly affected by pH, other parameters exceeding the desirable limit in this group were fecal coliform, TDS, Mg^{2+} and NO_3^-. The samples affected by many parameters along with sites exceeding the desirable limit in one or more parameters like TDS, Mg^{2+}, F^-, Ca^{2+} and fecal coliform were grouped in cluster III. Cluster IV had the samples mostly affected by fecal coliform; other parameters exceeding the desirable limit in this group were pH, TDS, Mg^{2+}, NO_3^- and hardness. All clusters were affected by fecal coliform (anthropogenic contamination), though the quantity of anthropogenic contamination varied between clusters.

Table 4: Correlation Matrix Showing the Relationship Between Physicochemical Variables

	pH	WT	Sal	EC	TDS	Ca^{2+}	Mg^{2+}	Na^+	K^+	HCO_3^-	Cl^-	SO_4^{2-}	PO_4^{3-}	NO_3^-	CO_3^{2-}	DO	Alk	Har	F^-
pH	–																		
WT	0.16	–																	
Sal	0.15	0.17	–																
EC	0.14	0.17	0.99*	–															
TDS	0.14	0.17	0.99*	0.99*	–														
Ca^{2+}	0.49*	0.13	0.32*	0.31*	0.31*	–													
Mg^{2+}	0.43*	0.10	0.46*	0.46*	0.46*	0.62*	–												
Na^+	0.24**	0.13	0.51*	0.51*	0.51*	0.57*	0.48*	–											
K^+	0.19	0.26**	0.43*	0.39*	0.39*	0.51*	0.38*	0.64*	–										
HCO_3^-	0.64*	0.12	0.33*	0.33*	0.33*	0.66*	0.85*	0.29*	0.28*	–									
Cl^-	0.22**	0.17	0.64*	0.64*	0.64*	0.51*	0.79*	0.75*	0.64*	0.54*	–								
SO_4^{2-}	0.34*	0.22**	0.59*	0.59*	0.59*	0.53*	0.58*	0.56*	0.51*	0.46*	0.67*	–							
PO_4^{3-}	0.26**	0.15	0.14	0.14	0.14	0.46*	0.21**	0.27*	0.29*	0.28*	0.20**	0.46*	–						
NO_3^-	0.10	0.07	-0.09	-0.10	-0.10	0.16	0.18	-0.03	0.03	0.14	0.02	-0.04	0.11	–					
CO_3^{2-}	0.50*	-0.10	0.13	0.13	0.13	0.23**	0.28*	0.19	0.08	0.48*	0.19	0.16	0.04	-0.05	–				
DO	0.10	0.03	-0.07	-0.08	-0.09	-0.19	-0.16	-0.15	-0.05	-0.13	-0.16	-0.06	-0.02	0.08	0.13	–			
Alk	0.64*	0.12	0.33*	0.33*	0.33*	0.66*	0.85*	0.30*	0.28*	1.00*	0.54*	0.46*	0.28*	0.14	0.48*	-0.13	–		
Har	0.48*	0.11	0.46*	0.46*	0.46*	0.75*	0.98*	0.53*	0.44*	0.86*	0.78*	0.61*	0.28*	0.19	0.28*	-0.18	0.86*	–	
F^-	0.25**	0.13	0.08	0.08	0.08	0.21**	0.43*	0.04	0.07	0.48*	0.25**	0.19	0.33*	0.15	0.13	-0.14	0.48*	0.40*	–

Note: *Significant value at $p <$ 0.01;

**Significant value at $p <$ 0.05 > 0.01;

WT - Water Temperature; Sal - Salinity; TDS - Total Dissolved Solids; EC - Electrical Conductivity; DO - Dissolved Oxygen; Alk - Alkalinity; and Har - Hardness.

Correlation of Physicochemical Parameters

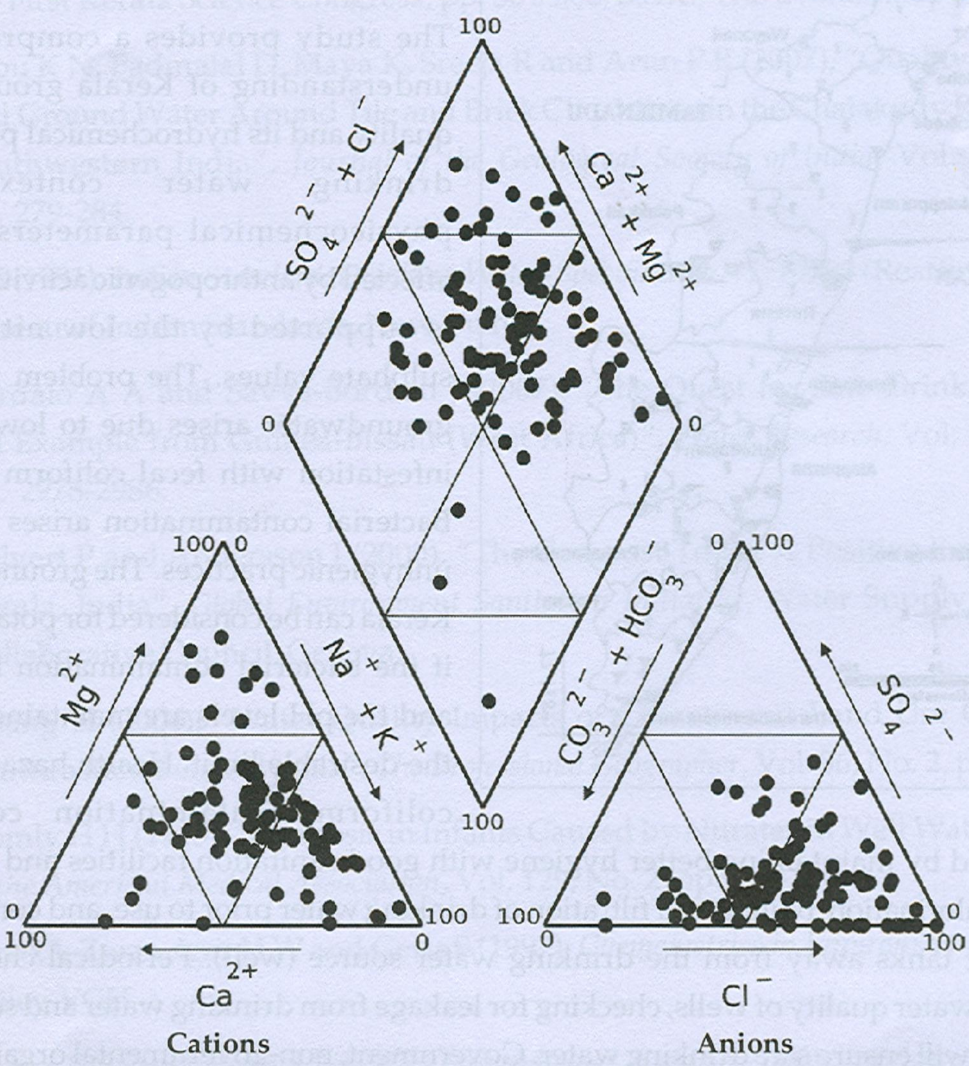
The relationship among water quality variables were analyzed by Pearson correlation coefficient at 95% confidence interval (Table 4). A strong positive correlation was found between Ca^{2+}, Mg^{2+}, HCO_3^-, alkalinity and hardness; and these variables also show positive correlation with pH, salinity, EC, TDS, Na^+, K^+, Cl^-, SO_4^{2-}, PO_4^{3-}, CO_3^{2-} and F^-. The correlation matrix shows that magnesium is the main contributor for alkalinity than calcium. DO and NO_3^- were not correlated with any parameters. Most of the correlated pairs are the result of natural processes than the anthropogenic inputs.

