ASSESSMENT OF QUALITY OF WELL WATER IN ELOOR, KERALA

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DECLARATION

I hereby declare that the thesis entitled "**ASSESSMENT OF QUALITY OF WELL WATER IN ELOOR, KERALA**" is a bonafide record of research work done by me during the course of research and that this thesis has not previously formed the basis for the award to me of any degree, diploma, associateship, fellowship or other similar title, of any other university or society.

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04.05.2010

CERTIFICATE

Certified that the thesis entitled **"ASSESSMENT OF QUALITY OF WELL WATER IN ELOOR, KERALA"** is a record of research work done independently by **DIVYA RANI THOMAS**, under my guidance and supervision and that it has not previously formed the basis for the award of any degree, diploma, associateship or fellowship to her.

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Introduction

1. INTRODUCTION

Safe and wholesome drinking water is a basic need for human development, health and well being, and it is an internationally accepted human right (WHO, 2001). However water pollution is a serious problem in India as almost 70 per cent of its surface water resources and a growing number of its ground water sources are contaminated by biological, organic and inorganic pollutants (Rao and Mamatha, 2004). The deterioration of water quality causes health hazards and death of human, livestock and aquatic lives, crop failure and loss of aesthetics. It is estimated that around 37.7 million Indians are affected by waterborne diseases annually, 1.5 million children are estimated to die of diarrhoea alone and 73 million working days are lost due to waterborne disease each year. The resulting economic burden is estimated at $600 million a year. The problems of chemical contamination is also prevalent in India with 1,95,813 habitations in the country affected by poor water quality (Khurana and Sen, n.d.).

Pollution of water resources occurs through point and diffuse sources. The main sources of point pollution are effluents from industries, sewage treatment plants and untreated domestic sewage. Whereas diffuse source of pollution may be contributed by anthropogenic activities such as fertilizer application, pesticides or chemicals of geochemical origin such as fluoride, arsenic and dissolved salts.

Among the various sources of water pollution, industries play a significant role in deteriorating water quality, mainly of chemical nature. Most of the industries discharge their effluents without proper treatment into nearby open pits or pass them through unlined channels to low lying depressions on the land resulting in contamination of groundwater, which has long been considered as one of the purest forms of water available in nature. The industrial wastes have a great deal of influence on pollution of water body by altering the physical, chemical and biological nature of water. Heavy metals are persistent in nature and therefore get accumulated in soil and plants. Dietary intake of heavy metals through drinking water and plants has long term detrimental health impacts including disorders of digestive system, respiratory system, nervous system etc. Transmission of waterborne diseases has been a matter of concern for many years. Hence microbiological examination is also important from a public health point of view.

Eloor industrial area is an island formed between two distributaries of river Periyar and is the largest industrial belt in Kerala with approximately 247 large and small functional industrial units (Loal Area Environment Committee, 2006). These industries manufacture petrochemical products, fertilizers, pesticides, rare-earth elements, rubber processing chemicals, zinc, chrome products etc. They consume about 189343 m^3 water per day, from river Periyar and discharge about 75 per cent as used water along with large quantity of effluents and pollutants. Each of these industries dispose their waste into environment in alarming proportion rendering the area toxic hotspot. Most of the industries discharge their effluents into Periyar river or its rivulets, which indirectly affect the groundwater quality of the area.

Previous studies conducted at Eloor proved that, the quality of environment in the area has degraded and people and animals here are at great risk of diseases. Greenpeace International and other Non Governmental Organizations are working for improving the conditions at Eloor. Even then the basic needs of people could not be met so far.

On the light of foregoing facts, the present study was designed to assess the quality of well water in Eloor industrial area in Ernakulam district of Kerala and to compare it with non industrial area Ollukara in Thrissur district of Kerala with the following objectives.

1. To assess the physical, chemical and microbiological quality of well water in Eloor industrial area and a non industrial area, Ollukara

2. To correlate the impact of industrialization on quality of well water.

Review of Literature

2. REVIEW OF LITERATURE

2.1 PHYSICAL QUALITY OF WATER

The physical characteristics of water are not of direct public health concern, but they do affect the aesthetic quality, which determines whether it is acceptable or not. Consumers usually judge the quality of water on the basis of physical qualities. They prefer drinking water which is not only safe, but also pleasing in appearance, taste and odour. If water is unpalatable or appears to be of poor quality, even though it may be quite safe to drink, the consumer may seek other water sources that may not be safe.

2.1.1 Temperature

Temperature of water is an important property that determines suitability of water for human use, industrial applications and aquatic ecosystem functioning. Temperature is indeed a fundamental factor for water quality, exerting a great influence over the aquatic system. Measurement of temperature is one of the most common physical assessments of water quality. Temperature impacts the physical, chemical and biological processes in water bodies and therefore the concentration of many variables. As water temperature increases, the rate of chemical reactions generally increases. Increased temperature also decreases the solubility of gases such as O_2, N_2, CO_2, and CH_4 in water. The temperature of water is controlled primarily by climate. Groundwater usually maintains a fairly constant temperature which for surficial aquifers, is close to the mean annual air temperature. However deep aquifers have higher temperature due to earth's thermal gradient.

Kaplay and Patode (2004) investigated the groundwater pollution due to industrial effluent at Tuppa, Maharashtra. Samples were collected from twenty five bore wells and forty two dug wells for a period of three years (1997, 1998 and 1999) during pre monsoon (May) and post monsoon (December) seasons.

Average temperature for three years was 29°C, 29.8°C and 29.02°C during pre monsoon and 26.99°C, 26.43°C and 27.20°C during post monsoon.

Nasrullah *et al.* (2006) investigated the groundwater quality of Gadoon Amazai industrial estate, Pakistan. Samples were taken from three tube wells and the temperature varied from 26.1-26.7°C.

Mishra and Bhatt (2008) analyzed the groundwater quality of Anand district, Gujarat. Water samples were taken from four different places named S-1, S-2, S-3, and S-4 during January 2007. Temperature of water samples was in the range of 29-31°C.

Raveen *et al.* (2008) studied the impact of pollution on quality of water in three freshwater lakes in Chennai named site 1, site 2 and site 3. Samples were analyzed during four seasons of year viz. post- monsoon (January-March), summer (April-June), pre-monsoon (July- September) and monsoon (October-December). The study revealed that mean temperature at site 1 was 23.4°C, 32.5°C, 31.6°C and 27.5°C, at site 2, 33.5°C, 22°C, 29.4°C and 34°C and 24.3°C, 36.4°C, 33°C and 29.43°C at site 3 during respective seasons.

Adekunle (2009) studied the effect of industrial effluents on quality of groundwater within Asa Dam industrial estate, Ilorin, Nigeria. Three wells were sampled and it was found that temperature of water was in the range of 27-28°C.

Adekunle *et al.* (2007) studied the impact of industrial effluents on quality of Asa river, Nigeria. Samples were taken from five points of the river and found that temperature of water varied from 26-29°C.

Agbaire and Obi (2009) investigated the influence of seasonal changes on the properties of river Ethiope water in Nigeria. Samples from six different sampling points were assessed for both dry (December) and wet (July) seasons. Mean temperature was 29.15°C during dry season and 27.73°C during wet season.

Ullah *et al.* (2009) assessed the groundwater contamination in Sialkot, an industrial city in Pakistan using water samples collected from twenty five localities during October-November, 2005 and found that mean temperature was 21.85°C.

John and Thanga (2010) investigated the seasonal change in potable water quality of coastal wards of Kollam Corporation. A total of ten samples were collected from dug wells of five different spots during pre-monsoon (February 2008) and monsoon (June 2008) seasons. Temperature varied from 25-28°C in all samples. Minimum temperature was recorded during monsoon and maximum during pre-monsoon months.

2.1.2 pH

pH is an important variable in water quality assessment as it influences many biological and chemical processes within a water body and all the processes associated with water supply treatment. When measuring the effect of an effluent discharge, it can be used to determine the extent of effluent plume in the water body. At a given temperature, pH indicates the acidic or basic character of a solution and is controlled by the dissolved chemical compounds and biochemical processes in the solution. pH is also an important operational parameter, as the effectiveness of disinfection with chlorine depends on its value. The pH of pure water is seven at 25°C, but when exposed to the carbon dioxide in the atmosphere this equilibrium results in a pH of approximately 5.2. Water with a low pH could be soft, acidic and corrosive. Therefore water could leach metal ions such as iron, manganese, copper, lead and zinc from the aquifer, plumbing fixtures and piping. Water with a pH >8.5 could indicate that the water is hard.

Reddy and Rao (1995) observed the pH of dug well samples of industrial polluted zones in Visakhapatnam area, Andhra Pradesh during May 1992. A total of eleven wells, six from Mindi and five from Gopalapatnam were sampled and it was found that the average pH was 6.28 and 6.52 at Mindi and Gopalapatnam respectively.

Nair *et al.* (2000) analyzed the pH of groundwater in Thrissur district, Kerala. Twenty water samples were collected from various parts of Thrissur district. The analysis revealed that pH of all the water samples was around seven.

Kaplay and Patode (2004) investigated the groundwater pollution due to industrial effluent at Tuppa, Maharashtra. Samples were collected from twenty five bore wells and forty two dug wells for a period of three years (1997, 1998 and 1999) during pre monsoon (May) and post monsoon (December) seasons. Average pH for three years was 6.99, 6.83 and 6.54 during pre monsoon and 7.10, 7.40 and 7.32 during post monsoon.

Adediji and Ajibade (2005) assessed the pH of dug well water in Ede area, Nigeria and reported that pH was in the range of 5.4-7.3.

Efe *et al.* (2005) studied the seasonal variation of pH of open well water in Western Niger Delta region, Nigeria and observed that mean pH was 4.9 during dry season (January, 2004) and 5.18 during wet season (June, 2004).

Laluraj *et al.* (2005) analyzed the pH of groundwater of shallow aquifers in the coastal zones of Cochin, Kerala. Samples were collected from twenty dug wells during post monsoon (November, 2003) and found that pH varied from 7.01-8.2.

Mahasim *et al.* (2005) assessed the pH of well water in North Eastern district of Kelantan, Shah Alam. The average pH was 6.5 during wet season and 5.7 during dry season and attributed low pH of water during dry season to great reduction in water volume in wells during dry season.

Phiri *et al.* (2005) assessed the impact of industrial effluents on water quality of receiving river in Malawi, Africa. Mean pH of river water was 6.3-7.5.

Laluraj and Gopinath (2006) studied the seasonal variation of pH of groundwater. Fifty five dug well samples were collected from Muvattupuzha river basin, Kerala during 2001 and it was concluded that pH varied from 5.5-8.0 during pre-monsoon and 5.6-8.1 during post monsoon.

Sisodia and Moundiotiya (2006) assessed the pH of water from Kalakho lake, Rajasthan. They observed that the average pH value of lake water ranged within 7.90-8.37 during summer, 7.05-7.27 during monsoon and 7.83-7.93 during winter.

The environment impact assessment on Eloor-Edayar industrial belt, Kerala revealed that pH of water samples was in the range of 5.7-8.3 at Eloor and 5.4-8.2 at Edayar. (Local Area Environment Committee, 2006).

Palanisamy *et al.* (2007) assessed the pH of groundwater in and around Gobichettipalayam, Erode, a non industrial area in Tamil Nadu. Twenty samples were analyzed during February-March, 2006 and the pH of water was in the range of 6.07-7.38.

Rajan *et al.* (2007) assessed the pH of well water in Varkala coast, Kerala. Six wells were sampled and found that pH was in the range of 4.58-6.74.

Shaiju *et al.* (2007) studied the pH of groundwater in Fort Cochin area in Kerala. Ten wells were sampled and the pH was in the range of 7-8.5.

Raveen *et al.* (2008) studied the impact of pollution on quality of water in three freshwater lakes in Chennai named site 1, site 2 and site 3. Samples were analysed during four seasons of year viz. post monsoon (January-March), summer (April-June), pre-monsoon (July-September), and monsoon (October-December). The study revealed that mean pH at site 1 was 7.2, 7.6, 6.9 and 6.4, at site 2, 6.4, 7.2, 7.4 and 6.9 and 6.8, 7.4, 8.1 and 7.2 at site 3 during respective seasons.

Shah *et al.* (2008) analysed the pH of bore well samples of forty villages of Gandhinagar taluka of Gujarat state during May 2009. They observed that the pH of samples was in the range of 7.26 -8.13.

Shankar *et al.* (2008) studied the impact of industrialization on groundwater quality in Peenya industrial area, Bangalore. Thirty samples were collected during October, 2006 and found that the pH was in the range of 6.05-8.30.

Adekunle (2009) studied the effect of industrial effluents on quality of groundwater within Asa Dam industrial estate, Ilorin, Nigeria. Three wells were sampled and it was found that pH of water was in the range of 6.9-7.3.

Agbaire and Obi (2009) investigated the influence of seasonal changes on the properties of river Ethiope water in Nigeria. Samples from six different sampling points were assessed for both dry (December) and wet (July) seasons. Mean pH was 6.80 during dry season and 6.99 during wet season.

Siddiqui and Sharma (2009) studied the pH of groundwater samples in Okhla industrial area, New Delhi. They analyzed ten water samples and found that pH varied in the range of 6.8-7.1.

Ullah *et al.* (2009) assessed the groundwater contamination in Sialkot, an industrial city in Pakistan using water samples collected from twenty five localities during October-November, 2005 and found that mean pH was 7.11.

John and Thanga (2010) investigated the seasonal change in potable water quality of coastal wards of Kollam Corporation, Kerala. A total of ten samples were collected from dug wells of five different spots during pre-monsoon (February 2008) and monsoon (June 2008) seasons. pH of the samples ranged from 6.02-7.52. Maximum pH was observed during monsoon and minimum during pre-monsoon season and concluded that maximum pH value might be due to consumption of CO_2 by phytoplankton and minimum value might be due to edaphic factors.

Patil and Patil (2010) conducted physicochemical analysis of selected groundwater samples of Amalner town, Maharashtra. Water samples from five sampling points named S1, S2 (tube wells), S3, S4 (open wells) and S5 (Municipal water supply) were analyzed during post monsoon period (November 2007-February 2008). Average pH at five sites was 7.1, 7.1, 7.1, 8.0 and 7.9 respectively.

Kumar *et al.* (2010) studied seasonal change in physico-chemical parameters of Periyar River at Neriamangalam, Kerala. Samples were analyzed from five stations during pre-monsoon, monsoon and post monsoon periods. The pH observed was in the range of 7.2-7.75 in pre-monsoon, 7.1-7.4 during monsoon and 7.22-7.68 in post monsoon. High pH values during pre-monsoon and post monsoon could be due to high photosynthesis of micro and macro vegetation resulting in high production of free CO_2 shifting the equilibrium towards alkaline side.

2.2 CHEMICAL QUALITY OF WATER

Chemical contaminants present in water can cause acute health problems to the consumers. The problem associated with chemical constituents of drinking water arises primarily from their ability to cause adverse health effects after prolonged period of exposure. Contaminants having cumulative toxic properties such as heavy metals and pesticides and those with carcinogenic properties are of particular concern.

2.2.1 Total hardness

Hardness is the soap-destroying power of water. This is caused mainly by bicarbonates and sulphates of calcium and magnesium. Chlorides and nitrate of calcium and magnesium can also cause hardness, but they occur in small concentration. Drinking water should be moderately hard. Hardness of water has several disadvantages: hard water consumes more soap and detergents, loss of efficiency of boilers, economic loss in industries, loss of palatability etc.

Reddy and Rao (1995) observed the total hardness of dug well samples of industrial polluted zones in Visakhapatnam area, Andhra Pradesh during May 1992. A total of eleven wells, six from Mindi and five from Gopalapatnam were sampled and the average value was found to be 648 mg/l and 728 mg/l at Mindi and Gopalapatnam respectively.

Nair *et al.* (2000) analyzed the total hardness of groundwater in Thrissur district, Kerala. Twenty water samples were collected from various parts of Thrissur district and it was found that eighteen samples were within the soft and very soft water range and the rest were in the medium hardness range.

Kaplay and Patode (2004) investigated the groundwater pollution due to industrial effluent at Tuppa, Maharashtra. Samples were collected from twenty five bore wells and forty two dug wells for a period of three years (1997, 1998 and 1999) during pre monsoon (May) and post monsoon (December) seasons. Average value of total hardness for three years was 717.80 mg/l, 664.62 mg/l and 784.45 mg/l during pre monsoon and 713.36 mg/l, 739.60 mg/l and 1043.82 mg/l during post monsoon.

Efe *et al.* (2005) studied the seasonal variation of total hardness of open well water in Western Niger Delta region, Nigeria and observed that mean hardness was 370-476 mg/l during dry season (January, 2004) and 468-470 mg/l during wet season (June, 2004).

Phiri *et al.* (2005) assessed the impact of industrial effluents on water quality of receiving river in Malawi, Africa. Mean total hardness of river water was 113.3 - 417.0 mg/l.

Sisodia and Moundiotiya (2006) assessed the total hardness of water from Kalakho lake, Rajasthan. They observed that the average value for lake water ranged within 117.25 -122.97 mg/l during summer, 71.73-94.25 mg/l during monsoon and 80.66 - 81.12 mg/l during winter.

Palanisamy *et al.* (2007) assessed the total hardness of groundwater in and around Gobichettipalayam, Erode, a non industrial area in Tamil Nadu. Twenty samples were analyzed during February-March, 2006 and the total hardness of water was in the range of 75-110 mg/l.

Rajan *et al.* (2007) assessed the total hardness of well water in Varkala coast, Kerala. Six wells were sampled and found that total hardness varied from 16 - 54 mg/l.

Shaiju *et al.* (2007) studied the total hardness of groundwater in Fort Cochin area, Kerala. Ten wells were sampled and found that total hardness varied from 0 - 600 mg/l.

Mishra and Bhatt (2008) analyzed the groundwater quality of Anand district, Gujarat. Water samples were taken from four different places named S-1, S-2, S-3, and S-4 during January 2007. Total hardness of water was in the range of 156-320 mg/l.

Raveen *et al.* (2008) studied the impact of pollution on quality of water in three freshwater lakes in Chennai, named site 1, site 2 and site 3. Samples were analyzed during four seasons of year viz. Post monsoon (January-March), summer (April-June), pre-monsoon (July- September), and Monsoon (October-December). The study revealed that mean total hardness at site 1 was 281 mg/l, 169 mg/l, 172 mg/l and 190 mg/l, at site 2, 241 mg/l, 173 mg/l, 154 mg/l and142 mg/l, and 212 mg/l, 181 mg/l, 168 mg/l and 172 mg/l at site 3 during respective seasons.

Shah *et al.* (2008) analysed the total hardness of bore well samples of forty villages of Gandhinagar taluka of Gujarat state during May 2009. They observed that the mean total hardness of samples was 194.63 mg/l.

Shankar *et al.* (2008) studied the impact of industrialization on groundwater quality in Peenya industrial area, Bangalore. Thirty samples were collected during October, 2006 and found that total hardness was in the range of 100-3012 mg/l.

Adekunle (2009) studied the effect of industrial effluents on quality of groundwater within Asa Dam industrial estate, Ilorin, Nigeria. Three wells were sampled and it was found that total hardness of water was in the range of 37-153 mg/l.

Shaji *et al.* (2009) assessed the suitability of well water for domestic purpose in and around Chavara industrial area, Quilon, Kerala for a period of six months from December 2006 to May 2007. Four wells representing four localities were assessed. The well water exhibited total hardness of 110-835 mg/l.

Siddiqui and Sharma (2009) studied the total hardness of groundwater samples in Okhla industrial area, New Delhi. They analyzed ten water samples and found that the total hardness varied in the range of 60-250 mg/l.

Ullah *et al.* (2009) assessed the groundwater contamination in Sialkot, an industrial city in Pakistan using water samples collected from twenty five localities during October-November, 2005 and found that mean total hardness was 200.80 mg/l. The higher level of total hardness could be due to the discharge from polluting industries and untreated wastes.

John and Thanga (2010) investigated the seasonal change in potable water quality of coastal wards of Kollam Corporation, Kerala. A total of ten samples were collected from dug wells of five different spots during pre-monsoon (February 2008) and monsoon (June 2008) seasons. Total hardness varied from 92 mg/l during monsoon to 40 mg /l during pre-monsoon.

Patil and Patil (2010) conducted physicochemical analysis of selected groundwater samples Amalner town, Maharashtra. Water samples from five sampling points named S1, S2 (tube wells), S3, S4 (open wells) and S5 (Municipal water supply) were analyzed during post monsoon period (November 2007-February 2008). Average hardness at five sites was 264 mg/l, 870 mg/l, 514 mg/l, 190 mg/l and 170 mg/l respectively.

2.2.2 Chemical Oxygen Demand (COD)

Chemical Oxygen Demand (COD) is the total measurement of all chemicals in water that can be oxidised. This measures the ability of hot chromic acid solution to oxidise organic matter. This analyzes both biodegradable and non-biodegradable organic matter. For industrial samples, COD may be the only feasible test because of the presence of bacterial inhibitors or other chemical interferences, which would interfere with Biochemical Oxygen Demand (BOD) determination. COD test also gives the fast measurements required in many treatment systems.

Vattakeril (1997) assessed the water quality of industrially polluted Kshipra river, Indore. Water samples were taken from six stations of river and observed that COD value ranges from 8-450 mg/l.

Otokunefor and Obiukwu (2005) studied the impact of refinery effluent on the physicochemical properties of effluent receiving sites of Bonny river estuary in Niger Delta area. Mean COD was 41.19 mg/l.

Sisodia and Moundiotiya (2006) assessed the COD of water from Kalakho lake, Rajasthan. They observed that the average COD value for lake water ranged within 111.5-116.6 mg/l during summer, 124-149.7 mg/l during monsoon and 108.3 - 115.7 mg/l during winter.

Mishra and Bhatt (2008) analyzed the groundwater quality of Anand district, Gujarat. Water samples were taken from four different places named S-1, S-2, S-3, and S-4 during January 2007. COD of water samples was in the range of 9-13.3 mg/l.

Shah *et al.* (2008) analyzed the COD of bore well samples of forty villages of Gandhinagar taluka of Gujarat state during May 2009. They observed the mean COD of samples as 1.75 mg/l.

Shaji *et al.* (2009) assessed the suitability of well water for domestic purpose in and around Chavara industrial area, Quilon, Kerala for a period of six months from December 2006 to May 2007. Four wells representing four localities were assessed. The well water exhibited high COD of 666.67-796.67 mg/l.

Siddiqui and Sharma (2009) studied the COD of groundwater samples in Okhla industrial area, New Delhi. They analyzed ten water samples and found that COD was in the range of 4.5-13 mg/l.

Kumar *et al.* (2010) studied seasonal change in physico-chemical parameters of Periyar River at Neriamangalam, Kerala. Samples were analyzed from five stations during pre-monsoon, monsoon and post monsoon periods. Station one and four showed higher COD values (16-18 mg/l) than rest of the stations. Comparatively lower COD was observed during monsoon and post monsoon and concluded that death and decay of plants and consequent increase in organic matter during dry season contributed to high COD values during dry season.

2.2.3 Nitrate

Nitrogen is a major constituent of the earth's atmosphere and occurs in many different gaseous forms such as elemental nitrogen, nitrate and ammonia. Nitrate is the common form of combined nitrogen found in natural waters. It may be biochemically reduced to nitrite by denitrification process, usually under anaerobic conditions. Even though nitrate is a common nitrogenous compound due to natural processes of the nitrogen cycle, anthropogenic sources have greatly increased the nitrate concentration, particularly in groundwater. Natural sources of nitrate to water include, igneous rocks, land drainage and plant and animal debris. This is an essential nutrient for aquatic plants and seasonal fluctuations can be caused by plant growth and decay. Waste materials are one of the anthropogenic sources of nitrate contamination of groundwater. Many sources of potential nitrate contamination of groundwater exist such as, sites used for disposal of human and animal sewage, industrial wastes related to food processing, and some polyresin facilities and sites where handling and accidental spills of nitrogenous materials may accumulate. Septic tanks are another example of anthropogenic source of nitrogen contamination of the groundwater. Nitrate occurs naturally in groundwaters as a result of soil leaching but in areas of high nitrogen fertilizer application it may reach very high concentrations. Intake of water containing high nitrate concentrations, above 10 mg/l can cause methemoglobinemia (infant cyanosis or blue-baby syndrome).

Singh *et al.* (2008) assessed the nitrate concentration of drinking water of North Eastern India. Samples were collected during monsoon (July- September) and non-monsoon (November- January) from groundwater and surface water resources. Nitrate concentration at Assam was 0.02 - 49.0 mg/l during non-monsoon. Nitrate concentration at other states during non-monsoon and monsoon were as follows; Arunachal Pradesh: 0.00-40.0 and 0.00-45 mg/l, Manipur: 0.01-0.34 and 0.00-24.6 mg/l, Meghalaya- 0.01-7.93 and 0.00-15.4 mg/l, Mizoram: 0.01-0.98 and 0.00-6.60 mg/l, Nagaland: 0.00-0.94 and 0.05-10.9 mg/l, Sikkim: 0.00-0.51 and 0.00-16.9 mg/l, Tripura: 0.02-0.98 and 0.01-29.1 mg/l.

Subrahmanyam and Yadaiah (2001) evaluated the effect of multiple industrial pollutants on groundwater system in Medak district, Andhrapradesh. Water samples were taken from dug wells and bore wells. Nitrate concentration was in the range of 2-11 mg/l in dug wells and 2-12 mg/l in bore wells.

Efe *et al.* (2005) studied the seasonal variation of nitrate content of open well water in Western Niger Delta region, Nigeria and observed that mean nitrate concentration was 52.4 mg/l during dry season (January, 2004) and 52.0 mg/l during wet season (June, 2004).

Phiri *et al.* (2005) assessed the impact of industrial effluents on water quality of receiving river in Malawi, Africa. Mean nitrate concentration of river water was 0.01-0.04 mg/l.

Rajan *et al.* (2007) evaluated the nitrate concentration of well water in Varkala coast, Kerala. Six wells were sampled and found that nitrate concentration varied from 20.91-21.81 mg/l.

Kumar *et al.* (2008) investigated the extent of nitrate pollution in dug well water of a coal mining area of Dhanbad, Jharkhand. Eight samples each were collected during December, 2006, March, 2007 and June, 2007. It was found that nitrate content in water varied from 2-30 mg/l, 8 - 40 mg/l and 12-65 mg/l during respective periods.

Shaji *et al.* (2009) assessed the suitability of well water for domestic purpose in and around Chavara industrial area, Quilon, Kerala for a period of six months from December 2006 to May 2007. Four wells representing four localities were assessed. The well water exhibited nitrate concentration of 1.12-4.97 mg/l.

Shankar *et al.* (2008) studied the impact of industrialization on groundwater quality in Peenya industrial area, Bangalore. Thirty samples were collected during October, 2006 and found that the nitrate concentration was in the range of 10-319 mg/l.

Siddiqui and Sharma (2009) studied the nitrate concentration of groundwater samples in Okhla industrial area, New Delhi. They analyzed ten water samples and found that the nitrate concentration was in the range of 2.4-8.9 mg/l.

Ullah *et al.* (2009) assessed the groundwater contamination in Sialkot, an industrial city in Pakistan using water samples collected from twenty five localities during October-November, 2005 and found that mean nitrate concentration in the area was 3.96 mg/l.

John and Thanga (2010) investigated the seasonal change in potable water quality of coastal wards of Kollam Corporation, Kerala. A total of ten samples were collected from dug wells of five different spots during pre-monsoon

(February 2008) and monsoon (June 2008) seasons. Nitrate concentration ranged between 0.1-4.64 mg/l with maximum value during pre-monsoon.

Patil and Patil (2010) conducted physicochemical analysis of selected groundwater samples in Amalner town, Maharashtra. Water samples from five sampling points named S1, S2 (tube wells), S3, S4 (open wells) and S5 (Municipal water supply) were analyzed during post monsoon period (November 2007-February 2008). Average nitrate concentration at five sites was 0.451 mg/l, 0.765 mg/l, 1.271 mg/l, 0.191 mg/l and 0.041 mg/l respectively. It was concluded that poor quality water in S2 and S3 could probably be due to sewage pond close to site 2 and large sewage flowing near the site S3.

Kumar *et al.* (2010) studied seasonal change in physico-chemical parameters of Periyar River at Neriamangalam, Kerala. Samples were analyzed from five stations during pre-monsoon, monsoon and post monsoon periods. Nitrate concentration was higher in all stations during pre and post monsoon seasons and most of the values were above the limit (45 mg/l) set by World Health Organization (WHO). There was considerable reduction in nitrate concentration during monsoon.

2.2.4 Fluoride

Fluoride present naturally in earth's crust is found in all natural waters at some concentration. In groundwater, low or high concentrations of fluoride can occur, depending on the nature of the rocks and the occurrence of fluoride-bearing minerals. High concentration of fluoride in groundwater beyond the permissible limit of 1.5 mg/l is a major health problem in India. 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. These range from mild dental fluorosis to crippling skeletal fluorosis as the level and period of exposure increases. Crippling skeletal fluorosis is a significant cause of morbidity in a number of regions of the world.

Singh *et al.* (2008) assessed the fluoride concentration of drinking water of North Eastern India. Samples were collected during monsoon (July- September) and non-monsoon (November- January) from groundwater and surface water resources. Fluoride concentration at Assam was 0.50-2.00 mg/l during non-monsoon. Fluoride concentration at other states during non-monsoon and monsoon were as follows; Arunachal Pradesh: 0.90-2.00 and 0.68-1.85 mg/l, Manipur: 0.00-1.00 and 0.03-0.09 mg/l, Meghalaya- 0.00-0.40 and 0.00-0.05 mg/l, Mizoram: 0.00-0.10 and 0.00-0.08 mg/l, Nagaland: 0.00-0.10 and 0.02-0.20 mg/l, Sikkim: 0.01-0.60 and 0.03-0.12 mg/l, Tripura: 0.00-0.80 mg/l and below detection limit.

