Studies on "The Soil Piping in the Highlands and Foothills of Kerala to avoid the disaster"

Final Report

Submitted to

National Disaster Management Authority

New Delhi

National Centre for Earth Science Studies

Ministry of Earth Sciences,

Government of India

State Emergency Operations Cell (HVRA Cell)

Dept. of Revenue and Disaster Management

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5.	**Key words**	**Soil piping, Tunnel erosion, Western Ghats, Kerala, highlands, foot hills, dispersive soils, mitigation**
6.	**Abstract**	The “Soilpiping”, also known as “tunnel erosion” is the subsurface erosion of soil by percolating waters to produce pipe-like conduits below ground especially in non-lithified earth materials. In Kerala except Thiruvananthapuram, Kollam and Alapuzha all other districts reported the occurrence of soil piping affected soils. Subsurface tunnelling is wide spread in the affected localities and their size varies from few centimeters to couple of meters. A classicification scheme of the tunnels based on its size was proposed in this study. Multi electrode resisitivity surveys are useful in detecting the presence of subsurface tunnelling. Chemical and physical characteristics of soil are responsible for soil piping. The saprolite clay associated with laterites in the shoulder slopes of the highlands are prone to soil piping. If the exchangeable sodium available in the clay is more than 6% the clay tend to become dispersive clay when associated with water. It is found that the Kaolinite clay with gibbsite containing the exchangeable sodium is prime target for soil erosion. Chemical amelioration and water management are the best options for controlling or mitigating the soil piping. The study has recommended to the Government to declare the soil piping as a state specific hazard in Kerala.
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The local people belongs to Cherupuzha, Chattivayal in Kannur district, Banasurasagar in Padinjarethara village in Wayanad , late Sri V K Balan and Britto Nelliyadukkam in Kasaragod district and Tattekanni and Peringassery in Idukki district are thanked for their support and cooperation with this research programme. The Thirumeni milk producers co-operative society has provided space for keeping automatic weather station. This team thank them for their help.

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G Sankar
Principal Investigator
NCESS

CONTENTS

CHAPTER 1

PROBLEM STATEMENT

1.1 Soil piping or tunnel erosion : definition and formation

The “Soilpiping”, (Figure 1.1) also known as tunnel erosion is the subsurface erosion of soil by percolating waters to produce pipe-like conduits below ground especially in non-lithified earth materials. Soil piping or “tunnel erosion” is the formation of subsurface tunnels due to subsurface soil erosion. Piping is an insidious and enigmatic process involving the hydraulic removal of subsurface soil causing the formation of an underground passage (Ingles, 1968). During rain percolating waters carries finer silt and clay particles and forms passage ways. The resulting "pipes" are commonly a few millimetres to a few centimetres in size, but can grow to a meter or more in diameter. They may lie very close to the ground surface or extend several meters below ground. Once initiated they become cumulative with time, the conduits expand due to subsurface erosion leading to roof collapse and subsidence features on surface. Since it happens in the underground, in many cases the phenomenon goes unnoticed. The cavities or pipes developed below the ground grow with respect to time and affect large extents of land in the form of subsidence thereby making it not suitable for cultivation. Occasionally the subsurface flow of water can result in conduits (pipes) through relatively insoluble clastic deposits. The piping results in caving and collapse of surficial conduits. This is an important process in the head ward extension of gullies, especially in arid semi-arid regions. The materials most subject to piping include fine- grained alluvium or colluvium, and some rocks (especially clay stone, mudstone and siltstone). The piping process involves a relatively weak, incoherent layer that becomes saturated and conducts water to some free face which transects this layer. The free face could be the wall or head of a gully, the head cut of a landslide, or a manmade excavation. Even though the pipe may be small when it first develops, it forms a conduit more permeable than the surrounding material.

As a result, the pipe will draw the subsurface flow from the weak, incoherent layer. The more flow that it carries the faster it will grow by enlarging its diameter and by head ward sapping. As the increased flow rates through the pipes further corrodes this conduit, the walls and roof may collapse. This produces a line of sinks, which then act as tunnel to convey surface runoff in to the developing pipes. The downstream portions of the pipe will be completely collapsed leaving an open gully. The general similarity of this process to karst formation (involving mainly solution) has led to “pseudokarst” being used for landforms that originate by piping.

(a) **(b)** (**c**)

Figure 1.1 *Soil piping effects (a) Land subsidence, (b) Tunnel formation and* ***(c)*** *Outlet of a pipe*

1.2 Global distribution

Piping is far more widespread than has often been assumed, forming in virtually all climates, in organic and mineral soils, on undisturbed and agricultural land and in certain unconsolidated sediments and bedrock (Jones, 1981; Dunne, 1990; Bryan and Jones, 1997). Soil pipes have been reported in a wide range of environments on every continent except Antarctica, from the tropical rain forest (Elsenbeer and Lack, 1996; Putty and Prasad, 2000) to periglacial regions with permafrost (Gibson et al., 1993; Quinton and Marsh, 1998; Carey and Woo, 2000; 2002). Piping appears to be of greatest geomorphological and hydrological significance in three environments: in organic soils on humid uplands, in bad land areas in arid and semiarid environments, and in degraded semiarid rangelands (Bryan and Jones, 1997). Piping in Histosols and Gleysols seems to require a humid temperate climate. In a literature review, Jones (1994) found that 60% of the studied sites with piping occurred in humid regions (Figure. 1.2). On the other hand, dispersive-type pipes occur in a Mediterranean or semiarid context. In a wetter climate, sodium is lost so rapidly from the materials by leaching that the dispersive role on the clay complex does not persist (Churchman and Weissman, 1995; Faulkner, 2006). Also, in humid climates, the organic matter remains a structuring agent within the topsoil. In drier climates, clay is frequently the only structuring agent, so its dispersion has a dramatic impact (Faulkner, 2006). Both a reasonable water supply and some desiccation effects are needed, which gives peaks in the in the occurrence of piping in the semiarid and temperate marine environments (Bryan and Jones, 1997).

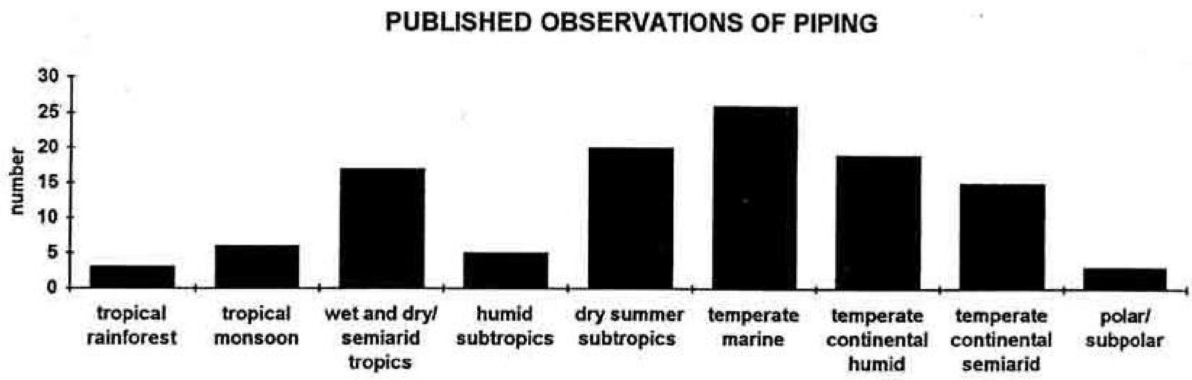


Figure 1.2 *The global distribution of published reports of Piping according to Jones 1994*

1.3 Piping materials and the process:

Tunnel erosion results from a complex interaction of chemical and physical processes associated with clay dispersion, mechanical scouring, entrainment and mass wasting. The tunnel erosion process was first described by Downes (1946) and more recently by Boucher (1990) and Vacher et al. (2004b). Occasionally the subsurface flow of water can result in conduits (pipes) through relatively insoluble clastic deposits. The piping results in caving and collapse of sacrificial conduits (Figure 1.3). This is an important process in the head ward extension of gullies, especially in arid semi–arid regions .The materials most subject to Piping includes loess, tuff, volcanic ash, fine- grained alluvium or colluviums, and some rocks (especially clay stone, mudstone and siltstone).

Field tunnel erosion may be initiated by a range of processes including loss or disturbance of vegetation resulting in the development of soil cracks and generation of surface runoff (Downes 1946; Crouch 1976; Laffan and Cutler 1977), formation of gully erosion which provides an outlet for water flow (Boucher and Powell 1994), increased infiltration due to ponding (Vacher *et al*. 2004*a*, 2004*b*), or disturbance and poor consolidation of dispersive clays (Ritchie 1965, 1963; Richley 1992). Overland flow with low electrolyte concentration enters the soil via desiccation cracks, resulting in the dispersion of sodic clay subsoil’s (Crouch 1976; Laffan and Cutler 1977). Provided the soil matrix has sufficient permeability to minimise pore blockages (Vacher et al. 2004*b*), dispersed soil material moves down slope through soil cracks, leaving behind a small tunnel or cavity (Richley 1992). Further rainfall events entrain and translocate more dispersed soil material, resulting in both head ward and tail ward linking of cavities into a continuous tunnel system (Laffan and Cutler 1977; Boucher and Powell 1994; Zhu 2003). Tunnel expansion enables flowing water to scour the base and undercut sidewalls, resulting in tunnel expansion through mass wasting (Laffan and Cutler 1977; Zhu 2003). Eventually undermining reaches an extent where complete roof collapse occurs and gullies form (Laffan and Cutler 1977). The general similarity of this process to karsts formation (involving mainly solution) has led to “pseudokarst” being used for landforms that originate by piping.

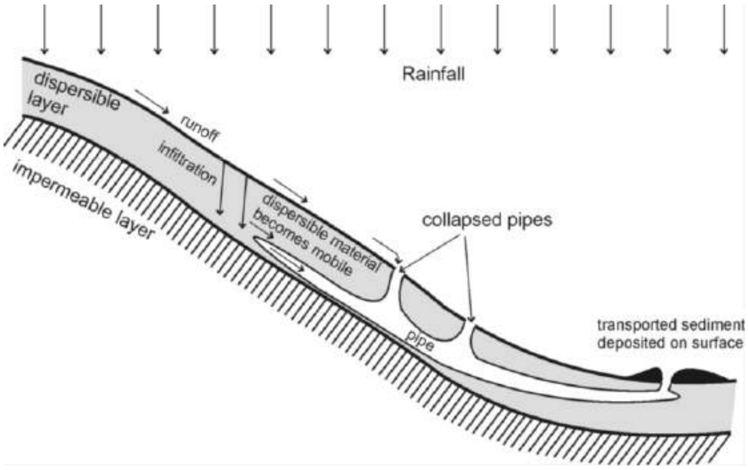


Figure 1.3 *Diagram illustrating the process of piping (Boucher, 1990)*

Piping most commonly occurs where dams and dikes, or deep ,pumped ,excavations below the water table have created large hydraulic head differentiate over relatively short distances .Such differences in head can become competent to transport disaggregated clastic rock particles ,such as sand grains ,in suspension through the more permeable parts of a permeable formation. By this kind of subterranean erosion pipes are formed ;the surficial expression of this process is commonly called “ boiling”(Jumikis,1962).Such pipes usually develop called in sand ,sand –and- gravel ,or in fine grained materials such as silt and clay. They will, unless controlled, undermine foundations and cause collapse of overlying structures. Piping with which engineers are most familiar is a direct result of man –made changes in hydraulic head in the ground water system at a construction site. However, exactly the same kind of piping can develop in nature without man’s interference or help.

Piping occurs on hillside slopes (Figure 1.3), on the crowns and the sides of miniature Badlands Mountains, and in bad land ravine or gully channels, valley floor, flood plain, terrace etc. However in all cases ,the basic essentials are all the same : (1) Water enough to saturate some part of the soil or bedrock above base level;(2)hydraulic head to move the water through a subterranean route;(3) presence of a permeable ,erodible soil or bedrock above the base level ;and (4)an outlet for flow.

1.4 Forms of piping

Piping takes many forms and performs a variety of functions. But most fundamentally for both geomorphology and hydrology it provides a rapid means of subsurface flow, erosion and runoff generation. Ritchie (1963) describes 3 forms of tunnel erosion (i) field tunnelling, (ii) tunnelling in earthworks i.e. ‘piping’ in dams, and (iii) tunnelling in strongly self- mulching clays. The first 2 forms of tunnelling are regarded as ‘true’ tunnelling, which result from the dispersion of sodic subsoils, while the third form of tunnelling is thought to be a purely mechanical process associated with water movement through large soil cracks. United States Department of the Interior (1960) and Vacher et al. (2004a, 2004b) have also reported the existence of tunnel erosion process in non-dispersive material resulting from the liquefaction of non-cohesive soils and mine spoil containing high silt and sand content.

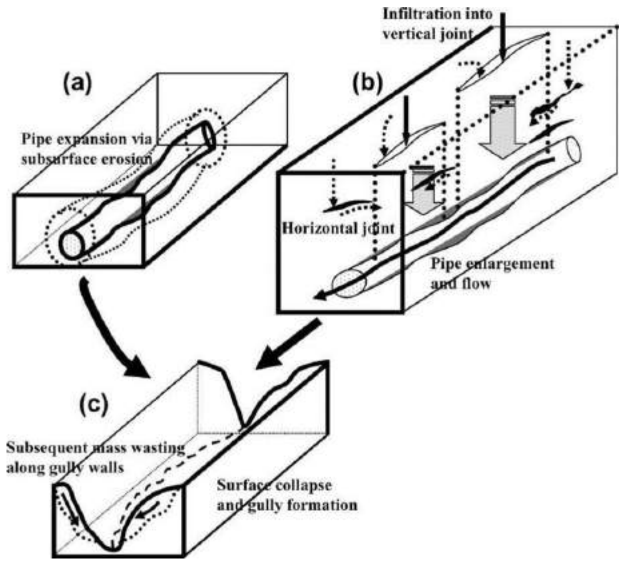


Figure 1.4 *Schematic of subsurface piping as a mechanism of gully formation (Billard et al., 1993)*

In the highlands of Kerala soil piping affects the lateritic areas. The saprolite clay is usually affected by this process. Depending on the size of the clay layer the resultant tunnel is formed. This is described in detail in subsequent chapters.

1.5 Soil texture

Considerable emphasis has been placed upon textural analyses in literature, despite the fact that properties such as structure, porosity, erodibility and drainage are of more direct relevance to the development of piping (Jones, 1981). Nevertheless, the best developed piping occurs in soils with high silt-clay content, which may favour piping by providing cracking potential, easily eluviated particles and stronger roofing to prevent destruction (Jones, 1981). Furthermore, the clay mineralogy plays a role in the susceptibility to piping of dispersive material. The specific mineralogy and the particular arrangements of the clay platelets will determine how ‘active’ they are in terms of physical changes (e.g. deflocculating) (e.g. Sumner, 1992; Sumner and Naidu, 1997; Faulkner, 2006; Impermeable soil layer Decreasing water permeability in the subsoil is an important factor for piping as pipes are often reported to develop at significant subsurface textural discontinuities in so called ‘duplex’ soils or texture-contrast soils (e.g. Rooyani, 1985; López Bermúdez and Romero Díaz, 1989; Fitzpatrick et al., 1995). Soil horizons with slightly differing clay content will experience differential swelling and shrinkage (Imeson and Kwaad, 1980). This differential swelling causes stresses and creates macro-pores, hence focusing through flow and pipe enlargement in particular horizons (Faulkner, 2006). Additionally, the occurrence of a highly permeable stratum underlain by impermeable strata is often reported as a requirement for piping (e.g. Parker and Jenne, 1967; Bryan and Yair, 1982; Farifteh and Soeters, 1999). Fletcher et al. (1954) stated that for piping to occur, a surface infiltration capacity greater than the subsoil permeability is needed, unless rodents or ploughing break the less permeable surface.

1.6 Human activity and land use change

Human activity has been blamed for the development of piping erosion in many parts of the world. According to Jones (1981), the problematic human activities can be divided into two categories: those which affect soil stability and those which affect the local water balance. The most commonly cited elements of human interference have been clearing land for agriculture and overgrazing, but also irrigation and construction works (Jones, 1981). Reduced protection of the soil by vegetation loss and livestock trampling leads to Irregular infiltration, which favours piping erosion (Downes, 1946; Parker, 1963; Bryan and Jones, 1997).

1.7 Chemical properties

Structural stability of a soil is affected by its salt and sodium content. In addition, cementing agents in sands and silts are lime (CaCO3) and sesquioxides (Al- and Fe-oxides). Assessment of the risk of mineral clogging of drainpipes as a result of the chemical composition of the soil requires knowledge of the cation exchange capacity, and the salinity and sodicity of the soil.

The pH of soil is the measure of hydrogen ions activity and depends on relative amounts of the absorbed hydrogen and metallic ions. It measures the acidity and alkalinity of a soil water suspension and provides good information about the soil properties such as phosphorous availability, base status and so on. Most of the soils that are prone to soil piping have pH values lying between 4 and 8.

The most significant effect of piping appears to be in the acidification of surface streams. Piping reduces the buffering of acid rainfall by reducing residence times and by directing flow through the upper organic horizons, reducing contact with weathering mineral surfaces (Jones and Hyett, 1987;

Gee and Stoner, 1989). It may also encourage the release of sulphates and organic acids from the peaty horizons by draining and aerating sections of the hillside (Jones, 1997b).

Electrical conductivity of the soil is a numerical expression of the ability of a soil-water mixture to carry an electrical current which depends on the total concentration of the ionized substances dissolved in the soil-water mixture. In soils, most of the focus has been on the effect of ESP and electrolyte concentration (EC) on excessive swelling and dispersion, and on the subsequent effects on hydraulic conductivity and crust formation on drying. Quirk and Schofield (1955) and many others since that time (Quirk 2001) have used plots of ESP against electrolyte concentration to define regions of stable versus reducing hydraulic conductivity or soil flocculation versus deflocculation / dispersion. They investigated the permeability of a soil to solutions of different SAR and EC.

Where comparatively low EC water is allowed to move through potentially dispersive soils, the leaching of salts out of the profile may produce spontaneous dispersion leading to the formation of tunnels. Hence, Hosking (1967), (quoted by Crouch, 1976) concluded that the only practical way of preventing tunnel development is to divert water away from the catchment areas of the tunnels.

Soils may contain slightly soluble salts such as lime and gypsum and highly soluble salts such as sodium chloride and sodium sulphate. The anions predominantly present in salty soils are Cl^- and SO_4^{2-}, yet some HCO_3^- at pH values of 6-8 and CO_3^{2-} at pH values higher than 8.5 may be found. Na^+, Ca^{2+} and Mg^{2+} are the predominant cations. The total dissolved solids (TDS) can be accessed from measuring the electrical conductivity (EC). The EC-value and TDS are linearly related (Richards, 1954).

Dispersive soils, or sodic soils, collapse or disperse to form dissolved slurry when in contact with fresh water (rain).These soils are highly prone to erosion often leading to tunnel or gully erosion .Unlike other forms of erosion, dispersion and tunnel erosion result from an imbalance in soil chemistry.

1 Tunnel erosion results from a combination of both chemical dispersion and physical transport of dispersed clay particles.
2 Soils with greater than 6% exchangeable sodium are prone to dispersion. The investigating team shall carry out physical, chemical and geotechnical analysis of the soil in the affected areas to understand the causes of piping. The subsurface mapping /investigation would require equipment such as, imaging resistivity meters and vibration sensing equipment. Tracer studies will also be conducted to determine the pipe layout and GPR studies shall be initiated wherever

required. Also come up with site specific mitigation measures to minimize/ arrest the process.

Soil piping is not an instant or as sudden process; it takes years depending on the area and type of soil present over there. Rosewell (1970) identified two preconditions that required for the formation of piping erosion (1) the soil must disperse into the water that moves through the soil and (2) the soil must have sufficient permeability in either the soil matrix or macro pores to enable the movement of dispersed clay particles without blockage. The physical properties which favors for the cause of piping are slope, elevation, rate of flow of underground water, structure, texture, porosity, and permeability of erodible material, chemical properties of soil like, clay mineralogy, pH, sodic soils, and electrical conductivity of soils. Until and unless these factors are not favorable, the soil may not be eroded and piping may not occur.

No single factor or group of factors is universally responsible for the development of piping (Jones, 1981), but the initiating factors vary in different situations. The conditions essential for piping listed by Parker (19630) are

- Sufficient water to saturate some part of the soil or rock above base level.
- Sufficient hydraulic head to remove the water through the subterranean route.
- A susceptible medium (Sacrificial deposit or rock) to convey the water through the subterranean route.
- An outlet for the flow.

Added to this in Kerala highlands soil piping is observed only where thick laterite cover is there. Dispersive clays associated with the saprolite layer below the laterite column is the ideal loci for soiling piping processes. The input of water may be from animal burrows or wilted region of long tap roots or infiltration pits etc.

1.8 Land subsidence by soil piping

Land subsidence is a gradual settling or sudden sinking of Earth’s surface due to removal of earth materials.

Land subsidence causes many problems including:

- Changes in elevation and slope streams, canals and drains
- Damage to bridges, roads, railroads, storm drains, sanitary sewers, canals, and levees
- Damage to private and public buildings
- Failure of well casings from forces generated by compaction of fine-grained material in aquifer systems.

- Permanent inundation of land, aggravates flooding, changes topographic gradients and ruptures the land surface.
- Reduces the capacity of aquifers to store water.

Due to its ability to destroy property on a large scale, subsidence is a very expensive type of mass wasting that also poses some risk to human lives.

Usually Land subsidence occurs naturally and artificially. Natural subsidence occurs due to many factors. Land subsidence can occur over a large area and smaller areas. Subsidence is a global problem. Lowering of the land surface of large areas has been a major unintended consequence of ground water and petroleum withdrawal by humans. In the limestone terrains the subsidence occurs due to development of solution cavities underground. Land subsidence can also occur in underground mining localities especially coal mines. Subsidence due to soil piping is mainly due to loss of subsurface support. Water percolating through pervious surficial materials gets diverted to weak pervious portions and the dispersive soils also carries out with this water leading to huge cavities. In order to produce surface subsidence, the erosion mechanism is believed to require three conditions (Aalen, 1969): (1) an impermeable stratum at the top of pervious easily erodible material to form as a roof for the tunnel formed, (2) water must have access to the erodible material with sufficient head to transport grains of silts or sand and (3) proper outlets available for the disposal of flowing water and carrying sediments.

1.9 Land subsidence in Kerala

During the last decade many piping incidences were reported by the Revenue department from different places in Kerala. In the beginning it was believed that this process is also due to landslides. In 2005, NCESS (then CESS) has investigated (Sankar 2005) land- subsidence in the Chattivayal locality of Thirumeni village, Kannur, Kerala. It was found out to be due to soil piping process. This was the first major incidence reported by NCESS on soil piping. At that time it was thought that it may be an isolated incidence. But subsequently such incidences were reported from many places in Kannur, Kozhikode and Idukki. After investigating the incidences reported from places like Chattivayal (Taliparamba taluk, Kannur district), Palakkayam (Mannarkkad taluk, Palakkad district), Pasukkadavu (Vadakara taluk, Kozhikode district), Padinjarethara and Kunnamangalam Vayal (Vythiri taluk, Wayanad district), Venniyanimala (Thodupuzha taluk, Idukki district) Peringassery , Tattekanni and Karuppilangad (Thodupuzha Taluk, Idukki district) Udayagiri (Udumbanchola taluk, Idukki) it was confirmed this process needs detailed studies. The recurrence of the phenomenon of soil piping during every monsoon in Thirumeni and Pulingom villages of Cherupuzha the matter was brought to the notice of the State Disaster Management Authority. Realizing the gravity of situation NDMA based on a proposal submitted by NCESS through SDMA sanctioned funds for this study. Subsurface soil erosion due to piping often results in land degradation. The cavities and pipes developed below the ground grow with respect to time and affect large extents of land in the form of subsidence, thereby making it not suitable for cultivation and related activities. *In short erosion due to piping in an area is like cancer affecting the human body. If unattended, it will spread and destroy vast amounts of valuable land in the State.*

In India there are not much work in this subject especially from a hazard point of view. Not much literature was also not available on India especially Kerala incidents. This handicap might reflect in this work. However an attempt has made here to bring out different aspects of soil piping problem in the highlands and foot hills of Kerala.

CHAPTER 2

OBJECTIVES AND METHODOLOGY

The objectives and methodology as projected in the project proposal is as follows;

2.1 Objectives

2.1.1 Document the areas affected by tunnel erosion/ soil piping in Kerala.

2.1.2 Determine the extent of the underground pipes using geophysical and geological methods.

2.1.3 Determine various physical and chemical processes taking place in the affected area in order to understand causative factors of piping.

2.1.4 Suggest mitigation measures to minimize or arrest this process.

2.2 Methodology

2.2.1 **Creation of a data base with primary and secondary data**:

Data regarding soil piping affected regions of the state is non-existent since this feature is not subjected to any studies in the state or for that matter in the country itself. Most primary surveys were done for data collection. Field surveys were carried out to collect the details of the piping affected locality. Tunnels surveys are extremely dangerous because of lack of oxygen at certain tunnels, improper lighting and chances of roof collapse. The tunnels which are old are relatively safe but they are infested with bats and at times reptiles. The secondary data was collected from Revenue department, Village and Taluk offices. The newspaper reports were also helpful in this study. As such no background data on soil piping in the state was available except the investigations carried out by the CESS since 2005. Data on soil piping affected places were tabulated in an excel format incorporating various aspects such as location, Lat/long, Village name, Panchayat, Taluk, District, type of pipes present, slope, geology etc. The locational data was correlated with different themes such that Geology, lineaments, drainage, administrative areas etc. on a GIS format to understand any locational affinity of these occurrences.

2.2.2 **Determination of Chemical characteristics responsible**

Soil piping or tunnel erosion is the combined result of chemical as well as mechanical processes. In order to understand the processes happening here samples collected from different soil horizons were subjected to chemical analysis. XRF analysis were carried out at NCESS to determine the major minor and trace elements and XRD analysis were also conducted at NCESS to determine the clay mineralogy. Wet chemical analysis was carried out in various labs including NCESS.

2.2.3 Determination of physical, geotechnical properties

Geotechnical investigation had been done on the piping affected regions to find out the various geotechnical properties of soil. Geotechnical properties of the soil affect the soil piping phenomenon are well understood. Undisturbed soil samples were collected from various regions and geotechnical properties (texture, Attenborough limits, shear strength/factor of safety etc.) evaluated from geotechnical lab of NIT Calicut and NIT-Kurukshetra.

2.2.4 Determination of the extent of the underground pipes

This study involved the study of the tunnels and cavities formed by soilpiping process. Since these tunnels and cavities are situated underground, indirect methods were used for detecting and mapping them. This study has depended on the geophysical tools to understand the subsurface features. Ground Penetrating Radar (GPR) was not available to this team so, electrical resistivity methods were used for field surveys. Standard four electrode aqua meters as well as multi electrode resistivity meter were used to study the underground cavities and tunnels.

2.2.5 Mitigation trials.

Since the soil piping is the result of both chemical and hydrological processes, any method to neutralise this process should address to these two aspects. Chemical field trials require large quantities of chemicals to be applied in the field, so laboratorary trails were conducted. The hydrological interventions in the field also requires huge funds for intervention work so designs based on filed data were made for implementation by the Government agencies.

2.3 Study area

This project documented and studied the areas affected by piping in the Western Ghats and its foothills in the state of Kerala. Out of the 14 revenue districts in the State , excepting Thiruvananthapuram, Kollam, Alappuzha Kottayam and Malappuram were found to be affected by soil piping. This study covered the entire highlands and foot hills of the Kerala state as mentioned in the proposal.

CHAPTER 3

SOIL PIPING IN THE STUDY AREA

3.1 Study area

This project documented and studied the areas affected by piping in the Western Ghats and its foothills in the state of Kerala. This study covered the entire highlands and foot hills of the Kerala state as mentioned in the proposal. Kerala State, bounded by north latitudes 8º17'30" and 12º47'40" and east longitudes 74º51'57" and 77º24'47" covers an area of 38,864 sq km and is located in the southwestern part of the Indian Peninsular shield. The state is divided into 14 districts. This linear strip of land is bounded by the Western Ghats on the east and the Arabians ea on the west. The state is divisible into four broad physiographic units. They are: (i) the low-level coastal strip fringing the Lakshadweep sea ranging in altitudes between 0-30 m, (ii) the landforms marked by laterite cappings between altitudes of 30m and 200 m, (iii) the foot hills of Western Ghats ranging in altitude from 200m to 600 m and (iv) the steeply rising Western Ghat hill ranges with altitudes reaching upto 2500 m.

3.1.2 Areas affected by soil piping

Data base on soil piping indicate that this phenomenon occurs in many areas in the Western Ghats of the Kerala region. Many of piping are located at Idukki and Kannur, Kasaragod and then followed by Kozhikode, Palakkad, Ernakulam, Pathanamthitta, and Wayanad. Data base prepared is being updated incorporating newer incidents. Data in the excel format (table 3.1) also in the GIS format (Figure 3.1) are being stored.

The data reveals that from the southern districts of Kollam and Trivandrum there are no reports of piping incidents. There are no reports of piping from the coastal districts of Alleppy coastal areas of the state. Incidents are reported from only highlands and foothills of the state. Even incidents of piping is reported at the time of writing this report from Kannur and Palghat districts. The piping events are severe in Kannur and Kasaragod districts. The Cherupuzha panchayat in the Kannur district is the most affected Panchayat in the state with the available database.The piping process is found to be extending into the nearly Coorg region of Karnataka state also.

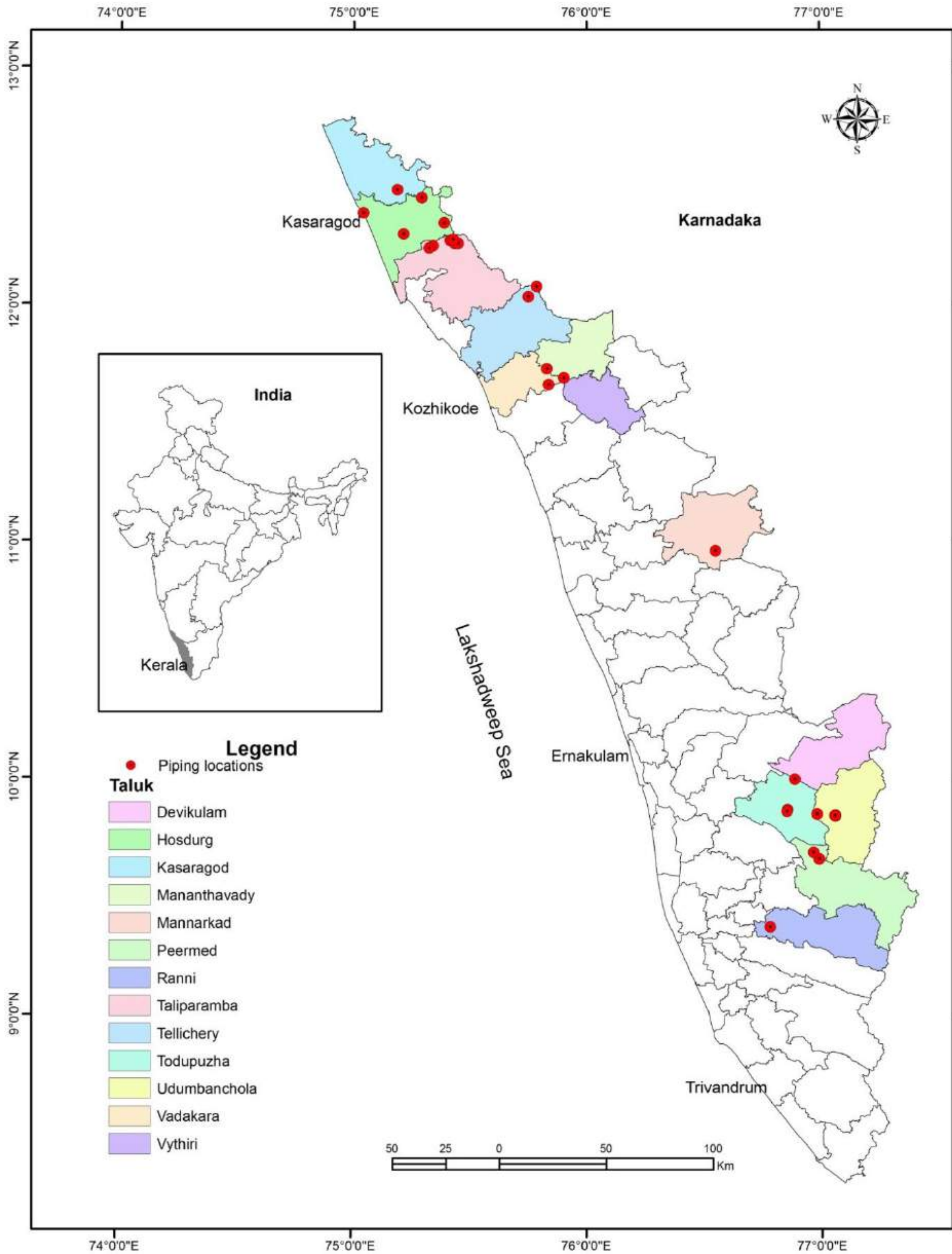


Figure 3.1 *Areas affected by soil piping in Kerala*

Geology

Geologically, Kerala region shows four major rock formations, namely, crystalline rocks of precambraian age, sedimentary rocks of tertiary confined to Neogene period, laaterites capping the crystalline and sedimentary rocks and recent and sub recent sediments forming the low-lying res and river valley. There are poradic paleozoic granites and pegmatite and Meso-cenozoic dykes intruding these rocks. The oldest rocks so far dated in Kerala are charnockites, which yielded an age of 2930 ± 50 Ma (Soman 1997&2002).Southern part of the State, south of Achankovil shear zone, exposes an assemblage of migmatised meta sedimentary and meta igneous rocks (Khondalite-Charnockite assemblage From north of the Achankovil shear zone upto the southern flank of the Palaghat Gap, the rocks are predominantly charnockites, charnockitic gneisses Munnar region representing the western continuation of the Madurai block in Tamil Nadu. Within the southern part of the Palaghat Gap, charnockite patches and hornblende biotite-gneisses are predominate. Towards the central and northern part of the Gap, migmatitic gneisses (hornblende biotite gneisses) and occasional patches of amphibolites, calc-granulite and granites are observed. Northern flank of the gap consists of a meta sedimentary sequence of khondalite and calc-granulite with crystalline lime stone bands. Granulites, schists, and gneisses, intruded by acid and alkaline plutons constitute the northern most part of the State (Soman**,** 2002; Figure 3.2). Khondalites are essentially garnet silliminite gneisses containing varying amount of graphite. These group of rocks are in abundance in areas south of Achankoil shear zone in the Thiruvananthapuram and Kollam districts. The data base indicates that the piping incidents rare in areas south of Achankovil where Khodalites are in abundance. Where as in areas dominated by Sargur group in Wayanad and Southern Karnataka soil piping incidences are prominent. The incidences are reported from areas where there are thick formations of laterites over the base crystalline rocks. Such incidences are reported from Idukki, Kozhikode districts. Soil piping incidences are not reported from Tertiaries or recent sediments in Kerala.

The state is gifted with ten soil types derived from the laterite base and has 12 distinct agro climatic zones. The undulating topography vibrant climate and vivacious hydrology in the background of ever active tectonics results in 44 river basins, 1750 sub basins and 4452 mini watersheds providing multitudes of lively micro ecosystems.

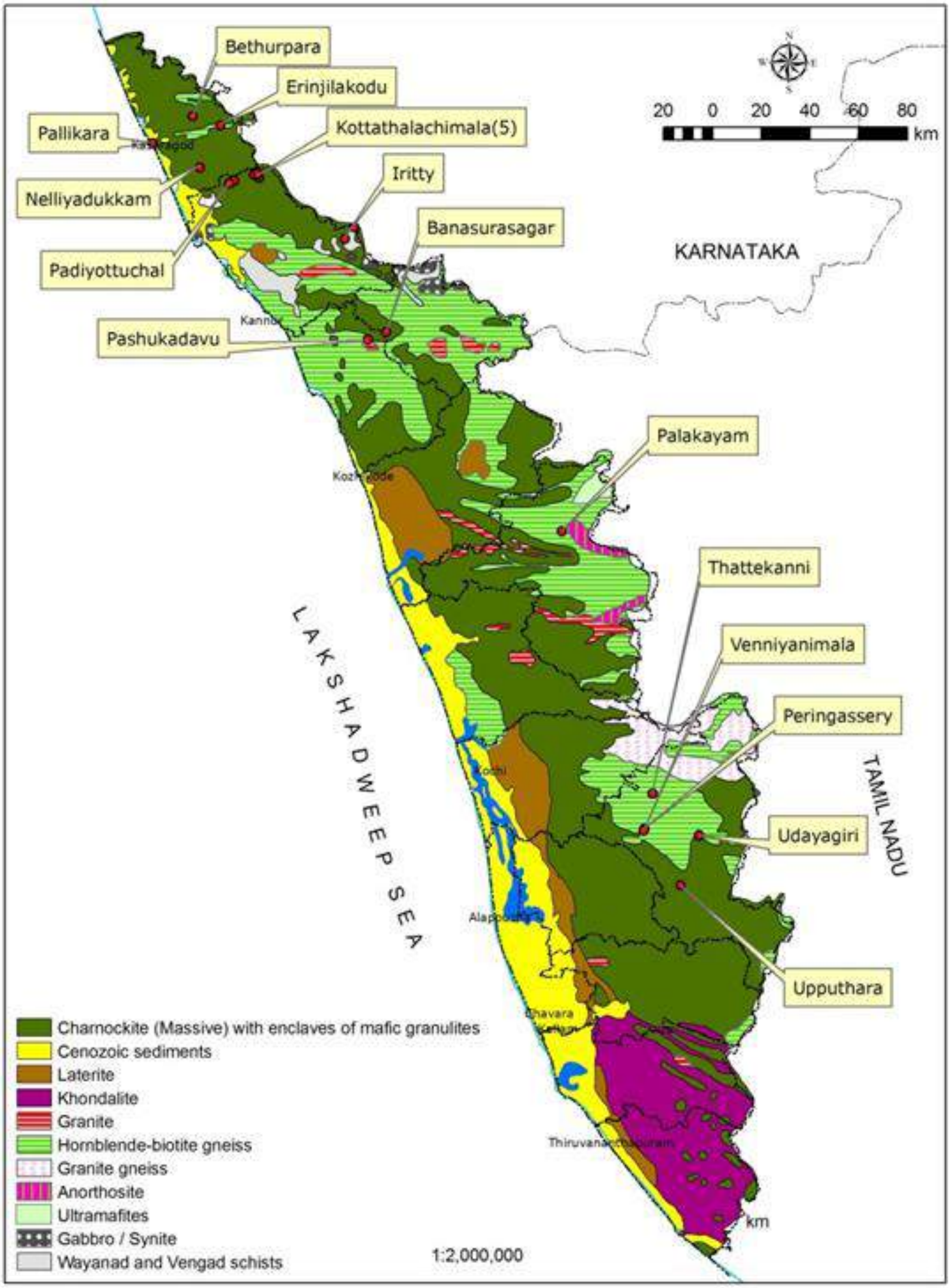


Figure 3.2 *Areas affected by soil piping in Kerala (Geology map: Courtesy GSI)*

Table 3.1 The places affected by soil piping in Kerala

District	**Taluk**	**Panchayat**	**Location**	**Co-ordinates**		**Remarks**	**Geology**	**Slope**	**Elevation m**	**Landuse**	**Soil**	Types of Pipe*
Idukki	Elemdesam	Peringassery	Peringassery	N 9º52'02.9"	E 76º51'28.4"	Well like subsidence and tunnel across the state highway	Charnokite (massive) with mafic granulite	This unit is on slope of 15 to 25 per cent	271	Mostly rubber platation, also coffee and cocoa	Deep well drained soil with strongly acidic, gravelly sand and gravelly clay subsoil layer with 30 to 60 percent gravel, lateritic soil	Small pipe in a well like subsidence
Idukki	Thodupuzha	Kanjikuzhi	Thattekanni	N 9º59'49.2"	E 76º53'18.3"	Mature tunnelling across the state highway	Hornblend biotite gneiss	This unit is on slope of 15 to 25 per cent	270	Mostly rubber platation, also coffee and cocoa	Deep well drained soil with strongly acidic,gravelly sand and gravelly clay lateritic soil	Mature pipe in combination with small pipe
Idukki	Thodupuzha	Kanjikuzhi	Venniyani Mala	N 9º51'39.3"	E 76º51'16.8"	Stabilized pipe	Charnokite (massive) with mafic granulite and Hornblend biotite gneiss	the general slope is +30degrees	492	Mostly rubber platation	Deep well drained soil with strongly acidic,gravelly sand and gravelly clay subsoil layer with 30 to 60 percent gravel, lateritic soil	Mature pipe
Idukki	Mariyapuram	Mariyapuram	Mariyapuram	N9°50'55.26"	E76°58'59.7"	Well like subsidence, occurred in Loose soil	Charnokite (massive) with mafic granulite and Hornblend biotite gneiss	the general slope is +30degrees	653	Rubber, Cacao, Coffee and Pepper	Loose soil on the near surface layer and the bottom layer contain fine grained red coloured clay rich lateritic soil.	Mature pipe

Idukki	Udumbanchola	Udayagiri	Udayagiri	N 9º50'39.3”	E 77º03'36.7”	Widespread occurrence	Charnokite (massive) with mafic granulite and Hornblend biotite gneiss	the general slope is +30degrees	973	Mostly rubber platation	Loose soil on the near surface layer and the botton layer contain fine grained red coloured clay rich lateritic soil.	Mature pipe
Idukki	Udumbanchola	Udayagiri	Udayagiri	N 9º50'31.7”	E 77º03'34.5”	Widespread occurrence						Mature pipe
									972			Mature pipe
Idukki	Udumbanchola	Udayagiri	Udayagiri	N 9º50'30.8”	E 77º03'36.7”	Widespread occurrence			970			Mature pipe
Idukki	Udumbanchola	Udayagiri	Udayagiri	N 9º50'31.7”	E 77º03'35.7”	Widespread occurrence			973			Mature pipe
Idukki	Kattapana	Upputhara	Nalaam Mile	N9º39'34.0"	E76º59'29.4"	Well like subsidence		This unit is on slope of 15 to 25 per cent	810	Mostly rubber and tea platation	Loose unconfined soil layer, and is in acidic nature, easily erodable.	Mature pipe
Kannur	Thaliparamba	Cherupuzha	Kottathalachimala	N 12º15'36.1”	E 75º26'08.7”	Type area for soil piping	Charnokite (massive) with mafic granulite	The upper slope is high slopes (+31^0) where as the lower slopes are about 24^0 .most of the piping occuered in break in slope	492	Mostly rubber platationand some part covered with forest	forest loamy soil -They are generally acidic and dark reddish brown to by a surf, Lateritic soil- which is the weathered product delivered under humid tropical conditions, they range from sandy loam to red loam.	Mature pipe, associated with small and Juvanile pipes
Kannur	Thaliparamba	Cherupuzha	Kottathalachimala	N 12º16'16”	E 75º25'48.8”	Type area for soil piping			485			Mature pipe
Kannur	Thaliparamba	Cherupuzha	Kottathalachimala	N 12º16'22.5”	E 75º25'21.8”	Type area for soil piping			233			Mature pipe
Kannur	Thaliparamba	Cherupuzha	Kottathalachimala	N 12º16'23.2”	E 75º25'02.2”	Type area for soil piping			415			Mature pipe
Kannur	Thaliparamba	Cherupuzha	Chattivayal	N12º15'34.1"	E75º26'08.7"	piping			414			Mature pipe

Kannur	Thaliparamba	Cherupuzha	Tabore	N12º15'37.9"	E75º27'00.2"	Medium sized tunnel affecting the foundation of house	Charnokite (massive) with mafic granulite		505		Lateritic soil in the area is highl clay contant porous, pitted, with red yellow, brown-gray and mottled colour	Mature pipe
								The slope terrain is less than 15degree	453	cashew trees and rubber plantation	Duricrust layer on the top of the land and underlined by lateritic soil, Laterite in the area is porous, pitted, with red yellow, brown-gray and mottled colour	Mature pipe
Kannur	Thaliparamba	Thirumeni	Thirumeni	N 12º15'36.0"	E 75º26'45.7"	First major occurrence reported						Over size
Kannur	Thaliparamba	Peringom	Padiyottuchal	N12º14'59.21"	E75º20'33.7"	Oversized tunnel			186			Mature pipe with lot of branching
Kannur	Thaliparamba	Peringom	Vayakkara	N12º04'42.1"	E75º47'15.9"	A complex oversized tunnelling in a habitats area			195			Over size
Kannur	Thaliparamba	Peringom	Ummrampoyil	N12º14'23.7"	E75º19'33.6"	Oversized pipe			180			Mature pipe with lot of branching
								The slope is less than 15 degrees		areca palm and rubber plants	Lateritic soil in the area is highl clay contant porous, pitted, with red yellow, brown-gray and mottled colour	Over size
Kannur	Iritty	Ayankunnu	Niranganpara	N12 2' 9.39"	E75 45' 7.19"	A complex mature tunnelling beneath a well						Over size
Kasaragod	Kasaragod	Kuttikol	Kuttikol	N12°29'12"	E75°11'22.9"	Stabilized oversized pipe	Charnokite (massive) with mafic granulite	The slope is less than 15 degrees	148	cashew trees and rubber plantation	Duricrust layer on the top of the land and underlined by lateritic soil, Laterite in the area is porous, pitted, with red yellow, brown-gray and mottled colour	Mature pipe

Kasaragod	Vellarikund	Karinthalam	Nelliyedukkam	N12º17.965	E75º13.042	Massive tunnelling affected houses above		The slope of the locality is more than 25 degrees	37	cashew trees and rubber plantation	Laterite in the area is porous, pitted, with red yellow, brown-gray and mottled colour	Mature pipe
Kasaragod	Kanhangad	Panathadi	Erinjilakodu	N12º27'09.3"	E75º17'37.6"	Mature and long tunnel		The slope is less than 15 degrees	125		Duricrust layer on the top of the land and underlined by lateritic soil, Laterite in the area is porous, pitted, with red yellow, brown-gray and mottled colour	Mature pipe occurs in combination with typical and small pipes
Kasaragod	Kanhangad	Pallikara	Pallikara	N12º23'15.8"	E75º02'39.2"	Affected State high way in the coastal lowland		The slope is less than 10 degrees	24	Cocanut aracanut plants	Brown hydromorhic soil are confined to solids are brown in colour and the surface texture varies from sandy to clay. Erodable clay rich laterites	Young pipe
Kasaragod	Vellarikund	Karinthalam	Mattankadavu	N12º20'50.5"	E75º23'24.8"	Mature tunnel		The slope of the locality is more than 25 degrees	54	cashew trees and rubber plantation	forest loamy soil -They are generally acidic and dark reddish brown to by a surf, Lateritic soil- which is the weathered product detivered under humid tropical conditions, they range from sandy loam to red loam	Mature pipe

Palakkad	Mannarkad	Thachampara	Palakkayam	N10° 57' 42.55"	E76° 33' 9.82"	Very localised small & young feature	Hornblend biotite gneiss	foot slope	180	Mixed crops	Virgin Forest Soil are rich in humus and organic matter and Black Cotton Soil is used for the cultivation of cotton. They exhibit mud cracks and have high water retaining power.	Mature pipe
Kozhikode	vadakara	Maruthomkara	Pasukadavu	N11º 39' 53"	E75º50'18"	Younger tunnelling in a landslide affected area	Charnokite (massive) with mafic granulite and Hornblend biotite gneiss and granite intrusion are seen	Slope +25	356	rubber	Lateritic soil is derived from the laterite under tropical climate with alternate wet and dry conditions. It is reddish in colour and well drained gravelly to clayey. The organic matter in the soil is very less with	Mature pipe, associated with small and Juvanile pipes
Pathanamthitta	Ranni	Kollamula	Pampa valley	N 9º22' 22.8"	E76º46' 55.2"	Well like subsidence	Charnokite (massive) with mafic granulite	Slope +25	60	Mostly rubber platation	weathering of the country rock under forest cover in major parts of Ranni blocksand also Lateritic soil is the most widely occurring in tis area This soil is the product of lateralization of the crystallines and sedimentaries under humid	Mature pipe occurs in combination with typical and small pipes
Wayanadu	Vythiri	Padinjarethara	Banasurasagar	N11º41'33"	E75º54'16"	Tunnelling affecting houses, location near to an Earth dam	Charnokite (massive) with mafic granulite and Hornblend biotite gneiss	The slope of the locality is less than 25 degrees	736	Mostly rubber platation	Loose soil on the near surface layer, it is highly erodable, permeable in nature,	Mature pipe, associated with small and Juvanile pipes
Wayanad	Mananthavady	Valamthode	Valamthode	N11°43'52.9"	E75°49'52.7"	Associated with a Landslide	(massive) with mafic granulite and Hornblend	The slope of the locality is less than 25 degrees	817	Mostly rubber platation		Small pipe associated with landslide

* Explained towards the end of this chapter

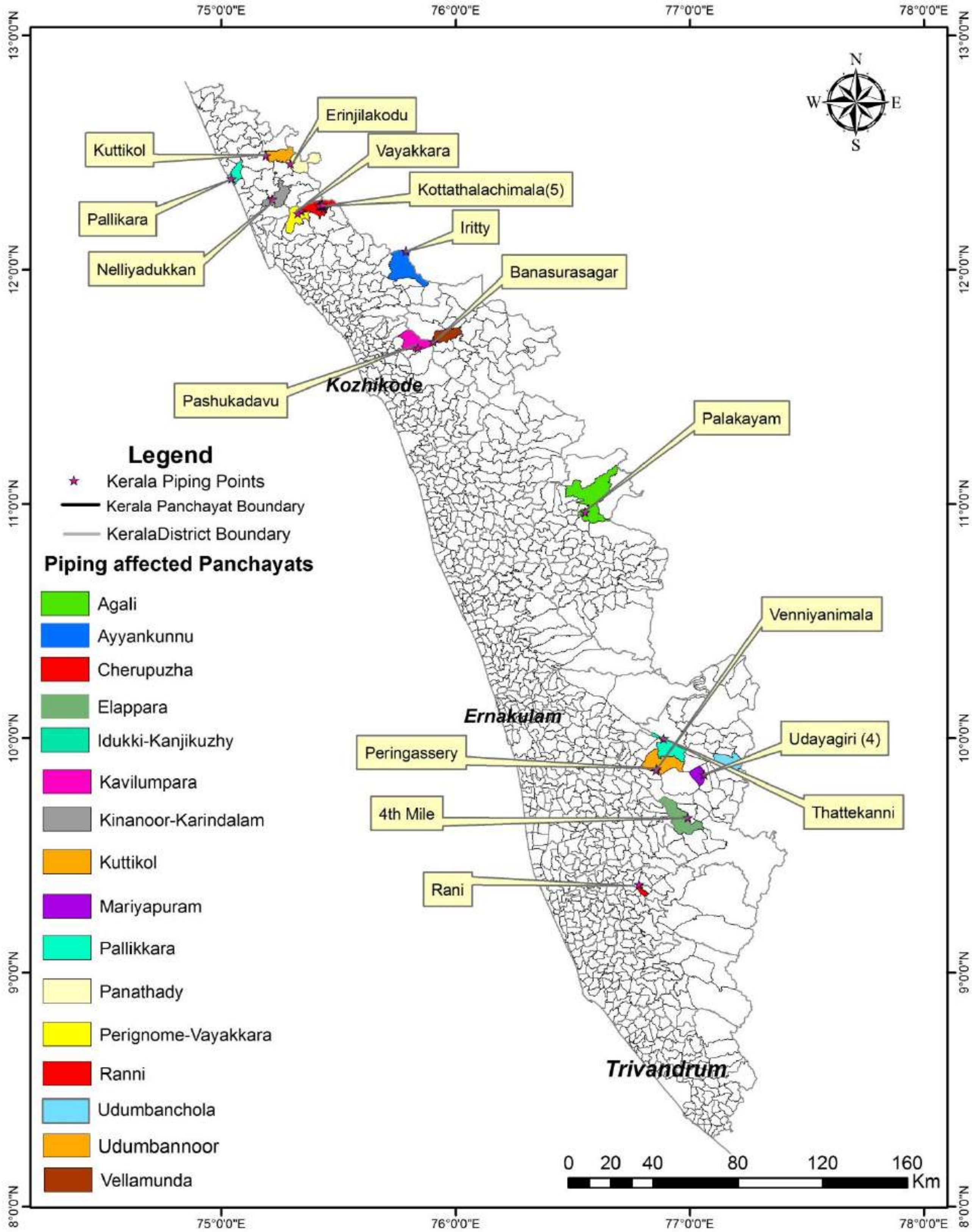


Figure 3.3 : Piping events in various Panchayats

3.1.4 Geomorphology

Geomorphologically the state can be divided into four main domains from east to west, ie., the Western Ghats, the foothills, the midland and the coastal low- land.

Western Ghats- is a continuous mountains, gorges, and deep-cut valleys. The Western Ghats form a wall of mountain penetrated near Palakkad; here, natural mountain pass known as Palghat Gap break through to access inner India. A breach in the continuity of the range marks the Palghat Gap with a sinisterly shift of 50 km between the shifted crests. The Wayanad plateau and Munnar upland fall within the zone. It forms almost an unbroken wall guarding the eastern frontier and helps the people of Kerala to lead a sheltered life of their own through centuries. The Western Ghats is also responsible for the high and steady rainfall in Kerala. It converts 48% of Kerala into highlands and studied with more than 40 peaks above 5000feet above mean sea level. Anamudi is the highest peak in South India. The hill ranges of the Western Ghats rise to an altitude of over 2500m above the MSL and the crest of the ranges marks the inter-state boundary in most of the places. The elevated lands slopes play host to groves of rubber and fruit trees in addition to other crops such as black pepper tapioca and other.

Foothills- The foothills of the Western Ghats comprise the rocky area from 200 to 600m.above MSL. It is a transitional zone between the high -ranges and midland.

Midland region- This forms an area of gently undulating topography with hillocks and mounds. Laterite capping is commonly noticeable on the top of these hillocks. The low, flattopped hillocks forming the laterite plateau range in altitude from 30-200m and are observed between coastal low-land and the foothills.

Coastal low- land- Coastal low-land is identified with alluvial plains, sandy stretches, abraded platforms, beach ridges, raised beaches, lagoons and estuaries. The low- land and the plains are generally less than 10m above MSL.

Soil piping is observed mainly in the highland and its foothills of the state. However micro and small pipes (pipe types are described in the subsequent chapters) are observed in the lateritic cutting in the midlands. The toppling and other failures occurring in the laterite cuttings along the railway lines are classic examples of this. The failure of the railway cutting near Mulanthuruthy is associated with water saturation of the laterite cutting due to micro and small pipes.

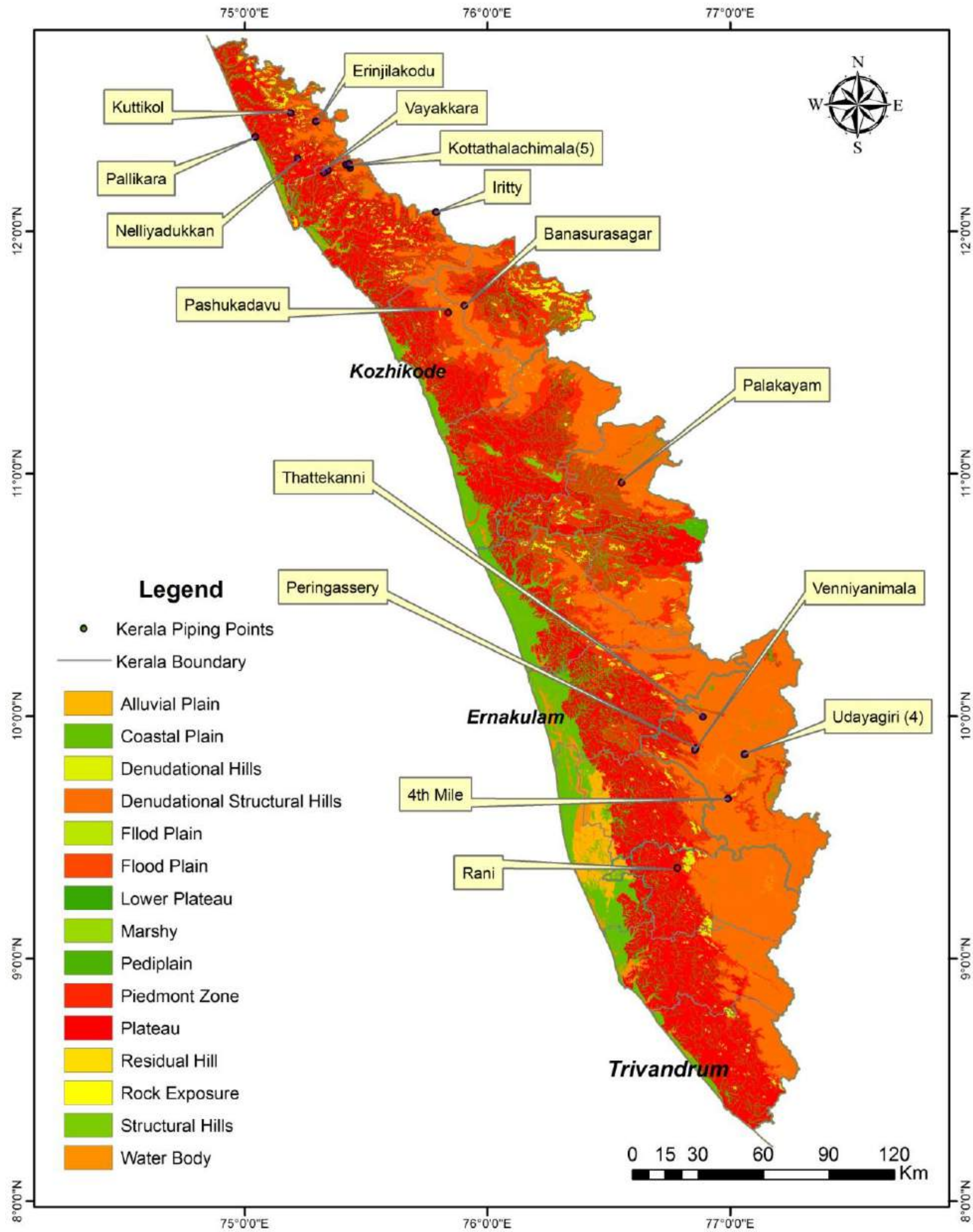


Figure3.4: Geomorphology of Kerala with piping points

3.1.5 Soil type

The soil survey department of Kerala has come out with the following types for the Kerala soils.The topo-lithosequence of Kerala along with variation in rainfall, temperature and alternate wet and dry conditions particularly from the western coast to high ranges in the east and swift flowing rivers lead to the development of different types of natural vegetation and soil. The soils of Kerala can be broadly grouped into coastal alluvium, mixed alluvium, acid saline, kari, laterite, red, hill, black cotton and forest soils (Figure 3.5).

a. Coastal alluvium

These soils of marine origin are identified along the coastal plains and basin lands as a narrow strip. The elevation of the coastal area is generally below 5m MSL. The area has high water table and in some areas it reaches above the surface during rainy season. The soils of the coastal plains are very deep with sandy texture. The texture generally ranges from sand to loamy sand with greyish brown to reddish brown and yellowish red colour. Sand content ranges from 80% and clay up to 15%. Even though these soils have high water table, the water holding capacity is poor due to the predominance of sand. Coconut is the major crop in the area. Cashew and other fruit trees are also grown

b. Mixed alluvium

These soils are developed from fluvial sediments of marine, lacustrine and riverine sediments or its combinations. They occur below 20m MSL in the lowland plains, basins, valleys and along the banks of major rivers. The mixed alluvium is mainly noticed close to coastal alluvium, Kuttanad and adjacent area and kole lands of Thrissur district. The soils are frequently flooded and submerged. The soils of depressions and broad valleys are subject to occasional flooding and stagnation. The ground water table of these soils is generally high and it reaches above the surface during rainy season. A wide variation in texture is noticed in these soils. Sandy clay loam to clay is the predominant texture. Sandy loam soils are also met with. Light grey to very dark brown is the common colour of the soil. Paddy, other annuals and seasonal crops like banana, tapioca and vegetables are grown here.

c. Acid saline soils

Acid saline soils are present throughout the coastal area in patches with very little extent. Major area of this soil is identified in the coastal tract of Ernakulam, Thrissur and Kannur districts. The area under these soils comprise of low-lying marshes, waterlogged and ill drained areas near the rivers and streams, which are subject to tidal waves. Sea and backwater tides make these soils saline. During monsoon season, when rainwater and fresh water from rivers enter the fields, salinity is partially washed off. The area under these soils occurs mostly on plains at or below sea level. A wide variation in texture from sandy loam to clay is noticed with dark grey to black colour. Paddy is the only crop that can be cultivated.

d. Laterite soils

Laterite and laterite soil are the weathering products of rock in which several course of weathering and mineral transformations take place. This involves removal of bases and substantial loss of combined silica of primary minerals. In laterite and laterite soils, over acidic rocks, induration and zonation are more pronounced. This induration is greater if the iron content is higher. These soils mainly occur in the midlands and part of lowlands at an elevation of 10 to 100m above MSL as a strip between the coastal belt and hilly mid-upland. The area comprises of mounds and low hills with gentle to steep slopes. Laterite soils are generally suitable for most of the dryland crops. It is mainly cultivated with coconut, arecanut, banana, tapioca, vegetables, yams, pepper, pineapple, fruit trees etc. The percentage of gravel content in the soil and reduced soil depth limits the choice of crops. In laterite outcrop area with shallow soils, only cashew can be grown with vegetables.

e. Black cotton soils

These soils are identified in alluvial plains, terraces and undulating plains of Chittur taluk in Palakkad district in patches. The elevation of the area ranges from 100 to 300m above MSL with gentle to moderate slope. These soils are developed on Khondalite suite of rocks traversed by lenticular bands of crystalline limestone and calc-granulites. These soils are very deep, black and calcareous. The texture of the soil ranges from clay loam to clay. They possess high shrink-swell capacity and hence exhibit the characteristic cracking during dry periods. A variety of crops such as coconut, sugarcane, cotton, chilly, pulses and vegetables are grown here.

f. Red soils

These are found mostly in the southern parts of Thiruvananthapuram district and in pockets in catenary sequence along the foot slopes of laterite hills and mounds. These soils are identified in undulating plains of lowland with a general slope of 3 to 10%. These are mostly very deep and homogeneous in nature. The texture of the soil generally ranges from sandy clay loam to clay loam with red to dark red colour. Gravels are rarely noticed in these soils. A variety of crops such as coconut, arecanut, banana, yams, pineapple, vegetables, fruit trees etc., can be grown under proper management.

g. Hill soils

The hill soils mostly occur above an elevation of 80m MSL. The area is hilly and has highly dissected denudational hills, elongated ridges, rocky cliffs and narrow valleys. The general slope range is above 10%. The texture of these soils generally ranges from loam to clay loam with average gravel content of 10 to 50%. In addition, stones and boulders are noticed in the subsoil. These soils have reddish brown to yellowish red/strong brown colour. Generally, increase in clay content is noticed down the profile. The depth of the soil varies considerably from 60 to 200 cm depending on the lie of the land, erodibility of soil and past erosion. These soils are mostly friable and subject to heavy soil erosion. The area is suitable for all dryland crops like rubber, coconut, arecanut and fruit trees based on the topography. Crops such as banana, pepper, pineapple, vegetables can be grown in foot slopes.

h. Forest soils

These soils are developed from crystalline rocks of archaean age under forest cover. They occur along the eastern part of the State, generally above an elevation of 300m above MSL. The area is hilly and mountainous with steep slopes, escarpments, elongated rocky summits and narrow 'V' shaped valleys. The depth of the soil varies considerably depending on erosion and vegetative cover. The soils are generally immature due to slow weathering process. Rock outcrops and stones are noticed on the surface. Gneissic boulders under different stages of weathering are noticed in the subsoil. The texture of the soil ranges from sandy clay loam to clay with reddish brown to very dark brown colour. Forest trees, shrubs and grasses are grown here.