Groundwater Chemistry

Groundwater Types

The groundwater types were determined by plotting the major cations and anions in the piper diagram (Figure 7). It shows that alkaline earths (Ca^{2+} and Mg^{2+}) significantly exceed the alkalis (Na^+ and K^+) and strong acids (Cl^- and SO_4^{2-}) significantly exceed the weak

Figure 7: Water Type Chemical Parameters Through Piper Diagram

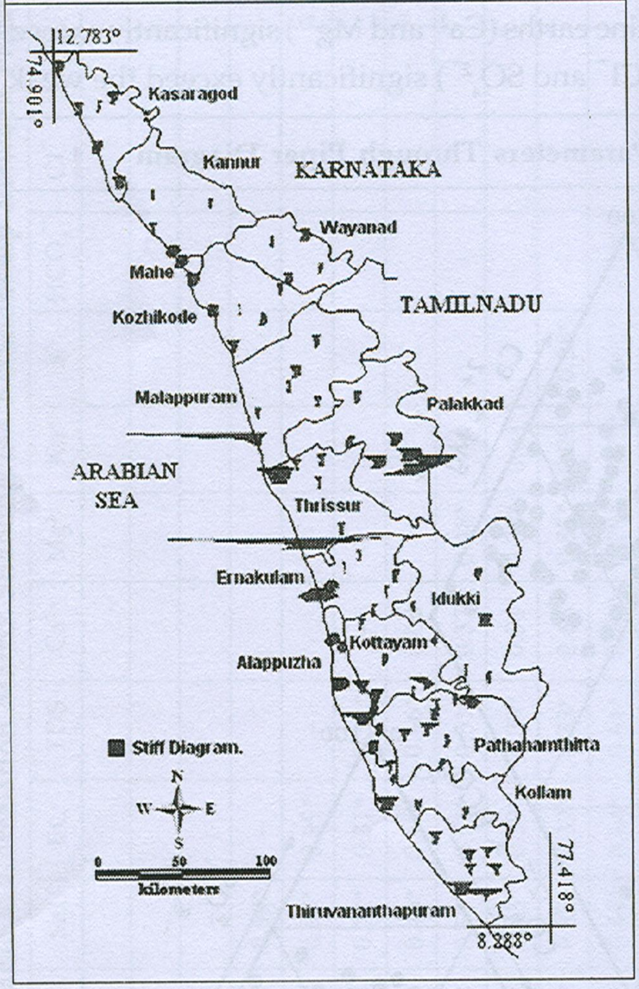


acids (HCO_3^- and CO_3^{2-}). Most of the samples were of mixed Ca-Mg-Cl type, followed by Na-Cl, Ca-HCO_3, Ca-Cl, mixed Ca-Na-HCO_3 and Na-HCO_3 types.

Spatial Trend in Groundwater

Stiff diagram (Figure 8) shows that Central Kerala had the highest amount of major ions than the other regions of Kerala, in particular, Kodungallur (Thrissur) with Na^+ plus K^+ (cations) and Cl^- (anions) and Ponnani (Malappuram district) with Na^+ plus K^+. It reveals that both Kodungallur and Ponnani groundwater is influenced by weathering, sea water intrusion, and anthropogenic activities like industrial wastewater and irrigation drainage. The other places having higher amount of ions, especially cations, and a few places also with anions are Palakkad, Thiruvananthapuram, Ernakulam, Alappuzha, Idukki, Kottayam and Kollam districts.

Figure 8: Stiff Diagram Reflecting the Variability of Major Ions



Conclusion and Suggestions

The study provides a comprehensive understanding of Kerala groundwater quality and its hydrochemical process. In drinking water context, the physicochemical parameters are not affected by anthropogenic activities, which is supported by the low nitrate and sulphate values. The problem in Kerala groundwater arises due to low pH and infestation with fecal coliform bacteria. Bacterial contamination arises from the unhygienic practices. The groundwater of Kerala can be considered for potable usage if the bacterial contamination is curbed and the pH levels are maintained within the desirable limit. Health hazard due to coliform contamination could be minimized by maintaining better hygiene with good sanitation facilities and practices such as chlorination, boiling and filtration of drinking water prior to use, and constructing the septic tanks away from the drinking water source (well). Periodical checking of drinking water quality of wells, checking for leakage from drinking water and septic tank pipelines will ensure safe drinking water. Government, non-governmental organizations, and local institutions can come forward to give free analysis of some important water quality parameters to provide health and hygienic condition. Also, conducting awareness programs to maintain hygienic condition around the drinking water source by the concerned government, non-government organizations, and local institutions would lead to safer drinking water forever.