Kumar (2000) studied the toxicological effects of industrial wastes in cattle of Eloor area. Fluoride levels in environmental and biological samples were analyzed and compared with non industrial area Mannuthy. Fluoride concentration of water was 0.931±0.163 mg/l in Eloor South, 0.77 ±0.069 mg/l in Eloor North and 0.123 ±0.045 mg/l in Mannuthy.

Subrahmanyam and Yadaiah (2001) evaluated the effect of multiple industrial pollutants on groundwater system in Medak district, Andhrapradesh. Water samples were taken from dug wells and bore wells. Fluoride concentration was in the range of 0.5-1 mg/l in dug wells and 0.5-3.5 mg/l in bore wells.

Ravindran and Reji (2004) studied the fluoride contamination in Mundur and Kanjikode in Palghat District in Kerala. Results showed that fluoride content in open well and bore well samples were in the range of 0.2-2.7 mg/l. Study also pointed out a direct relationship between depth of groundwater source and fluoride content.

Laluraj and Gopinath (2006) studied the seasonal variation of fluoride concentration of groundwater. Fifty five dug well samples were analysed from

Muvattupuzha river basin, Kerala during 2001 and it was found that fluoride concentration was <0.5 mg/l during both seasons.

The environment impact assessment on Eloor-Edayar industrial belt, Kerala revealed that fluoride concentration of water samples from Edayar varied from below detection limit to 0.3 mg/l (Local Area Environment Committee, 2006).

Palanisamy *et al.* (2007) assessed the fluoride content of groundwater in and around Gobichettipalayam, Erode, a non industrial area in Tamil Nadu. Twenty samples were analyzed during February-March, 2006 and the fluoride content of water is in the range of 0.00-0.86 mg/l.

Shah *et al.* (2008) analysed the fluoride concentration of bore well samples of forty villages of Gandhinagar taluka of Gujarat state during May 2009. They observed that the mean fluoride concentration of samples was 0.85 mg/l.

Shankar *et al.* (2008) studied the impact of industrialization on groundwater quality in Peenya industrial area, Bangalore. Thirty samples were collected during October, 2006 and found that the fluoride concentration was in the range of 0.4-5.88 mg/l.

Siddiqui and Sharma (2009) studied the fluoride concentration of groundwater samples in Okhla industrial area, New Delhi. They analysed ten water samples and found that the fluoride concentration was in the range of 1.0-3.1 mg/l.

Ullah *et al.* (2009) assessed the groundwater contamination in Sialkot, an industrial city in Pakistan using water samples collected from twenty five localities during October-November, 2005 and found that mean fluoride concentration was 0.68 mg/l.

2.2.5 Iron

Iron is the second most abundant metal in the earth's crust and most commonly found in nature in the form of its oxides. It can enter a water system by leaching natural deposits and from iron-bearing industrial wastes, effluents from pickling operations or acidic mine drainage. Staining of laundry and plumbing may occur at concentrations above 0.3 mg/litre. It also results in a metallic taste in the water. Higher levels of iron may also discolour the water or result in sediment. Iron also promotes undesirable bacterial growth, especially of iron bacteria including Gallionella, Leptothrix etc. within distribution system, resulting in the deposition of a slimy coating on the piping. They also impart an unpleasant odour to water.

Singh *et al.* (2008) assessed the iron content of drinking water of North Eastern India. Samples were collected during monsoon (July- September) and non-monsoon (November- January) from groundwater and surface water resources. Iron content at Assam was 0.12 -85.76 mg/l during non-monsoon. Iron concentration at other states during non-monsoon and monsoon were as follows; Arunachal Pradesh: 0.03-11.90 and 0.01-16.12 mg/l, Manipur: 0.22-6.78 and 0.01-9.49 mg/l, Meghalaya- 0.01-13.67 and 0.01-8.38 mg/l, Mizoram: 0.01-17.28 and 0.01-13.68 mg/l, Nagaland: 0.10-3.65 and 0.09-3.41 mg/l, Sikkim: 0.01-1.38 and 0.005-3.08 mg/l, Tripura: 0.12-19.25 mg/l and 0.11-27.11 mg/l.

Reddy and Rao (1995) observed the iron content of dug well samples of industrial polluted zones in Visakhapatnam area, Andhra Pradesh during May 1992. Five wells were sampled from Gopalapatnam and reported that the average iron concentration was 0.762 mg/l.

Suvarnakumari *et al.* (1997) studied the qualitative characteristics of groundwater along Chittar sub basin, Thiruvananthapuram by the systematic analysis of water samples from twenty five dug wells. Results were compared with WHO standards and she opined that high iron content observed in 96% of samples might be derived from lateritic formation in the study area.

Nair *et al.* (2000) analysed the iron content of groundwater in Thrissur district, Kerala. Twenty water samples were collected from various parts of Thrissur district and found that iron content of water samples were in the range of 0-2 mg/l.

Ezeronye and Ubalua (2005) studied the effect of abattoir and industrial effluents on heavy metal quality of Aba river, Nigeria. Samples were collected from five sampling points of the river during dry season (November-March) and rainy season (April-November). Mean iron concentration was 0.89 mg/l during dry season and 0.74 mg/l during rainy season.

Laluraj and Gopinath (2006) studied the seasonal variation of iron concentration of groundwater. Fifty five dug well samples were collected from Muvattupuzha river basin in Kerala, during 2001 and it was concluded that iron content varied from 0-4.7 mg/l during pre-monsoon and 0-1.2 mg/l during post-monsoon.

Nasrullah *et al.* (2006) investigated the groundwater quality of Gadoon Amazai industrial estate, Pakistan. Samples were taken from three tube wells and it was found that iron concentration varied from 0.04-0.037 mg/l.

The environment impact assessment on Eloor-Edayar industrial belt identified the concentration of pollutants present in well water samples collected from Eloor area, Kerala. Iron concentration was in the range of 0.02-2.94 mg/l. (Local Area Environment Committee, 2006).

Rajan *et al.* (2007) assessed the iron content of well water in Varkala coast, Kerala. Six wells were sampled and the iron concentration varied from 0.01-0.16 mg/l.

Shankar *et al.* (2008) studied the impact of industrialization on groundwater quality in Peenya industrial area, Bangalore. Thirty samples were collected during October, 2006 and reported that iron concentration was in the range of 0-1.44 m g/l. The higher iron content might be due to rusting of casing pipes, non usage of bore wells for long periods and disposal of scrap iron in open areas due to industrial activity.

Agbaire and Obi (2009) investigated the influence of seasonal changes on the properties of river Ethiope water in Nigeria. Samples from six different sampling points were assessed for both dry (December) and wet (July) seasons. Mean iron concentration was 0.026 mg/l during dry season and iron was absent during wet season.

Siddiqui and Sharma (2009) studied the iron concentration of groundwater samples in Okhla industrial area, New Delhi. They analyzed ten water samples and it was found that the concentration of iron was in the range of 145.4-278 µg/l.

Ullah *et al.* (2009) assessed the groundwater contamination in Sialkot, an industrial city in Pakistan using water samples collected from twenty five localities during October-November, 2005 and reported that mean iron concentration in the area was 0.30 mg/l.

2.2.6 Lead

Pipes, fittings, solder and the service connections of some household plumbing systems contain lead and contaminate the drinking water. Lead is a cumulative poison. Long-term exposure may cause kidney damage, anaemia, nerve and brain damage and death. Minor symptoms include abdominal pain, decreased appetite, constipation and fatigue. Pregnant women, infants and children up to six years of age are most vulnerable. Lead cause delay in physical and mental development, in infants and children.

Singh *et al.* (2008) assessed the lead content of drinking water of North Eastern India. Samples were collected during monsoon (July- September) and non-monsoon (November- January) from groundwater and surface water resources. Lead content at Assam was 0.001-0.005 mg/l during non-monsoon. Lead concentration at other states during non-monsoon and monsoon were as follows; Arunachal Pradesh: 0.00-0.49 and 0.00-0.64 mg/l, Meghalaya- 0.001-0.004 and 0.00-0.005 mg/l, Mizoram: 0.00-0.11 and 0.00-0.84 mg/l, Nagaland: 0.00-0.124 and 0.12-0.80 mg/l, Sikkim: 0.01-1.38 mg/l during non monsoon, Tripura: 0.001-0.114 mg/l and 0.03-0.692 mg/l. No lead could be detected in Manipur during both seasons.

Reddy and Rao (1995) observed the lead content of dug well samples of industrial polluted zones in Visakhapatnam area, Andhra Pradesh during May 1992. Six wells were sampled from Mindi and the average concentration of lead was 0.132 mg/l.

Ezeronye and Ubalua (2005) studied the effect of abattoir and industrial effluents on heavy metal quality of Aba river, Nigeria. Samples were collected from five sampling points of the river during dry season (November-March) and rainy season (April-November). Mean lead concentration was 0.08 mg/l during dry season and 0.05 mg/l during rainy season.

Otokunefor and Obiukwu (2005) studied the impact of refinery effluent on the physicochemical properties of effluent receiving sites of Bonny river estuary in Niger Delta area. Mean lead concentration was <0.01 mg/l.

Nasrullah *et al.* (2006) investigated the groundwater quality of Gadoon Amazai industrial estate, Pakistan. Samples were taken from three tube wells and found that concentration of lead varied from 0.21-1.2 mg/l.

The environment impact assessment on Eloor-Edayar industrial belt identified the concentration of pollutants present in well water samples collected from Eloor area. Lead concentration was in the range of below detectable level to 0.44 mg/l. (Local Area Environment Committee, 2006).

Shaiju *et al.* (2007) studied the concentration of lead of groundwater in Fort Cochin area, Kerala. Ten wells were sampled and it was found that lead concentration varied from 0-2000 ppb.

Shankar *et al.* (2008) studied the impact of industrialization on groundwater quality in Peenya industrial area, Bangalore. Thirty samples were collected during October, 2006 and found that lead was absent in all samples.

Agbaire and Obi (2009) investigated the influence of seasonal changes on the properties of river Ethiope water in Nigeria. Samples from six different sampling points were assessed for both dry (December) and wet (July) seasons. Mean lead concentration was 0.015 mg/l during dry season and 0.005 mg/l during wet season.

Buragohain *et al.* (2009) studied the seasonal variation of lead concentration of groundwater in Dhemaji district, Assam. Samples were collected from twenty different sites in both wet season (May 2008-October 2008) and dry season (November 2008-April 2009). Mean lead concentration was 0.277 mg/l in dry season and 0.194 mg/l in wet season. They concluded that higher levels of metals in groundwater during dry season might be due to concentration effect.

Siddiqui and Sharma (2009) studied the lead concentration of groundwater samples in Okhala industrial area, New Delhi. They analyzed ten water samples and found that the lead concentration was in the range of 10.4-55.4 μg/l.

Ullah *et al.* (2009) assessed the groundwater contamination in Sialkot, an industrial city in Pakistan using water samples collected from twenty five localities during October-November, 2005 and reported that mean lead concentration in the area was 0.49 mg/l.

2.2.7 Mercury

Sources of mercury in drinking water include erosion of natural deposits, discharge from refineries and factories. Long-term daily intake of approximately 0.25 mg of mercury as methyl mercury can cause the onset of neurological symptoms. Target organs of mercury poisoning are brain and kidneys. Mercury poisoning results in weakness, loss of appetite, insomnia, indigestion, diarrhoea, loosening of teeth, muscle tremors, renal problems and brain damage following large doses.

Thirunavukkarasu (2000) assessed the toxicological effects of industrial wastes in cattle of Eloor area in Kerala. Mercury levels in environmental and biological samples were analyzed and compared with non industrial area Mannuthy in Kerala. No mercury could be detected in water samples from both areas.

Ezeronye and Ubalua (2005) studied the effect of abattoir and industrial effluents on heavy metal quality of Aba river, Nigeria. Samples were collected from five sampling points of the river during dry season (November-March) and rainy season (April-November). Mean mercury concentration was 0.01 mg/l during both seasons.

Siddiqui and Sharma (2009) studied the mercury concentration of groundwater samples in Okhala industrial area, New Delhi. They analyzed ten water samples and it was found that the mercury concentration was in the range of 0.5-1.2μg/l.

2.2.8 Zinc

Zinc is a metal that is normally found in small amounts in nature. It is used in many commercial industries and can be released into the environment during mining and smelting activities. People living near smelters or industries using zinc could be exposed to higher levels of zinc by drinking water, breathing air and touching soil that contains the metal. Exposure to high levels of zinc over long periods of time may cause adverse health effects. Zinc imparts an undesirable astringent taste to water. Eating or drinking too much zinc in a short period of time can lead to stomach cramps, nausea and vomiting. Intake of large amounts of zinc for longer periods may cause anaemia, nervous system disorders, damage to the pancreas and lowered levels of "good" cholesterol.

Singh *et al.* (2008) assessed the zinc content of drinking water of North Eastern India. Samples were collected during monsoon (July- September) and non-monsoon (November- January) from groundwater and surface water resources. Zinc content at Assam was 0.002-5.16 mg/l during non-monsoon. Zinc concentration at other states during non-monsoon and monsoon were as follows; Arunachal Pradesh: 0.01-5.15 and 0.02-3.65 mg/l, Manipur: 0.00-1.56 and 0.003-4.54 mg/l, Meghalaya: 0.00-6.71 and 0.01-3.41 mg/l, Mizoram: 0.004-5.19 and 0.005-3.54 mg/l, Nagaland: 0.00-4.51 and 0.01-2.46 mg/l, Sikkim: 0.007-4.77 and 0.004-1.91 mg/l, Tripura: 0.02-12.16 and 0.00-5.71 mg/l.

Reddy and Rao (1995) investigated the zinc content of dug well samples of industrial polluted zones in Visakhapatnam area, Andhra Pradesh during May 1992. A total of eleven wells, six from Mindi and five from Gopalapatnam were sampled and it was found that the average concentration of zinc was 0.349 mg/l and 0.02 mg/l at Mindi and Gopalapatnam respectively.

Ezeronye and Ubalua (2005) studied the effect of abattoir and industrial effluents on heavy metal quality of Aba river, Nigeria. Samples were collected from five sampling points of the river during dry season (November-March) and rainy season (April-November). Mean zinc concentration was 5.08 mg/l during dry season and 4.55 mg/l during rainy season.

Otokunefor and Obiukwu (2005) studied the impact of refinery effluent on the physicochemical properties of effluent receiving sites of Bonny river estuary in Niger Delta area. Mean zinc concentration was 0.05 mg/l.

Nasrullah *et al.* (2006) investigated the groundwater quality of Gadoon Amazai industrial estate, Pakistan. Samples were taken from three tube wells and it was reported that zinc concentration varied from 0.21-1.2 mg/l.

The environment impact assessment on Eloor-Edayar industrial belt identified the concentration of pollutants present in well water samples collected from Eloor area. Zinc concentration was in the range of below detectable level to 6.00 mg/l. (Local Area Environment Committee, 2006).

Siddiqui and Sharma (2009) studied the zinc concentration of groundwater samples in Okhla industrial area, New Delhi. They analysed ten water samples and found that the concentration of zinc was in the range of 500.6-3067 μg/l.

Ullah *et al.* (2009) assessed the groundwater contamination in Sialkot, an industrial city in Pakistan using water samples collected from twenty five localities during October-November, 2005 and reported that mean zinc concentration in the area was 0.16 mg/l.

2.2.9 Cadmium

Cadmium is a natural element in the earth's crust. It is usually found as a mineral combined with other elements such as oxygen, chlorine, or sulfur. Contamination of drinking water may occur as a result of the presence of cadmium as an impurity in the zinc of galvanized pipes or cadmium-containing solders in fittings, water heaters, water coolers and taps. Cadmium enters soil, water, and air from mining, industry, and burning coal and household wastes. Cadmium accumulates primarily in kidneys and has a long biological half-life in humans of 10-35 years. Drinking water with very high levels severely irritates the stomach, leading to vomiting and diarrhoea. Long-term exposure to lower levels of cadmium in air, food, or water leads to a buildup of cadmium in the kidneys and possible kidney disease.

Singh *et al.* (2008) assessed the cadmium content of drinking water of North Eastern India. Samples were collected during monsoon (July- September) and non-monsoon (November- January) from groundwater and surface water resources. Cadmium content at Assam was 0.00-0.005 mg/l during non-monsoon. Cadmium concentration at other states during non-monsoon and monsoon were as follows; Arunachal Pradesh: 0.01-0.38 and 0.00-0.018 mg/l, Meghalaya- 0.00-0.005 and 0.00-0.01 mg/l, Mizoram: 0.001-0.16 and 0.003-0.05 mg/l, Nagaland: 0.00-0.10 and 0.006-0.02 mg/l, Sikkim: 0.00-0.18 and 0.001-0.007 mg/l, Tripura: 0.001-0.057 mg/l and 0.01-0.02 mg/l. No cadmium could be detected in Manipur during both seasons.

Reddy and Rao (1995) observed the cadmium concentration of dug well samples of industrial polluted zones in Visakhapatnam area, Andhra Pradesh during May 1992. Six wells were sampled from Mindi and it was found that the average cadmium concentration was 0.346 mg/l.

Nisha (2001) studied the toxicological effects of industrial wastes in cattle of Eloor area, Kerala. Cadmium levels in environmental and biological samples were analyzed and compared with non industrial area Mannuthy, Kerala. Cadmium concentration of water was 0.033±0.007 mg/l in Eloor South, 0.026±0.07 mg/l in Eloor North and 0.014±0.007 mg/l in Mannuthy

Nasrullah *et al.* (2006) investigated the groundwater quality of Gadoon Amazai industrial estate, Pakistan. Samples were taken from three tube wells and reported that cadmium concentration varied from 0.007-0.025 mg/l.

Buragohain *et al.* (2009) studied the seasonal variation of cadmium concentration of groundwater in Dhemaji district, Assam. Samples were collected from twenty different sites in both wet season (May 2008-October 2008) and dry season (NOvember 2008-April 2009). Mean concentration was 0.039 mg/l in dry season and 0.020 mg/l in wet season. They concluded that higher levels of metals in groundwater during dry season might be due to concentration effect.

Siddiqui and Sharma (2009) studied the cadmium concentration of groundwater samples in Okhla industrial area, New Delhi. They analyzed ten water samples and found that the cadmium concentration was in the range of 3.5-15.3 µg/l.

2.3 MICROBIOLOGICAL QUALITY OF WATER

Water intended for human consumption should be free from pathogenic microorganisms and bacteria indicative of pollution with excreta. Drinking water with poor microbial quality can cause intestinal and other infectious diseases in human beings and animals. Infants, young children, debilitated individuals, those who are living under insanitary conditions, sick and elderly are at great risk of waterborne diseases (Park, 2009).

2.3.1 Aerobic Plate Count (APC)

Assessment of Aerobic Plate Count (APC) is the basic test for drinking water quality. The test gives a measurement of total number of viable organisms present in water, but not the type of bacteria. APC should be monitored over a certain period in order to identify significant changes in microbial load.

Oommen (1981) concluded that type construction of well does not have any direct bearing on the bacteriological quality of well water except *Clostridium perfringens.* Cattle keeping have also no significant influence on bacteriological quality of well water in Mannuthy area in Kerala though all wells under study showed evidence of recent or past faecal contamination.

Obi *et al.* (2002) assessed the microbial quality of river water sources in rural Venda communities in South Africa. Water samples were collected from eight rivers over a period of five months (April-October 2001). Heterophilic plate count was in the range of 1.8×10^{2} cfu/ml-1.3×10^{6} cfu/ml.

Ambili *et al.* (2003) assessed the bacterial quality of drinking water retailed in and around Thrissur, Kerala. A total of 50 one-litre bottles consisted of 10 bottles each belonging to five brands viz., A, B, C, D and E were tested. The mean APC of the samples belonging to the five brands was 2.20 ± 0.02, 2.26 ± 0.02, 2.32 ± 0.02, 2.35 ± 0.02 and 2.42 ± 0.02 log_{10} cfu/ml.

Latha *et al.* (2003) investigated bacteriological quality of well water in and around Thrissur, Kerala. Water samples had APC of $2.3x10^2$ to $1.03x10^4$ cfu/ml in pucca wells and $9x10^2$ to $3x10^5$ cfu/ml in kutcha wells.

Ezeronye and Ubalua (2005) studied the effect of abattoir and industrial effluents on heavy metal quality of Aba river, Nigeria. Samples were collected from five sampling points of the river and found that mean APC was in the range of $0.059x10^6$ and $1.01x10^8$.

Prejit *et al.* (2006) analysed microbial quality of dug wells of Thrissur district, Kerala during monsoon season. Water samples from eighty dug wells were analyzed and found that mean APC was 3.38 ± 0.073 log_{10} cfu/ml. They opined that depth of well had a positive correlation with APC.

Adekunle (2009) studied the effect of industrial effluents on quality of groundwater within Asa Dam industrial estate, Ilorin, Nigeria. Three wells were sampled and concluded that the wells were highly contaminated with total bacterial count in the range of 1200-1375 cfu/ml.

2.3.2 Coliform Count

Coliform group of organisms include *Escherichia coli*, Klebsiella, Enterobacter and Citrobacter spp. They are constantly present in great abundance in human intestinal tract. These organisms are foreign to potable waters, and hence their presence in water indicates faecal contamination. They have greater resistance to the forces of natural purification than the water borne pathogen.

Obi *et al.* (2002) assessed the microbial quality of river water sources in rural Venda communities in South Africa. Water samples were collected from eight rivers over a period of five months (April-October 2001). Coliform count was in the range of $6.0x10^2$ cfu/ml-$3.7x10^4$ cfu/ml.

Ambili *et al.* (2003) assessed the bacterial quality of drinking water retailed in and around Thrissur, Kerala. A total of 50 one-litre bottle consisted of 10 bottles each belonging to five brands viz., A, B, C, D and E were tested. None of the samples was positive for coliforms.

Latha *et al.* (2003) investigated bacteriological quality of well water in and around Thrissur, Kerala. Water samples had coliform count of 1-10cfu/ml in pucca wells and 5-120 cfu/ml in kutcha wells.

Prejit *et al.* (2006) analyzed microbial quality of dug wells of Thrissur district in Kerala during monsoon season. Water samples from eighty dug wells were analyzed and found that mean coliform count was 11.57 ± 2.84 cfu/ml. They opined that depth of well has a positive correlation with coliform count.

Rajan *et al.* (2007) assessed the total coliforms of well water in Varkala coast, Kerala. Six wells were sampled and found that MPN index was 19/ml.

Chitanand *et al.* (2008) evaluated the bacterial quality of groundwater in Nanded city of Marathwada region, India. Samples were collected from tube wells and hand pumps of ten different localities during winter, summer and monsoon seasons from October 2003 to September 2004. Concentration of total coliforms/100 ml was in the range of 4-550 during winter, 0-57 during summer and 9-1000 during monsoon. It was concluded that higher densities of indicator organisms during monsoon season could be due to poor filtering action of soil of the region and more percolation as well as seepage of domestic sewage through soil.

Mishra and Bhatt (2008) analyzed the groundwater quality of Anand district, Gujarat. Water samples were taken from four different places named S-1, S-2, S-3, and S-4 during January 2007. Most probable number of coliforms was 280-440 mg/l.

Adekunle (2009) studied the effect of industrial effluents on quality of groundwater within Asa Dam industrial estate, Ilorin, Nigeria. Three wells were sampled and concluded that the wells are highly contaminated with coliform count in the range of1600- >1800 MPN/100 ml.

Singh *et al.* (2009) assessed the bacteriological quality of groundwater in Arkavathi and Vrishabhavathi river basins, Bangalore and found that average count of total coliforms in open wells was 82 cfu/ml, which was above WHO guidelines.

Susiladevi *et al.* (2009) evaluated the microbial status of groundwater in and around Cuddalore town, Tamil Nadu, nearly situated to an industrial area. Coliform count revealed an MPN index of 8-182/100ml. They opined that the increase in microbial load was probably due to addition of untreated sewage, drainage and industrial waste. Highest bacterial contamination was observed during pre monsoon period.

John and Thanga (2010) investigated the seasonal change in potable water quality of coastal wards of Kollam Corporation, Kerala. A total of ten samples were collected from dug wells of five different spots during pre-monsoon (February 2008) and monsoon (June 2008) seasons. Total coliforms were very high in all the wells ranging from 7-1680 MPN during different seasons.

Nair and Mathews (2010) assessed the bacterial quality of well water in and around Thiruvalla, Kerala. Ten samples of well water were collected. All samples gave positive presumptive coliform test.

Kumar *et al.* (2010) studied seasonal change in physic-chemical parameters of Periyar River at Neriamangalam, Kerala. Samples were analyzed from five stations during pre-monsoon, monsoon and post monsoon periods. Evidence of faecal pollution was observed at all the stations with highest value during monsoon period (1100 MPN/100 ml), irrespective of the stations. Stations one and four showed higher levels of coliforms, which might be due to the effluent discharge from the industry working at those stations.

2.3.3 *Escherichia coli* Count

Escherichia coli is a type of faecal coliform bacteria, commonly found in intestinal tract of warm blooded animals. The presence of *Escherichia coli* in water is a strong indication of recent sewage or animal waste contamination. Among the hundreds of strains of *E.coli, E. coli* O157: H7 is an emerging cause of foodborne and waterborne illness. This causes severe diarrhoea and in some cases renal failure and death.

Obi *et al.* (2002) assessed the microbial quality of river water sources in rural Venda communities in South Africa. Water samples were collected from eight rivers over a period of five months (April-October 2001). Faecal coliform count was in the range of $1.5x10^3$ cfu/ml-$6.3x10^4$ cfu/ml.

Ambili *et al.* (2003) assessed the bacterial quality of drinking water retailed in and around Thrissur, Kerala. A total of 50 one-litre bottle consisted of 10 bottles each belonging to five brands viz., A, B, C, D and E were tested. None of the samples was positive for *E. coli.*

Latha *et al.* (2003) investigated bacteriological quality of well water in and around Thrissur, Kerala. Water samples had *E. coli* count of 0-2 cfu/ml in pucca wells and 0-25 cfu/ml in kutcha wells.

Laluraj *et al.* (2005) calculated the MPN index for faecal coliforms of groundwater of shallow aquifers in the coastal zones of Cochin, Kerala. Samples were collected from twenty dug wells during post monsoon (November, 2003) and the study revealed a high incidence of faecal coliform, which ranged 93-460 MPN index /100 ml, indicating poor sanitary condition and improper waste disposal.

Prejit *et al.* (2006) analyzed microbial quality of dug wells of Thrissur district, Kerala during monsoon season. Water samples from eighty dug wells were analyzed and found that mean *E. coli* count was 11.57 ± 2.84 cfu/ml and concluded that presence of human activity near the well was related to *E. coli* count.

Rajan *et al.* (2007) assessed the *E. coli* count of well water in Varkala coast, Kerala. Six wells were sampled and found that MPN index was 2/ml.

Shaiju *et al.* (2007) studied the *E. coli* count of groundwater in Fort Cochin area, Kerala. Ten wells were sampled and found that MPN index was 0-450/100 ml.

Chitanad *et al.* (2008) evaluated the bacterial quality of groundwater in Nanded city of Marathwada region, India. Samples were collected from tube wells and hand pumps of ten different localities during winter, summer and monsoon seasons from October 2003 to September 2004. Concentration of faecal coliforms/100 ml was in the range of 3-126 during winter, 0-22 during summer and 5-200 during monsoon. It was pointed out that depletion in the groundwater level and evaporation of domestic sewage due to intense heat of summer are two main factors contributing to very low number of indicator organisms in summer season.

Adekunle (2009) studied the effect of industrial effluents on quality of groundwater within Asa Dam industrial estate, Ilorin, Nigeria. Three wells were sampled and concluded that the wells are highly contaminated and showed the presence of fecal coliforms.

Susiladevi *et al.* (2009) evaluated the microbial status of groundwater in and around Cuddalore town, Tamil Nadu, nearly situated to an industrial area. Fifteen groundwater samples were collected and *E. coli* was present in 60% of samples.

2.3.4 Enterococcal Count

Enterococci are a secondary indicator of faecal pollution. Because of their existence in faeces, they are considered as indicators of water quality (Jay, 1997). They generally do not multiply in water, especially if the organic matter content is low. Presence of enterococci in water is considered as confirmatory evidence of recent faecal pollution of water (Park, 2009).

Obi *et al.* (2002) assessed the microbial quality of river water sources in rural Venda communities in South Africa. Water samples were collected from eight rivers over a period of five months (April-October 2001). Enterococcal count was in the range of $1.0x10^1$ cfu/ml-$2.5x10^4$ cfu/ml.

Ambili *et al.* (2003) assessed the bacterial quality of drinking water retailed in and around Thrissur, Kerala. A total of 50 one-litre bottle consisted of 10 bottles each belonging to five brands viz., A, B, C, D and E were tested. The mean enterococcal count of the samples belonging to the five brands was 0.43 ± 0.18, 0.43± 0.18, 0.33 ± 0.14, 0.79 ± 0.18 and 0.57± 0.18 log_{10} cfu/ml respectively.

Latha *et al.* (2003) investigated bacteriological quality of well water in and around Thrissur, Kerala. Water samples had enterococcal count of 0-1 cfu/ml in pucca wells and 0-9 cfu/ml in kutcha wells.

Prejit *et al.* (2006) analysed microbial quality of dug wells of Thrissur district, Kerala during monsoon season. Water samples from eighty dug wells were analyzed and found that mean enterococcal count was 14.56 ± 6.07 cfu/ml.

Rajan *et al.* (2007) assessed the enterococcal count of well water in Varkala coast, Kerala. Six wells were sampled and found that MPN index was 5/ml.