The soil types are important for the development of soil pipes or initiation of piping. A clay rich horizon with well drained upper soil layers with poorly drained lower strata are the ideal scenario for pipe development. That is the reason why such incidences are more in lateritic areas.

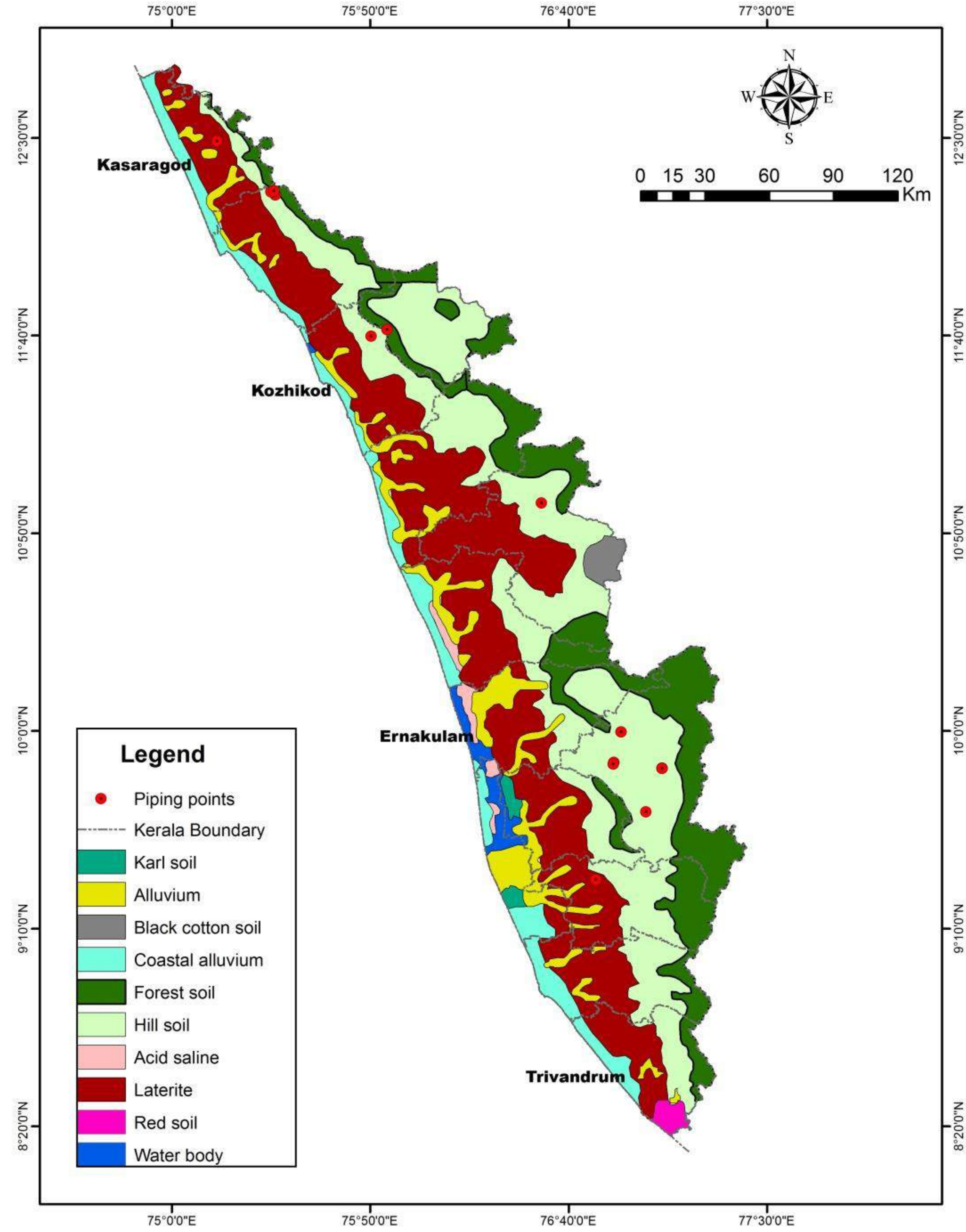


***Figure 3.5**: Soil map of Kerala with Piping locations*

(source: Soil survey department, Kerala)

3.1.6 Drainage network of Kerala

Kerala is drained by 44 rivers, many of which originate from the Western Ghats (figure 3.6). Except Kabini, Bhavani and Pambar which are east- flowing, the rest of rivers are west- flowing and join the Arabian Sea.

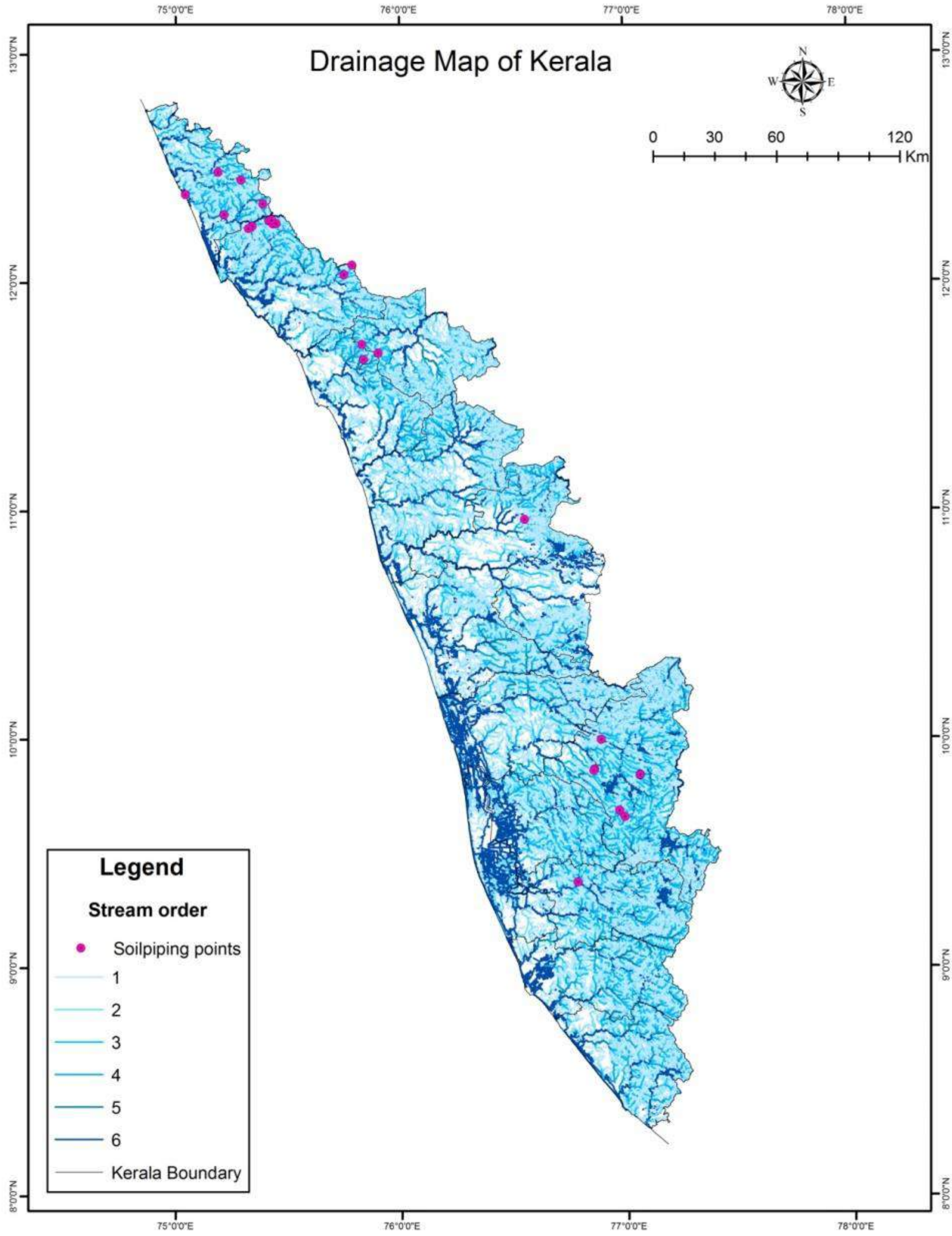


Figure3.6*: Drainage map of Kerala with piping points*

A few of them drain into the backwaters. Most important rivers (with their length in km in paranthesis) of the state, are Chandragiri(105), Valapatnam (110), Achankovil (120) Kallada (121), Muvattupuzha (121), Chalakudy (130), Kadalundi(130), Chaliyar (169), Pampa (176) ,Bharathapuzha (209) and Periyar (244).The soilpiping process is closely associated with the surface and subsurface hydrology. Also this process requires sufficient hydrologic head to remove the clay particles to down slope regions. Like landslides in the Western Ghats, the soil piping also initiates in the topographic hollow regions where the first order streams exist. The subsurface configuration usually develops like the dendritic pattern of the surface drainage with higher and lower order streams. The entire surface and subsurface hydrology is thus affected by this process. This is indicated by the non-recharging characteristics of the open wells in the affected localities.

3.1.7 Landuse

According to 2011 census, the population density of the state of Kerala is very high (859/km^2) when compared to the national average (382/ km^2) . The landuse in general by and large controlled by the topography of the region (Figure 3.7). In The eastern highland region is characterised by the forests and plantations. In plantation type tea, rubber and coffee dominates. There is teak plantations associated with the forests. The foot hills and midlands are dominated by the rubber plantations and mixed crops, whereas the coastal areas are mostly urbanised and supports coconuts and mixed crops. Coastal areas are dominated by wetlands such as coastal lagoon and estuaries.

The highland lands and its foot hills are the areas dominated by the plantations and deforested areas . The replanting of rubber plants takes place after 20-22 years, the taproot remains and it acts as conduits for transmitting water to the lower clay horizons. Cultivation of tuber crops attracts borrowing animals which in turn makes conduits on the ground to promote quick water inflow to the lower layers of the weathered horizon. Since the pH and the exchangeable sodium play an important role in soil piping processes, the role of fertilizers need detailed review. So far the piping incidences are widely reported from plantations and deforested areas.

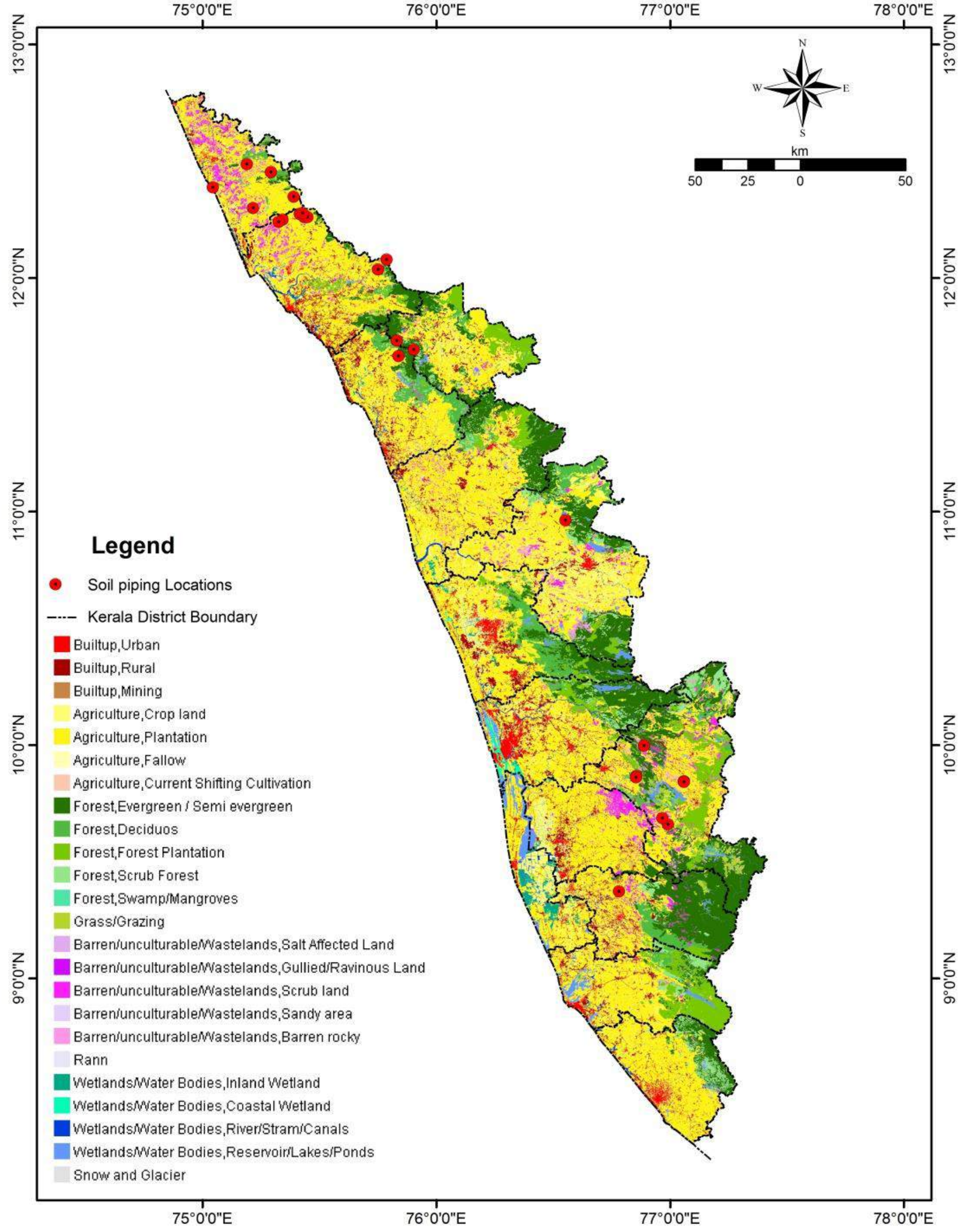


Figure 3.7: *Landuse map of Kerala with piping locations (NRSC, ISRO, 2014)*

3.2 Classification of soil pipes

In nature, soil pipes are formed by the process of subsurface erosion; these kinds of pipes are stable or unstable, which depend upon, geomorphology, soil type, hydrogeology etc. Most of them often go unnoticed because of the subsurface process. Different types of pipes are observed in the high lands and each pipes having its own characteristics. The classification is mainly depending on the size of common soil pipes observed in the state. In many places these pipes are existing in combination. Many places it is like underground drainage network like dendritic network. Based on the size pipe are classified in to four stages of formation. The following classification has been arrived. This classification has been arrived based on the samples from Kerala occurrences.

3.2.1 **Micro pipes (Juvenile pipe)**

Micro pipes or juvenile pipe (figure 3.8a) are the initial stage of piping. The diameter of pipe is <5cm. Clayey and lateritic soils are favorable for the formation of juvenile pipes. Juvenile pipes often found in the laterite cutting made for railways and roads. These pipes often saturate the laterite cutting Mulanthuruthy (figure 3.8b). The failure of the railway cutting occurred during 2012 near Mulanthuruthy near Ernakulam is a typical failure affected by such juvenile pipes. The juvenile pipes when present in large numbers in an area indicates the susceptible nature of the soil to soil piping.

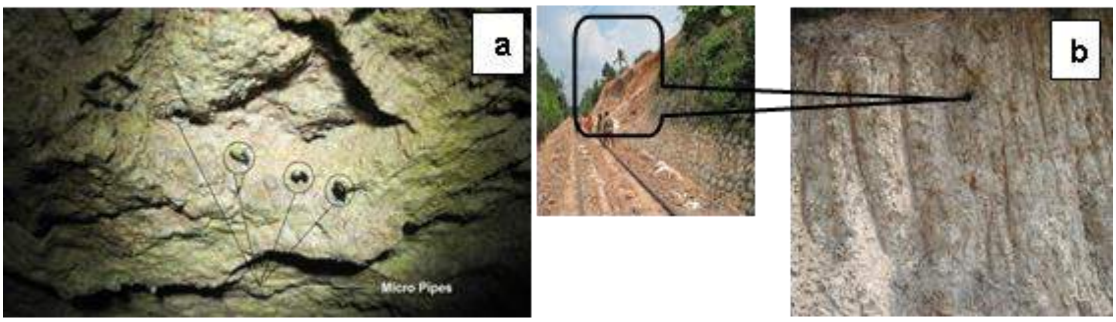


Figure 3.8: Micro (Juvenile) pipes.

3.2.2 **Small pipes (Younger pipe)**

Small pipes (Figure 3.9a) are the second stage of development of the soil pipe. The diameter of pipe is ranges from 5cm - 30cm; it may combine together or individually developed as the formation of small pipe. Often road cuttings topple in the lateritic area after being saturated during monsoon rains. This type of pipe is seen nearby Banasurasagar dam in Figure 2.7b, is indicative of the dispersive soils occurring in that area. The presence of these pipes indicates that the terrain is very susceptible to piping.

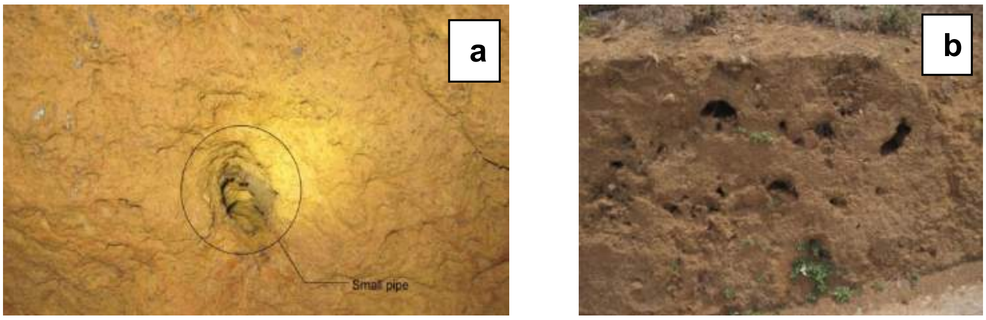


Figure 3.9: Small (Younger) pipes

3.2.3 **Typical pipes (Mature pipe)**

Mature pipe (Figure 3.10) is the third stage of development of pipe. The diameter of pipe ranges from 30cm to 5m. It may have an outlet; it acts as an underground drainage. This is the common pipes seen in the Western Ghats. The land subsidence is often caused by the growth of these pipes. This often branches in to smaller pipes giving an appearance of dendritic pattern. The size of the tunnel reduces towards the outlet attaining an overall shape of a funnel. The outlet of these pipes is often located in the lower side slopes or the valley. Here the water comes out as a fountain rather than a spring. These type of pipes are common in the affected localities. In Kerala Kottathalachimala (Kannur) , Iritty, Tattekanni (Idukki) are typical examples.

Figure 3.10: Typical pipes (Mature pipe)

3.2.4 **Oversized pipes (Huge pipe)**

It is next stage of pipe after development of a typical pipe. The diameter of huge pipe (Figure 3.11) is >5m. It will also have an outlet. It acts as an underground drainage, it has no definite shape. These pipes often associate with their lower versions such as typical / mature pipes. These pipes are almost stable, the water erosion is very less and the walls of pipes are so hard Huge pipes are located in the Kasaragod (Kuttikol / Nelliyadukkam) and Kannur (Umrampoyil) districts

Figure 3.11: Oversized pipes (huge pipes)

3.3 Major areas affected by tunnel erosion/ soil piping in Kerala.

Field surveys were conducted in all the major affected localities in the state. A brief description of the geo environmental aspects of these sites is given here.

3.3.1 Kasaragod

Kasaragod is the northern district of Kerala, bordering Karnataka State. It lies between 12º 02' -12º 48'N latitude and 74º 51' - 75º 25'E longitude. The population is mainly agrarian and the major crops raised are coconut, arecanut, cashew, rubber, paddy, pepper etc. Kasargod district is divided into two taluks (Kasargod and Hosdurg) and 75 villages. The district has one revenue division, 6 Block Panchayaths (Manjeshwar, Kasargod, Kanhangad, Nileshwar, Karadka and Parappa) and 38 GramaPanchayaths and three Municipalities (Kasargod, Kanhangad and Nileshwar).

a) Geology

The major rock type noticed in the district comprise of Charnokite, granites Hornblende biotite gneiss, Laterite, Alluvium and gneisses of Archean age, schistose rock of Sargur metamorphic complex, tertiary sedimentary rock and recent to sub recent deposits (Figure2.12).

a) Soil types

There are four major soil types encountered in the district. They are Lateritic Soil, Brown Hydromorphic Soil, Alluvial Soil and Forest Loam. Lateritic soil is the most predominant soil type of the district and it occurs in the midland and hilly areas and it is derived from laterites. Laterite is the most wide spread and extensively developed aquifer in the district. They widely vary in their physico-chemical characteristics. The laterite is generally underlain by thick lithomargic clay which is the preliminary lateralization front. The thickness of lithomargic clay varies from about 0.5m to 5.0m at places. Laterite is more ferruginous, porous and hard in northern parts of the district compared to those in the southern parts of the district. Due to its porous nature the dug wells tapping laterite get recharged fast and also the water escapes as sub-surface flow and water level falls quite fast especially in wells located on topographic highs and hill slopesBrown

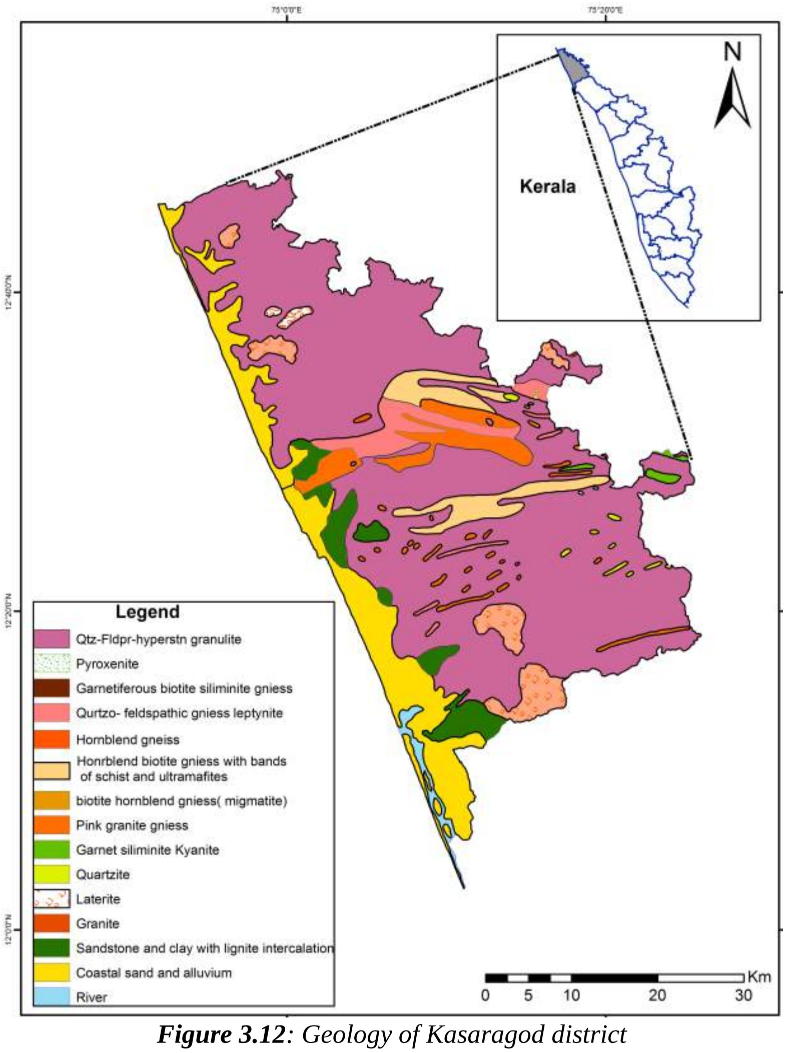


***Figure 3.12**: Geology of Kasaragod district*

hydromorphic soil is confined to the valleys between undulating topography in the midlands and in the low lying areas of the coastal strip. They have been formed as aresult of transportation and sedimentation of materials from adjoining hill slopes. The alluvial soil is seen in the western coastal tract of the district. The coastal plain is characterised by secondary soils which are sandy and sterile with poor water holding capacity. The width of the zone increases towards the southern part of the district. Forest loamy soil is found in the eastern hilly areas of the district and are characterised by a surface layer rich in organic matter.

b) Hydrogeology

Four hydrogeological units encountered are Alluvium (including valley fills) laterites weathered crystalline and fractured crystalline. Coastal Alluvium occurs as narrow strips parallel to the coast south of Kasargod. The width of alluvium increases to the south and attains about 5 km. around Trikaripur. North of Kasargod (in Kasargod and Manjeshwar blocks), the alluvium occurs as isolated patches close to the coast and have limited thickness. In the Kanhangad and Nileshwar blocks even though the width of alluvium is more, potential zones are seen in the top portion only followed by Tertiary sediments at deeper levels which does not contain potential granular zones. Valley fills occur in between laterite hills which are composed of colluvium and alluvium. The water level ranges from 2.93 m to 5.63 m bgl in pre-monsoon period and 1.20 to 3.20 m bgl in post monsoon period. The water level fluctuation is in the range of 0.98 to 2.68 m

c) Geomorphology

The district can be divided into three Physiographical units viz. the coastal plains, the midlands and the eastern highland regions. The coastal plains with an elevation of less than 10m occur as narrow belt of alluvial deposits parallel to the coast. To the east of coastal belt is the midland region with altitude ranging from 10 to 300m above msl. The midland area is characterised by rugged topography formed by small hillocks separated by deep cut valleys. The midland regions show a general slope towards the western coast. To its east is the high land region. The midland and hill ranges of the district present a rugged and rolling topography with hills and valleys. Along the midlands the hills are mostly laterite and the valley are covered by valley fill deposits.

3.2.1.1 **Location of the affected area**

a) Nelliyedukkam

A new incident of land subsidence has occurred in the Nelliyedukkam locality (N12°17’58.0”, E75°13’02.5”) in Kinanoor village, Vellarikund taluk in the Kasaragod district (ref. figure: 2.13). The incident has occurred in 2014 August 2nd. The affected locality is in the side slope region of the laterite mesa. The pipe is in mature type and diameter of the entrance is around 5m, inside diameter is in 20m. This is an example of combination of mature and huge pipes. The subsurface pipe was partially filled by subsided earth materials (figure3.13c). The soil is in thick and underlying the well-developed laterite. The slope of the terrain as well as the tunnel orientation is towards NE-SW direction.

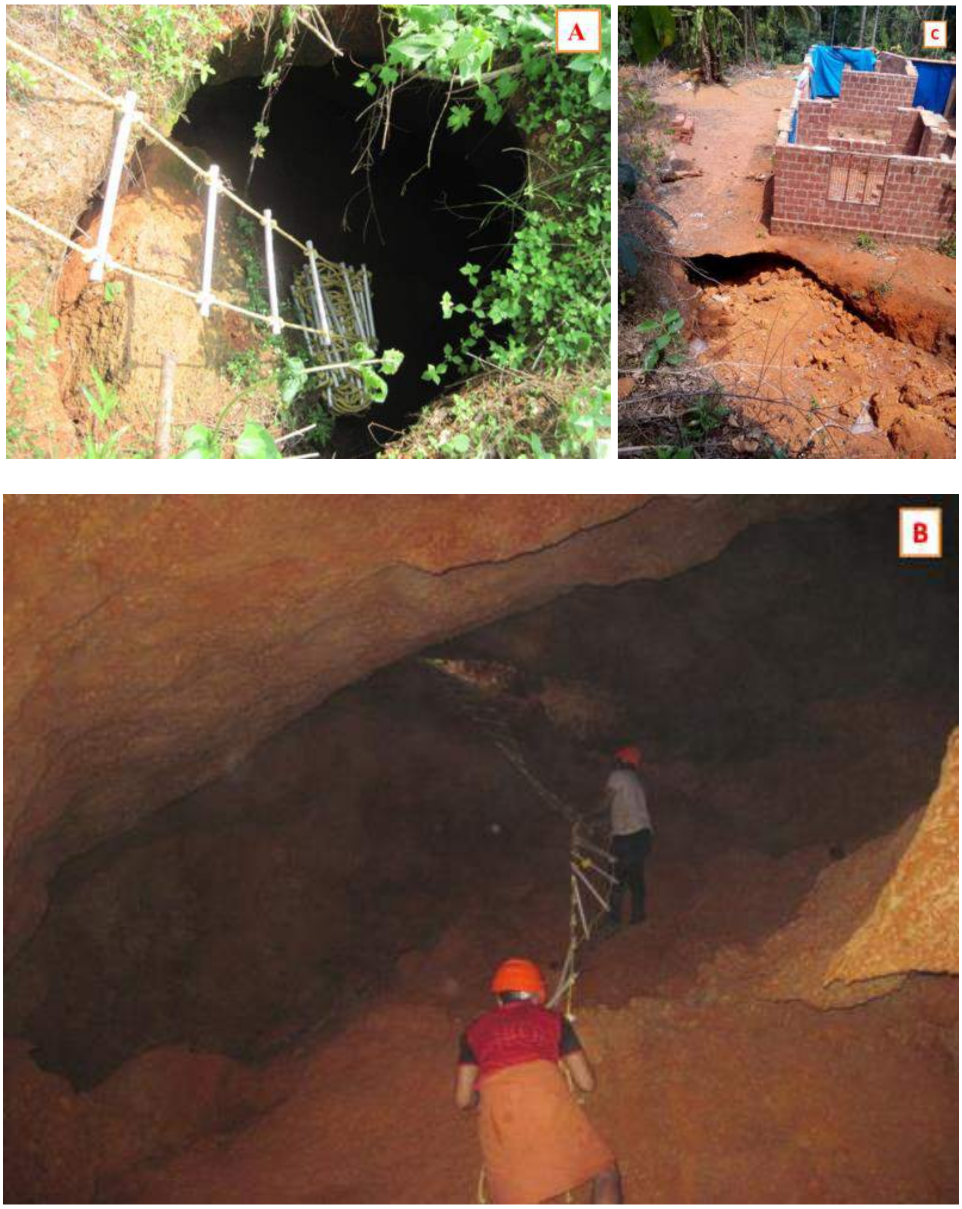


Figure: 3.13 *Land subsidence and tunnelling, Nelliyadukkam*

Field investigations revealed that the entire locality is affected by soil piping. Piping process has affected the Saprolite clay of the laterite. Ground fissures indicative of ground movement are seen at few places. The initial investigations have established the presence of more than one subsurface erosional channel. Pipe outlet (Figure 3.14) is located at 50m north of this area. In this area a huge tunnel shaped pipe in combination with a typical pipe was formed here. Sudden collapsing of the top surface of the tunnel has happened due to the continued erosion. Surface fissures were also identified in the premises of the tunnel. The entire Nelliyadukkam region is prone to soil piping. Most of the wells in this region doesn't properly respond to high rainfalls. The water table remain stable even during monsoon rains. The open mine pit of the nearby clay mine also revealed the presence of underground tunnels. The chemical characteristics and the mitigation etc. are described in the subsequent chapters.

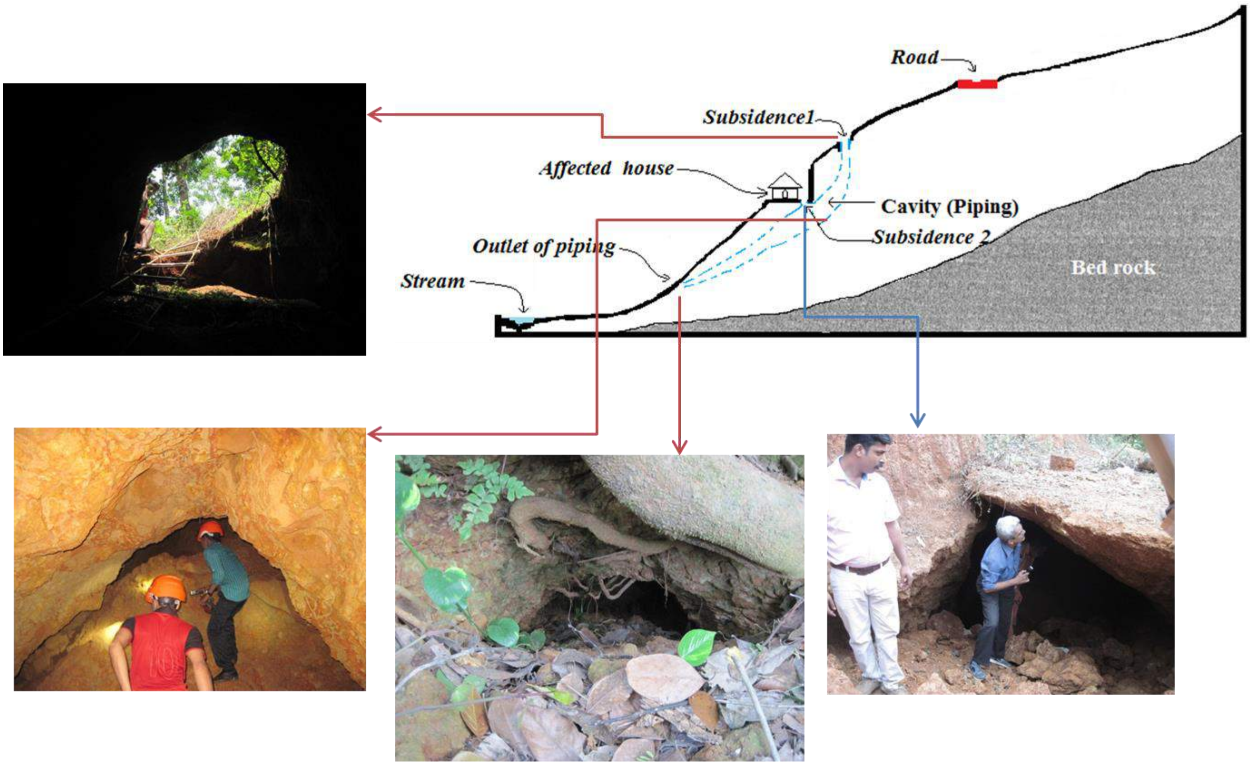


Figure 3.14: *Land subsidences due to soilpiping in Nelliyadukkam, Kasaragod*

b) Kuttikol

The other locations are Kuttikol panchayath at Kasaragod taluk; Muttonkadavu at Karindalam village (Figure 2.15, Loc. E12°20'54.1"and N75°23'16.3"), the pipe occurs in lateritic terrain at gently sloping area;the size of pipe is around 30m diameter therefore it included to the oversized / huge pipe in the piping classification.

Figure3.15*: Piping in Kuttikol, Kasaragod district*

c) Erinjilakodu

The another Piping occurs in the Erinjilakodu in Kolichal village (Figure 2.16, Loc. 12°27’11.3” and N75°17’35.7”) is of mature piping category, and also the terrain is lateritic.

***Figure 3.16**: Piping and affected well in Erinjilakodu, Kolichal village*

d) Pallikara

The piping occurs in Pallikara (subsidence in Kanhangad - Kasaragod State Highway, (Figure 2.17) is in lowland area and also in lateritic terrain, in this pipe comes under typical pipes category in Kasaragod district

***Figure 3.17**: Soilpiping incidence occurred in state highway Pallikara, Kasaragod district*

3.3.2 Kannur District

Kannur district lies between latitudes 11° 40' to 12° 48' North and longitudes 74° 52' to 76° 56' East. The district is bound by the Western Ghats in the East (Coorg district of Karnataka State), Kozhikode and Wayanad districts, in the South, Lakshadweep Sea in the West and Kasaragod district in the North. Kannur district is divided into 3 taluks (Taliparambu, Kannur and Thalassery), 5 municipalities (Payyanur, Taliparambu, Kannur, Azhikode and Koothuparambu), 9 blocks (Payyanur, Kannur, Thalasserry, Taliparambu, Edakkad, Irikkur, Iritty, Peravur and Koothuparambu), 81 panchayats and 129 villages.

3.3.2.1 Geology

The geological formations in the district are of Archean and recent age. Archean formations comprise of gneisses and charnokites. Quaternary formations are alluvium and laterite. Archaeans occupy the midland and highland regions of the district having rock types of basic charnokites and hornblende-biotite gneiss. The remaining portions in the coastal area are covered by laterite, alluvium, lime-shies, lignified woods, etc. Archaean formations like foliated hornblende-biotite gneiss (grey or white in colour) are one of the main rock types in the northern portion of the district. Recent formations like laterite are developed on a limited scale along the coastal areas (Figure3.18).

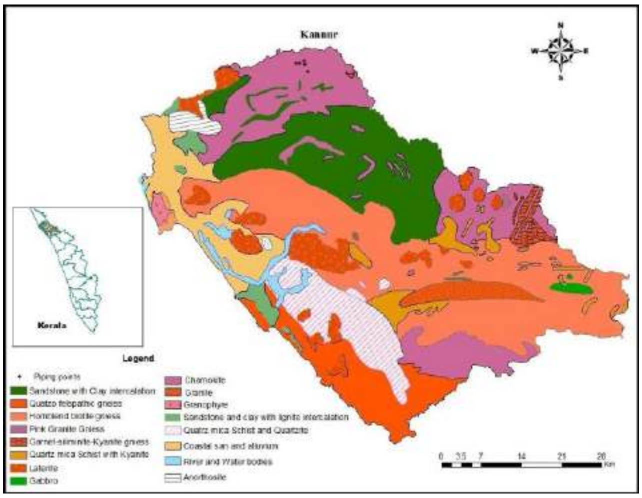


Figure 3.18: *Geology of Kannur district*

3.3.2.2 Hydrogeology

Kannur district is underlain by charnockites, pyroxene granulites, garnetiferous gneisses, hornblende biotite gneisses and schistose rocks overlain by Tertiaries and coastal alluvium along the coast ranging in age from Archaean to Recent. These rocks have undergone weathering and lateritisation. The hydrogeological units encountered in the district are (i) consolidated formations (weathered and fractured crystallines) (ii) Semi consolidated sediments equivalent to Warkalies of Southern Kerala and Laterite formations and (iii) unconsolidated formations (Recent alluvium occurring along the coast).

3.3.2.3 Geomorphology

Kannur district can be divided physiographically into three distinct geomorphologic units viz the coastal plains and lowlands in the western part, the central undulatory terrain comprising the midland region and eastern highland region. The coastal plains occurs as a narrow belt of alluvial deposits running parallel to the coast with a maximum width of about 15 km. Midland region forms a plateau land at certain places covered by a thick cover of laterite. The hilly tract in the eastern part consists of highly rugged terrains. The Ezhimala peak (259.69m) with the characteristic N-S alignment is a distinct physiographic unit in the coastal plains. Minor cliffs of laterite generally rising to an elevation of 50 to 60 m above mean sea level are found at Mahe, Thalasserry and Bekal coast. The midland region presents a plateau land covered by a thick cover of laterite. This is immediately to the east of the coastal strip, rising from 40 to 100 m above msl. The valleys in the plateau are gorge like and V shaped cut by youthful streams. The hilly tract along the eastern part of the district constitutes the highland region and is highly rugged. Development of bad land topography along the margins of the valley is a common feature observed in the district. (Source : Ground water information booklet - Kannur district, GWD, Kerala)

3.3.2.4 Soil Types in the district

Important soil types in the district can be classified as forest loam, lateritic soil, riverine alluvium, brown hydromorphic soil, Hydromorphic Saline soil and coastal alluvium soil. Forest Loam are restricted to the eastern part of the district and are developed over the crystalline rocks of the Western Ghats. These are shallow immature soils occurring under canopy of vegetation mantling the gneissic/charnokite parent rocks in various stages of chemical weathering. These are dark reddish colour to black in colour with a loam to silty loam in texture and have wide variation in depth. These are mainly seen in Panoor, Iritty, Alakkode, Kannavam and Aralam area of the district. Lateritic soil is the most predominant soil type found in the midland area of the district. These are mostly reddish brown to yellowish red in colour. The texture of the soil ranges from gravelly loam to gravelly clayey loam. Extensive structures of indurate laterite with hard surface are very common. The soil is formed as a product of residual weathering under tropical climatic conditions. The depth of weathering changes from 5 to 20m. Riverine Alluvium Soil occur mostly along the banks of Valapattanam and Kuppam rivers. This soil shows a general predominant of sand fraction. They show wide variation in their physiochemical properties and arrangement of layers depending on prominence features. Brown Hydromorphic soil occurs quite extensively occupying valley bottoms. These are found in Chalode, Vengad, Ancharakandy, Kankol and Karimbam regions. They exhibit wide variation in physiochemical properties and morphological structures resulting from transportation and deposition under varying conditions. These are generally deep brown in colour. Surface texture varies from sandy loam to clay. Hydromorphic Saline soil are seen in the coastal tract of the district especially at Cheruthazham, Kannapuram, Dharmadam area and are generally deep brownish in colour and poorly drained. The profile shows wide variation in texture and these soil show characteristic aquatic properties. Salinity is due to the inflow of tidal water in to this area through the network of the back waters and estuaries. During rainy season these areas are almost free of salts. Coastal Alluvium Soil are seen along the coastal tract of the district and they are developed from the recent marine deposits. Sand is the prominent fraction of this formation. The surface structure observed is loamy sand and sandy loam.

3.3.2.5 Landuse and Vegetation

Kannur district is very rich in vegetation. Natural vegetation, except in some coastal regions, consists of forests. But, in spite of generally favorable climatic conditions, vegetation is not uniform. Thus, plant communities, ranging from mangroves to evergreen forests are seen.

The coastal region is a comparatively narrow zone, characterised by secondary soil which is rather lose and sandy. The sterile sandy tract supports only a poor vegetation of the psammophyte type. Plants are few and mostly prostrate. Erect species are small and short. Owing to very poor water holding capacity of the soil, these plants are provided with special xerophytic adaptations. Another conspicuous feature of this area is the mangrove vegetation, found at the estuaries of rivers and backwaters, and often extending to the interior along their banks.

Major part of the district comes under midland region with numerous hills and dales and it presents an undulating surface gradually ascending and merging into the slopes of Western Ghats. Soil is secondary and lateritic with underlying rock of laterite or disintegrated gneiss. Typical flora of this area is deciduous forest consisting of a mixture of evergreen and deciduous trees. Undergrowth consists of a variety of annuals and perennials.

The mountains are a continuation of the midland region, gradually ascending to the main ridge of the Western Ghats. Soil in the western slopes is a ferruginous red, sandy loam. Vegetation over the whole area is of the forest type, irregular distribution of teak, localized areas of bamboo and landuse rubber, areca palm and coconut trees dominance, change of good quality forest into open grass lands.

3.3.2.6 Reported incidences in Kannur

a) Kottathalachimala

Soil piping was first observed in the Thirumeni region of Kottathalachimala. This area can be considered the type area of soil piping in the state. The entire hill rages are affected by different types of soil piping. There are more than six piping incidences have been occurred in Kottathalachimala at Kannur district. The Piping affected locality is Kottathalachi Mala situated in the Thirumeni village in the Taliparamba taluk of the Kannur district (Figure3.19). The area falls in the ward 2 (Chattivayal ward) of the Cherupuzha Grama Panchayat. Chattivayal is located in the

S-E side slopes of Kottathalachi mala which is 801meters in elevation above msl, there are two incidence reported in this area. More than four incidences reported in the S-W side of the Kottathalachi mala. The area is approachable by road from Cherupuzha via Thirumeni and Pulingom.

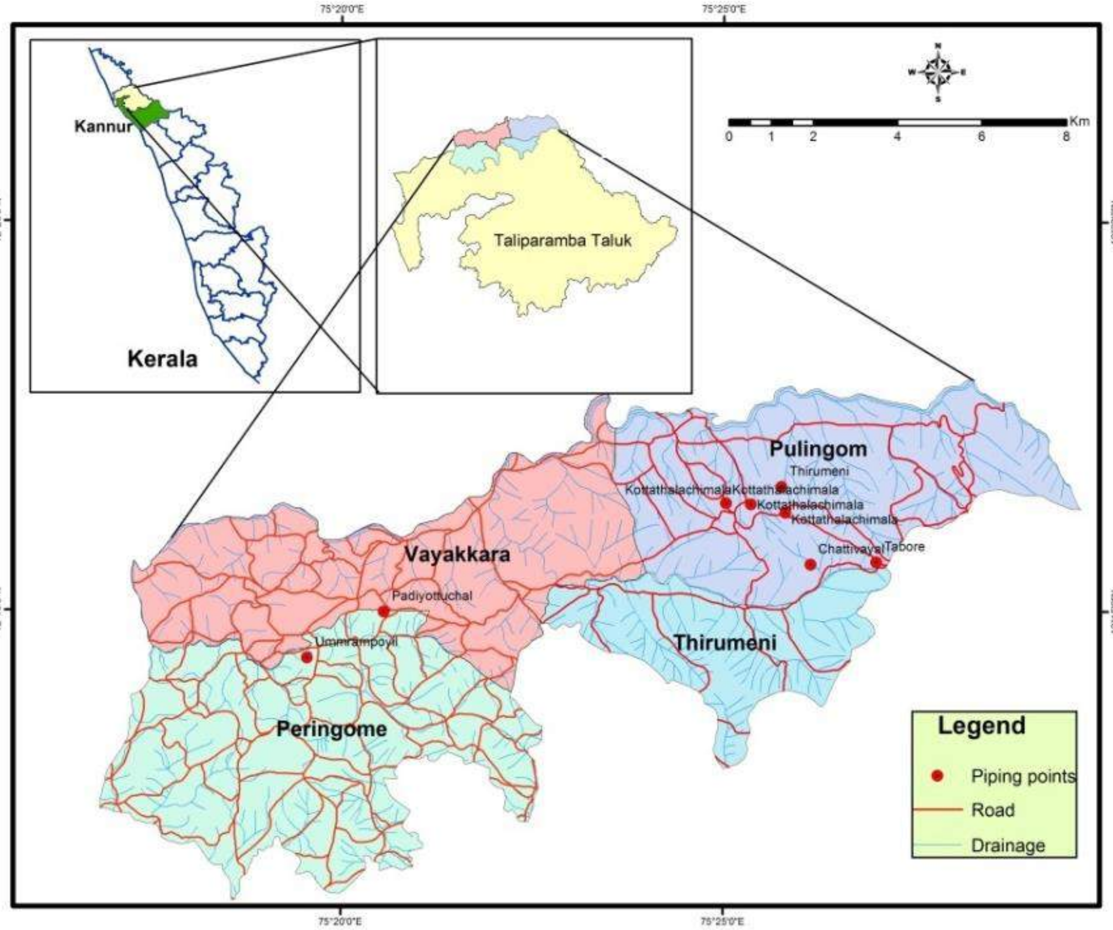


***Figure 3.19**: Soil piping in Kannur district*

The affected locality is situated in the highland region with elevations reaching up to 801m in the Kottathalachi mala is a dome shaped hill located in the highland region of Kannur district in Kerala. The upper slope is characterized by s high slopes (+31^0) where as the lower slopes are about 240. The Kottathalachi mala is characterized by radial drainage indicating its shape. Many lower order streams of originate from this hill jointed in Thejaswini River. Thirumeni chal a Third Order Stream and its tributaries drain through the locality. Charnokites rocks dominates Precambrian crystalline basement of the area. The rock type seen in the area is pyroxene granulite. The overburden material above the basement is clay rich loamy soil. The side slope of the Kottathalachi mala is characterized by thick soil cover especially the area where the incidents (subsidences) occurred. The average overburden thickness is about 15m. The soil column is unconformably lying over the hard crystalline rock. Piping is located in this area having lateritic soil. Since groundwater follows the topography, the steeply sloping terrain produces high hydraulic gradient in the region. The area covers moderate vegetation, some part covered by forest and the main landuse of the piping occurred areas are rubber plats, areca palm and coconut trees are the land use

Collection of meteorological and hydrologic data

The importance of lateral pipe flow on runoff generation in the hillslopes has been described in many case studies around the world. However such studies in hillslope area are done in isolation and usually focus on the idiosyncrasies of individual hillslope characteristics and pipe flow response at a single site (Reference). Therefore the first order control on pipe flows remain poorly understood. Here we are presenting a new inter-comparison of pipe flow in response to rainfall at well instrumented sites. Our objective was to find out the relation between subsurface runoff and rainfall on the lateral pipe flow on hillslopes by looking for commonality across different hillslope types. Despite the large differences between the study sites in topography, climate, soil type and soil matrix hydraulic conductivity, we found a common pipe flow responses to rainfall. There is no surface runoff from these areas.

The V-notch Constructed of started was completed (figure 3.19) and data collection has been started (table 3.2). The Automatic weather station was also installed (Figure 3.19b and table 2). Arrangements were made locally for daily observation and to collection of data. The V-notch weirs were installed in open channels, coming from the piping outlet, to determine discharge (flowrate). The basic principle is that discharge is directly related to the water depth above the crotch (bottom) of the V; this height is called head (h). The V-notch design causes small changes in discharge to have a large change in depth allowing more accurate head measurement than with a rectangular weir.

a. *Discharge flow measuring from V-notch wire* ***b.*** *Rainfall- Automatic weather station*

Figure 3.19 *meteorological and hydrologic data from Kannur district*

V-notch weir equation or Kindsvater-Shen equation is given below USBR (1997)

$$Q = 4.28C \tan(\theta/2)\,(h + k)^{5/2}$$

Where

Q= Discharge (m^3/S)
C= Discharge Coefficient
θ= V-notch Angle
h= Water head (in meter)
k=Head correction faction (m)

Table 3.2. *Rain data (AWS) and discharge data (V-notch) at June-July, 2013*

Sl.No.	Date	Rain (mm)	Water Head(m)	Discharge (m^3/S)
1	18/06/2013	162.8	0.49	0.23
2	19/06/2013	31.2	0.36	0.11
3	20/06/2013	112.6	0.47	0.21
4	21/06/2013	8.2	0.33	0.09
5	22/06/2013	61.0	0.34	0.09
6	23/06/2013	73.2	0.34	0.09
7	24/06/2013	51.0	0.47	0.21
8	25/06/2013	69.0	0.49	0.23
9	26/06/2013	36.2	0.44	0.18
10	27/06/2013	48.2	0.46	0.2
11	28/06/2013	17.8	0.36	0.11
12	29/06/2013	21.2	0.34	0.09
13	30/06/2013	27.0	0.29	0.06
14	01/07/2013	21.4	0.24	0.04
15	02/07/2013	43.0	0.36	0.11
16	03/07/2013	140.0	0.71	0.58
17	04/07/2013	46.2	0.49	0.23
18	05/07/2013	33.4	0.47	0.21
19	06/07/2013	26.2	0.47	0.21
20	07/07/2013	29.0	0.41	0.15
21	08/07/2013	37.6	0.34	0.09
22	09/07/2013	26.4	0.33	0.09
23	10/07/2013	27.2	0.33	0.09
24	11/07/2013	74.8	0.39	0.13
25	12/07/2013	21.2	0.39	0.13
26	13/07/2013	27.2	0.33	0.09
27	14/07/2013	27.0	0.29	0.06
28	15/07/2013	32.0	0.32	0.08
29	16/07/2013	18.8	0.36	0.11
30	17/07/2013	36.0	0.39	0.13
31	18/07/2013	18.0	0.33	0.09
32	19/07/2013	52.2	0.41	0.15
33	20/07/2013	66.4	0.41	0.15
34	21/07/2013	29.8	0.37	0.11
35	22/07/2013	43.4	0.34	0.09
36	23/07/2013	19.2	0.27	0.05
37	24/07/2013	58.4	0.39	0.13
38	25/07/2013	54.8	0.41	0.15
39	26/07/2013	92.0	0.38	0.12

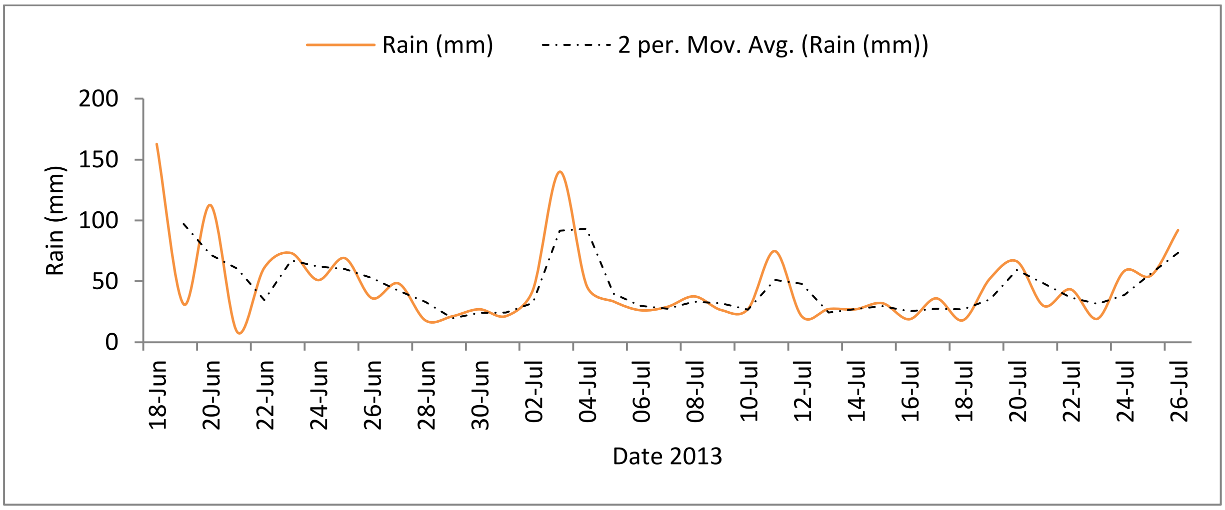


Figure 3.20a :*Line graph of rainfall (June-July, 2013) from the piping outlet in Kannur dist.*

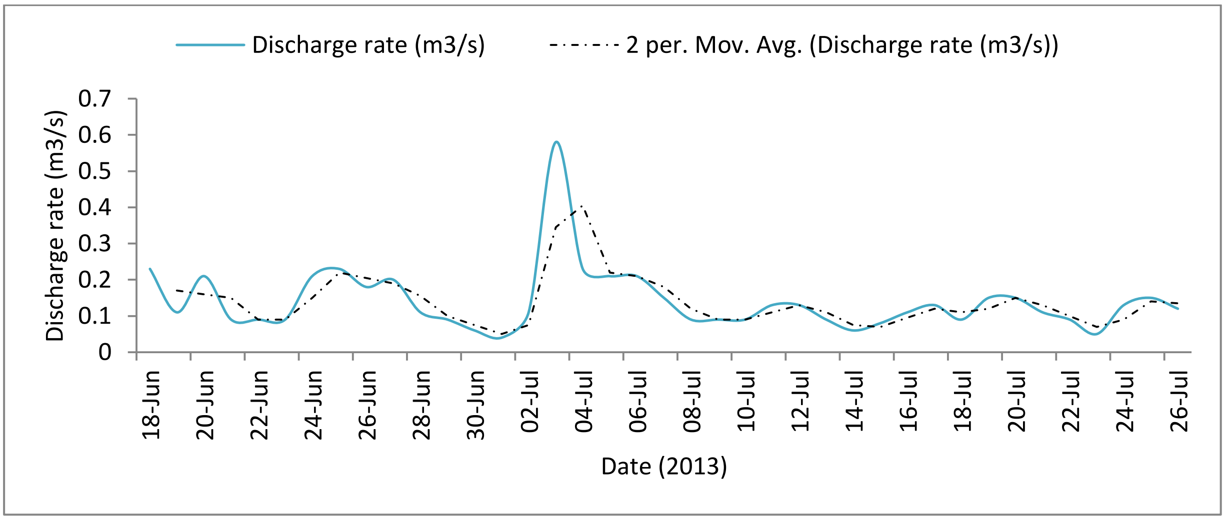


Figure 3.20b: *Line graph of Discharge (June-July, 2013) from the piping outlet in Kannur dist.*

Figure3.21: *Reinstallation of Automatic Weather Station (AWS)*

The AWS was reinstalled in a new location at Thirumeni milma society building (Figure14 & 15) because at previous location power supply was lacking during rainy season

Table 3. *Rain data (AWS) and discharge data (V-notch) at August - September, 2013*

Sl.No.	Date	Water Head (m)	Rain (mm)	Discharge rate (m3/s)
1	01/08/2013	0.445	33.6	0.196919314
2	02/08/2013	0.41	38.4	0.147777225
3	03/08/2013	0.38	5	0.122261973
4	04/08/2013	0.41	64.8	0.147777225
5	05/08/2013	0.37	19.2	0.114394429
6	06/08/2013	0.36	37.2	0.106838739
7	07/08/2013	0.345	28	0.096080655
8	08/08/2013	0.33	0	0.086000166
9	09/08/2013	0.345	19.4	0.096080655
10	10/08/2013	0.36	15.2	0.106838739
11	11/08/2013	0.345	2.8	0.096080655
12	12/08/2013	0.33	0.8	0.086000166
13	13/08/2013	0.345	27.2	0.096080655
14	14/08/2013	0.36	0	0.106838739
15	15/08/2013	0.33	3.2	0.086000166
16	16/08/2013	0.36	26.6	0.106838739
17	17/08/2013	0.37	11.4	0.114394429
18	18/08/2013	0.37	23	0.114394429
19	19/08/2013	0.36	24.8	0.106838739
20	20/08/2013	0.36		0.106838739
21	21/08/2013	0.33	11.8	0.086000166
22	22/08/2013	0.345	8	0.096080655
23	23/08/2013	0.345	0.6	0.096080655
24	24/08/2013	0.33	5	0.086000166
25	25/08/2013	0.315	8.6	0.076582414
26	26/08/2013	0.3	5.2	0.067812199
27	27/08/2013	0.29	0	0.062317463
28	28/08/2013	0.28	0	0.057098904
29	29/08/2013	0.25	0	0.043051967
30	30/08/2013	0.23	0	0.034978038
31	31/08/2013	0.23	0	0.034978038
32	01/09/2013	0.24	1.2	0.038889342
33	02/09/2013	0.25	2.4	0.043051967
34	03/09/2013	0.265	2.2	0.0497784
35	04/09/2013	0.265	0	0.0497784
36	05/09/2013	0.265	0	0.0497784
37	06/09/2013	0.265	0	0.0497784
38	07/09/2013	0.265	0	0.0497784
39	08/09/2013	0.265	0	0.0497784
40	09/09/2013	0.29	10.6	0.062317463
41	10/09/2013	0.3	10	0.067812199
42	11/09/2013	0.28	4.2	0.057098904
43	12/09/2013	0.265	17.8	0.0497784
44	13/09/2013	0.25	55.8	0.043051967
45	14/09/2013	0.25	2.4	0.043051967
46	15/09/2013	0.24	23.6	0.038889342
47	16/09/2013	0.23	85.4	0.034978038
48	17/09/2013	0.23	14.4	0.034978038
49	18/09/2013	0.215	2.6	0.029570741
50	19/09/2013	0.19	8	0.021738789
51	20/09/2013	0.19	10	0.021738789

52	21/09/2013	0.2	12.2	0.024698734
53	22/09/2013	0.19	3	0.021738789
54	23/09/2013	0.2	0	0.024698734
55	24/09/2013	0.18	6.8	0.01900256
56	25/09/2013	0.165	4.5	0.015304649
57	26/09/2013	0.165	2.2	0.015304649
58	27/09/2013	0.19	0	0.021738789
59	28/09/2013	0.2	0	0.024698734
60	29/09/2013	0.19	0	0.021738789

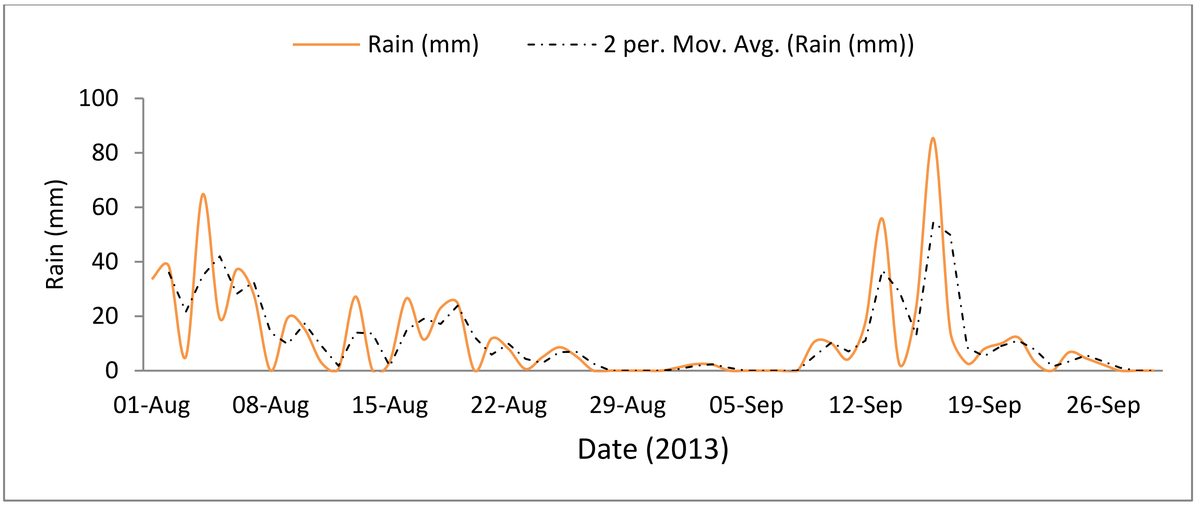


Figure 3.22a *Line graph of rain rate and their moving average from the piping outlet in Kannur dist.*

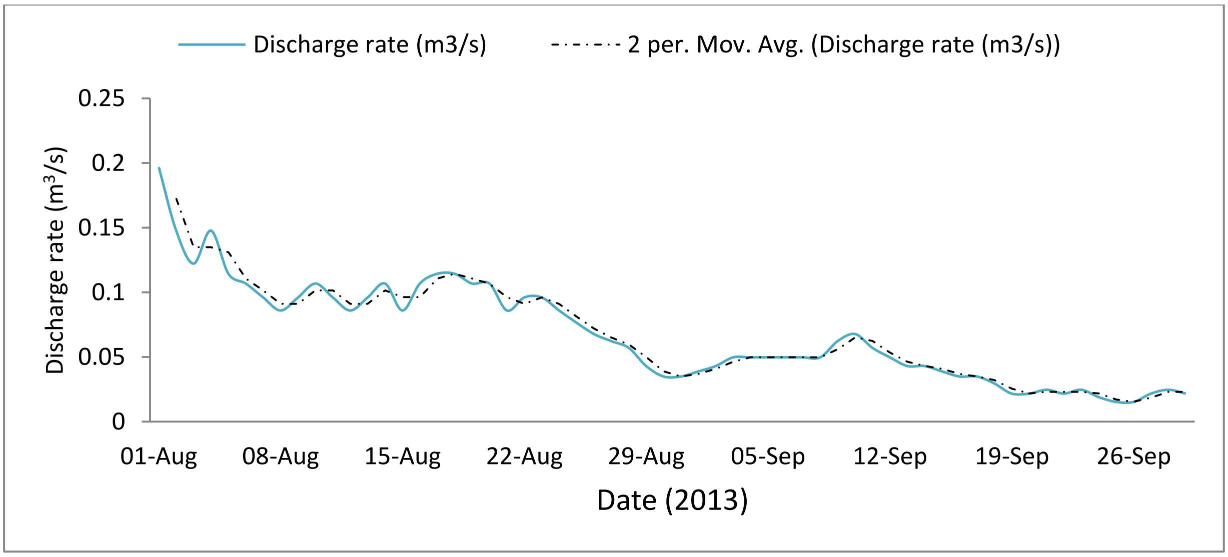


Figure3.22b *Line graph of discharge rate and their moving average from the piping outlet in Kannur dist.*

The graphs show the relationship between rainfall and discharge of piping outlet. It shows that discharge from the piping outlet depends on the rainfall. From the graph, the relationship between subsurface flow and rainfall is a linear function. This is due to the saturation condition of the soil in this area.

b) Subsidence in Chattivayal

The study conducted in the locality revealed that there are two such depressions due to subsidence in the eastern hill slope and the three more incidences occurred in the western slope and the locality indicating that the area is prone to such incidences.