Acknowledgment: This work was funded by *Malayala Manorama* as a part of 'Palathulli' project. The authors thank Ajith Babu, Thomas Mathew and local reporters of the *Malayala Manorama* newspaper for their assistance during the field work. They are grateful to Ahalya, K V Gururaja, Sudhira, K G Avinash and Malvikaa for their help during the field work and laboratory analysis, and Alakananda and Supriya for useful comments.

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Evaluation of the Quality of Drinking Water in Kerala State, India

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Received April 16, 2009; revised and accepted March 15, 2010

Abstract: The quality of tap water from water supplies from 14 districts of Kerala state, India was studied. Parameters like pH, water temperature, total dissolved solids, salinity, nitrates, chloride, hardness, magnesium, calcium, sodium, potassium, fluoride, sulphate, phosphates, and coliform bacteria were enumerated. The results showed that all water samples were contaminated by coliform bacteria. About 20% of the tap water samples from Alappuzha and 15% samples from Palakkad district are above desirable limits prescribed by Bureau of Indian Standards. The contamination of the source water (due to lack of community hygiene) and insufficient treatment are the major cause for the coliform contamination in the state. Water samples from Alappuzha and Palakkad have high ionic and fluoride content which could be attributed to the geology of the region. Water supplied for drinking in rural areas are relatively free of any contamination than the water supplied in urban area by municipalities, which may be attributed to higher chances of contamination in urban area due to mismanagement of solid and liquid wastes. The study highlights the need for regular bacteriological enumeration along with water quality in addition to setting up decentralised region-specific improved treatment system.

Key words: Tap-water quality, drinking water quality, Kerala, fluoride, Alappuzha, Palakkad.

Introduction

The interactions between water and human health are indeed complex. Human health may be affected by the ingestion of contaminated water, either direct or through food, and by the use of contaminated water for purposes of personal hygiene and recreation. As per the recent estimates by the World Bank, 21% of communicable diseases in India are water related. With the importance of water supply and sanitation to health it is necessary to consider the status of these services globally and regionally. Those without access to an adequate and safe water supply and appropriate sanitation are those most at risk from water-borne diseases. Access to safe drinking water and adequate sanitation is a recognised universal human need. Population growth, industrialisation and agricultural development are leading to constantly increasing demands for water. Hence all countries are endeavouring to improve the evaluation of their water resources. Historically, civilizations in India, as around the world, have largely evolved and developed around water bodies as most human activities, including agriculture and industry, depend on water. During the six decades of post-independence, India has witnessed phenomenal development of water resources and has largely successfully met the demand of water for many of the diverse uses in the country. Infrastructure for safe drinking water has been provided to about 85 per cent of India's urban and rural population. Water supply and sanitation were added to the national agenda during the first five-year planning period.

Drinking water system in Kerala is managed and maintained by the state government through the Kerala Water Authority (KWA) and local governments. The

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history of organized piped water supply in rural Kerala dates back to the beginning of twentieth century. KWA came into existence on 1st April 1984 in the place of the erstwhile Public Health Engineering (PHE). KWA is one of the main agencies for the design, construction, operation and maintenance of water supply and sewerage schemes in the whole state. KWA has been implementing piped water supply schemes based on surface and groundwater sources. It also executes water supply projects and accelerates rural water supply schemes on behalf of the government of India. In 2003, KWA were operating 63 urban and 1700 rural water supply schemes and another 224 urban and rural water supply schemes were under different stages of implementation (State Planning Board, 2002).

A survey conducted by Rajiv Gandhi National Drinking Water Mission revealed that in Kerala piped water reaches 20.4 million people, who constitute around 64 per cent of the total population as on July 2003, which includes 59 percent of the rural population and 79 per cent of the urban population. Alternative forms of water supply schemes existing in the state were community managed. Community management in drinking water supply recently emerged as an alternative to the prevailing institutional set up. All community managed schemes in the state are funded by either central government or external agencies like World Bank and Royal Netherlands Embassy. *Jalanidhi* is the community water supply schemes initiated in the state with the help of World Bank.

The water quality of ground water and surface water of Kerala state is continuously reported for high level of chemical and biological contamination. The Report of Fifth Five-Year Plan (Govt. of Kerala, 1974) of Government of Kerala revealed that 99 percent of the panchayats in Kerala faced drinking water scarcity of varying duration and intensity. Panikar and Soman (1984) studied the health status of Kerala and observed that gastro-intestinal system contribute to the largest proportion of diseases. Study by Aravindan and Kunhikannan (1987) in Alappuzha district revealed that diseases like diarrhea, dysentery, typhoid, worm infestations, and infectious hepatitis accounted for 50 percent of illnesses. Aravindan (1989) documented that Kollam district was one among the four districts with the highest rates of diarrhea mortality in the state. Abhayambika et al. (1989) observed that lack of protected water supply and inadequate toilet facilities were the major risk factors in the three southern districts of Kerala. Kannan et al. (1991) conducted a study in all the fourteen districts of Kerala on the health status of rural households and reported that the incidence of diarrhea cases was more among persons using public wells and public taps. Another survey (Anonymous, 1994) reported that Kerala is identified as the only place in the world with such large numbers of open dug-wells and by poor environmental conditions and unhygienic behavioural practices the drinking water sources get frequently contaminated; the incidence of water-borne diseases gets thereby aggravated.

Radhakrishnan et al. (1996) on the bacteriological quality of water in the coastal Kerala showed that all the samples of dug-well water in the area were coliform positive. The MPN values ranged from 41 to 1200/100 ml. It was further recorded that 20 wells out of 35 were located within a distance of 10 m from septic tank and 90 percent of the people in the area defecated in open places. A study conducted by Panicker et al. (2000) in Kottayam municipality, on the bacteriological quality of various drinking water sources, indicated that almost all dug-well water samples had faecal coliform count much above the WHO standards. Pillai and Ouseph (2000) observed that more than half the Kerala population utilize dug wells as the sole source of drinking water and they also stated that outbreaks of water-borne diseases were due to consumption of contaminated water from poorly protected wells. Calvert and Andersson (2000) observed that sanitation is very poor in villages along the coast of Kerala. Over 80 percent of the households have no latrines and at least 50 percent obtained water from communal wells, which are heavily contaminated due to open-air defecation and nearby pit-latrines.