Chitanand *et al.* (2008) evaluated the bacterial quality of groundwater in Nanded city of Marathwada region, India. Samples were collected from tube wells and hand pumps of ten different localities during winter, summer and monsoon seasons from October 2003 to September 2004. Enterococcal count/100 ml was in the range of 0-84 during winter, 0-9 during summer and 2-111 during monsoon.

2.4 IMPACT OF WATER QUALITY

2.4.1 Animal health impact

Patra *et al.* (2000) described industrial flourois in cattle and buffalo around Udaipur, India. Signs of dental discolouration, difficulty in mastication, bony lesions, lameness, debility and mortality were observed in domesticated animals reared around superphosphate fertilizer plant in Udayapur, Rajasthan, India. It was concluded that fodder and water contaminated by the fumes and dusts emitting from the plant resulted in the development of chronic flourotic lesions.

Kumar *et al.* (2001) investigated the effect of fluoride toxicity on cattle in Eloor industrial area, Kerala. They observed dental lesions, lameness, palpable bony lesions and debility in affected animals. Mean fluoride concentration in plasma, milk and bone samples were 1.25±0.13 ppm, 0.50±0.40 ppm, 35.48±5.35 ppm, 3523.05±591.88 ppm at Alupuram, 1.02±0.05 ppm, 0.43±0.03 ppm, 28.20±3.31 ppm, 0.00 ppm at Eloor centre and 0.91±0.05 ppm, 0.41±0.05 ppm, 26.53±1.40 ppm, 0.00 ppm at Eloor north against 0.11±0.12 ppm, 0.08±0.01 ppm, 5.03±0.58 ppm and 420.39±62.23 ppm at control area Mannuthy, Kerala.

Thirunavukkarasu *et al.* (2001) assessed the mercury toxicity in cattle of Eloor industrial area, Kerala. Mean mercury concentration in blood, dung, milk and urine was higher than that of control area. The haematological parameters, serum protein, creatinine, blood urea nitrogen and serum and urine enzyme level showed no significant difference.

Lemos *et al.* (2002) described lead poisoning in a herd of 120 Nelore cows of which 35 were affected and died after a clinical course of 2 to 7 days with clinical signs related to cortical neurological disturbances. The source of lead was fumes from a car battery recycling plant which had a failure in its filtering system.

Liu (2003) diagnosed lead poisoning combined with cadmium in sheep and horses in the vicinity of non ferrous metal smelters in China. The concentration of lead and cadmium in blood, hair and tissues of the affected sheep and horses were significantly higher than reference values and control animals.

Nisha *et al.* (2009) assessed the cadmium concentration and relation with serum biochemical parameters in cattle of Eloor industrial area. Serum cadmium concentrations were significantly higher in test than control group. Blood urea nitrogen and creatinine levels were also found to be higher in test area.

2.4.2 Human health impact

International NGO Greenpeace conducted study on "Status of Human Health at Eloor Industrial Estate, Kerala" and indicated an alarming incidence of diseases like cancer, bronchitis, congenital malformations, asthma, allergic dermatitis and stomach ulcers amongst the residents. A first level report of the study revealed that the chances of being affected by cancer in Eloor were 2.85 times higher than in any other place. Children were 2.63 times more at risk of being born with congenital abnormalities. Chances that children may die due to birth defects had increased 3.8 times. Death due to bronchitis in Eloor was up by 3.4 times. Death due to Asthma was up by 2.2 times (Anonymous, n.d.).

Lee *et al.* (1983) reported industrial lead poisoning in a thirty four year old man who had been working in a plastic manufacturing factory for ten years and had contact with lead based stabilizer. Abdominal colic and anaemia was observed and blood lead level was 100 μg /100 ml.

A study was conducted to examine the children of lead exposed construction workers who were at high risk for paediatric lead poisoning. Blood samples were analysed and compared with controls, who were children of neighbours employed in non lead industries. It was observed that children of lead exposed construction workers were six times more likely to had a blood lead level of 10 μg/dl or greater than control (Whelan *et al.*, 1997).

Raviraja *et al.* (2008) reported lead toxicity in a family, manufacturing lead acid batteries for 14 years. Symptoms such as abdominal pain, joint pain, generalized weakness and head ache was observed and blood lead level was 3.92 ± 0.94 μmol /l.

Health survey conducted at Eloor, Kerala revealed that Eloor residents were at higher risk of respiratory problems, musculo-skeletal problems, allergy, cardiac and neurological disorders, heart diseases, reproductive disorders, renal problems and cancer than residents of Pindimana, a non-industrial area in Kerala. (Health Survey of Nine Wards of Eloor Gramapanchayath, 2008).

Raju *et al.* (2009) evaluated the fluoride contamination of groundwaters of Sonbhadra district, Uttar Pradesh, India. It was found that people in the worst fluoride affected villages suffered from dental and skeletal flourosis such as mottling of teeth, deformation of ligaments, bending of spinal column and ageing problem.

2.4.3 Environmental impact

Kumar *et al.* (2001) analysed fluoride content of forage and sludge samples in Eloor industrial area, Kerala. It was observed that mean fluoride concentration in forage and sludge samples were 302.51 ± 38.99 ppm, 212.75 ± 4.18 ppm at Alupuram, 251.70 ± 23.11 ppm, 101.74 ± 9.72 ppm at Eloor centre and 228.25 ± 29.02 ppm, 65.52 ± 15.28 ppm at Eloor north respectively. Corresponding concentrations at control area, Mannuthy in Kerala was 3.83±0.16 ppm and 2.58±0.05 ppm.

Thirunavukkarasu *et al.* (2001) assessed the mercury level in sludge and fodder samples from Eloor industrial area, Kerala and found that mercury levels were higher than that of control samples, but not to an extent of producing typical symptoms of poisoning.

Analysis of soil samples and paddy from Chakkarachal paddy field-Edayar, Kerala pointed out that concentration of zinc and cadmium was above the limits set by United States Public Health Standards. Lead concentration exceeded the Canadian Sediment Quality Guidelines. Iron concentration was 139640 mg/Kg and 16160 mg/ Kg in soil and paddy, respectively (Local Area Environment Committee, 2006).

Local Area Environment Committee (2006) analysed the soil and sediment samples from Eloor, Kerala. Zinc, iron, lead and cadmium concentrations were in the range of 42.0-3271.0 mg/Kg, 6385.0-80075.0 mg/Kg and 48.0-578.0 mg/Kg, 3-21 mg/Kg in soil and 116.0-1449.0 mg/Kg, 18900.0-50260.0 mg/Kg, 180.0-598.0 mg/Kg and 6.0-19.0 mg/Kg in sediments, respectively.

Pruvot *et al.* (2006) evaluated the cadmium and lead contamination in soil, crop contents, vegetables and lawn grasses around a lead smelter in the North of France and compared with reference area unaffected by smelter emission. It was found that concentration of metals in soil, crops, vegetables and grasses were higher in areas around lead smelter than that of reference area.

Akinola *et al.* (2008) assessed the lead and cadmium in soil and tissues of plants grown around textile industry at Ibeshe, Nigeria, and results were compared with non industrial area. It was concluded that concentration of lead and cadmium in soil and plant tissues were higher in industrial area than in non industrial area.

Materials and Methods

3. MATERIALS AND METHODS

In the present study, a total of 200 well water samples consisting of 100 each from Eloor industrial area in Ernakulam district of Kerala state and Ollukara, a non - industrial area in Thrissur district of Kerala state was collected and analyzed for comparative evaluation of physical, chemical and microbiological qualities (Plate 1). Of the 100 samples, 25 samples each were collected during four different seasons of the year viz. summer (February), pre-monsoon (March-May), monsoon (June-September) and post monsoon (October-November). The samples were analyzed for physical parameters like temperature and pH, chemical parameters like total hardness, Chemical Oxygen Demand (COD), nitrate, fluoride, iron and heavy metals like lead, mercury, zinc and cadmium and microbiological parameters like Aerobic Plate Count, Coliform, *Escherichia coli* and Enterococcal counts. Samples were also collected from Kuzhikandam creek of Eloor, into which industries discharge their effluents for analysis (Plates 2, 3, 4 and 5).

3.1 STUDY AREA

Eloor, the study area, about 20 km away from the queen of Arabian Sea, is the industrial hub of Kerala. It is an island spread over an area of 14.21 km^2, located between north latitudes $9^{\circ}\ 3'$ and $10^{\circ}\ 6'$ and east longitudes $76^{\circ}\ 20'$ and $76^{\circ}\ 28'$. Soil of this area is sandy loam type. The study was carried out in three wards of Eloor Grama panchayath, viz. ward 3 (Methanam East), ward 4 (Panchayath Head Quarters) and ward 20 (Depot) (Plate 6). The study area is well known for large and small-scale industries. These industries account for 25% of the industries of the state. The major industrial units in the area include Fertilizers and Chemicals Travancore Limited (FACT), Hindustan Insecticides Limited (HIL), Indian Rare Earths Limited (IRE), Travancore Cochin Chemicals Limited (TCC), Merchem Limited etc.

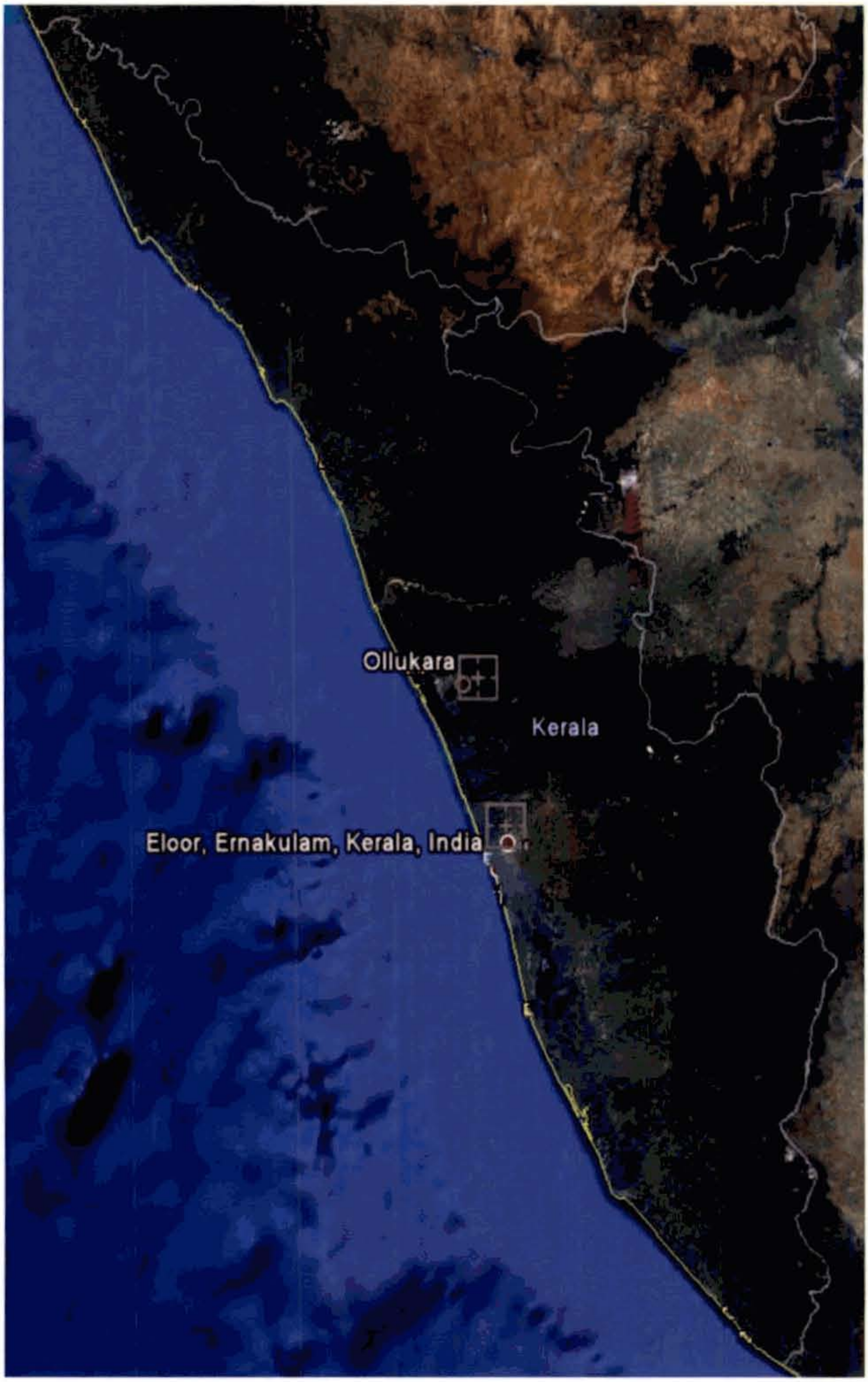

Plate 1. Study areas

Plate 4 Habitation close to Kuzhikandam creek, Eloor

Plate 5 Sampling from Kuzhikandam creek, Eloor

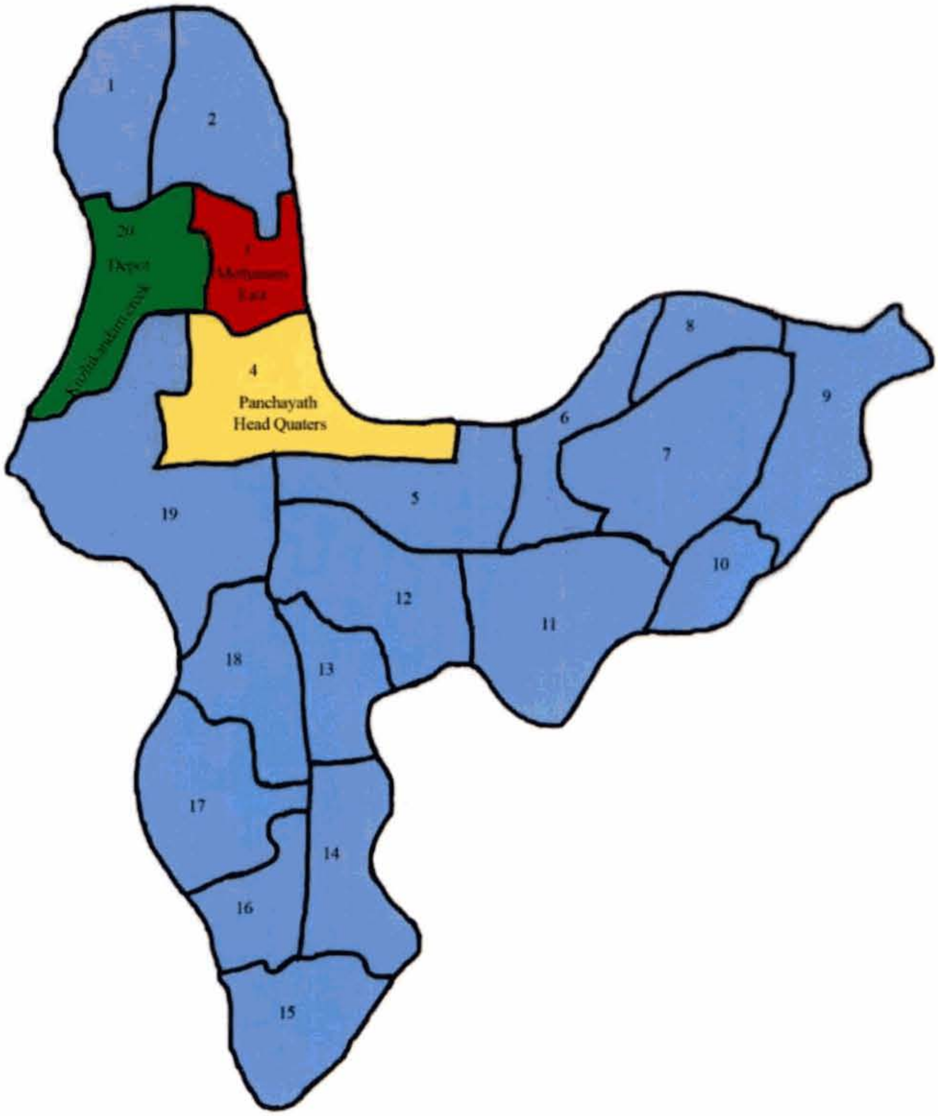

Plate 6. Map of Eloor Gramapanchayath showing study areas

Plate 2. Discharge of effluents into Kuzhikandam creek, Eloor

Plate 3 Polluted Kuzhikandam creek, Eloor

For comparative evaluation, three divisions, 11 (Nettiserry), 14 (Krishnapuram) and 13 (Mannuthy) of Thrissur corporation spreading over an area of 2408 km^2 were selected. Thrissur district lies between North latitudes 10° 10′ and 10° 46′ and east longitudes 75° 57′ and 76° 54′. This area is about 80 km away from the earlier one and free of any polluting industries. Generally the soil is laterite. Before collection of water samples for analysis, a survey was conducted using a well designed questionnaire (Appendix I) in selected households of Eloor and Ollukara about characteristics of well and practices among the people, their health problems and animal health problems. The wells were also classified into pucca and kutcha wells, prior to sampling.

3.2 COLLECTION OF SAMPLES

Wells were randomly selected for the study from the area which is falling within 1.5 km radius of industrial units. Samples for analysis were taken directly from wells in sterile glass bottles of 250 millilitre capacity, after rinsing the bottles three times with water. In order to collect the samples directly from well, bottle with a string attached to neck was used. Another long clean string was tied to the end of sterile string and the bottle was lowered into the water and allowed to fill up. Then the bottle was raised and stoppered. The collected samples were transported to laboratory in ice within an insulated container and analyzed within 24 hours of collection.

3.3 PHYSICAL QUALITY OF WATER

3.3.1 Temperature

Temperature of each sample was taken in situ as described by Chapman and Kimstach (1996), using mercury filled glass thermometer having 0.1° C graduations. Temperature was recorded in ° C.

3.3.2. pH

To measure the pH of water the method described by Chapman and Kimstach (1996) was adopted. The pH was recorded using a digital pH meter (Cyberxan), after calibration with standard buffer solutions having pH four and seven. Before measuring the pH, temperature of the sample was brought to room temperature. The electrode was rinsed with distilled water and immersed into the sample and the pH was read after allowing a period of one minute for the meter to stabilize. The electrodes were rinsed and repeated on a fresh sample. The readings were taken and values noted to two decimal places.

3.4 CHEMICAL QUALITY OF WATER

3.4.1 Total Hardness

Total hardness of the samples was estimated using Total hardness test kit (Hi-media). To 25 millilitre sample taken in a test tube, one spoonful of reagent 1 was added and mixed well followed by 20 drops of reagent 2. The test tube was mixed well and observed for the appearance of pink colour. Reagent 3 or 4 was then added drop by drop, as per the manufacturer's protocol counting the number of drops till pink colour changed to blue. Total hardness was calculated using the formula 5 x number of drops of reagent 3 or 25 x number of drops of reagent 4 and expressed in mg/l of calcium carbonate.

3.4.2 Chemical Oxygen Demand (COD)

COD of the samples was measured using test kit (Merck). COD solution A (0.30 millilitre) and COD solution B (2.30 millilitre) were mixed in the given reaction cells. Water sample (3.00 millilitre) was then added and mixed vigorously after closing the cells. The cells were heated for 120 minutes at 148 °C in the preheated

Thermoreactor TR 320 (Merck). The hot reaction cells were removed from Thermoreactor and allowed to cool in the cell rack. COD was measured photometrically in Spectroquant NOVA 60 (Merck) after cooling of the cells. Results were recorded as mg/l COD.

3.4.3 Nitrate

Nitrate concentration of the samples was measured using Nitrate test kit (Merck). Reagent NO_3-1 (4.00 millilitre) and 0.50 millilitre sample was mixed in clean dried test tube. Reagent NO_3 -2 (0.50 millilitre) was added to that and mixed thoroughly. The hot reaction tubes were allowed to stand for 10 minutes. The samples were filled into the cell and measured photometrically in Spectroquant NOVA 60 (Merck). Results were recorded as mg/l NO_3.

3.4.4 Fluoride

Fluoride concentration of the samples was estimated using Fluoride test kit (Merck). To 2 millilitre Reagent F-1 in a test tube, 5 millilitre sample was added and mixed. One spoonful of Reagent F-2 was added and shaken vigorously until the reagent was completely dissolved. The tubes were left at room temperature for 5 minutes and filled into cell and measured in Spectroquant NOVA 60 (Merck). The results were expressed as mg/l F.

3.4.5 Iron

Concentration of iron in the samples was estimated using Iron test kit (Merck). To eight millilitre of sample in the test tube, added one drop Reagent Fe - 1and mixed well. Further 0.50 millilitre Reagent Fe - 2 was added to that and mixed again. Then Reagent Fe-3 was added as per the manufacturer's protocol and shaken vigorously until the reagent was completely dissolved. The tubes were left to stand for 10 minutes and then the sample was filled into cell and measured photometrically in Spectroquant NOVA 60 (Merck). Results were expressed as mg/l Fe.

3.4.6 Lead

Lead concentration of the samples was estimated using Lead test kit (Merck). Reagent Pb-1 and Pb-2 (0.50 millilitre each) was mixed in a clean dried test tube and to that eight millilitre sample was added and mixed thoroughly. The sample was filled in the cell and measured in photometer Spectroquant NOVA 60 (Merck). The concentration was recorded as mg/l Pb.

3.4.7 Mercury

Concentration of mercury in water was estimated in Spectroquant NOVA 60 (Merck) by extraction photometric determination with Michler's thioketone. To five millilitre sample, one millilitre reagent 1 and 1.5 millilitre reagent 2 was added and mixed well. The samples were filled into 50 mm cells after five minutes reaction time. The measurement was done in Spectroquant NOVA 60 after selecting the corresponding method. The concentration was recorded as mg/l Hg.

3.4.8 Zinc

The procedure described by Lokeshwari and Chandrappa (2006) was modified and adopted for the estimation of zinc. The samples were analyzed on an Atomic Absorption Spectrophotometer (Perkin Elmer) using acetylene gas as fuel (at 80 psi) and air as an oxidizer. Operational conditions were adjusted to yield optimal determination (Wave length of 213.9 nm). The calibration curve was prepared by running suitable concentrations of the standard solutions (1 mg/l). Samples were aspirated into the fuel rich air-acetylene flame and the concentrations of the metals were determined from the calibration curves. Average values of three replicates were taken for each determination. The concentration was recorded as mg/l Zn.

3.4.9 Cadmium

In order to measure the concentration of cadmium, the procedure described by Lokeshwari and Chandrappa (2006) was modified and adopted. The samples were analyzed on an Atomic Absorption Spectrophotometer (Perkin Elmer) using acetylene gas as fuel (at 80 psi) and air as an oxidizer. Operational conditions were adjusted to yield optimal determination (Wave length of 228.8 nm). The calibration curve was prepared by running suitable concentrations of the standard solutions (1 mg/l). Samples were aspirated into the fuel rich air-acetylene flame and the concentrations of the metals were determined from the calibration curves. Average values of three replicates were taken for each determination. The concentration was recorded as mg/l Cd.

3.5 MICROBIOLOGICAL QUALITY OF WATER

3.5.1 Processing of samples

In order to estimate the microbial load per millilitre of water, each sample was agitated thoroughly and 10 millilitre was transferred to 90 millilitre sterile normal saline (diluent) so as to form one in ten dilution of the sample. Further 10 fold serial dilutions were prepared by transferring one milliliter of inoculum to nine milliliter of the diluent. Dilutions were made upto 10^{-3} and selected dilutions of each sample were used for estimation of various microbial loads per millilitre of sample. All aseptic precautions were taken during collection and processing of water samples.

3.5.2 Microbial Counts

3.5.2.1 Aerobic Plate Count

Aerobic Plate Count (APC) of each sample was estimated by pour plate technique, as described by Morton (2001). From the selected ten fold dilution of each sample, one millilitre of the inoculum was transferred on to duplicate petridishes of uniform size. To each of the inoculated plates about 10-15 millilitre sterile molten standard plate count agar (Merck) (Appendix II) maintained at 45°C was poured and mixed with the inoculum by gentle rotary movement i.e., clock wise, anticlock wise, forward and backward. The inoculated plates were left at room temperature and allowed to solidify, and were incubated at 37°C for 24 h. At the end of incubation, plates showing between 30 and 300 colonies were selected and counts were taken with the help of a colony counter. The number of colony forming units (cfu) per millilitre of sample was calculated by multiplying the mean colony count in duplicate plates with the dilution factor and expressed as $\log_{10}$ cfu/millilitre.

3.5.2.2 Coliform Count

Coliform Count (CC) per millilitre of sample was estimated according to the procedure described by Kornacki and Johnson (2001). From the selected ten fold dilution 0.1 millilitre of inoculum was inoculated onto duplicate plates of Violet Red Bile Agar (VRBA) (Hi-media) (Appendix II) and was uniformly distributed with a sterile 'L' shaped glass rod. The inoculated plates were incubated at 37°C for 24 h. At the end of incubation purplish red colonies with a diameter of at least 0.5 mm, surrounded by a reddish precipitation zone were counted as coliforms. The number of organisms per millilitre of sample was estimated by multiplying the mean count in duplicate plates with the dilution factor and expressed as $\log_{10}$ cfu/millilitre.

3.5.2.3 Escherichia coli Count

Escherichia coli Count (ECC) per millilitre of sample was estimated as prescribed by Kornacki and Johnson (2001). To estimate the organisms, 0.1 millilitre of inoculum from the selected dilution was transferred onto duplicate plates of Eosin Methylene Blue (EMB) agar (Merck) (Appendix II)and was evenly distributed over the medium with a sterile 'L' shaped glass rod. The inoculated plates were incubated at 37°C for 24 h. At the end of incubation, colonies with a greenish black metallic sheen on deflected light were counted as *Escherichia coli.* The number of organisms per millilitre of sample was estimated by multiplying the mean count in duplicate plates with the dilution factor and expressed as $\log_{10}$ cfu/millilitre.

3.5.2.4 Enterococcal Count

Enterococcal Count (EC) per millilitre of sample was estimated as per the procedure described by Hartman *et al.* (2001). From the selected dilution 0.1 millilitre of the inoculum was transferred onto duplicate plates of Karl Friedrich (KF) streptococcal agar (Hi-media) (Appendix II) and was uniformly distributed over the medium with a sterile 'L' shaped glass rod. The inoculated plates were incubated at 37°C for 24 h. At the end of incubation, pink to dark red colonies with a diameter between 0.5 and three millimeter and surrounded with a narrow whitish zone were counted as enterococci. The number of organisms per millilitre of sample was estimated by multiplying the mean count in duplicate plates with the dilution factor and expressed as $\log_{10}$ cfu/millihlitre.

3.6 STATISTICAL ANALYSIS

Analysis of variance (ANOVA) was done for comparing the data (Snedecor and Cochran, 1994) using SPSS package (version 10).

Results

4. RESULTS

In the present investigation physical, chemical and microbiological qualities of well water from Eloor and Ollukara were assessed to correlate the impact of industrialization on quality of well water.

4.1 SURVEY RESULTS

The results of the survey conducted to assess characteristics of well and practices among the people, their health problems and animal health problems in Eloor and Ollukara are given in table 1, 2 and 3.

Table 1. Characteristics of well and practices among the people in Eloor and Ollukara

Criteria	Eloor	Ollukara
Source of drinking water (%)		
well	20	100
house connection	80	0
Practice of drinking boiled water (%)	92	80
Source of water for other purposes (%)		
well	48	100
house connection	52	0
People not using well (%)	20	0
Pucca wells (%)	80	60
Average depth of wells in meters	6.5	8.5
Wells having distance >15 m from polluting source (%)	32	36
Practice of disinfection of well (%)	48	52
Frequency of disinfection (%)		
once in a year	24	12
twice in a year	52	52
thrice in a year	24	0
six times a year	0	36

N=25

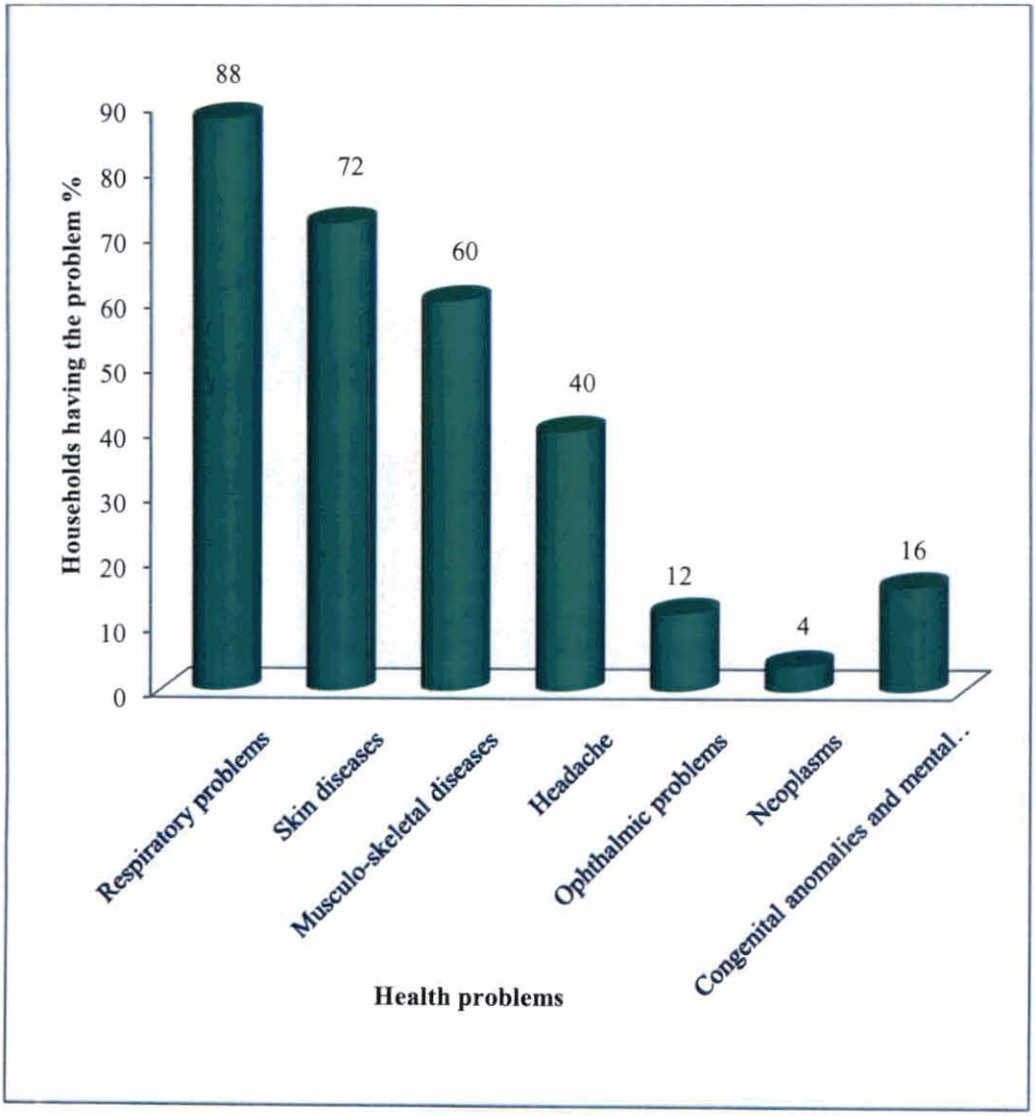

Fig. 1 Major human health problems in Eloor and Ollukara

From the survey conducted among 25 households in Eloor it was understood that 20 per cent of people did not use their wells for any purpose. Disinfection was practiced by 48 per cent and 52 per cent households in Eloor and Ollukara, respectively.