***a**. Piping Inlet, **b.** Middle opening of pipe, **c**. Piping Outlet*

***Figure3.20**: Subsidence associated with Piping in Chattivayal*

The field survey conducted in the locality revealed that there are two such depressions in Eastern Slope of the Kottathalachimala due to subsidence in this locality indicating that the area is prone to such incidences (Figure3.20a, b and b). This indicates that there are underground pipes present in this locality, many of them falls in the small to typical category pipes. Quick draining of water through these depressions proves the presence of the pipes. There are a number of dug wells in the area. But none of them sustain water even during high rainfall times such as monsoons. The locals have complained that water level never gains after certain level even during rains. This indicates that there is considerable loss or leakage is occurring in the wells.

The subsidence due to piping had occurred very close (within 10m) to the house where Smt. Lisy Francis used to stay. The field examination of the subsided area indicated that severe soil erosion is taking place due to water flow through the underground pipes. The soil erosion is responsible for enlargement of the conduits followed by subsidence. The conduits show caving on the side walls of the conduit which resulted in the subsidence. Since the caving is still going on it shall definitely affect the stability of the basement of the house, which is located nearby. The area receives good rains during monsoons. Good discharge of ground water through the pipes shall make the area vulnerable for further subsidence.

In the western side slope of the Kottathalachimala there are three main piping reported at different nature. In the side slope of the hill there are three main pipes are seen at different characteristics, the orientation pipes are in NE- SW direction. It's occurred in lateritic terrain, the lateral extension of the pipe is almost 50m and 5m diameter, also horizontal pipe convey the terrain slope. The slope gradient ranges from 8 to 24%. The site is located (Figure. 3.23, 3.24 and 3.25) at a 435 elevation. The lithologicaly of the site consists of clayey coarse silt to fine sand with clay layers, overlain by heterogeneous mixer of soil and boulders are seen in the area. The soil map (bench mark of Kerala) indicates silty clay loam soils with minor gleyic colour patterns and argic horizons. Soil textural analysis of samples taken at the study site (depth of10to 200 cm) showed a silt loam texture with silt fractions (2-63 m) ranging from 66 to 77%. The hydrology of the region is characterized by many springs with a high drainage density.

Figure: 3.23 *Stable Soilpipes in Kottathalachimala, Kannur*

Figure 3.24: *Unstable Soilpipes in Kottathalachimala, Kannur*

Figure: 3.25 *Soilpipes in weathered rock in Kottathalachimala, Kannur*

c) Piping in Cherupuzha

The newly reported incidents are in Kannur are [Padiyottuchal(Figure 3.26, Loc. N12°14’59.2” and E75°20’33.7”), Ummrampoil(Figure 2.27, Loc. N12°14’23.7” and E75°19’33.6”), Vayakkara (Figure 3.28, Loc. N12°14’58.0” and E75°19’50.7”) and Malankadavu in Palavayal village (Loc: N12°18’5.6” and E75°23’48.5”) in Peringom village are in Kannur district and soil samples were collected. From the field observation the tunnels are old and the area is dominated by the laterites. Field investigations revealed that the entire locality is affected by soil piping. Piping process has affected the Saprolite clay of the laterite.

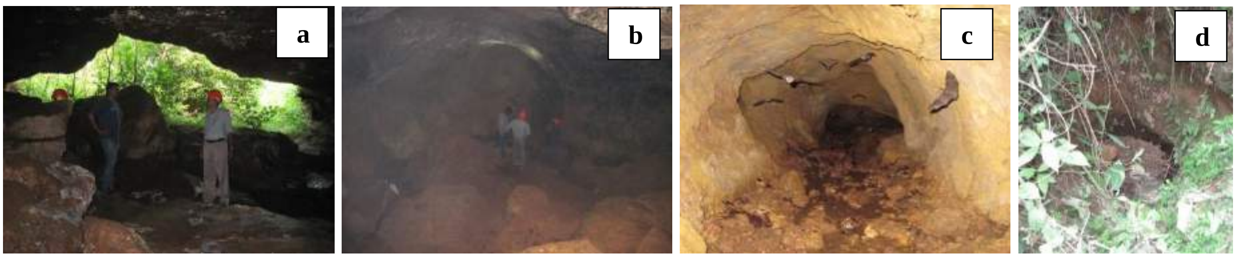


Figure: 3.26: *The newly reported incidents in Padiyottuchalat Kannur district*

Figure 3.27: *Inlet and out let of the Pipe in Umrampoyil, Kannur*

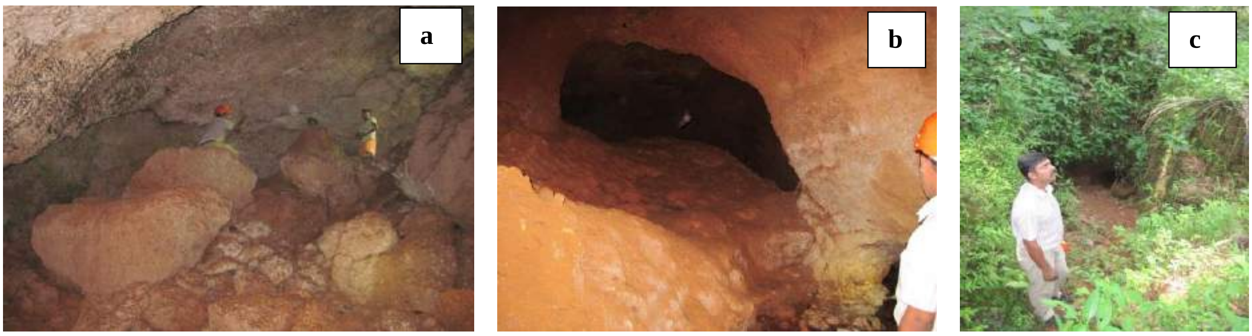


Figure 3.28: *Oversized Piping in Lateritic terrain by erosion of clay layer in Vayakkara, Kannur*

d) Piping in Iritty

The piping incident occurred in Iritty during July 2014 in the Niranganpara locality in Ayyankunnu panchayat, Thalasseri taluk in the Kannur district has evoked lot of media attention. A subsidence has occurred inside a well (GPS location is N12°02’09.4”E75°45’07.2”). The affected locality is in the foot hills and surrounded by hilly area. Piping has affected the saprolite portion of the laterite. Piping outlet is located at 120m north of this area. The soil is 1.5m thick and overlying the well-developed laterite. The slope of the terrain as well as the tunnel orientation is towards North West direction. The underground tunnels formed are found to be affecting the affecting the ground water storage of the wells in this area.

Figure: 3.29 *Soilpiping affected well at Niranganpara, Kannur*

3.3.3 Idukki district

a) Geology

Idukki district comes entirely under the Western Ghats region and the main rock types seen granite, charnokite, biotite gneiss, and granite gneisses in Archaean age. Granitic plutones are seen in north eastern part of Idukki district. Granite are characterised by the presence of quartz, orthoclase, plagioclase and various accessory minerals like biotite hornblende etc., which are massive and bad aquifers. Granites are igneous rock with pink or grey colour. Pink granite gneisses are exposed along the intrastate boundary of Idukki district. The charnokites are seen commonly in Thodupuzha, Peerumedu, Kumily and Nedumkandam areas and they possess characteristic of both igneous and metamorphic rock they exhibit intrusive relation with country rocks and are distinctly foliated. The colour of rock is bluish grey. Biotite gneiss is metamorphic rock, characterised by their gneissic structure. Gneissic structure is a composite structure due to the alteration of schistose and granulose band and tentacles. Colour of the rock is generally grey. Central part of Idukki district mainly comprises of gneisses.

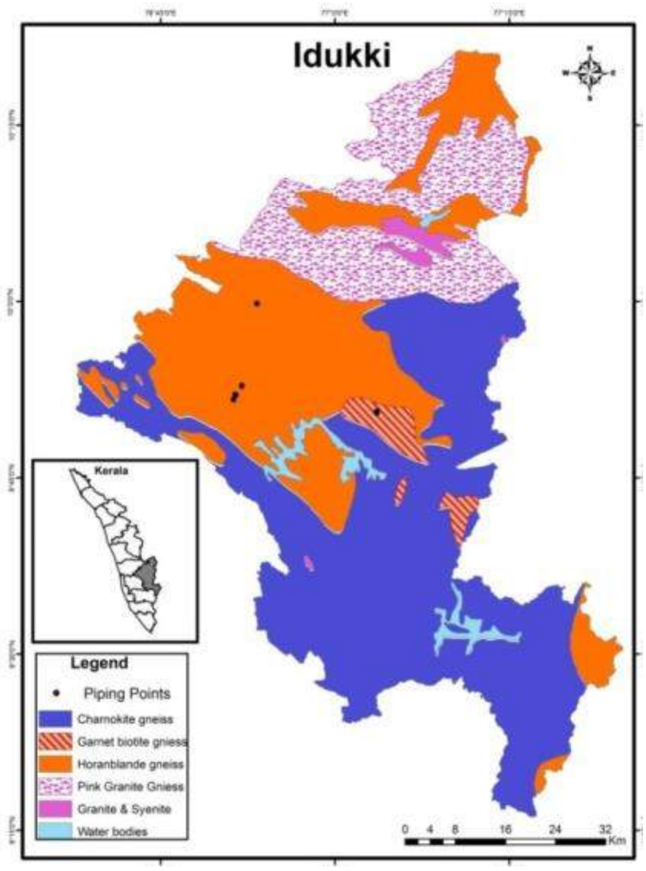


Figure 3.30 *Piping points in Idukki district with Geology (GSI, 1995)*

b) Soil series

There are four major soil types encountered in the district. They are forest loams, lateritic soils, brown hydromorphic soils and alluvial soils. About 60 % of the district is covered under forest loams which are the product of weathering of the rock under forest cover. They are characterized by a surface layer very rich in organic matter. They are generally acidic, high in nitrogen and poor in bases, due to heavy leaching. They are dark reddish brown to black with loamy to silty loam texture. In denuded areas leaching and deposition of humus in the lower layer is common.

The lateritic soils are derived from laterites and are encountered mainly in Elamdesam and Thodupuzha blocks of the district. They are well-drained and are low in plant nutrients and organic matter. The fertility of the soil is generally poor with low available nitrogen and phosphorous.

Brown hydromorphic soils are confined to valley portions in undulating terrain. These soils are formed as a result of transportation and sedimentation of materials from adjoining hill slopes and are brownish black in colour. The surface texture varies from sandy loam to clay.

Alluvial soils are seen as narrow strips along the banks of rivers in the district. They are more common along the banks of Thodupuzha River. The surface texture of these soils range from sandy loam to clay and they are fertile.

c) Geomorphology

A major part of the district falls in the hill ranges of Western Ghats except for Thodupuzha block and western part of Elamdesam block which fall in the mid land region of the State. The average elevation of the mid land region ranges from 40 –60 m amsl. The mid land area is characterizedby rugged topography formed by small hillocks separated by deep valleys. The general slope of the area istowards west. The hill ranges can be subdivided into foot hills, plateau region and high ranges. The foot hill region is a narrow strip of land where midland region grades into the plateau regions. Theelevation of this region ranges from 80 to 500 m amsl and slope is very steep, ranging from 30 to 50% and occasionally up to 80%. The width of the foot hill ranges from 2 to 8 km. Plateau region is the most important physiographic unit of the district and is characterizedby moderately sloping large land mass with a slope of less than 30% and an elevation of less than 1500 m amsl. Major part of the district fall in this region. The region is incised by a number of deep cut streams. The area in the north eastern part of the district is characterizedby high mountains with elevation more than 1500 m amsl. The highest peak in South India, Anamudi (2693 m amsl) is in the north central part of the district. There are several steep falls within the region.

d) Hydrogeology

The important hydrogeological units encountered in the district are laterites, weathered crystallines and fractured crystallines.

Laterites constitute aquifers in the mid land regions of the district. Laterites are generally underlain by lithomargic clay, the thickness of which varies from about 0.5 to 4.0 meters.

The weathered crystalline rock forms important aquifers throughout the district. The thickness of weathering ranges from less than 2.0 to around 20 meters. In the steep slopes and high ranges, where the weathered mantle is very thin or absent perennial phreatic aquifers are virtually non-existent. The thickness of weathered zone is more in weathered granitic terrains especially in parts of Devikulam, Adimali and Nedumkandam blocks.

The deeper fractured crystalline aquifers are under semi confined to confined conditions. They are tapped through bore wells for domestic, agriculture as well as for water supply. Potential fractures are encountered to depth varying from 10 to 120 m bgl, but generally they are encountered within 75 m depth. The depth to water level ranges from 4to 40m bglin pre monsoon period and from 2to 33m bgl in post monsoon period.

3.3.2.7 Reported incidence in Idukki

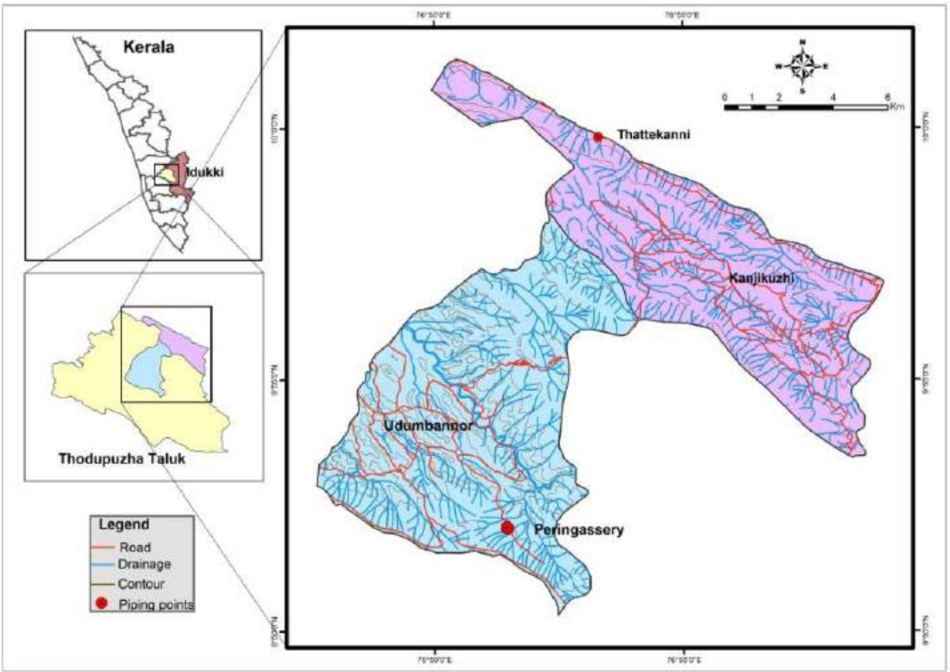


Figure: 3.31 *Piping Location map of Idukki district*

a) Peringassery

The Piping affected locality is Peringassery in the Udumbanoor and Kanjikuzhi village in the Thodupuzha taluk of the Idukki district. Peringassery is located on the Paramada - Udumbanoor road. The expose cavity of the subsidence has a diameter of about 2.5m. (Younger pipes) It is about 12 meters deep. The cavity is believed to be interconnected by underground pipe like features. The soil type is mainly lateritic on the top and clayey in the bottom. The landuse is mainly mixed crops with rubber. A spring is seen emerging about 200m north of the collapsed section. This could be an outlet of the pipe. This pipe is ferrying water beneath the main Paramada - Udumbanoor road. The figure 3.33 shows a schematic section of the piping affected locality that indicating pipes cut across the road.

Figure:3.32 *Soilpiping in Peringassery, Idukki district*

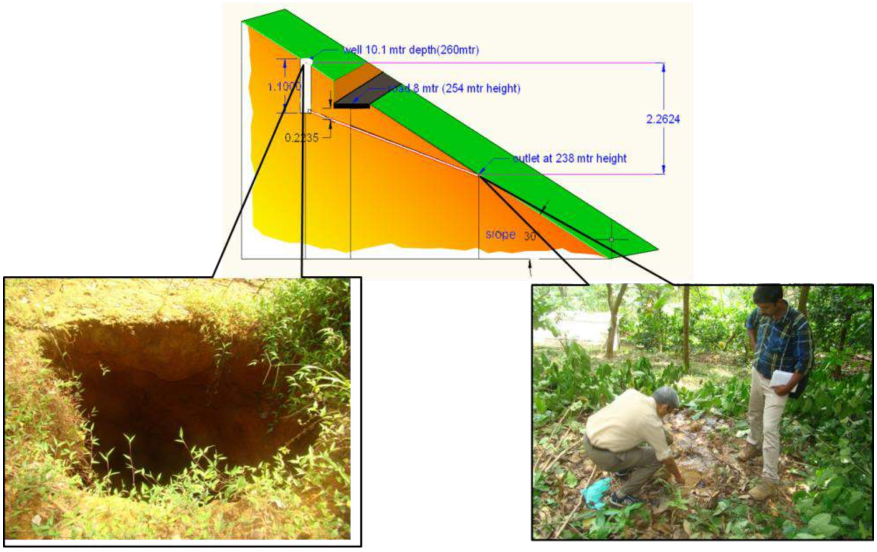


Figure:3.33 *landsubsidence due to soilpiping in Peringassery, Idukki district*

b) Thattekanni

Another land subsidence has occurred at Thattekanni on the Neriyamankalam- Idukki road (Figure 3.34). The subsidence vent has a diameter of 1m. It is about 6-7 meter deep. The cavity is interconnected by typical pipes which are little more than 5m in combination with younger pipes. The soil column is unconformably lying over the hard crystalline rock. Piping is located in this area having lateritic soil. Since groundwater follows the topography, the steeply sloping terrain produces high hydraulic gradient in the region. Piping can affect materials ranging from clay- size particles to gravels, but is most common in fine grained soil such as fine- grained soils such as fine sand silt and coarse clay.

Figure:3.34 *Soilpiping in Thattekanni, Idukki District*

c) Udayagiri

A series of land subsidences had occurred in the Udayagiri locality of Thankamany Village in the Udumbanchola taluk on 18.8.2010. The affected locality (N 09^0 50’ 30.8”, E 77^0 03’ 36.7”) is situated in the Udayagiri in the Thankamany village of Udumbanchola taluk in the Idukki district. It is also forms part of the Kamakshi Grama Panchayat. The affected area is located in Gothambu road which in turn joins the Chembakappara to Thankamoni main road.

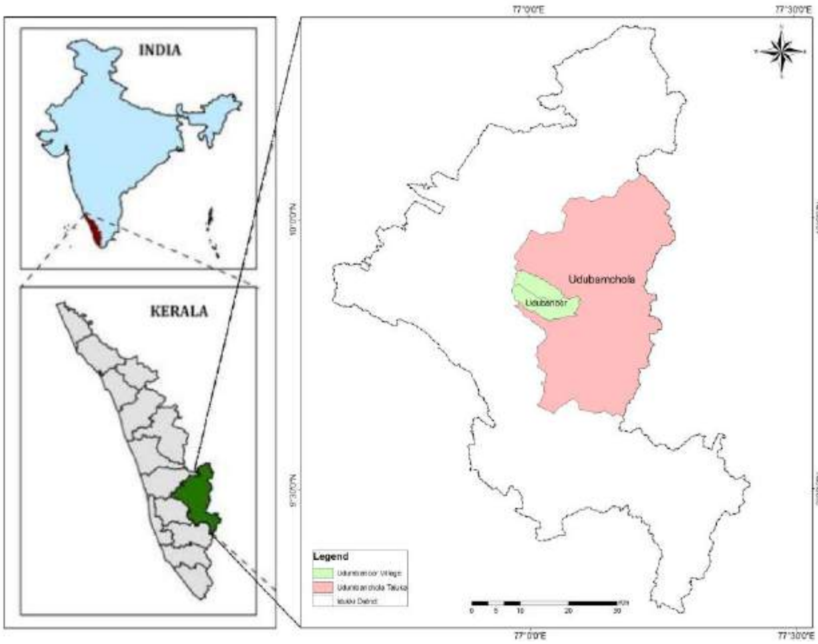


Figure 3.35: *location of the affected area.*

The area is situated on highland region of the state. A dome shaped hill of 1072 meters dominates the landform and because of this radial type drainage is seen in this area. The affected is located in the east facing slope of this hill. In this region the general trend of the major drainage and landforms is NW–SE. This locality falls in the Chinnar sub-basin of the Periyar drainage basin. The area receives copious rainfall but a reliable rain gauging was not available for the study. Precambrian crystalline such as Charnockites and gneisses form the bedrock of the area. The soil thickness or overburden material rather thick in many places. Clay size sediments which is red in colour predominates the sediments in the overburden followed by sand sized sediments derived from the weathered horizon. At places the weathering thickness is rather high. The slope where the incident has occurred is 25 degrees. The general landuse of the area is coffee, cardamom, arecanut etc.

The underground pipes in this area are generally occurring in combination with different types of pipes. The commonly occurring types are mature pipes in combination with small pipes. There are indications of discharge of water through the bottom of this subsidence caves. The underground water flow is free flow indicating that the water is flowing through a void or fee space. The in situ inspection of the site also revealed the existence of an underground channel. The discharge of ground water through the underground tunnel is located about 250 meters down-slope in a valley (figure3.36 a). It is observed that the sidewall of the cave is gradually collapsing due to the erosion of the flowing water. The water which is flowing through the caves (figure 3.36b) finally emerges out in a valley head (figure 3.36c) located about 250meters downslope. This effluent system of underground drainage causes subsurface erosion by a process known as “Piping” or Tunnel erosion. Usually these tunnels are funnel shaped and when it finally emerges out the outlet is rather very small in diameter in comparison to the upslope area.

a. roof collapse *b. inside tunnel* *c. outlet*

***Figure 3.36**: Tunnel formations in Udayagiri area*

Another prominent subsidence (N 09^0 50’ 31.3” E 77^0 03’ 34.7”) has occurred in the same Udayagiri locality on 14.8.2010 at 5.30pm (Figure 3.36). The subsidence crater has a diameter of 3meter and depth of 7meters to the top of the debris of the roof which is accumulated on the floor. The material of the roof is fine red clay and overlying the weathered basement. Piping has taken place at this contact. Piping has taken all the weathered coarse material and it was found deposited in the valley head located downslope in the NW direction. (N 09^0 50’ 33.6” E 77^0 03’ 34.0”) and (N 09^0 50’ 33.3” E 77^0 03’ 37.1”). It is suspected that there are a number of outlets. The tunnels are of mature type in combination with small and micro pipes. These out lets are small in dimension and it is observed that the weather coarse sediments are found deposited in this locality. The outlet (figure 3.37c) locality is marsh with constant input of water through these pipes (figure 3.37b).

a. View from inside the subsidence crater b. 7 Branching of tunnels c. One of the pipe outlets

***Figure 3.37** Different types of pipe in Udayagiri area*

Udayagiri locality has experienced land subsidence in the earlier years also. The first subsidence (N 09^0 50’ 31.7” E 77^0 03’ 34.5”) occurred in 2002 along a wide foot path off the Gothampu road. (Figure 3.38). At the time of inspection the subsidence crater is filled with sediments and debris material. Signs of subsurface water could be seen on the bottom walls. The diameter of the crater is about 2m and the depth is about 2m. The inlet pipe and outlet pipes are blocked due to debris from the collapsed material.

Figure 3.38: *One of the old subsidence crater observed in Udayagiri*

Another subsidence (N 09^0 50’ 30.8” E 77^0 03’ 36.7”) also occurred along the banks of the path during the same period (figure 3.39). This crater has a depth of about 2.65 m and has a diameter of about 3.25 m. Both these subsidence craters are situated on side slopes of the 1072 hill which is conical in shape. The slope where these incidences had occurred is sloping towards W-NW. There are subsurface pipes present which are like to run in NNE-SSW direction. However more investigations are required to determine the exact direction of pipe pathways.

Figure 3.39*: A subsidence crater formed along the path way*

Apart from the land subsidence occurred during SW monsoon of 2010 the other specific indications about soil-piping are available in two wells located in the area. infact one of the visible signs of soil piping was the stable water level in wells despite copious rain. This shows that the water is getting lost somewhere in the subsoil. Another indication was the mismatch between the quantity of rain received and the water flowing through the stream/nalas present in the area especially in the downstream side. In most cases large quantities of water is being lost through sub soilpipes.

One such well (figure 3.40) is located (N 09 ^{0} 50' 31.7" E 77 ^{0} 03' 35.7") near Mrs. Jolly's residence (N 09 ^{0} 50' 31.3" E 77 ^{0} 03' 35.8"). This well was collapsed in 2002 and in unusable in the present condition. The depth of the well at present is 9meters up to the top of the filled material.

Figure 3.40*: opening of a subsurface tunnel within the well*

The pipe is oriented in NE- SW direction. Mrs Jolly Moolayil (Kamakshi Panchayat No IV/25) house is situated about 8m from this collapsed well. The inhabitants of the house complained to this team of noise of water flow and rumbling sounds associated with that from the basement, especially during rainy seasons. This indicates that there are chances of pipe formation beneath this house. Eventhough the formation of subsoil pipe formation is a slow process but once it reaches closer to the ground subsidence may occur suddenly. There are indications of settling seen as indicated by a number of cracks (Figure 3.41) on the wall of Mrs Jolly's house. During high rains and when the discharge through the pipes is high the chances of erosion is rather high. So this area should be subjected to detailed investigations. It is recommended that the family should be relocated to a safer locality during high rains. The other houses in this locality are not showing any visible indications of instability at the time of inspection

Figure 3.41: *Cracks on the wall (Mrs. Jolly's house)*

The water levels in deep wells in this area are also not responding to inputs from the rainfall. This well is situated at an elevation of 973m and the general slope is +30degrees.The well located (N 09 0 50' 29.8" E 77 0 03' 32.5") has very little water at the time inspection which happened to be a rainy season. This deep well is resting on basement hard rock. Piping indicated by caving is observed in the NE- SW direction just above the basement. Water is escaping through this pipe. As per local enquiry the piping was observed during 2004.

Nalaam Mile

The area is situated on highland region, the landform is contain dendritic type drainage is seen in this area. The affected is located in the east facing slope of this hill. In this region the general trend of the major drainage and landforms is NW–SE. This locality falls in the sub-basin of the Periyar drainage basin. The area receives copious rainfall but a reliable rain gauging was not available for the study. Piping occurs in very fine and loose soil area. It is very close piping

Figure 3.42: *Inlet and outlet of Piping in Nalaam mile, Idukki district*

3.3.5 Wayanad district

a. Geomorphology

The district may be divided into three physiographic zones- Wayanad plateau (WP), Central Sahyadri High land (CH) and Mountainous regions of Central Sahyadri (MR) as per Soil Survey

Organisation. On the basis of topographic features the area can be divided into different physiographic zones like high ranges with rugged topography, high ranges with moderately rugged topography, intermontane valley and flood plains.

High ranges with rugged topography include hill ranges in the west, northwest and southwestern part of Wayanad district and elevation ranges from 1400 to 2100 m amsl. This area is occupied by dense mixed jungles and is having rugged topography with steep slopes and narrow valleys. Hill ranges along the eastern part and isolated hills come under high ranges with moderately rugged topography. The altitude of the physiographic zones ranges between 1000 and 1400 m amsl with moderate slope.

Intermontane valleys are the valleys between high ranges. These areas are occupied by colluvium formed by depositional processes. Erosional intermontane valleys are also reported. The flood plains with apparent alluvial thickness of more than 10 m are quite common and form productive aquifers.

The landform units identified in Wayanad are alluvial plain, flood plain, valley fill, linear ridge, hillcrest, sloping terrain, rocky slope (scarp face) and hilly terrain. The flood plain and Ground Water Information Booklet of Wayanad District valley fill are the major fluvial landforms whereas moderately sloping terrain (S2), highly sloping terrain (S3), rocky slope (scarp face), linear ridge and hillcrest are major denudational landform units. Flood plains are relatively smooth valley floors adjacent to and formed by rivers, which are subject to overflow. There is no lithological control over land use in the area. Landform unit with highest slope (90^{o}) identified in the study area is scarp face (rocky slope). Landform studies and data from well inventoried in different landform units of the study area indicate that fluvial and gently sloping terrains are promising zones of groundwater. Denudational landforms are unproductive zones.

b. Soil Characteristics

In the study area there are four types of soil viz. laterite soil, brown hydromorphic soil, forest loam and riverine alluvium.

Laterite soil seen in some areas of Wayanad is reddish brown in colour, formed under tropical monsoonal climate with alternate wet and dry seasons. The organic matter in the soil is very less with moderate nitrogen, phosphorous and potash. The pH of soil ranges between 5.5 and 6.5 and texture is clayey loam to silty loam with 5 to 20 % coarse fragments. Laterites on high grounds are more compact when compared to the low-lying areas. Forest soil is found in Mananthawady, Kalpetta and Sulthan Bathery blocks. They are rich in organic matter, nitrogen and humus. Forest loam is dark reddish brown in colour formed by weathering under forest cover with loamy to silty loam texture. The pH of the soil ranges between 5.3 and 6.3 and is slightly acidic in nature. Brown hydromorphic soil (BHS) is mainly seen between undulating topography in Wayanad district. The BHS is very deep brownish in colour with sandy loam to clayey texture. The BHS is formed by transportation and sedimentation of material from hill slopes. The pH of this soil ranges between 5.2 and 6.3 and is slightly acidic in nature. Alluvial soils are found along the banks of Kabani, Chaliyar and its tributaries. Riverine alluvium is very deep with sandy loam to clayey loam texture. Majority of the area under riverine alluvium was once occupied by paddy. Those areas are now utilized for the cultivation of various crops especially plantain. The riverine alluvium contains moderate organic matter, nitrogen, phosphorous and potash.

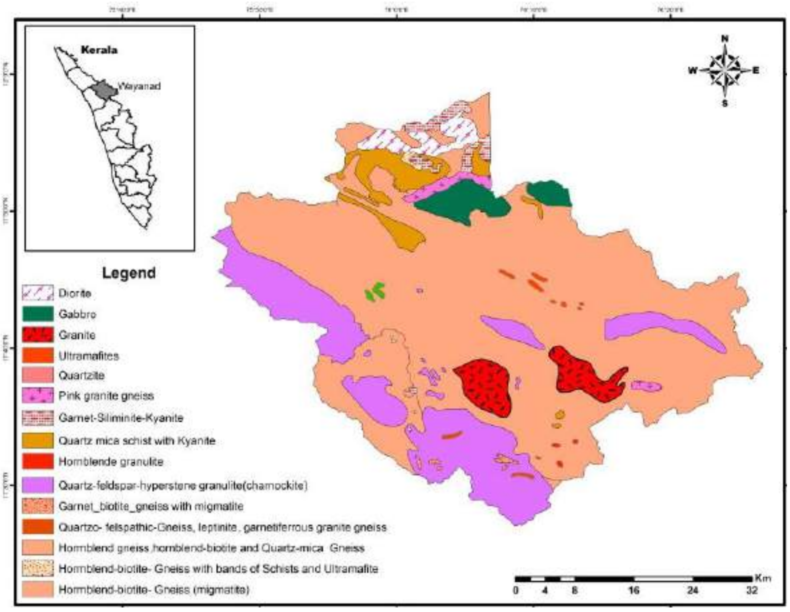


Figure:3.43 *Geological map of Wayanad district*

c. Hydrogeology

All the four blocks in the district are having similar hydrogeological conditions. The major water bearing formations in the district are weathered/fractured crystallines, alluvium and valley fills. Alluvium and valley fills are seen along the river courses and broad valleys. The alluvial aquifers are better represented in Kalpetta and SulthanBathery blocks and considerable thickness of this formation are seen in and around Muttil, Kainatti, and Varadur and in different parts of Panamaram Watershed. The thickness of alluvium varies from 3 to 9m and that of valley fills from 2 to 9m. In these formations groundwater occurs under phreatic condition. Dug wells are suitable abstraction structures for this formation with depth range varying from 3.5 to 7.8 mbgl. The depth to water level varies from 2.6 to 3.7 mbgl during pre-monsoon (April) and from 0.70 to 2.60 during post monsoon (November). The yield of dug wells in this formation ranges from less than

500 LPH to about 10,000 LPH with pumping duration ranging from less than 1 to 4 hours in a day. The hard rocks (crystalline) cover the entire district with thin deposits of alluvium and valley fills over it as mentioned above. Groundwater occurs under phreatic condition in weathered crystallines. Semi confined to confined conditions exists in deep fracture system, which forms potential aquifers and is developed by bore wells. The depth of wells and water levels in the weathered crystallines varies with respect to the parent rock formation as depicted in the hydrogeological map.

The weathered granite and granitic gneisses in Kalpetta and SulthanBathery Blocks form potential phreatic aquifers along valleys and topographic lows. The depth of dug wells in this formation generally varies in the range of 6 to 9m with water levels ranging from 4 to 8 mbgl during pre-monsoon and from 3 to 5 mbgl during post monsoon. The weathered charnockites seen in Kalpetta block and along the hill ranges of the Western Ghats form poor aquifer and can sustain only domestic wells. The depth of wells in this formation generally varies in the range of 7 to 10 m with water levels ranging from 4 to 9 mbgl during pre-monsoon and from 3 to 7 m during post monsoon.

The weathered migmatite and gneiss seen along the central portion of the district form moderately potential aquifers and cover a major area of all the four blocks. The depth of dug wells in this formation generally varies from 14 to 20 m with water levels ranging from 10 to 15 mbgl during pre-monsoon and from 8 to 11 m during post monsoon. The weathered gabbro and diorite rocks are seen in the northern portion of Mananthavady block form moderately potential aquifers. The depth of wells in this formation generally varies from 8 to 12 m with water levels ranging from 5 to 12 mbgl during pre-monsoon and form 3 to 11 mbgl during post monsoon.

3.3.5.1 Banasurasagar, Vythiri taluk Wayanad:

During 2006, a portion of the land belonging to Mr Mamooty a resident of the Padinjarethara village (Figure 3.46, Loc: N 11°41'33" / E75°54'16") subsided and water started gushing out with huge force. The water pressure was enormous and the discharge continued for months together. This indicates that the water is flowing under a very high hydraulic head. Interestingly this area is located very near to the Banasurasagar dam. Investigations revealed that this subsidence is also caused by soil piping. This locality is connected by an underground pipe downstream and emerges out as a spring.

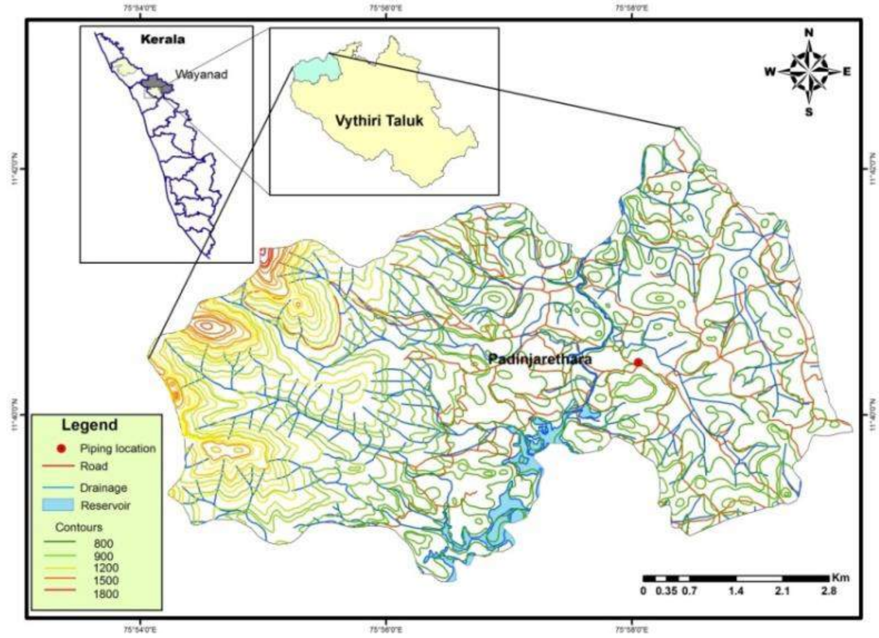


Figure:3.44 *Piping location in Vythiri taluk, Wayanad*

The process continued for few months and the dischrge stopped leaving behind a subsidence pit connected upstream and downstream by small tunnels.The mitigation work was carried out by filling up by stones and earth. This is the practice carried out by the locals. This area will be under obersation and if required chemical amelioration techniques will be adopted to prevent new erosion. In the down stream locality wall cracks have been observed in few houses located in the down slope side indicating land subsidence. Since the whole area is affected by soilpiping the SDMA is alerted for a detailed investigation of Banasurasagar dam site .

Figure 3.45. *Subsidence at Banasurasagar, Vythiri taluk Wayanad district*

Detailed geophysical work was carried out to differentiate the water conduits present in the area. This is decribed in deatiled in the chapter detailing the geophysical surveys. A mitigation plan is suggested for this area in the chapter dealing with mitigation.

CHAPTER 4

GEOPHYSICAL INVESTIGATIONS

4.1 Geophysical investigations (Electrical Resistivity Surveying)

Electrical resistivity surveys are carried out to measure the earth resistivity by driving a direct current (DC) signal into the ground and measuring the resultant potentials (voltages) generated in the earth. The earth resistivity so measured is a physical characteristic of the geological formation and indicate the resistance offered by the medium to the flow of electric current. Resistivity varies with texture of the rock, nature of mineralization and conductivity of electrolyte contained within the rock. It changes from formation to formation as well as within a particular formation. It increases with grain size and tends to be maximum at the grains are coarse and compact. The resistivity drastically reduces with increase in clay content. The clay is commonly dispersed throughout the medium as coatings on grains or disseminated masses or as thin layers or lenses.

An electrical resistivity survey will be effective only if the target of interest has a resistivity contrast with the surrounding medium. For example, underground void spaces, buried rock boulders, hard rock basements etc. exhibit high resistivity values and therefore will be in contrast with the surrounding medium. Similarly, water saturated sub-surface layers, filled pot-holes; metallic objects etc. exhibit lower resistivity values and hence offer a contrast with the surrounding medium. In such circumstances, electrical resistivity method could succeed in delineating the subsurface structures. This is the basis of selecting electrical resistivity methods for the present study. However, it is to be understood with caution that a resistivity contrast could be similar for different features and therefore, the inferences from geological evidences or multiple geophysical methods are extremely important for the clarity and confirmation of the results.

4.1.1 Types of electrical methods by Using Analogue Resistivity meter

Electrical resistivity surveys are carried out by sending current into the earth using two electrodes (current electrodes) separated by a specific distance, measuring the potential generated in the subsurface due to the current field using another set of electrodes (potential electrodes), estimating the resistance offered by the subsurface medium to the flow of current and determining the resistivity of the medium based on the resistance and the electrode configuration constant. Generally, electrical resistivity surveys are carried out using two techniques, namely Electrical Resistivity Profiling (ERP) and Vertical Electrical Sounding (VES).

A) Vertical electrical sounding (VES): In a VES, the distance between the current electrodes are increased with respect to a fixed point, known as the sounding point. Here, the measured resistance values at the surface reflect the vertical distribution of resistivity values in the subsurface earth medium and the depth of investigation depends on the distance between the two current electrodes.

B) Electrical Resistivity Profiling (ERP): In an ERP, the set of electrodes are shifted from one point to the other along a preferred line/profile without changing their relative configuration and the resistivity value is measured at each point to get an idea of the lateral variation of resistivity within a certain level of depth. The ERP data are generally plotted as X-Y graph with apparent resistivity values on the Y-axis and ERP stations of the profile on the X-axis. It shows the apparent resistivity variation along a specified profile for different current electrode separation. It indicates the lateral variation of apparent resistivity at different depth levels (www.geovision.com / pdf / 5.06.2015).

4.1.1.1 Electrical resistivity instrumentation

Electrical resistivity instrumentation systems (Figure4.1) basically consist of a transmitter and receiver. The transmitter supplies a low frequency (typically 0.125 to 1 cycles/second or “Hertz”) current waveform that is applied across the current electrodes. Either batteries or an external generator, depending on power requirements can supply power for the transmitter.

Figure: 4.1 *Earth resistivity meter (M/s. Anvic Systems - Resistivity meter)*

Instrumentation consists of following:

- Energy source (Battery).

  In this current single long direct current or low frequency square wave with commutator.

  Low frequency alternate current also used

- Potentiometer

The voltage between the measuring electrodes in usually measured through voltmeter may be used.

- Two potential and current electrodes.

  Generally steel or copper clad steel stakes driven in a few inches in to the ground

4.1.1.2 Electrical resistivity Survey at Kottathalachimala

Geophysical investigations in the study area are planned to characterize the subsurface geological features, in general, and soil pipes in particular. It is proposed to experiment with electrical resistivity Characterization of the near-surface layers for studying the geo-electric quality of the subsurface earth and describing the relative disposition of soil pipes. Accordingly, six electrical resistivity profiles (ERP) are laid across three suspected soil pipes. Subsequently, vertical electrical soundings (VES) are conducted at five locations, selected at random, in Kottathalachimala area of Cherupuzha. The locations of these studies are depicted in Figure 4.2. The locations of the VES are selected based on their tentative nearness to the soil pipes. Further, 21 VES are conducted across four profiles over a soil pipe of which the inlet and outlet locations are known. The layout of these VES locations is given in Figure 4.4. A detailed description of the studies and their tentative results are given hereunder.

Figure: 4.2 *Electrical resistivity surveys in progress in Kottathalachimala*

Six ERPs are laid in the study area at locations selected at random considering the nearness to three suspected soil pipe locations to capture a preliminary idea of the lateral variation in resistivity at different depth domains. It was carried out using Schlumberger array for four-different current electrode separation, that of AB/2=5m, AB/2=10m, AB/2=15m, and AB/2=20m. The station interval selected for the ERP was 10m (5m near the suspected soil pipes). Subsequently, two VES are carried out using Schlumberger configuration at two spots selected at random based on tentative nearness to the soil pipes. The stations have been located using a hand held Global Positioning System (GPS) and brought to a base map (Figure 4.4). The VES are carried out with a maximum current electrode spread of150m (AB/2=75m). Further, near to the Location1of Figure 4.4, 21VES are carried out with prefixed and closely spaced stations (Station interval=2.5m) along 4profiles across a known soil pipe of which the inlet and outlet of the pipe are known. The VES are carried out with a maximum current electrode spread of 70m (AB/2=35m).The layout of the four profiles and the inlet and outlet locations of the soil pipe are depicted in Figure 4.4.

The electrical resistivity measurements have been carried out using Resistivity Meter namely Aqua meter manufactured by M/s. Anvic Systems, Pune (Figure 4.3). It has a maximum output of 300 V and 500 mA using a rechargeable battery as power source. It measures resistance with a precision of ±0.001ohms.

The VES data has been interpreted using a forward modelling programme (Zhody, 1993) and the result has been used in a reverse modelling programme (IPI2WIN, 2003) to estimate the layer thickness and layer resistivity values of the subsurface.

Figure 4.3: *Aquameter (M/s. Anvic Systems - Resistivity meter)*

4.1.1.3 Constraints of the study

The study area is part of the Western Ghats region of Kerala and hence, highly undulating. The soil thickness is restricted at places with intermittent exposure of crystalline and laterites. The undulating ground with bench-cut terrain, rock boulders, duricrust formations etc., pose problems for the smooth conduct of the electrical resistivity studies. The duricrust, at places, enhances the contact resistance leading to ambiguous resistivity values. Generally, in an electrical resistivity survey, the subsurface layers are to be characterized from the resistivity data based on reference to the geological inference obtained from geological maps, stratigraphic information, litho-log from drill data or information on litho-sequence from open wells, depth to water table etc.

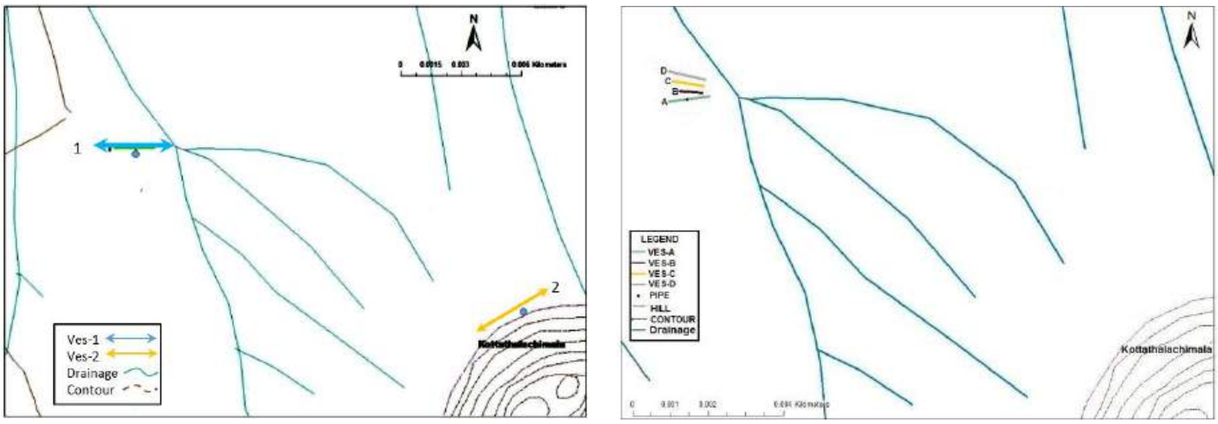


Figure 4.4*: Location of Geophysical investigations (ERP & VES)*

4.1.1.4 Analysis and Results

a) Vertical Electrical Soundings at two piping locations

The data obtained for the two VES conducted at two piping locations that have been interpreted using a forward modelling program method find out the layer resistivities, layer thickness and domain depth (Table 4.1). It provided a pseudo resistivity section which is further used for reverse modelling to generate a geo-electric section (Table 4.2).

Table 4.1 *Layer parameters of the pseudo-resistivity section at the two VES locations*

LR- Layer resistivity in ohm-m; LT- Layer thickness in meters; D-Depth in meters

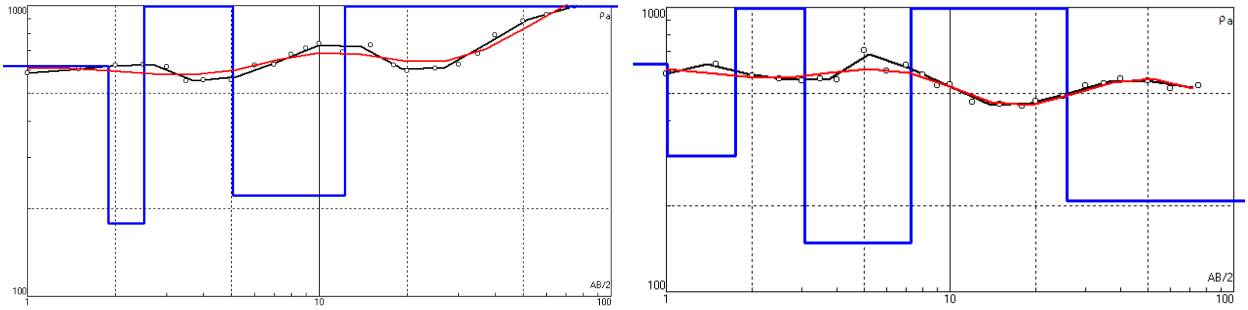
VES No	Parameter	L1	L2	L3	L4	L5	L6	L7	L8	L9	L10	L11	L12
1	LR	524	678	579	383	402	721	1064	889	552	506	837	1596
	LT	0.54	0.25	0.37	0.54	0.79	1.16	1.71	2.50	3.67	5.39	7.91	
	D	0.54	0.79	1.15	1.69	2.48	3.65	5.35	7.85	11.53	16.92	24.83	99999
2	LR	571	544	485	532	644	564	354	298	432	635	668	509
	LT	0.54	0.25	0.37	0.54	0.79	1.16	1.71	2.50	3.67	5.39	7.91	
	D	0.54	0.79	1.15	1.69	2.48	3.65	5.35	7.85	11.53	16.92	24.83	99999

Table 4.2*. Geo-electric section deduced from the two VES data*

TR- True Resistivity (ohm-m); H- Thickness (m); TD- Total Depth (m)

VES No.	Parameter	L1	L2	L3	L4	L5	L6	L7	L8	TD	RMS error for best-fit(%)
1	TR	657	1457	333	2790	268	3025	--	--	--	3.89
	H	0.45	0.67	1.17	2.99	5.73	--	--	--	11.01	
2	TR	479	1296	315	1758	128	839	1833	833	--	1.71
	H	0.31	0.40	0.79	1.53	3.33	2.64	8.12	--	17.12	

The VES data indicates 6-8 layered near-surface geo-electric section. The depth to bedrock exhibits significant variation. The bedrock at VES-1 was encounter data depth of around 11m below ground level where as it was not encountered even at a depth of around 17m at VES-2.



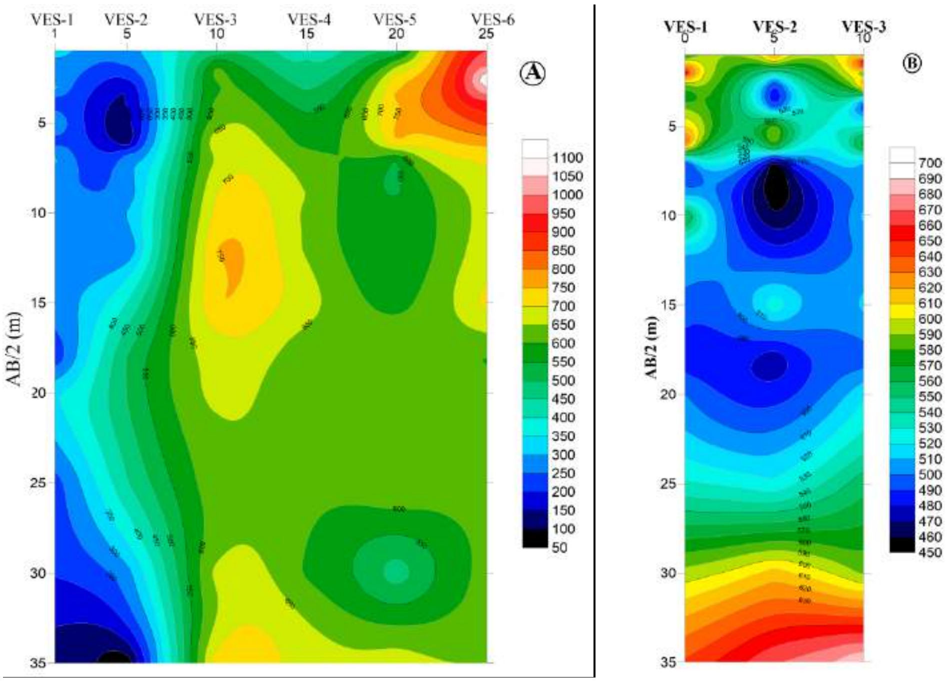
a. Vertical electrical sounding 1 *b. Vertical electrical sounding 2*

***Figure 4.5**: 1D inversion of apparent resistivity data from soundings VES-1 and VES-2 (Labelled as VES-1and VES-2 in modelled curves and cross-sections).*

Two resistivity 1D graph were generated from *IPI2win* software, the calculated layered models and estimated smooth model (Figure 4.5, red lines) grouped by apparent resistivity (black line) shown in Figure 4.5a and 4.5b, is a program for 1D automatic and manual interpretation of VES curves. From the graph (Figure 4.5a) the given section comprise 4 geoelectrical discontinuities, ($\rho1 < \rho2 > \rho3 < \rho4$) the lowest apparent resistivity value at a depth of 2 to 5m and increase the resistivity at a depth of 7m and it is again decreasing. The actual piping position is 4 to 6m bgl., that means the resistivity variation in the 1D graph gives the details slightly shifting from the actual point. From the second graph gives the same resistivity at different depth. The depth at which 5m, sudden increase in the resistivity is possibly due to piping.

b) **Electrical Resistivity Profiles**

The apparent resistivity data obtained for four different AB/2 values at each station interval of th e four profiles have been plotted in surfer as 2D apparent resistivity contour graph, which is given below.



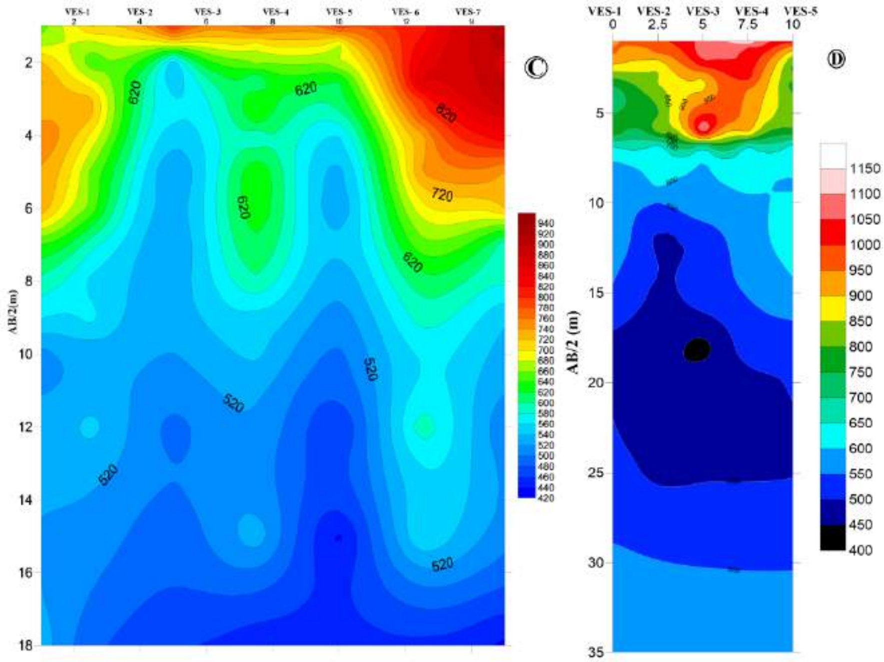


Figure 4.6: *Apparent resistivity section along Profile A, B, C and D,*

The Layer resistivity and thickness of the pseudo-resistivity section generated based on forward modeling for Profile A, B, C and D are given in Table 4.3, 4.4, 4.5 and 4.6respectively and the true geo-electric section based on reverse modeling are given in Table 4.7, 4.8, 4.9and 4.10.

Table 4.3: Layer parameters of the pseudo-resistivity section- VES of Profile A

LR- Layer resistivity in ohm-m; H- Layer thickness in meters

VES NO	Parameter	L1	L2	L3	L4	L5	L6	L7	L8	L9	L10
1	LR	414	299	234	254	323	371	387	383	292	113
	D	0.54	0.79	1.16	1.7	2.5	3.66	5.38	7.9	11.59	
2	LR	427	209	80	82	184	371	593	616	289	
	D	0.68	0.99	1.46	2.14	3.14	4.61	6.77	9.93		
3	LR	360	401	434	471	526	592	648	694	746	810
	D	0.48	0.71	1.04	1.53	2.25	3.3	4.84	7.11	10.43	
4	LR	377	430	481	519	534	541	562	600	647	696
	D	0.4	0.71	1.04	1.53	2.25	3.3	4.84	7.1	10.43	
5	LR	480	880	1292	1325	973	659	538	540	616	734
	D	0.48	0.71	1.04	1.53	2.25	3.3	4.84	7.11	10.43	
6	LR	897	854	1724	1251	1089	592	469	508	596	694
	D	0.48	0.71	1.04	1.53	2.25	3.3	4.84	7.11	10.43	

Table 4.4: Layer parameters of the pseudo-resistivity section- VES of Profile B

LR- Layer resistivity in ohm-m; H- Layer thickness in meters

VES NO	Parameter	L1	L2	L3	L4	L5	L6	L7	L8	L9	L10
B1	LR	479	616	642	542	414	350	369	466	634	
	D	0.56	0.83	1.22	1.78	2.62	3.84	5.64	8.28		
B2	LR	520	412	357	385	383	297	268	354	583	1045
	D	0.54	0.79	1.16	1.7	2.5	3.66	5.38	7.9	11.59	
B3	LR	626	752	636	457	442	505	436	361	485	974
	D	0.54	0.79	1.16	1.7	2.5	3.66	5.38	7.9	11.59	

Table 4.5: Layer parameters of the pseudo-resistivity section- VES of Profile C

LR- Layer resistivity in ohm-m; H- Layer thickness in meters

VES NO	Parameter	L1	L2	L3	L4	L5	L6	L7	L8
1	LR	539	646	704	883	878	572	312	586
	D	0.54	0.79	1.16	1.7	2.49	3.65	5.36	
2	LR	665	629	676	728	702	605	513	472
	D	0.6	0.87	1.28	1.88	2.77	4.06	5.96	
3	LR	1397	399	448	715	729	559	457	465
	D	0.54	0.79	1.16	1.7	2.49	3.65	5.36	
4	LR	766	718	678	657	627	574	519	
	D	0.54	0.79	1.16	1.7	2.49	3.65	5.36	
5	LR	1128	1049	920	938	707	511	440	402
	D	0.6	0.87	1.28	1.88	2.77	4.06	5.96	
6	LR	772	804	808	778	725	637	528	444
	D	0.6	0.87	1.28	1.88	2.77	4.06	5.96	
7	LR	852	869	901	857	715	557	455	412
	D	0.6	0.87	1.28	1.88	2.77	4.06	5.96	

Table 4.6: Layer parameters of the pseudo-resistivity section- VES of Profile D

LR- Layer resistivity in ohm-m; H- Layer thickness in meters

VES NO	Parameter	L1	L2	L3	L4	L5	L6	L7	L8	L9	L10
1	LR	950	1000	911	810	752	636	451	361	451	714
	D	0.54	0.79	1.16	1.7	2.5	3.66	5.38	7.9	11.59	
2	LR	1098	1043	969	866	740	616	525	471	444	
	D	0.56	0.83	1.22	1.78	2.62	3.84	5.64	8.28		
3	LR	1088	1197	1146	892	648	550	499	438	460	608
	D	0.54	0.79	1.16	1.7	2.5	3.66	5.38	7.9	11.59	
4	LR	954	1276	1339	973	618	529	539	449		
	D	0.66	0.97	1.43	2.09	3.07	4.51	6.62			
5	LR	1159	801	696	728	748	732	585	387	389	707
	D	0.54	0.79	1.16	1.7	2.5	3.66	5.38	7.9	11.59	

Table 4.7: Geo-electric section deduced along Profile A

TR- True Resistivity (ohm-m); H- Thickness (m); TD- Total Depth (m)

VES NO	Parameter	L1	L2	L3	L4	L5	L6	L7	TD	RMS error for best-fit (%)
1	TR	368	141	796	136	771	31.8	2.53		5.76
	H	0.87	1.04	1.12	2.09	4.81	2.14		12.07	
2	LR	204	557	29	2934	4225	104	6.59		10.85
	LT	0.28	0.51	0.75	0.71	1.97	4.56		8.78	
3	TR	271	1657	219	2689	227	85311			2.87
	H	0.39	0.47	0.99	2.56	9.03			13.44	
4	TR	259	1379	305	1431	393	5760			2.41
	H	0.46	0.31	1.22	1.93	17.7			21.62	
5	TR	266	3176	215	2626	181	8873			2.96
	H	0.45	0.54	2.66	3.23	10.5			17.38	
6	TR	885	1888	495	537	812				2.77
	H	0.88	0.82	0.47	12.9				15.07	

Table 4.8. Geo-electric section deduced along Profile B

TR- True Resistivity (ohm-m); H- Thickness (m); TD- Total Depth(m)

VES NO	Parameter	L1	L2	L3	L4	L5	L6	TD	RMS error for best-fit(%)
1	TR	476	1742	227	754	191	21457	13.84	2.61
	H	0.64	0.45	1.19	4.29	7.27			
2	TR	692	326	1309	400	3360		17.24	3.64
	H	0.83	0.97	0.54	14.90				
3	TR	400	1326	169	1163	252	140000	14.92	3.97
	H	0.37	0.6	0.97	2.48	10.5			

Table 4.9. Geo-electric section deduced along Profile C

TR- True Resistivity (ohm-m); H- Thickness (m); TD- Total Depth(m)

VES NO	Parameter	L1	L2	L3	L4	L5	L6	TD	RMS error for best-fit(%)
1	TR	626	923	905	204	2053		8.44	1.75
	H	0.96	1.09	2.23	4.16				
2	LR	903	404	1603	420	1530		16.99	1.75
	H	0.50	0.62	0.89	14.98				
3	TR	1072	211	1150	303	574	330	9.58	2.95
	H	0.64	0.43	0.93	1.93	5.65			
4	TR	833	434	1136	170	770		7.27	2.49
	H	0.82	1.12	2.12	3.21				
5	TR	1210	294	978	502	285	985	18.01	1.89
	H	0.42	0.22	0.55	3.39	13.43			
6	TR	748	1741	461	1122	128	5815	9.98	1.27
	H	0.73	0.38	1.09	2.76	5.02			
7	TR	899	1370	571	319	4747		17.12	2.49
	H	1.31	0.56	3.95	11.3				

Table 4.10. Geo-electric section deduced along ProfileD

TR- True Resistivity (ohm-m); H- Thickness (m); TD- Total Depth(m)

VES NO	Parameter	L1	L2	L3	L4	L5	L6	L7	L8	TD	RMS error for best-fit(%)
1	TR	721	1608	347	939	317	1090			13.07	2.24
	H	0.38	0.58	0.67	2.4	9.04					
2	LR	1019	931	541	308	1242				17.61	2.5
	LT	0.63	1.42	5.06	10.5						
3	TR	995	2188	304	874	133	32998			14.35	3.76
	H	0.79	0.56	1.53	4.65	6.82					
4	TR	3417	432	2433	158	1244	22.3			9.30	2.11
	H	0.29	0.35	0.88	1.34	6.44					
5	TR	1386	396	1644	257	1304	216	30630		16.58	1.97
	H	0.53	0.39	0.83	1.32	2.58	10.93				

The layer resistivity indicates tentative correspondence with geological layer, which need to be investigated and confirmed further.