Rahiman et al. (2003) examined the bacteriological quality of water from wells at Ponnani and revealed that most of the samples had human faecal pollution. All the strains of *Escherichia coli* encountered in the samples showed multiple antibiotic resistances. Panicker et al. (2000) studied in the bacteriological quality of Kottayam municipality on various drinking water sources and indicated that almost all dug-well water samples had faecal coliform count much above the WHO standard. A study on the bacterial quality of water in selected wells in Kerala jointly conducted by Kerala Water Authority and Kerala Pollution Control Board (KWA, 1991) showed that water in none of the open wells investigated was safe for drinking. This was a startling observation because more than 50 percent of the population of Kerala used dug-well water for drinking. The study also indicated the need for a detailed investigation for finding out the factors related to the deterioration of water quality in the state.

The scope of the present study is the evaluation of drinking water quality, based on a set of specific parameters, in all geographical regions of Kerala. No pertinent published data were found in literature, although scattered results may be found in unpublished reports of government agencies. Most of the parameters selected for analysis are obligatory from the Indian standard specifications for drinking water IS: 10500 (Reaffirmed 1993), comprising both physicochemical (i.e. pH, conductivity and total dissolved solids) and chemical properties which are related to the hardness (Cl^-, Na^+, K^+, Ca^{2+} and Mg^{2+}), ions (F^-, NO_3^-, PO_4^{3-} and SO_4^{2-}) as well as coliform bacteria.

Study Area

Kerala State located in the south-western corner of India has a total geographic area of 38,863 km^2 (Figure 1). According to the 2001 census Kerala's population is 31.84 million persons which included 15.47 million males and 16.37 million females. Although Kerala accounts for only one per cent of the total area of India, it contains about three per cent of the country's population. The population density of the state is about 819 people per square kilometre, three times the national average. Kerala is one of the densest states in the country and it recorded a decadal population growth of +9.42% (2,740,101 persons). By year 2050 the population in Kerala is likely to grow to two times that figure i.e., 64 million. Hence, there is considerable pressure on all natural resources especially water and land. Concerted efforts to formulate proper plans for sustainable development of water resources in Kerala are therefore very important.

Methods

A total of 87 sites scattered throughout Kerala was chosen, covering all 14 districts. At least four samples were collected from each district. For statistical purposes Kerala was divided into fourteen geographical regions (Figure 1) to which the results presented herewith correspond. Samples were collected as per the established protocols and precise instructions, avoiding any contamination during sampling and transportation. The samples were collected from randomly selected frequently used municipal and/or communal water supply taps of a village or town during the pre-monsoon of 2007 (April and May). Samples were collected after clearing stagnant water in the tap (for about one minute). In addition, for each sample a detailed questionnaire was completed with information regarding its exact origin and nature of treatment.

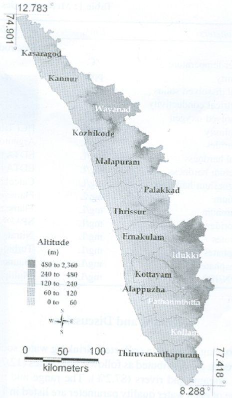


Figure 1: Kerala with district boundary and topography.

Water samples were collected from each source in clean polythene containers of 2.5 L capacity. The sample containers were labeled with a unique code and date of collection. pH, water temperature, total dissolved solids, salinity and nitrates were recorded on spot using Extech Combo electrode and Orion ion selective electrode. Other parameters like chloride, hardness, magnesium, calcium, sodium, potassium, fluoride, sulphate, phosphates, and coliform bacteria were analyzed in lab. All analyses were carried out as per methodologies in standard methods for the examination of water and wastewater APHA (1998). Detailed methods are listed in Table 1. Coliform bacteria were estimated by using standard multiple tube fermentation technique (MTFT), nine multiple tube dilution technique using double and single strength Bromo-Cresol Purple MacConkey medium and membrane filter techniques by using M-EC test agar and MPN index was calculated from MPN table (APHA, 1998). All analysis and plots of data in this article were carried out in the statistical and programming environment (http://www.r-project.org).

Table 1: Methodologies used for analysing water samples

Parameters	*Units*	*Methods*	*Section no. APHA, 1998*
pH	-	Electrode method	4500-H^+ B
Water temperature	°C		2550 B
Salinity	ppm		2520 B
Total dissolved solids	ppm		2540 B
Electrical conductivity	µS		2510B
Dissolved oxygen	mg/L	Iodometric method	4500-O B
Alkalinity	mg/L	HCl Titrimetric method	2320 B
Chlorides	mg/L	Argentometric method	4500-Cl^- B
Total hardness	mg/L	EDTA titrimetric method	2340 C
Calcium hardness	mg/L	EDTA titrimetric method	3500-Ca B
Magnesium hardness	mg/L	Calculation method	3500-Mg B
Sodium	mg/L	Flame emission photometric method	3500-Na B
Potassium	mg/L	Flame emission photometric method	3500-K B
Fluorides	mg/L	SPADNS method	4500-F^- D
Nitrates	mg/L	Nitrate electrode method	4500-NO_3^- D
Sulphates	mg/L	Turbidimetric method	4500-SO_4^{2-} E
Phosphates	mg/L	Stannous chloride method	4500-P D
MPN/100	mg/L	Multiple tube fermentation technique	9221 B

Results and Discussion

According to the data collected, drinking water sources in Kerala are distributed as follows: bore holes (12.79%) and, streams and rivers (87.2%). The range and mean value of each water quality parameter are listed in Table 2. In all drinking water samples examined in the present study, the parametric values set in accordance with Bureau of Indian Standards, Drinking Water Specification: IS: 10500 (Reaffirmed 1993) were exceeded by 12.79% of the samples examined for pH, followed by those examined for total dissolved solids (10.46%) and fluoride (8.13%), whereas regarding nitrates, alkalinity, chlorides, hardness, calcium, and magnesium, the violations correspond to less than 5% of the total number of samples analyzed (Table 3).