Major human health problems in Eloor and Ollukara are given table 2. Respiratory problems and skin diseases were the major health problems in Eloor. Musculo-skeletal diseases were also a problem in 60 per cent of households. Neoplasms, congenital anomalies and mental retardation were also reported in some of the households in Eloor (Figure 1). In Ollukara, health problems were comparatively very less.

Table 2. Major human health problems in Eloor and Ollukara

Major health problems	Household having the problem (%)	
	Eloor	Ollukara
Respiratory problems	88	12
Skin diseases	72	0
Musculo-skeletal diseases	60	0
Head ache	40	0
Ophthalmic problems	12	0
Neoplasms	4	0
Congenital anomalies and mental retardation	16	0

N=25

Health problems among animals in Eloor are shown in table 3. Digestive disorders were reported in 55.56 per cent animals. Whereas, reproductive problems were reported in 27.59 per cent (Figure 2).

Table 3. Health problems among large and small animals in Eloor

Health problems	Animals having the problem (%)
Digestive disorders	55.56
Reproductive disorders	27.59
Skin diseases	24.14
Lameness	6.9

N=29

4.2 CASES RECORDED IN ELOOR VETERINARY HOSPITAL

Retrospective analysis of cases recorded in Eloor Veterinary Hospital from January 2005 to December 2009 was carried out. The results are given in table 4. It was found that 26.28 percent of total cases recorded were digestive disorders. Respiratory diseases and reproductive disorders accounted for 4.49 and 4.96 per cent respectively (Figure 3).

Table 4. Cases recorded in Eloor Veterinary Hospital

Disorders	Cases recorded (%)
Digestive disorders	26.28
Respiratory diseases	4.49
Metabolic Diseases	0.58
Deficiency diseases	3.45
Skin diseases	2.85
Parasitic Conditions	41.48
Reproductive disorders	4.96
Miscellaneous	15.91

N=22085

172993

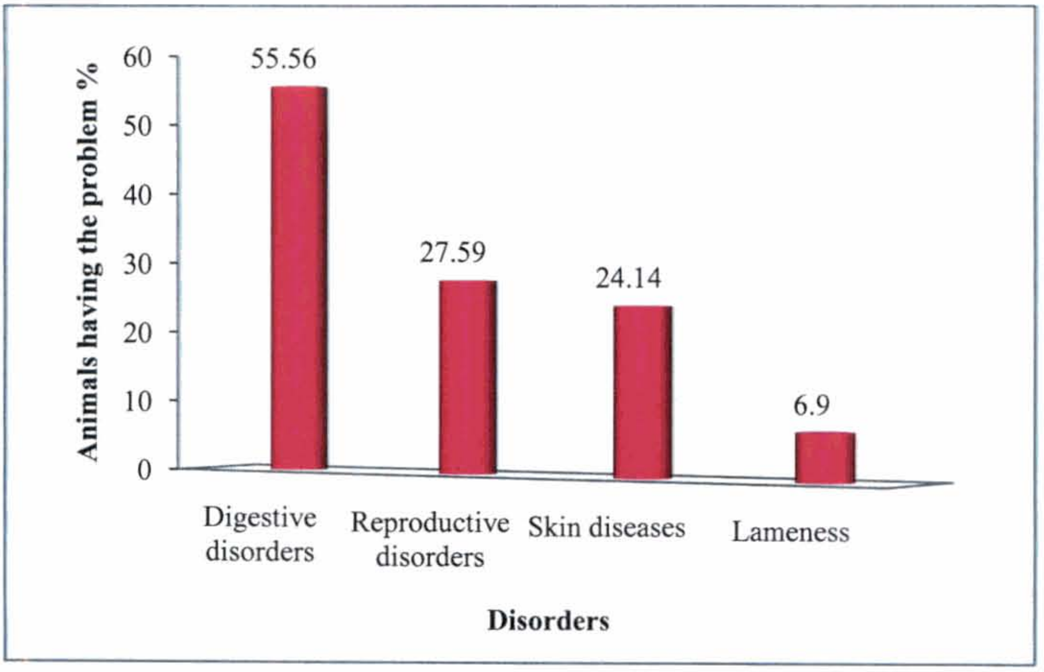

Fig. 2 Health problems among small and large animals in Eloor

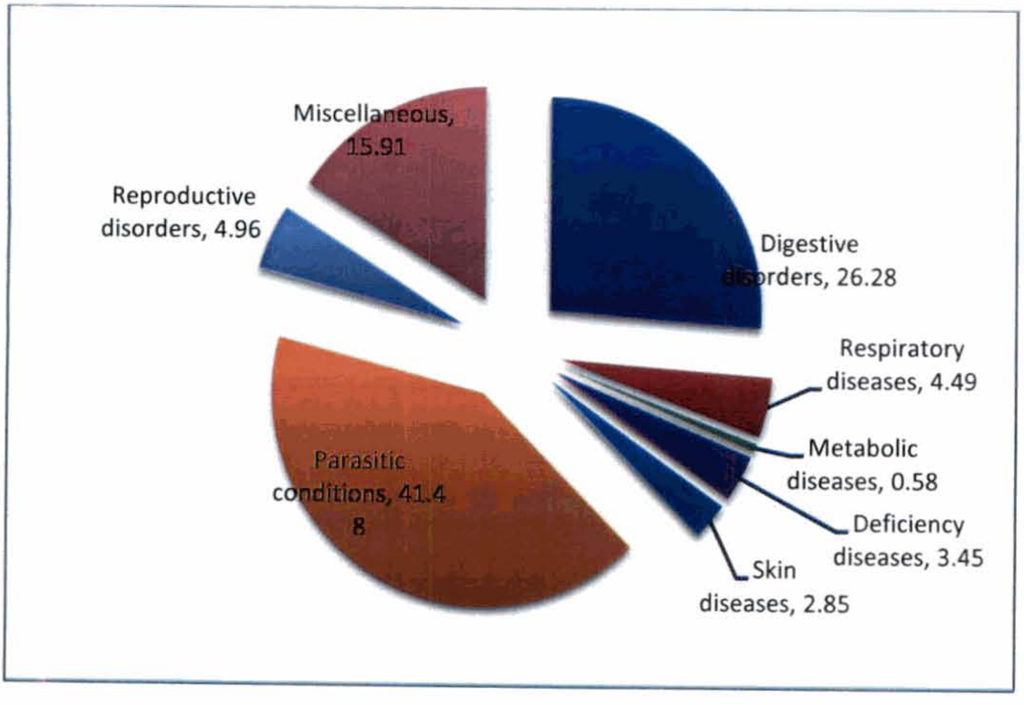

Fig. 3 Cases recorded in Eloor Veterinary Hospital for past five years

4.3 PHYSICAL QUALITY OF WATER

All water samples collected from Eloor and Ollukara were analyzed for temperature and pH.

4.3.1 Temperature

The mean temperatures of water from Eloor and Ollukara are given in table 5 and figure 4. Analysis of data by Analysis of Variance (ANOVA) revealed significant ($p<0.05$) difference between mean temperatures of samples from two areas with higher value at Eloor (28.18±0.11 °C) than Ollukara.

Table 5. Mean temperature of water from Eloor and Ollukara

Area	Mean ± SE (°C)
Eloor	28.18 ± 0.11^{a}
Ollukara	27.76 ± 0.13^{b}

Figures bearing different superscript differ significantly; N=100 in each group

The mean temperatures of water from Eloor and Ollukara during four seasons are given in table 6 and figure 5. Highest temperature was recorded during pre-monsoon in Eloor and summer in Ollukara.

Table 6. Mean temperature of water from Eloor and Ollukara during four seasons

Season	Mean ± SE (°C)	
	Eloor	Ollukara
Summer	28.56 ± 0.20^{bc}	28.68 ± 0.26^{c}
Pre-monsoon	28.96 ± 0.16^{c}	27.50 ± 0.13^{b}
Monsoon	27.00 ± 0.12^{a}	26.32 ± 0.01^{a}
Post monsoon	28.20 ± 0.15^{b}	28.52 ± 0.13^{c}

Figures in a column bearing different superscript differ significantly; N=25 in each group

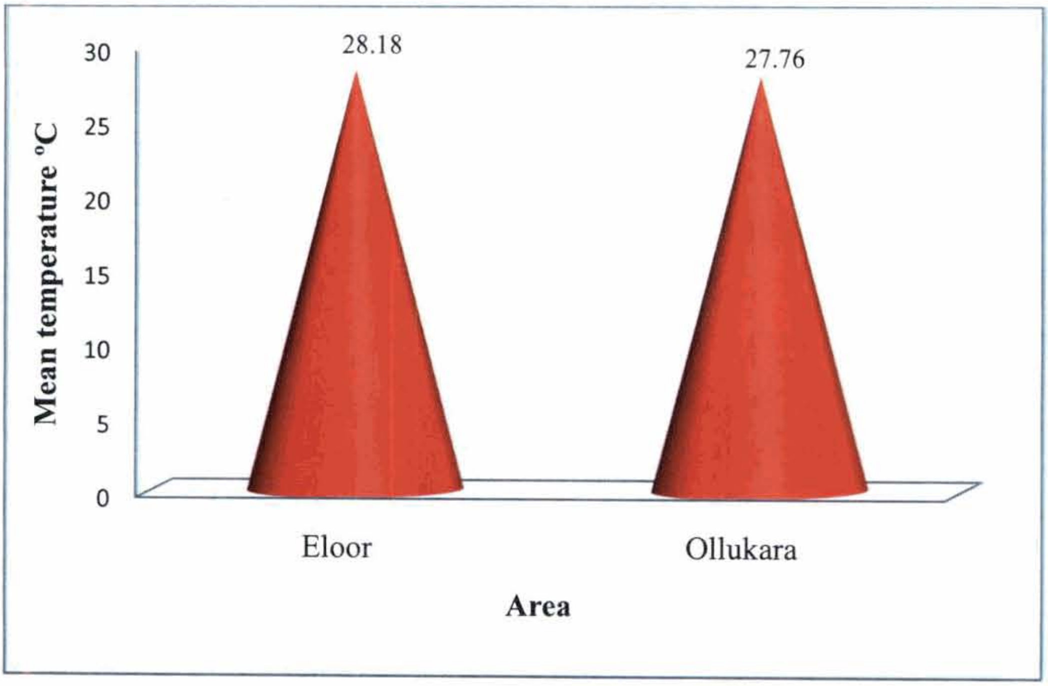

Fig. 4 Mean temperature of water from Eloor and Ollukara

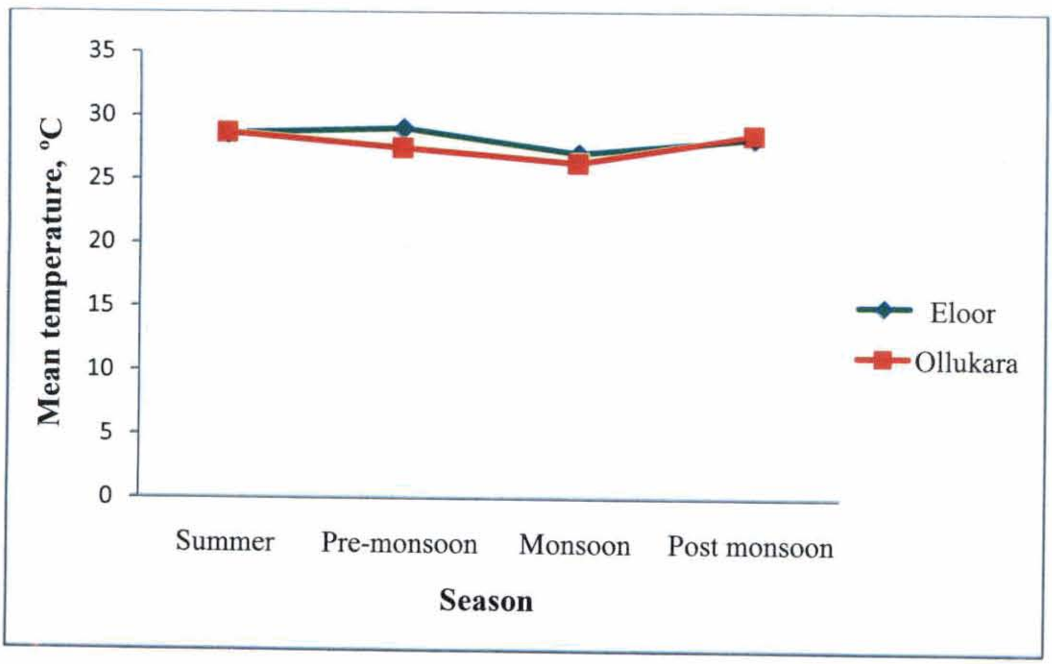

Fig. 5 Mean temperature of water from Eloor and Ollukara during four seasons

4.3.2 pH

The mean pH of water from Eloor and Ollukara are given in table 7 and figure 6. Analysis of data by ANOVA revealed highly significant ($p<0.01$) difference in mean pH of water samples from two areas. Lower pH was recorded in samples collected from Ollukara (5.18±0.06).

Table 7. Mean pH of water from Eloor and Ollukara

Area	Mean ± SE	BIS (IS: 10500, 1991) Desirable Limit
Eloor	5.99±0.08^{a}	6.5-8.5
Ollukara	5.18±0.06^{b}	

Figures bearing different superscript differ significantly; N=100 in each group

Table 8. Mean pH of water from Eloor and Ollukara during four seasons

Season	Mean ± SE	
	Eloor	Ollukara
Summer	5.75±0.19	4.98±0.07^{b}
Pre-monsoon	5.88±0.19	4.58±0.04^{a}
Monsoon	6.03±0.12	5.19±0.06^{c}
Post monsoon	6.30±0.09	5.95±0.08^{d}

Figures bearing different superscript differ significantly; N=25 in each group

The mean pH of water from Eloor and Ollukara during four seasons is given in table 8 and figure 7. Analysis of data revealed no significant difference in pH between four seasons in Eloor, where as significant difference ($p<0.05$) in pH between four seasons was observed in Ollukara with lowest pH during pre-monsoon.

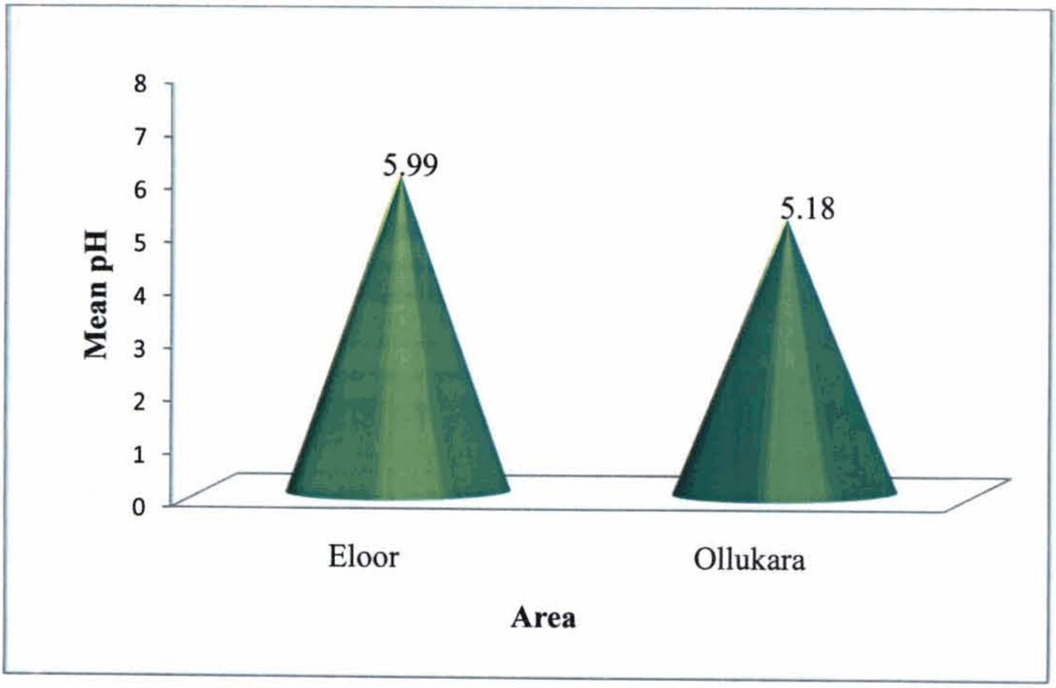

Fig. 6 Mean pH of water from Eloor and Ollukara

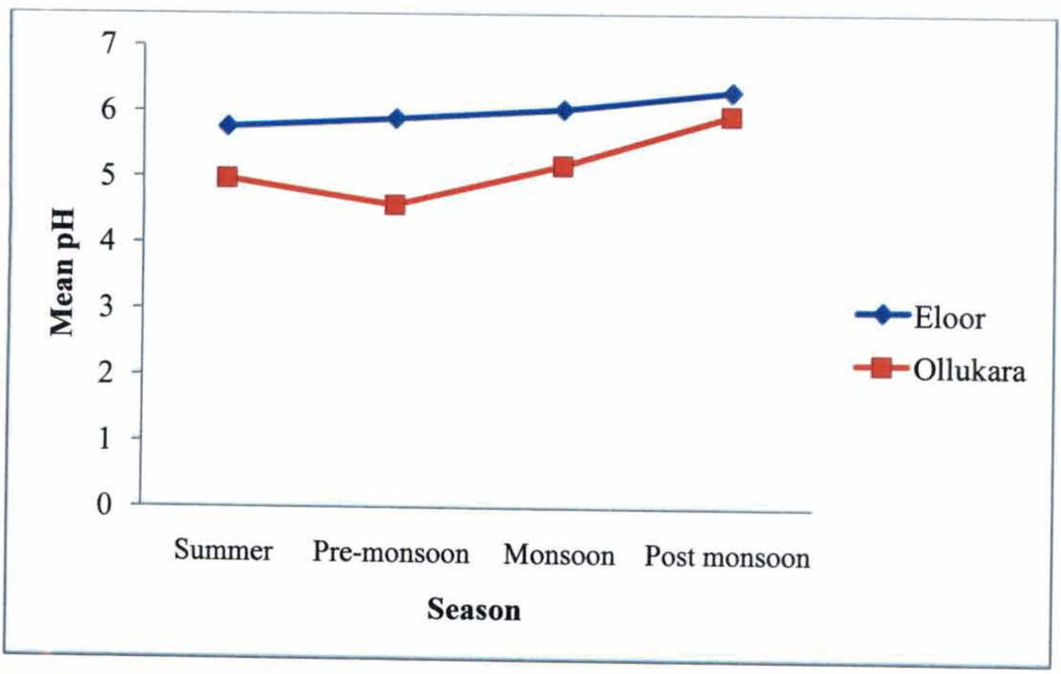

Fig. 7 Mean pH of water from Eloor and Ollukara during four seasons

4.4 CHEMICAL QUALITY OF WATER

All water samples collected from Eloor and Ollukara were subjected to analysis for total hardness, Chemical Oxygen Demand (COD), nitrate, fluoride, iron, lead, mercury, zinc and cadmium. Major chemical contaminants in well water from Eloor are given in plate 7.

4.4.1 Total hardness

The mean total hardness of water from Eloor and Ollukara is given in table 9 and figure 8. Analysis of data by ANOVA revealed highly significant ($p<0.01$) difference between mean total hardness of water samples from two areas.

Table 9. Mean total hardness of water from Eloor and Ollukara

Area	Mean ± SE (mg/l)	BIS (IS: 10500, 1991) Desirable Limit
Eloor	337.50 ± 38.92^{a}	300 mg/l
Ollukara	13.33 ± 0.34^{b}	

Figures bearing different superscript differ significantly; N=100 in each group

The mean total hardness of water from Eloor and Ollukara during four seasons are given in table 10 and figure 9. Analysis of data revealed no significant difference in total hardness between four seasons in Eloor, where as significant difference ($p<0.05$) in total hardness between seasons was observed in Ollukara with lowest total hardness during summer (11.00±0.50 mg/l) and highest during monsoon (15.60±0.78 mg/l).

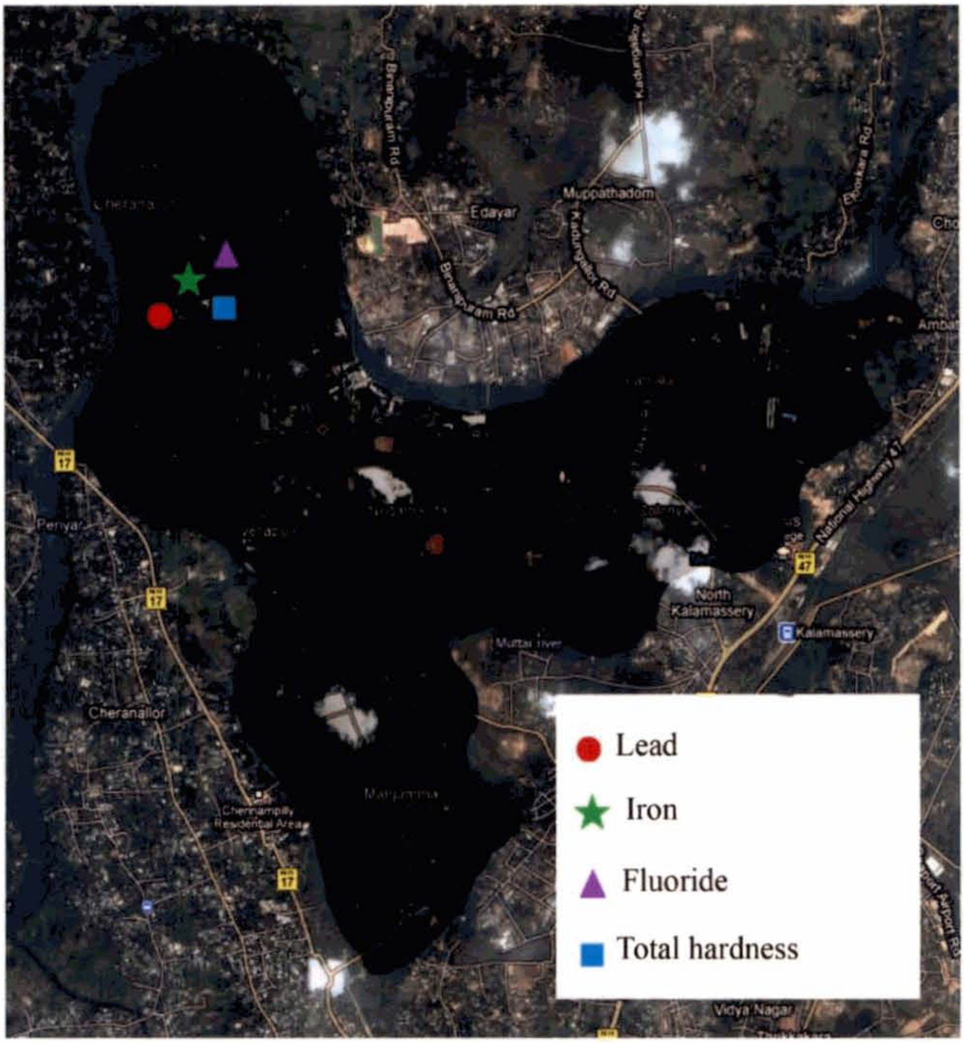

Plate 7. Major chemical contaminants in study area in Eloor

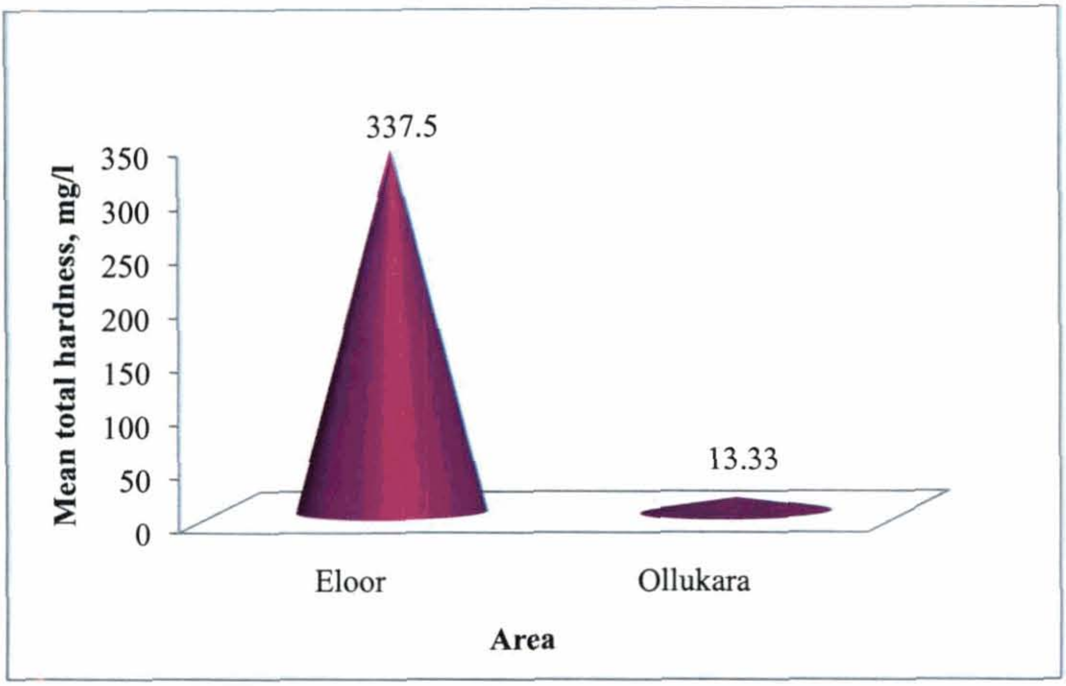

Fig. 8 Mean total hardness of water from Eloor and Ollukara

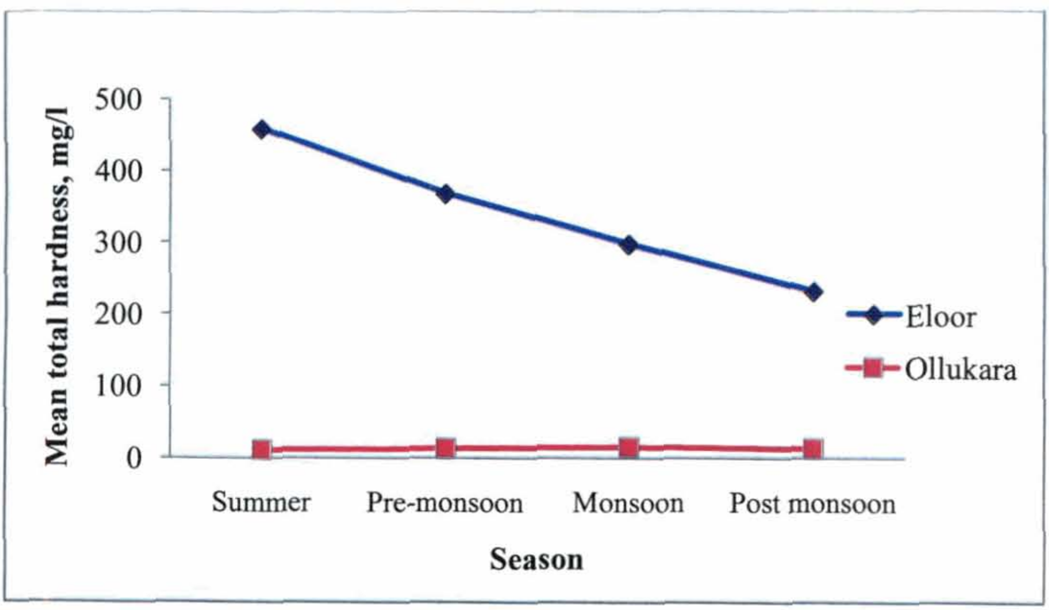

Fig. 9 Mean total hardness of water from Eloor and Ollukara during four seasons

Table 10. Mean total hardness of water from Eloor and Ollukara during four seasons

Season	Mean ± SE (mg/l)	
	Eloor	Ollukara
Summer	457.20±105.42	11.00±0.50^{a}
Pre-monsoon	366.80±106.80	13.33±0.49^{b}
Monsoon	296.00±33.53	15.60±0.78^{c}
Post monsoon	230.00±13.15	13.40±0.63^{b}

Figures bearing different superscript differ significantly; N=25 in each group

4.4.2 Chemical Oxygen Demand (COD)

The mean COD of water samples from Eloor and Ollukara are given in table 11. Analysis of data by ANOVA revealed no significant difference between mean COD of water samples from two areas.