4.1.2 Digital Multi-electrode Resistivity Meter

Multi-function digital DC resistivity/IP meter- wdjd-4

The WDJD-4 multi-function digital DC resistivity/IP Meter is a new generation instrument with 32 single-chip and 24 bit A/D technology. It can carry out Resistivity and IP survey at the same time. This system can be widely used for metal and non-metal mineral resources exploration, geotechnical investigations, as well as in hydrogeology and engineering geological prospecting, such as searching for groundwater, identification of soil pipes, investigating dam base, studying flood protection levee for incipient faults and conducting geothermal survey. It can conduct not only general electrical resistivity/IP survey but also multi-electrode 2D Resistivity imaging. It features high accuracy, fast sounding speed, mass memory capability and easy operation, in association with flexible multi-electrode converter. Its self-check function can even locate each converter. WDJD-4 system can connect many multi-electrode converters in series to compose cascade connection by communication cable. The measured data of WDJD-4 can be processed by other multi-electrode resistivity software, which makes the interpretation more convenient (new.wtsgeo.com/wdjdj-3.html/3.05.2015).

4.1.2.1 Components

A multi-function Digital DC Resistivity/IP Meter (Figure: 4.7), is having a WDJD-4main frame, WDZJ-4 switcher box (Multiplex Electrode Converter), 12V rechargeable battery as a transmitting power source developed by BTSK/WTS Limited, electrodes, multi-electrode cables etc. It features multiple functions, high accuracy, fast speed, high reliability and excellent expandability. In order to conduct multi-electrode 2D electrical resistivity survey, the instrument system will automatically select current electrodes and potential electrodes according to a specific electrode array, and gives measured results of all the data points of a cross-section. The data so gathered is processed and interpreted using RES2DINV Software.

Figure 4.7: *Digital multi electrode resistivity meter (WDJD-4 Multi-function Digital DC Resistivity/IP Meter)*

4.1.2.2 Methodology

There are mainly three types array, Schlumberger, Wenner and dipole-dipole array used for investigation of soil pipes.

(a) Schlumberger array:

The Schlumberger array (Figure 4.8a) consists of four collinear electrodes. The outer two electrodes are current (source) electrodes and the inner two electrodes are the potential (receiver) electrodes. The potential electrodes are installed at the center of the electrode array with a small separation, typically less than one fifth of the spacing between the current electrodes. The current electrodes are increased to a greater separation during the survey while the potential electrodes remain in the same position until the observed voltage becomes too small to measure.

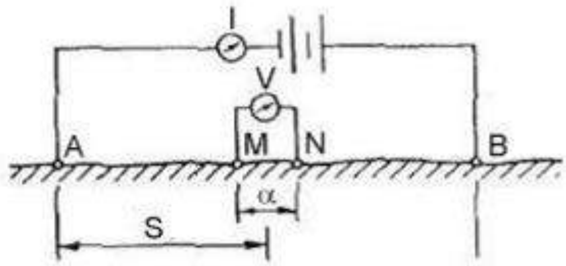


Figure 4.8a: *Schlumberger array configuration*

(b) Wenner array

In Wenner array the electrode configuration (figure 4.8b), in which four electrodes are deployed in a line, with equal spacing between the two potential electrodes, and between each current electrodes and its nearest potential electrode. Its geometric factor (K_g) is $2\pi a$, where a is electrode spacing .The Wenner array has five variations, three referred to as the tri potential method with α, β, and γ configurations.

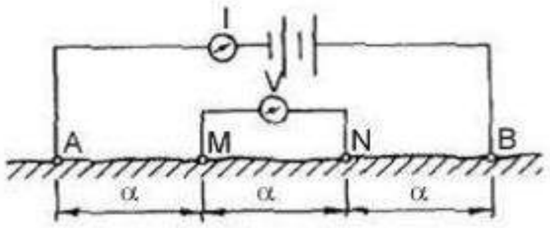


Figure 4.8b: *Wenner array configuration*

(c) Dipole – dipole

The Dipole-Dipole array is a type of electrode configuration for a Direct Current Resistivity Survey and is defined by its electrode array geometry. The dipole-dipole array (figure 4.8c) is one member of a family of arrays using dipoles (closely spaced electrode pairs) to measure the curvature of the potential field. This array is especially useful for measuring lateral resistivity changes and has been increasingly used in geotechnical applications (Environmental geophysics /resistivity methods, Dr M. H Loke, 1997) (Figure: 4.8a, 4.8b, 4.8c).

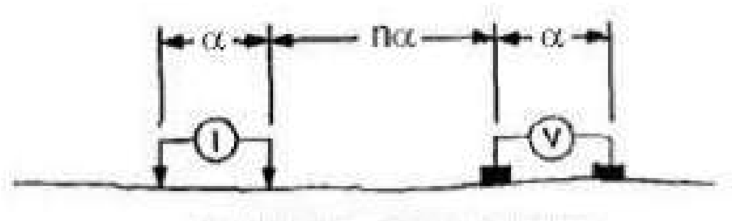


Figure 4.8c: *Dipole – Dipole configuration*

4.1.2.3 The 2D Electrical Resistivity Imaging

The electrical resistivity profiles were laid almost perpendicular to the suspected alignment of the soil pipes with the probable location of pipes as the centre point. The maximum length of the profile was depending on the electrode separation; 60 electrode was using with a WDZJ-4 switcher box (Figure 4.9)i.e., the profile length achieved is 150m when the electrode separation is 2.5m and the same is only 60m for the electrode separation of 1m. GPS co-ordinates were marked at certain electrode positions such as at 1, 11, 21, 31, 41, 51, and 60 to label the position and apply the elevation correction. In order to nullify the contact resistance, if any, at the electrodes, Grounding Resistance (Rg) was initially measured for the set of electrodes by setting the desirable maximum limit of Rg to 5 K. Ohms considering the requirement of improving the signal to noise ratio. On switching on for Rg measurements the instrument automatically highlight the electrode number where the Rg is higher than 5 K. Ohms. For such electrodes, corrective measures have to be taken to improve the ground contact by tight pegging of the electrode and/or by pouring saline water. After ensuring that all the electrodes are well grounded without contact resistance beyond the desirable limit, the switcher box is connected and measurement mode initiated.

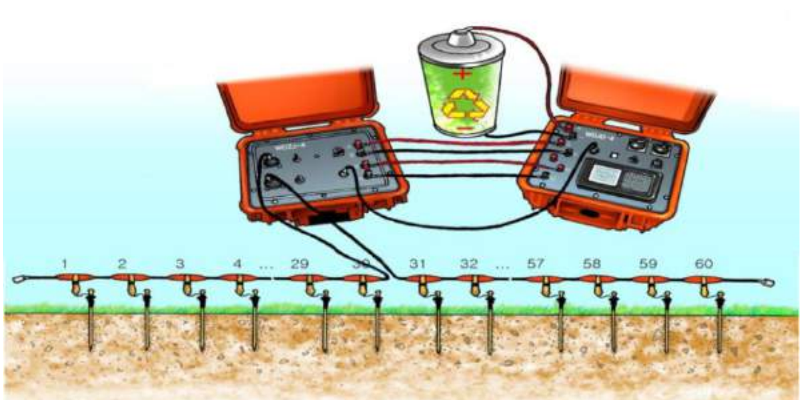
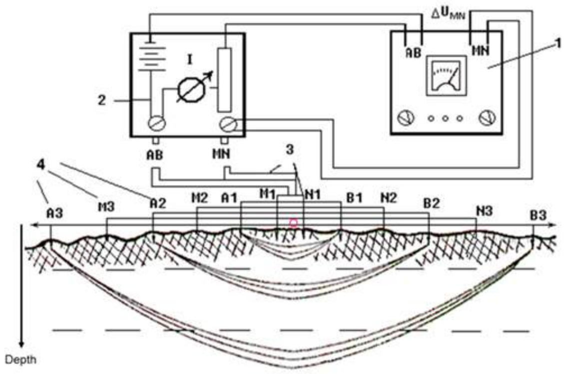


Figure 4.9: *Survey Layout sketch for 2D ERT of WGMD-4 Model*

The instrument is facilitated to measure Wenner, Schlumberger & Dipole-Dipole array. The instrument generates the resistivity data for various combinations and layers and is stored in the

WDJD-4 mainframe which could be transferred to an external computer facility. The data so gathered is interpreted using a RES2DINV Software. In order to do the interpretation using this software, the data gathered and stored is converted to a compatible format using WDAFC.EXE program and subsequently interpreted. The depth of Penetration of digital electrical resistivity imaging was shown in the figure 4.10.



a) A, B Current Electrodes; b) M, N Potential Electrodes, c) O is Mid-point

Figure 4.10: *Model for depth of Penetration of Electrical Resistivity Imaging*

4.1.3 Electrical resistivity survey at Idukki district

Field investigations were carried out using Electrical Resistivity Imaging technique at piping affected localities of Tattekanni and Peringassery in Idukki district, during 27/1/2014 to 31/1/2014, and Cherupuzha locality during 17th to 22 March 2014 with the WDJD- 4 instrument. This was to locate and map the alignment of 'Soil Pipes'. Four resistivity profiles were laid across suspected soil pipes at Peringassery where the inlet and outlet locations of the pipes are known. Similarly, three resistivity profiles were laid at Thattekanni across the suspected alignment of the soil pipe nearer to the inlet portion. The layout of these Electrical Resistivity Profile (ERP) locations is given in Figure 4.11 and Figure 4.16.

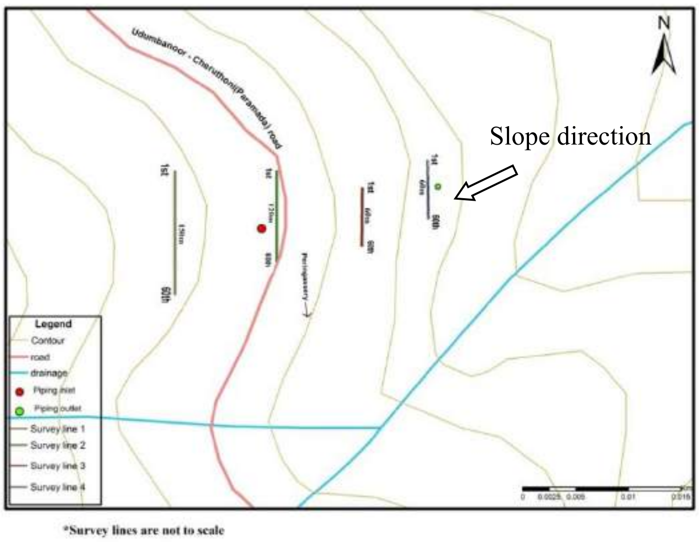


Figure 4.11: *The Electrical resistivity survey layout in Peringassery*

The resistivity data obtained along each of the ERP were retrieved to a computer and converted for interpretation by RES2DINV software. The interpretation of each ERP data gathered in specific array system provides the measured apparent resistivity pseudo section, calculated apparent resistivity pseudo section and inverse model resistivity section. The location wise details of the study are given hereunder.

4.1.3.1 ERP Survey at Peringassery

The interpreted ERP images of the four profiles 1, 2,3,4 and 5 using Schlumberger array are given as Figure 4.12, 4.13, 4.14, 4.15 and 4.16 respectively. The resistivity inverse model sections so deduced are qualitatively interpreted as follows.

Profile 1

The figure 4.12 shows the 2D true resistivity model using Schlumberger array along Profile 1. This profile is laid 25m east of the inlet spot of the soil pipe on its upper slope portion and oriented in the N - S direction. The inverse model resistivity section, prima facie indicates a highly anisotropic near-surface layers. There are high resistivity patches, near-surface, extending all along the profile with varying thicknesses. In general, the resistivity section covering up to a depth of 33m indicate moderate resistivity values except for the patchy high resistivity zones. The moderate resistivity with lateral and vertical variation may be indicative of differential weathering. Within this zone there are two horizontally stratified layers of highly saturated zone, the one between the northern tip and central point is at a depth of 6m and the other at a depth of 17.5m located between the central point and southern side of the profile. The central portion of the profile exhibits relatively lower resistivity in comparison to the nearby zones which is indicative of more promising recharge zone. Within this zone, a conspicuous low resistivity round-shaped feature is seen at a depth of 5m almost in the middle of the profile probably a higher saturated zone.

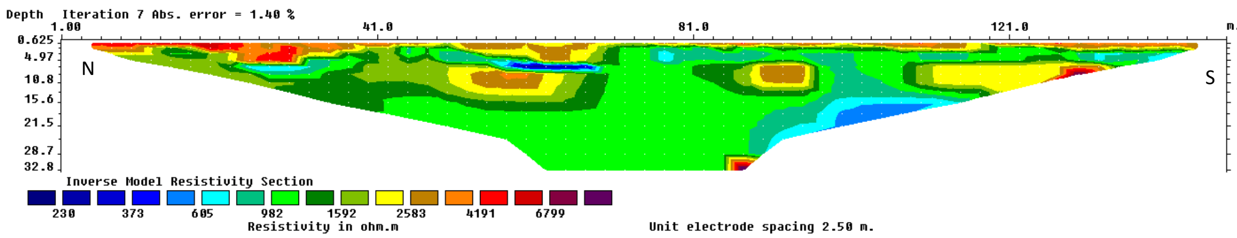


Figure 4.12: *Profile 1 Schlumberger array at Peringassery*

Profile 2 and 3

Two profiles are laid across the suspected soil pipe and 4m west of its inlet on the downslope side; the first (Figure 4.13a) with an electrode spacing of 2m (Profile length 120m) and the second (Figure 4.13b) with an electrode spacing of 1m (Profile length- 60m). The Profiles are laid in NS direction with the midpoint near the suspected soil pipe. The inverse model resistivity section indicates a differential section on the southern and northern portion the soil pipe. The southern section exhibits a very thick weathered/fractured horizon beyond 12 m at the central portion of the profile. On the northern portion, the weathered/fractured horizon indicates around 3m thickness. The weathered zone on the northern side, the thickness which is almost uniform, indicates vertical patches of moderate resistivity and the zone above the suspected soil pipe indicates relatively the lowest resistive patch. The horizon also indicates surficial patches of saturated soil zones especially on top of the location of soil pipe. In and around the soil pipe location, below the weathered zone, a very high resistive strata is exhibited which could be suspected as a fluvial barrier. Hence concentration of a fluvial force over the high resistive zone could be suspected.

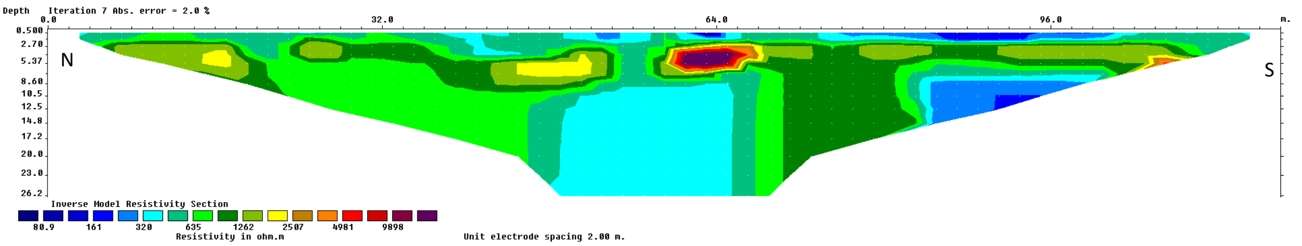


Figure: 4.13a *Profile 2 Schlumberger arrays (120m stretch) at Peringassery*

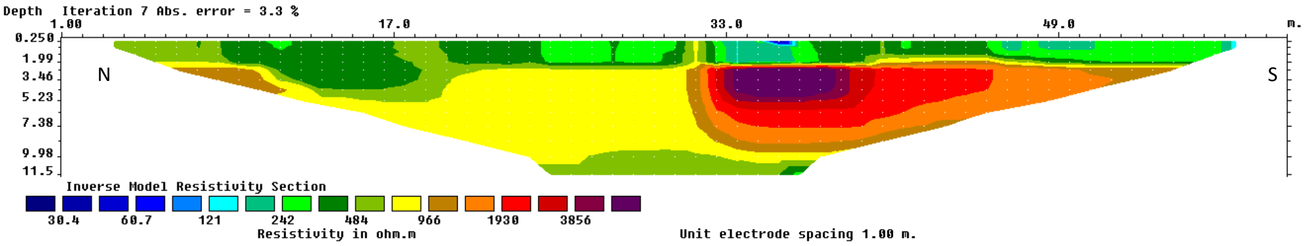


Figure: 4.13b*. Profile 3, Schlumberger arrays (60m stretch) at Peringassery*

Profile 4

This profile was of length 60m and electrode spacing of 1m was laid parallel to the Profile 2 and 3 at 15m to its west. It was laid such that the midpoint of the profile falls on the top of the suspected soil pipe considering its interpolated orientation and that it is linear. The inverse model resistivity section prima facie indicates highly anisotropic near-surface layers with high resistivity patches seen all along the profile with varying thicknesses. The thickness of the highly anisotropic resistivity section, in general varies from 1.5m in the central portion to 5m on the peripheral areas of the profile. At the central portion, a 7m wide moderately resistive layer is encountered with a saturated spot on the northern part of this layer at a depth beyond 10m.

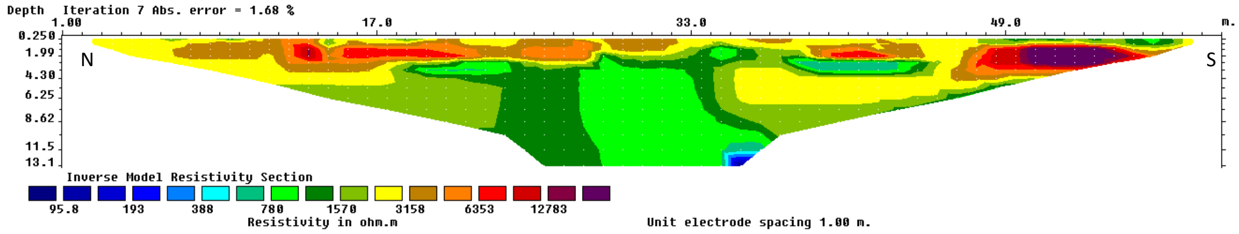


Figure: 4.14. *Profile 4, Schlumberger array at Peringassery*

Profile 5

The profile 5 with electrode spacing of 1m and length of 60m is laid parallel to the Profile 4 across the suspected soil pipe about 25m west of it in the down slope side. The inverse model resistivity section indicates high resistivity patches all along the profile except at the central portion of the profile. The soil pipe location is very shallow and falls within the electrode stations of 29 and 39. The location indicates low resistivity zones which extend towards depth. The profile also encountered two highly saturated zones having resistivity lower that 350 Ωm, one in the northern part at a depth of 4m and another in the southern part at a depth of 7m.

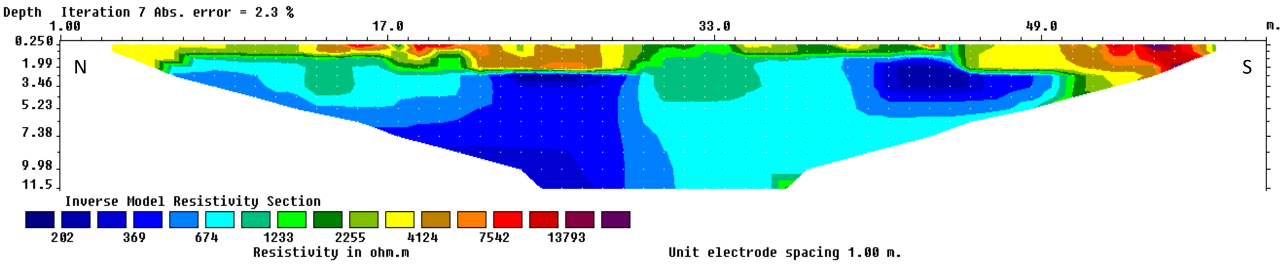
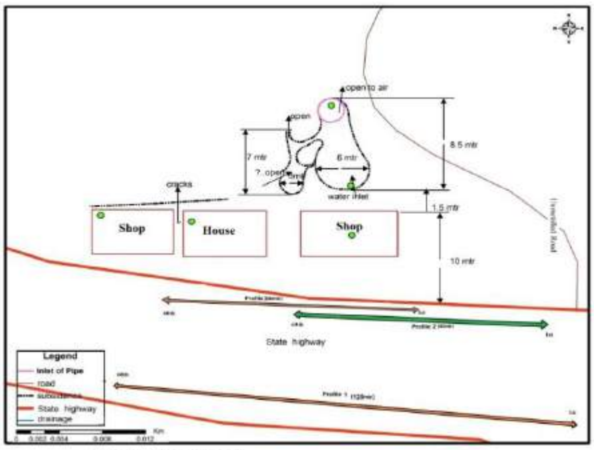


Figure 4.15*: Profile 5, Schlumberger array at Peringassery*

4.1.3.2 ERP Survey at Thattekanni

Though three ERPs are laid, only two data are found acceptable as the 1st Profile indicated significant errors due to high contact resistance. The interpreted ERP images for the two profiles 2 and 3 using Schlumberger array are given as Figure 4.17 and 4.18. The resistivity sections so deduced are qualitatively interpreted as follows.



* Survey lines are not to scale

Figure 4.16: *The electrical resistivity survey layout in Thattekanni*

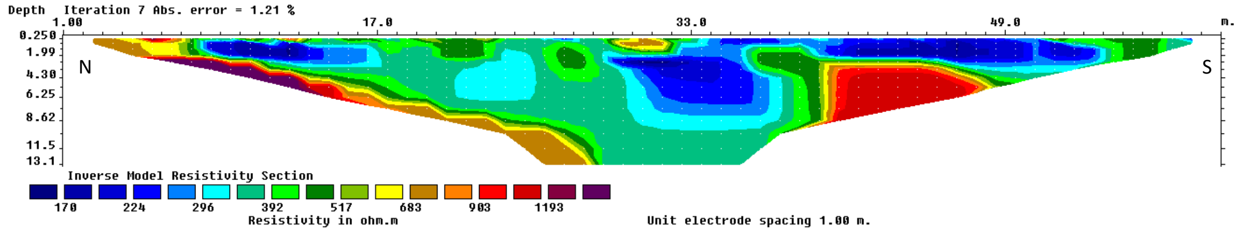


Figure 4.17: *Profile 1 Schlumberger array at Thattekanni*

Profile 7

The profile was laid near to a soil pipe in the EW direction at 1m electrode spacing. The low resistivity near-surface anomaly is extending up to a depth of 3.5m and laterally extending from the electrode station 13 to 35. A low resistivity patch is seen at a depth of 4.30m which indicates a saturated zone. The moderate resistivity layer in the eastern side may be indicative of differential weathering and high resistivity on the western side may be indicating hard crystalline rock.

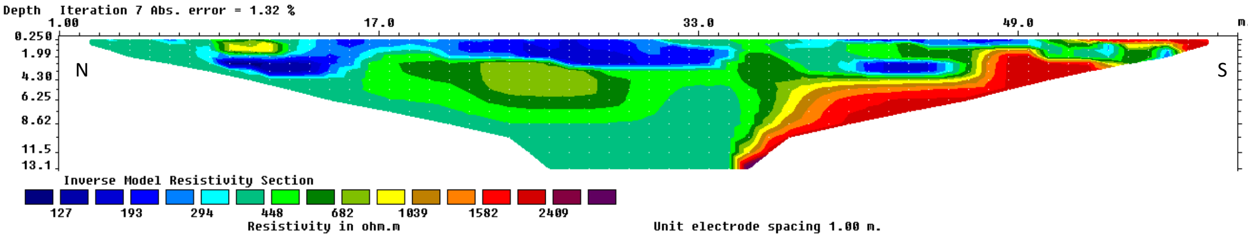


Figure 4.18: *Profile 2 Schlumberger array at Thattekanni*

Results

The qualitative interpretation of the resistivity section indicates that the technique could delineate the conductive zones where soil pipes are formed. This is evident from the profile 2/3 and profile 5 laid at Peringassery and profile 2 at Thattekanni as these profiles are close to the inlet and outlet of the pipes and the possible orientation of pipes at these locations are known. However, the geometry of the soil pipe is not found decipherable from the resistivity section probably due to higher electrode separation in comparison to the diameter of the soil pipe. Further, the data generated could be interpreted in Dipole-Dipole and Wenner array mode and the inference from these will also have to be seen. Therefore, repeating the survey with a lesser electrode separation as well as interpreting the data in different mode will be attempted.

4.1.4 Electrical Resistivity Surveys at Kannur

Experiments using Electrical Resistivity Survey techniques continued at Kottathalachimala near Cherupuzha, Kannur district across the alignment of a known soil pipe by using the WGMD-4 Multi-function instrument. Electrical resistivity tomography has been carried out over five mutually parallel profiles using a 60 electrode-setup (Figure 4.9). A minimum of 0.25m to a maximum of 2.0m spacing has been used as electrode configuration. Use of larger electrode spacing has been constrained due to the nature of the terrain. The five survey profiles were laid in the West-East direction (Figure 4.20). Profiles are laid above the existing soil pipe. The terrain gently slopes towards north hence the elevation gradually decreases from profile 1 to profile 5. ERT at profile 1 is carried out using five different electrode spacing. Profile 1a,1b,1c,1d and 1e correspond to ERT at profile 1 with electrode spacing equal to 0.25m, 0.50m, 1.00m, 1.50m and 2.00m respectively.

Figure 4.19: *Electrical resistivity survey at Kottathalachimala, Kannur*

Profile 2 & 3 were laid almost parallel to profile 1 at a distance of about 27m north of it. The central electrode for profile 2 is about 8m east of central electrode of profile 3. Profile 2a and 2b correspond to electrode spacing of 0.50m and 1.00m respectively. Profile 3a and 3b correspond to electrode spacing of 1.50m and 2.00m respectively. Profile 4 was laid further towards north at a distance of about 18m from profile 2 & 3. The electrode spacing used for profile 4a and 4b are 1.00m and 1.50m respectively. Profile 5 was laid in the NW-SE direction with the first electrode towards north-west. Electrode spacing of 1.00m and 1.50m has been used for profile 5a and 5b respectively.

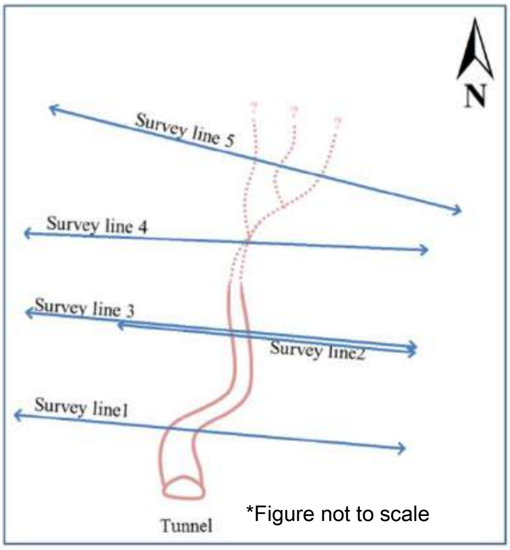
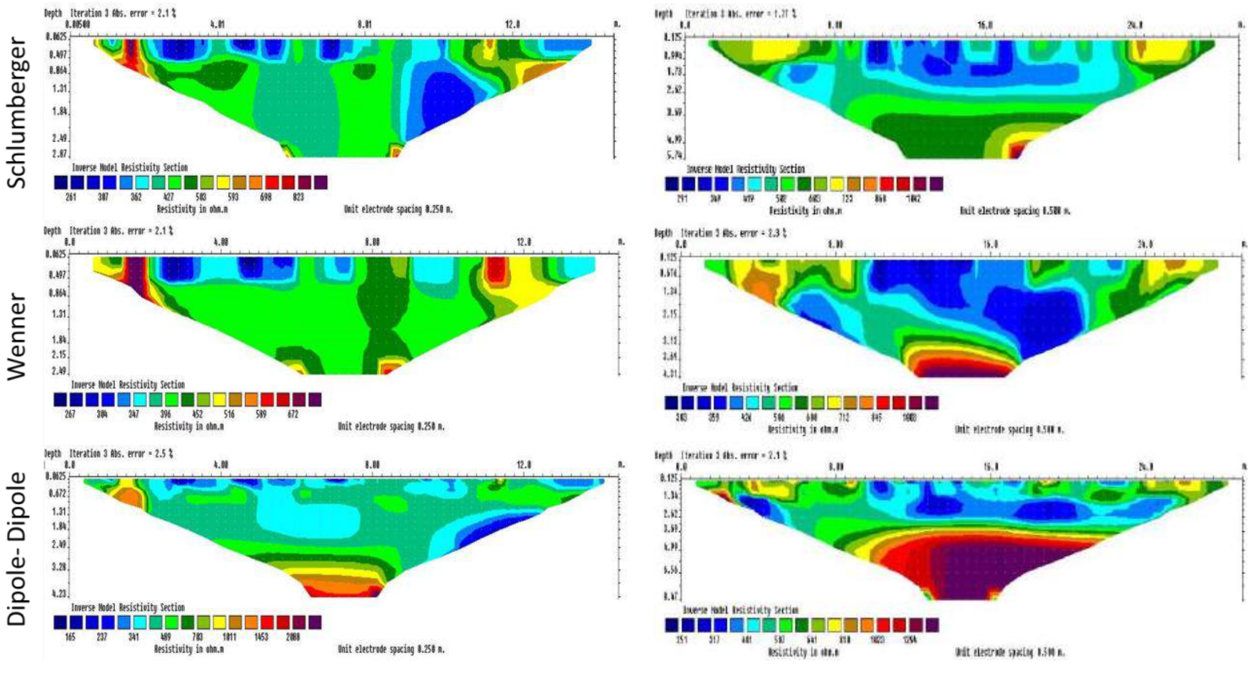


Figure 4.20: *The Layout sketch of Electrical resistivity survey line*

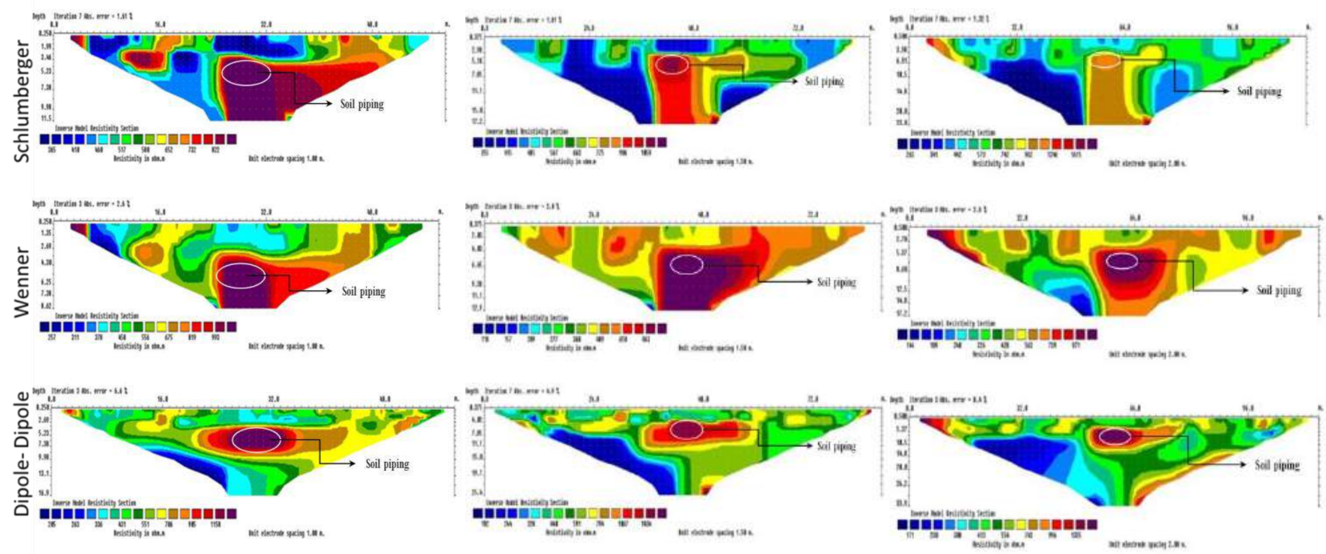
Survey line1: Profile 1 is laid at right angles to the tunnel orientation near to the entrance of tunnel. Profile 1a and profile 1b (Figure 4.21) has an electrode spacing of 0.25m and 0.50m with a horizontal stretch of 15m and 30m on the ground respectively. Electrical resistivity cross section for Schlumberger, Wenner and dipole-dipole configurations of profile 1a and 1b as shown in Figure 4.21a and 4.21b respectively. The maximum depth of investigation is achieved in dipole-dipole configuration followed by Schlumberger array and Wenner array, in which the depth was not more than 4.3m. The Schlumberger and Wenner configurations helped us to understand the top soil layer, which is weathered and inhomogeneous in nature. The dipole-dipole configuration provided the maximum depth and a highly resistive region could be observed for this array at a depth of about 3.5m just beneath the central electrode in profile 1b. This high resistive region could be attributed to the roof of the tunnel. The presence of high resistive zone vertically below the central electrode is strengthened from the Geoelectrical sections of profile 1b. The tunnel roof is observed at a depth of about 3.0-3.5 m from the surface in all three electrode configurations. While the Schlumberger and Wenner configurations helped us to determine the tunnel roof, the dipole-dipole configuration indicated the extension of the high resistivity zone towards east.



***a**. Profile 1a 0.25m electrode spacing* ***b**. Profile 1b at 0.50m electrode spacing*

Figure: 4.21.*Electrical Resistivity Tomographic section of Survey line1*

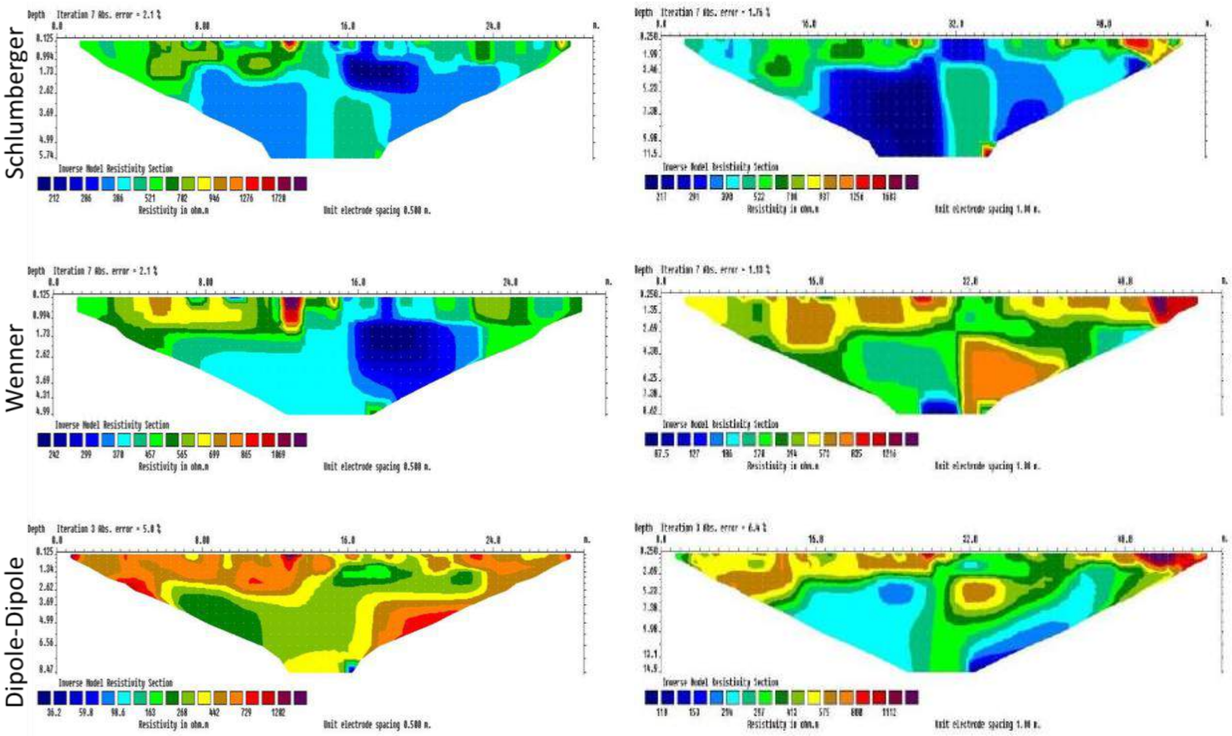
Profiles 1c, 1d and 1e are laid with an electrode spacing of 1.0m, 1.5m and 2.0m respectively. It is observed that Schlumberger and Wenner were not found to be useful for mapping the tunnel cross-sections. Both the configurations showed the tunnel extending indefinitely with depth. The two configurations fail to map the tunnel bottom even though from physical observations it is known that the actual vertical extent of the tunnel is lesser than the interpreted depth of the two arrays. The dipole-dipole array clearly brings out the entire tunnel cross-section. Further, as observed in dipole-dipole configuration for profile 1b, there was an asymmetry in the tunnel cross-section, with eastward (rightward) extension of the high resistive zone and the absence of the same in the westward direction. This feature was observed in all the three configurations (Figure 4.22) for 1.0m, 1.5m and 2m spacing. This could be an indication of the presence of another tunnel like feature, smaller as compared to the soil pipe under study, located parallel and towards east (right) of the original tunnel. The asymmetric eastward (rightward) extension of the soil pipe is further strengthened in all electrode configurations for 1.5m spacing. In the dipole-dipole setup (Figure 4.22b); we also observe a low resistivity zone adjacent to the west (left) wall of the tunnel but about 2m to 3m below the soil pipe. The true resistivity value is very low and can possibly be corresponding to a water saturated zone. Profile 1e (Figure 4.22c) has an electrode spacing of 2.0m and hence provides the highest depth of investigation for survey line 1. Apart from the eastward extension, the presence of low resistivity zone towards west of the tunnel is manifested in profile 1e. The survey line 1 with profiles1a-e play an important role in establishing the response of various array types to soil pipe and related geological features. The unique response of Schlumberger array type can hence be of importance in distinguishing a tunnel from a region of high resistivity such as a buried boulder. Although Schlumberger array fails to map the vertical extent of the soil pipe, it provides a better lateral resolution compared to the dipole-dipole configuration.



a. *Profile 1c at 1.0m electrode spacing* ***b***. *Profile 1d at 1.50m electrode spacing* ***c***. *Profile 1e at 2.0m electrode spacing*

Figure 4.22: *Electrical Resistivity Tomographic section of survey line 1*

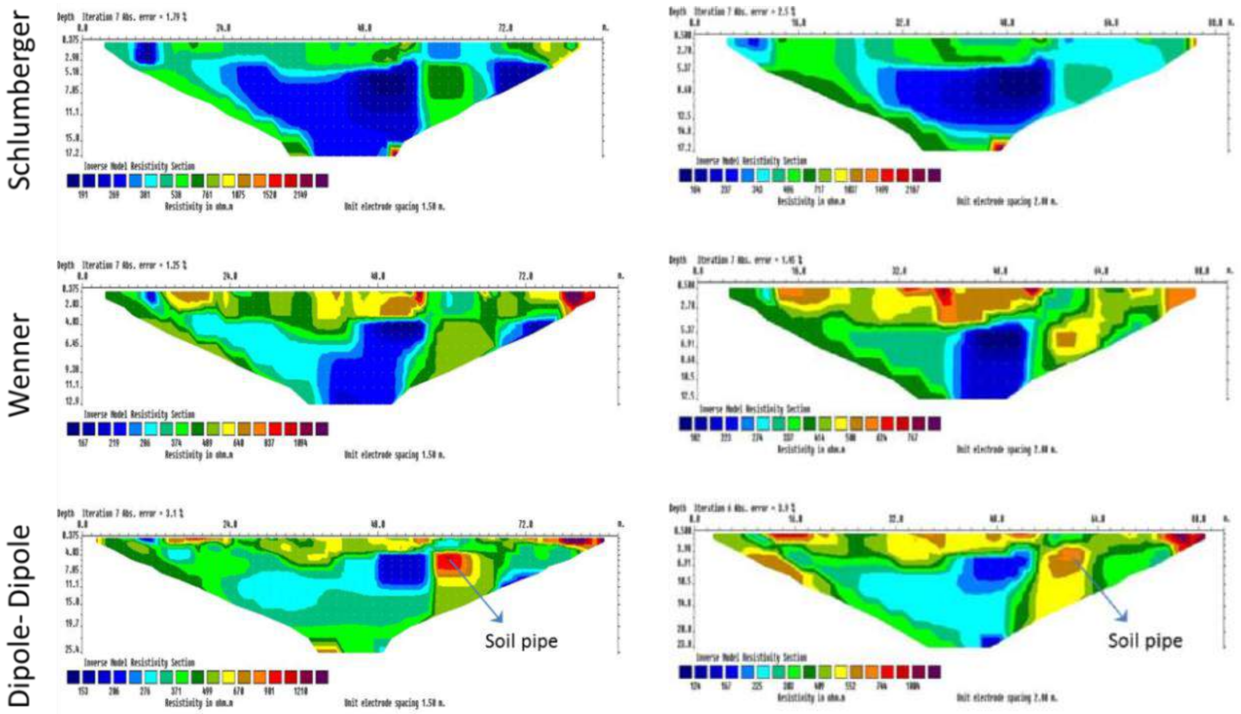
Survey line 2: As discussed, survey line 2 was laid parallel to survey line 1 at a distance of 27m north of line 1. Two profiles with electrode spacing of 0.5 m and 1.0 m were conducted. For profile 2a (Figure 4.23a) with an electrode spacing of 0.5m, the maximum depth achieved was 8.5 m. Although the Schlumberger array exhibited tunnel-like response (indefinite vertical continuation of high resistive zone) just below the central electrode, geo-electric sections from Wenner and dipole-dipole did not exhibit similar feature. Except for inhomogeneous weathered top layer, the three configurations did not show much correlation. The profile 2b (Figure 4.23b) was laid across the same survey line but with a greater electrode separation of 1.0m. The top inhomogeneous weathered layer can be observed here. A region of high resistivity can be observed at a depth of 2.5m from the surface below the central electrode location. This region shows a typical Schlumberger response for tunnel like feature. This feature can also be observed for Wenner configuration. From this profile it is observed that the tunnel cross-section is smaller than at the tunnel entrance. Due to topographic constraints on the eastern side of the survey line, a profile with higher electrode spacing could not be conducted.



***a**. Profile 2a with 0.50m electrode spacing* ***b**. Profile 2b with 1.0m electrode spacing*

***Figure 4.23:** Electrical Resistivity Tomographic section of survey line 2*

Survey line 3: For achieving a wider spread, **s**urvey line 3 was laid along line 2 by shifting the center westwards by 8m and then increasing the electrode spacing. As a result, we expect the anomalous region to shift towards east (right) for survey line 3. Both the profiles on survey line 3, profile 3a (Figure 4.24a) and 3b (Figure 4.24b), with an electrode spacing of 1.50m and 2.00m respectively, exhibit pipe like anomaly, shifted eastward as expected. As seen in profile 2b, the tunnel size is smaller compared to tunnel entrance (survey line 1). As a continuation from survey line 1, we can observe a water saturated zone adjacent to the western wall of the tunnel. However, unlike survey line 1, the water saturated zone is located at the same depth as the tunnel for line 3. While this zone was deeper as compared to tunnel at the entrance, its presence at approximately the same depth as the tunnel 27m north of entrance could indicate that this water saturated zone acts as a source for smaller soil pipes which were observed on the left wall of the tunnel on internal examination.



***a**. Profile 3a with 1.50m electrode spacing* ***b**. Profile 3b with 2.0m electrode spacing*

Figure 4.24: *Electrical Resistivity Tomographic section survey line 3*

Survey line 4: Survey line 4 is 18m north of survey line 2&3. Profiles 4a (Figure 4.25a) and 4b (Figure 4.25b) correspond to electrode spacing of 1.0m and 1.5m respectively. These profiles indicate an inhomogeneous subsurface. However, there is no indication of any tunnel-like characteristic in the Geoelectrical section for any of the three configurations. This may be due to the tapering of the tunnel in this section. The high resistivity region close to the surface towards the western side in profile 4b probably represents a rocky top surface.

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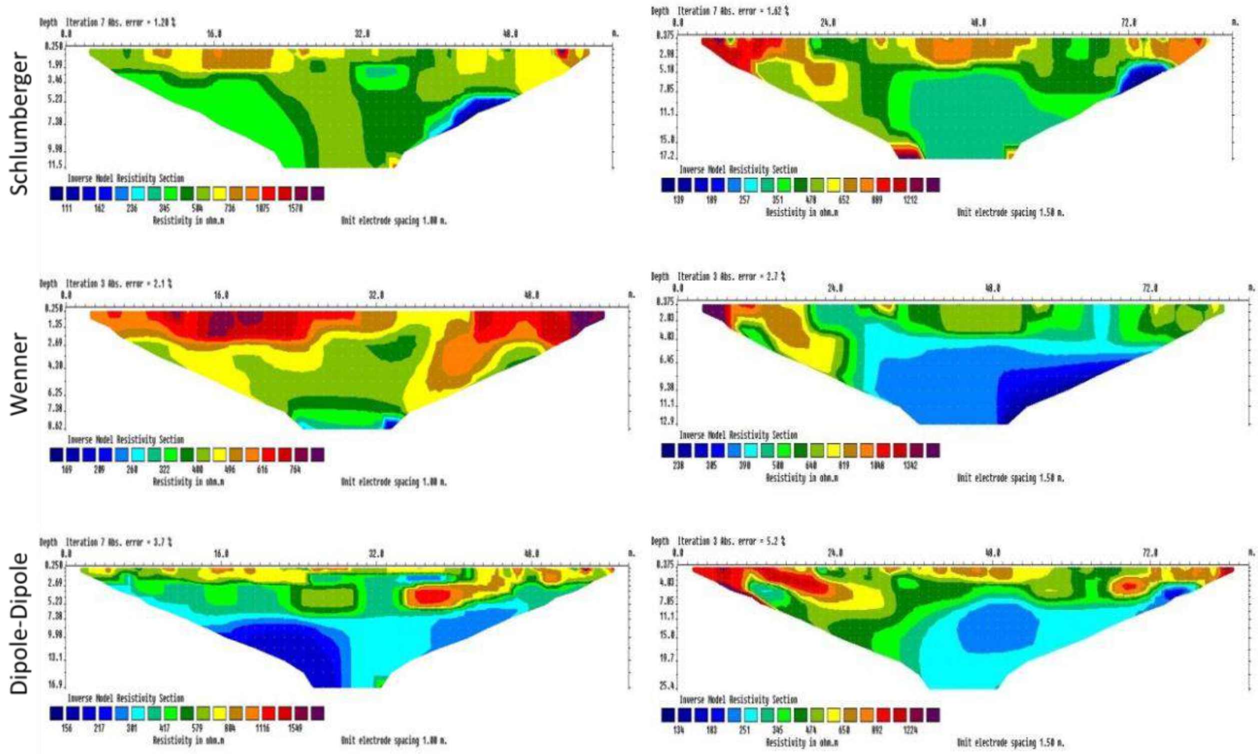
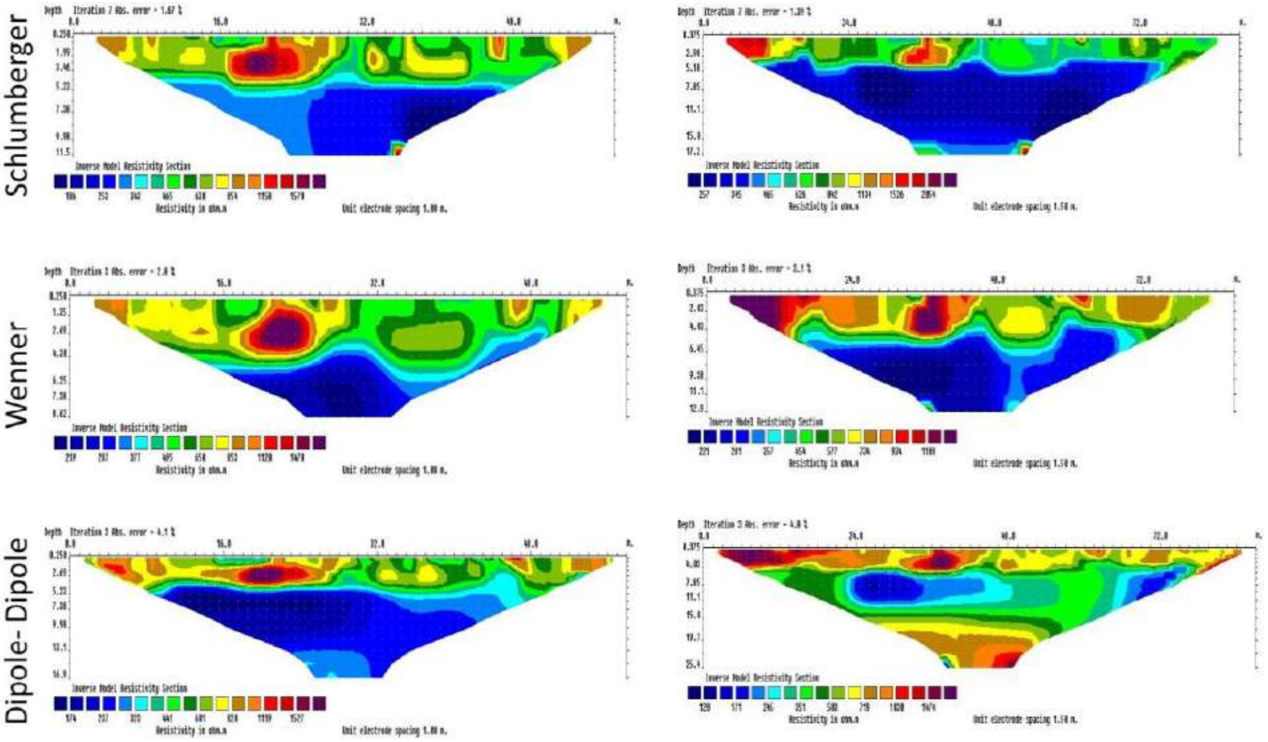


a. *Profile 4a with 1.00m electrode spacing* ***b.*** *Profile 4b with 1.50m electrode spacing*

Figure: 4.25. *Electrical Resistivity Topographic sections survey line 4*

Survey line 5: Survey line 5 runs in the NW-SE direction. Rocky outcrops were observed on the surface for this survey line. Profile 5a (Figure 4.26a) shows a high resistivity region close to the surface at a distance of about 8m from the central electrode in the north-east direction. The same feature can also be observed in profile 5b (Figure 4.26b). However, the inhomogeneous top layer for this survey line makes it difficult to associate the anomaly with any geological feature. The anomaly could be indicative of small underground soil pipe or a boulder. Since, the Schlumberger configuration response for the feature is different than Schlumberger response for soil-pipe as observed for survey lines 1, 2 & 3, the source of anomaly remains inconclusive. However, we do observe a water saturated layer extending from a depth of about 4m to 17m from the surface.



a. *Profile 5a at 1.0m electrode spacing* *b.Profile 5b at 1.50m electrode spacing*

Figure 4.26: *Electrical Resistivity Tomographic section survey line 5*

Results

ID and 2D surveys have been carried out in Kottathalachimala. The result indicated that the area has a complex geology. The results of VES gives scanty hope as water filled horizons are either thin having depth to bedrock above 15m in just two stations or made up of clay horizon. However, the result of ERT show areas favorable for siting productive borehole especially in profile TR1 at surface position 120m interpreted to be water filled fractured rock and profile TR 8 at ground position 130 m as a good bedrock depression where subsurface water accumulates.

It was also discovered that 2D survey gives a better result than 1D because of its ability to image the subsurface vertically and laterally which enhances continuity. Geoelectrical layers from two VES points separated by a distance would not give a comprehensive imaging as the 2D does.

4.1.5 Electrical resistivity survey at Nelliyedukkam, Kasaragod

Electrical Resistivity Survey was carried out at Nelliyadukkam, Kasaragod across the alignment of a known soil pipe by using multi-function Digital DC Resistivity/IP Meter (WDJD-4), having WDZJ-4 switcher box. All survey lines are in east west direction, the suspected soilpiping is in south to north direction. A total of 7 survey lines were laid (Figure 4.28), 3 on above the known soil pipe, 3 surveys were laid on east side of the piping and one on the roadside. Sixty electrodes used for survey at 1m and 2m spacing, so, total survey line went up to 60 and 120m respectively.

The terrain gently slopes towards north and profiles were across the slope so that there was no elevation correction needed while the data on processing. Profile GPS co-ordinates were marked on 1, 15, 30, 45, 60 electrodes to label the electrode position & corresponding elevation. In survey line $S_1$and S_2, the instrument was placed at the centre of the target (above the cavity) to arrive greater depth of penetration. S_3 and S_4 laid 15m east from the tunnelling. S_5 is laid directly down of the survey line S_1. The survey line S_6 is in 20m east of S_5, survey line S_7 laid in road side near subsidence1.The best resultant cross-sectional Electrical Resistivity Tomographic section is plotted (Figure 4.29a to 4.34c).

Figure: 4.27. *Survey is conducted in soil piping area (Nelliyedukkam, Kasaragod district)*

The survey tools included electrodes, connecting cables, multi resistivity meter, battery pack, laptop to deliver data gathered from the instrument in a graphic manner. Survey was done using 60 electrodes extended equally (30 each) to both sides with an interval of 2 meters.