In terms of geographical distribution, most parameters were beyond desirable limits recorded in 20% of the sites of Alappuzha district, followed by Palakkad (15%) and Thrissur districts (12%). It is also noteworthy that one fourth of Kerala's population resides in these three districts. Importantly the samples recorded above permissible values belong to Palakkad and Alappuzha districts for chlorides, hardness, calcium, and fluoride (Table 4).

Physico-chemical Parameters

In all samples pH values vary from 5.93 to 9.05, with an average of 7.17±0.58. In 68% of the study sites it was in neutral state (Figure 3). It is noted that water should be preferably slightly alkaline in order to assure protection of pipe work and metallic fittings from corrosion. Water temperature ranged from 25.6 to 34.8°C. The highest total dissolved solid values were detected in the Alappuzha district (1920 mg/L), followed by those determined in the Thrissur district (702 mg/L) and Palakkad district (611.4 mg/L) (Figure 3).

Table 2: Range and mean value of water quality parameters recorded in this study

Parameters	*Range*	*Mean±SD*
pH	5.93-9.05	7.17±0.58
Water Temperature	25.6-34.8	31.64±1.83
Salinity	5.8-1380	159.05±184.12
Conductivity	2.5-27700	597.00±2968.02
Total Dissolved Solids	9.2-1920	222.34±256.89
Alkalinity	4-304	51.35±57.86
Chlorides	10.01-1751.92	60.00±187.92
Hardness	12-500	61.16±76.94
Calcium	1.28-440.88	19.89±47.95
Magnesium	0.18-80.76	10.07±11.78
Sodium	0.37-1259.6	34.75±138.43
Potassium	0.39-53.9	5.68±7.17
Fluorides	0.1-1.6	0.55±0.30
NO_3^-	0.01-54.9	4.83±9.88
SO_4^{2-}	0.01-71.51	8.77±13.32
Phosphates	0.01-0.40	0.09±0.08
MPN/100	2-350	32.09±64.00

Table 3: Percentage (%) of samples analyzed in the present study in which the parametric values are above desirable and above permissible limits of BSI, Drinking Water Specification: IS: 10500 (Reaffirmed 1993)

Parameter	*% of samples above desirable limits*	*% of samples above maximum permissible limits*
pH	12.79	No relaxation
NO_3^-	3.48	0
Alkalinity	3.48	0
Chlorides	1.16	1.16
Hardness	2.32	0
Calcium	2.32	1.16
Magnesium	5.81	0
Fluorides	8.13	3.48
SO_4^{2-}	0	0
Total dissolved Solids	10.46	0
Coliform	67.44	No relaxation

Table 4: Percentage (%) of sites from each district studied in the present study in which the parametric values are above desirable and above permissible limits of BSI, Drinking Water Specification: IS: 10500, (Reaffirmed 1993) with the parameters

Districts	*% of sites*	*Parameters*
Kasargod	2	Coliform
Pathanamthitta	3	pH, Coliform
Idukki	4	pH, Coliform
Kollam	4	pH, Coliform
Kozhikode	4	Coliform
Malappuram	4	Coliform
Kottayam	6	Magnesium, TDS
Thiruvananthapuram	6	pH, F, Coliform
Wayanad	6	pH, F, Coliform
Ernakulam	7	Coliform
Kannur	8	pH, Coliform
Thrissur	12	pH, TDS, Colifrom
Palakkad	15	pH, Alka, Ha, Calcium, Magnesium, F, TDS, Coliform
Alappuzha	20	pH, NO_3, Alkalinity, Chlorides, Hardness, Calcium, Magnesium, Fl, TDS, Coliform

The highest concentrations of chloride, hardness, calcium, fluoride, sodium and potassium were found in Alappuzha districts (1751.92 mg/L, 500 mg/L, 440.88 mg/L, 1.6 mg/L, 1259.6 mg/L and 53.9 mg/L respectively), followed by the Palakkad district records 86.09 mg/L, 424 mg/L, 92.99 mg/L, 1.4 mg/L, 69.78

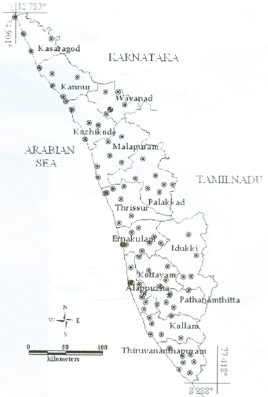


Figure 2: Tap water sampling points in Kerala districts.

mg/L and 13.77 mg/L respectively. Higher level of ionic values are also observed in Thrissur and Kottayam districts (Figure 3), indicating that in all these areas the "parent" water is enriched with salt that occurs either naturally or due to over pumping, resulting in intrusion of marine waters in the ground water. Calcium and magnesium are known to occur naturally in water due to its passage through mineral deposits and rock strata and contribute to its total hardness. Their highest concentrations, particularly those of magnesium, recorded in Palakkad and Kottayam districts (80.77 and 40.58 mg/L respectively) (Figure 3).

Concentration of NO_3^-, PO_4^{3-} and SO_4^{2-}

The highest concentrations of nitrates were found in samples from the Alapuzha district varying from 17.1 to 54.9, with an average of 33.26 mg/L, followed by those recorded in the Idukki (9.8 and 11.4 mg/L) and Kannur (7.61 and 8.27 mg/L) (Figure 4). Violations of the parametric value of Drinking Water Specification: IS: 10500 (Reaffirmed 1993) were detected exclusively in