Table 11. Mean chemical oxygen demand of water from Eloor and Ollukara

Area	Mean ± SE (mg/l)
Eloor	105.19±5.00
Ollukara	93.10±2.83

N=100 in each group

Table 12. Mean chemical oxygen demand of water from Eloor and Ollukara during four seasons

Season	Mean ± SE (mg/l)	
	Eloor	Ollukara
Summer	150.56±14.07^{c}	95±7.30
Pre-monsoon	93.04±7.46^{ab}	79.67±2.71
Monsoon	81.68±5.75^{a}	90.60±6.29
Post monsoon	95.48±3.04^{b}	106.48±3.80

Figures bearing different superscript differ significantly; N=25 in each group

The mean COD values of water from Eloor and Ollukara during four seasons are given in table 12 and figure 10. Analysis of data revealed no significant difference in COD between four seasons in Ollukara, whereas significant difference in COD between seasons ($p<0.05$) was observed in Eloor with lowest COD during monsoon (81.68±5.75) and highest during summer (150.56±14.07).

4.4.3 Nitrate

The mean nitrate concentrations of water from Eloor and Ollukara are given in table 13. Analysis of data revealed no significant difference between mean nitrate concentrations of samples from two areas.

Table 13. Mean nitrate concentration of water from Eloor and Ollukara

Area	Mean ± SE (mg/l)	BIS (IS: 10500, 1991) Desirable Limit	WHO guideline, 2006
Eloor	4.16±0.37	45 mg/l	50 mg/l
Ollukara	4.16±0.13		

N=100 in each group

Table 14. Mean nitrate concentration water from Eloor and Ollukara during four seasons

Season	Mean ± SE (mg/l)	
	Eloor	Ollukara
Summer	3.54±0.35[a]	3.35±0.21[a]
Pre-monsoon	3.20±0.43[a]	4.22±0.27[b]
Monsoon	3.95±0.74[ab]	3.95±0.20[ab]
Post monsoon	5.96±1.10[b]	5.13±0.84[c]

Figures in a column bearing different superscript differ significantly; N=25 in each group

The mean nitrate concentrations of water from Eloor and Ollukara during four seasons are given in table 14 and figure 11. Analysis of data revealed significant difference ($p<0.05$) in mean nitrate concentration between seasons in Eloor and Ollukara, with highest concentration observed during post monsoon.

4.4.4 Fluoride

The mean fluoride concentrations of water from Eloor and Ollukara are given in table 15 and figure 12. Analysis of data revealed highly significant difference ($p<0.01$) between mean concentration of water samples collected from two areas.

Table 15. Mean fluoride concentration of water from Eloor and Ollukara

Area	Mean ± SE (mg/l)	BIS (IS: 10500, 1991) Desirable Limit	WHO guideline 2006
Eloor	0.14±0.02[a]	1.0 mg/l	1.5 mg/l
Ollukara	0.04±0.01[b]		

Figures bearing different superscript differ significantly; N=100 in each group

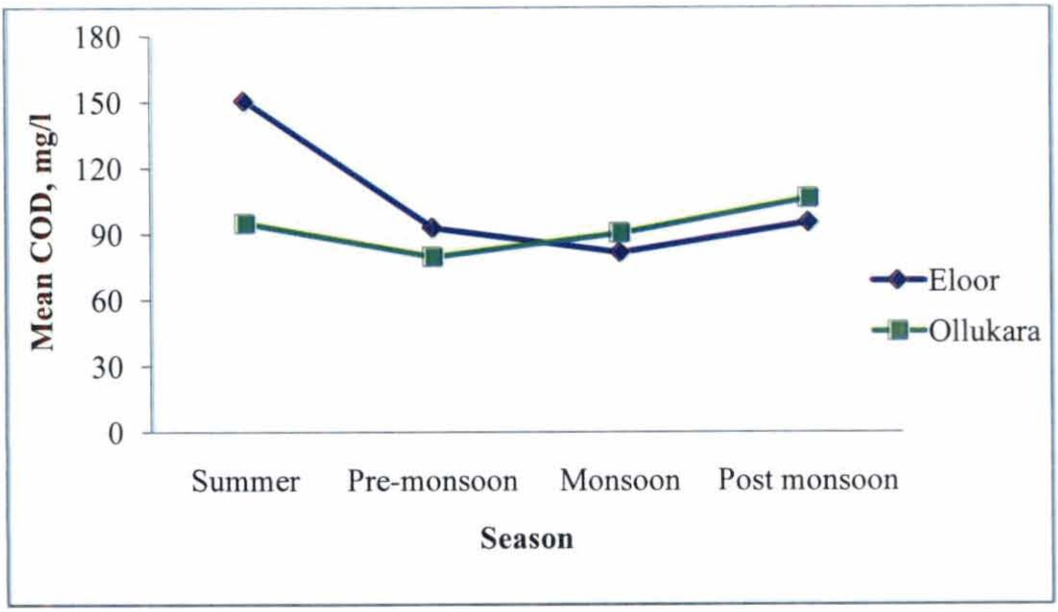

Fig. 10 Mean chemical oxygen demand of water from Eloor and Ollukara during four seasons

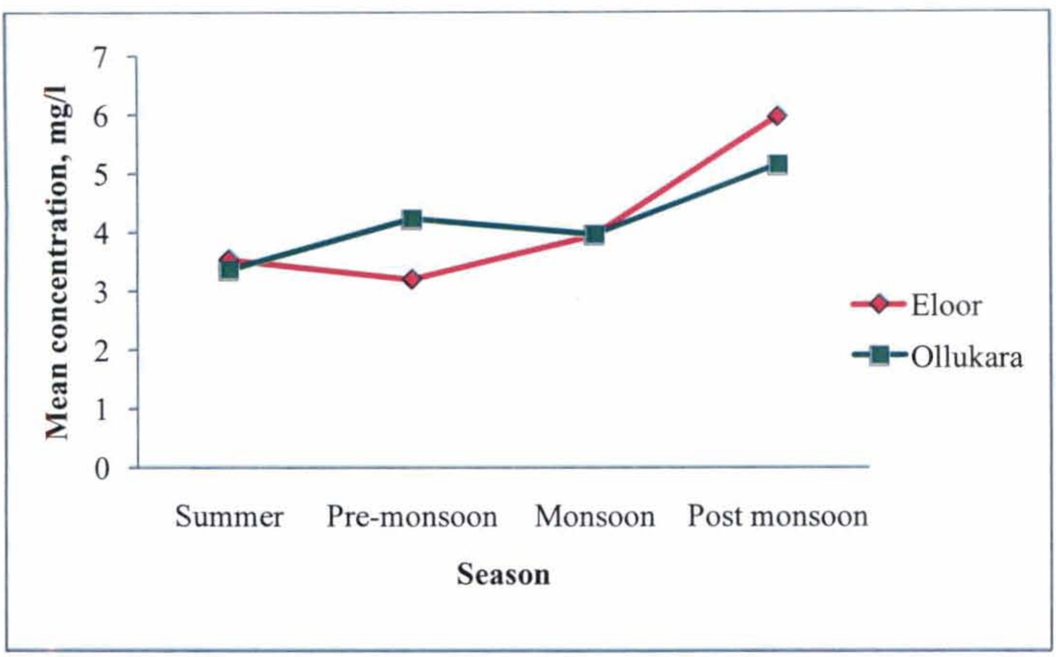

Fig. 11 Mean nitrate concentration water from Eloor and Ollukara during four seasons

The mean fluoride concentration of water from Eloor and Ollukara during four seasons are given in table 16 and figure 13. Analysis of data revealed no significant difference in mean fluoride concentration between seasons in Eloor. Lowest fluoride concentration was observed during post monsoon and highest during pre- monsoon in Ollukara.

Table 16. Mean fluoride concentration of water from Eloor and Ollukara during four seasons

Season	Mean ± SE (mg/l)	
	Eloor	Ollukara
Summer	0.21±0.06	0.06±0.01[b]
Pre-monsoon	0.10±0.05	0.09±0.02[b]
Monsoon	0.19±0.05	0.02±0.01[a]
Post monsoon	0.05±0.04	0.00±0.00[a]

Figures bearing different superscript differ significantly; N=25 in each group

4.4.5 Iron

The mean iron concentration of water from Eloor and Ollukara are given in table 17 and figure 14. Analysis of data revealed highly significant ($p<0.01$) difference between mean iron concentration of water samples collected from Eloor and Ollukara.

Table 17. Mean iron concentration of water from Eloor and Ollukara

Area	Mean ± SE (mg/l)	BIS (IS:10500,1991) Desirable Limit
Eloor	0.61±0.09[a]	0.3 mg/l
Ollukara	0.11±0.09[b]	

Figures bearing different superscript differ significantly; N=100 in each group

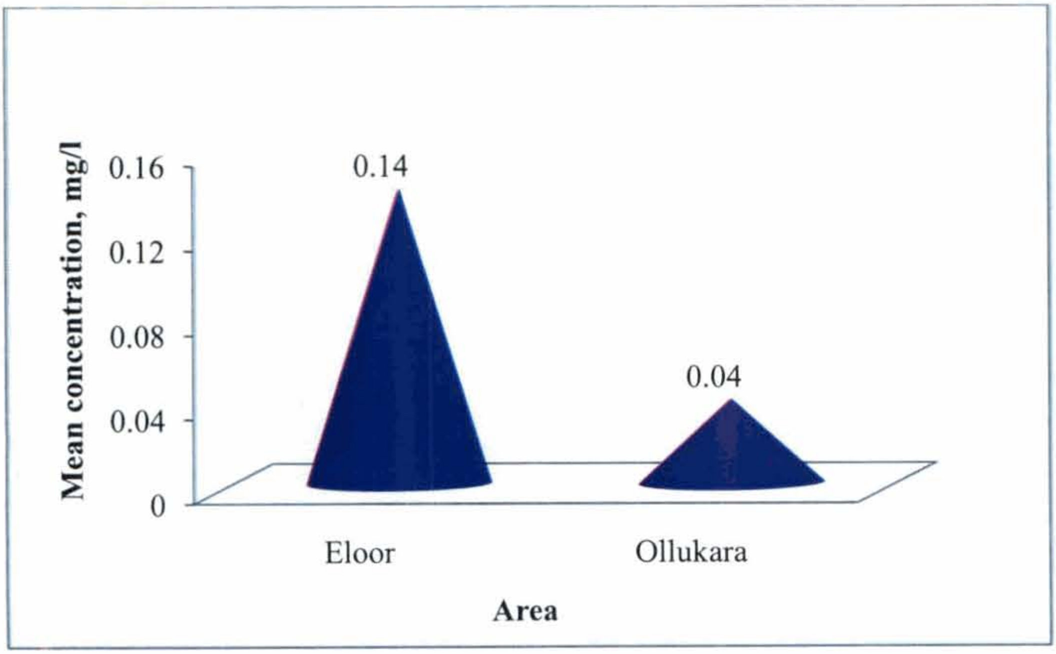

Fig. 12 Mean fluoride concentration of water from Eloor and Ollukara

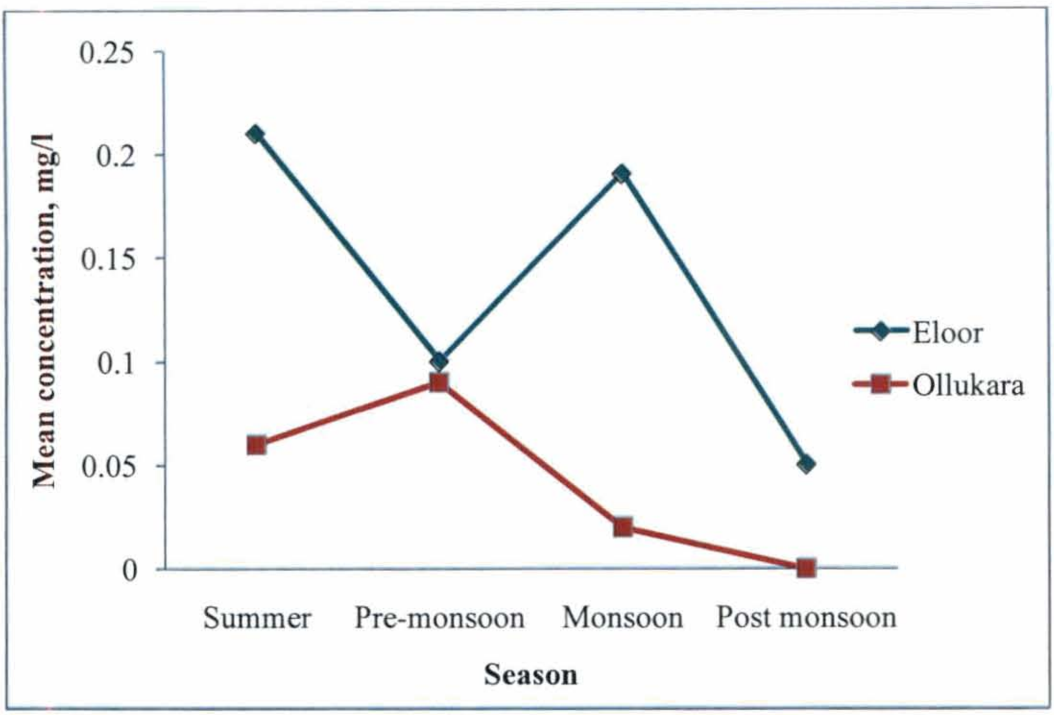

Fig. 13 Mean fluoride concentration of water from Eloor and Ollukara during four seasons

The mean iron concentration of water from Eloor and Ollukara during four seasons is given in table 18 and figure 15. Analysis of data revealed no significant difference in mean iron concentration between seasons in Eloor, whereas samples collected from Ollukara had significant ($p<0.05$) seasonal variation with highest iron content during post monsoon.

Table 18. Mean iron concentration of water from Eloor and Ollukara during four seasons

Season	Mean ± SE (mg/l)	
	Eloor	Ollukara
Summer	0.95±0.33	0.09 ± 0.02^{ab}
Pre-monsoon	0.47±0.09	0.07 ± 0.01^{a}
Monsoon	0.29±0.02	0.12 ± 0.01^{bc}
Post monsoon	0.72±0.09	0.17 ± 0.001^{c}

Figures bearing different superscript differ significantly; N=25 in each group

4.4.6 Lead

The mean lead concentration of water from Eloor and Ollukara are given in table 19 and figure 16. Analysis of data by ANOVA revealed highly significant ($p<0.01$) difference in mean lead concentration between samples collected from Eloor and Ollukara.

Table 19. Mean lead concentration of water from Eloor and Ollukara

Area	Mean ± SE (mg/l)	BIS (IS: 10500, 1991) Desirable Limit	WHO guideline, 2006
Eloor	0.56 ± 0.07^{a}	0.05 mg/l	0.01 mg/l
Ollukara	0.09 ± 0.01^{b}		

Figures bearing different superscript differ significantly; N=100 in each group

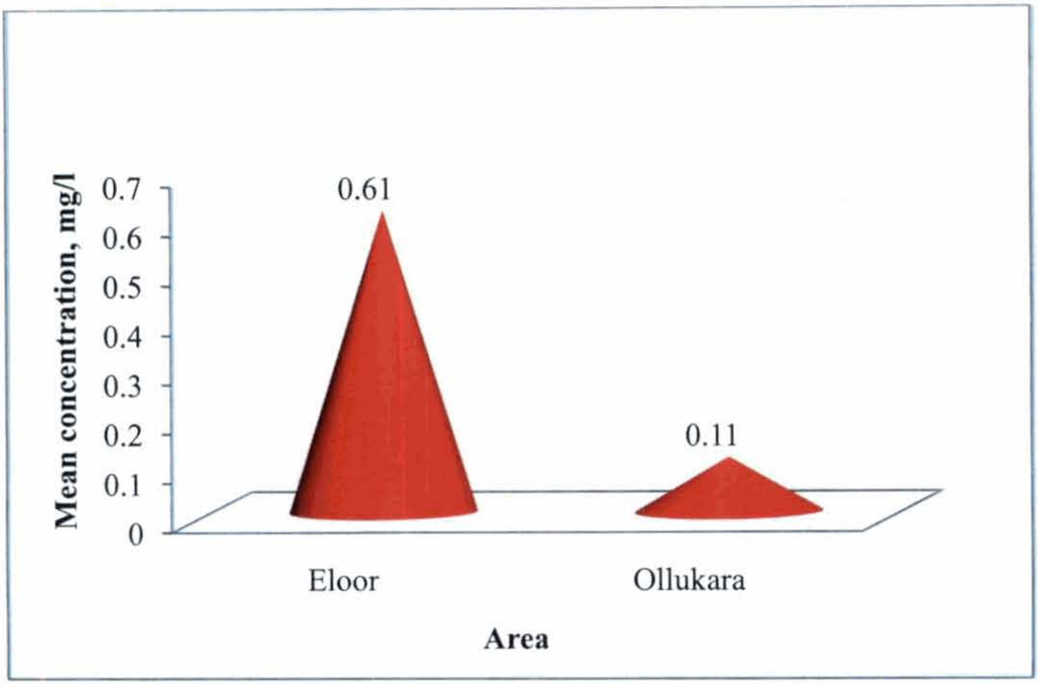

Fig. 14 Mean iron concentration of water from Eloor and Ollukara

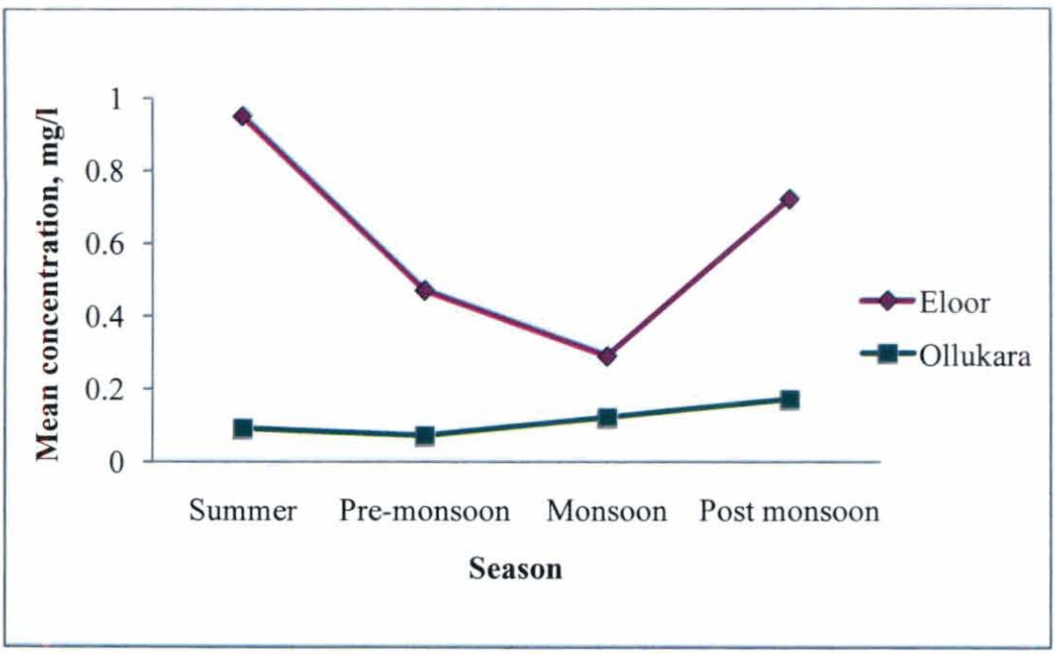

Fig. 15 Mean iron concentration of water from Eloor and Ollukara during four seasons

The mean lead concentration of water from Eloor and Ollukara during four seasons is given in table 20 and figure 17. Analysis of data revealed no significant difference in mean lead concentration between seasons in Eloor, whereas samples collected from Ollukara had highest lead concentration during monsoon.

Table 20. Mean lead concentration of water from Eloor and Ollukara during four seasons

Season	Mean ± SE (mg/l)	
	Eloor	Ollukara
Summer	0.65±0.17	0.09±0.03[ab]
Pre-monsoon	0.72±0.16	0.08±0.01[a]
Monsoon	0.30±0.03	0.13±0.01[b]
Post monsoon	0.56±0.12	0.07±0.01[a]

Figures bearing different superscript differ significantly; N=25 sample in each group

4.4.7 Mercury

During the entire period of study, no mercury could be detected in water samples collected from Eloor and Ollukara.

4.4.8 Zinc

The mean zinc concentration of water from Eloor and Ollukara is given in table 21. Analysis of data revealed no significant difference in mean zinc concentration between the two areas.

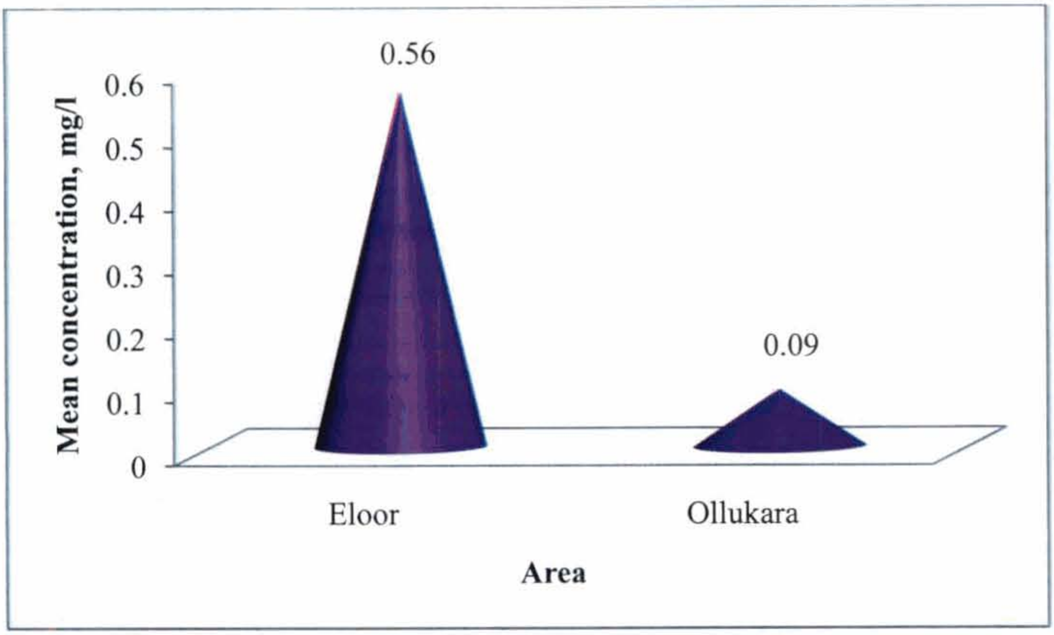

Fig. 16 Mean lead concentration of water from Eloor and Ollukara

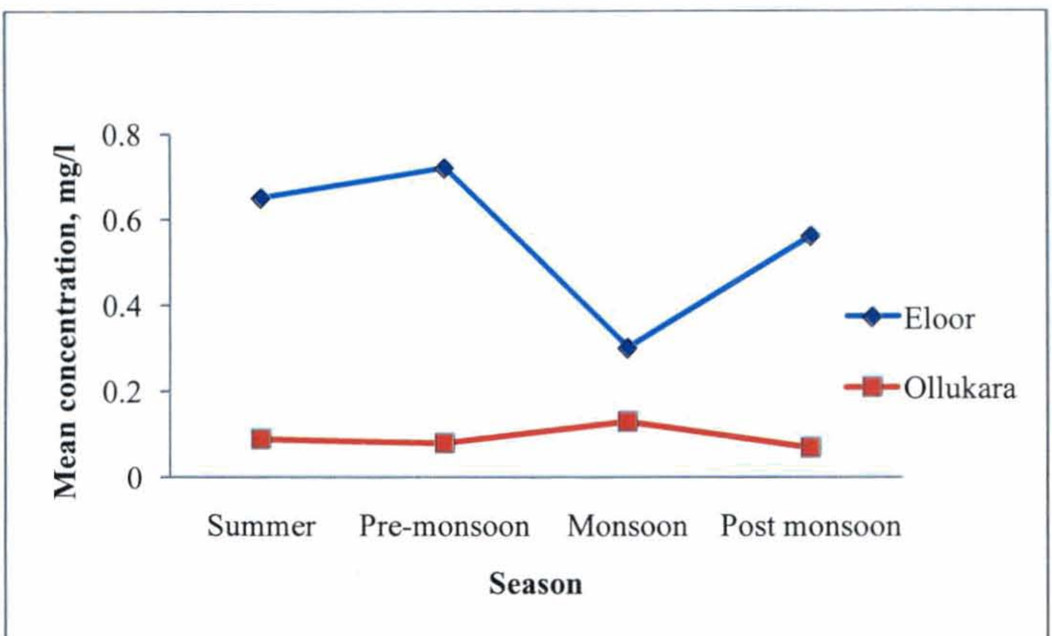

Fig. 17 Mean lead concentration of water from Eloor and Ollukara during four seasons

Table 21. Mean zinc concentration of water from Eloor and Ollukara

Area	Mean ± SE (mg/l)	BIS (IS: 10500, 1991) Desirable Limit
Eloor	0.12±0.01	5 mg/l
Ollukara	0.09±0.06	

N=100 in each group

Table 22. Mean zinc concentration of water from Eloor and Ollukara during four seasons

Season	Mean ± SE (mg/l)	
	Eloor	Ollukara
Summer	0.21 ± 0.04^{b}	0.05 ± 0.01^{a}
Pre-monsoon	0.06 ± 0.01^{a}	0.07 ± 0.01^{ab}
Monsoon	0.09 ± 0.02^{a}	0.10 ± 0.01^{b}
Post monsoon	0.11 ± 0.02^{a}	0.14 ± 0.01^{c}

Figures in a column bearing different superscript differ significantly; N=25 in each group

The mean zinc concentrations of water from Eloor and Ollukara during four seasons are given in table 22 and figure 18. Seasonal variation was observed in both areas. Mean zinc concentration was highest during summer in Eloor and monsoon in Ollukara.

4.4.9 Cadmium

The mean cadmium concentrations of water samples from Eloor and Ollukara are given in table 23. Analysis of data revealed no significant difference in mean cadmium concentration between two areas.

Table 23. Mean cadmium concentration of water from Eloor and Ollukara

Area	Mean ± SE (mg/l)	BIS (IS: 10500, 1991) Desirable Limit	WHO guideline 2006
Eloor	0.02±0.00	0.01 mg/l	0.003 mg/l
Ollukara	0.02±0.00		

N=100 in each group

Table 24. Mean cadmium concentration of water from Eloor during four seasons

Season	Mean ± SE (mg/l)	
	Eloor	Ollukara
Summer	0.003±0.001[a]	0.00±0.00[a]
Pre-monsoon	0.01±0.003[a]	0.01±0.002[a]
Monsoon	0.05±0.005[b]	0.04±0.002[c]
Post monsoon	0.01±0.002[a]	0.01±0.001[b]

Figures in a column bearing different superscript differ significantly; N=25 in each group

The mean cadmium concentrations of water from Eloor and Ollukara during four seasons are given in table 24 and figure 19. Significant difference ($p<0.05$) in mean cadmium concentrations between seasons were observed with highest concentration during monsoon season in both Eloor and Ollukara.

4.5 MICROBIOLOGICAL QUALITY OF WATER

All the samples collected from Eloor and Ollukara were subjected to microbiological examination for estimation of aerobic plate count, coliform count, *Escherichia coli* count and enterococcal count.