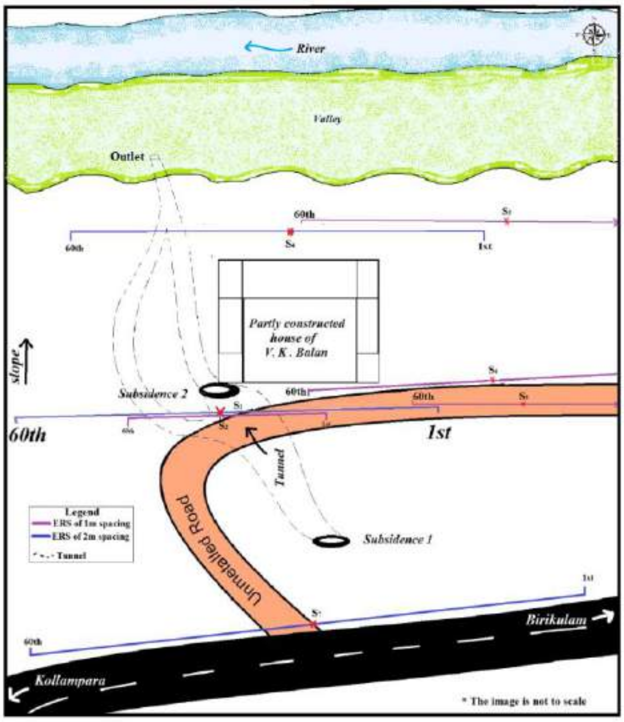
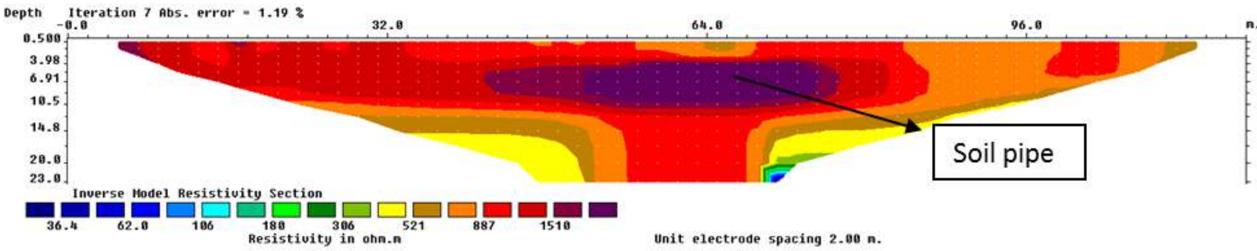
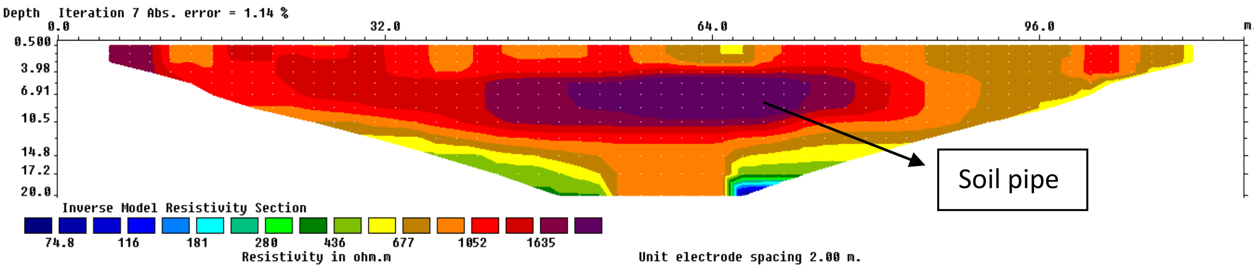


Figure: 4.28. Lay-out of the Study area at Nelliyedukkam, Kasaragod

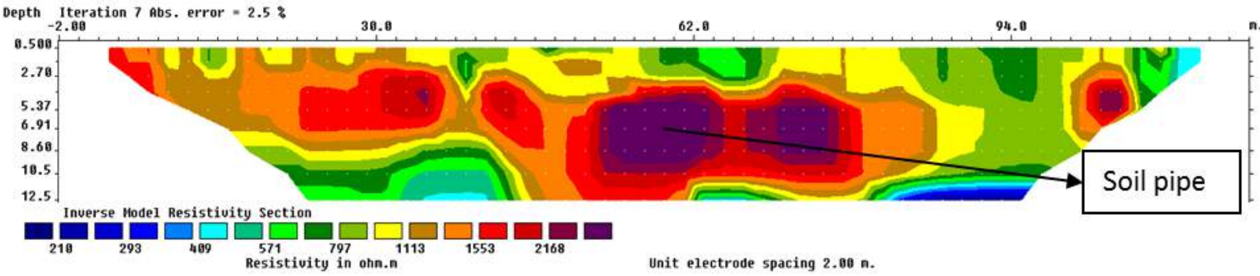
Survey line 1 (S_1): The qualitative interpretation of the resistivity section indicates that the technique could delineate the conductive zones where the soil pipes were formed, evident from the profile laid at Nelliyedukkam. These profiles are directly above the pipes and the possible orientation of pipes at these locations is known. The total depth of information obtained from the figure 7 is 23m. The resistivity value changes from 36.4 to 1510Ωm. The presence of high resistive zone vertically below the central electrode is strengthened from the Geoelectrical sections of profile. The tunnel roof was observed at a depth of about 3.98m from the surface in all three electrode configurations. While the Schlumberger (Figure 4.29a) and Wenner (Figure 4.29b) configurations helped us in determining the tunnel roof, the high resistivity zone could be seen extending at a depth of 3.98 to 10.5m, in the schlumberger configuration. The data generated by schlumberger configuration was more accurate than Dipole-Dipole (Figure 2.29c) and Wenner array mode.



a. *Schlumberger array at 1m electrode interval*



b. *Wenner array at 1m electrode interval*

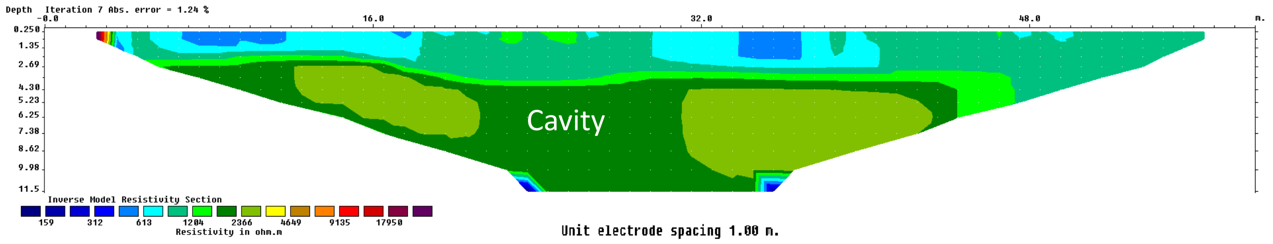


c. *Dipole-Dipole array at 1m electrode interval*

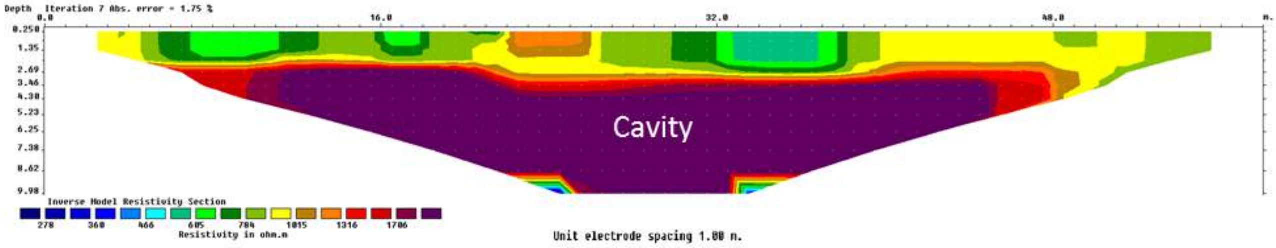
Figure 4.29: *Electrical Resistivity Tomographic section survey line 1*

Survey line 2 (S_2): This profile was also laid at the same point of profile $S_1$with an electrode interval of 1m. Depth of information obtained was 11.5m and high resistivity value obtained was 2366 Ωm. From the schlumberger and Wenner images, a sudden increase of resistivity (~500 to

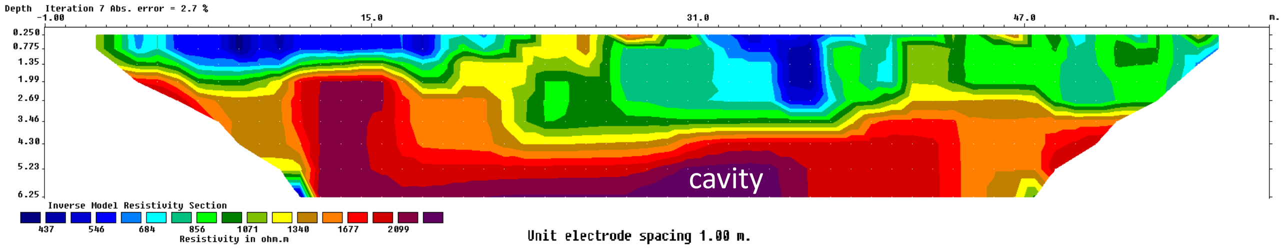
2366Ωm) was indicated at a depth of 2.69 m indicating the starting point of tunnel section. The high resistivity zone continued up to a depth of 11m. The lateral extends of the tunnel was more visible in this profile.



a. *Schlumberger array at 1m electrode interval*



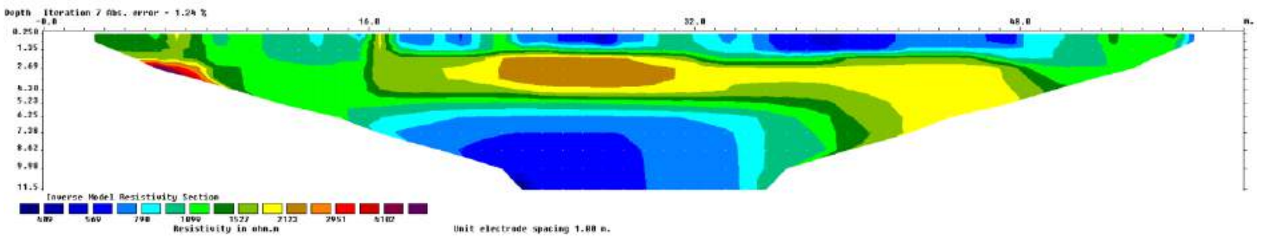
b. *Wenner array at 1m electrode interval*



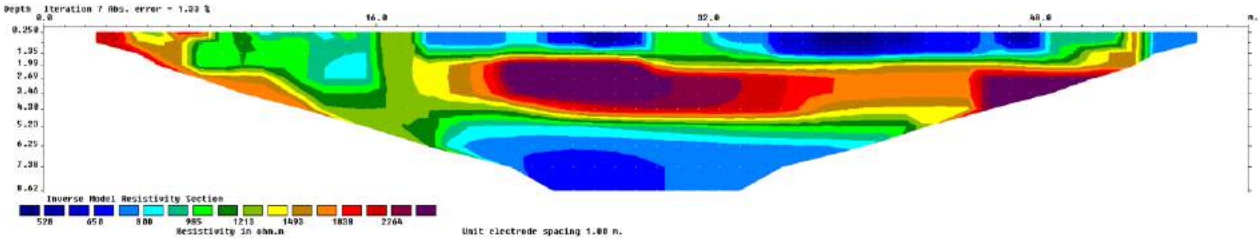
c. *Dipole-Dipole array at 1m electrode interval*

Figure 4.30: *Electrical Resistivity Tomographic section survey line 2*

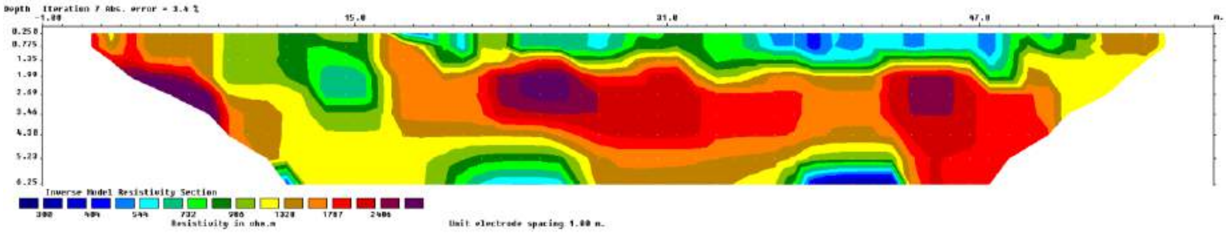
Survey line 3(S_3): This profile (S_3) was laid 15m east of the survey line S_1 at an electrode interval of 1m. From the figure 4.30a and 4.30b,a high resistive zone (>2264 Ωm) was seen in the middle portion in between station 22 and 33 at the depth of approximate 2m to 4.38m which is an indication of a tunnel like feature. This feature was also observed in Wenner configuration. It has a lateral extent of 11m and thickness of 2.38m underline by low resistant water saturated zone.



a. *schlumberger array at 1m electrode interval*



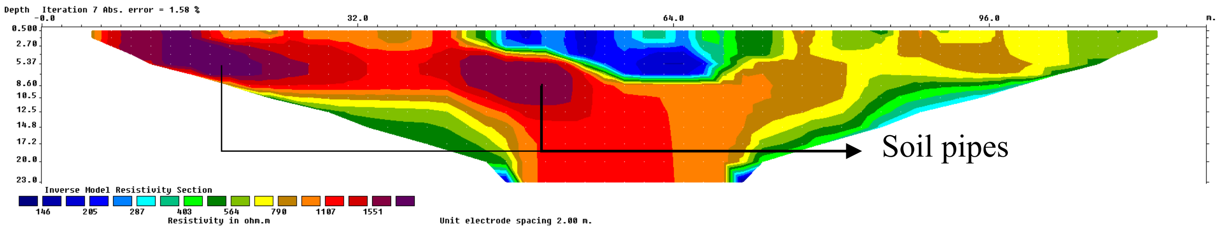
b. *Wenner array at 1m electrode interval*



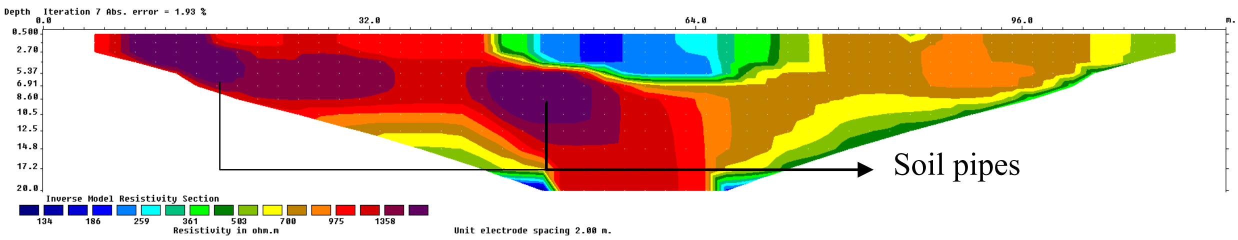
c. *Dipole-Dipole array at 1m electrode interval*

Figure 4.30: *Electrical Resistivity Tomographic section survey line 3*

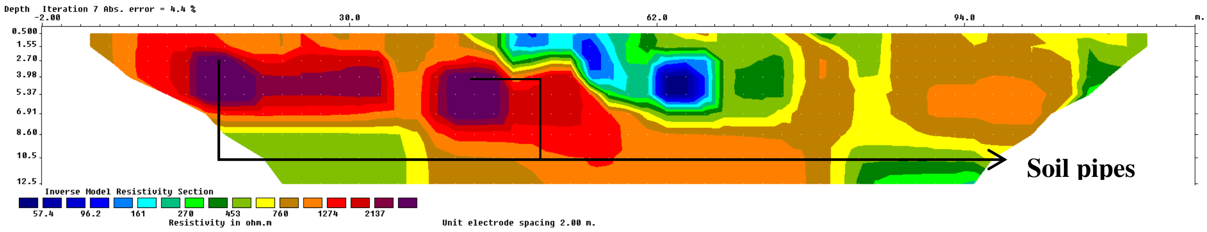
Survey line 4 (S_4): The surveyline 4 is laid across the soil pipe (east to west direction) and the mid point of the profile is 12m north of the pipe. The electrode intervel was 2m, the total distance of the profile was 120m and the maximum depth of penetration achieved was 23m. Two high resistive (>1551 Ωm) zone was identified at a depth of ~ 5.37mwhich indicated pipes. From this profile it was observed that the tunnel cross-section was bigger than the tunnel entrance. This figure (Figure 4.31a, b, c) indicated branching of the pipe. In the dipole –dipole configuration it was indicated clearly.



a. *Schlumberger array at 2m electrode interval.*



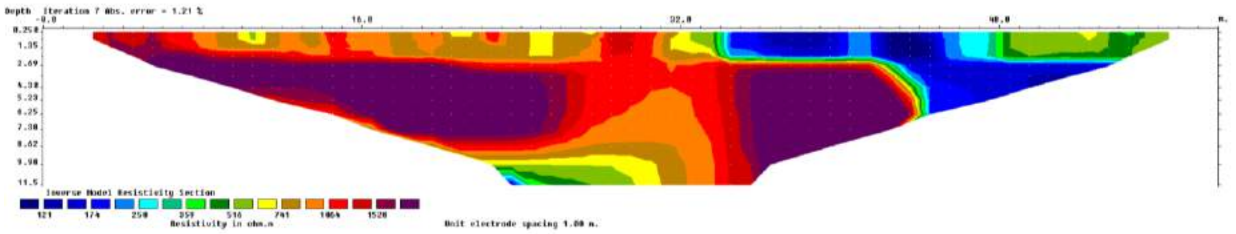
b. *Wenner array 2m electrode interval*



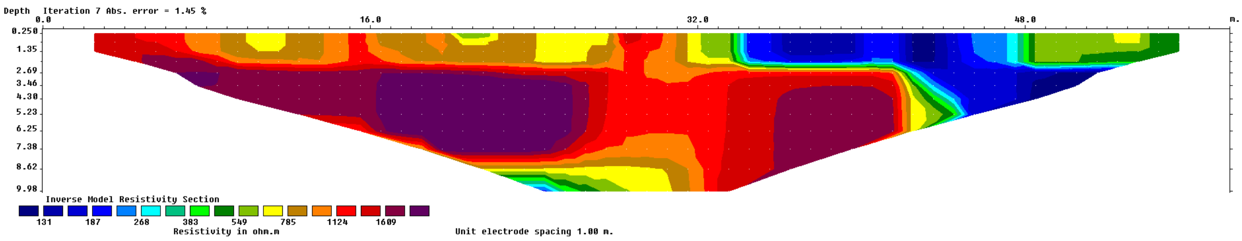
c. Dipole-Dipole array 2m electrode interval

***Figure 4.31:** Electrical Resistivity Tomographic section survey line 4*

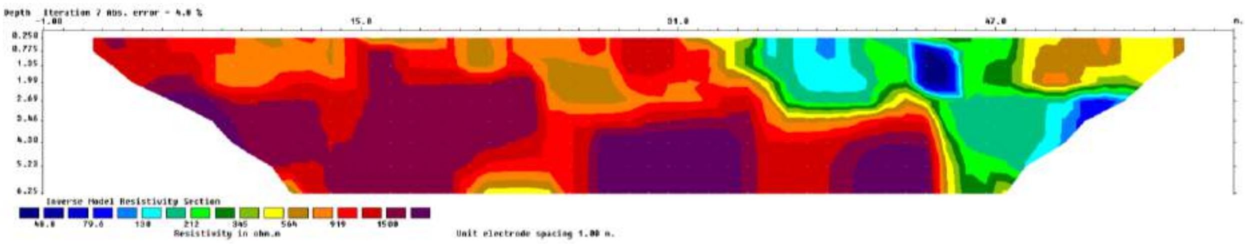
Survey line 5 (S_5): This survey line has E-W orientation and is parallel to $S_3$and has a station interval of 1m. The first electrode position was at east side. From this profile the high resistive zone with a lateral extent of almost 10m and detected at a depth of 2.69m to 7.38m may not be a pipe like feature. This is because the dipole-dipole configuration indicated that the high resistive zone continued downwards and the apparent resistivity values of 1528 Ωm was less than the value generally obtained from known piping area. Therefore, the high resistive zone may be indicative of a high resistive rock bolder.



a. Schlumberger array at 1m electrode interval



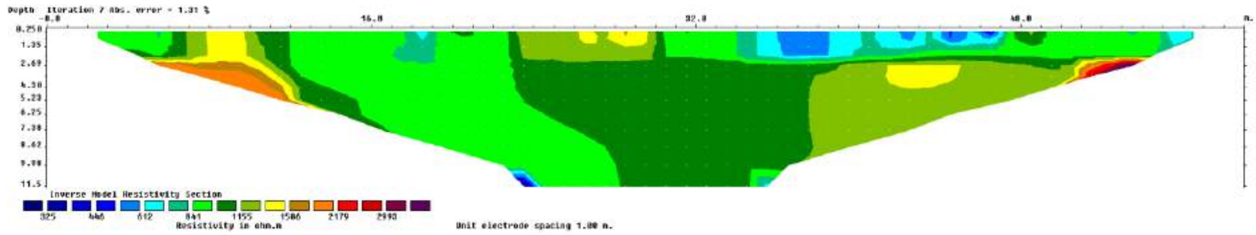
b. Wenner array at 1m electrode interval



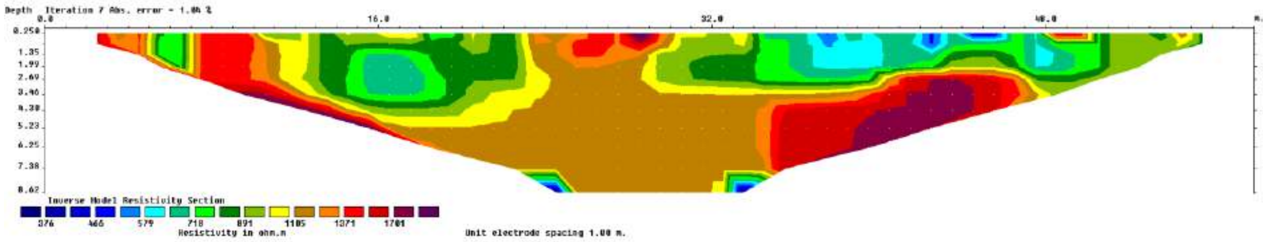
c. Dipole-Dipole array at 1m electrode interval

***Figure 4.32:** Electrical Resistivity Tomographic section survey line 4*

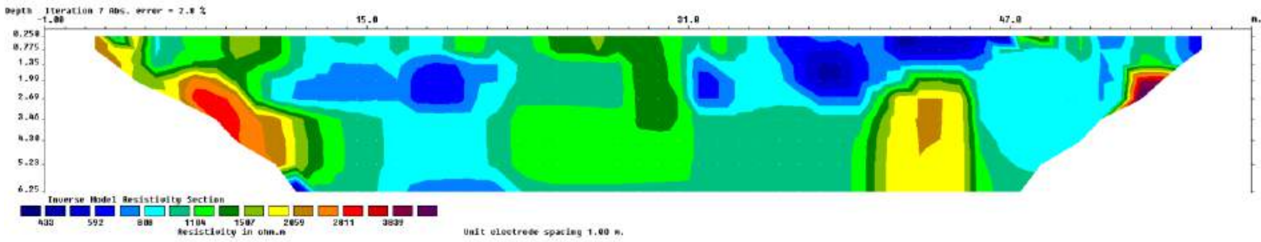
Surveyline 6 (S_6): Survey line S_6 runs in the E - W direction with midpoint placed at 10m towards north from the survey line S_3. This profile (Figure 4.33) showed moderately low resistivity at shallow depth and relatively high resistivity at a depth of 2.62m which continued further. The same feature was also observed in profile S_3. The inhomogeneous layer made it difficult to attribute the anomaly to any specific geological feature. The anomaly could be indicative of small underground soil pipe or a boulder. Since, the Schlumberger configuration response for the feature was different from the normal Schlumberger response to soil-pipe as observed for survey lines S_1, S_2& S_4, the anomaly could not be interpreted conclusively.



a. Schlumberger array at 1m electrode interval



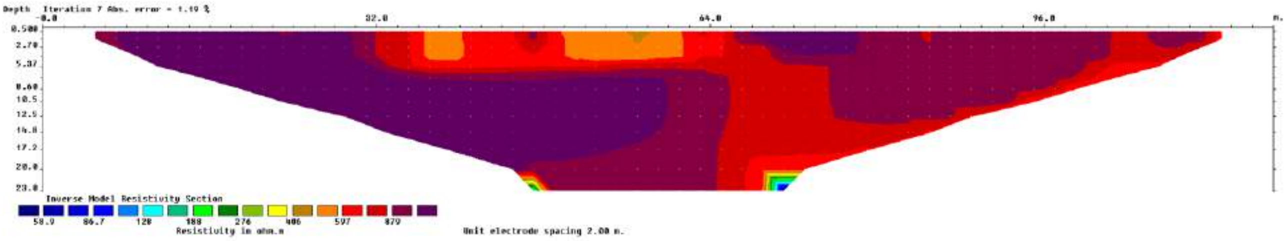
b. Wenner array at 1m electrode interval



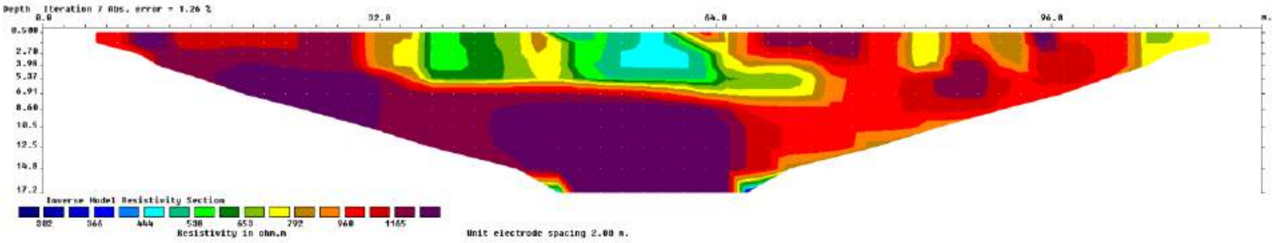
c. Dipole-Dipole array at 1m electrode interval

Figure 4.33: *Electrical Resistivity Tomographic section survey line 4*

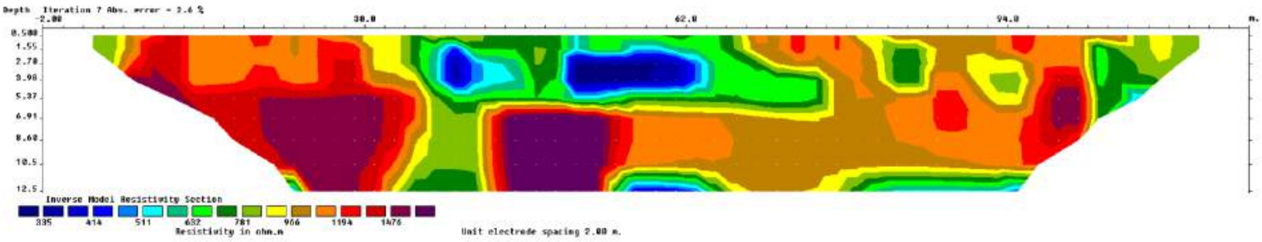
Survey line 7 (S_7): The survey was carried out on the road side; the contact resistance was relatively higher than the other profiles because of the hard nature of the road fillings. The resistivity of the top hard layer was found relatively higher and this probably represented rock-dominated top layer.



a. Schlumberger array in piping area.



b. Wenner array in piping area



c. Dipole-Dipole array in piping area

Figure 4.34: *Electrical Resistivity Tomographic section survey line 4*

Conclusion

The resistivity image generated using schlumberger, Wenner and Dipole-Dipole configuration for station interval of 1m and 2m exhibited resistivity anomalies in correspondence with soil pipes. The profile laid on the top of the soil pipes showed high resistive zone indicating tunnels as the resistivity of cavity is much higher than resistivity of surrounding hard rocks. The surrounding regions of this high resistive zones indicated lower resistivity values attributable to saturated soil beds. None of the profiles could trace the bed rock as the depth of investigation was limited, though certain profiles reached up to a depth of 23m. The physical attributes of the soil pipes measured, generally at the inlet and outlet points, matched well with the results obtained from the electrical resistivity imaging. Therefore, electrical resistivity imaging technique is found to be a tool for locating spatial disposition and geometry of near-surface soil pipes.

Comparing various (Schlumberger, Wenner and dipole-dipole) arrays, the Schlumberger gives the depth of information and it is useful for differentiate cavities from the rock boulders; Wenner array gives information about the piping in shallower depths. If the pipe is in shallow, Wenner array useful for the study the upper layers of the piping and the Dipole-Dipole array gives the clear cut picture of the cross section of pipes. It also gives the information about branching of tunnels.

4.1.6 General Comparison of Analog and Digital multi-electrode Resistivity meter

Analog (Aquameter) meters give display of both injected current and the measured potential difference on non-linear scales. Readings obtained from such meters are prone to many serious errors that could conceal the desired information. Moreover, in the computation of resistance by analog meters, results are compromised by the compounded errors due to current and voltage readings. In an effort to significantly reduce such errors, reduce cost and produce a user-friendly device it was resorted to develop a digital resistivity meter using the state of the art technology. This is an on-going new approach that combines software and hardware to produce a device that could be utilized for various purposes dictated by the use of peripherals and accustomed software, thereby reducing the amount of hardware requirements as most of the control is handled by the software. The software does most of the functions previously done by the hardware, thus, making the whole set up portable, cheaper, more rugged and easier to operate during field usage. The readings of the meter are given in digital format; therefore, errors due to parallax are highly minimized.

Field data obtained from Aquameter (four electrode configurations) and Digital multi-electrode resistivity meter during electrical resistivity survey shows that the multielectrode surveys give useful in piping related surveys. In Aquameter, the data gives the depth information in single line with vertical variation and is useful for 1D resistivity graph information. It does not give the lateral information. For 1D to 2D conversion, a series of different surveys has to be carried out by shifting the central point of the layout in each survey. The manual shifting of the survey layout can distorted the data. The data generated from the digital multi-electrode resistivity meter gives high data quality and quantity. It gives vertical and lateral data variation. Figures 4.5a and 4.22 show the profile obtained by Aquameter (four electrode configurations) and Digital multi-electrode resistivity meter at the same location. The Digital resistivity instrument directly gives 2D inversion data. The principal advantage of 2D inversion is that it allows for dimensional clarity that is not obtained in 1D inversion at depth. The figure 4.6 is the 2D graph of 6 profiles of data generated by the Aquameter. Each profile has having a horizontal distance of 5m. 22 data point was obtained in a single survey. The figure 4.22 is 2D inverse model of single survey of data generated by the Digital multi-electrode resistivity meter.

4.2 Field trials using Geophones

The water flow in an underground pipe or when vehicular movement occurs over the cavities it often produces ground vibrations. The geophone (figures 4.35) was subjected to field trials (figure 4.36) to understand the responses during vibrations caused by various activities. Here the geophone is used for measuring the ground vibrations at Thattekanni in Idukki district. It has a natural frequency 4.5 Hz. Data logger (-8 to 24V DC) for real-time recording and conversion of analogue to digital signals.

Figure 4.35: *Geophone and data logger*

4.2.1 Field test along the road over a tunnel

Field trials were conducted in Thattekanni, were the road was affected by Soilpiping. The field trials indicated that the geophones are responding well to various types of ground vibrations.

Figure 4.36: *Field trial at Thattekanni, Idukki*

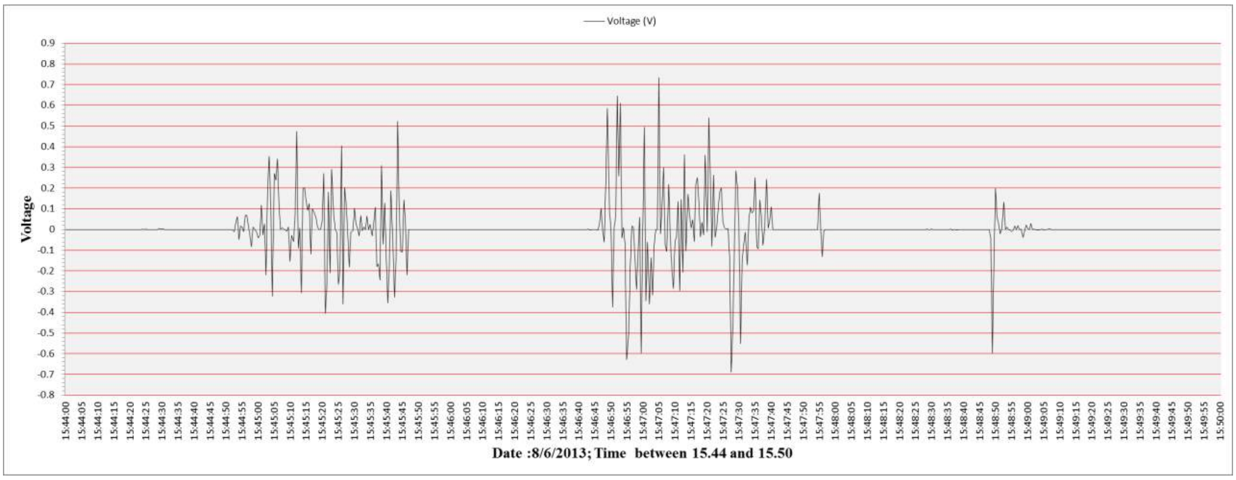


Figure 4.37: *Vibrations when vehicle passing through a pipe affected road*

From the graph ground vibrations generated (time: 3:44:52PM to 3:45:48PM and 3:46:42PM to 3:48:04PM) by vehicle passing through the road in piping occurred area. the ground vibration formed is greater than the normal than, due to the caving, the signals recorded by geophone.

4.3 Investigations with Push camera

As it is a water resistant it is mainly used to investigate the piping affected wells which are so deep and difficult to study. Digital video recorder is a rugged, industrial quality video processing device. It allows us to record videos, image and audio, view live feeds and play back recorded feeds while in the field and is specially designed to work with Inuktun cameras. The design of this combination in the field is very useful for the users. Camera with 12 high intensity LEDs, weight just 0.12Kg and connected with Digital video recorder can be easily used to know the interior, diameter and characteristics of the investigated pipe by continuously monitoring where one cannot enter. As it is water resistant it can be used to know the deep wells which are affected by piping in the field.

The Crystal Cam camera is a unique, high-performance micro video camera that is compact, lightweight and readily affordable designed and developed by Inuktun (Figure. 4.38 with built-in LED lighting and its high resolution, low lux camera, the Crystal Cam is very effective in low light environments. The camera head is completely encased in transparent epoxy, making it virtually indestructible while operating in the most confined spaces, hazardous areas and to depths up to 304m / 1000ft. The Cam can even survive to depths of 1,000-feet underwater. It is mainly used to internal inspection of pipes, tanks and wells in the field. The push camera is a very useful tool in the field where it is inaccessible in areas like narrow soil pipes where one cannot enter. Cavities formed by piping occur in different shapes and sizes. It often occurs as dendritic pattern, with smaller tanners joins to form big tunnels. Sometimes big tunnels branches into smaller tunnels. Some of these tunnels are smaller in size and therefore not accessible for investigation. In order to investigate these tunnels push (field) cameras are used. It is mainly used to internal inspection of tunnels, tanks and wells in the field. It is very useful in the field in order to know the most confined pipes, piping affected wells it is also used as a drop camera to investigate under waters up to a depth of 300m.

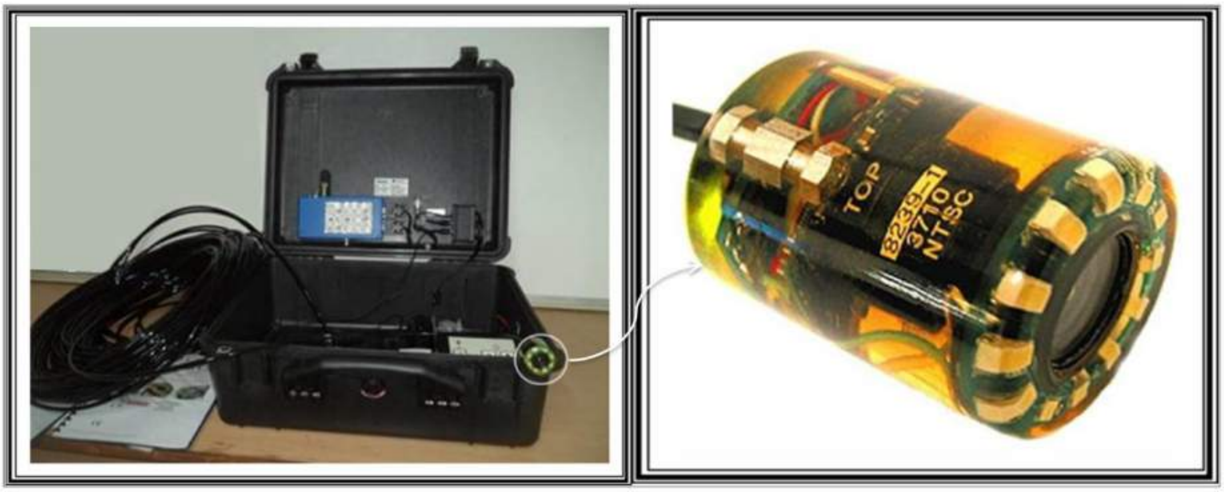


Figure 4.38: *A Inuktun's compact Crystal Cam camera (Push camera) and Cables*

4.3.1 Investigations with Push camera

Push camera (underwater / borehole camera) was used (Figure 4.39) for visual investigation of tunnel branches at Chattivayal in Kannur district for studying sediment deposition and branching. The information from camera was recorded the video and picture mode (Figure 4.40)

Figure4.39 *Using of push camera inside the Tunnel in Chattivayal, Kannur*

Figure. 4.40 *The images taken from inside the pipes (filled with water) by using push Camera*

The studies conducted using this camera helped in the characterisation of branch tunnels and their classification. The usage camera is difficult where the tunnel is rugged with many bends. To overcome this this camera may be fitted on a robotic platform for mobility within complex tunnels.

CHAPTER 5

DETERMINATION OF CHEMICAL AND PHYSICAL PARAMETERS

Soil piping is the subsurface soil erosion by ground water. In Kerala this occurs in the saprolite layer from by removing clay by physical and chemical processes. Samples were collected (table 5.1) from the localities affected by soil piping and other unaffected soil sections to determine various parameters. The measurement of pH, EC, and TDS were conducted at the time of sample collection in the field itself. The pH and conductivity of the sample is measured by a portable standard instrument (EUTEC 650), which has an accuracy of 0.01 pH and 0.01 conductivity. All chemical parameters were analysed by the methods suggested by APHA (1998). The dissolved nutrients and Fe were estimated in the filtered sample through 0.45 µm cellulose nitrate filter paper. All colorimetric estimations were done with u v-visible spectrophotometer SHIMADZU-160A.

5.1 Soil Sampling

Table 5.1 *Soil Sample locations*

Sl No.	Sample No	Sample Code	Location	Co-Ordinates		Elevation (m)	Sample Type
				Lattitude	Longitude		
1	**I1**	6/1/PRY-A	Peringassery	9^{0}52'08.4"N	76^{0}51'24.2"E	271	Soil (outside the pipe)
2	**I2**	6/1/PRY-E		9^{0}52'08.4"N	76^{0}51'24.2"E	270	Soil (outside the pipe)
3	**I3**	6/1/PRY-B		9^{0}52'08.4"N	76^{0}51'24.2"E	268	Soil (outside the pipe)
4	**I4**	6/1/PRY-Ei		9^{0}52'2.9"N	76^{0}51'28.4"E	263	Soil (Inside the pipe)
5	**I5**	6/1/PRY-Ci		9^{0}52'2.9"N	76^{0}51'28.4"E	262	Soil (Inside the pipe)
6	**I6**	6/1/VM-B	Venniyanimala	9^{0}51'39.3"N	76^{0}51'16.8"E	492	Soil (Inside the pipe)
7	**I7**	6/1/VM	Thattekanni	9^{0}51'39.3"N	76^{0}51'16.8"E	492	Soil (Inside the pipe)
8	**I8**	6/1/TK-Ci1		9^{0}59'55.6"N	76^{0}53'15.2"E	270	Soil (Inside the pipe)
9	**I9**	6/1/NP-B	Neendapara	10^{0}01'19.0"N	76^{0}50'09.6"E	270	Soil (outside the pipe)
10	**I10**	6/1/TK1	Thattekanni	9^{0}59'55.6"N	76^{0}53'15.2"E	270	Soil (outlet of the pipe)
11	**I11**	6/1/TK-Bi		9^{0}59'55.6"N	76^{0}53'15.2"E	270	Soil (Inside the pipe)
12	**I12**	6/1/NP-E	Neendapara	10^{0}01'19.0"N	76^{0}50'09.6"E	418	Soil (outside the pipe)
13	**I13**	6/1/NP- C		10^{0}01'19.0"N	76^{0}50'09.6"E	418	Soil (outside the pipe)
14	**I14**	6/1/TK-Ci2	Thattekanni	9^{0}59'55.6"N	76^{0}53'15.2"E	270	Soil (Inside the pipe)
15	**I15**	6/1/NP-A	Neendapara	10^{0}01'19.0"N	76^{0}50'09.6"E	418	Soil (outside the pipe)
16	**I16**	6/1/TK2	Thattekanni	9^{0}59'55.6"N	76^{0}53'15.2"E	270	Soil (outlet of the pipe)
17	**K1**	13/2KTM –C	Kottathalachimala	12^{0}16'16.0"N	76^{0}25'48.8"E	418	Soil (outside the pipe)
18	**K2**	13/2KTM –B		12^{0}16'16.0"N	76^{0}25'48.8"E	418	Soil (outside the pipe)
19	**K3**	13/2KTM		12^{0}16'16.0"N	76^{0}25'48.8"E	418	Weathered rock (Inside the pipe)
20	**K4**	13/2/KTM		12^{0}16'16.0"N	76^{0}25'48.8"E	418	Weathered rock (Inside the pipe)
21	**K5**	13/2/KTM		12^{0}16'21.8."N	75^{0}25'21.8"E	236	Soil (Inside the pipe)

Sl No.	Sample No	Sample Code	Location	Co-Ordinates		Elevation (m)	Sample Type
22	**K6**	13/2/KTM	Kottathalachimala	12^{0}16'21.8."N	75^{0}25'21.8"E	236	Soil (Inside the pipe)
23	**K7**	13/2/KTM				236	Soil (Inside the pipe)
24	**K8**	13/2/KTM				236	Weathered rock (Inside the pipe)
25	**K9**	13/2/KTM				415	Weathered rock (Inside the pipe)
26	**K10**	13/2/KTM				415	Soil (Inside the pipe)
27	**K11**	13/2/KTM				416	Weathered rock (Inside the pipe)
28	**K12**	13/2/KTM(Ch) –E	Thirumeni	12^{0}15'34.4"N	75^{0}26'00.0"E	414	Soil (outside the pipe)
29	**K13**	13/2/KTM(Ch) –E				414	Soil (outside the pipe)
30	**K14**	13/2/KTM(Ch) -B				414	Soil (outside the pipe)
31	**K15**	13/2/KTM(TM)	Thirumeni	12^{0}15'34.4"N	75^{0}26'00.0"E	414	Soil (Inside the pipe)
32	**K16**	13/2/KTM(TM)				414	Soil (Inside the pipe)
33	**K17**	13/2/KTM(Ch	Thirumeni	12^{0}15'36.0"N	75^{0}26'45.7"E	453	Soil (Inside the pipe)
34	**K18**	13/2/KTM(Ch)	Thirumeni	12^{0}15'36.0"N	75^{0}26'45.7"E	454	Soil (Inside the pipe)
35	**K19**	13/2/KTM(Ch)		12^{0}16'01.7"N	75^{0}25'11.6."E	384	Soil (Inside the pipe)
36	**K20**	13/2/KTM(Ch)	Chattivayal	12^{0}16'02.4"N	75^{0}25'11.6."E	353	Soil (Inside the affected well)
37	**K$_{21}$**	13/2/KTM(Ch)	Chattivayal	N12º15'36"	E75º26'06.9"	405	Soil (Inside the pipe)
38	**K$_{22}$**	13/2/KTM(Ch)				405	Soil (Inside the pipe)
39	**K$_{23}$**	13/2/KTM(Ch)				405	Soil (Inside the pipe)
40	**K$_{24}$**	13/2/KTM(Ch)				405	Soil (Inside the pipe)
41	**K$_{25}$**	13/2/KTM(Ch)				405	Soil (Inside the pipe)
42	**K$_{26}$**	13/2/KTM(Ch)	Chattivayal	N 12º15'40.2"	E 75º26'04.0"	415	Soil (Inside the pipe)
43	**K$_{27}$**	13/2/KTM(Ch)				415	Soil (Inside the pipe)
44	**K$_{28}$**	13/2/KTM(Ch)				415	Soil (outside the pipe)
45	**K$_{29}$**	13/2/KTM(Ch)				415	Soil (outside the pipe)
46	**K$_{30}$**	13/2/KTM(Ch)				415	Soil (outside the pipe)
47	**K$_{31}$**	13/2/KTM(Ch)				415	Soil (outside the pipe)
48	**K$_{32}$**	13/2/KTM(Ch)				415	Soil (outside the pipe)
49	**K$_{33}$**	13/2/KTM(Tb)	Tabor	N 12º15'37.9"	E 75º27'00.2"	505	Soil (outside the pipe)
50	**K$_{34}$**	13/2/KTM(Tb)				505	Soil (outside the pipe)
51	**K$_{35}$**	13/2/KTM(Tb)				505	Soil (outside the pipe)
52	**K$_{36}$**	13/2/KTM(Tb)				505	Soil (outside the pipe)
53	**K$_{37}$**	13/2/KTM	Kottathalachimala	N 12º16'16.0"	E 75º25'48.8"	505	Soil (outside the pipe)
54	**K$_{38}$**	13/2/KTM					Soil (outside the pipe)
55	**K$_{39}$**	13/2/KTM					Soil (outside the pipe)
56	**K$_{40}$**	13/2/KTM					Soil (Inside the pipe)
57	**K$_{41}$**	13/2/KTM					Soil (Inside the pipe)
58	**K$_{42}$**	13/2/KTM					Soil (Inside the pipe)
59	**K$_{43}$**	13/2/KTM					Soil (Inside the pipe)
60	**K$_{44}$**	13/2/KTM					Soil (Inside the pipe)
61	**K$_{45}$**	13/2/KTM	Kottathalachimala	N 12º16'16.2"	E 75º25'48.8"	418	Soil (outside the pipe)

Sl No.	Sample No	Sample Code	Location	Co-Ordinates		Elevation (m)	Sample Type
62	**K_{46}**	13/2/KTM	Kottathalachimala	N 12º16'16.2"	E 75º25'48.8"	418	Soil (outside the pipe)
63	**K_{47}**	13/2/KTM					Soil (outside the pipe)
64	**K_{48}**	13/2/KTM					Soil (outside the pipe)
65	**K_{49}**	13/2/KTM					Soil (outside the pipe)
66	**K_{50}**	13/2/KTM					Soil (outside the pipe)
67	**K_{51}**	13/2/KTM	Chattivayal	N 12º15'35.6"	E 75º25'53.4"	406	Soil (outside the pipe)
68	**K_{52}**	13/2/KTM	Chattivayal				Soil (outside the pipe)
69	**I_{17}**	6/1/4th Mile	4th Mile	N 9º39'34.0"	E 76º59'29.4"	810	Soil (outlet of the pipe)
70	**I_{18}**	6/1/4th Mile					
71	**I_{19}**	6/1/4th Mile					
72	**I_{20}**	6/1/4th Mile		N 9º39'37.4"	E 76º59'28.5"	877	Soil (Inside the pipe)
73	**I_{21}**	6/1/4th Mile					
74	**I_{22}**	6/1/4th Mile					
75	**K_{53}**	13/2/KTM	Chattivayal	N 12°15'38.5"	E 75°26'06.3"	394	Soil (Inside the pipe)
76	**K_{54}**	13/2/KTM		N 12°15'35.4"	E 75°26'03.9"	387	Soil (Inside the pipe)
77	**K_{55}**	13/2/KTM		N 12°15'39.6"	E 75°26'03.9"	406	Soil horizon C (outside the pipe)
78	**K_{56}**	13/2/KTM		N 12°15'39.6"	E 75°26'03.9"	406	Soil horizon B (outside the pipe)
79	**K_{57}**	13/2/KTM		N 12°15'39.6"	E 75°26'03.9"	406	Soil horizon A (outside the pipe)
80	**K_{58}**	13/2/KTM		N 12°15'39.6"	E 75°26'03.9"	406	Soil horizon O (outside the pipe)
81	**K_{59}**	13/2/KTM	Kottathalachimala	N 12°16'27.8"	E 75°25'20.0"	233	Soil (Inside the pipe)
82	**K_{60}**	13/2/KTM		N 12°16'27.8"	E 75°25'20.0"	233	Soil (Inside the pipe)
83	**K_{61}**	13/2/KTM		N 12°16'21.3"	E 75°25'45.7"	485	Soil horizon A (inside the pipe)
84	**K_{62}**	13/2/KTM		N 12°16'21.3"	E 75°25'45.7"	485	Soil horizon B (inside the pipe)
85	**K_{63}**	13/2/KTM		N 12°16'21.3"	E 75°25'45.7"	485	Soil horizon C (inside the pipe)
86	**K_{64}**	13/2/KTM		N 12°16'29.0"	E 75°25'59.7"	471	Soil (Inside the pipe)
87	**K_{65}**	13/2/KTM		N 12°16'22.5"	E 75°25'46.3"	476	Rock (outside the pipe)
88	K66	13/2/KTM	Kottathalachimala	N 12°16'27.8"	E 75°25'20.0"	233	Soil (outside the pipe)
89	**KZ**66	14/3/KTL-1	Kuttikol	N 12°29'12"	E 75°11'22.9"	135	Soil (Inside the affected well)
90	**KZ**67	14/3/KTL-2	Kuttikol	N 12°29'14"	E 75°11'39.5"	179	Soil (Inside the pipe)
91	**W68**	11/4/WAY-1	Padinjarethara	N 11°43'52.9"	E 75°49'52.7"	817	Soil (Non piping)
92	**W69**	11/4/WAY	Banasuram	N 11°40'25.3"	E 75°58'04.0"	736	Soil (outside the pipe)
93	**W70**	11/4/WAY-6	Banasuram	N 11°40'25.3"	E 75°58'04.0"	736	Soil (outside the pipe)

Where,

__6__- Idukki district, __13__- Kannur district, __14__- Kasaragod, __11__- Wayanad, __1__, __2__and __3__ -Sample locations, PRY-Peringassery, __TK__- Thattekanni, __VM__- Venniyanimala, __KTM__- Kottathalachimala, __Tb__- Tabor, __Ch__- Chattivayal, __KTL__-Kuttikol, __WAY__- Wayanad, __A__, __B__, __C__, and __E__- Soil horizons

Figure 5.1 *Soil Sample collecting from Piping and Non piping Area*

5.2 Soil chemistry and Sedimentological studies

The soil samples were prepared for analytical tests following Hesse P R, (1971) method. The samples were dried as rapidly as possible. Drying is carefully carried out to avoid secondary reaction. Large lumps of soil were crushed and roots of plants were removed and the sieved fine soil was used for the analytical experiments.

The chemical parameters like pH, electrical conductivity, total dissolved solids, organic carbon and other organic matter were estimated. XRD and XRF analysis were carried out in 8 and 10 samples respectively. Soil texture analysis was also conducted. Dispersion test has been conducted to know about the dispersive property of the soil.

5.2.1 pH

The pH of soil is the measure of hydrogen ions activity and depends on relative amounts of the absorbed hydrogen and metallic ions. It measures the acidity and alkalinity of a soil water suspension and provides good information about the soil properties such as phosphorous availability, base status and so on. The pH of the soil was determined using 1:10 soil-water (w/v) suspension. 10 g of the air dried soil was mixed with 100 ml distilled water in a beaker. The soil-water mixture was stirred at least 5 times over a 30 minutes interval to allow for soil and water to reach equilibrium. After reaching the equilibrium, the pH of the mixture was measured using the glass electrode after thorough mixing. pH meter was calibrated using buffer solution before the measurements were done.

5.2.2 Electrical Conductivity (EC)

Electrical Conductivity of the soil is a numerical expression of the ability of a soil-water mixture to carry an electrical current which depends on the total concentration of the ionized substances dissolved in the soil-water mixture and the temperature at which the measurement was done. Conductivity is a good criterion of the degree of mineralization and soluble salts in the soil. It depends upon the ratio of the soil to water ratio. The EC of the soil was determined using 1:10 soil-water (w/v) suspension. 10 g of the air dried soil was mixed with 100 mL distilled water in a beaker. The soil-water mixture was stirred at least 5 times over a 30 minutes interval to allow for soil and water to reach equilibrium. The mixture was left overnight in order to obtain a clear supernatant solution into which conductivity electrode was dipped for EC measurement.

5.2.3 Total Dissolved Solids (TDS)

Total Dissolved Solids is a measure of the combined content of all inorganic and organic substances contained in a soil water mixture. The TDS of the soil was determined using 1:10 soil-water (w/v) suspension. 10 g of the air dried soil was mixed with 100 mL distilled water in a beaker. The soil-water mixture was stirred at least 5 times over a 30 minutes interval to allow for soil and water to reach equilibrium. Then mixture was left undisturbed for few minutes to obtain a clear supernatant solution into which conductivity electrode was dipped for TDS measurement.

Analytical report –Idukki

Table5.2. *Analytical report of soil samples from Idukki locations*

SL.NO	Sample Taken from	Sample No.	pH	Electrical Conductivity (μs/m)	Total DissolvedSolids (ppm)
1	Piping Area	I1	5.84	5.32	3.77
2		I2	6.98	3.82	2.65
3		I3	6.68	4.18	3.05
4		I4	5.85	7.33	5.22
5		I6	5.91	5.49	3.95
6		I7	5.55	7.35	5.24
7		I8	5.56	8.2	5.91
8		I10	6.21	4.43	3.06
9		I11	5.8	8.21	5.9
10		I14	6.55	4.8	3.41
11		I16	6.29	3.8	2.42
12		I-17	5.63	10.85	7.70
13		I-18	5.74	13.22	9.38
14		I-19	5.96	5.22	3.70
15		I-20	6.02	10.16	7.21
16		I-21	5.71	6.66	4.72
17		I-22	6.00	3.84	2.72
18	Non-Piping Area	I9	5.91	5.26	3.6
19		I12	5.71	5.13	3.54
20		I13	6.7	5.21	3.75
21		I15	6.14	6.76	4.68

The pH values of the samples (Table 5.2) from Idukki range from 5.00 - 6.98. The samples collected from Peringassery (Sample- I2) records highest pH reading (6.98), whereas the sample Sample-I17 (collected from Upputhara, Idukki) records the lowest reading (5.63). pH shows below 7 ranges it should be acidic in nature, above 7 shows alkaline in nature. The change in pH affects the degree of dissociation of weak acids and bases. The soil samples collected from,piping and non-piping area was showed in low pH values therefore all the samples are acidic in nature. (Table 5.2) The maximum of values EC and TDS is at 13.22μs/m and 9.38ppm is respectively from the samples I17 collecting from Upputhara.

Analytical report –Kannur

Table 5.3. *Analytical report of soil samples from Kannur locations*

SL.NO	Sample code	pH	Electrical Conductivity(µs/m)	Total Dissolved Solids (ppm)
1	K1	5.69	5.14	3.7
2	K2	5.7	8.24	6.1
3	K5	4.31	44.22	32.28
4	K6	5.36	15.88	11.68
5	K7	5.72	11.18	8.19
6	K10	6.02	4.73	3.63
7	K12	5.96	5.14	3.7
8	K13	6.33	4.23	3.16
9	K14	6.52	5.86	4.23
10	K16	6.88	4.33	3.28
11	K17	6.11	4.23	3.08
12	K18	6.45	5.36	3.96
13	K19	6.84	5.78	4.39
14	K20	6.3	5.31	3.99
15	K53	6.32	27.4	21.76
16	K54	6.54	19.56	15.33
17	K55	6.58	8.41	6.56
18	K56	6.53	14.86	11.41
19	K57	6.29	21.84	16.17
20	K58	6.54	34.58	26.68
21	K59	6.9	12.89	9.94
22	K60	6.54	18.7	14.66
23	K61	6.5	25.02	18.89
24	K62	6.74	8.38	6.5
25	K63	6.74	11.4	8.81
26	K64	6.95	17.98	14.39

The $_pH$ values of the soil samples from Kannur at different piping locations is ranges from 4.31 - 6.95 (Table 5.3). The samples collected from K-64 records highest p^H reading (6.95) while that from K-5 records the lowest reading (4.31). The change in p^H affects the degree of dissociation of weak acids and bases. All the samples show acidic in nature. There was a huge variation in EC (4.23 µs/m to 34.58) and TDS (3.16 to 26.68) in the piping area at Kannur compare to Idukki piping area.

The results shows that the parameters like EC and TDS of soil samples collected from Soil Idukki district is less than that from the Kannur district. Which is collected from inside the pipe, this result indicate that lowest P^H value indicate the piping area is in oxidising environment. So the chemical erosion is prominent in this region.

5.2.4 Organic carbon and organic matter

Organic Carbon

Carbon occurs in the soil in elemental form in the inorganic forms of carbonate, hydrogen carbonate and carbon dioxide and organically as plant and animal matter, their immediate decomposition products and more resistant humus. Wet digestion method or Walkley-Black method (rapid dichromate oxidation technique) was used for the estimation of organic carbon. For the wet combustion of organic matter soil was heated with potassium dichromate as the oxidizing agent and sulphuric acid to convert all forms of carbon into carbon dioxide. The potassium dichromate in excess after oxidation of carbon was titrated against ferrous ammonium sulphate. 0.5 g air dried sieved soil was added with 1N potassium dichromate solution and swirled gently to disperse the soil. To this, 20 ml of concentrated sulphuric acid was added and swirled for one minute. The sulphuric acid used contains containing 1.25 % silver sulphate to precipitate chloride as silver chloride so that chloride does not contribute to oxidation of the organic matter. The solution was allowed to stand for half an hour to make the reaction complete. After half an hour the solution was diluted with distilled water and added with 10 drops of diphenyl amine indicator. Then it was titrated with 0.5 M Ferrous ammonium sulphate solution. The end point is indicated by the colour change of the solution from yellow to red with an intermediate green colour formation. The blank determination of organic carbon content was measured as above without soil. The organic carbon content of the soil was calculated in percentage by the formula.

$$\textbf{Organic carbon (\%)} = \mathbf{10(B-T)/\ B *0.003*100/S}$$

Where,

B -Volume of ferrous ammonium sulphate required for blank titration in ml.

T -Volume of ferrous ammonium sulphate required for soil sample in ml.

S –Weight of soil in gram

Organic matter (%) = % Organic carbon *1.724

Organic matter

The term soil organic matter embraces the non-mineral fractions of the soil such as any vegetable or animal matter of the sample. Organic matters contribute to the physical condition of a soil by holding moisture and by affecting the structure. It is the direct source of plant nutrient elements, the release of which depends on the microbial activity and by affecting the action exchange capacity, organic matter is directly involved in the availability of nutrient elements. Soil organic matter is estimated from its organic carbon content.

Table 5.4 *Estimation of soil organic carbon and matter*

SL.NO	Sample	Organic Carbon (%)	Organic Matter (%)
1	I-1	1.83	3.15
2	I-2	0.84	1.44
3	I-3	1.02	1.75
4	I-4	0.75	1.29
5	I-5	0.69	1.18
6	I-9	0.48	0.82
7	I-11	0.09	0.16
8	I-14	0.01	0.02
9	I-15	0.96	1.97
10	I-17	2.49	4.3
11	I-18	2.04	3.52
12	I-19	0.97	1.67
13	I-20	2.98	5.14
14	I-21	3.4	5.87
15	I-22	2.49	4.3
16	K-1	0.36	0.62
17	K-2	0.33	0.57
18	K-5	0.06	0.1
19	K-6	0.37	0.63
20	K-10	0.21	0.36
21	K-12	1.05	1.81
22	K-13	1.11	1.89
23	K-15	0.63	1.08
24	K-19	0.57	0.98
25	K-20	0.93	1.6

Analysis of organic Carbon and organic matter (table 5.4) shows the lowest range 0.10% and 0.02%, samples were collected from I-14 (inside the piping). Sample I-21 shows an organic carbon percentage of 3.40 % and organic matter percentage of 5.87%. This soil sample was collected from a depth of 50 cm with an elevation of 877m.soil samples were collected from Upputhara near Nalaam mile (inside the piping). Occurrences of organic matter in tropics where high temperature and abundant precipitation are prevalent laterite soils in general, do not accumulate organic matter except under special conditions like swamping or forest vegetation. But on a review of the data obtained by many workers, it is revealed that no characteristic limit can be fixed for it, in general, since it appears to fluctuate between 0.1 to 17% as in the case of some soils. The Lowest range of organic carbon and organic matter indicated that the sampling areas become eroded. Lowest range of organic carbon and organic matter which increase the soil erosion activity, leads to reducing the soil stability.

The table 5.4 shows organic carbon and organic matter percentage of soil samples collected Upputhara near Nalaam mile, Peringassery and Venniyanimala in Idukki district. In the Sample I-9 shows a relatively less organic carbon percentage (0.48%) and organic matter (0.82%). This sample was collected from a piping affected locality with an elevation of 492m. In general vertical distribution of organic carbon in soil is decreasing as depth increases. By comparing piping and non piping area, organic carbon is rich in non-piping area and low in piping area.

5.2.5 XRF analysis

The XRF facility in NCESS consists of a Bruker model S4 Pioneer sequential wavelength-dispersive X-ray spectrometer (XRF) and sample preparation units. All major and trace elements are determined on sample pellets for which fused glass disk cannot be made. XRF analysis (Figure 5.5) of samples show the presence of excess level of SiO_2, Al_2O_3, MnO, Fe_2O_3 and TiO_2 revealed that, the soil sample shows the laterite property. Mature laterites are made up of primarily of iron, aluminium, silica, titanium and water. The sesquioxides form the major constituent as their hydrated oxides followed by kaolinite substances. Generally laterites are poor in alkali and alkaline earth metals.

Table 5.5: *Estimation of major elements by XRF and Calculated CIA*

Sample No.	SiO_2	TiO_2	Al_2O_3	MnO	Fe_2O_3	CaO	MgO	Na_2O	K_2O	P_2O_5	CIA(%)
K-1	41.5778	1.2068	31.6807	0.1431	24.5264	0.0669	0.2487	0.0125	0.2361	0.3009	99.0138
K-2	42.8363	1.1217	38.4336	0.0584	16.5216	0.1402	0.4324	0.0234	0.3038	0.1285	98.7987
K-5	46.7706	0.8890	37.0886	0.0693	13.7047	0.1501	0.5773	0.0462	0.5773	0.1270	97.9570
K-6	44.3822	0.7890	35.8463	0.0812	17.6365	0.1740	0.5222	0.0348	0.4525	0.0812	98.1885
K-8	50.5178	1.1005	29.5948	0.0337	12.0043	0.1909	1.0108	0.3481	4.8623	0.3369	84.5660
K-10	49.1495	0.4712	41.1804	0.1060	6.0423	0.6595	1.4018	0.3180	0.5418	0.1296	96.4419
K-12	33.3520	0.9515	41.8430	0.3720	21.8261	0.3182	0.5785	0.0548	0.4932	0.2107	97.9719
K-13	36.5425	1.4323	31.9489	0.4934	27.9316	0.3445	0.6486	0.0383	0.3934	0.2265	97.6280
K-14	40.9856	1.4551	34.5444	0.9007	19.9548	0.7851	0.9932	0.0808	0.1848	0.1155	97.0481
K-15	42.1630	1.2721	34.9844	0.0945	20.4569	0.1225	0.3998	0.0187	0.3676	0.1205	98.5664
K-19	50.1667	0.6128	35.8752	0.0227	9.7933	0.4198	0.8625	0.2497	1.9064	0.0908	93.3008
K-20	48.0959	1.3263	34.2434	0.3094	8.6979	4.1439	1.3043	0.5195	1.1936	0.1658	85.3941
K-21	34.8250	1.4622	26.6072	0.6026	34.3245	0.3981	0.7173	0.0767	0.6994	0.2869	95.7734
K-22	34.0369	1.4870	26.2887	0.7431	35.4755	0.3473	0.6361	0.0608	0.6660	0.2586	96.0743
K-23	34.5122	1.5043	26.8850	0.5606	34.7321	0.2648	0.6092	0.0450	0.6572	0.2296	96.5282
K-24	34.2687	1.4772	26.7301	0.5934	35.0660	0.2823	0.6320	0.0453	0.6482	0.2569	96.4781
K-25	34.5448	1.4673	26.5715	0.6169	35.0721	0.2735	0.5582	0.0439	0.6279	0.2239	96.5648
K-26	37.8263	1.2501	28.0993	0.5745	29.4480	0.4587	1.0485	0.1263	0.8463	0.3220	95.1532
K-27	37.6034	1.2039	28.8576	0.5712	28.6754	0.6188	1.1388	0.1569	0.8273	0.3468	94.7372
K-28	35.5922	1.3670	28.5024	0.2367	32.1108	0.2112	0.7330	0.0581	1.0651	0.1235	95.5277
K-29	34.9363	1.3095	28.8304	0.2855	32.6746	0.2630	0.6783	0.0447	0.8258	0.1520	96.2173
K-30	33.2254	1.5060	28.8584	0.1388	34.1598	0.1654	0.6416	0.0435	1.1135	0.1478	95.6187
K-31	32.2944	1.4686	29.1321	0.1664	35.0446	0.1502	0.5697	0.0434	0.9829	0.1476	96.1181
I-1	39.6866	1.7914	33.5808	0.0960	22.5719	0.0614	0.6468	0.0493	1.3568	0.1592	95.8131
I2	56.6949	0.7094	29.0649	0.0317	10.0497	0.0547	0.8200	0.1911	2.2711	0.1125	92.0305
I-3	43.5614	1.5919	33.1276	0.0410	19.3281	0.1019	0.5378	0.0855	1.5063	0.1185	95.1357
I-4	61.7737	0.5881	28.8821	0.0028	6.6892	0.0339	0.7873	0.0846	1.1001	0.0581	95.9513
I-5	53.5846	0.9011	30.4432	0.0247	11.0316	0.0472	1.2876	0.1547	2.4118	0.1135	92.0931
I-9	36.8668	1.4577	30.9042	0.8462	27.9227	0.7576	0.9576	0.0439	0.1582	0.0852	96.9884
I-11	48.9626	1.3968	31.2702	0.1452	13.3755	0.2346	1.1846	0.1564	2.7264	0.5476	90.9342
I-14	48.8789	1.2402	31.5236	0.1341	12.5807	0.3686	1.3744	0.2570	3.1060	0.5364	89.4153
I-15	37.0120	1.6556	41.9283	0.1461	16.3121	0.2678	1.3027	0.0852	0.8765	0.4139	97.1513

a. Estimation XRF results By CIA

The chemical index of alteration (CIA) has been widely used as a proxy for chemical weathering in sediment source area. The CIA actually reflects the integrated weathering history in the drainage basins and therefore, caution should be taken while using it as a direct and quantitative proxy for evaluating the intensity of instantaneous chemical weathering in continents. Chemical Index of Alteration (CIA) is a powerful tool for study of the paleo-climatic record preserved in siliciclastic sedimentary successions. These CIA values are compatible with a prominent influence of physical weathering on the production of the diamictite detrital silicate matrix.