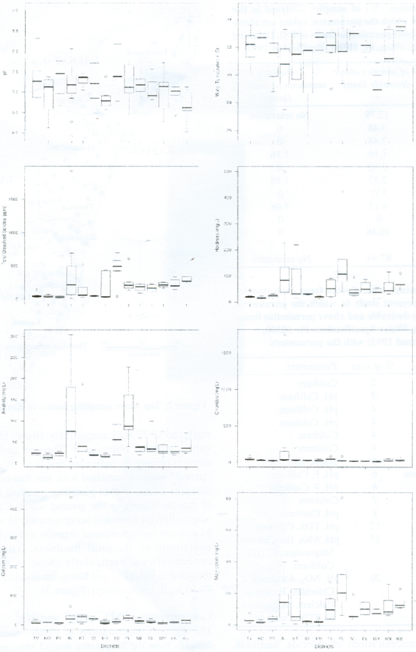
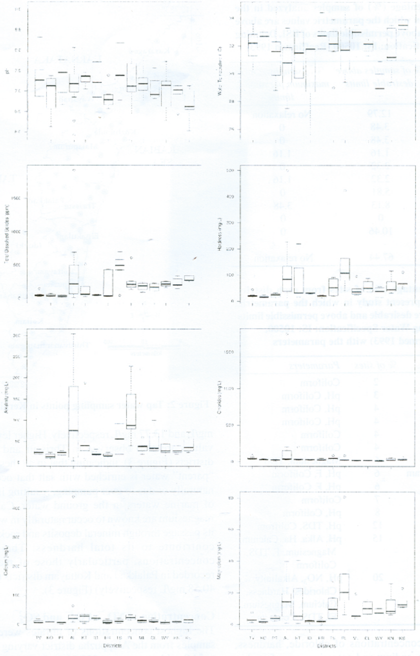


Figure 3: Box plot of pH, water temperature, total dissolved solids, hardness, alkalinity, Cl⁻, Ca^{2+} and Mg^{2+} in drinking water from the fourteen districts in Kerala (TV – Thiruvanthapuram; KO – Kollam; PT – Pathanamthitta; AL – Alappuzha; KT – Kottayam; ID – Idukki; ER – Ernakulam; TS – Thrissur; PL – Palakkad; ML – Malappuram; CL – Kozhikode; WY – Wayanad; KN – Kannur; KS – Kasaragod).



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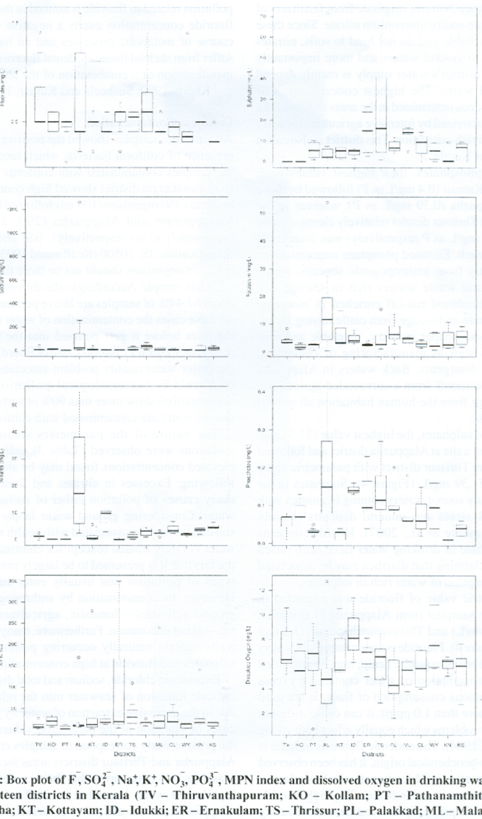

Figure 4: Box plot of F^-, SO_4^{2-}, Na^+, K^+, NO_3^-, PO_4^{3-}, MPN index and dissolved oxygen in drinking water from the fourteen districts in Kerala (TV – Thiruvanthapuram; KO – Kollam; PT – Pathanamthitta; AL – Alappuzha; KT – Kottayam; ID – Idukki; ER – Ernakulam; TS – Thrissur; PL – Palakkad; ML – Malappuram; CL – Kozhikode; WY – Wayanad; KN – Kannur; KS – Kasaragod).

Alappuzha district. Nitrates originate from fertilizers of potassium nitrate and/or ammonium nitrate. Since these salts are very soluble and do not bind to soils, nitrates migrate easily to ground waters and more importantly this particular district's water supply is mainly depend on the ground water. The highest concentrations of nitrates were indeed determined in the areas of Alappuzha which are characterized by intensive agricultural activity such as lowland rich cultivation. This district is also called as "rich bowl of Kerala".

Regarding phosphates, their highest values were determined in Kannur (0.4 mg/L as P) followed by those found in Alappuzha (0.39 mg/L as P), whereas in the Ernakulam and Thrissur district relatively elevated value (0.23 and 0.27 mg/L as P respectively) was detected in single sample each. Elevated phosphate concentrations originate mainly from anthropogenic sources, which include domestic waste waters rich in sewage and detergents, agricultural run-off enriched in inorganic fertilizers, manure and sludge from cattle raising farms, wastes of pulp and paper industry, vegetable and fruit processing, as well as manufacturing of chemicals, fertilizers and detergents. Back waters in Alappuzha districts receive runoff from a surrounded agricultural area and sewage from the human habitation all around the back waters.

In the case of sulphates, the highest value (71.51 mg/L) recorded from a site at Alappuzha district and followed by samples from Thrissur district with parametric value of 65.53 and 51.39 mg/L (Figure 4). Sulphates occur naturally in many source waters coming in contact with particular rock strata and mineral deposits (mainly gypsum) (Beamonte et al., 2007). Health concerns regarding sulphate in drinking water have been raised due to reports claiming that diarrhea may be associated with the consumption of water rich in sulphates.

The parametric value of fluoride was exceeded in drinking water samples from Alappuzha (1.6 mg/L), Palakkad (1.4 mg/L) and Thiruvananthapuram (1.2 mg/L) districts (Figure 4). Fluoride occurs naturally in waters and the threat it poses to public health may be attributed to long-term consumption of water containing excess fluoride. Continuous consumption of fluoride are used up in excess (more than 1.0 ppm); it can cause different kinds of health problems which equally affect both young and old (WHO, 1984). The endemic fluorosis in India is largely of hydro-geochemical origin. It has been observed that low calcium and high bicarbonate alkalinity favour high fluoride content in groundwater. The high fluoride in these districts is primarily derived from the country rock, i.e. hornblende biotite gneiss, since no man-made pollution related to fluoride is noticed in the area. Higher fluoride concentration exerts a negative effect on the course of metabolic processes and an individual may suffer from skeletal fluorosis, dental fluorosis, nonskeletal manifestation or a combination of the above (Susheela and Kharb, 1990; Susheela and Kumar, 1991).