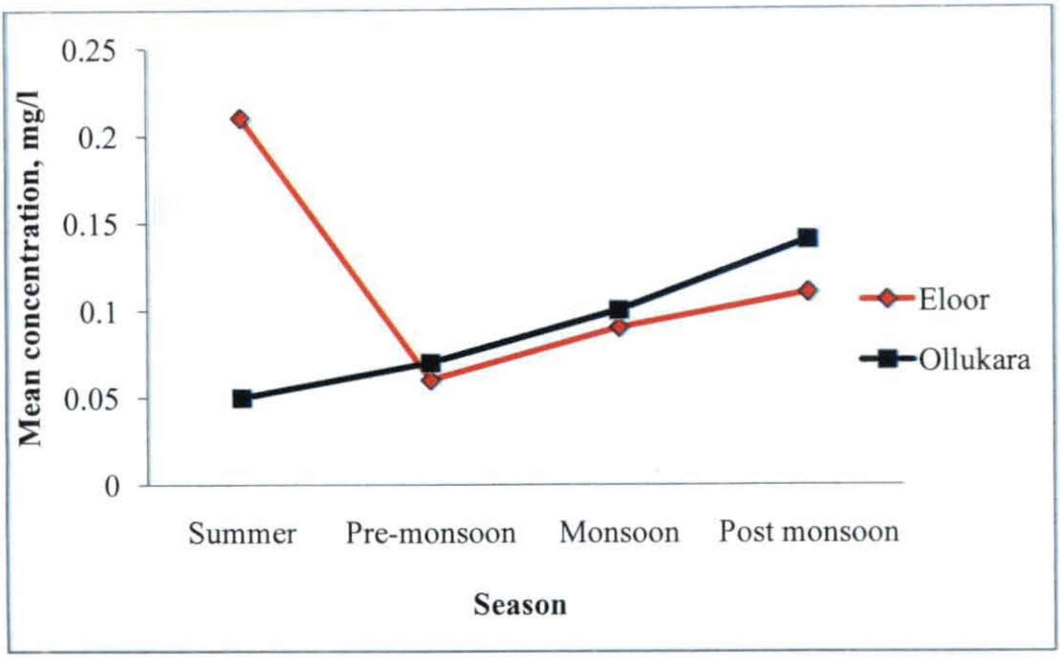

Fig. 18 Mean zinc concentration of water from Eloor and Ollukara during four seasons

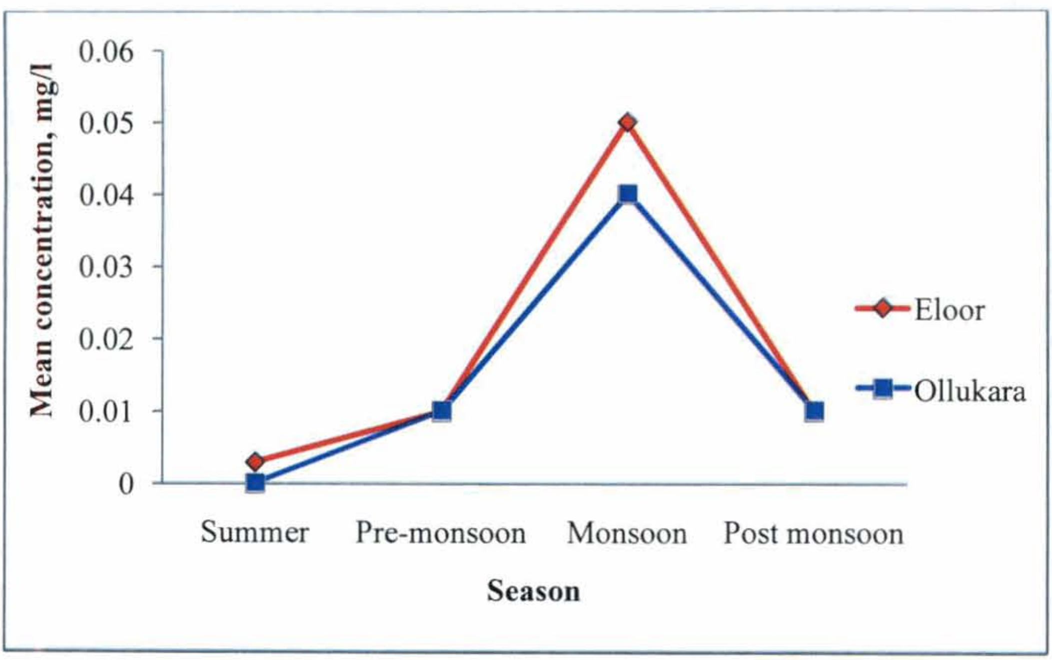

Fig. 19 Mean cadmium concentration of water from Eloor during four seasons

4.5.1 Aerobic Plate Count

The mean aerobic plate count of water from Eloor and Ollukara is given in table 25 and figure 20. Analysis of data revealed highly significant ($p<0.01$) difference between mean counts of Eloor and Ollukara.

Table 25. Mean aerobic plate count of water from Eloor and Ollukara

Area	Mean ± SE (log_{10} cfu/ml)
Eloor	3.92 ± 0.07^{a}
Ollukara	2.88 ± 0.06^{b}

Figures bearing different superscript differ significantly; N=100 in each group

The mean aerobic plate count of water from Eloor and Ollukara during four seasons is given in table 26 and figure 21. Significant ($p<0.05$) difference in mean aerobic plate count between seasons were observed in Ollukara with highest aerobic plate count during summer (3.36±0.10 log_{10} cfu/ml).

Table 26. Mean aerobic plate count of water from Eloor and Ollukara during four seasons

Season	Mean ± SE (log_{10} cfu/ml)	
	Eloor	Ollukara
Summer	3.90±0.17	3.36 ± 0.10^{c}
Pre-monsoon	4.15±0.14	2.88 ± 0.13^{b}
Monsoon	3.90±0.12	2.89 ± 0.08^{b}
Post monsoon	3.74±0.11	2.37 ± 0.70^{a}

Figures bearing different superscript differ significantly; N=25 in each group

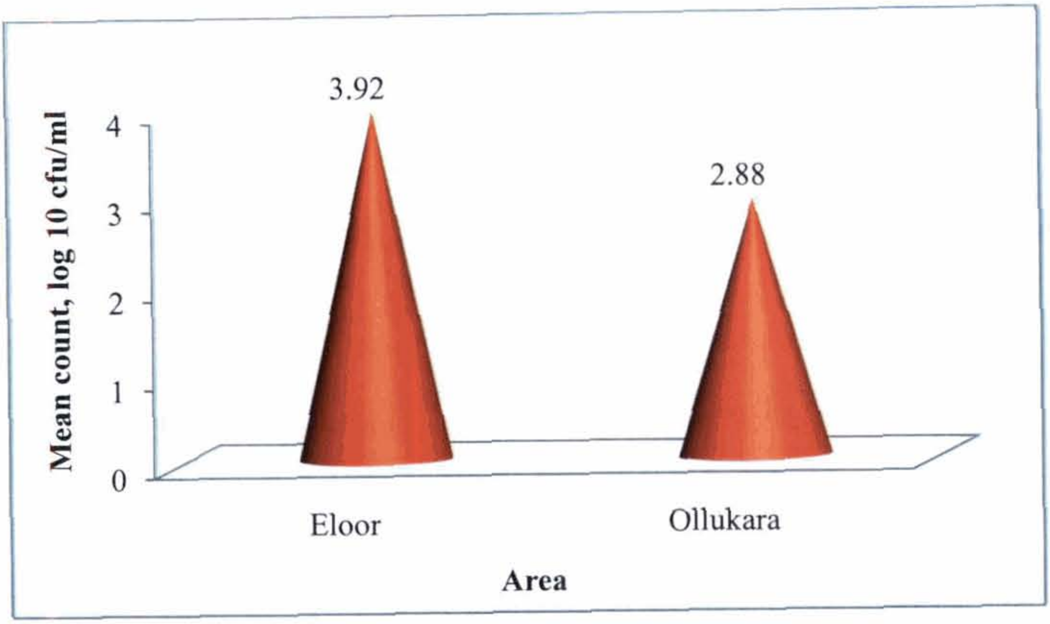

Fig. 20 Mean aerobic plate count of water from Eloor and Ollukara

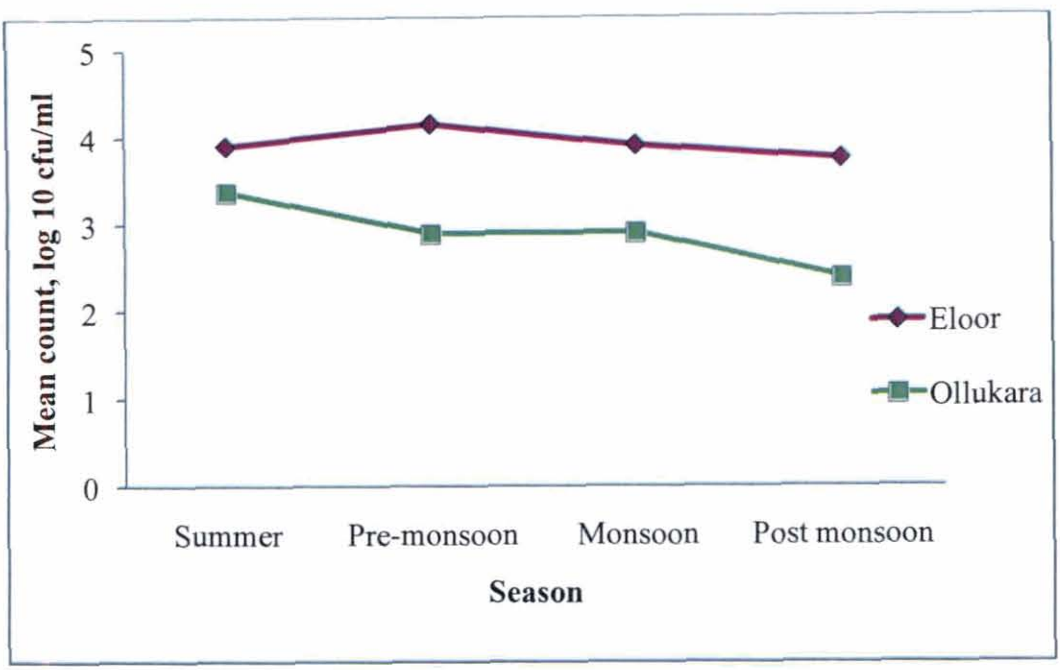

Fig. 21 Mean aerobic plate count of water from Eloor and Ollukara during four seasons

4.5.2 Coliform Count

The mean coliform count of water from Eloor and Ollukara is given in table 27 and figure 22. Analysis of data revealed significant ($p<0.05$) difference in mean coliform count between Eloor and Ollukara.

Table 27. Mean coliform count of water from Eloor and Ollukara

Area	Mean ± SE (log_{10} cfu/ml)	BIS (IS: 10500, 1991) Desirable Limit
Eloor	1.32 ± 0.07^{a}	0/ 100 ml
Ollukara	0.98 ± 0.07^{b}	

Figures bearing different superscript differ significantly; N=100 in each group

The mean coliform count of water from Eloor and Ollukara during four seasons is given in table 28 and figure 23. Significant ($p<0.05$) difference in mean coliform count between seasons was observed in Ollukara with highest coliform count during monsoon (1.19±0.63 log_{10} cfu/ml).

Table 28. Mean coliform count of water from Eloor and Ollukara during four seasons

Season	Mean ± SE (log_{10} cfu/ml)	
	Eloor	Ollukara
Summer	1.31±0.17	0.61 ± 0.10^{a}
Pre-monsoon	1.32±0.16	1.05 ± 0.15^{b}
Monsoon	1.38±0.18	1.19 ± 0.63^{b}
Post monsoon	1.26±0.16	1.17 ± 0.10^{b}

Figures bearing different superscript differ significantly; N=25 in each group

4.5.3 *Escherichia coli* count

The mean *Escherichia coli* count of water from Eloor and Ollukara is given in table 29. Analysis of data revealed no significant difference in mean *Escherichia coli* count between Eloor and Ollukara.

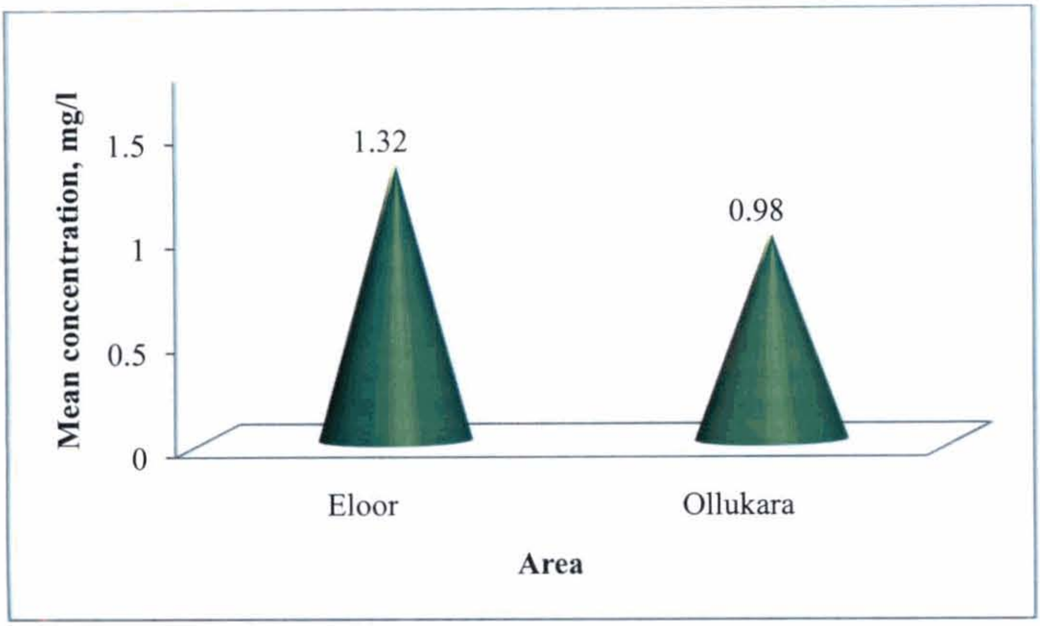

Fig. 22 Mean coliform count of water from Eloor and Ollukara

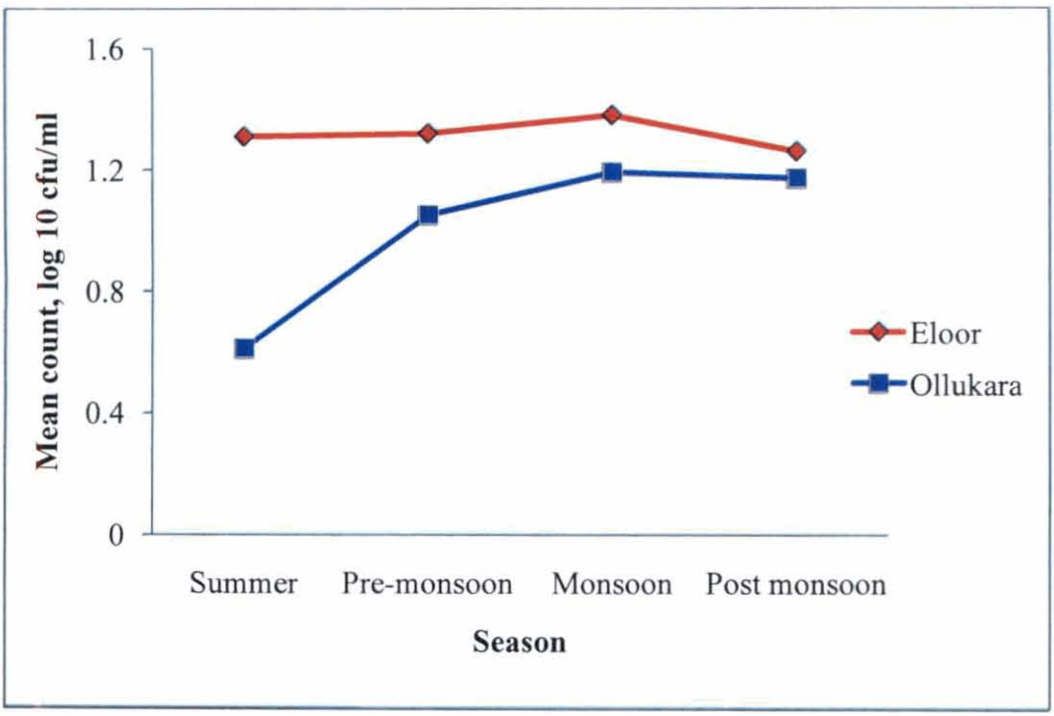

Fig. 23 Mean coliform count of water from Eloor and Ollukara during four seasons

Table 29. Mean *Escherichia coli* count of water from Eloor and Ollukara

Area	Mean ± SE (log_{10} cfu/ml)	BIS (IS:10500,1991) Desirable Limit
Eloor	0.54±0.08	0/ 100 ml
Ollukara	0.29±0.05	

Figures bearing different superscript differ significantly; N=100 in each group

The mean *Escherichia coli* count of water from Eloor and Ollukara during four seasons is given in table 30 and figure 24. Analysis of data revealed no significant difference in mean *Escherichia coli* count between seasons in Eloor and Ollukara.

Table 30. Mean *Escherichia coli* count of water from Eloor and Ollukara during four seasons

Season	Mean ± SE (log_{10} cfu/ml)	
	Eloor	Ollukara
Summer	0.61±0.18	0.06±0.06
Pre-monsoon	0.78±0.16	0.35±0.11
Monsoon	0.48±0.13	0.34±0.12
Post monsoon	0.30±0.13	0.29±0.05

N=25 in each group

4.5.4 Enterococcal count

The mean enterococcal count of water from Eloor and Ollukara is given in table 31. Analysis of data revealed no significant difference in mean enterococcal count between Eloor and Ollukara.

Table 31. Mean enterococcal count of water from Eloor and Ollukara

Area	Mean ± SE (log_{10} cfu/ml)
Eloor	0.61±0.08
Ollukara	0.80±0.06

N=100 in each group

The mean enterococcal count of water from Eloor and Ollukara during four seasons is given in table 32 and figure 25. Analysis of data revealed no significant difference in mean enterococcal count between seasons in Ollukara, but seasonal variation was observed in Eloor with highest count during summer (1.37±0.18 log_{10} cfu/ml).

Table 32. Mean enterococcal count of water from Eloor and Ollukara during four seasons

Season	Mean ± SE(log_{10} cfu/ml)	
	Eloor	Ollukara
Summer	$1.37±0.18^{b}$	0.81±0.16
Pre-monsoon	$0.27±0.13^{a}$	0.51±0.14
Monsoon	$0.38±0.11^{a}$	0.89±0.17
Post monsoon	$0.43±0.15^{a}$	0.97±0.17

Figures bearing different superscript differ significantly; N=25 sample in each group

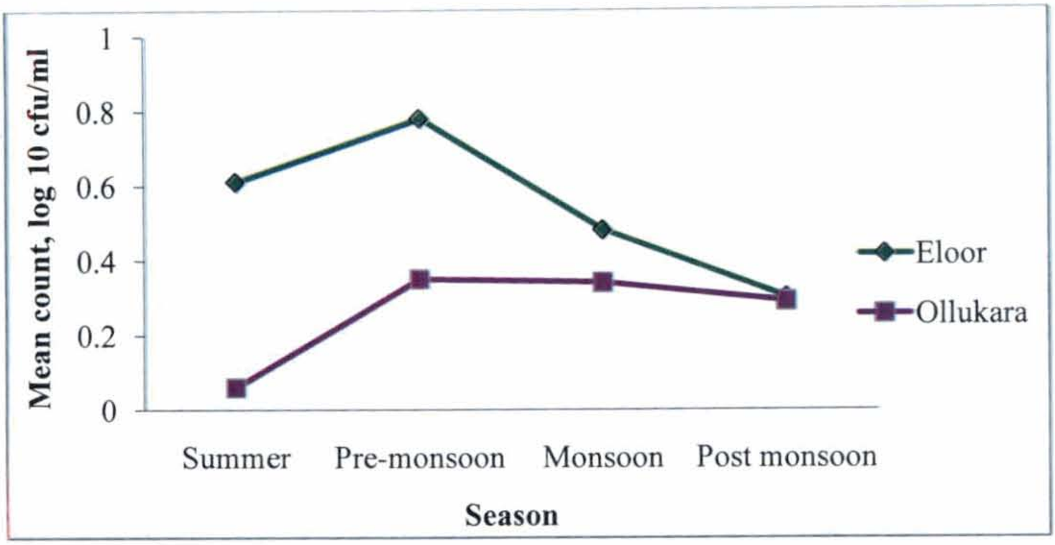

Fig. 24 Mean *Escherichia coli* count of water from Eloor and Ollukara during four seasons

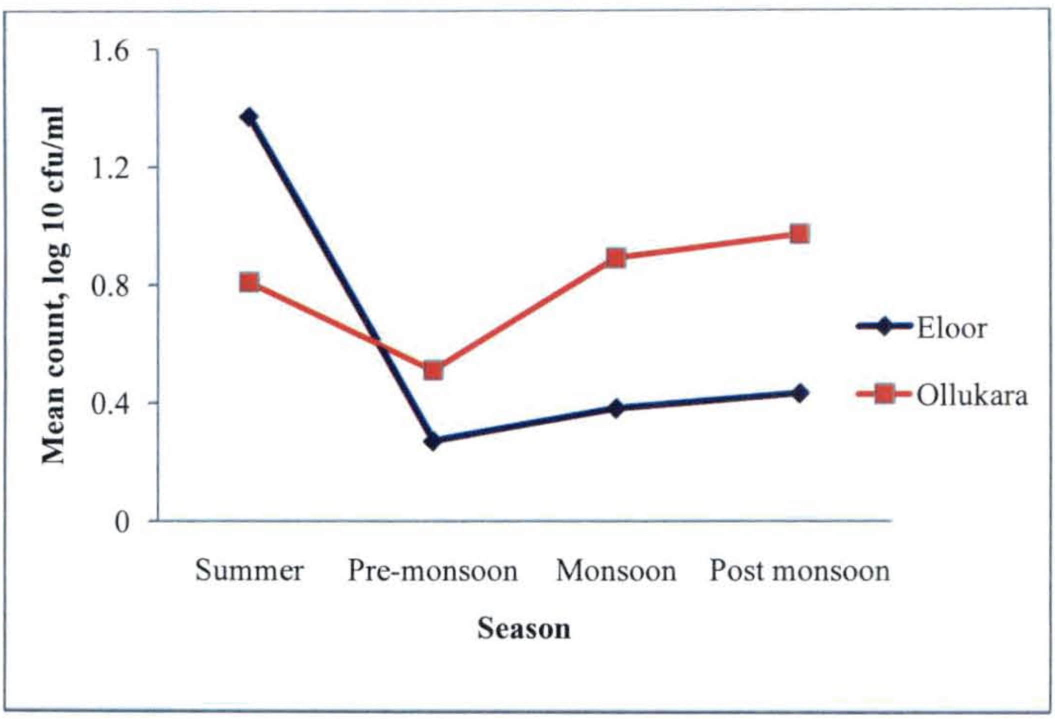

Fig. 25 Mean enterococcal count of water from Eloor and Ollukara during four seasons

4.6 PHYSICAL, CHEMICAL AND MICROBIOLOGICAL QUALITY OF WATER FROM KUZHIKANDAM CREEK

Physical, chemical and microbiological quality of water from Kuzhikandam creek was studied for four seasons and results are given in table 33, 34 and 35 respectively. Slightly higher temperature than well water and acidic pH was observed. Total hardness, Chemical Oxygen Demand and concentration of iron, lead and cadmium were exceedingly high. Coliforms were present in all seasons. *Escherichia coli* were present only during summer season, whereas enterococci were detected in summer and monsoon seasons.

Table 33. Physical quality of water from Kuzhikandam creek

Season	Physical quality	
	Temperature (°C)	pH
Summer	30	6.36
Pre-monsoon	28	4.76
Monsoon	28	5.81
Post monsoon	29	5.95

Table 34. Chemical quality of water from Kuzhikandam creek

Season	Chemical quality parameters (mg/l)								
	Total Hardness	Chemical oxygen demand	Nitrate	Fluoride	Iron	Lead	Mercury	Zinc	Cadmium
Summer	2575	215	3.4	0.63	2.71	2.38	0	0.21	0.02
Pre-monsoon	2550	355	2.8	1.7	9.48	3.61	0	0.08	0
Monsoon	2250	557	2.4	1.21	9.12	2.72	0	0.12	0.05
Post monsoon	2300	195	2.8	0.68	3.18	0.37	0	0.06	0.02

Table 35. Microbiological quality of water from Kuzhikandam creek

Season	Microbiological quality (log_{10} cfu/ml)			
	Total viable count	Coliform count	*Escherichia coli* count	Enterococcal count
Summer	5.33	3	2.78	3.25
Pre-monsoon	5.27	1	0	0
Monsoon	4.01	1.85	0	1.6
Post monsoon	3.6	1.48	0	0

4.7 SAMPLES MEETING THE BIS (IS: 10500: 1991) STANDARDS FOR DRINKING WATER

Percentage of samples meeting BIS standards for drinking water is given in table 36 and 37. It was found that concentration of nitrate, fluoride, mercury and zinc were within this limit for all samples throughout the year in Eloor. In Ollukara all samples were within this limit for total hardness, nitrate, fluoride, mercury and zinc during four seasons. However the desirable limit for pH could not be met.

4.8 SAMPLES MEETING THE WHO GUIDELINES (2006) FOR DRINKING WATER

Percentage of samples meeting WHO guidelines (2006) for drinking water is given in table 38 and 39. It was found that concentration of nitrate, fluoride and mercury were within this limit for all samples throughout the year in Eloor and Ollukara.non of the samples met the WHO guidelines for cadmium and lead during monsoon season.

Table 36. Percentage of samples from Eloor meeting BIS (IS: 10500: 1991) standards

Season	pH	Total hardness	Nitrate	Fluoride	Iron	Lead	Mercury	Zinc	Cadmium	Coliform count	*E.coli* count
Summer	28	60	100	100	40	0	100	100	96	84	64
Pre-monsoon	32	64	100	100	44	0	100	100	72	20	48
Monsoon	28	76	100	100	68	0	100	100	4	8	60
Post monsoon	32	84	100	100	0	0	100	100	56	24	80

Table 37. Percentage of samples from Ollukara, meeting BIS (IS: 10500: 1991) standards

Season	pH	Total hardness	Nitrate	Fluoride	Iron	Lead	Mercury	Zinc	Cadmium	Coliform count	*E.coli* count
Summer	0	100	100	100	96	44	100	100	100	56	9
Pre-monsoon	0	100	100	100	100	42	100	100	83	29	71
Monsoon	0	100	100	100	100	100	100	100	0	16	72
Post monsoon	8	100	100	100	100	68	100	100	52	16	64

Table 38. Percentage of samples from Eloor meeting WHO guidelines, 2006

Season	Cadmium	Lead	Nitrate	Fluoride	Mercury
Summer	68	0	100	100	100
Pre-monsoon	64	0	100	100	100
Monsoon	0	0	100	100	100
Post monsoon	52	0	100	100	100

Table 39. Percentage of samples from Ollukara meeting WHO guidelines, 2006

Season	Cadmium	Lead	Nitrate	Fluoride	Mercury
Summer	100	20	100	100	100
Pre-monsoon	76	0	100	100	100
Monsoon	0	0	100	100	100
Post monsoon	16	32	100	100	100

Discussion

5. DISCUSSION

5.1 SURVEY

5.1.1 Characteristics of wells and practices among people in Eloor and Ollukara

Due to industrialization, the quality of air, water and environment in Eloor has deteriorated and people in Eloor find problems in sustaining their lives. They crave for pure water, fresh air and clean environment. From the survey conducted among 25 households in Eloor it was understood that 20 per cent of people did not use their wells for any purpose (Table 1). All selected household had free house connection as source of water and 80 per cent utilized this as their drinking water source. Still 20 per cent used their wells for drinking purpose even though they had house connections. In their view well water was clean without any odour or impurities and they could not appreciate any problem with well water. They were unaware about the chemical pollution of their wells and the deteriorating quality of water. It was observed that water was turbid and yellowish in colour especially during summer season (Plate 9). Majority (80 per cent) of them complained that water was hard and it consumes more soap and lather formation is difficult. Some of them found difficulties in cooking with their well water, so that rice and pulses take more time to get cooked. Some had reported falling and roughness of hair with the well water (16 per cent). Some (24 per cent) had also highlighted odour and burning sensation with well water. Still some others (eight per cent) were not using their wells even for gardening and had the opinion that wilting of plants occurs with such water. Even with these problems, 48 per cent used well water for other purposes such as bath or toilet purpose, washing clothes, cooking and gardening.

Lack of continuous supply of water through the house connection was another important challenge. Sometimes water may not be available for two to three days. In such situations people are forced to drink well water and to arrange sufficient facilities to store large volume of water.

Plate 8. Steined well in Eloor

Plate 9. Yellowish and turbid nature of well water in Eloor

Majority of people (92 per cent) in Eloor and 80 per cent in Ollukara had the practice of drink boiled water. Disinfection was practiced by 48 per cent and 52 per cent households in Eloor and Ollukara, respectively. Bleaching powder was the disinfectant invariably used in both Eloor and Ollukara. It was pointed out that the quantity of bleaching powder used was not sufficient for effective disinfection. Fifty two per cent wells were disinfected twice in a year in both Eloor an Ollukara. Thirty six per cent were regularly disinfected at intervals of two months in Ollukara, but in Eloor even a single well was not disinfected in this interval. Thirty two per cent wells in Eloor and 36 per cent wells in Ollukara did not conform the minimum distance from the nearest polluting source such as septic tank, animals shed, manure pit, waste disposal site etc. To avoid bacterial contamination, the wells should be located not less than 15 metres from likely source of contamination (Park, 2009). Close proximity of some of the wells to polluting sources also added to poor quality of water. Twenty per cent households in Eloor reported that their well water samples were taken for analysis by some agency. But they were unaware about the results.

Results of analysis of water from Kuzhikandam creek in Eloor (Table 34) showed that it was heavily polluted with metallic impurities such as iron, lead and cadmium. Total hardness was also found to be very high indicating chemical pollution. Coliforms were present in all seasons with highest count during summer (Table 35). *Escherichia coli* were present only during summer season. During summer season, due to the availability of least amount of water, concentration occurs, leading to higher total viable count, coliform and *Escherichia coli* counts. Whereas, enterococci were detected in summer and monsoon seasons with higher counts during summer. This creek carries highly contaminated water including effluents from Hindustan Insecticide Limited (HIL), Merchem Limited, Indian Rare Earths Limited (IRE) and Fertilizers and Chemicals Travancore Limited (FACT) and draining into the river Periyar making the river a sewage canal carrying a myriad of hazards and toxic industry borne pollutants. In 1999, Green Peace India did a sampling study of Eloor and found 111 different chemicals in

Kuzhikandam creek including 39 persistent organic pollutants. In present investigation, it was observed that wells situated on either side of Kuzhikandam creek contain higher concentration of iron, lead and cadmium and as distance of wells from Kuzhikandam creek increased there was considerable reduction in the concentration of pollutants.