The CIA is defined as

$$CIA = \frac{Al_2O}{(Al_2O_3 + Na_2O + K_2O + CaO*)} x100$$

where the major element oxides are given in molecular proportions. CaO* represents the CaO content in silicate minerals only (Fedo et al., 1995). Kaolinite has a CIA value of 100 and represents the highest degree of weathering. Illite is between 75 and 90, muscovite at 75, the feldspars at 50. Fresh basalts have values between 30 and 45, fresh granites and granodiorites of 45 to 55. Data and trends can be displayed well in A–CN–K (Al2O3– CaO*+Na2O – K2O) ternary diagrams. The combination of these features makes the CIA the presently preferred weathering index (Nesbitt and Young, 1982; Fedo et al., 1995).

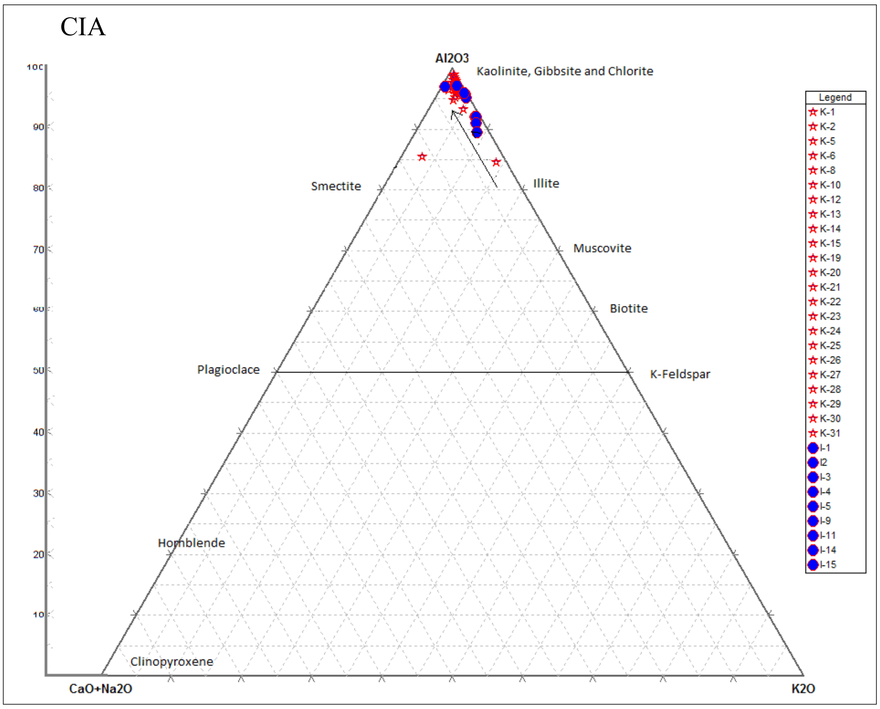


Figure 5.2: *Al_2O3–(CaO*+ Na_2O)–K_2O (A–CN–K) diagram for the investigated soil (Compositions as molar proportions, CaO* represents CaO of the silicate fraction only).*

From the XRF result of selected samples plotted on the (A–CN–K) diagram, the mineral compositions, weathering trends and weathering intensity give the following conclusions: A-CN-K diagram illustrates the weathering trend of saprolite materials, (Nesbitt and Young, 1984; 1989). The analysed samples plot is very close to the Kaolinite Gibbsite Chlorite corner tie lines, suggesting very poor weathering conditions or albite-rich sources with less K mobility. The degrees of weathering for the sediment samples are fairly different throughout the sequence. The weathering process took place in two stages, marked by a rapid depletion of silica, Magnesium, alkalies and enrichment of Al_2O3 and Fe_2O_3 and K_2O during the first stage. The second stage has been marked by gradual depletion of SiO_2, CaO, MgO, Na_2O and K_2O with enrichment of Al_2O_3, Fe_2O_3 and TiO_2.

b. Correlation method

Table 5.6*Correlation matrix of selected sample from Idukki obtained using XRF analysis.*

	SiO_2	TiO_2	Al_2O_3	MnO	Fe_2O_3	CaO	MgO	Na_2O	K_2O	P_2O_5
SiO2	1									
TiO2	-0.9267	1								
Al2O3	-0.6862	0.6692	1							
MnO	-0.5639	0.3093	-0.0041	1						
Fe2O3	-0.8850	0.7813	0.2989	0.7393	1					
CaO	-0.5694	0.3426	0.1037	0.9358	0.6321	1				
MgO	-0.0139	-0.0684	0.2496	0.0768	-0.2686	0.3082	1			
Na2O	0.4875	-0.4196	-0.2958	-0.3716	-0.6049	-0.1296	0.5475	1		
K2O	0.4820	-0.2799	-0.3175	-0.5588	-0.5858	-0.3696	0.4088	0.8962	1	
P2O5	-0.1928	0.3299	0.3801	-0.0928	-0.1366	0.2045	0.6770	0.5270	0.5328	1

Table 5.7 *Correlation matrix of selected sample from Kannur obtained using XRF analysis.*

	SiO_2	TiO_2	Al_2O_3	MnO	Fe_2O_3	CaO	MgO	Na_2O	K_2O	P_2O_5
SiO2	1									
TiO2	-0.6924	1								
Al2O3	0.1836	-0.3153	1							
MnO	-0.5973	0.4524	-0.3685	1						
Fe2O3	-0.8962	0.6521	-0.5751	0.6220	1					
CaO	0.0704	0.0598	0.1119	0.2092	-0.1991	1				
MgO	0.3781	-0.1624	0.1452	0.0092	-0.4731	0.4031	1			
Na2O	0.5291	-0.3339	0.1369	-0.2145	-0.5989	0.6723	0.7131	1		
K2O	0.5250	-0.1498	-0.1705	-0.4526	-0.4349	-0.0620	0.4398	0.5691	1	
P2O5	-0.1149	0.3255	-0.1255	0.1125	0.0682	-0.0285	0.3840	0.1801	0.3914	1

The correlation coefficients for the oxides are shown in (Tables 5.11 and 5.12) Regression accordance tests were run to understand the meanings of the interpretations of the correlation coefficients. The majority of the correlation coefficients were significant with a 95% and 99% probability.

The table 5.6 shows correlation of major elements of soil samples collecting from piping area in Idukki district. The computed correlation coefficient of silica shows significantly negative relationship with TiO_2, CaO, MnO and Fe_2O_3, Al_2O_3 in Idukki area (Table 5.12). These relationships reveal that with the increase of SiO2 there is correspondingly decrease in MnO, Fe_2O_3, TiO_2, CaO, MgO, Na_2O and vice versa. The negative relationship of silica with manganese and Fe2O3 probably indicates that manganese and Fe2O3 are the substitutes of silica.

The highly variable silica/alumina ratio and sympathetic relationship of silica with Al_2O_3, Fe_2O_3 and K2O favors the coexistence of quartz and alumino-silicate minerals in the soil. Silica shows a sympathetic relationship with Al_2O3, Fe_2O3, P_2O_5 and K_2O. The positive relationship of silica with these elements is possibly due to the presence of potash feldspar and other alumino-silicate minerals. (Table 5.7)

The positive relationship of MnO with Fe_2O_3 and the constant MnO/Fe (total iron) (Table 5.6 and 5.7) ratio indicate that iron and manganese were delivered in the same proportion. The constant MnO/Fe ratio suggests co-precipitation of Mn and Fe under fairly oxidizing condition. The SiO2 content and the SiO_2/Al_2O_3 ratio are the most commonly used geochemical criteria for delineating the sediment maturity (Potter, 1978), which also reflect the abundance of quartz, feldspar and clay contents in the sediments. Even the alkali content ($Na_2O + K_2O$) is very much applicable for index of chemical maturity and also a measure of the feldspar content.

5.2.6 Determination of exchangeable sodium percentage and Ca & Mg ratio

A sodic soil, by definition, contains a high level of sodium relative to the other exchangeable cations (i.e. calcium, magnesium and potassium).The presence of excessive amounts of exchangeable sodium reverses the process of aggregation and causes soil aggregates to disperse into their constituent individual soil particles. This is known as deflocculation and occurs in sodic soil. A sodic soil with few stabilizing agents (e.g. humus, clay or sesquioxides) in the topsoil will ultimately be susceptible to erosive soil loss during intense rainfall or irrigation cycles via rill and gully erosion. In Australia, soil with an ESP greater than 6 % is considered to be sodic. However, soil dispersion problems may occur at a higher or lower ESP depending upon clay type.

Table 5.8 *Exchangeable sodium percentages common standard*

Exchangeable Sodium Percentage	<6	6-10	10-15	15-25	25
Classification	Non-sodic	Sodic	Moderately Sodic	Strongly Sodic	Very strongly Sodic

(http://www.terragis.bees.unsw.edu.au/terraGIS_soil)

Table 5.8 shows a high percentage of exchangeable sodium on 53.53 at Kottathalachimala, the soil samples were collected from inside the piping affected area. And least (9.86) in Thattekanni soil samples were collected from soil profile of the affected area. All the soil samples are above the limit. These results revealed that all the sampling area is affected by sodic soil.

Ca: Mg ratio is also one of the important factors for determining sodic soil if CA: Mg ratio of less than 2 also indicates tendency to disperse. All the results show less than 2 ranges, which indicate that the affected area is prone to clay dispersion. From this result, Kottathalachimala is highly susceptible to clay dispersion.

Previous studies and reports shows that If the non-saline soils with an exchangeable sodium percentage (ESP) above 5 are liable to disperse in water .The exchangeable sodium percentage (ESP) value gives potential for clay dispersion. (Bernie McMullen, 2000),

Table 5.9 *List exchangeable sodium, Potassium, Magnesium and calcium*

Sample Id	Exchangeable Na (cmol/kg)	Exchangeable K (cmol/kg)	Exchangeable Mg (cmol/kg)	Exchangeable Ca (cmol/kg)	ESP(%)	CEC (cmol /kg)
1/KTM-C	14.13	0.83	9.16	7.00	45.40	31.12
7/KTM	1.74	0.02	4.79	3.00	18.21	9.55
6/VM-B	2.18	0.05	4.80	2.80	22.17	9.83
14/TK-C1	2.03	0.31	6.38	4.40	15.47	13.12
16/KTM-4	10.86	0.51	6.35	5.60	46.56	23.32
6/KTM	9.78	0.89	4.80	2.80	53.53	18.27
11/TK-B	1.51	0.20	8.40	5.20	9.86	15.31
5/PRY-C1	1.54	0.24	3.98	3.20	17.18	8.96
2/KTM-B	12.93	0.06	7.95	6.80	46.61	27.74
2/PRY-E	0.95	0.001	5.18	0.40	14.54	6.53
9NP-B	5.10	0.25	5.36	3.00	37.19	13.71

5.2.7 XRD analysis

X-ray diffraction (XRD) is a rapid analytical technique primarily used for phase identification of a crystalline material and can provide information on unit cell dimensions. X-ray diffraction is most widely used for the identification of unknown crystalline materials (e.g. minerals, inorganic compounds). Determination of unknown solids is critical to various geological applications. The XRD facility at CESS, consists of a PAN analytical 3 kW X'pert PRO X-ray diffractometer.It can be used for the following studies. Characterization of crystalline materials, Identification of fine-grained minerals such as clays and mixed layer clays that are difficult to determine optically, Determination of unit cell dimensions, Measurement of sample purity.

Datasets and results

Table 5.10. *Peak List of Soil sample (6/1/TK-C3)*

Pos. [°2Th.]	Height [cts]	FWHM Left [°2Th.]	d-spacing [Å]	Rel. Int. [%]
8.7453	86.31	0.4015	10.11151	22.25
12.3664	202.21	0.2676	7.15765	52.12
18.2851	387.97	0.0836	4.85198	100.00
20.1465	47.37	0.4015	4.40771	12.21
21.4390	45.07	0.5353	4.14480	11.62
24.8804	267.82	0.2007	3.57875	69.03
26.6131	346.17	0.0836	3.34955	89.23
37.7064	45.67	0.2676	2.38573	11.77
45.3669	48.62	0.3346	1.99911	12.53
50.7299	14.03	0.8029	1.79965	3.62

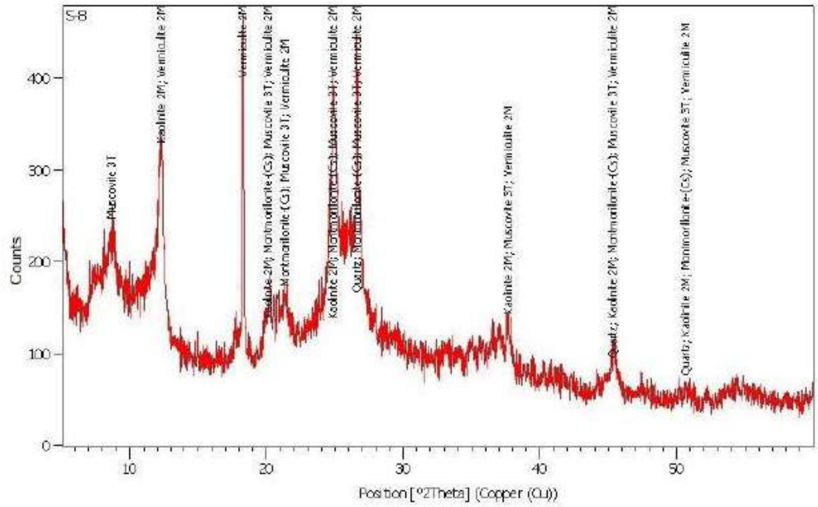


Figure5.3: *X-ray diffractogram of soil samples (6/1/TK-C3) at Idukki*

Table 5.11: *Peak List of Soil sample (6/1/NP-B)*

Pos. [°2Th.]	Height [cts]	FWHM Left [°2Th.]	d-spacing [Å]	Rel. Int. [%]
7.2871	25.36	0.4015	12.13142	4.04
8.9831	18.47	0.8029	9.84439	2.95
12.2962	627.14	0.3011	7.19836	100.00
18.3149	99.08	0.0836	4.84415	15.80
19.9901	38.40	0.4015	4.44183	6.12
21.3382	39.75	0.5353	4.16415	6.34
24.9175	608.92	0.2676	3.57352	97.09
37.6790	61.10	0.3346	2.38741	9.74
51.0611	23.10	0.4015	1.78875	3.68

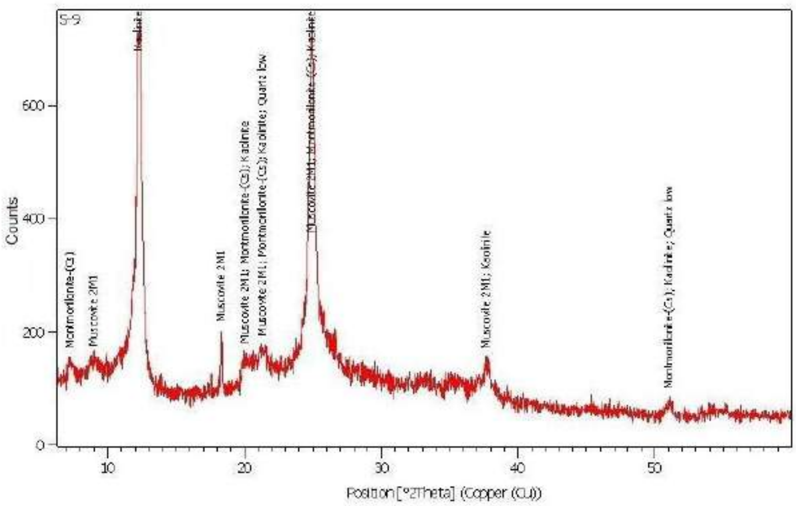


Figure 5.4: *X-ray diffractogram of soil samples (6/1/NP-B) at Idukki*

Table 5.12. *Peak List of Soil sample (6/1/PRY-B)*

Pos. [°2Th.]	Height [cts]	FWHM Left [°2Th.]	d-spacing [Å]	Rel. Int. [%]
8.8122	94.08	0.1338	10.03496	8.68
12.3664	1083.34	0.1171	7.15766	100.00
17.7451	67.30	0.2007	4.99840	6.21
18.3093	816.82	0.0836	4.84562	75.40
20.1654	25.47	0.6691	4.40360	2.35
21.3906	92.91	0.3011	4.15406	8.58
24.8266	1073.84	0.1171	3.58639	99.12
26.6378	275.53	0.1338	3.34651	25.43
33.6222	32.60	0.4015	2.66560	3.01
37.7843	151.60	0.2007	2.38099	13.99
45.4670	70.53	0.3346	1.99495	6.51
51.0713	56.61	0.3346	1.78841	5.23

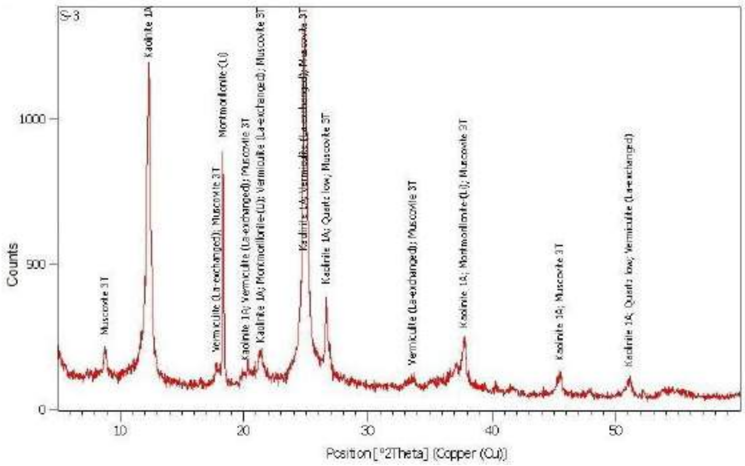


Figure: 5.5: *X-ray diffractogram of soil samples (6/1/PRY-B) at Idukki*

Table 5.13 *Peak List of Soil sample (6/1/PRY-A)*

Pos. [°2Th.]	Height [cts]	FWHM Left [°2Th.]	d-spacing [Å]	Rel. Int. [%]
12.281(3)	262(5)	0.47(1)	7.20122	100.00
18.265(3)	146(14)	0.08(1)	4.85327	55.77
20.13(4)	20(3)	0.68(8)	4.40706	7.52
21.31(2)	47(3)	0.85(5)	4.16526	18.08
24.850(4)	252(5)	0.50(1)	3.58009	96.18
26.62(2)	43(3)	0.55(4)	3.34630	16.33
33.39(5)	12(2)	0.8(1)	2.68117	4.77
34.96(3)	17(3)	0.4(1)	2.56463	6.46
37.33(4)	27(3)	1.34(9)	2.40686	10.49

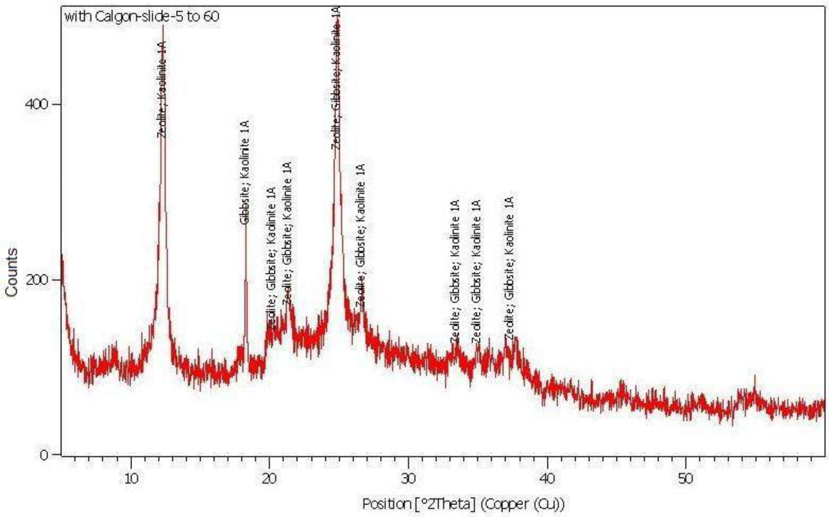


Figure: 5.6: *X-ray diffractogram of soil samples (6/1/PRY-A) at Idukki*

Table: 5.14 Peak *List of Soil sample (6/1/PRY-E)*

Pos. [°2Th.]	Height [cts]	FWHM Left [°2Th.]	d-spacing [Å]	Rel. Int. [%]
8.7842	113.21	0.2676	10.06683	48.93
12.3371	144.66	0.2676	7.17461	62.52
18.2986	105.82	0.1004	4.84843	45.73
20.0310	43.49	0.4015	4.43285	18.79
24.9152	176.52	0.3346	3.57384	76.28
26.6446	231.40	0.0836	3.34567	100.00
45.2529	19.97	0.8029	2.00388	8.63

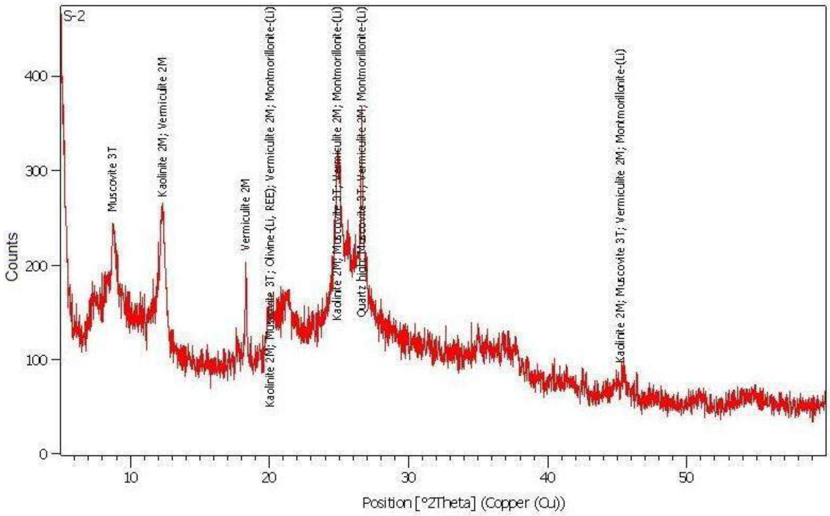


Figure 5.7: *X-ray diffractogram of soil samples (6/1/PRY-E) at Idukki*

Table 5.15 *Peak List (6/1/NP-A)*

Pos. [°2Th.]	Height [cts]	FWHM Left [°2Th.]	d-spacing [Å]	Rel. Int. [%]
7.1367	27.36	0.4015	12.38662	3.82
12.3289	292.62	0.2676	7.17936	40.82
18.2935	716.81	0.0836	4.84977	100.00
20.2881	161.27	0.0836	4.37725	22.50
21.3641	84.80	0.2676	4.15916	11.83
24.8955	325.85	0.2342	3.57662	45.46
26.6151	69.97	0.2007	3.34931	9.76
33.3013	21.73	0.8029	2.69055	3.03
37.6582	98.01	0.2007	2.38868	13.67
41.6760	22.00	0.4015	2.16721	3.07
44.2522	26.76	0.2007	2.04685	3.73
45.5003	29.92	0.2007	1.99356	4.17

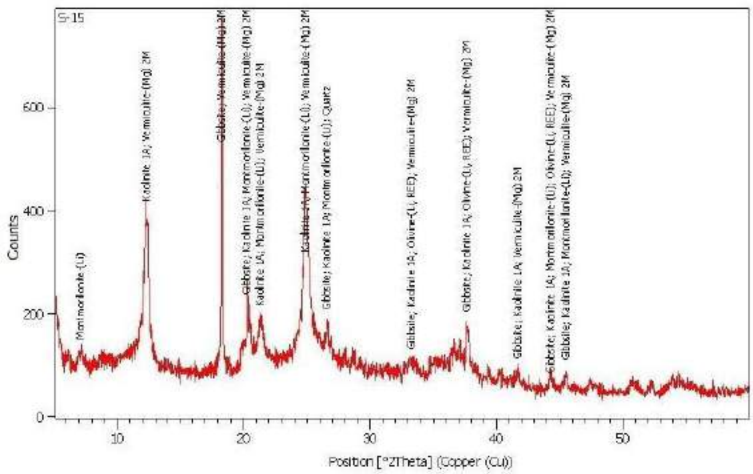


Figure: 5.8: *X-ray diffractogram of soil samples (6/1/NP-A) at Idukki*

According to the XRD results, gibbsite and kaolinite is more dominant followed by Quartz. Gibsite indicate prominent leaching material which confirms the erosional actvity in that region. Muscovite (KAl_2 ($AlSi_3O_{10)}$ (F, OH) $_2$), Vermiculite, Montmorillonite, Kaolinite ($Al_2Si_2O_5$ (OH) $_4$ are the minerals present in the sample. The natural weathering of the cave can leave behind concentrations of aluminosilicates which were contained within the bedrock.

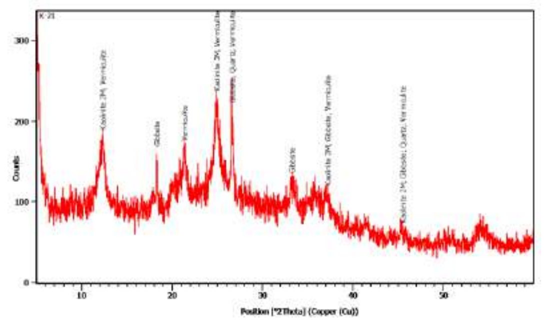
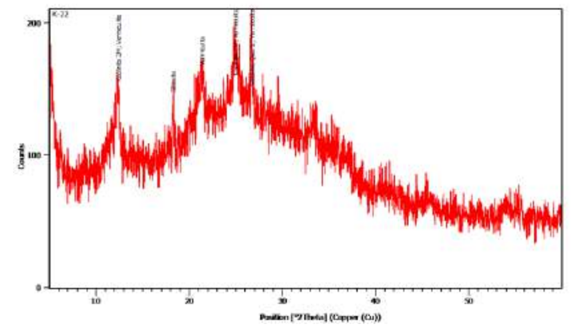
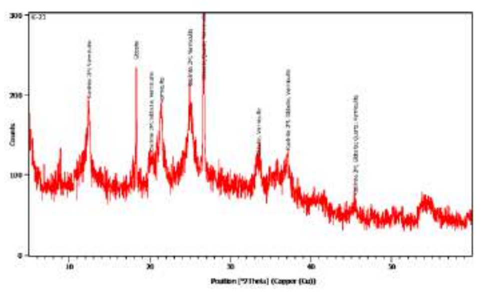
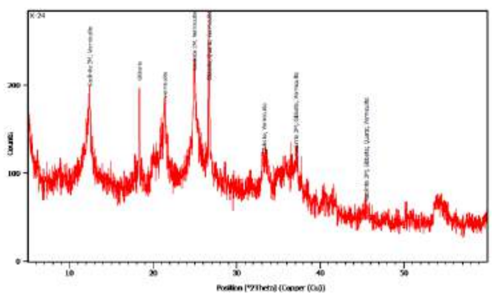
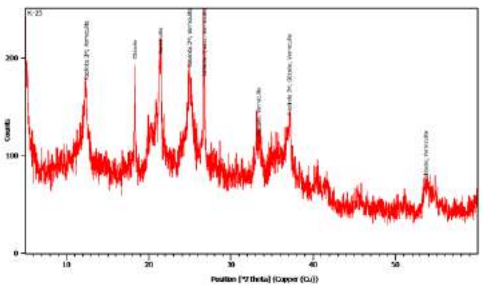
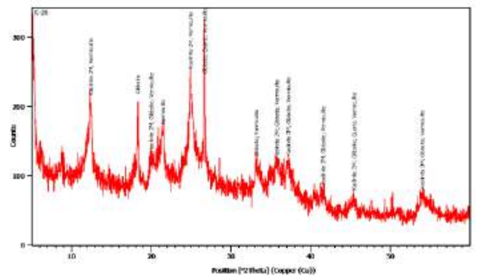
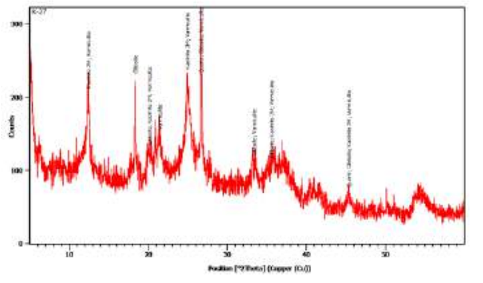
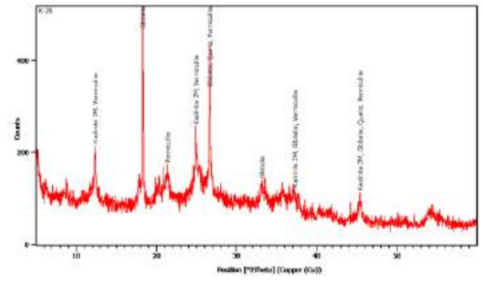
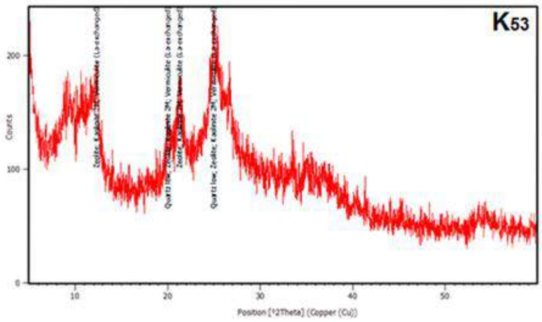
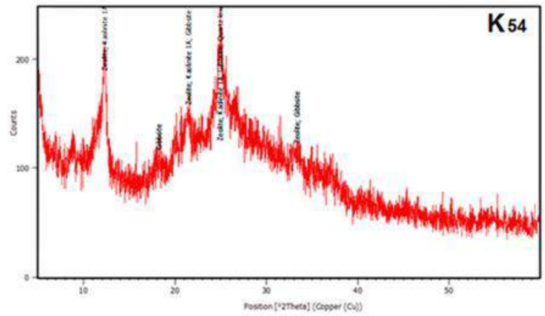
	
a. 13/2/KTM (K21)	**b.** 13/2/KTM (K22)
	
c.13/2/KTM (K23)	**d.**13/2/KTM (K24)
	
e. 13/2/KTM(K25)	**f.** 13/2/KTM(K26)
	
g. 13/2/KTM (K27)	**h.** 13/2/KTM (K28)

***Figure: 5.9:** X-ray diffractogram of soil samples from Kottathalachimala at Kannur*

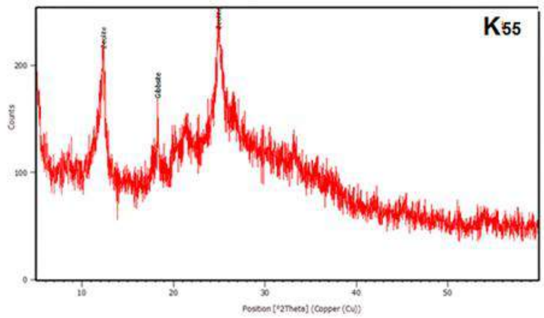
In tune with the earlier results the soils from Thirumeni also dominated by gibbsite and kaolinite followed by Quartz, Vermiculite. Earlier studies have indicated that Gibbsite undergoes leaching and promotes chemical erosional actvity in the region (Figure 5.9). All the soil samples {13/2/KTM-(K21) to 13/2/KTM-(K28)} collected from piping affected area indicated the presence of Gibbsite.



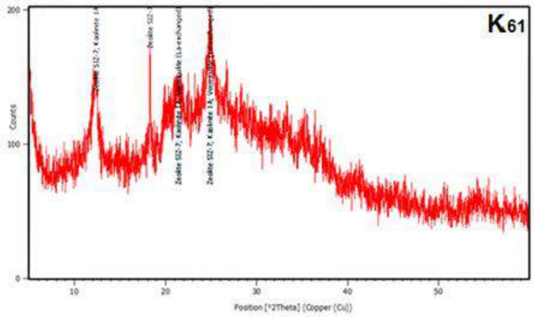
X-ray diffractogram of clay fraction for sample **K53**



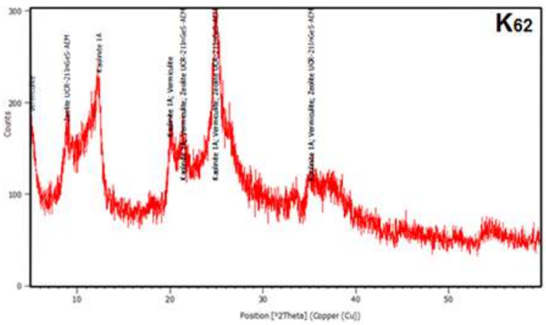
X-ray diffractogram of clayfraction sample **K54**



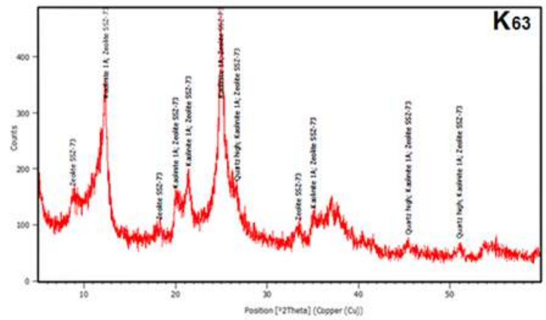
X-ray diffractogram of clay fraction for sample **K55**



X-ray diffractogram of clay fraction for sample **K61**

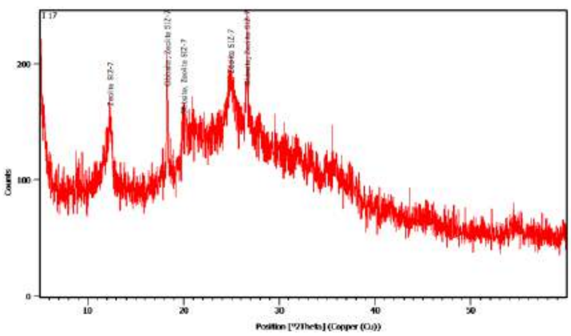


X-ray diffractogram of clay fraction for sample **K62**

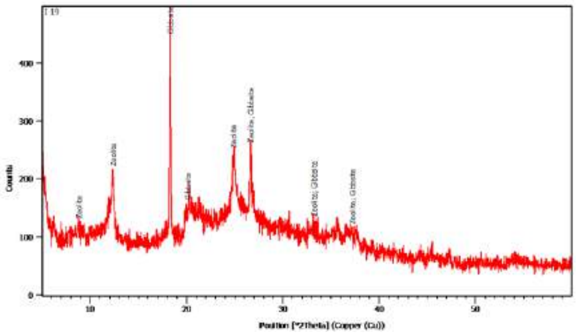


X-ray diffractogram of clay fraction for sample **K63**

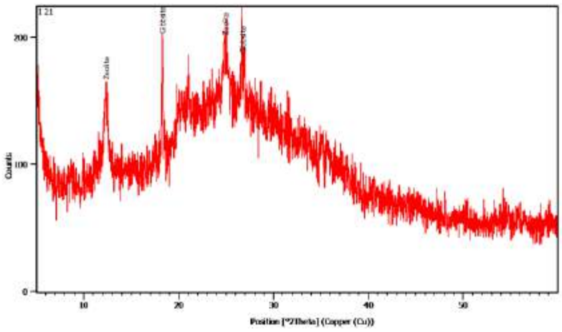
Figure: 5.10: *X-ray diffract gram of soil samples from Chattivayal at Kannur*



***a**. XRD result of sample I-17*



b.** XRD result of sample I-19**c



c. XRD result of sample I-21
***Figure: 5.11:** X-ray diffractogram of soil samples from Idukki*

XRD analysis was carried out on 5 samples collected from Kasaragod (KSD), Kannur (KTM) and Wayanad (WAY) soil samples.

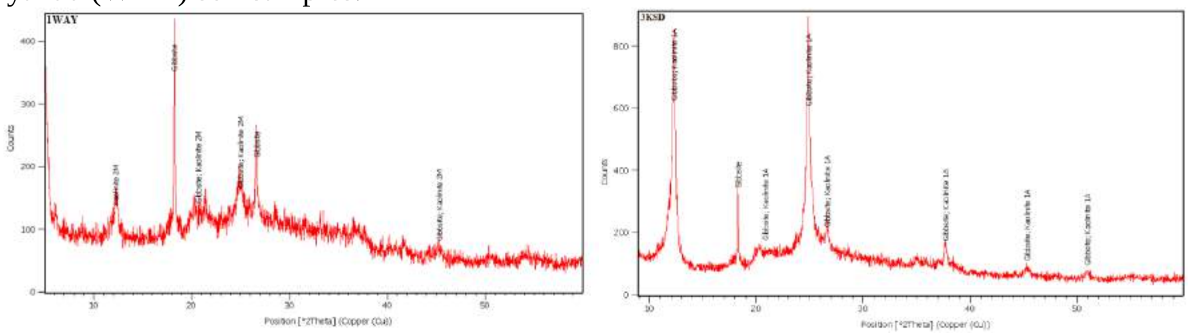


***Figure5.12:** X-ray diffract gram of soil samples from Wayanad (W68) and Kasaragod, Kz 66*

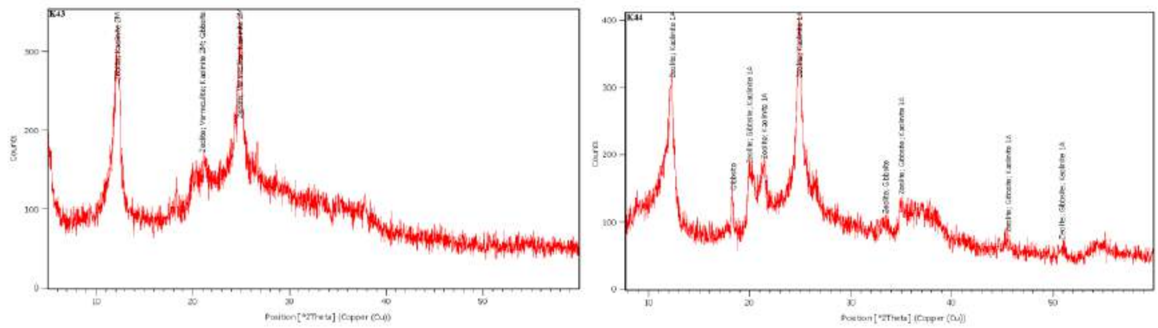


***Figure: 5.13:** X-ray diffract gram of soil from inside the piping at Kannur, (K 43) and (K 44)*

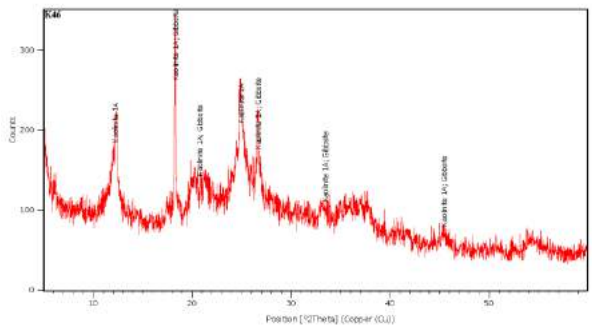


***Figure 5.14:** X-ray diffractogram of soil samples from inside the piping at Kannur, (K 46)*

According to the XRD results (Figure-5.11 to 5.14) most of the soil samples from the affected area shows that the presence of Gibbsite, Kaolinite and followed by Vermiculate. These minerals indicate prominence of leaching material which leads to the erosional actvity in that region.

Presence of Zeolite seen in the laterite cavities is an indication of hydrothermal activities take place in that region.

Previous studies confirming the formation of this mineral under other environments and during the initial stages of weathering (Delvigne, 1965) Hsu (1977) stated that there is no relationship between the age of a soil and the presence of gibbsite and and another study by Herbillon (1978) inferred that gibbsite is typically an intrazonal mineral. pH and high Mg and Si activities in solution, do not favour the formation of gibbsite (Pedro and Bitar, 1966). The XRD results shows that the presence of Gibbsite and zeolite. Gibbsite is a secondary mineral mainly of tropical and alteration product of many aluminous and alumina-silicate minerals under intense weathering conditions. Gibbsite indicates prominent leaching material which confirms the erosional actvity in that region. Zeolite having the property of high porosity indicates the ability of storing water with in its pores and in conditions if the pores are completely saturated by water they start eroding. Presence of these clay minerals gives clear indication of soil piping in the affected area.

5.2.8 Soil textural analysis

Textural analyses were carried out by pipette analysis. By far the pipette method is the one most widely used for analysing the grain size distribution of silt and clay. Usually the settling velocities used in pipette analysis are calculated from Stocks' low. Sample preparation methods are following

1. Coning and Quartering
2. Removal of substances that interfere with dispersal
3. Removal of organic matter
4. Pipette analysis
5. Drying and weighing.

Table 5.16 *Textural analysis of soil samples in Idukki*

SL.NO	Sample code	Sand (%)	Silt (%)	Clay (%)	Depth in meter (bgl)
1	6/1/PRY-A	33.15	33.31	33.52	1
2	6/1/PRY-E	44.18	37.70	18.10	1.3
3	6/1/PRY-E1	44.33	43.07	12.59	1.3
4	6/1/PRYC	47.33	45.31	7.29	3
5	6/1/VM-B	70.6	23.6	5.79	2
6	6/1/VM	75.28	22.0	2.7	1.7
7	6/1/TK-C3	51.96	34.92	13.11	3
8	6/1/PRY-B	28.61	35.76	35.61	2
9	6/1/NP-A	45.02	38.08	14.81	0.5
10	6/1/NP/-B	49.93	41.05	8.96	1
11	6/1/TK-B1	55.21	33.76	11.00	2

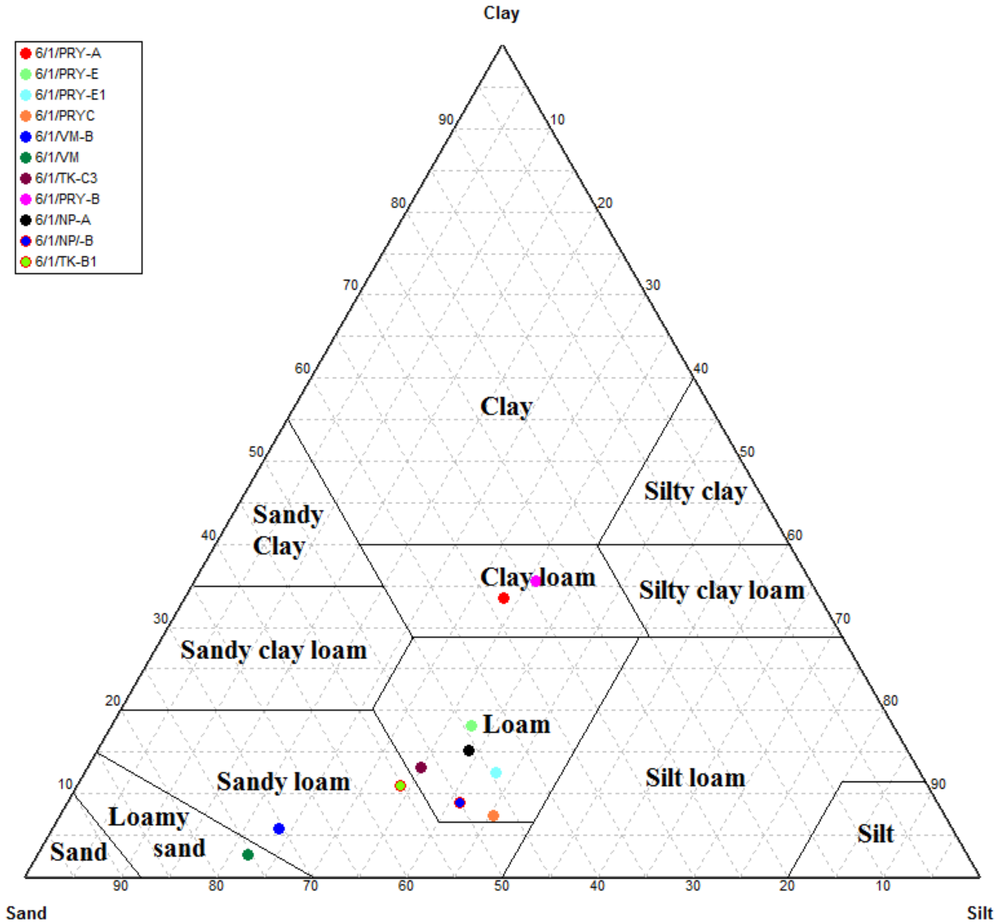


***Figure 5.15**: Textural diagram of soil sample in the piping and non-piping area*

The textural analysis of the samples from the affected area shows (table 5.16) all samples collecting from inside the piping, shows less percentage clay. The high percentage sand shown by the sample 6/1/VM is 75.28 and minimum percentage is shown by 6/1/PRY-B (28.61). The maximum percentage of silt (45.3%) was shown by (16/1/PRYC) and the minimum 22.0 was shown by 6/1/VM. Higher values of clay 35.61% was indicated by 6/1/PRY-B sample and a lower value of clay (2.7%) were shown by 6/1/VM.

***Table 5.17** Textural analysis of soil samples from Idukki and Kannur*

SL.NO	Sample code	Sand (%)	Silt (%)	Clay (%)	Depth in meter (bgl)
1	6/1/TK Out let-2	82.2	10.46	7.20	0
2	13/2/KTM-1,C	15.00	57.49	27.46	4.00
3	13/2/KTM-7	73.8	18.9	7.30	3.25
4	6/1/NP-C	78.24	17.05	4.70	6.00
5	13/2/KTM-6	73.93	19.51	6.52	3.00
6	6/1/TK-Out let-1	90.87	4.46	4.63	0
7	6/1/TK-C1	62.00	29.6	8.40	3.00
8	13/2/KTM-2,B	20.08	57.68	22.20	2.00

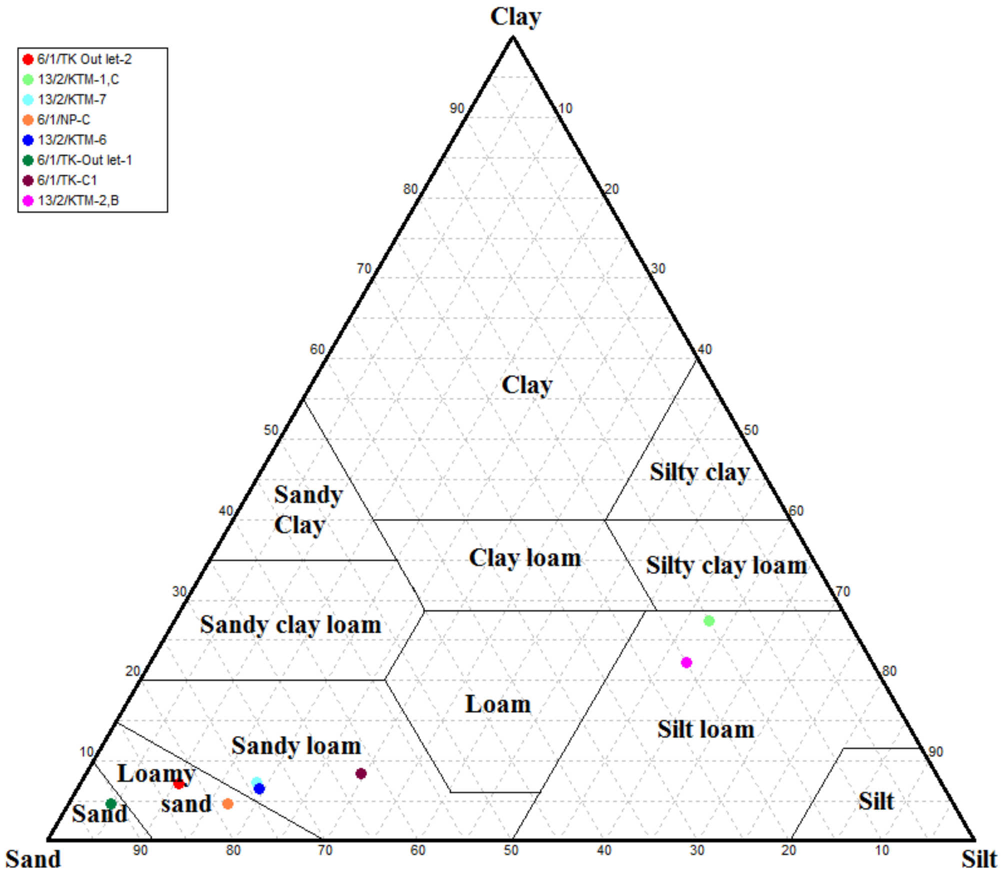


Figure 5.16 *Textural diagram of soil sample in the piping and non-piping area*

The textural analysis of the samples from the affected area shows (Table 5.17) a high percentage of sand. The maximum percentage shown by 6/1/TK, (sample taken from piping out let) is 90.87and minimum percentage is shown by 13/2/KTM-1C (15.00%). The maximum percentage of silt (57.68%) was shown by (13/2/KTM-2, B) and the minimum 18.9 was shown by 13/2/KTM-7. Higher values of clay 27.46% was indicated by 13/2/KTM-1, C sample and a lower value of clay (4.63%) was shown by 6/1/TK-Out let-1.

Most of samples (Sl No. 1, 2, 3, 6, and 7) are falls in sand silt clay region, samples (4) falls under sandy silt region and Sample (8) in clayey sand region. According to textural analysis, samples show high percentage of sand. This result revealed that all the soil samples are not affected by piping; silty and clayey portion is removed.

Table 5.18 *Textural analysis of soil samples from Idukki and Kannur*

SL.NO	Sample code	Sand (%)	Silt (%)	Clay (%)	Depth in meters (bgl)
1	13/2/KTM-21	27.07	30.07	42.82	0.25
2	13/2/KTM-22	30.14	21.69	48.10	0.50
3	13/2/KTM-23	33.58	20.85	45.55	0.75
4	13/2/KTM-24	33.83	19.94	46.21	1.00
5	13/2/KTM-25	35.24	16.99	47.76	1.25
6	13/2/KTM-26	43.14	25.91	30.91	0.15
7	13/2/KTM-27	45.01	25.32	29.65	0.35
8	13/2/KTM-28	43.64	12.76	43.58	0.50

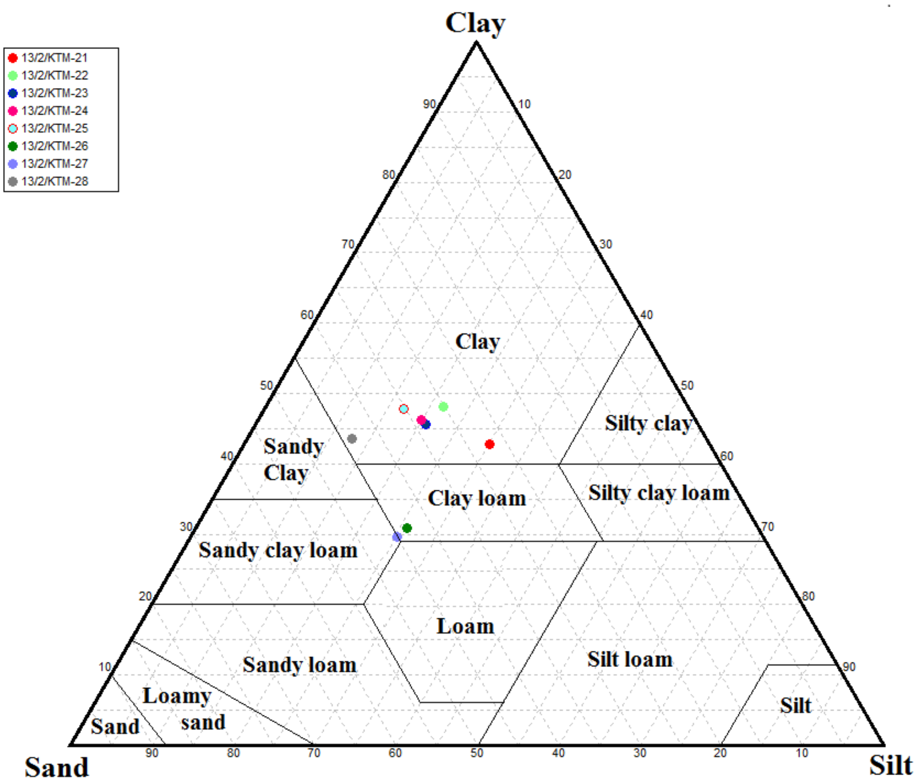


Figure 5.17 *Textural diagram of soil sample in the piping area*

The textural analysis of the samples from premise of piping shows (Table 5.18) a high percentage of sand. The maximum percentage is shown by 13/2/KTM (27.45%).01and minimum percentage is shown by 13/2/KTM-21(27.07%). The maximum percentage of silt (30.07%) was shown by (13/2/KTM-21) and the minimum 12.76 was shown by 13/2/KTM-28. Higher values of clay (48.10%) were indicated by 13/2/KTM22, lower value of clay (29.65%) was shown by 13/2/KTM-28.

Table 5.19 Textural analysis of soil samples from Kannur

Sl. No	Sample No	Sand percentage	Silt Percentage	Clay percentage	Depth in meter (bgl)
1	K53	45.08	16.45	38.46	Wall of the Pipe
2	K54	72.34	21.25	05.71	2.00
3	K55	34.85	13.77	51.37	4.50
4	K56	34.27	38.38	27.35	3.00
5	K57	29.87	13.83	56.29	0.50
6	K58	30.65	25.23	44.11	0
7	K59	76.80	10.50	12.69	Wall of the Pipe
8	K60	66.54	08.87	24.59	Wall of the Pipe
9	K61	40.41	26.99	32.59	0.30
10	K62	41.45	13.47	45.07	0.80
11	K63	51.87	09.48	38.72	3.50
12	K64	76.00	15.91	08.08	Inside the Pipe

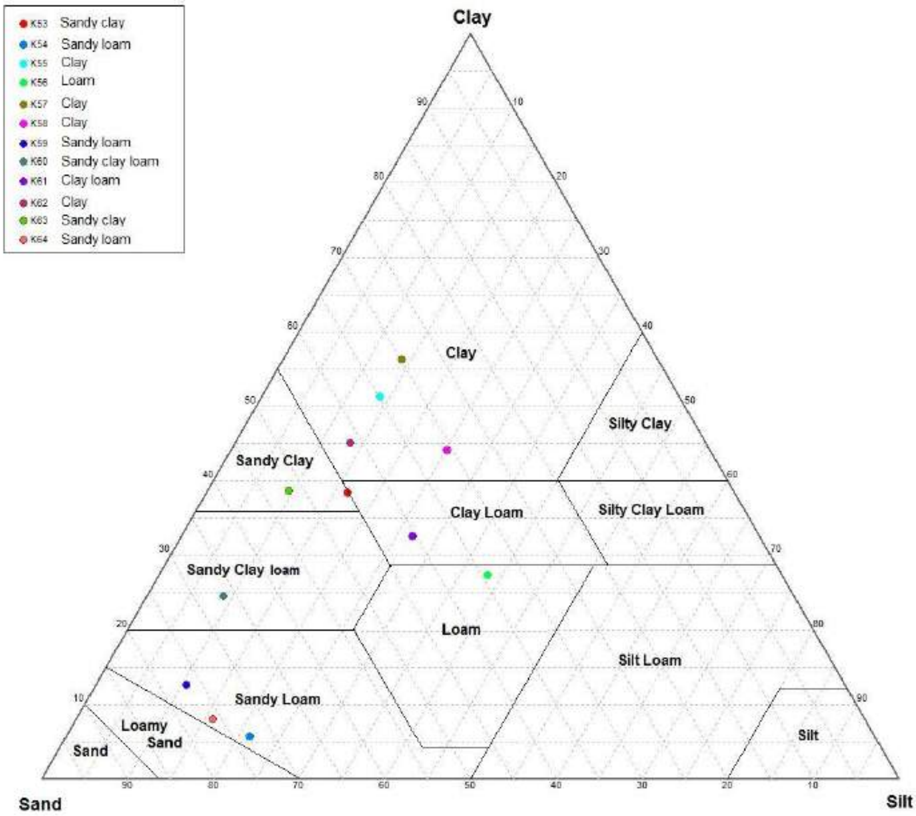


Figure 5.18 *Textural diagram of soil sample in the piping area*

In the figure 5.18 the sample K53 is sandy clay taken from inside the piping in Kannur district at Chattivayal and the sample K54 was sandy loam from outlet of the same piping area. K53 sample is a Forest loam soil with Sandy clay structure and weak granular to moderate sub granular blocky structure. K54 sample is a riverine soil having sandy loam texture and structure less. The third sample K55 is dominated by Clay, sample K56 is dominated by Loam, Sample K57 is dominated by clay and K58 is also dominated by Clay. These four samples were taken from the same area in horizon wise at Chattivayal near the piping effected area is mostly dominated by Clay. K59 sample was dominated by Sandy Loam, K60 sample was dominated by Sandy clay loam, and both these samples were taken from one of the pipe at Kottathalachimala, both the sandy loam and sandy clay loam texture indicating Forest Loam soil having a weak granular to moderate sub granular structure. The next three samples were taken from study area where the sample K61 dominated by Clay Loam, K62 dominated by Clay and K63 dominated by Sandy Clay indicating that mostly the soil is dominated by clay, Clay Loam, Clay, Sandy clay texture of this samples show it is a Forest loam soil having a weak granular to moderate sub granular blocky structure. K64 is dominated by Sandy Loam texture indicating this is a Riverine alluvium soil and it is structure less.

The soil samples collected from piping area (K53, K54, K59, K60, K61, K62, K63, K64) in horizon wise are mostly dominated by sand and less proportion of clay and silt indicating that the soils are mostly eroded. The very less amount of silt itself indicates the level of subsurface soil erosion which leads to piping. The remaining samples were collected from non-piping area in horizon wise shows a high dominance of clay.

Table 5.20 *Textural analysis of soil samples from Idukki*

SL.No.	Sample No	Sand%	Silt%	Clay%	Depth in meter (bgl)
1	I-17	50.68	15.69	33.61	20
2	I-18	44.97	23.37	31.65	50
3	I-19	59.68	15.13	25.17	75
4	I-20	54.97	19.97	25.04	35
5	I-21	53.79	16.26	29.93	50
6	I-22	44.57	21.49	33.71	75

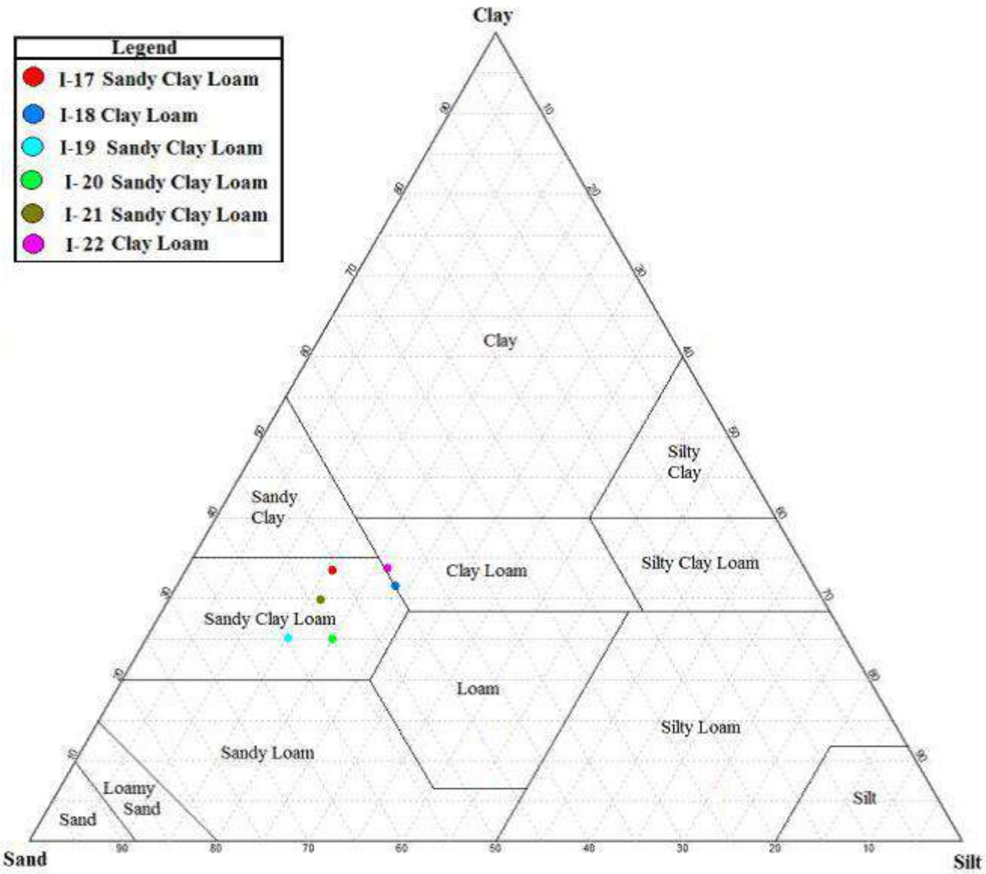


Figure 5.19 *Textural diagram of soil sample in the piping area*

From the figure 5.19 the sample I-17, I-19, I-20, I-21 falling under Sandy Clay Loam region, I-18 and I-22 fall under clay loam region. Samples of I-23 and I-24 are falling under Loam region and sample number I-25 falling under silty Loam region. From this we can interpret that in non-piping area texture of soil is dominated by sandy loam texture and in piping area the texture of soil is dominated by Loam and silty loam.