Coliform Contamination

All tap water samples showed the positive result for the presence of coliform bacteria, which records 100% of the samples contaminated with coliform. The samples from Ernakulam district showed high count of coliform bacteria (350 organisms/100 ml) followed by Kottayam, Malappuram and Alappuzha (280, 240 and 170 organisms/100 ml respectively). BSI Drinking Water Specification: IS: 10500 (Reaffirmed 1993) suggest that coliform organisms should not be more than 10 per 100 ml in any sample. According to the abovesaid legislation about 67.44% of samples are above permissible level. In all these cases the contamination of water takes place at the river before it gets pumped into the water supply reservoir. Central Pollution Control Board reported that the major water quality problem associated with rivers of Kerala is bacteriological pollution. Our own investigations show more than 90% of surface water and ground water are contaminated with coliform.

The nature of the parameters studied in which violations were observed (Table 3) indicates that the elevated concentrations found may be attributed to the following: Excesses in nitrates and fluorides indicate many causes of pollution either of surface or ground water. Considering ground water in particular, such substances may be associated with health risks. Ground water is rarely treated (except for chlorination), due to the fact that it is presumed to be largely immune to these types of pollution that usually enter surface water. However, its contamination by anthropogenic, above-ground activities—domestic, agricultural, industrial etc.—is not uncommon. Furthermore, many groundwater wells contain naturally occurring pollutants, such as sulphates and fluoride at high concentration.

Excesses in chloride, sodium and total dissolved solids indicate intrusion of seawater into the related aquifers due to the excessive extraction of water by pumping. All cases of violation of the parametric values recorded in the present study correspond to samples collected from Alappuzha and Thrissur districts areas located near the seashore. It is noteworthy that the parametric values of legislation were exceeded in 20% of sites in the Alappuzha district and 15% of sites in the Palakkad district with scarce water resources (Table 5). Despite

Table 5: Percentage (%) of sites where the parametric values set in accordance with Drinking Water Specification: IS: 10500 (Reaffirmed 1993) are exceeded

*Districts**	*% contamination*	*Parameters*
Alappuzha	85.71	Chlorides, Hardness, Calcium, Fl
Palakkad	14.28	Hardness

*One from each of the geographical regions studied
The last column shows the parameters among those examined in which excesses were observed

the fact that the mineralogical background of a region is important, the quantitative and qualitative problems seem closely interlinked. Excesses in the Alappuzha and Palakkad districts are followed by Thrissur (12%) and those of the coastal districts Kannur (8%) and Ernakulam (7%).

It should be underlined that most of violations of the parametric values took place in district which is the densely populated district in Kerala (1492/km²) and having the maximum floating population as tourists. The violations of the parametric values in hilly districts in Pathanamthitta, Wayanad and Idukki were detected less than 5%. In these places violations are observed in pH and coliform, which is acidic due to organic material leaching from forest floors and defecation in open respectively. The districts of Kasargod, Pathanamthitta, Idukki, Kollam, Kozhikode, Ernakulam and Malappuram recorded only coliform violations. Even though Ernakulam district samples violated only coliform, this district need a special attention because the maximum coliform count (350 organisms/100 ml) was recorded here. It is also important to make a note on the decades old poorly maintained pipe supply system, which can be good host for development of bacterial biofilm. The phenomena of treated water getting contaminated in pipe supply before it reaches the consumer's tap are well documented (Percival et al., 2000). Moreover the proportion of water-borne disease outbreaks associated with the distribution system failures has been increasing over the years (Moe and Rheingans, 2006).

Among the samples collected from urban areas, 87.8% of the samples are beyond the permissible limit as per BIS standards, of which 65.85% of samples were with one parameter exceeding the permissible range, 19.51% of samples with two parameters and 2.44% of sites with more than two parameters. In case of rural samples, 73.33% of samples exceed the desirable limit, of which 48.89% of sites were with one parameter exceeding the permissible range, 20% of sites with two parameters and 4.44% of sites with more than two parameters. Even though only 26.67% of rural samples are within the BIS drinking water permissible limit, it supplies good quality water than urban water supply systems, whose samples only 12.2% are within the BIS drinking water permissible limit. In general rural water supply schemes supply a better quality of water than the water supplied in the urban areas. This could be attributed to less contamination in the source (river/bore well) in rural areas and also to poor treatment facilities in urban water supply coupled with the high contamination in the river and ground water in the urban areas.

Conclusion

The present study investigates the drinking water quality of Kerala state with an aim to understand their potability. It is concluded that drinking water supplied all over the state is contaminated with coliform bacteria. The quality of water supplied in Palakkad and Alappuzha districts are not in the desirable limit prescribed by Bureau of Indian Standards Drinking Water Specification: IS: 10500. The most important deviations from good quality, reflected in excesses of the levels provided by BIS Drinking Water Specification, were found in water stressed low land, Alappuzha district. Their freshwater resources are scarce; the "parent" waters are frequently affected by marine water intrusion into the aquifers and the water distribution method (supply of water by boat with tank) is very unhygienic in condition. Community owned reverse osmosis units can be supplied to each island villages of this district, which can provide good-quality water. The next, which records violation of water quality standards, is Palakkad. This district receives very less rainfall (233 cm/year), when comparing with all other districts of the state. In this district along with the improved water treatment facility rain water harvesting programmes should be promoted to increase the depleted groundwater table. The problems found in the rest of Kerala are mostly related to the contamination of source water (surface and ground waters) by agricultural run-off or percolation of waters laden with agrochemicals (e.g. nitrates, phosphates). Comparatively, water supplied in rural areas are better in water quality than the water supplied in urban areas by municipalities, which may be attributed higher chances of contamination in urban areas due to mismanagement of solid and liquid wastes.