5.1.2 Human health and allied aspects

Of the 25 households surveyed, 88 per cent in Eloor and 12 per cent in Ollukara were suffering from respiratory problems (Table 2). Members of all 25 household had the opinion that air was polluted and had a noxious smell and smog. Air quality changes were noticed during morning hours. They experienced, discomforts including dyspnoea, nausea, vomiting, sneezing, frequent cough, general weakness, irritation of eyes and ephiphora, whenever the quality of air changed. Health survey conducted in nine wards of Eloor (2008) also reported that 85.2 per cent of the people experience breathing problem. The people in Eloor talk of nights when the stench of chemicals was so strong that breathing became difficult. This was corroborated by The Assistant Surgeon of Primary Health Centre Eloor. According to them, most of the cases brought to the hospital are either respiratory or cutaneous problems. Survey results also revealed that 72 per cent suffer from one or other type of skin problem mainly due to contact with contaminated water. Sixty per cent suffered from musculoskeletal diseases. The problems associated with drinking contaminated water were not a major problem as majority did not depend on wells for drinking water. Problems crop up only when the panchayath water supply gets disrupted. Gastrointestinal disorders including nausea and vomiting were also reported by a few (20 per cent), after drinking contaminated water. Prevalence of neoplasm, congenital anomaly and mental retardation was also higher in Eloor than that of Ollukara. Four per cent of households experienced neoplasm, whereas sixteen per cent suffered from congenital anomalies and mental retardation. Some (eight per cent) had lost their parents, who were employees of HIL, due to neoplasm. Health problems were lower in Ollukara. In Eloor, 32 per cent households depended on primary health centre for treatment facilities and the rest on private hospitals. In Ollukara all the households depended on private hospitals. Health insurance policies were present in 12 per cent and 20 per cent households in Eloor and Ollukara respectively.

5.1.3 Animal health problems

Among the health problems in animals, digestive disorders (55.56 per cent) were found to be main problem reported by the farmers (Table 3). These included anorexia, enteritis and indigestion, suggestive of cadmium toxicity. Nisha (2001) also observed prevalence of cadmium toxicity in cattle of Eloor industrial area. Retrospective analysis of case record in Eloor Veterinary Hospital for past five (Table 4) years also revealed incidence of digestive disorders (26.28 per cent). The Senior Veterinary Surgeon, Veterinary Hospital Eloor, opined that seasonal enteritis was one of the main problems especially during monsoon season. During that time animals drink water from water logged area such as paddy field and road contaminated with industrial effluents. Gastroenteritis is also associated with lead toxicity due to the caustic action of lead on alimentary mucosa (Radostits *et al.*, 2007). Sandhu and Brar (2000) suggested that anorexia along with colic is a predominant sign of lead poisoning in cattle and diarrhoea may be present in some cases. It was pointed out that house connection was the drinking water source for animals and animals were fed with locally available grass and concentrates.

Reproductive disorders were reported in 27.59 per cent of animals (Table 3). These mainly include anoestrum, repeat breeding and abortion. Retrospective analysis of cases also pointed out that 4.96 per cent of cases recorded in hospital were reproductive disorders. Some of the farmers complained that 4-5 inseminations were required for conception. Some of them sold their animals because of infertility problems. Even though the average number of artificial insemination per conception was 1.8 to 2 in the panchayath, it had gone as high as five to six in some areas especially near to Kuzhikandam creek indicating the severity of pollution in the area. Abortion in cattle at 5 to 6 month of gestation was also reported by some farmers. This could be attributed to lead toxicity

(Sandhu and Brar, 2000). Cadmium toxicity also causes reproductive disorders by disturbing carbohydrate metabolism and producing glucose intolerance. Skin diseases were reported in 24.14 per cent animals and are accounted for 2.85 per cent of cases recorded in Veterinary hospital. Lameness was reported in 6.9 per cent of animals (Table 3). This might be attributed to fluoride toxicity, as high fluoride concentration disrupts osteogenesis leading to inadequate matrix formation and defective mineralization. Cheeran *et al.* (1987) and Kumar (2000) reported symptoms of fluoride toxicity in cattle of Eloor industrial area such as lameness, reluctance to move, palpable bony exosotosis particularly in metacarpal and metatarsal, ribs and mandibular bones. It was also understood that eight per cent animals were insured in Eloor.

5.2 PHYSICAL QUALITY OF WATER

5.2.1 Temperature

The mean temperature of well water from Eloor and Ollukara is given in table 5. A significantly ($p<0.05$) higher temperature was observed in well water in Eloor (28.18 ±0.11 °C). It could be attributed to higher ambient temperature of Eloor due to industrial activities, since well water temperature is mainly influenced by ambient temperature (Chapman and Kimstach, 1996). Mean temperature of water from Kuzhikandam creek was 28.75 °C. Slightly higher temperature could be attributed to the discharge of effluents with a higher temperature into the creek. People in Eloor also have the opinion that, water from creek has elevated temperature.

Seasonal variation in temperature of well water in Eloor and Ollukara is shown in table 6. The temperature ranged from 27-28.96 °C and 26.32-28.68 °C in Eloor and Ollukara, respectively. The lowest temperature was recorded during monsoon in Eloor and Ollukara, and the highest temperature was recorded during pre-monsoon in Eloor and summer in Ollukara which was in accordance with ambient temperature pattern. (Kaplay and Patode, 2004; Agbaire and Obi, 2009 and John and Thanga, 2010).

5.2.2 pH

Mean pH of well water in Eloor and Ollukara are given in table 7. The pH of well water is mainly influenced by volume of water (Mahasim *et al.*, 2005), soil type (CESS, 1984), presence of chemicals and application of acidic fertilizers. The pH of well water in Eloor was 5.99±0.08. A similar result was observed by Local Area Environment Committee (2006) in Eloor. Even though the soil type of Eloor is sandy loam, which is of higher pH (Malik *et al.*, 2010), pH of well water in Eloor was 5.99. It could be due to discharge industrial effluents, which of acidic pH (Local Area Environment Committee, 2006) to the surface water bodies, which in turn percolate in to well water. Water from Kuzhikandam creek had almost similar pH (5.72), indicating discharge of acidic effluents (Table 33).

Mean pH of water from Ollukara was 5.18±0.06. It might be due to laterite soil, which is highly acidic with pH range of 4-4.5 (Mathew and Thampatti, 2007). Moreover, this area encompasses agricultural fields using acid producing fertilizers like ammonium sulphate and super phosphate of lime which can also lead to low pH of water. Whereas, Nair *et al.*, (2000) observed higher pH of around 7.0 in ground water samples in Thrissur district.

Change in pH of well water during four seasons is given in table 8. Significant seasonal variation was not observed in Eloor. In both areas pH was higher during monsoon and post monsoon and lower during summer and pre-monsoon seasons. The higher pH values during rainy season could be due to high photosynthesis of micro and macro vegetation resulting in production of high CO_2, shifting the equilibrium towards alkaline side (Kumar *et al.*, 2010). The observation was similar to the findings of Agbaire and Obi (2009) and John and Thanga (2010). According to Langmuir (1997) acid pH of water may be due to dissolved carbon dioxide and organic acids (Fulvic and Humic acids) which are derived from the decay and subsequent leaching of plant materials. During dry seasons such as summer and pre-monsoon there may be death and decay of plants due to lack of sufficient water which increases the organic acid content of water in turn causing acidity. In addition great reduction in water volume in the wells also decreases the pH during dry season (Mahasim *et al.*, 2005).

Acceptable range of pH for drinking water is 6.5-8.5 (IS: 10500, 1991). In the present investigation well water samples from Eloor and Ollukara were not within acceptable range. Low pH of groundwater can cause gastrointestinal disorders especially hyperacidity, ulcers and burning sensation (Laluraj and Gopinath, 2006). Water with pH below 6.5, causes corrosion of metal, pipes, resulting in the release of toxic metals such as zinc, lead, cadmium, copper etc. Burning sensation reported by a few households in Eloor could be attributed to the low pH of ground water. Higher values of pH hasten the scale formation in water heating apparatus and also decrease the germicidal potential of chlorine. High pH induces the formation of trihalomethanes (Shah *et al.,* 2008). These are reported to be toxic and carcinogenic (Latifoglu, 2003). They are formed in drinking water primarily as a result of chlorination of organic matter present in water (WHO, 2005). Chloroform is the most common trihalomethane and the principal disinfection by-product in chlorinated drinking-water (LeBel and Williams, 1995).

5.3 CHEMICAL QUALITY OF WATER

5.3.1 Total hardness

Total hardness of water from Eloor and Ollukara are given in table 9. Significantly ($p<0.01$) higher total hardness (337.50 ± 38.92 mg/l) was observed in well water samples collected from Eloor. Similarly, higher total hardness was observed in well water in and around Chavara industrial area, Quilion, Kerala, by Shaji *et al.,* (2009). The higher total hardness could be due to the discharge of effluents and untreated waste (Ullah *et al.*, 2009) from polluting industries to nearby surface water sources. Mean total hardness of water from Kuzhikandam creek was 2418.75 mg/l, indicating the nature of pollution and chemical load of creek (Table 34). It was observed that wells close to this creek exhibited higher total hardness, in the range of 900-1575 mg/l. Futhermore. one of the wells close to the creek recorded a total hardness of 2350 mg/l.

In Ollukara, which was free of such industries, water was found to be soft. Mean total hardness of water was 13.33±0.34 mg/l. Nair *et al.* (2000) observed total hardness in the range of 1-13 degrees in groundwater from various parts of Thrissur district. Highest value of total hardness was observed during summer in well water from Eloor and Kuzhikandam creek (Table 10, 34). It could be due to the low water level and high rate of evaporation during summer (Sisodia and Moundiotiya, 2006). In Ollukara highest total hardness was observed during monsoon. Similar observation was made by Efe *et al.,* (2005) in open wells in western Niger delta region Nigeria, as well as John and Thanga (2010) in coastal wards of Kollam Corporation, Kerala. It could be due to the leaching of sulphates and carbonates during monsoon season to well water.

The desirable limit for total hardness in drinking water as per the Bureau of Indian Standards (IS: 10500, 1991) is 300 mg/l. Well water from Eloor had total hardness above the desirable limit. Hardness is the property of water which prevents the lather formation with soap and increases the boiling point of water. Normally water hardness does not cause any direct health problems, but may cause economic problems. Hardness below 300 mg/l is considered potable but beyond this limit produces gastrointestinal irritation. People of Eloor (80 per cent) opined that their well water is hard as it consumes more soap and lather formation is difficult. Some of them found difficulties in cooking with their well water, so that rice and pulses take more time to get cooked. . Some had reported falling and roughness of hair with the well water (16 per cent). Extremely hard water may lead to increased incidences of urolithiasis. A number of studies have demonstrated that there is statistically significant negative correlation between water hardness and cardiovascular diseases (Ullah *et al.,* 2009). Hard water also deposits incrustation in kitchen utensils as well as increases soap consumption. Such water can thus be both nuisance and economic burden to the consumer.

5.3.2 Chemical oxygen demand (COD)

Mean COD of well water from Eloor and Ollukara is given in table 11. Mean COD of water samples from Eloor was higher than that from Ollukara, but did not differ significantly. The mean COD was 105.19±5.00 and 93.10±2.83 mg/l in Eloor and Ollukara, respectively, Water from Kuzhikandam creek revealed the mean COD of 330.5 mg/l (Table 34). The higher values of COD indicate the presence of oxidizable organic matter (Garge, 1998). The entry of sewage water, industrial effluents and the agricultural runoff might be responsible for increased level oxidizable organic matter (Sisodia and Moundiotiya, 2006). Vattakeril (1997) and Shaji *et al.*, (2009) also observed high COD values in water samples around industrial area.

Seasonal variation in mean COD of well water from Eloor and Ollukara is given in table 12. In Eloor, the highest and lowest COD were observed during summer and monsoon, respectively. The higher COD could be due to death and decay of plants and subsequent increase in organic matter during summer (Kumar *et al.*, 2010). The lower COD observed during monsoon could be due to the effect of dilution. While in Ollukara, highest and lowest COD were observed during post monsoon and pre monsoon, respectively. The entry of sewage water and the agricultural runoff might be responsible for increased level of COD (Sisodia and Moundiotiya, 2006) during post monsoon in Ollukara. Unlined nature of most of the wells might have facilitated this.

5.3.3 Nitrate

Mean nitrate concentration of well water from Eloor and Ollukara is given in table 13. Mean nitrate concentration was 4.16 ± 0.37 mg/l and 4.16 ± 0.13 mg/l in water samples collected from Eloor and Ollukara, respectively. Whereas, water from Kuzhikandam creek had lower nitrate concentration (2.85 mg/l) (Table 34). The observed values were well within the WHO guidelines (2006) for nitrate in drinking water (50 mg/l) and the Bureau of Indian Standards (IS: 10500, 1991) desirable limit (45 mg/l). Shaji *et al.* (2009) reported nitrate concentration in the range of 1.12-4.97 mg/l in well water around Chavara industrial area, Quilon, Kerala. Usually nitrate is not present in pure water. However, nitrate detected in well water samples might have originated from decaying organic matter (Subrahmanyam and Yadaiah, 2001), discharge of sewage and industrial wastes and runoff from agricultural fields containing nitrate fertilizers (Kumar *et al.*, 2008).

Seasonal variation in mean nitrate concentration of well water from Eloor and Ollukara is given in table 14. It was found that in Eloor mean nitrate concentration was lowest during pre - monsoon and highest during post monsoon. In Ollukara, mean nitrate concentration was lowest during summer and highest during post monsoon. The highest mean nitrate concentration during post monsoon might be due to application of nitrogenous fertilizers to agricultural land during rainy season and subsequent seepage through soil. During rainy season, there was reduction in nitrate concentration in Kuzhikndam creek and increased concentration in wells. This could be due to discharge of nitrate from creek to wells under the influence of rain. According to Chattopadhyay *et al.* (2005) seasonal variation of nitrate is mostly caused by plant growth and decay. They observed higher nitrate values in surface waters of Chalakudy river basin, Kerala during June and August, coinciding with the monsoon when there is luxuriant plant growth and abundance of decayed vegetative matter. Singh *et al.*, (2008) also obtained higher nitrate concentration during monsoon than non monsoon season.

Nitrate in drinking water as such are not toxic to health and about 85 per cent of ingested nitrate are rapidly adsorbed from gastrointestinal tract in healthy individuals and excreted by kidney. But usually nitrates are converted to nitrites and toxic effects are encountered and may cause potential health hazards. Higher level of nitrate may cause methaemoglobinemia or Blue- baby syndrome in infants, in which blood loses its ability to carry sufficient oxygen. It may also be carcinogenic in adults. Nitrate may also react with creatinine present in vertebrate muscles to form nitrosarcosine which is carcinogenic (Simmons, 1974).

5.3.4 Fluoride

Mean fluoride concentration of well water from Eloor and Ollukara is given in table 15. Mean fluoride concentration was 0.14±0.02 mg/l at Eloor and 0.04±0.01 mg/l at Ollukara and showed highly significant ($p<0.01$) difference in mean concentration between two areas. The observed values were well within the WHO guidelines (2006) for fluoride in drinking water (1.5 mg/l) and Bureau of Indian Standards (IS: 10500, 1991) desirable limit (1 mg/l). The mean fluoride concentration was 1.05 mg/l in Kuzhikandam creek (Table 34). Detectable level of fluoride was present in wells located near to Kuzhikandam creek and The Fertilizers and Chemicals Travancore Limited (FACT). Fluoride is released into air in gaseous state and in particulate matter from factories producing phosphatic fertilizers (Sharma and Pervez, 2004). This might cause contamination of soil, water and forage not only in the vicinity of the plant, but as far as 14 km. downwind from the factory (Radostits *et al.*, 2007). Udyogamandal division of The Fertilizers and Chemicals Travancore Limited (FACT) in Eloor was such a unit, manufacturing phosphatic fertilizers. Gypsum produced in the factory as a by product during the manufacturing of fertilizers, contains fluoride (Local Area Environment Committee, 2006) (Appendix III). This could be one of the sources of fluoride in well waters of Eloor. Moreover, proximity to sea also elevates the fluoride content of water in coastal zones due to salt water intrusion (CGWB, 2003). The result obtained in Eloor was lower than that observed by Kumar, (2000) in well water of Eloor industrial area. Negligible concentration of fluoride observed in well water from Ollukara might be derived from what was present in the earth's crust. The observed value was lower than that obtained by Kumar (2000) in well water of Mannuthy, Kerala.

Seasonal variation in mean fluoride concentration of well water from Eloor and Ollukara is given in table 16. Significant seasonal difference was not observed in fluoride concentration of well water from Eloor. This might be due to continuous industrial activities irrespective of season. Even then highest concentration was observed during summer and lowest during post monsoon.

From the first hand information from the people surveyed, it was understood that gypsum was accumulated in the compound of the factory itself. This favoured leaching during monsoon season increasing the concentration of fluoride in well water during monsoon. Whereas minimum fluoride concentration observed in Ollukara during monsoon and post monsoon might be due the availability of large volume of water leading to dilution of chemicals present. The high concentration during summer and pre-monsoon could be due to depletion of water leading to the concentration effect (Buragohain *et al.* 2009). However, Singh *et al.* (2008) observed higher fluoride concentration during monsoon than non monsoon in ground waters of North Eastern India.

Fluoride is present universally in almost every water, earth crust, minerals, rock etc. It is also present in toothpaste, drugs, cosmetics, mouth wash etc. A small amount of fluoride is beneficial for human health to prevent dental caries. However when consumed in higher doses (>1.5 mg/l) it leads to dental fluorosis or mottled enamel and excessively high concentration (>3 mg/l) of fluoride may lead to skeletal fluorosis. Crippling skeletal fluorosis can occur in water supply containing more than 10 mg/l of fluoride. Severity of fluorosis depends on the concentration of fluoride in drinking water, daily intake, continuity and duration of exposure and climatic condition. In India an estimated 62 million people, including 6 million children suffer from fluorosis because of consuming fluoride contaminated water (Raju *et al.*, 2009). During the survey, it was found that 6.9 per cent animals were having lameness. This could be attributed to fluoride toxicity through ingestion of contaminated water and forage. Cheeran *et al.* (1987) and Kumar (2000) reported symptoms of fluoride toxicity including lameness, reluctance to move, palpable bony exosotosis particularly in metacarpal and metatarsal, ribs and mandibular bones, in cattle of Eloor industrial area.

5.3.5 Iron

Mean iron concentration of well water from Eloor and Ollukara is given in table 17. Mean iron concentration was higher in Eloor (0.61±.09 mg/l) and had highly significant ($p<0.01$) difference with mean concentration at Ollukara (0.11±0.09 mg/l). The value observed in Ollukara was within the Bureau of Indian Standards (IS: 10500, 1991) desirable limit (0.3mg/l) for drinking water, whereas the value obtained for well water in Eloor was much above this limit. The higher iron content observed in Eloor might be due to the influence of industrial units, discharging iron containing waste products. Analysis of waste products (Local Area Environment Committee, 2006) generated by Hindustan Insecticides Limited (HIL), Merchem Limited and The Fertilizers And Chemicals Travancore Limited (FACT) showed that significant amount of iron is generated by these industrial units (Appendix III). These industries discharge their waste products into nearby creek or other surface water bodies which ultimately leads to ground water contamination in the area. A similar finding was made by Local Area Environment Committee (2006) in well waters of Eloor. Whereas, Reddy and Rao (1995) recorded higher iron concentration (0.762 mg/l) in dug well samples of industrial polluted zones of Visakhapatnam. On the contrary, Nasrullah *et al.*, (2006) obtained lower iron concentration (0.04-0.037 mg/l) in ground water of Gadoon Amazai industrial estate in Pakistan. The iron concentration obtained in Ollukara might be due to the distribution of laterite soil, containing excess iron (Mathew and Thampatti, 2007). Furthermore, leaching of iron can take place easily under existing anoxic condition (Laluraj and Gopinath, 2006).

Analysis of water sample from Kuzhikandam creek revealed mean iron concentration of 6.12 mg/l (Table 34). It was observed that wells located close to Kuzhikandam creek had higher iron concentration in the range of 1-2 mg/l. Even, exceedingly higher concentration of 8.02 mg/l was recorded in one well. Some of the people residing near to Kuzhikandam creek complained that their water often gets red colour and taste of rust. The Assistant Surgeon, of Primary Health Centre, Eloor reported that they often get the complaint of red colour of water.

Seasonal variation in mean iron concentration of well water from Eloor and Ollukara is given in table 18. Significant difference between mean iron concentrations of four seasons could not be observed in Eloor. However, iron concentration was highest during summer (0.95±0.33 mg/l) and lowest during monsoon (0.29±0.02 mg/l). The higher level of iron in groundwater during summer might be due to concentration effect. (Buragohain *et al.*, 2009). Similar observation was made by Laluraj and Gopinath (2006) with increased iron concentration during pre-monsoon and decreased concentration during post monsoon in dug well samples from Muvattupuzha river basin in Kerala. Mean iron concentration in Ollukara during four different seasons showed significant difference. Lower concentration was observed during summer and pre-monsoon, whereas monsoon and post monsoon concentrations were higher with highest during post monsoon. The higher concentration of iron observed during rainy season there could be due to leaching of iron naturally present in laterite soil. The unlined nature of wells in Ollukara facilitated the entry of iron from soil into well, increasing the iron content after rain. Valsalakumar (2003), observed higher iron concentration during monsoon and post monsoon than summer in well water from Nattakom, an industrial area in Kottayam, Kerala and attributed higher iron concentration to the contribution of laterite rocks in deeper layers of soil.

Toxic effect due to exposure to iron leads to abdominal discomfort, lethargy and fatigue. Liver is the major site of iron storage. Excess iron deposition leads to shrinkage of liver, followed by fibrosis and cirrhosis. Congestive cardiomyopathy is the most common defect that occurs with iron overload. Ingestion accounts for most of the toxic effect of iron because iron is absorbed rapidly in gastrointestinal tract. In animals early signs of oral ingestion include drowsiness, depression, vomiting and haemorrhagic diarrhoea. Later dehydration, acidosis, shock and coma may develop. The Senior Veterinary Surgeon of Veterinary Hospital Eloor, opined that digestive disorders, responding quickly to liver stimulants is a common problem in Eloor. This could be attributed to excess iron in drinking water.

5.3.6 Lead

Mean lead concentration of well water from Eloor and Ollukara is given in table 19. Higher lead concentration was recorded in well water from Eloor

(0.56±0.07 mg/l) and was significantly ($p<0.01$) different from that of Ollukara (0.09±0.01), both were above the WHO guidelines, 2006 (0.01 mg/l) and IS: 10500, 1991 (0.05 mg/l) for lead in drinking water. Water sample from Kuzhikandam creek showed a mean lead concentration of 2.27 mg/l (Table 34). It was observed that wells located close to Kuzhikandam creek had higher lead concentration in the range of 0.4-1.8 mg/l. Eloor being an industrial area is subjected to the discharge of effluent containing lead to nearby water bodies. Analysis of waste products (Local Area Environment Committee, 2006) generated by Hindustan Insecticides Limited (HIL), Merchem Limited and Fertilizers And Chemicals Travancore Limited (FACT) showed that significant amount of lead is generated by these industrial units in their waste products (Appendix III). The effluents rich in lead are discharged to water bodies nearby and subsequently affect the groundwater quality of the area. The Environment Impact Assessment on Eloor-Edayar Industrial Belt (Local Area Environment Committee, 2006) obtained lead concentration in the range of below detectable level to 0.44 mg/l in well water samples collected from Eloor. Lead concentration recorded in Ollukara might have originated from lead naturally present in soil. This could also be attributed to lower pH of well water (Rosborg *et al.*, 2003) and soil (Nordberg *et al.*, 1985) in Ollukara, as acidification of soil and water may increasingly mobilise potentially toxic elements such as cadmium, lead and mercury (Nordberg *et al.*, 1985; Aastrup *et al.*, 1995; Johansson *et al.*, 1995). This makes them more available in the food chain.

Seasonal variation in mean lead concentration of well water from Eloor and Ollukara is given in table 20. Even though there was no significant seasonal variation in lead concentration in Eloor, monsoon sample showed lowest concentration (0.03±0.03 mg/l) and pre-monsoon season showed highest concentration. In Eloor, water bodies were exposed to continuous discharge of effluents irrespective of season. This may be the reason for lack of significant seasonal variation in lead concentration in Eloor. Combined effect of decreased amount of water and slight leaching during pre-monsoon shower might have contributed to higher lead concentration during pre-monsoon. Lowest lead concentration was observed during monsoon season and could be attributed to dilution. Ezeronye and Ubalua (2005) and Agbaire and Obi (2009) obtained lower lead concentration during wet season and higher concentration during dry season. It was found that mean lead concentration in Ollukara was highest (0.13±0.01 mg/l) during monsoon (table 16.). This could be attributed to the leaching of lead naturally present in soil during rainy season and may contaminate the ground waters. Singh *et al.* (2008) who assessed the lead content of ground water of North Eastern India observed lower lead concentration during non monsoon and higher concentration during monsoon season.

Acute effects of lead poisoning are hallucination, delusion, poor memory and irritability. Exposure to lead is cumulating over time. High concentration of lead in body can cause death or permanent damage to central nervous system and kidneys. This damage commonly result in behaviour and learning problems, memory and concentration problems, high blood pressure, hearing problem, headache, reproductive problem, digestive problems, muscle and joint pain. Lead poisoning stunts a child's growth, damages the nerves system and cause learning disabilities. It is also linked to crime and antisocial behaviour in children. During the survey, it could be understood that, people in Eloor are affected with headache, blood pressure and musculoskeletal problems. Cases of muscular dystrophy were observed in two families. According to the Assistant Surgeon of Primary Health Centre Eloor, blood pressure was a major problem there with almost 80 per cent of people above the age of 20 years being affected. A case of mental retardation was also observed in one household in Eloor. These could be attributed to lead toxicity. It was noted that a school for mentally retarded children is functioning in the panchayath. In animals lead poisoning causes neurological signs preceded or accompanied by gastrointestinal malfunctions. Death of cattle, following nervous signs as reported by one farmer might be attributed to lead poisoning due to its affinity to nervous system. Abortion in cattle at 5 to 6 month of gestation was also reported by some farmers suggestive of lead toxicity (Sandhu and Brar, 2000). Radostits *et al.* (2007) reported that gastroenteritis is also associated with lead toxicity due to the caustic action of lead on alimentary mucosa. This could account for digestive disorders reported in 55.56 per cent animals in Eloor. Because of size and charge similarities, lead can substitute for calcium included in bone. Children are especially susceptible for lead because developing skeletal system requires high calcium levels. Lead that is stored in bone is not harmful but if high levels of calcium are ingested later, the lead in the bone may be replaced by the calcium and mobilized.

5.3.7 Mercury

Throughout the entire period of study no mercury could be detected in well water samples collected from Eloor and Ollukara. This supports the finding of Cheeran *et al.*, (1987) and Thirunavukkarasu (2000). The reasons for the non detectable level of mercury could be that most of the industries emit only inorganic salts of mercury as effluent which are highly unstable in sediments and could be transformed by anaerobic microorganisms in the water to methyl mercury which get bio accumulated in food chain (Wolfe *et al.*, 1998). Moreover, methyl mercury which is a highly lipid soluble compound could be detected only in sediments, plants or fishes and not in clean well water.

5.3.8 Zinc

Mean zinc concentration of well water from Eloor and Ollukara is given in table 21. Samples collected from Eloor and Ollukara were well within the limit of 5 mg/l as prescribed by Bureau of Indian Standards (IS: 10500, 1991). There was no significant difference in mean zinc concentration between Eloor and Ollukara. But higher concentration was observed in Eloor (0.12±0.01 mg/l). This finding was in agreement with the report of Local Area Environment Committee (2006). Slightly higher zinc concentration observed in Eloor might be due to the influence of Binani Zinc Factory situated at Binanipuram which discharge effluents into river Periyar, inturn affecting the ground water quality of well near to river Periyar. Analysis of waste products generated by Hindustan Insecticides Limited (HIL), Merchem Limited and Fertilizers and Chemicals Travancore Limited (FACT) was conducted by environment impact assessment on Eloor- Edayar

Industrial Belt (Local Area Environment Committee, 2006). The analysis report pointed out that significant amount of zinc is generated by these industrial units (Appendix III). These industries discharge their effluents to Kuzhikandam creek at Eloor, which inturn deteriorate the ground water quality. This also contributed to significantly higher zinc concentration at Eloor. Analysis of well water samples collected from Ollukara also showed zinc concentration which is not significantly different from that of Eloor, but numerically lower. This could have been derived from zinc which is naturally present in earth's crust (80 mg/kg), (Local Area Environment Committee, 2006). Lower pH of groundwater also accounts for higher zinc concentration (Aastrup *et al.*, 1995, Johansson *et al.*, 1995), which might have contributed to some amount of zinc in well water of Ollukara.

Seasonal variation in mean zinc concentration is shown in table 22. The concentration was highest during summer season in Eloor. During summer, depletion of water leads to greater concentration of metals (Buragohain *et al.* 2009). Similar finding was made by Ezeronye and Ubalua (2005) who studied the effect of abattoir and industrial effluents on heavy metal quality of Aba river Nigeria. Mean zinc concentration was highest in post monsoon in Ollukara. This could be attributed to the leaching of zinc present in soil. Singh *et al.,* (2008) who assessed zinc concentration of drinking water of North Eastern India also observed increased zinc concentration during monsoon and decreased concentration during non monsoon.

5.3.9 Cadmium

Mean cadmium concentration of water samples from Eloor and Ollukara are given in table 23. It was observed that mean cadmium concentration was similar in both areas exceeding the WHO guideline (0.003 mg/l) and IS: 10500, 1991 (0.01 mg/l) for cdamium in drinking water. The similar cadmium concentration was also observed in Kuzhikandam creek (Table 34). Nisha (2001) reported a mean cadmium concentration of 0.03 mg/l and 0.01 mg/l in water samples from Eloor and Mannuthy respectively. Analysis of waste products generated by Hindustan Insecticides Limited (HIL), Merchem Limited and Fertilizers and

Chemicals Travancore Limited (FACT) was conducted by Environment Impact Assessment on Eloor- Edayar Industrial Belt (Local Area Environment Committee, 2006), and found that these industries discharged some amount of cadmium in their waste products (Appendix III), deteriorating the groundwater quality. Well water from Ollukara also showed similar amount of cadmium as that of well water from Eloor. This might have been derived from soil, which accumulates cadmium through the application of soil additives such as phosphatic fertilizers and sewage sludge (Ramachandran and D'souza, 1999). Cadmium is found in earth crust at an average concentration of 0.1 mg/kg (Local Area Environment Committee, 2006). Adsorption capacity of soils for cadmium increases with increase in pH of soil (Ramachandran and D'souza, 1999). In Ollukara, due to the distribution of highly acidic laterite soil, adsorption capacity of soil for cadmium might be low leading to availability of free cadmium in soil which in turn enters the groundwater sources. These might be the reasons for cadmium in well water of Ollukara.