Table 5.21 Textural analysis of soil samples from Idukki

SL.NO	Sample	Sand (%)	Silt (%)	Clay (%)	Depth in meter (bgl)
1	K39	53.06	10.41	36.52	1.00
2	K40	26.82	46.82	26.36	1.50
3	K41	31.44	28.80	39.76	2.00
4	K42	23.75	21.38	54.86	3.00
5	K43	34.97	26.74	38.29	4.00
6	K44	52.25	21.06	26.72	5.00
7	K45	53.39	34.37	12.25	0.35
8	K46	56.78	17.98	25.23	0.50
9	1WAY	59.65	21.86	18.48	0
10	6-WAY	68.96	4.58	26.46	0
11	3KSD	52.59	13.73	33.68	0
12	5-KSD	36.07	22.69	41.24	0

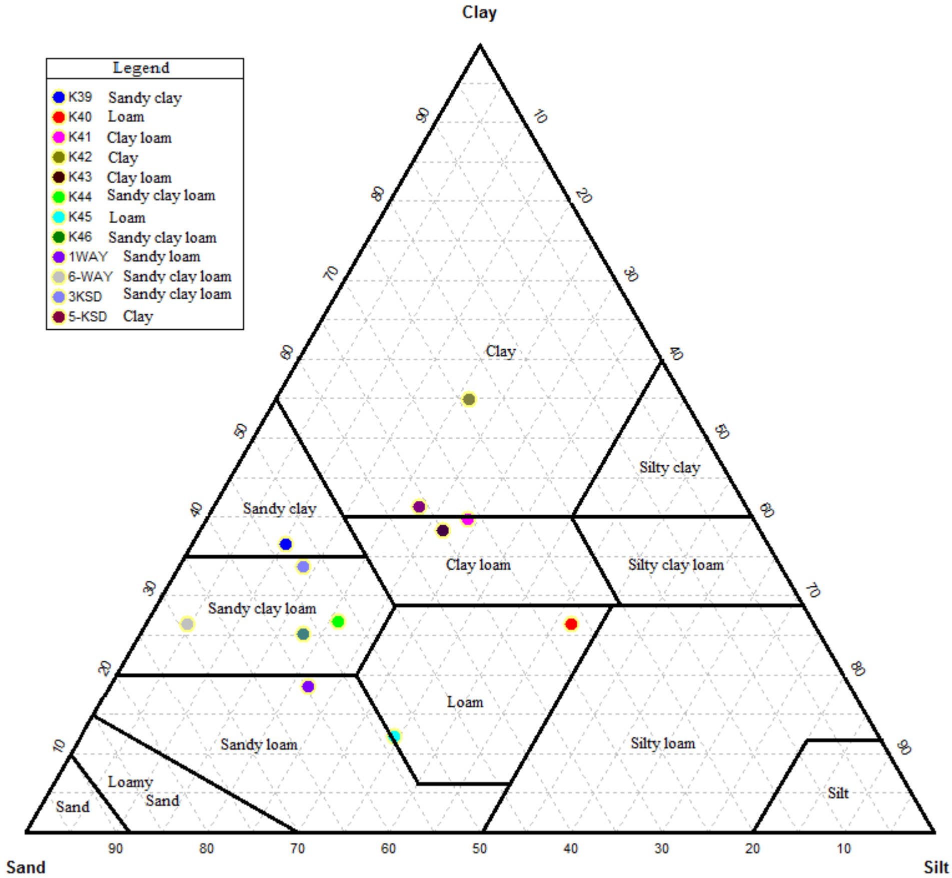


Figure 5.20 *Textural diagram of soil sample in the piping and non-piping area*

The textural analysis of the samples from the affected area shows (table 5.21) a high percentage of sand. The maximum percentage shown by 6-WAY-(68.96%) and minimum percentage is shown by K-42 (23.75%). The maximum percentage of silt (46.82) was shown by (K-40) and the minimum 4.58was shown by 6-WAY.Higher values of clay K42% was indicated by 54.86% and a lower value of clay (12.25%) was shown by K45. In Textural analysis reveals that, depletion of clay or high percentage of sand which indicate that, sampling area is highly affected by soil piping.

Conclusion

Soil piping phenomena occur in acidic soil. Soil texture describe the proportion of three sizes of soil particle- sand (large), silt (medium) and clay (small). Soil texture is the most important physical property of the soil. Texture analysis gives the difference in sand silt, clay percentage, of piping and non-piping area. The results show that, sand percentage of the piping area is dominant and clay percentage is dominant in non- piping area. Decrement of Organic matter contributes to enhance the soil piping activity. According to the XRF study, presence of some major elements (Na, K) does not shows the significant effect. According to the XRD results, Gibbsite and Kaolinite is more dominant followed by Quartz. Gibbsite indicates prominent leaching material which confirms the erosional actvity in that region. The result of Exchangeable Sodium percentage, calcium and Magnesium ratio shows that the soil affected by dispersion.

5.3 Hydrogeochemical analysis

5.3.1 Water Sampling

20 Water samples for the chemical lab analysis were taken from areas of piping and non-piping areas of Kannur and Kasaragod Districts.10 samples were taken from non-piping areas of Kasaragod District (figure 5.24) among which 2 samples are from Surangam and 8 samples are from well water. Another 10 samples were taken from piping area of Kannur District (figure 5.25). The chemical parameters were analyzed based on the result (table 5.22) and graphical representations are given below pH, Total Dissolved Solids, Electrical Conductivity, Total Hardness, Magnesium, Calcium, Sodium, Potassium.

__Figure 5.21__ Water sample collecting from piping and non-piping areas

Table 5.22*Water sample details of piping and non-piping areas*

Sl No.	Sample No	Distric	Location	Co-Ordinates		Sample taken from	(Piping/ Nonpiping)
				Latitude	Longitude		
1	S1	Kasaragod	Uliyathadukka	12º36'15.49	75º00'04.57"	Well	Non piping
2	S2	Kasaragod	Kudulu	12º31'33.62	75º59'07.32"	Well	Non piping
3	S3	Kasaragod	Fort road	12º29'48.69	75º59'21.14"	Well	Non piping
4	S4	Kasaragod	Mannipady	12º32'2.0	75º59'58"	Well	Non piping
5	S5	Kasaragod	Mannipady	12º32'21.9	74º59'49.3"	Well	Non piping
6	S6	Kasaragod	Mulleria	12º33'18.25	75º11'9.17"	Well	Non piping
7	S7	Kasaragod	Mythri nagar	12º33'18.25	75º11'9.17"	Well	Non piping
8	S8	Kasaragod	Arootmoole	12º33'18.25	75º11'9.17"	Well	Non piping
9	S9	Kasaragod	Mythri nagar	12º33'47.84	75º10'6.23"	Well	Non piping
10	S10	Kasaragod	Arthipallam	12º34'10.47	75º04'1.31"	Well	Non piping
11	S11	Kannur	Kottathalachimala	12º16.461	75º25.340'	Inside the piping	Piping
12	S12	Kannur	Kottathalachimala	12º16.503'	75º25.310'	Inside the piping	Piping
13	S13	Kannur	Kottathalachimala	12º16.509'	75º25.327'	Inside the piping	Piping
14	S14	Kannur	Kottathalachimala	12º16.508'	75º25.354'	Inside the piping	Piping
15	S15	Kannur	Kottathalachimala	12° 16.361'	75º25.755'	Inside the piping	Piping
16	S16	Kannur	Kottathalachimala	12º16.406'	75º25.773'	Inside the piping	Piping
17	S17	Kannur	Kottathalachimala	12^{0}16'23.2"	75^{0}26'02.2"	Inside the piping	Piping
18	S18	Kannur	Chattivayal	12º15.660'	75º26.090'	Outlet of Piping	Piping
19	S19	Kannur	Nelliyeukkam	12º15.589'	75º26.120'	Inside the piping	Piping
20	S20	Kannur	Nelliyeukkam	12º15.662'	75º26.077'	Inside the piping	Piping

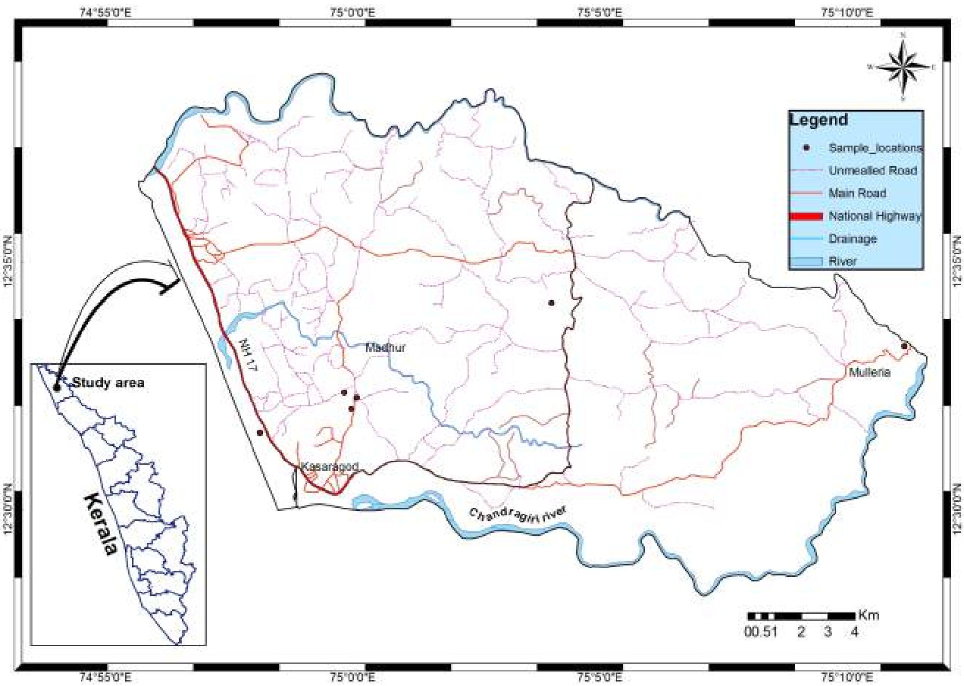


Figure: 5.22: *Water Sample locations of Non-piping area in the Kasaragod District*

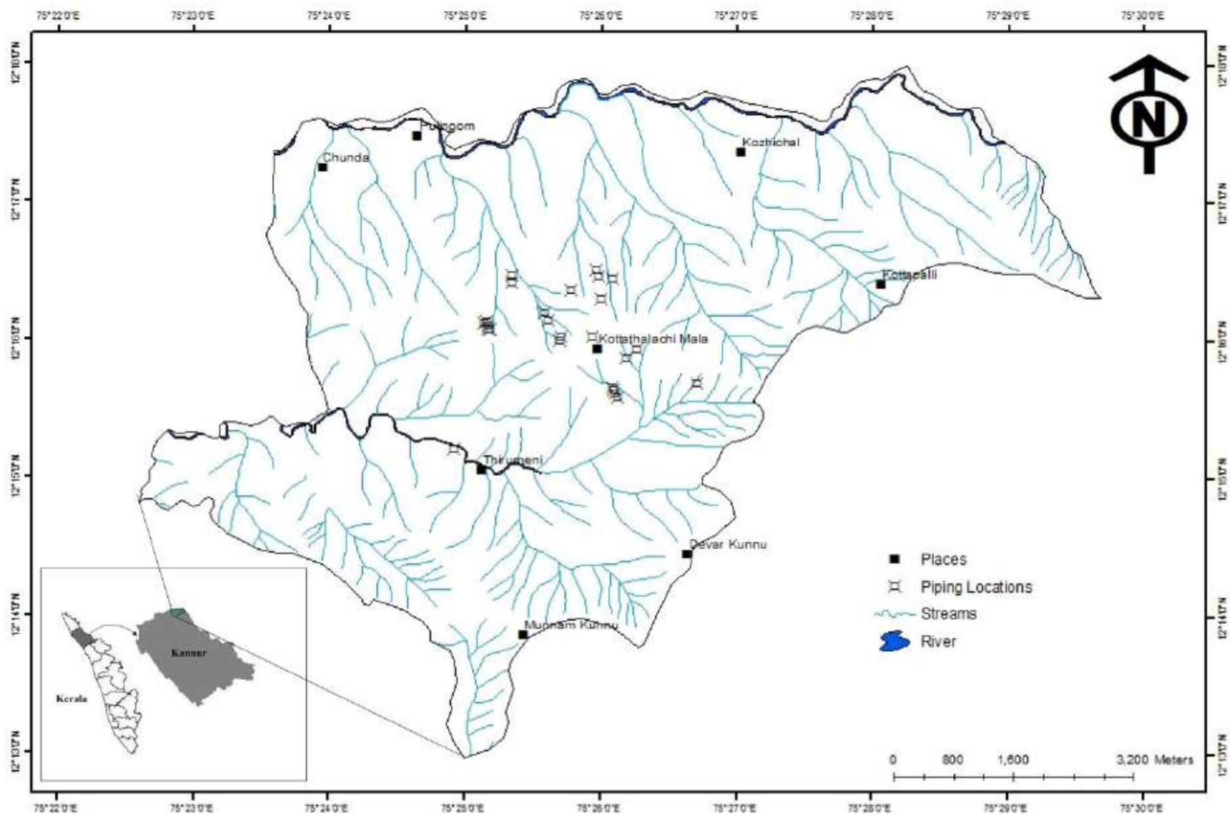


Figure: 5.23: *Sample locations of piping area in the Kannur District*

5.3.2 pH

Samples 1 to 10 represents water samples from Non-piping area, Samples (S6, S8 and S10) from 'Surangam' is basic in character while other water samples are slightly acidic in nature. Samples 11 to 12 represents water samples from piping area. These water samples show acidic nature.

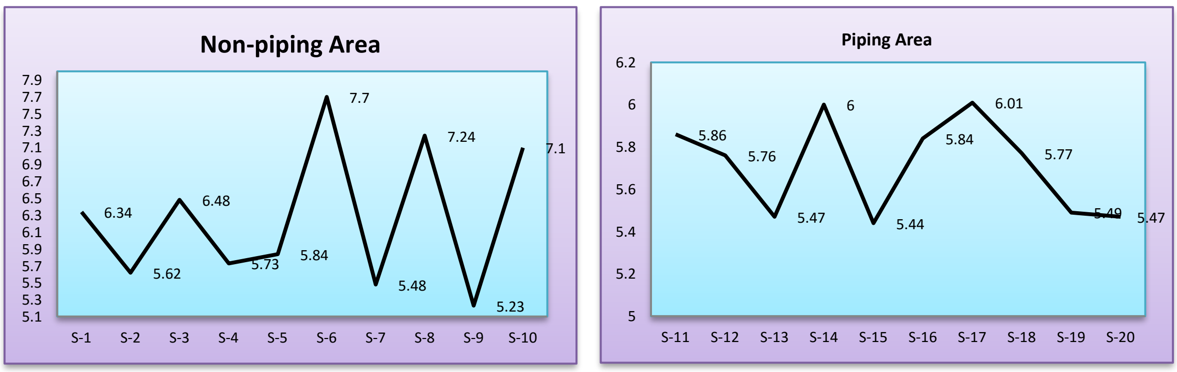


Figure: 5.24: *Graphical representations of pH values water samples.*

5.3.3 Electrical Conductivity

Conductivity is one way to measure of the inorganic materials including calcium, bicarbonate, nitrogen, phosphorus, iron, sulphur and other ions dissolved in a water body. Electrical Conductivity of water sample from the Piping area does not show much difference. Compare to samples of Non-piping area is slightly higher values (198.2, 130.6) of EC than from piping area.

Variation in conductivity can result through changes in geology of an area. It can also be due to seepage of groundwater, Industrial and agricultural effluent, storm water runoff and sewage effluent flowing into the stream.

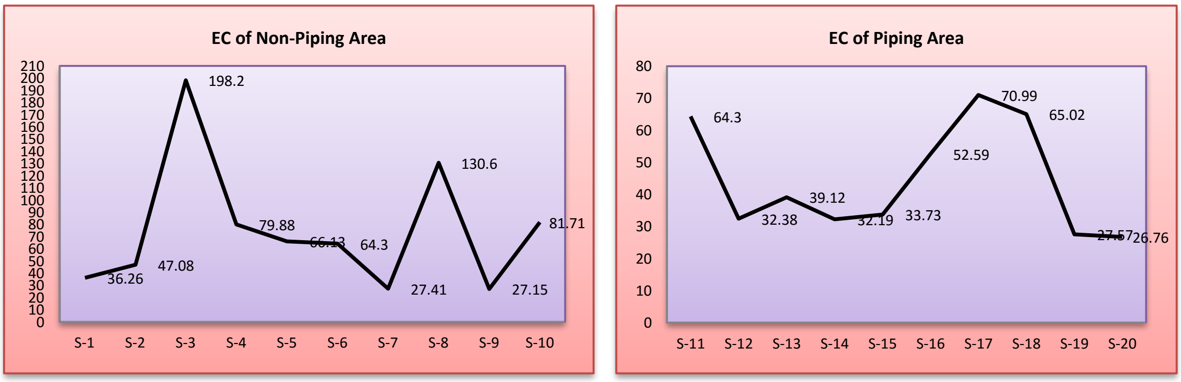


Figure 5.25: *Graphical representations of EC value from Non-piping and Piping area.*

5.3.4 Total Dissolved Solids (TDS)

The most common source of dissolved solids in water is from the weathering of sedimentary rocks and the erosion of the earth's surface. Since many minerals are water soluble, high concentrations can accumulate over time through the constantly reoccurring process of precipitation and evaporation. Groundwater usually has higher levels of TDS than surface water, since it has a longer contact time with the underlying rocks and sediments. Water Sample from the Piping and non-piping area the amount of Total Dissolved Solids in Non-piping areas are varying as compared piping area, some samples shows higher values198.2 to lower values 27.15. The amount of Total dissolved solids of water samples from piping area show a constant trend (figure5.26). The minerals (salts, such as sodium and calcium bonded to chloride and carbonate) and small amounts of soluble minerals are deposited by the weathering of sedimentary rocks and erosion of the earth's surface.

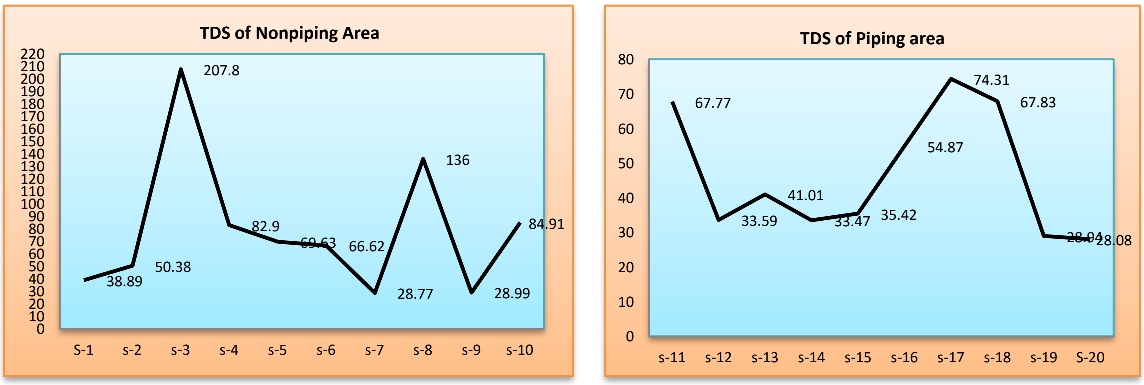


Figure 5.26: *Graphical representations of TDS values water samples.*

5.3.5 Total Hardness

Water becomes hard by being in contact with soluble, divalent, metallic cations. The two main cations that cause water hardness are calcium (Ca^{2+}) and magnesium (Mg^{2+}). Calcium is dissolved in water as it passes over and through limestone deposits. Magnesium is dissolved as water passes over and through dolomite and other magnesium bearing formations. Because groundwater is in contact with these geologic formations for a longer period of time than surface water, groundwater is usually harder than surface water. The hardness of water from piping area (1.2 to 3.8) shows lower values than of water from Non-piping area (0.4 to 9.2).

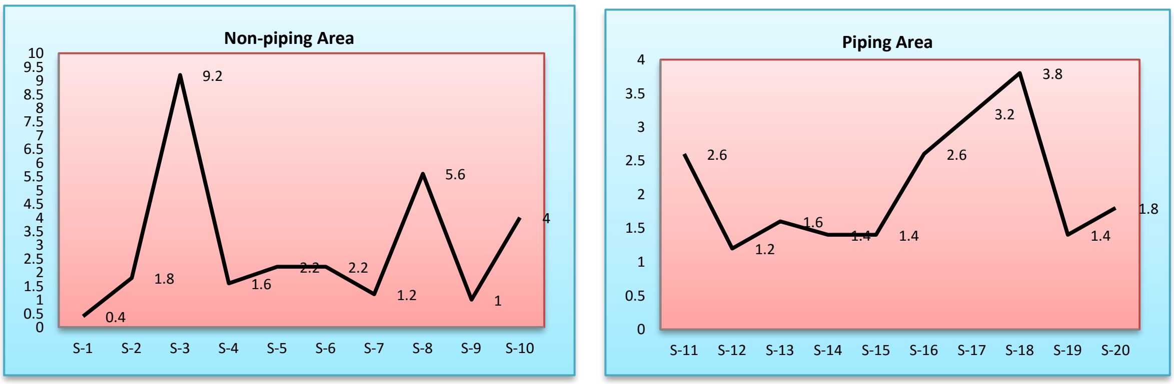


Figure: 5.27*Graphical representations of total hardness water samples.*

5.3.6 Calcium and Magnesium Hardness

Hardness caused by calcium is called calcium hardness, regardless of the salts associated with it. Likewise, hardness caused by magnesium is called magnesium hardness. Since calcium and magnesium are normally the only significant minerals that cause hardness, it is generally assumed that:

Total Hardness = Calcium Hardness + Magnesium Hardness

(mg/L as $CaCO_3$) (mg/L as $CaCO_3$) (mg/L as $CaCO_3$)

= 2.50 X Calcium conc. (mg/L as Ca^{2+}) + 4.12 X Magnesium conc. (mg/L as Mg^{2+})

Salts that contribute to salinity, such as calcium and magnesium, do not have this effect because they are smaller and tend to cluster closer to clay particles. Calcium and magnesium will generally keep soil flocculated because they compete for the same spaces as sodium to bind to clay particles. Increased amounts of calcium and magnesium can reduce the amount of sodium-induced dispersion.

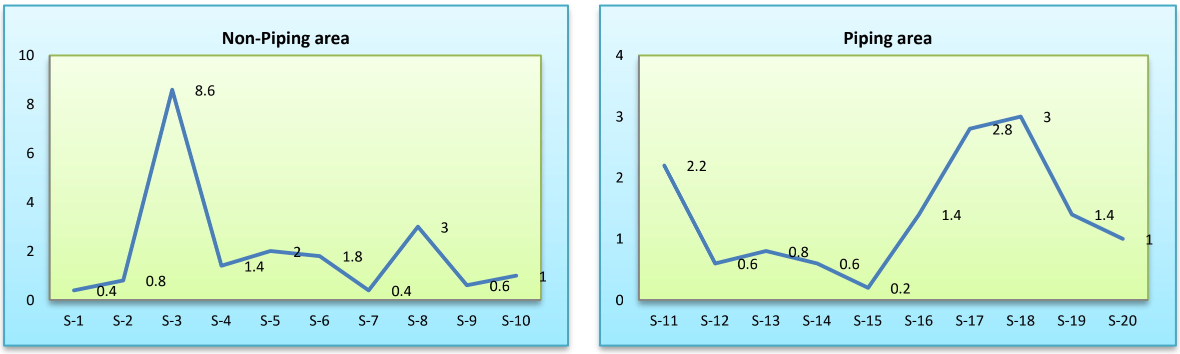


Figure: 5.28 *Graphical representation of Ca hardness of water samples.*

Calcium Hardness of Non-piping area and Piping area generally does not shows larger variations except sample S_3 (8.6). The water collected from inside of the pipe showing much variation.

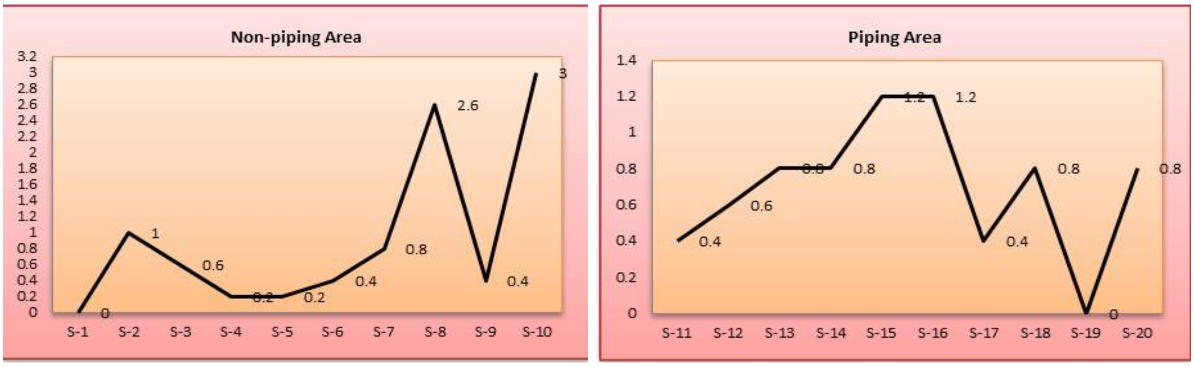


Figure: 5.29 *Graphical representation of Mg hardness of water samples.*

5.3.7 Sodium

The primary physical processes associated with high sodium concentrations are soil dispersion and clay platelet and aggregate swelling. The forces that bind clay particles together are disrupted when too many large sodium ions come between them. When this separation occurs, the clay particles expand, causing swelling and soil dispersion. Soil dispersion causes clay particles to plug soil pores, resulting in reduced soil permeability. The three main problems caused by sodium-induced dispersion are reduced infiltration, reduced hydraulic conductivity, and surface crusting**.** The major implications associated with decreased infiltration due to sodium-induced dispersion include reduced plant available water and increased runoff and soil erosion.

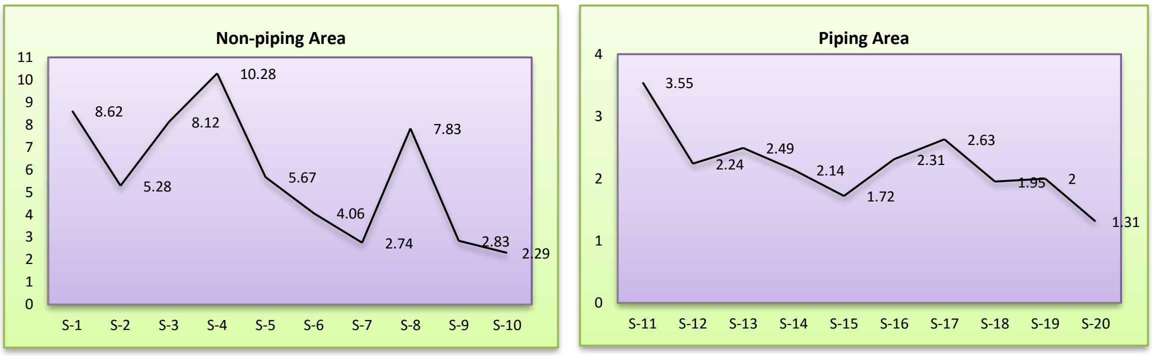


Figure: 5.30 *Graphical representation of Na. percentage of water samples.*

5.3.8 Potassium

Since clay and organic matter particles hold potassium ions in an exchangeable or available form, potassium does not leach from silty or clayey soils. Some leaching may take place in very sandy soils because sandy soils do not contain enough clay to hold the potassium. Organic matter particles hold most positively charged nutrients tightly. Potassium is an exception because the attraction between potassium ions and organic matter particles is relatively weak. Consequently, some potassium leaches from organic soils (peats and mucks). Loss of potassium by leaching is one reason sandy and organic soils often test relatively low in available potassium, especially when tested in the spring. These soils require precise annual potassium applications, since it is not possible to build up high potassium reserves.

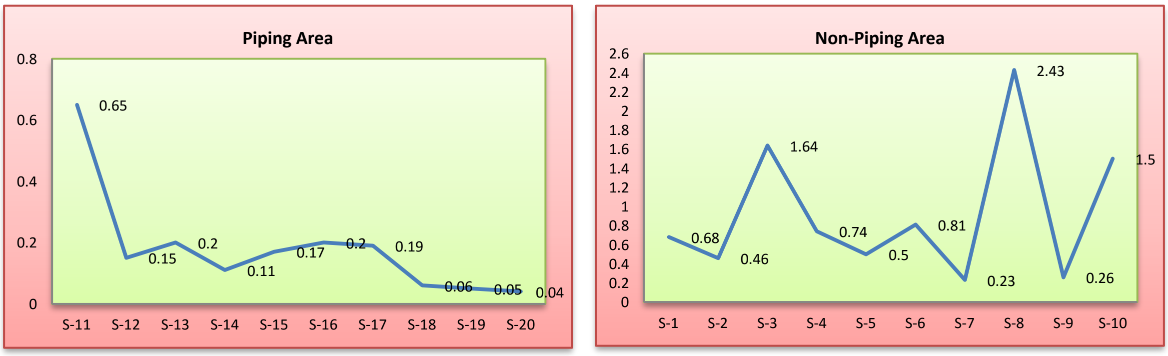


Figure 5.31 *Graphical representation of Potassium percentage of water samples.*

CHAPTER 6

GEOTECHNICAL INVESTIGATIONS

6.1 Introduction

The geotechnical investigations were carried out with the assistance of the Civil engineering department of the NIT Kurukshetra. Geotechnical investigation had been done on the soil piping affected regions and non- affected localities to find out the various geotechnical properties of soil. Physical, chemical, topographical and hydrological factors responsible for soil piping are attempted in many countries. But in India very little work had done to find out how the geotechnical properties of the soil affect this phenomenon. Undisturbed soil samples were collected from different regions and geotechnical properties evaluated in the geotechnical lab of NIT Calicut and Kurukshretra.

6.2 Sample Collection

6.2.1 Types of samples

Soil samples collected to determine the engineering properties were in two different forms as disturbed samples and undisturbed samples.

1. Disturbed samples: These are the samples in which the natural structure of the soil gets disturbed. These types of samples represent the composition and the mineral content of the soil. Index properties like grain size, plasticity characteristics, specific gravity can be determined using disturbed samples.
2. Undisturbed samples: These are the samples in which the natural structure of the soil and the water content are retained. It is really impossible to get truly undisturbed samples. Some disturbance is inevitable.

Undisturbed samples are used for determining the engineering properties of the soil, such as compressibility, shear strength, and permeability. Some index properties like shrinkage limit can also be determined. In the current study the samples collected were undisturbed.

6.2.2 Types of samplers

Various types of samplers are usually available to collect the samples from the field.

a. **Split-spoon samplers**: The most commonly used sampler for obtaining a disturbed sample of the soil is the standard split-spoon sampler. The inside diameter of the split tube is 38 mm and outside diameter is 50 mm. This sampler is used mainly in conducting standard penetration test. If the soil encountered in the bore hole is fine sand and it lies below the water table, the sample recovery become difficult. For such soils, a spring-core catcher device is used to aid recovery. The split tube may be provided with a thin metal or plastic tube liner collected, the liner and the sample it contains are removed from the tube and the ends are scaled.

b. **Scraper bucket samplers**: If a sandy deposit contains pebbles, it is not possible to obtain samples by standard split-spoon sampler or split-spoon sampler fitted with a spring core catcher. The pebbles come in-between the springs and prevent their closure. For such deposits, a scraper bucket sampler can be used. A scraper bucket sampler can also be used for obtaining the samples of cohesion less soils below the water table.

c. **Shelby tubes and thin-walled samplers**: These are used for obtaining undisturbed samples of clay. The samplers pushed into the soil by a continuous rapid motion without impact or twisting. The tube should be pushed to the length provided for the sample. At least after 5 minutes after pushing the tube into its final position, the tube is turned 2 revolutions to shear the sample off at the bottom side before it is withdrawn. The tube is taken out and its ends are sealed before transportation.

d. **Piston samplers**: A piston sampler consists of a thin-walled tube with a piston inside. The piston keeps the lower end of the sampling tube closed when sampler is lowered to the bottom of the hole. After the sampler has been lowered to the desired depth, the piston is prevented from moving downward by a suitable arrangement, which differs types of piston samplers. The thin tube sampler is pushed past the piston to obtain the sample. The piston remains in close contact with the top of the sample. The presence of the piston prevents rapid squeezing of the soft soils into the tube and reduces the disturbance of the sample. Piston samplers are used for getting undisturbed soil samples from soft and sensitive clays.

e. **Denison sampler**:

The Denison sampler is a double-walled sampler. The outer barrel rotates and cuts into the soil. The sample is obtained in the inner barrel. The inner barrel is provided with a liner. It may also be provided with a basket-type core retainer. The sampler is lowered to the bottom of the drilled hole. A downward force is applied on the top of the sampler. A fluid under pressure is introduced through the inner barrel to cool the coring bit when the outer barrel rotates. The rotation of the outer barrel is continued till the required length of the sample is obtained. Denison sampler is mainly used for obtaining samples to stiff to hard cohesive soils and slightly cohesive sands. However it cannot be used for gravelly soils, loose cohesion less sands and silts below ground water table and very soft cohesive soils.

f. **Hand carved samplers**:

Hand carved samples can be obtained if the soil is exposed, as in a test pit, shaft or tunnel. Hands carved samples are also known as chunk samples. The soil should have at least a trace of cohesion so that it can stand unsupported for some time. To obtain a sample, a column of soil is isolated in the pit. The soil is carefully removed from around the soil column and it is properly trimmed. An open-ended box is then placed over the soil column. The space between the box and the soil column is filled with paraffin. A spade or a plate with sharp edges is inserted below the box and the sample is cut at its base. The box filled with the soil sample is removed. It is turned over and the soil surface in the box is trimmed and any depression is filled with paraffin. These are undisturbed samples.

The sampler used in this study was thin walled samplers having size 10.5 cm diameter and 22 cm long. They were pushed into the soil to the complete length by light hammering and the outside soil was removed properly. The soils obtained in the samplers were covered tightly to avoid loss of moisture content. Undisturbed samples were collected from the various depths of piping and non-piping regions.

Figure6.1: *Sample collection- various stages*

Table 6.1: *Locations of sample collection*

Piping region- Kasaragod	Elevation	Non-piping region- Kasaragod	Elevation (m)	Non-piping region- Calicut	Elevation (m)
Sample 1	30 m	Sample 6	63.6	Sample 11	100.94
Sample 2	28.7 m	Sample 7	61.4	Sample 12	100.73
Sample 3	27.7 m	Sample 8	61	Sample 13	102
Sample 4	26.5 m	Sample 9	60	Sample 14	98.6
Sample 5	26 m	Sample 10	57.4		

6.3 Analysis of Various Geotechnical Properties

Undisturbed samples were carried to the geotechnical lab of NIT Calicut to conduct various tests. Sieve analysis, Atterberg's limits, specific gravity, permeability and direct shear tests were carried out on the samples. The sample extruded from the samples using sample extruder.

Figure 6.2: *.Sample extrusion*

Various tests conducted on the samples were specific gravity test(G), grain size analysis, Atterberg's limits(i.e. liquid limit, plastic limit and shrinkage limit), bulk density, moisture content, permeability, and shear strength characteristics(i.e. cohesion and angle of internal friction).All the tests were conducted in accordance with IS standards.

6.3.1 *Atterberg's limits*

The water content at which soil changes from one state to other is known as consistency limits or Atterberg's limits. The water content alone is not an adequate index property of a soil. At the same water content, one soil may be relatively soft, whereas another soil may be hard. However, the soils with same consistency limits behave somewhat in a similar manner. Thus consistency limits are very important index properties of fine grained soils. A soil containing high water content is in a liquid state. It offers no shearing resistance and can flow like liquids. It has no resistance to shear deformation and, therefore the shear strength is equal to zero. As the water content is reduced, the soil becomes stiffer and starts developing resistance to deformation. At some particular water content, the soil becomes plastic. The soil in the plastic state can be moulded into various shapes. As the water content is reduced, the plasticity of the soil decreases. Ultimately the soil passes from the plastic state to semi-solid state when it stops behaving as plastic. It cracks when moulded.

a. **Liquid limit**:

The water content at which soil changes from liquid state to plastic state is known as liquid limit. In other words, the liquid limit is the water content at which soil ceases to be liquid. At liquid limit, the clay is practically like a liquid, but possesses a small shearing strength. The liquid limit depends on the clay mineral present.

The liquid limit is determined in the laboratory either by Casagrande's apparatus or by cone penetration test. Testing done as per IS: 2720. About 100 gm of an air dried sample passing 425 micron is required for the test. The soil sample is mixed thoroughly mixed with distilled water in the evaporating dish to form a uniform paste. A portion of the paste is placed in the cup of the liquid limit device. Level the mix so as to have maximum depth of 1 cm. Draw the grooving tool through the sample along the symmetrical axis of the cup, holding the tool perpendicular to the cup. Now rotate the handle at a rate of 2 revolutions per second and the number of blows is counted till the two parts of the soil sample come into contact at the bottom of the groove. Take 10gm of the soil near the closed groove and determine the water content of the soil by oven drying method. By altering the water content of the soil sample repeat the procedure. The liquid limit is determined by plotting the graph the semi-logarithmic scale between the number of blows as abscissa on logarithmic scale and the corresponding water content as ordinate on simple linear scale. The liquid limit is arbitrarily taken as the water content when the soil has shear strength just sufficient to withstand the shearing stress induced in 25 blows.

b. **Plastic limit:**

Plastic limit is the water content below which the soil stops behaving as a plastic material. It begins to crumble when rolled into a thread of soil of 3 mm diameter. At this water content, the soil loses its plasticity and passes to a semi-solid state.

For determination of plastic limit of a soil, it is air-dried and sieved through a 425 micron IS Sieve. About 30g soil is taken in an evaporating dish. It is mixed thoroughly with distilled water till it becomes plastic and can be easily moulded with fingers. About 10g soil is taken in one hand and ball is formed. The ball is rolled with fingers on a glass plate to from a soil thread of uniform diameter. If the diameter of thread becomes smaller than 3 mm, without crack formation, it shows that the water content is more than the plastic limit. The soil is kneaded further. This results in the reduction of water content, as some water is evaporated due to the heat of the hand. The soil is re-rolled and the procedure repeated till the thread crumbles. The water content at which the soil can be rolled into a thread of approximately 3 mm in diameter without crumbling is known as plastic limit.

c. Plasticity index:

The plasticity index may be calculated as the difference between liquid limit and plastic limit. It is the range of water content over which the soil remains in the plastic state.

d. **Shrinkage limit:**

Shrinkage limit is the water content at which the soil is saturated. It is also defined as the maximum water content at which a reduction of water will not cause a decrease in the volume of the soil mass.

For the determination of shrinkage limit in the laboratory, about 50 g of soil passing a 425 micron sieve is taken and mixed with distilled water to make creamy paste. The paste is then placed in the shrinkage dish without any air voids. The required mixing water content is little greater than the liquid limit. Coat a thin layer of Vaseline or grease inside of the shrinkage dish and then weigh. Fill the dish in three layers by placing soil paste about one third the capacity of the dish. The firm surface should be properly cushioned by a rubber sheet. Weigh the dish full of wet soil immediately and allow it to dry in air until the colour of soil pat turns light. Then dry in an oven at 105˚ to 110˚ C. Cool the dish with dry pat in desiccators and weigh. Remove the dry pat from dish, clean and dry the shrinkage dish and determine the empty mass. Weigh the empty mercury weighing dish also. Keep the shrinkage dish in the large porcelain or stainless steel dish, fill it to overflowing with mercury and remove the excess by pressing the plain glass plate firmly over the top of the dish, taking care not to entrap air. Transfer the contents of the shrinkage dish to the mercury weighing dish and weigh. Place the glass cup in a large dish, fill to over flowing with mercury and remove the excess by pressing the glass plate. Wipe off any mercury adhering on the side and then place the cup full of mercury to another large dish. Place dry soil part on the surface of mercury and submerge it under mercury by pressing with the glass plate with prongs. Transfer the mercury displaced by the dry part to the mercury weighing dish and weigh.

The Atterberg’s limits do not directly helps to identify the soils of highly erodible nature but the higher the values of liquid limit, plastic limit, and plasticity index, the higher is the resistance to disperse in water. High plasticity index tends to be clayey and thus have low infiltration rates. Hence, more water requirement gives the material a certain degree of stability in certain situations (Rienks et al 2000). The increasing trend of liquid limit and plasticity index shows an increase of clay content and high ion exchange capacity, or a combination there of. Watts *et al*. (1996) found the critical amount of water needed for dispersion to be close to the plasticity limit. The shrink/swell potential of clayey soils can be identified by the shrinkage characteristics (Cerato and Lutenegger, 2000).

6.3.2 Particle size analysis

The knowledge of grain size analysis of a soil is very useful in the present geotechnical world. The results of this analysis are widely used for the soil classification, design of filters, construction of earth dams, highway embankments and determining the mode of bearing capacity computations and for construction of building, hydraulic structures and road construction etc.

Grain size analysis of a soil generally carried out by two methods.

1. Dry sieving
2. Wet sieving

Dry sieving: It consists of shaking the soil by a mechanical device through sieves of known aperture size. Dry sieve analysis is suitable for cohesion less soils, with little or no fines.

Wet sieve analysis: If the soil contains a substantial quantity of fine particles, a wet sieve analysis is required. All lumps are broken into individual particles. A representative soil sample in the required quantity is taken, using a riffler, and dried in oven. The dried sample is taken is taken in a tray and soaked with water. If deflocculation is required, sodium hexa-meta-phosphate, at the rate of 2g per litre of water is added. The sample is stirred and left for a soaking period of at least one hour. The slurry is then sieved through a 4.75 mm IS sieve, and washed with a jet of water. The material retained on the sieve is the gravel fraction. It is dried in an oven, and sieved through set of coarse sieves.

The material passing through 4.75 mm sieve is sieved through a 75 micron sieve. The material is washed until the wash water becomes clear. The material retained on the 75 micron sieve is collected and dried in an oven. It is then sieved through the set of fine sieves of the size 2mm, 1 mm, 600 micron, 425 micron, 300 micron, 150 micron, and 75 micron. The material retained on pan is equal to the total mass of soil minus the sum of masses of material retained on all sieves.

6.3.3 Hydrometer analysis:

This method is used for the grain size analysis of the soil passing through 75 micron sieve. Sieve out of fraction passing 4.75 mm IS sieve, to determine the percentage of various sized (silt and clay) particles and to plot the grain size distribution curve. This method is not applicable if less than 10 percent of the material passes 75 micron IS sieve. It is done according to IS : 2720, part 4-1985.

6.3.4 Bulk density

Bulk density is an indicator of soil compaction and its health. The bulk density of a soil affects the infiltration, root depth, soil porosity, available water capacity and soil microorganism activity, which influence the key soil process and productivity. It is dependent on soil organic matter, soil texture, the density of soil mineral (sand, silt, and clay) and their packing arrangement. Bulk density usually increases with the soil depth since the subsurface layers are more in more compacted form and have less organic matter. If for a soil bulk density is low it indicates the low porosity and low compaction.

The most popular methods using for the determination of bulk density of the samples are core cutter method and sand replacement method.

6.3.5 Core cutter method:

It is a field method for determination of mass density. A core cutter consists of an open, cylindrical barrel, with a hardened, sharp cutting edge. The method is quite suitable for soft, fine grained soils. It cannot be used for stoney, gravelly soils. The method is practicable only at the places where the surface of soil is exposed and the cutter can be easily driven.

6.3.6 Specific gravity test

Specific gravity of a soil is the ratio of the weight of a given volume of soil particles in air to the weight of an equal volume of water at a temperature of 4 ˚C. The specific gravity of a soil is often used in relating a weight of soil to its volume. Although specific gravity is employed in the identification of minerals, it is of limit value for identification or classification of soils because the specific gravity values of most soils fall within a narrow range. It is an important factor required for computing the most of the soil properties e.g. void ratio of soil, unit weight, particle size determination by hydrometer method, degree of saturation of a soil etc.

6.3.7 Density bottle method:

Clean bottle with distilled water, dry it in an oven and cool in desiccators and then weigh it with its stopper. Keep about 10-15 g of the oven dried cool soil in the bottle and weigh. The soil may be pulverized to pass 2 mm IS sieve before use, if required. Cover the soil with air free distilled water from the plastic or glass wash bottle and leave for a period of 2-2.5 hours for soaking. Add more water to fill the bottle to about its half. Keep the bottle without stopper in the vacuum desiccators and slowly apply partial vacuum for about 1-1.5 hours until there is no further loss of air. Gently stir the soil in the density bottle by a clean glass rod, wash off carefully the adhering particles from the rod with some drops of distilled water and see that no soil particles are lost. Close the vacuum desiccators and again apply the vacuum. Repeat the process till no more air bubbles are observed in the soil water mixture. Now take out the density bottle from the vacuum desiccators and fill it completely with air free distilled water.

6.3.8 Direct shear test

The shear strength of a soil mass is its property against sliding along internal planes within itself. The stability of slope in an earth dam or hills and the foundations of structures built on different types of soils depend upon the shearing resistance offered by the soil along the possible slippage surface. Shear parameters are also used in computing the safe bearing capacity of the foundation soils and the earth pressure behind retaining walls. In a direct shear test the sample is sheared along a horizontal plane. This indicates that the failure plane is horizontal. The normal stress on this plane is the external vertical load divided by the area of the soil sample. The shear stress at failure is the external lateral load divided by the corrected area of soil sample.

The main advantage of direct shear apparatus is its simplicity and smoothness of operation and the rapidity with which testing programmes can be carried out. The direct shear test is generally conducted on cohesion less soils as CD test. It is convenient to perform and it gives good results for strength parameters. It is occasionally used to determine the strength parameters of silt and clay under unconsolidated-un drained and consolidated drained conditions.

6.3.9 Permeability test

Permeability is defined as the property of a porous material which permits the passage or seepage of water through its interconnecting voids. Permeability is involved in the problems of flow of water through soils, such as seepage under dams, the squeezing out of water from a soil by the application of a load and drainage of sub-grades and backfills, computation of losses from canals etc. The two different methods to determine permeability of soils are Constant head permeability test and Variable head permeability test

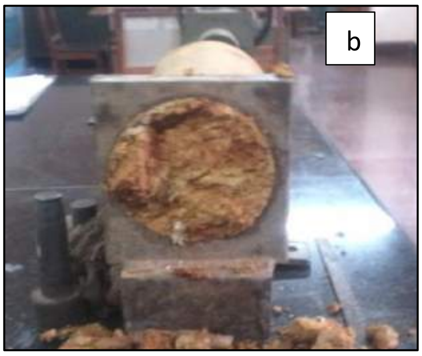
1. **Constant head permeability test:**

The co-efficient of permeability of a relatively more permeable soil can be determined in a laboratory by constant head permeability meter. The test is conducted in an instrument known as constant-head permeameter.

2. **Variable head permeability test:**

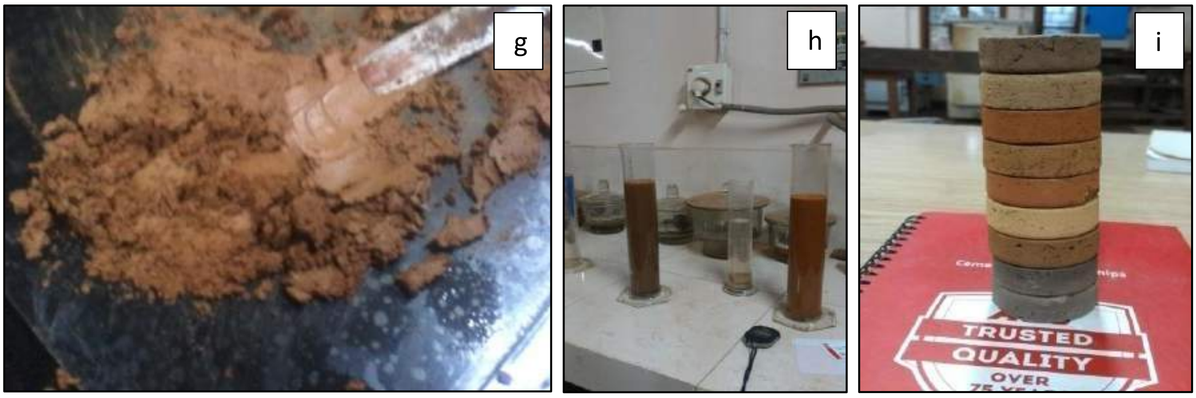
For relatively less permeable soils, the quantity of water collected in the graduated jar of the constant-head permeability test is very small and cannot be measured accurately. For such soils, the variable head permeability test is used. After the soil specimen in the mould is completely saturated, disconnect the water storage from the outlet at the bottom and connect the selected standpipe to the inlet at the top of plate. Fill the standpipe with water. Open the stop cock at the top and allow water to flow out so that all the air in the cylinder is removed. After about 5 minutes, close the stop cock and allow the water to flow through the soil specimen and establish a steady flow. Note the height h1 at time t1 and of the water level in the stand pipe from the centre of the outlet and at the same instant start a stop watch. Allow sufficient time so that the water level lowers by about 15 to 20 cm. Stop the watch and note the height h2 at time t2 of the water level in the reservoir at that instant. Repeat the observations from the same height and for same height difference till three successive observations give about same time interval. Alternatively fill the reservoir again with water and repeat the above observations by noting the heights h1 and h2.

Piping erosion will increase the permeability, but the soils susceptible to piping are of low permeable, increased gradients and pore pressure build up. For clean sands and gravel mixtures, the hydraulic conductivity varies from 10^{-1} to 10^{-3} cm/s, whereas for very fine sands to homogeneous clays the permeability value varies from 10^{-4} to 10^{-9} cm/s (Lambe 1951).



a. Sample Extrusion *b. Side View of Sample* *c. Direction module Conversion*

d.Taking reading from aperture *e. Soil sample after directure testing* *f. Plastic limit test*



g. Sample for liquid limit test *h. Hydrometer analysis test* *i. Soil pats for shrinkage limit test*

Figure 6.3: *Lab testing - various stages*

6.4 Discussion

Samples were collected from three different regions, the piping and non-piping regions of Kasaragod and from non-piping area of Calicut. Comparisons were done between the soil properties at 3 various regions of piping and non-piping region of Kasaragod district and non-piping region of Calicut district. The soils of all these regions were basically laterite in nature.

Results of various engineering properties of undisturbed samples, collected from the various depths of the piping region and the non-piping region of Nelliyadukkam locality has been summarized in the following tables. A detailed geotechnical investigation was done on this soil samples. Various geotechnical properties tested in the piping and non-piping region of Kasaragod district is shown Table 6.2.

Table6. 2: *Summary of laboratory results of soil at piping and non-piping region (Kasaragod Nelliyadukkam locality)*

	Piping region(Kasaragod)					Non piping region(Kasaragod)				
	S 1	S 2	S 3	S 4	S 5	S 6	S 7	S 8	S 9	S 10
γ(g/cc)	2.116	1.77	1.817	1.57	1.57	1.36	1.56	1.543	1.544	1.47
w (%)	19.89	17.54	18.74	37.93	43.15	45.6	39.006	29.725	36.605	32.75
γ_d	1.77	1.506	1.53	1.14	1.097	0.934	1.122	1.189	1.13	1.107
LL (%)	45	45	42	46	46.5	47.5	45	40	50	51
PL (%)	33.77	31.14	21.84	28.37	22.7	35	37.2	24.17	29.38	30.66
PI (%)	11.23	13.86	20.16	17.63	23.8	12.5	7.8	15.83	20.62	20.34
SL (%)	16.61	21.31	16.98	26.7	16.34	25.11	25.48	18.89	24.19	25.49
Sp. gr.	2.6	2.7	2.495	2.525	2.311	2.75	2.582	2.28	2.13	2.268
c(kpa)	100	60	45	15	50	50	65	10	5	20
ϕ	18.53	26.57	21.06	24.71	34.99	21.8	22.62	35.37	23	28.93
Class	GP-GM	GW-GM	GW	GW-GM	GW-GC	GW-GM	GW-GC	GW-GM	GW-GM	GW-GM

Cu	1.8	18.33	8.7	200	11	71.4	85.7	114.29	736.84	388.23
Cc	0.83	2.64	2.37	2.79	2.33	2.31	3.1	2.161	8.2	6.2
G (%)	91.19	84.4	86.33	60.03	78.54	75.9	65	46.29	35.57	51.46
S (%)	3.18	9.64	12.05	25.11	14.96	14.63	23.85	40.19	22.92	19.2
M (%)	5.32	3.94	0.91	9.94	1.77	5.64	5.42	10.55	31.49	23.92
C (%)	0.32	2.02	0.71	4.92	4.73	3.83	5.73	2.97	10.02	5.42
K(cm/s)	1.2x10^{-3}	2x10^{-3}	1x10^{-3}	3.7x10^{-4}	3.5x10^{-5}	3x10^{-3}	2x10^{-3}	2x10^{-3}	7x10^{-4}	2x10^{-3}
e	0.47	0.79	0.63	1.21	1.11	1.94	1.32	0.92	0.88	1.05
S (%)	98	59.94	74.21	79.15	89.84	64.64	76.31	73.67	88.6	70.74

Table6.3*: Description of notations*

Notations	*Description*
γ	Bulk unit weight of soil
w	Water content
γ_d	Dry unit weight of soil
LL	Liquid limit
PL	Plastic limit
PI	Plasticity index
SL	Shrinkage limit
c	Cohesion
ϕ	Angle of internal friction
Cu	Co-efficient of uniformity
Cc	Co-efficient of curvature
G	Gravel
S	Sand
M	Silt
C	Clay
K	Permeability
e	Void ratio
S	Degree of saturation
GP	Poorly graded gravel
GM	Silty gravel
GC	Clayey gravel
GW	Well graded gravel

In the piping region, the soil strata were hard and compacted at the top surface and become loose at the bottom. Compactness of strata at the top surface is shown by the bulk density results. Bulk density evaluated at top surface of the piping region was 2.116 g/cc and was 1.57 at the wall of piping region. The water content increases with depth at the piping region which indicates the easy draining of top surface and accumulation of water at the bottom strata. The permeability results verify the above statement i.e. the permeability of the top surface is high and which decreases with depth. The permeability value at the top surface was found to be 1.2×10^{-3} cm/s and at bottom it was found to be 3.5×10^{-5} cm/s. Sieve analysis has conducted on various samples to separate the fractions, and the results reflect the presence of Saprolite at the wall of piping erosion. The gravel percentage was more than 50 % at every depth, but the percentage value decreased with depth. This indicates that the soil became less coarse with depth. Presence of the high amount of sand and silt at the wall of piping gives a conclusion that the clay content may be dispersed into the water and lost. Loss of clay content increased the void ratio of the soil. The classification of the soil samples was done as per IS classification system according to the particle fractions and consistency limits. The soil classifications of various soils are included in Table 6. 2. Soils of dark colours or low clay accumulation content are found to be having low tunnel erosion potential, here the surface soil at the piping region is blackish red and as going to the bottom the color changes to yellowish red.

From the geotechnical test results, it is obtained that water easily infiltrates into the A horizon during rainfall and get accumulated in the B horizon. Thus, a perched water table is assumed to be formed in the boundary. The lateral subsurface flow which is formed at the contact zone is the reason for the formation of soil pipes. Plasticity index value found at the wall of piping was 23.8% and which is comparatively a high value. High plasticity index values at the wall of piping region reflect the positive correlation of sodium adsorption ratio and plasticity index as the sodium content was found to be high at this region.

In the non-piping region of Kasaragod district, the strata were almost uniform in density. Percentage of fines was found to be high in the non-piping region of Kasaragod and gravel percentage was comparatively low than the piping area. As the percentage of clay is higher the liquid limit and plastic limit values were high for the samples collected. Plasticity values increase with the decrease of particles size (increase in total surface area). The chances of sub surface erosion are low in the non-piping region because the permeability is uniform in each layer and no chances for the accumulation of water at lower layers. As there was not a high difference in permeability at various depths of the non-piping region the water content obtained at different depths were almost same. Thus in non-piping region the water can easily drains into the underground.

Particle size distributions of samples collected from the various regions of Kasaragod were shown in figure6.4 and the plasticity charts were shown in figure 6.5.

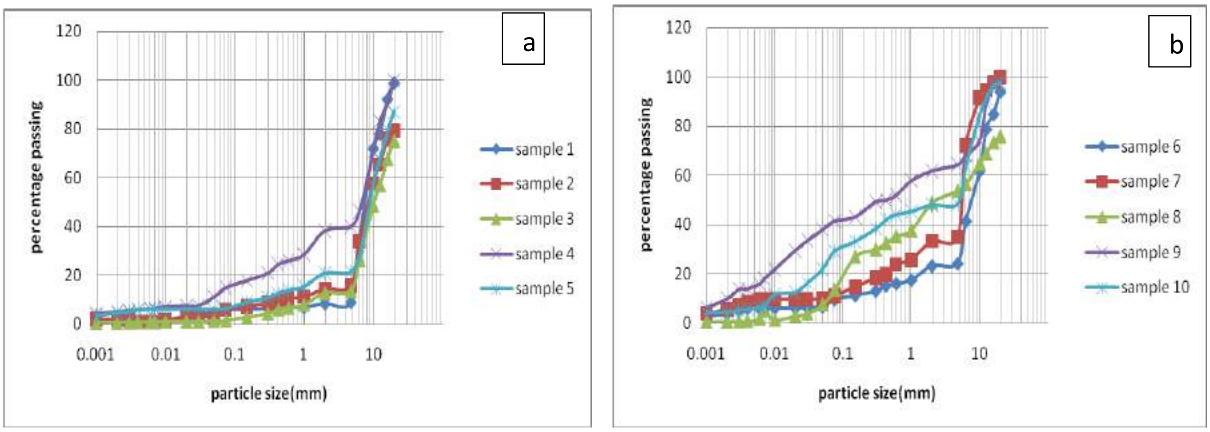


Figure 6.4: *Particle size distribution graph (a) piping region (Kasaragod) (b) non-piping region (Kasaragod)*

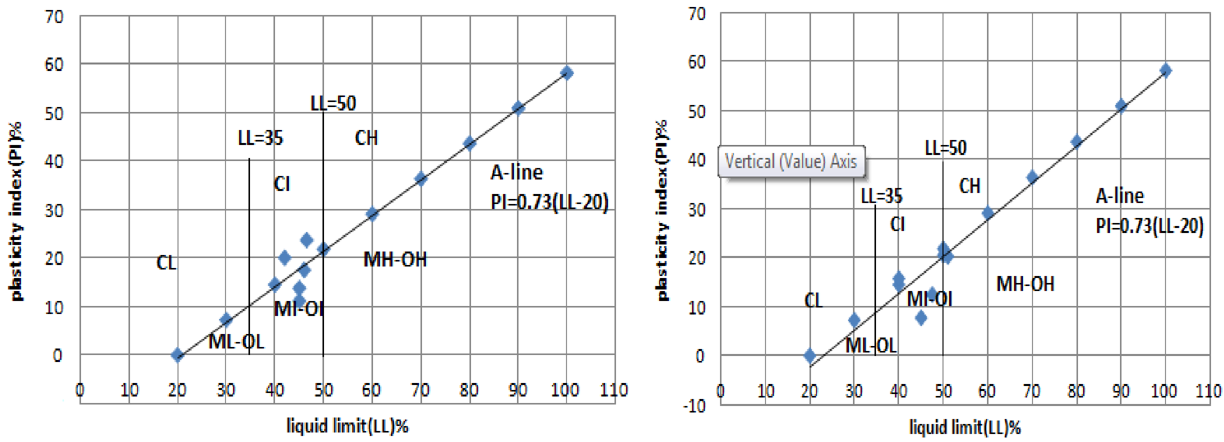


Figure 6.5*: Plasticity chart (a)piping region(Kasargod) (b) non-piping region(Kasargod)*

The co-efficient of uniformity and co-efficient of curvature values obtained for different soil samples are included in table 6.2. The values help in the classification of soil. The samples collected were well graded in nature with a slight variation in the dominance of clay and silt content at bottom. In the piping region, the clay is assumed to be lost due to dispersion. As the soil is well sorted it is understood that the particle size distribution is not the factor which makes the soil unstable.

From the comparison of geotechnical properties of the soils at the piping and non-piping region of Nelliyadukkam locality of Kasaragod district, the parameters found to have an effect in piping erosion was obtained as the difference in the permeability of strata at various depth of the same region, increase of fine content at bottom and comparatively higher plasticity index at bottom. Rest of the properties were insufficient to decide whether the soil is of piping susceptible (dispersible) or not.

Table 6.4: *Summary of laboratory results of soil non-piping region(Kozhikode IIM Site)*

	Non-piping region(Kozhikode)			
	S 11	S 12	S 13	S 14
γ(g/cc)	1.5	1.86	1.79	1.4
w(%)	40	27.10	38.1	50.8
γ_d	1.07	1.40	1.30	0.928
LL(%)	59	42	46	60
PL(%)	37.99	25	32.4	38
PI(%)	21.01	17	13.6	22
SL(%)	35.08	34	36.55	45.5
Specific gravity	2.68	2.54	2.65	2.70
C(kpa)	40	15	40	35
ϕ	25	39.23	26.56	35.53
class	GW-GC	GW-GM	GW-GM	GW-GM
Cu	37.78	220	30.77	252.5
Cc	1.817	5.05	2.02	2.475
G(%)	63.51	63.96	76.36	66.56
S(%)	28.99	19.54	16.18	16.02
M(%)	0.959	12.11	6.18	13.32
C(%)	6.648	4.39	1.28	4.1
K(cm/s)	1.2×10^{-3}	3.0×10^{-5}	2×10^{-5}	4.4×10^{-3}
e	1.50	0.81	1.04	1.91
S(%)	71.47	84.98	97.08	71.81

Kozhikode district, a non-piping region was choose to compare the properties with the piping region of Kasaragod and which was far away from the piping susceptible soil belt of northern Kerala. Piping phenomena was not reported in the current study area. The test result shows that the properties of soils do not show notable changes with piping region. The test results of the non-piping regions of Kozhikode were shown in Table 6.4.

6.5 Conclusion

The areas subjected to piping erosion were found to be mainly laterite regions. Field investigation and laboratory results show that the visual classification, Atterberg's limits and particle size analysis do not provide sufficient basis to differentiate between dispersive clays and ordinary erosion resistant clays. The soils at both piping and non-piping region were found to be well graded soils, which show that the particle size distribution is not the factor which makes the soil unstable. Presence of high dispersible sodium content makes the soil erodible and for such soils the plasticity index found to be high. Here the plasticity index of the piping region was high and which proves this positive correlation of plasticity index and presence of sodium content. At the piping region as the permeability of the top strata was high and decreased with bottom, it results in the accumulation of water at the bottom layers and leads to lateral subsurface flows. The current study area was of sloping nature and which was situated almost middle side slope of the high lands. The high rainfall at the region was found to be high by the weather forecasting results. And this water is found to be playing the main role in the piping erosion phenomena. The properties of soil were almost same in all regions but the soil at piping region becomes dispersible with the presence of water. The mitigation works suggested in the area should include proper dewatering techniques.