A statewide water quality monitoring network should be established as soon as possible. Specifically, the state monitoring network should include at least the following important elements such as, measurement of a core set of variables at all water distribution centres, with regional flexibility to measure additional variables where needed, followed by technical coordination that establishes standard procedures and techniques with respect to the state local condition and periodic review of the monitoring water supply system. The treatment facilities observed all over Kerala confirms that the currently followed treatment is only chlorination without any scientific knowledge on the water quality of source. In most of the cases the chlorination is not sufficient enough to kill the bacteria.

This study aimed to bring out the overall tap water quality of Kerala, which is also having limitation like number of sample (minimum four samples per district), while many others remain unidentified. Under this perspective and taking into consideration that the existing drinking water supply systems and quality of water are not sufficient, there is a need for at least periodical simple water quality testing to be carried out by the water supply laboratories to ensure the best quality water to the people.

Acknowledgement

This work was funded by *Malayala Manorama* as a part of "*Palathulli*" project. The authors are thankful to the Mr Ajith Babu, Mr Thomas Mathew and many local reporters of the *Malayala Manorama* newspaper for their assistance during the fieldwork. We are also thankful to Dr Ahalya, Dr K.V. Gururaja, Dr Sudhira K.G. Avinash and Ms Malvikaa for their help in fieldwork and laboratory analysis.

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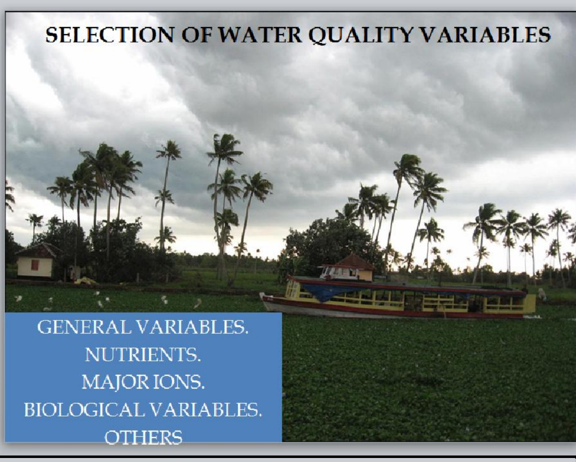

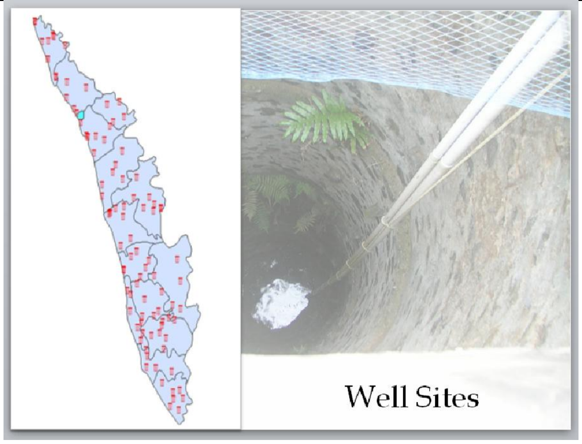

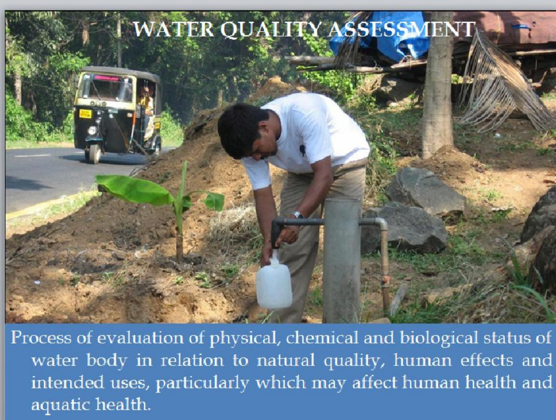

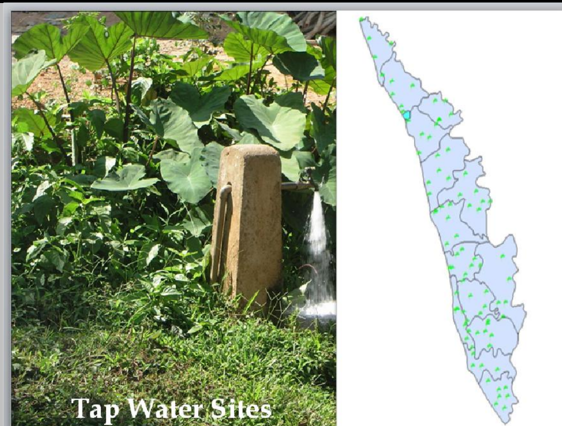

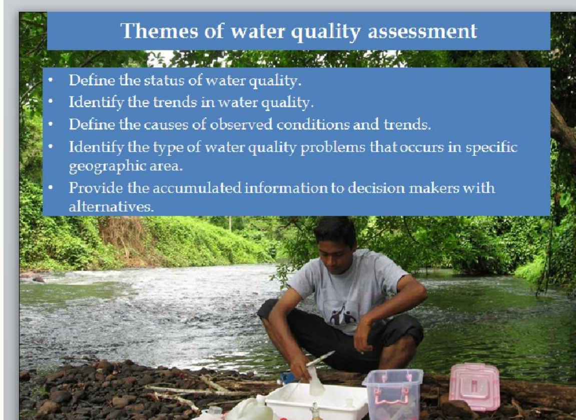

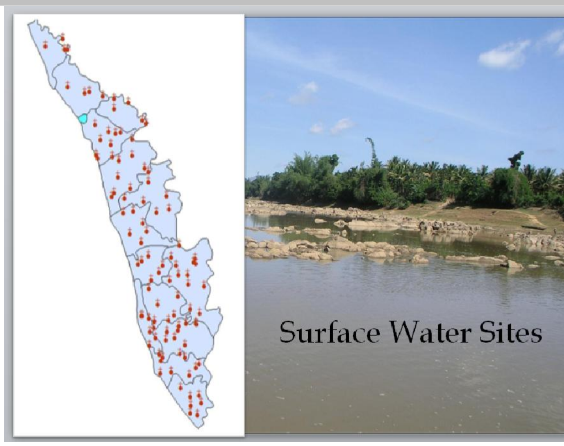

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