Seasonal variation in cadmium concentration of well water from Eloor and Ollukara is shown in table 24. Cadmium concentration was found to be highest in monsoon season in both Eloor and Ollukara. This might be due to leaching of cadmium present in soil. This observation is in agreement with Singh *et al.,* 2008. Cadmium concentration was lowest during summer, as observed by Buragohain *et al.,* 2009 in ground water sources of Dhemaji district, Assam.

Cadmium is found associated with sulphide ores of zinc, copper, lead and is obtained as a by-product during processing of these ores. Cadmium is more mobile in aquatic environment than most other metals. It is also bio accumulative and persistent in the environment. Cadmium has no biochemical and nutritional function and is highly toxic to human being, plants and animals. In human being and animals cadmium causes kidney damage. In lower doses cadmium can produce coughing, headache and vomiting. Relatively higher per cent of digestive system and respiratory system disorders reported in animals and human beings could be attributed to this. In larger doses cadmium can accumulate in liver and kidneys and can replace calcium in bones, leading to painful bone disorders and renal failure. Kidney is considered to be the critical target organ in humans chronically exposed to cadmium by ingestion.

5.4 MICROBIOLOGICAL QUALITY OF WATER

5.4.1 Aerobic plate count (APC)

Mean aerobic plate count of water of Eloor and Ollukara is given in table 25. It was observed that mean APC was higher in Eloor (3.92 ±0.07 log_{10} cfu /ml) than that of Ollukara (2.88±0.06 log_{10} cfu /ml) and the difference was highly significant ($p<0.01$). Prejit *et al.,* (2006) reported a mean APC of 3.38 ± 0.073 log_{10} cfu/ml in dug wells of Thrissur district. Whereas, Latha *et al.* (2003) observed APC in the range of $2.3x10^2$ to $1.03x10^4$ cfu/ml in pucca wells and $9x10^2$ to $3x10^5$ cfu/ml in kutcha wells in and around Thrissur, Kerala.

Ezeronye and Ubalua (2005) who studied the impact of abattoir and industrial effluents on Aba river Nigeria reported in the range of $0.059x10^6$ and $1.01x10^8$. Adekunle (2009) observed 1200-1375 cfu/ml in ground waters within Asa Dam industrial estate, Nigeria. The higher count obtained at Eloor might be attributed to the presence of Kuzhikandam creek, a heavily polluted creek in Eloor and other polluting sources. From the survey it could be understood that 36 percentage of house hold have animals. Close proximity of wells to animal shed is a major contributing factor for increased APC in Eloor. Animal rearing is practiced only in four percentage of household in Ollukara. Seventy two per cent of wells were not covered in Eloor, whereas most of the wells were covered using nets in Ollukara so that chances of contamination are reduced. Forty eight per cent of people at Eloor and 52 percent at Ollukara have practice of disinfection of well. Thirty six per cent wells under study in Eloor were disinfected regularly at the interval of two months. Whereas, in Eloor not even a single well was disinfected at this interval. Turbid nature of well water also impedes with disinfection in Eloor. These might have increased mean APC at Eloor. Even though no significant difference between four seasons was observed in Eloor (Table 26), highest mean count was observed during pre monsoon. In Ollukara significant difference between seasons, could be observed with highest count during summer. It might be due to depletion of water in wells during dry seasons leading higher count due to concentration.

5.4.2 Coliform count

Mean coliform count of well water from Eloor (1.32±0.07 log_{10} cfu /ml) was significantly ($P<0.05$) different from that of Ollukara (0.98±0.07 log_{10} cfu /ml). Higher coliform count in Eloor could be attributed to the effluent discharge from nearby industries (Kumar *et al.,* 2010). Coliform organisms indicate faecal contamination of water. Chances of contamination by animal excreta was also more in Eloor because more farmers own animals and some of them failed to keep more than 15 meters distance between well and animal shed and well and manure pit. Prejit *et al.* (2006) reported mean coliform count of 11.57 ± 2.84 cfu/ml in dug wells of Thrissur district. Mean coliform count was highest during monsoon in Eloor and Ollukara (Table 28). The result was in agreement with Chitanand *et al.,* (2008) who observed higher count of indicator organisms during monsoon season and attributed that to poor filtering action of soil and more percolation as well as seepage of domestic sewage through soil. As per IS: 10500 (1991), coliforms should be absent in 100 ml water. Only 16 per cent samples were within this limit during four seasons.

Presence of coliforms in water indicates faecal contamination faecal contamination. So care must be taken to avoid such organisms.

5.4.3 *Escherichia coli* count

Even though significant difference in mean *E. coli* count between well water from Eloor and Ollukara was not observed, mean *E. coli* count was higher in samples collected from Eloor (0.54±0.08 log_{10} cfu/ml) than that of Ollukara (0.29±0.05 log_{10} cfu/ml). Latha *et al.* (2003) reported *E. coli* count of 0-2 cfu/ml in pucca wells and 0-25 cfu/ml in kutcha wells in and around Thrissur, Kerala. Prejit *et al.* (2006) observed mean *E. coli* count of 11.57 ± 2.84 cfu/ml in dug wells of Thrissur district, Kerala. Higher *E. coli* count observed in well water from Eloor could be attributed to the practice of animal rearing and type of wells. Prejit *et al.,* (2006) found that poorly constructed wells without adequate drainage or covering or platform harbour counts of *E. coli.* In Eloor 92 per cent of wells were uncovered without adequate drainage or platform. This could be the reason for higher *E. coli* counts at Eloor. Seasonal variation in mean *E. coli* count of water from Eloor and Ollukara was as given in table 30. Even though significant difference in mean *E. coli* count between four seasons was not observed in well water from Eloor and Ollukara, mean *E. coli* count was highest during pre-monsoon in both areas. This might be attributed to depletion of water level during dry seasons. As per IS: 10500 (1991), *E. coli* should be absent in 100 ml water. Only nine per cent samples were within this limit in all seasons.

Escherichia coli, a type of faecal coliform bacteria, is found in intestinal tract of warm blooded animals. The presence of *Escherichia coli* in water is an indication of recent sewage or animal waste contamination. Among *E. coli,* O 157: H7 is an emerging waterborne pathogen. This causes severe diarrhoea, renal failure and death.

5.4.4 Enterococcal count

Mean enterococcal count was 0.61±0.08 log_{10} cfu/ml in Eloor and 0.80±0.06 log_{10} cfu/ml in Ollukara and found no significant difference between Eloor and Ollukara. Presence of enterococci in water is a confirmatory evidence of recent faecal pollution of water (Park, 2009). Latha *et al.* (2003) observed enterococcal count of 0-1 cfu/ml in pucca wells and 0-9 cfu/ml in kutcha wells in and around Thrissur, Kerala. Whereas Prejit *et al.* (2006) reported mean enterococcal count of 14.56±6.07 cfu/ml in dug wells of Thrissur district. The slightly higher concentration in Ollukara could be attributed to the proximity of wells to septic tanks, as 36 per cent of wells were very close to septic tank in Ollukara.

Mean count was highest during summer in Eloor. It was pointed out that enterococcal count of Kuzhikandam creek was also highest during summer. This could be attributed to the concentration of organisms due to depletion of water during summer. Whereas, higher count observed during monsoon and post monsoon in Ollukara could be due to seepage from nearby septic tanks, facilitated by unlined nature of wells.

5.5 IMPACT OF INDUSTRIALIZATION ON QUALITY OF WELL WATER IN ELOOR

Major industrial units functioning in study area in Eloor were Fertilizers and Chemicals Travancore Limited (FACT), Hindustan Insecticides Limited (HIL), Indian Rare Earths Limited (IRE) and Merchem Limited. Effluents from these industries are discharged to nearby surface water source which inturn percolate into wells. It is understood that significantly higher total hardness and higher concentration of fluoride, iron and lead recorded in well water from Eloor might have derived from the discharged industrial effluents containing these pollutants.

From the entire study it could be concluded that the potability of water was questionable in both Eloor and Ollukara. It was observed that not even a single sample from Eloor met the specifications for drinking water, WHO guidelines (2006) for nitrate, fluoride , cadmium and lead and IS: 10500 (1991) for pH, total hardness, nitrate, fluoride, iron, lead, mercury, zinc, cadmium, coliform count and *E. coli* count . Whereas, only eight per cent of samples from Ollukara meet these specifications. From the comparative evaluation, it was clear that the groundwater contamination in Eloor is purely chemical origin, while in Ollukara it was attributed to peculiarities of soil type and household pollution. Construction of sanitary wells, keeping adequate distance from polluting sources, with adequate platform, drainage and parapet is recommended. Steining of wells and covering the wells with nets should also be adopted. Disinfection of wells with required amount of suitable disinfectant at regular interval also helps to minimize pollution mainly of microbial origin. Education of households on safe handling and use of drinking water is also recommended.

Summary

6. SUMMARY

In the present study physical, chemical and microbiological quality of well water from Eloor, an industrial area was evaluated and compared with Ollukara, a non industrial area, to correlate the impact of industrialization on quality of well water. A total of 200 well water samples consisting of 100 each from both areas were taken for the study. Of the 100 samples, 25 samples each were collected during four different seasons of the year viz. summer (February), pre-monsoon (March-May), monsoon (June-September) and post-monsoon (October-November), to assess change in the quality of well water with the seasons. The samples were analyzed for physical parameters like temperature and pH, chemical parameters like total hardness, Chemical Oxygen Demand (COD), nitrate, fluoride, iron and heavy metals like lead, mercury zinc and cadmium and microbiological parameters like Aerobic Plate Count, Coliform, *Escherichia coli* and Enterococcal counts. Samples were also collected and analyzed from Kuzhikandam creek of Eloor, into which industries discharge their effluents. The characteristics of wells were assessed through direct observation and practices among people in Eloor and Ollukara were studied by survey using a well designed questionnaire. The impact of industrialization on human and animal health was surveyed. Retrospective study of all cases recorded in Eloor Veterinary Hospital for past five years was carried out and discussions were made with Senior Veterinary Surgeon, Veterinary Hospital, Eloor and Assistant Surgeon, Primary Health Centre, Eloor to study the health problems related to industrialization among animals and human being in Eloor.

Results on temperature of well water revealed that the temperature was higher in Eloor than in Ollukara. The temperature ranged from 27-28.96 °C and 26.32-28.68 °C in Eloor and Ollukara, respectively. The lowest temperature was recorded during monsoon in Eloor and Ollukara, and the highest temperature was recorded during pre-monsoon in Eloor and summer in Ollukara.

The pH of well water in Eloor and Ollukara was 5.99 ± 0.08 and 5.18 ± 0.06, respectively. In both areas pH was higher during monsoon and post monsoon and lower during summer and pre-monsoon seasons.

Mean total hardness of water was significantly ($p<0.01$) higher in Eloor (337.50 ± 38.92 mg/l) than in Ollukara (13.33±0.34 mg/l). Highest value of total hardness was observed during summer in Eloor and monsoon in Ollukara.

Mean COD of water samples was 105.19±5.00 in Eloor and 93.10±2.83 mg/l in Ollukara. In Eloor, the highest and lowest COD were observed during summer and monsoon, respectively. While in Ollukara, highest and lowest COD were observed during post monsoon and pre monsoon, respectively.

Mean nitrate concentration was 4.16 ± 0.37 mg/l and 4.16 ± 0.13 mg/l in water samples collected from Eloor and Ollukara, respectively. In Eloor mean nitrate concentration was lowest during pre - monsoon and highest during post monsoon. In Ollukara, mean nitrate concentration was lowest during summer and highest during post monsoon.

Mean fluoride concentration in well water samples from Eloor (0.14±0.02 mg/l) was significantly ($p<0.01$) higher than that of Ollukara (0.04±0.01 mg/l). No significant seasonal difference was observed in fluoride concentration in well water from Eloor. Whereas, significant seasonal variations were observed in fluoride concentrations in Ollukara viz. lower during monsoon and post monsoon, and higher during summer and pre-monsoon.

Mean iron concentration was higher in Eloor (0.61±.09 mg/l) and had highly significant ($p<0.01$) difference with mean concentration in Ollukara (0.11±0.09 mg/l). Significant difference in mean iron concentrations between four seasons could not be observed in Eloor, whereas in Ollukara, four different seasons showed significant difference. Lower concentration was observed during summer and pre-monsoon and higher in monsoon and post monsoon.

A significantly higher ($p<0.01$) lead concentration was recorded in well water from Eloor (0.56±0.07 mg/l) than that from Ollukara (0.09±0.01). There was no significant seasonal variation in lead concentration in Eloor. Whereas, in Ollukara, there was significant seasonal difference in mean lead concentration with highest (0.13±0.01 mg/l) during monsoon and the lowest during pre-monsoon (0.08±0.01 mg/l).

Throughout the entire period of study no mercury could be detected in well water samples collected from Eloor and Ollukara.

There was no significant difference in mean zinc concentration between well water samples from Eloor (0.12±0.01 mg/l) and Ollukara (0.09±0.06 mg/l). In Eloor, the concentration in summer season was significantly higher than during other seasons. In Ollukara mean zinc concentration in post monsoon was significantly higher than during other seasons.

Mean cadmium concentration was similar in both areas (0.02±0.00 mg/l). It was found to be significantly higher during monsoon season at both Eloor and Ollukara.

It was observed that mean Aerobic Plate Count was higher in Eloor (3.92 ±0.07 $\log_{10}$ cfu /ml) than that of Ollukara (2.88±0.06 $\log_{10}$ cfu /ml) and the difference was highly significant ($p<0.01$). There was no significant difference observed between four seasons was in Eloor. In Ollukara, significant difference between seasons could be observed with highest count during summer.

The mean coliform count of well water from Eloor (1.32±0.07 $\log_{10}$ cfu/ ml) was significantly ($P<0.05$) higher than that of Ollukara (0.98±0.07 $\log_{10}$ cfu/ ml). There was no seasonal variation in mean coliform in Eloor. Whereas significant seasonal variation in mean colifrom count between seasons was observed in Ollukara with highest count during monsoon and lowest during summer.

The mean *E. coli* count in well water from Eloor and Ollukara did not differ significantly with values of (0.54±0.08 log_{10} cfu/ml in Eloor and 0.29±0.05 log_{10} cfu/ml in Ollukara. There was no seasonal difference in mean *E. coli* count between four seasons in well water from Eloor and Ollukara, mean *E. coli.*

The mean enterococcal count in well water samples from Eloor (0.61±0.08 log_{10} cfu/ml) and Ollukara (0.80±0.06 log_{10} cfu/ml) did not show significant difference. In summer, mean count was significantly higher in Eloor. There was no seasonal difference enterococcal count in Ollukara.

From the survey conducted among 25 households having wells in Eloor and Ollukara, it could be concluded that 20 and 100 per cent of households, used well as source of drinking water in Eloor and Ollukara respectively. Eighty percent wells were pucca wells in Eloor, whereas only 60 per cent of wells were pucca in Ollukara. Disinfection of wells was practiced by 48 and 52 per cent respectively in Eloor and Ollukara. Only 32 and 36 per cent wells respectively had distance more than 15 metre from nearest polluting source.

Among the major human health problems in Eloor, 88, 72, 60, 40,12, 4 and 16 per cent of household reported respiratory problems, skin diseases, musculoskeletal diseases, headache, ophthalmic problem, neoplasm and congenital anomalies and mental retardation, respectively. Whereas in Ollukara, health problems were comparatively very less and only 12 per cent house hold reported respiratory problem.

Among the major animal health problems in Eloor, 55.56, 27.59, 24.14 and 6.9 per cent animals had digestive disorders, reproductive disorders, skin diseases and lameness, respectively.

Retrospective analysis of cases recorded in Eloor veterinary hospital, from January 2005 to December 2009, revealed that 26.28, 4.49, 0.58, 3.45, 2.85, 41.48, 4.96 per cent cases were digestive disorders, respiratory diseases, metabolic diseases and deficiency diseases, skin diseases, parasitic conditions and reproductive disorders respectively.

Analysis of water from Kuzhikandam creek in Eloor revealed that the creek was chemically polluted and acts as a source of nearby groundwater sources.

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Appendix

APPENDIX I

Survey on Characteristics of well and practices among people in Eloor and Ollukara.

1. Date of survey:
2. Name and address of head of the family:

Ph.No. Ward No. House No.

3. Details of family members

Sl No.	Name	Age (Y)	Sex	Relationship with head of the family	Occupational details

4. Are you a native of this place? Y/N

How long you are staying here?

.....Years/.....Months

5.Nearest industry and distance from your home

Industry:

Distance: .....m/.....km

6. Health problems among family members

Sl.No	Name	Health problems

7. Where do you go for treatment?

a) P.H.C. b) Private clinic (specify) c) Private hospital (specify)

8. Any of the family members have congenital defects, mental retardation or learning difficulties

Y/N

If yes,

Age: Type of abnormality:

9. Is there any health insurance policies?

Y/N

If yes,

Name of policy:

Number of family members insured:

10. Food habits among family members

Vegetarian Non –Vegetarian

11. Which among the following food items do you produce and consume

a) vegetables b) fruits c) coconut d) chicken e) egg f) fish

g) meat h) others (specify) i) NA

If not consuming, reason:

12. Have any of your neighbours migrated to other places recently? Y/N

If yes, reason

13. Source of drinking water

a) well b) public connection c) others(specify)

14. Practice of drinking

a) boiled b) non-boiled c) other purification methods

14. Source of water for other purposes

a) well b) public connection c) others (specify)

15. Use of well water

a) drinking b) cooking c) cleaning utensils d) washing clothes e) bath/toilet purpose f) gardening g) not using

If not using,

Reason

How long

16. Details of well

(a). Type of well pucca/kutcha

(b). lining present/absent

(c). platform present/absent

(d). parapet present/absent

(e). covering present/absent

(f). depth of well

17. Growth of vegetation inside well present/absent

18. Distance between well and kitchen: m

19. Distance between well and animal shed: .... m

20. Method of disposal of animal excreta

21. Distance between well and place of disposal of animal excreta. m

22. Distance between latrine and well ..... m

23. Distance between neighbour's latrine and well ..... m

24. Distance between domestic waste disposal and well ..... m

25. Distance between well and Kuzhikandam Thodu ..... m

26. Practice of disinfection of well: Y/N

If yes,

a) disinfectant

b) at what interval

27. Testing of well water by any agency Y/N

If yes,

a) agency

b) when and at what interval

c) result

28. The quality of water you are using

a) colour

b) odour

c) taste

d) turbidity

e) hardness

f) others (specify)

29. Quality of air

a) clear without any noxious smell

b) clear with noxious smell

c) smog without noxious smell

d) smog with noxious smell

30. Discomforts during change in air quality

a) dyspnoea b) nausea c) vomiting d) coughing e) sneezing

f) general weakness g) irritation of eyes and epiphora h) head ache

i) others (specify)

31. Details of death

Sl No.	Name	Age	Sex	Relationship with head of the family	Reason for death

32. Rearing of animals Y/N

If yes, Number of animals

Animal	Cattle	Buffalo	Heifer	Calves	Goat	Dog	Cat	Poultry
No.								

33. Feeding

a) stall feeding b) let out for grazing

34. Type of feed

a)concentrate b)green grass c) paddy straw

35. Source of grass/straw

a) locally available b) brought from other places

36. Source of water

a)well b) public connection c) others(specify)

37. Health problems among animals

Animal	Age	Sex	Health problems

38. Details of death

Animal	Age	Reason

39. Is there any animal health insurance policies

Y/N

If yes,

-Name of policy

-Number of animals insured

Appendix II

Composition and reconstitution of media used

1. **Plate Count Agar (Merck)**

Ingredient	gm/litre
Casein enzyme hydrosylate	5
Yeast extract	2.5
D (+) glucose unhydrous	1
Agar- Agar	14
Final pH	7±0.2 at 25 °C

Suspend 22.5 g in 1 litre of distilled water. Dissolve the powder completely by heating in a water bath. Sterilize by autoclaving for 15 minutes at 121 °C

2. **Violet Red Bile Agar (Hi- media)**

Ingredient	gm/litre
Peptic digest of animal tissue	7
Yeast extract	3
Lactose	10
Bile salt mixture	1.5
Sodium chloride	5
Neutral red	0.03
Crystal violet	0.002
Agar -Agar	15
Final pH	7.4±0.2 at 25 °C

Suspend 41.35 grams in 1000 ml distilled water. Heat to boiling to dissolve the medium completely. Cool to 45 °C and immediately pour into sterile petri plates.

3. Eosin Methylene Blue Agar (Merck)

Ingredient	gm/litre
Peptic digest of animal tissue	10
Di potassium hydrogen phosphate	2
Lactose monohydrate	5
Sucrose anhydrous	5
Eosin	0.4
Methylene blue	0.065
Agar -Agar	13.5
Final pH	7.2 ± 0.2 at 25 °C

Suspend 36.0 g in 1 litre of distilled water. Dissolve the powder completely by heating in a water bath. Sterilize by autoclaving for 15 minutes at 121 °C. Cool to 45 °C and immediately pour into sterile petri plates.

4. **KF Streptococcal Agar Base (Hi-media)**

Ingredient	**gm/litre**
Proteose peptone	10
Yeast extract	10
Sodium chloride	5
Sodium glycerophosphate	10
Maltose	20
Lactose	1
Sodium azide	0.4
Bromocresol purple	0.015
Agar	20
Final pH	7.2±0.02 at 25 °C

Suspend 76.4 gm in 100 ml distilled water. Heat to boiling to dissolve the medium completely. Continue heating for 5 more minutes. Cool to 50 °C and add 1 ml of 1 % sterile, 2, 3, 5-triphenyl tetrazolium chloride sodium per 100 ml sterile medium and pour into sterile petri plates.

Appendix III

Main industries in Eloor generating heavy metals and pesticides in Eloor

Products of Hindustan Insecticides Limited, Eloor	
Sl.No	Name of the products
1	DDT(tech)
2	DDT 50% WDP
3	Endosulfan(tech)
4	Hindan 35 EC
5	Dicofol(Tech)
6	Hilfol 18.5 EC
7	Mancozeb 75 WP
8	Recovered Sulphuric acid
9	Recovered Hydrocholoric acid

Analytical data of Sludge of Hindustan Insecticides Limited, Eloor		
Sl.no	Determinant	Concentration (mg/kg)
1	zinc	4560
2	iron	30720
3	lead	1500
4	cadmium	8

(Source: Local Area Environment committee, 2006)

Products of Merchem Limited , Eloor	
Sl.no	Name of the product
1	Accelerators
2	Antioxidant
3	Sodium sulphate

	Analytical data of Sludge of Merchem Limited , Eloor	
Sl. No	Determinant	Concentration (mg/kg)
1	zinc	578.5
2	iron	57750
3	lead	128
4	cadmium	8.2

(Source: Local Area Environment committee, 2006)

Products of Indian Rare Earths Limited	
Sl.no	Name of the products
1	Rare earth chloride
2	Trisodium phosphate
3	Rare earth fluoride
4	Cerium oxides
5	Thorium oxalate
6	Evaporated lye

Analytical data of Sludge of Indian Rare Earths Limited		
Sl.no	Determinant	Concentration (mg/kg)
1	Zinc	115
2	Iron	2372
3	Lead	636
4	Cadmium	6

(Source: Local Area Environment committee, 2006)

Products of Fertilizers and Chemicals Travancore Limited, Eloor	
Sl.no	name of the products
1	Ammonia
2	Phosphoric acid
3	Ammonium sulphate
4	Ammonium phosphate
5	Carbon dioxide
6	Gypsum

Analytical data of Sludge of Fertilizers and Chemicals Travancore Limited, Eloor		
Sl.no	**Determinant**	**Concentration (mg/kg)**
1	Zinc	16.64
2	Iron	634
3	Lead	34
4	Cadmium	6.4
5	Fluoride	368

(Source: Local Area Environment committee, 2006)

ASSESSMENT OF QUALITY OF WELL WAER IN ELOOR, KERALA

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ABSTRACT

A comparative assessment of physical, chemical and microbiological quality of well water from Eloor, an industrial area in Ernakulum District of Kerala, India and Ollukara, a non industrial area, in Thrissur district of Kerala, India, was carried out to correlate the impact of industrialization on quality of well water. A total of 200 well water samples consisting of 100 each from both areas were taken for the study. Of the 100 samples, 25 samples each were collected during four different seasons of the year viz., summer (February), pre-monsoon (March-May), monsoon (June-September) and post-monsoon (October-November), to assess change in the quality of well water with the seasons.

Mean temperature of well water was higher in Eloor than in Ollukara. The lowest temperature was recorded during monsoon in Eloor and Ollukara, and the highest temperature was recorded during pre-monsoon in Eloor and summer in Ollukara. Acidic pH was observed in both areas, with significantly lower pH in Ollukara. Higher pH values were observed during monsoon and post monsoon and lower during summer and pre-monsoon seasons.

Mean total hardness of water was higher in Eloor than in Ollukara and the difference was highly significant. Highest value of total hardness was observed during summer in Eloor and monsoon in Ollukara. Mean COD of water samples showed no significant difference between two areas. In Eloor, the highest and lowest COD were observed during summer and monsoon, respectively. While in Ollukara, highest and lowest COD were observed during post monsoon and pre monsoon, respectively. Mean nitrate concentration was similar in water samples collected from Eloor and Ollukara with lowest concentration observed during pre - monsoon and summer in Eloor and Ollukara respectively, whereas it was highest during post monsoon in both areas. Mean fluoride concentration in well water samples from Eloor was significantly higher than that of Ollukara and no significant seasonal difference was observed in fluoride concentration in well water from Eloor. However, significant seasonal variations were observed in fluoride concentration in Ollukara viz., lower during monsoon and post monsoon, and higher during summer and pre-monsoon. Mean iron concentration was higher in Eloor and had highly significant difference with mean concentration in Ollukara. Significant difference in mean iron concentrations between four

seasons could not be observed in Eloor, whereas in Ollukara, four different seasons showed significant difference. Lower concentration was observed during summer and pre-monsoon and higher during monsoon and post monsoon. A significantly higher lead concentration was recorded in well water from Eloor than that from Ollukara. In Ollukara, there was significant seasonal difference in mean lead concentration with highest during monsoon and the lowest during pre-monsoon seasons respectively. Throughout the entire period of study no mercury could be detected in well water samples from both areas. There was no significant difference in mean zinc concentration between well water samples from Eloor and Ollukara. In Eloor, the concentration in summer season was significantly higher than during other seasons. In Ollukara mean zinc concentration in post monsoon was significantly higher than during other seasons. Mean cadmium concentration was similar in both areas and was found to be significantly higher during monsoon season at both Eloor and Ollukara.

It was observed that mean Aerobic Plate Count was higher in Eloor than that of Ollukara and the difference was highly significant. There was no significant difference observed between four seasons in Eloor. In Ollukara, significant difference between seasons could be observed with highest count during summer. The mean coliform count of well water from Eloor was significantly higher than that of Ollukara. There was no seasonal variation in mean coliform count in Eloor. Whereas significant variation in mean colifrom count between seasons was observed in Ollukara with highest count during monsoon and lowest during summer. The mean *E. coli* count in well water from Eloor and Ollukara did not differ significantly. There was no difference in mean *E. coli* count between four seasons in well water from Eloor and Ollukara. The mean enterococcal count of well water samples from Eloor and Ollukara did not show significant difference. The mean count was significantly higher in Eloor during summer, but there was no seasonal difference in enterococcal count in Ollukara.

From the survey conducted among 25 households having wells in Eloor and Ollukara, it could be concluded that 20 and 100 per cent of households, used well as source of drinking water in Eloor and Ollukara respectively. Eighty percent wells were pucca wells in Eloor, whereas only 60 per cent of wells were pucca in Ollukara. Disinfection of wells was practiced by 48 and 52 per cent respectively in Eloor and Ollukara. Only 32 and 36 per cent wells respectively had distance more than 15 metre from nearest polluting source. Among the major human health problems in Eloor, 88, 72, 60, 40, 12, 4 and 16 per cent of household reported respiratory problems, skin diseases, musculoskeletal diseases, headache, ophthalmic problem, neoplasm and congenital anomalies and mental retardation, respectively, which were suggestive of iron, lead and cadmium toxicity and poor quality of air. Whereas in Ollukara, health problems were comparatively less and only 12 per cent house hold reported respiratory problem. Among the major animal health problems in Eloor were digestive disorders, reproductive disorders, skin diseases and lameness indicating iron, lead, cadmium and fluoride toxicity. Retrospective analysis of cases recorded in Eloor veterinary hospital, from January 2005 to December 2009, also revealed symptoms of iron, lead and cadmium toxicity in animals. It was observed that Kuzhikandam creek in Eloor was heavily polluted and acted as a potent source of groundwater pollution.

From the comparative study, it was clear that the groundwater contamination in Eloor was purely chemical of industrial origin, while in Ollukara it was attributed to the soil type and household pollution. Construction of sanitary wells, keeping adequate distance from polluting sources, with adequate platform, drainage and parapet is recommended. Steining of wells and covering the wells with nets should also be adopted. Disinfection of wells with sufficient quantity of suitable disinfectant at regular interval also helps to minimize pollution mainly of microbial origin.