CHAPTER 7
MITIGATION MEASURES

7.1 Repair and rehabilitation of tunnel-affected land

The importance of integrating mechanical, vegetative, and chemical treatments for the repair of field tunnel erosion has been recognized (Boucher 1994), although Boucher (1995) acknowledges that reclamation measures are inadequate to control tunnel erosion due to the likelihood of reoccurrence. Techniques for the control and repair of field tunnel erosion have traditionally focused on re-establishing perennial vegetation following mechanical disturbance of the tunnel systems. Contour furrows (drains), deep ripping, chisel ploughing, and contour ripping have been employed to destroy existing tunnels and divert water away from tunnel-prone areas (Colcough 1965, 1971; Floyd 1974; Boucher 1995). However, use of these techniques often failed, resulted in further tunnel erosion, or, at best, only provided short-term benefits (Floyd 1974; Crouch 1976; Boucher 1995). Mechanical, chemical and re-vegetation techniques are available and it may be appropriate to use a combination of these to suit the particular situation. Here all the techniques available are discussed and three typical mitigation measures suggested for Nelliyadukkam (Kasaragod) and Banasurasagar (Wayanad) are suggested.

7.2 Mechanical techniques

a. Control Animal burrows

Rabbits and other burrowing animals create localized access for runoff to enter the subsoil and start tunnel erosion.. In the highlands and foothills many such burrowing animals burrow the farmland for food and shelter. Existing burrows need to be ripped, and the disturbed soil ameliorated with gypsum and re-vegetated. Storm water should not be allowed to charge these burrows.

b. Compaction

Carefully controlled compaction at or near the optimum moisture content has been widely used to prevent ‘piping’. Ritchie (1965) demonstrated that the degree of compaction is the single most important factor responsible for the ‘piping’ failure of dams constructed from dispersive clays.

A higher degree of compaction reduces soil permeability, restricting the movement of water and dispersed clay through the soil matrix, which decreases the severity of dispersion and restricts tunnel development (Vacher et al. 2004). However dispersive soils can be difficult to compact as they lose strength rapidly at or above optimum moisture content, and thus may require greater compaction force than other soils (McDonald et al.1981).Bell and Bryun (1997) and Bell and

Maud (1994) suggest that dispersive clays must be compacted at a moisture content 1.5-2% above the optimum moisture content in order to achieve sufficient density to prevent piping (Elges 1985). Normal earth moving machinery including bull-dozers, excavators and graders do not provide sufficient compaction force to reduce void spaces or achieve adequate compaction in dispersive soils. A sheep foot roller of appropriate weight is usually required to compact dispersive soils. However in Kerala highlands where the affected land is vast and rugged this method may not be feasible. Compaction could be adopted in specific site specific cases such as construction of road or earth dam etc.

7.2.1 Engineering interventions:

a. Dewatering techniques

Reducing the amount of water that flows onto and into the affected/eroded area is the only practical way to prevent or retard tunnel development. Diversion techniques could include graded banks with appropriate soil amelioration of the bank and channel.

b. Deep rip around the site

The soil surface around tunnel erosion areas is often hard-set which prevents infiltration. As a result, surface water can only enter the soil at points of weakness such as cracks and holes. Deep ripping or chisel ploughing around and above the erosion area will promote more even infiltration into the topsoil.

Piping under foundations of buildings

There are many cases reported in the Western Ghats of Kerala where piping was observed under foundations of buildings and which cause subsidence problems for such buildings. In Kerala in places such as Nelliyadukkam (Kasaragod), Iritty (Kannur), Kottathalachimala (Kannur), Vavalmala (Kannur), Banasurasagar (Wayanad), Tattekanni and Peringassery (Idukki) and Pampa Valley, Ranny , Pathanamthitta (figure 7.1) are classic examples.

Figure7.1: *Subsidence occurred in Ranny, Pathanamthitta*

Proper dewatering techniques are necessary for preventing further piping problems in such areas. But the renovation of subsided building is also equally important. For the diversion of both surface and subsurface water filter drains can be used with geotextile layer. In well like subsidence occurs in combination with underground drains; Used tyre could be used to trap sediments. To prevent effect of surface and ground water in damaged foundations, French drains are found to be suitable option. Hydraulic barriers can also be provided in such areas for protecting the foundation. Damaged foundation in the problematic site can be renovated using polyurethane resin.

c. Diverting water at source

The diversion of water could be done either in the top soil to nearby streams or within the tunnel floor. The tunnel floor is usually hard and impermeable, so deep ripping the floor will break-up existing flow lines. Rip and excavate tunnels in all directions to at least 15 cm below the tunnel base. Finish by ripping along the contour. Diverting water at source may the most effective and cost effective method to control soil piping or tunnel erosion.

d. Hydraulic barrier

This technique for diverting surface and subsurface water away from footings has been proposed as an alternative, or an addition to pier or post foundations. The hydrological barrier technique involves construction of sand and gypsum filled trench to the depth of the foundations around the upslope area of the dwelling. The sand – gypsum mixture acts to trap the dispersed silts pugging up the developing tunnel while allowing the water to come into contact with the gypsum and rise through the sand and away from the footings. An earth mound immediately above the sand filled trench acts to prevent surface runoff entering the trench. The hydrological barrier can be installed either during construction or fitted to existing dwellings after construction. The hydrological barrier technique has only been experimented in Tasmania. The design principles result from successful use of sand blocks for the prevention of tunnel erosion resulting from the installation of optical fibre cables in dispersive soils (Richley 1995 & 2000, Hardie *et al.*, 2007). This type of barrier may not be effective in places where the hydraulic head is very high as in the case of Kerala. In Kerala proper RCC structure (Figure 6.2) or any proper civil engineering structure should be made to divert water.

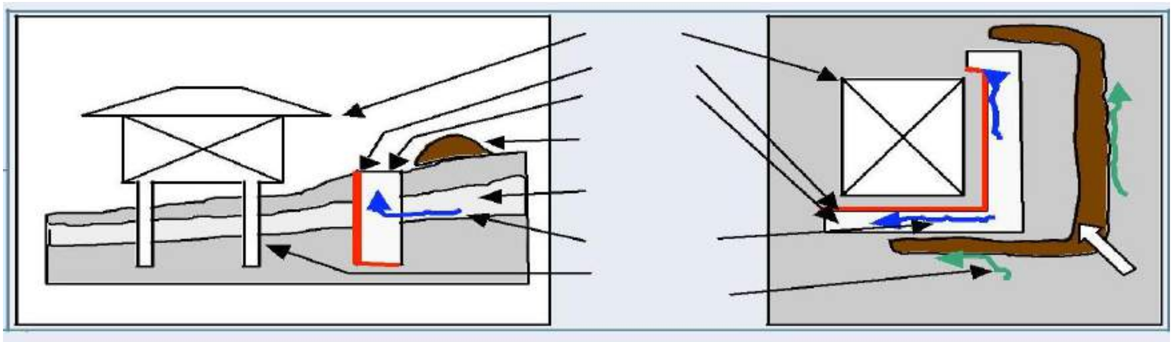


__Figure 7.2:__ Hydraulic barrier for the protection of building foundations (Panjami 2016)

e. French drain

A French drain (Figure 7.3) is a trench filled with gravel or rock or containing a perforated pipe that redirects surface water and groundwater away from an area. A French drain can have perforated hollow pipes along the bottom to quickly vent water that seeps down through the upper gravel or rock. French drains are primarily used to prevent ground and surface water from penetrating or damaging building foundations. Alternatively, French drains may be used to distribute water, such as a septic drain field at the outlet of a typical septic tank sewage treatment system. French drains are also used behind retaining walls to relieve ground water pressure.

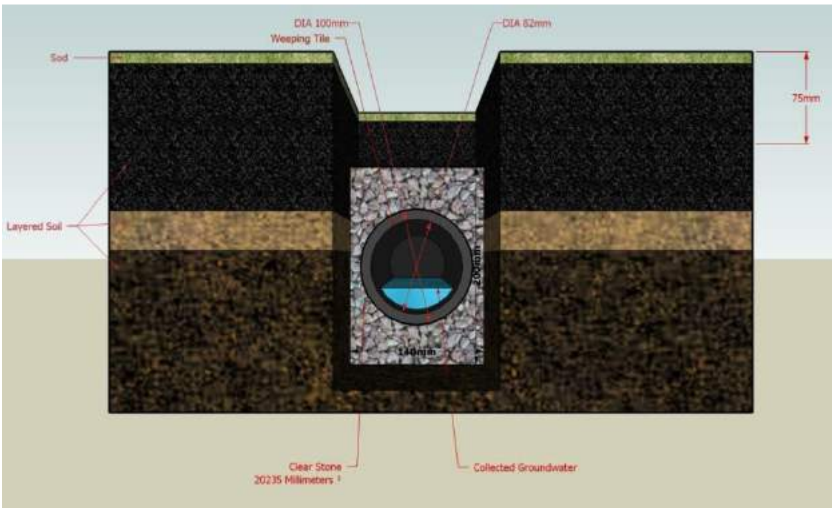


__Figure7.3:__ Typical sketch of a French drain (Panjami 2016)

f. Underpinning using Polyurethane resins

Many methods are available for the rectification of foundation by the subsidence problems, such as underpinning, slab jacking and chemical grouting. Underpinning of the foundation is found to be the best suitable renovation method for the damaged foundation in the study area. It is the process of strengthening the foundation of an existing building, accomplished by extending the foundation in depth or in breadth so that it can rest in more strong strata. Use of micro piles and jet grouting are the two common methods of underpinning.

Underpinning by expanding resin injection has the advantages over the other methods on the piping erosion case. In this method a mix of structural resins and hardeners is injected into the tunnel, formed by piping erosion under the foundation of the house. On entering the ground the chemical reaction of the resin and hardener mix will takes place and expansion will occur. The mix fills the hollow space and compacts any weak soil and thus the structure placed above get raised from the subsidence and re-levelled. The underpinning using expanding resins is a new method developed recently. The technique can provide an effective and efficient solution for many of the differential settlement problems like erosion of the soil, settlement due to adjacent work, and consolidation or collapsible soil. Usually expanding polyurethane resins are preferred for the individual houses and buildings. The pressure exerted during the chemical reaction and expansion helps to raise the structure. Resin filled in the cracks prevents the further water flow and decrease the permeability of the soil. The applicability of the polyurethane resins depends on the strength of soil required for the specific application. Different polyurethane resins can yield different density, permeability and shear strength. Expanding polyurethane resins are formed from the exothermic reaction between a polyol and an isocyanate, mixed in specific volumetric proportions according to their product specification. During the reaction a large amount of carbon dioxide is produced and which causes volume expansion with production of foam.

There are mainly two types of polyurethanes based on their reaction to water, hydrophilic polyurethanes and hydrophobic polyurethanes. As name indicates hydrophilic polyurethanes reacts in presence of water. They absorb water while curing and cure to a flexible foam and these types are typically single component products. While hydrophobic polyurethanes does not require water for the reaction. The expansion rate of hydrophobic polyurethanes is higher than hydrophilic and it is about 20 times the original volume

Piping under Road

Surface and subsurface water from the sides of roads can be collected by providing filter drains with geosynthetic cover. The pipe generated below the subgrade by the subsurface erosion of dispersive soils can be rehabilitated by using polyurethane expansive resins.

a. Filter drains

Filter drains (Figure 7.4) are provided along the sides of roads which collect water from the surface and surface and then diverted properly without causing any piping failures in such areas. The perforated pipe provided at the bottom collect water. Geosynthetic layers provide around the filter drain. The material for the perforated pipe can be concrete, galvanized pipe, plastic etc.

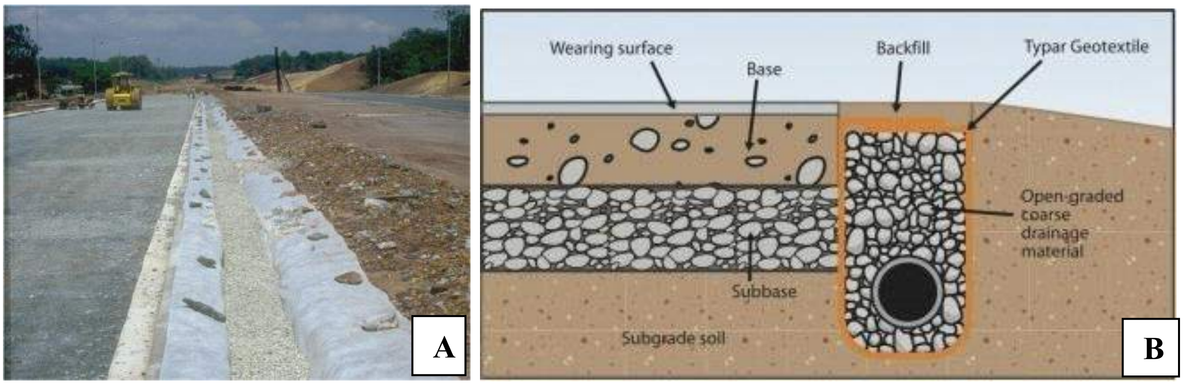


***Figure*7.4:** *Filter drain along A- road B- Cross section (Panjami 2016)*

b. Application of polyurethane grout

The uses of polyurethane resins (Figure 7.5) are found to be a good solution for settlement issues on both concrete and asphalt roadways. In these applications the polyurethane grout is to raise sunken concrete roadway, improve geo-material performance, increase load bearing capacity, stabilize soil conditions and prevent piping and soil erosion.

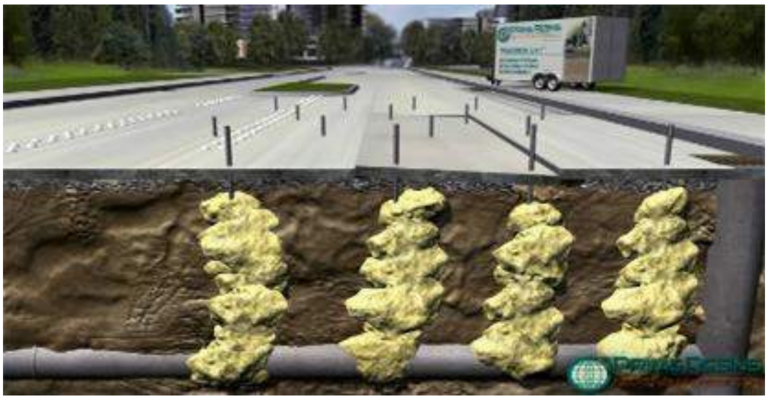
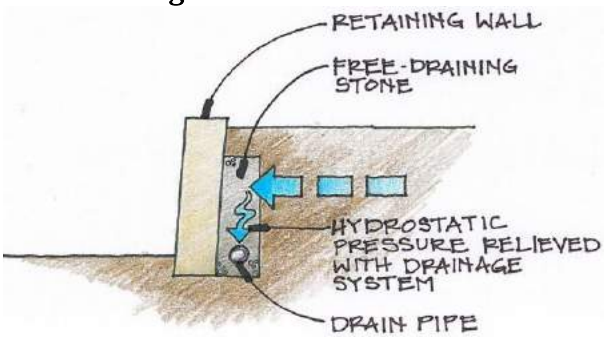


Figure7.5: *Typical road section treated with Polyurethane grout (Panjami2016)*

Railway track

Unstable slopes along the sides of rail road cause serious stability problems. Collapse of the slopes can be occurred by piping. Retaining walls with vertical drains (Figure 7.6) behind it are suitable methods in such case.

a. **Retaining wall**



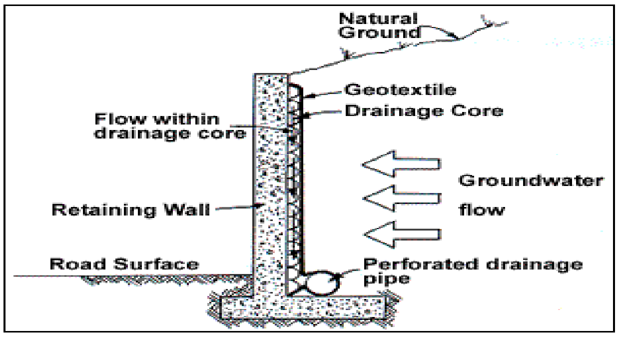


Figure7.6 *Typical sectiond of retaining walls suitable for stabilisation of lateritic railway cutting prone to soil piping (Panjami 2016)*

b. **Gabbion wall**

Gabbion walls (Figure 7.7) are one of the suitable methods for the slope protection besides the railway tracks. The pipes formed along the wall can be covered with gabion wall and providing vegetation over this so that the further problems on stability can be minimized. Micro pipes or juvenile pipe are the initial stages of piping. The diameter of pipe is ranges from <5cm. Clayey and lateritic soils are favourable for the formation of juvenile pipes. Juvenile pipes are commonly found in the besides of railway track. These kinds of pipes are preferred to be mitigated by providing gabion walls.

Figure7.7 *Gabions along railway tracks (Panjami 2016)*

The gabions are long-lasting, simple-to-install, and have been certified by numerous authorities worldwide, including Brasil, France, Italy, South Africa and the UK. The structures are flexible and can accommodate differential settlement easily without being damaged; ideal for seismic areas or soft ground.

7.3 Chemical Treatments

Identification and avoidance of dispersive soils

The risk of tunnel erosion resulting from construction activities on dispersive soils can be reduced or eliminated by identifying and avoiding areas containing dispersive soils. The presence and severity of dispersive soils can vary enormously over short distances. In many instances, large scale soil survey and screening of soils for dispersion, (using the Emersion crumb test) can be used to site dwellings and infrastructure away from dispersive soils. Advice should be sought from a suitably qualified and experienced engineer or soil professional. Prevention of tunnel erosion or ‘piping’ in earth dams built with dispersive clays has involved a combination of approaches including; chemical amelioration, controlled compaction, and sand filters.

7.3.1 Dispersion Test

Soil erosion occurs in dispersive soils (Vacher et.al. 2004) which typically contain greater than 6.0% exchangeable sodium (ESP). These soils are known as sodic soils or Sodosoils (Isbell 2002), or in the past may have been referred to as Solodic, Solonetz or Solodized –solonetz (Doyle and Habraken1993).Other soils such as Vertisols, Kurosols and Kandosols may also contain sodic or dispersive soil layers. When a sodic soil comes into contact with non-saline water; water molecules are drawn in-between the clay platelets causing the clay to swell to such an extent that individual clay platelets are separated from the aggregate, this process is known as dispersion while sodic soils are generally dispersive ,it is an important to acknowledge that not all sodic soils disperse ,and that not all dispersive soils are sodic(Summer1993).Factors such as silt and high magnesium content may induce non-sodic soils (ESP‹ 6%) to disperse ,while organic matter,clay mineralogy ,acidity ,and high content may prevent sodic soils (ESP› 6%) from dispersing (Raine and Loch 2003,Rengasamy 2002).

A simple test has been conducted to know about the dispersive property of the soil. The procedure as follows:

- Collect soil aggregates of 1-2 cm diameter
- If moist, dry the aggregates in the sun for a few hours until air dried.
- Place the aggregates in shallow glass jar or dish of distilled water.
- Leave the aggregates in water without shaking or disturbing them for 2 hours.
- Observe the result.

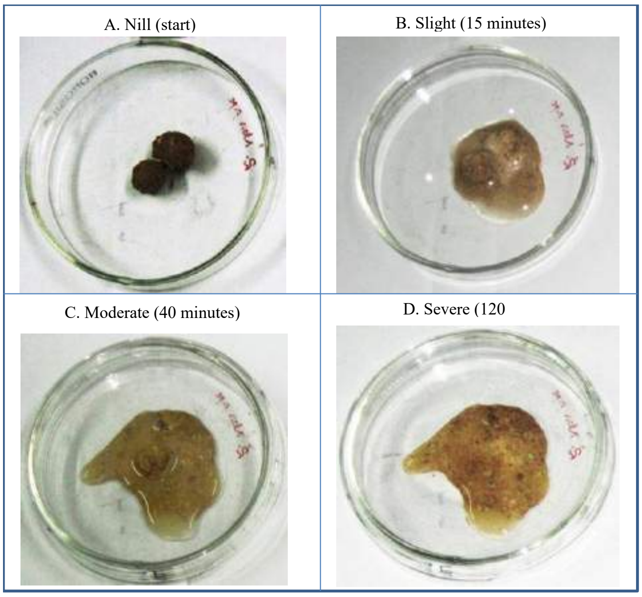


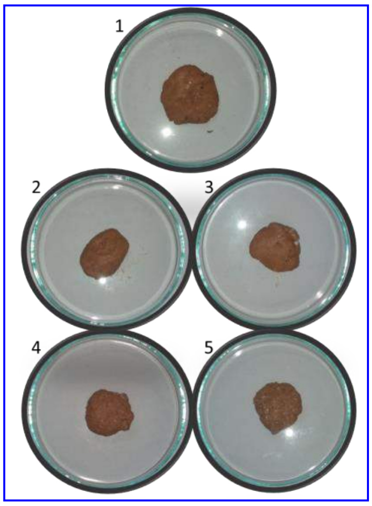
Figure 7.8 *Dispersion test (Sample from Kottathalachimala , Kannur)*

The test conducted with the soil samples from Kannur indicates that they are of dispersive in nature. This was further confirmed by the chemical test to determine the presence of exchangeable sodium. All the soil samples from the piping affected localities indicated the presence of exchangeable sodium more than 5%. So the best technique to control the soil piping is by chemical amelioration to neutralize the exchangeable Na+ with K+ or Mg+ by supplementing with gypsum or hydrated lime.

7.3.2 Mitigation trials by using Gypsum

Chemical amelioration by adding gypsum ($CaSO_4 2H_2O$) improves physical properties of sodic soils such as infiltration rate and hydraulic conductivity in addition to decreasing excess Na+ levels. Gypsum (calcium sulphate) is more effective than lime for the treatment of dispersive soils as it increases the electrolyte concentration in the soil solution as well as displacing sodium with calcium within the clay structure (Raine and Loch 2003). Hydrated lime (calcium hydroxide) has been widely used to prevent piping. Rates of application have varied depending on soils and degree of compaction used in construction.

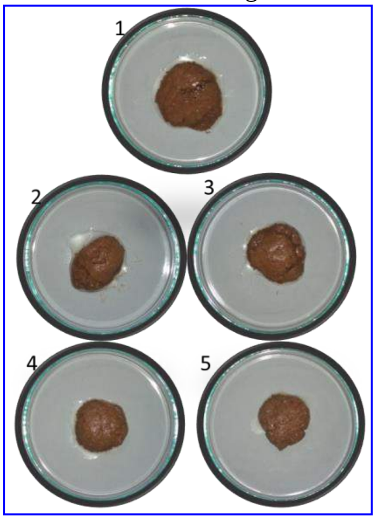
Even though chemical amelioration is a slow process, lab scale experiments were done for visually estimating the nature of dispersion with the addition of gypsum Laboratory testing usually indicates that only around 0.5 –1.0% hydrated lime is required to prevent dispersion. For the analysis, sample taken from the Kannur at piping affected area. The 10g of 5 soil sample taken in each watch glass mixed with at Gypsum of 0 to 2g respectively and 2ml water added to each sample. It is observe at a particular time interval (figure 6.9a-h), when the high percentage of dispersion taken place in the sample 1it contain no gypsum, and the low percentage of dispersion in the sample 5 contain 2g of gypsum, Dispersion rate is found to be varying depends on the amount of gypsum added. Dispersion seems to retard with the addition of gypsum (figure 6.9)



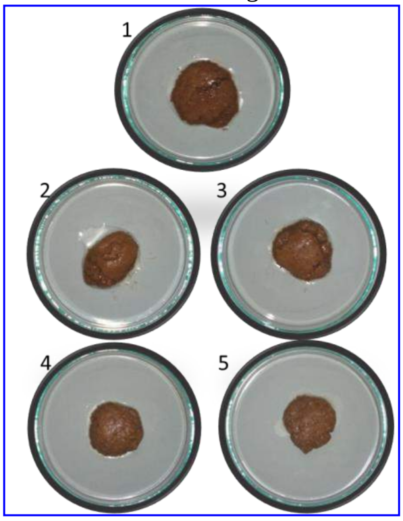
a. Before adding water

b. After adding water

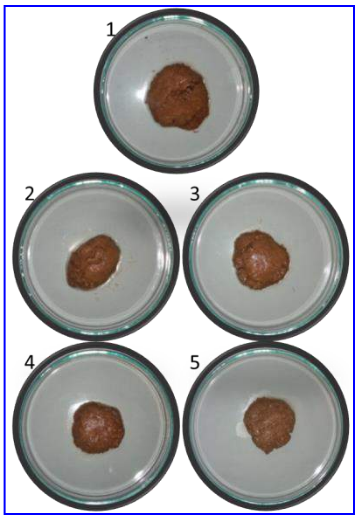
c. After 15min



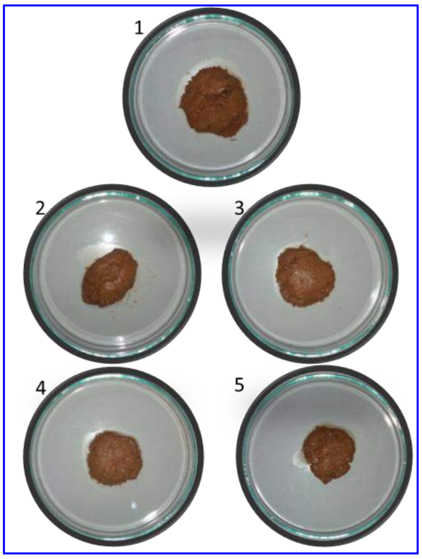
d. After 30min



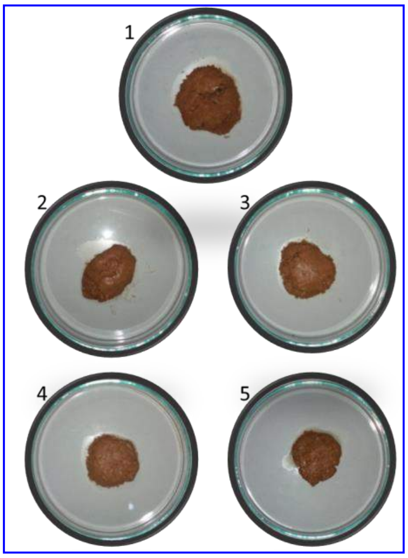
e. After 45min



f. After 1hr



g. After 1.30hr



h. After 15hr

Figure: 7.9 *Dispersion test of soil sample by the addition of Gypsum*

{(1)0g of Gypsum, (2) 0.5g of Gypsum, (3).1g of Gypsum, (4)1.5g of Gypsum, (5) 2g of Gypsum}

The experiment conducted is far from conclusive and requires more lab and field trials for any conclusive quantitative results.

7.4 Agrostological Measures

7.4.1 Re vegetation techniques

Re-establish vegetation as soon as earthworks are completed. The plants will provide a protective groundcover, slow water flow, reduce excessive soil water, and bind the soil. Non-dispersive topsoil may have to be brought onto the site to produce a level finish and establish a rapid vegetation cover.

7.4.2 Plant species for specific functions

A range of vegetative control measures including the use of pastures, trees, and shrubs have been employed to control field tunnel erosion either with or without prior mechanical intervention. The choice of pasture, trees, or a combination of pasture and trees for the rehabilitation of tunnel-affected land is related to the risk of desiccation resulting in surface soil cracking and uneven infiltration of runoff into the subsoil. Dense plantings of Pinus radiata have been used to successfully control tunnel erosion in New Zealand (Trangmar 2003) and Tasmania (Colcough 1973). However, Boucher (1995) recommends that reclaimed tunnel-affected areas should be re-vegetated with a widely spaced tree cover in association with a combination of perennial and annual pastures, rather than a dense stand of trees or pasture alone. Floyd (1974) argues that a dense healthy pasture is preferable to tree planting as pasture promotes even infiltration and minimises soil cracking.

Grass will provide a fast growing cover on new earthworks. Vigorous, growing grass will encourage microbial activity which will, in turn, improve both soil structure and aggregate stability. The composition of

Annual and perennial species to be sown should suit the local climate and soil properties. Annuals provide quick cover and protection and perennial species have extensive and deep root systems that bind the soil and

Promote water uptake. Trees planted above and around the reclaimed area will prevent soil water building up and creating an erosion risk.

7.4.3 Mitigation plans suitable for Kerala

In Kerala soil piping or field tunnel erosion occurs mainly in the saprolite clay region below the lateritic profile. Usually it occurs in the slope break region on the side slope regions of the Western

Ghats. In most of the cases the catchment area will be large therefore runoff will be high associated with high discharge. Since the state enjoys two monsoons SW and NE for a majority of the year these areas experiences good rains. There should be two types of approaches needed for mitigating the soil piping process here.

1. Long term chemical amelioration plans and
2. Immediate site specific interventions to divert water

Before taking up any intervention plans the detailing of the site is required in terms of its tunnel configuration. This is done using the geophysical surveys such as multi electrode resistivity surveys. After having an understanding of the disposition of the subsurface tunnels plans could be made. Chemical amelioration techniques should include the usage of gypsum and lime in the area. The catchment area should be surveyed properly to detect any burrows or pits that my encourage large scale water intake into the soil. These pits and burrows should be ripped, and the disturbed soil ameliorated with gypsum and re-vegetated. A proper water management plan should be in place before taking up any intervention plans. Here mitigation plans for three localities such as Nelliyadukkam in Kasaragod, Ranny in Pathanamthitta and Padinjarethara in Wayanad districts are discussed.

7.5 Mitigation plan for Nelliyadukkam subsidence

Land subsidence has occurred in the Nelliyedukkam locality (N12°17’58.0”, E75°13’02.5”) in Kinanoor village, Vellarikund taluk in the Kasaragod district on 2014 August 2nd. The affected locality is in the side slope region of the laterite mesa. The pipe is in mature type and diameter of the entrance is around 5m, inside diameter is in 20m. This is an example of combination of mature and huge pipes. The subsurface pipe was partially filled by subsided earth materials (figure 7.10). The soil is in thick and underlying the well-developed laterite. The slope of the terrain as well as the tunnel orientation is towards NE-SW direction.

Field investigations revealed that the entire Nelliyadukkam locality is affected by soil piping. Piping process has affected the Saprolite clay of the laterite. Ground fissures indicative of ground movement are seen at few places. The initial investigations have established the presence of more than one subsurface erosional channel towards the out let side. Pipe outlet (Figure 6.10) is located at 50m north of this area. In this area a huge tunnel shaped pipe in combination with a typical pipe was formed here. Sudden collapsing of the top surface of the tunnel has happened due to the continued erosion. Surface fissures were also identified in the premises of the tunnel.

***Figure7.10**: Collapsed pipe due to subsurface erosion*

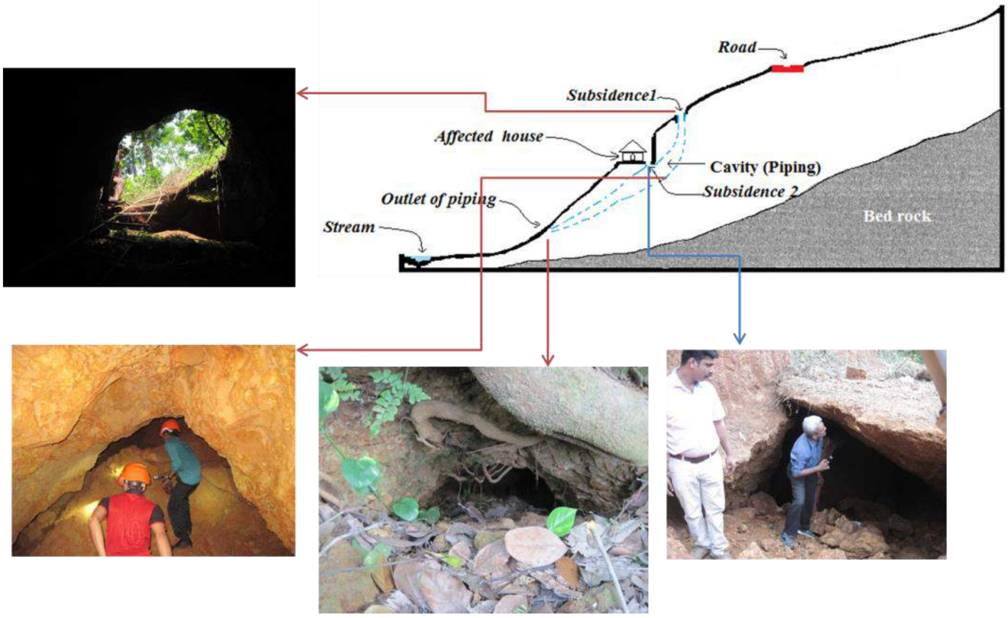


***Figure7.11:** Soil piping in Nelliyadukkam, Kasaragod*

In order to design the dewatering structures and to locate the subsurface pipes resistivity surveys were conducted in Nelliyadukkam, Kasaragod. Electrical Resistivity Surveys were carried out across the possible alignment of a known soil pipe. All survey lines were in east west direction, the suspected pipes are in the south - north direction (figure 7.11). A total of 7 survey lines were laid. The Electrical Resistivity Tomographic section is plotted (Figure 7.12) clearly brings out the existence of the pipe. Propagation of the tunnels could be deciphered by combining all the 7 results and filed surveys.

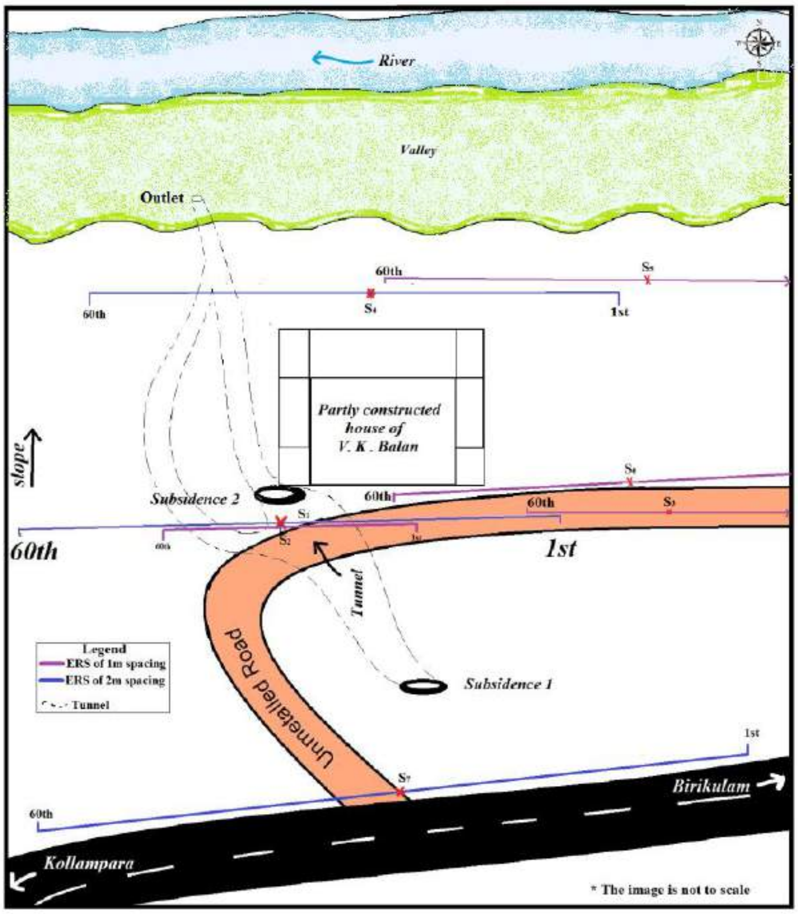
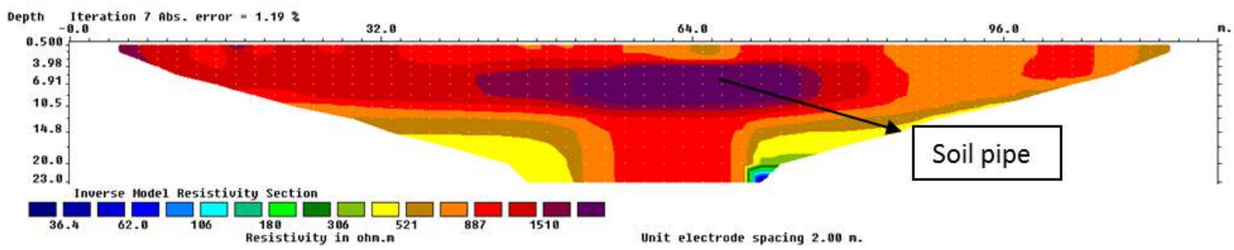
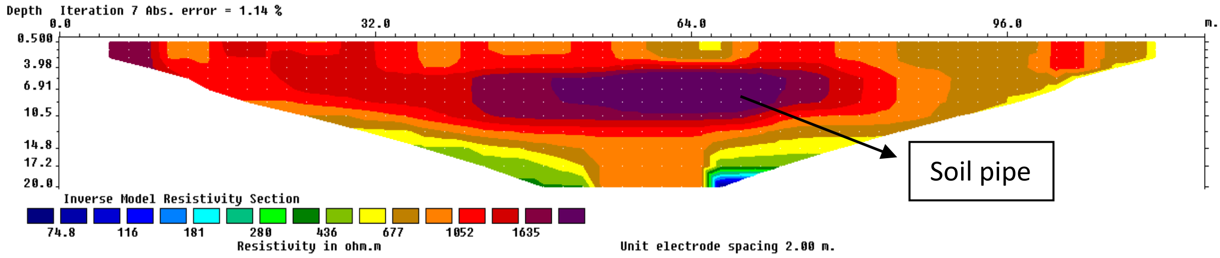


Figure 7.12*: Electrical resistivity Survey layout Nelliyadukkam, Kasaragod*

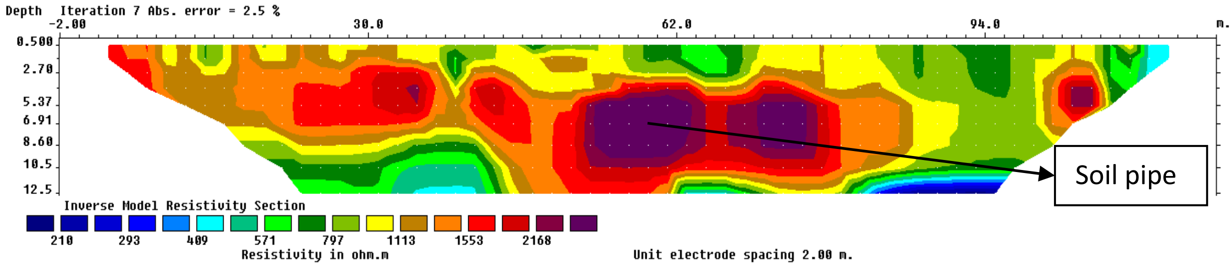
The electrical resistivity surveys (ERS) are extremely useful in identifying the subsurface tunnels. The ERS conducted in survey line 1 output is shown in figure 6.12a, b and c.



***a.** Schlumberger array at 1m electrode interval*



b. Wenner array at 1m electrode interval



c. Dipole-dipole array at 1m electrode interval

***Figure** 7.13: Electrical Resistivity Tomographic section survey line 1*

Mitigation measures suggested:

The mitigation measure suggested in Nelliyadukkam locality are proper diversion of seepage water by constructing a hydraulic barrier and the damaged foundation is recommended to be renovated by underpinning using polyurethane resins. It is always better to prevent the water from getting to the foundation of the house, than to attempt to control it after it gets there.

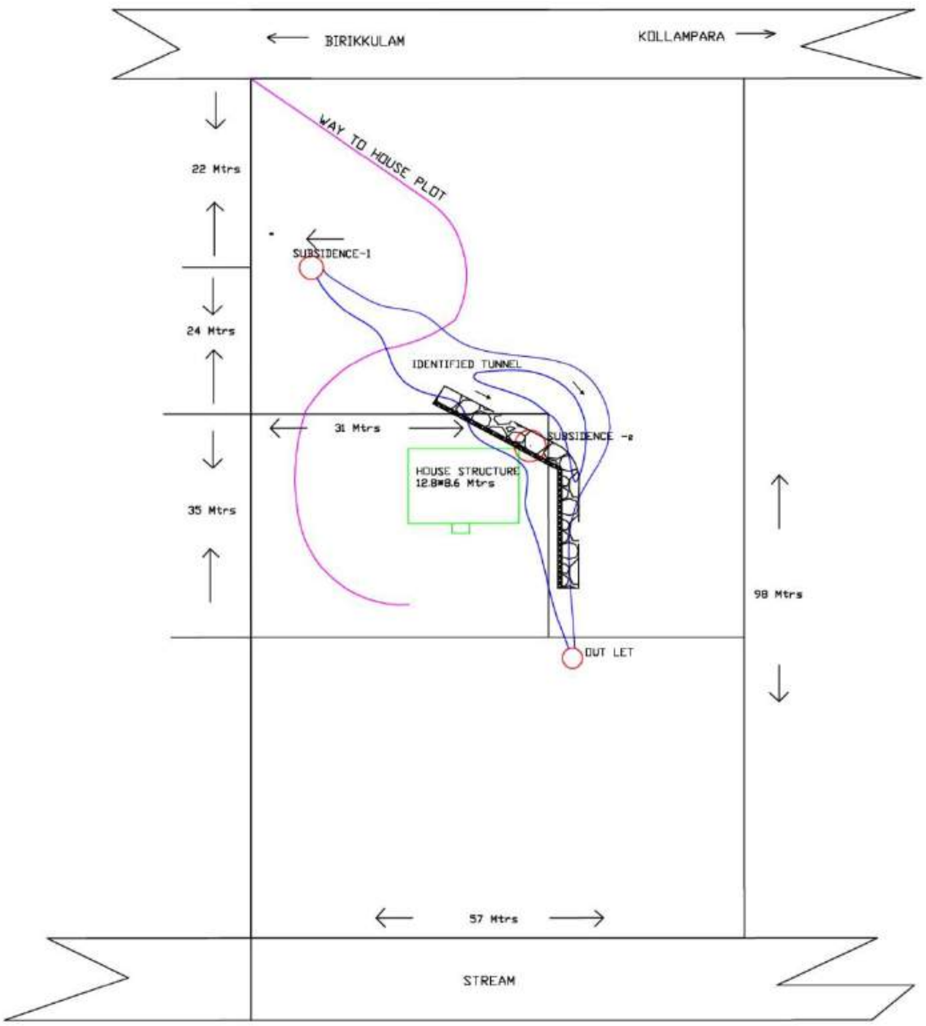


***Figure**7.14: Water divertion plan at Nelliyadukkam*

The water is recommended to divert by means of a hydraulic barrier made of concrete so that foundation can be protected from presence of water. The location and dimension details of the hydraulic barrier are shown in figure. The hydraulic barrier here acts as water proofing for the foundation and which helps the seepage water to divert properly.

The failed location is situated in the middle of a long side slope with very head. Here the gradient is high and water discharge is high during monsoons. A proper RCC structure is needed to protect the foundation of house affected by the piping erosion. The catchment of this locality should be treated and surface water should be diverted through lined open drains.

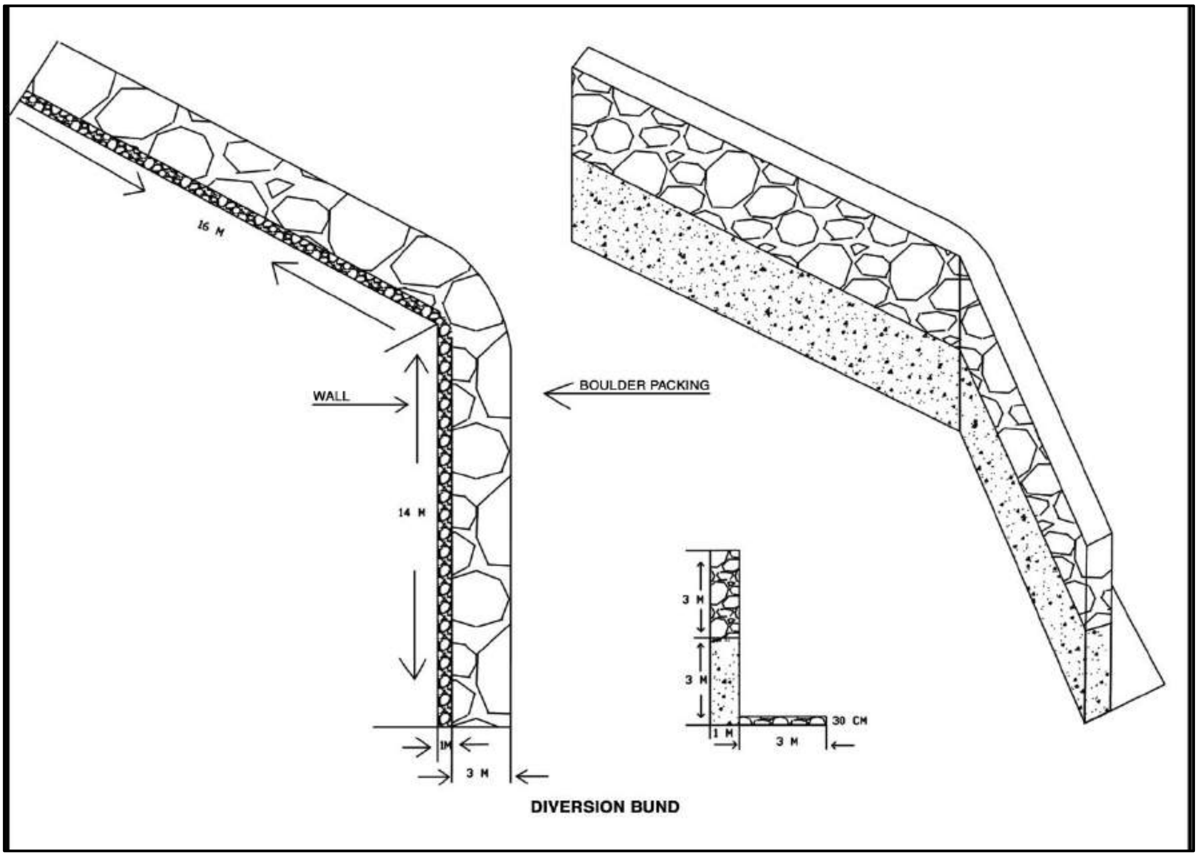


Figure7.15: *Section of the hydraulic barrier to protect the foundation*

Rectification of damaged foundation also bears at most importance in this study. Many methods are available for the rectification of foundation by the subsidence problems, such as underpinning, slab jacking and chemical grouting. Underpinning of the foundation is found to be the best suitable renovation method for the damaged foundation in the study area. It is the process of strengthening the foundation of an existing building, accomplished by extending the foundation in depth or in breadth so that it can rest in more strong strata. Use of micro piles and jet grouting are the two common methods of underpinning.

7.6 Mitigation work suggested at Ranny

Soil piping associated with a well like subsidence (figures 7.16) near a residence was noticed on 6 April 2011 in the Kollamulla village of Pathanamthitta district. As the subsidence pit was located very near to the dwelling place the district administration has requested NCESS to inspect the land and suggest suitable interventions. The affected house is located in a +25^{o} slope.

Figure: 7.16 *Subsidence occurred in Kollamula village, Pathanamthitta district*

The house is constructed on a terraced platform cut out of the natural hill slope. The soil in general was reddish in colour and showed laterization at the bottom. The house itself is well constructed concrete structure. About 300 meters from this affected house, another soil piping incident was reported about 25 years ago. There were many such incidences were located in the nearby areas. The pipe identified was of typical in nature.

The following suggestions were given to the PWD. These measures use only locally available material

1. The sink hole formed may be filled up by Soil from outside affected site (Kollamula village) and the land may be reclaimed.
2. The filling should be completed before the peak monsoon showers.
3. The floor where the tunnel is passing should to pack with used motor tyres, with large ones on the bottom with decreasing diameter tyres upwards. These tyres will trap the sediments flowing across the tunnel.
4. A non-degradable mesh should be provided at the entrance of the outflow section to prevent sediments escaping the tyre packing
5. A method of filling up of the sink hole is illustrated in figure 14 which may be used by the PWD Executive Engineer concerned as a guide.
6. Loose debris inside the sink hole must be removed before filling up the sink hole
7. After removal of the debris from the sink hole, three to four sacks of lime shall applied inside the sink hole.
8. The ground must be compacted after filling up the sink hole.

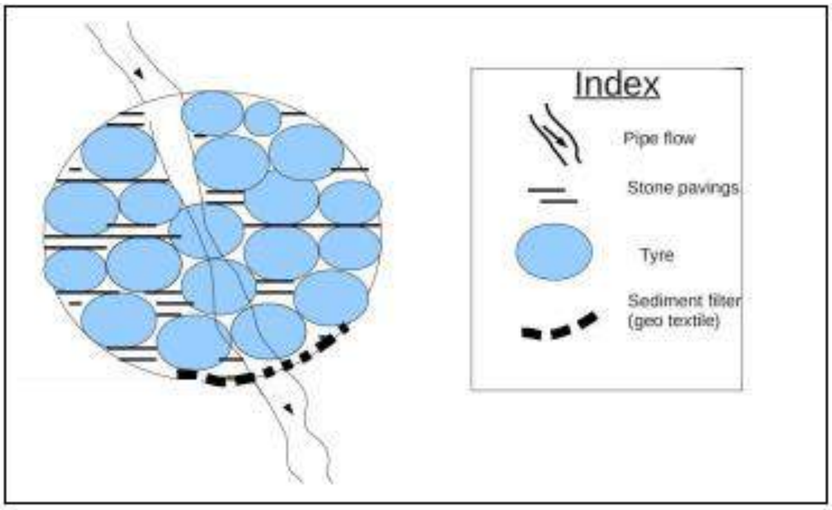


Figure: *7.17 Design prepared for mitigation work at the collapsed site in Ranny*

7.7 Banasurasagar, (Wayanad)

Landsubsidece has occurred in the Banasurasagar Dam road in the Padinjarethara Village Wayanad in 2006 where a portion of the land (N 11°41'33" / E75°54'16") subsidided (Figure 7.18a) and water started spourting out with huge force indicating that the water is flowing under a very high hydraulic head. The study assumes importance as this area is located very near to the Banasurasagar dam, which is an earth dam. Investigations revealed that the subsidence is caused by soil piping. The initial investigation revealed that this locality is underlained by subsurface tunnels and pipes and it emerges out as a springs in the nearby valley.

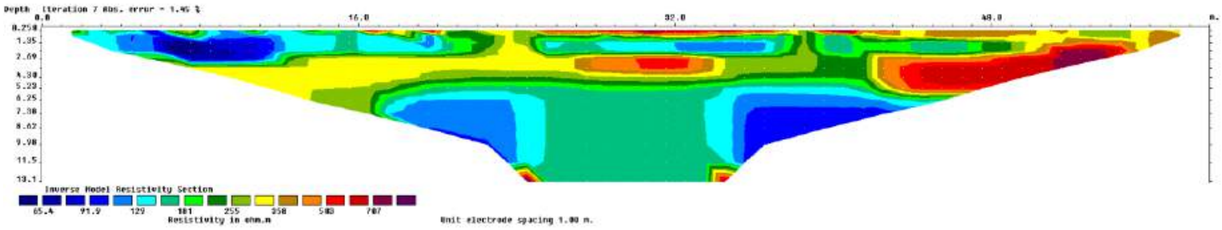
a. Before filling subsided area 2006 *b. After filling subsided area2014*

Figure: *7.18 Mitigation experiment by locals at Banasurasagar, Vythiri taluk Wayanad*

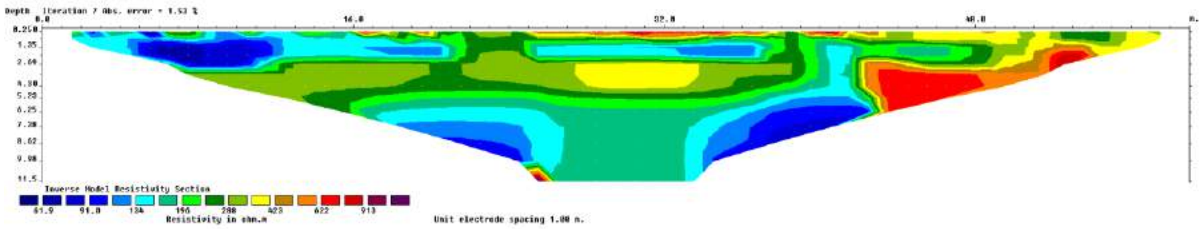
The owner of the affected land reclaimed the subsided pit with earth (figure 7.18b) as advised by the Nirmithi kendra. Unforunatly the pit was filled up by the locally available earth which is prone to soil piping. Also there were no efforts to divert the water passing through the tunnel. The reclaimed area started showing signs of disintergration during the next monsoon with water sprouting out through the cavity.During this period the buildings situated in the down slope region started showing signs of subsidence by exhibiting surfacial cracks. Since the whole area is affected by soilpiping the State Disaster Management Authority was alerted and a detailed investigation of nearby Banasurasagar dam which is an earth and rockfill dam was taken up.

The electrical resistivity profiles (figure 7.19a, b, and c) were laid almost perpendicular to the suspected alignment of the soil pipes with the probable location of pipes as the centre point. Accordingly, four profiles in two locations were laid across the suspected soil pipes that are in the West to East direction. One location is situated in the downslope direction and the second one is located in the village road situated in the upslope direction of the affected site.

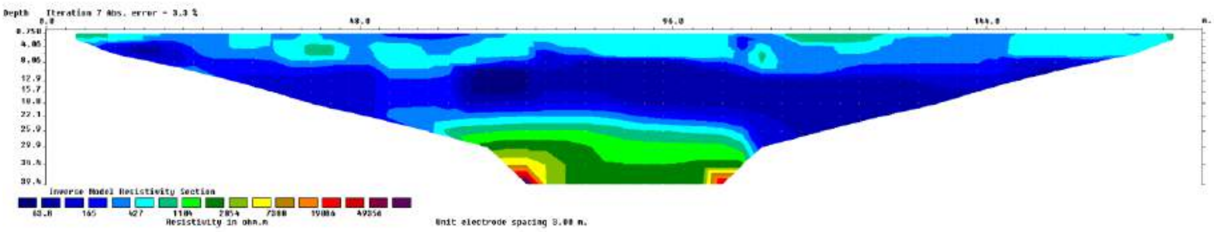
The results of the electrical resistivity survey with 1m electrode spacing were conducted long the Banasura sagar dam – Padinjarethara road across the suspected pipe on the indicates the presence of a saturated zone / tunnel.



a. *ERT of Schlumberger array at 1m spacing*



b*. ERT Wenner of array at 1m spacing*



c*. ERT Dipole-Dipole of array at 1m spacing*

Figure 7.19: *Electrical Resistivity Tomographic section at Banasurasagar dam*

Based on the information about the subsurface configuration a dewatering plan is being prepared to divert the subsurface water so that the dwelling units situated on ground could be saved from subsidence.

a. Cracks on the walls nearby house *b. Near by Banasurasagar dam*

***Figure: 7.20**: Detailed investigation of nearby Banasurasagar dam*

Dewatering is suggested to mitigate the piping related problems in this area. The plan is given in figure 7.21 . It is proposed to collect water coming from upslope direction on a well like structure the it should be be diverted to lower levels to save the house.

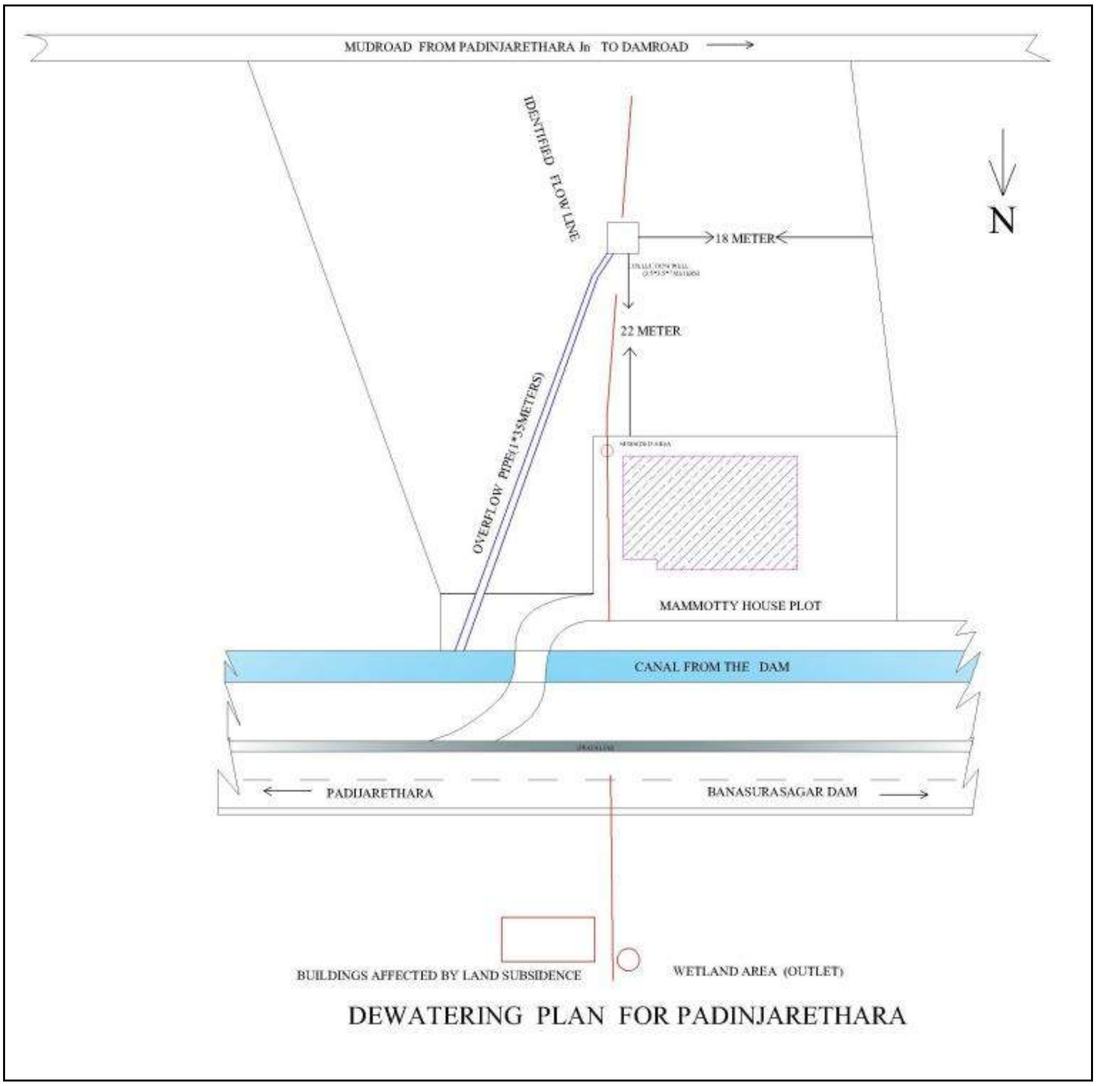


***Figure 7.21:**Suggested dewatering plan is to mitigate the piping in Banasurasagar dam*

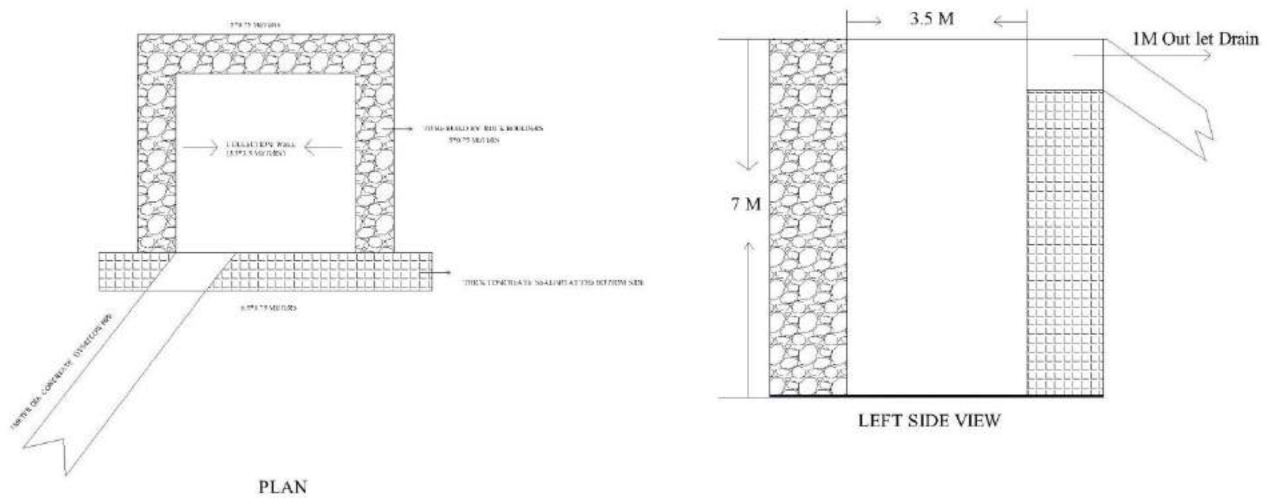


Figure 7.22: *Side view and cross-sectional of dewatering plan*

The plan and cross sectional drawings are shown in figure 7.21. The well is 7m in depth with an effective inside length and breadth of 3.5m x 3.5m. The structure will have an out flow section of 1m in diameter. Since the soil thickness is very high construction of barriers might not yield desired results. If the intervention is carried out the government then the well could be used as a community well for the locals.

CHAPTER 8

CONCLUSIONS AND RECOMMENDATIONS

8.1 Conclusions

8.1.1 General

- Tunnel erosion due to soil piping is a serious problem in the Western Ghats
- Soil piping is the main reason for the land subsidence in the Western Ghats and its foots in Kerala
- Most of the tunnelling occur where deforestation has taken place
- Piping also occurs in areas where removal of large trees such as rubber or any other trees without removing their long tap roots have taken place.
- Land subsidence due to soil piping is at present observed mainly from the lateritic side slopes in the Western Ghats of Kerala.
- Excepting districts of Alappuzha, Kollam and Trivandrum all other districts are affected by the soil piping problem.
- Many places the tunnel formation has grown beyond any possibilities of mitigation
- Studies suggested that many infrastructure facilities especially communications line like roads have been affected by tunnel formation due to soil piping
- The acidic nature of the soil as well as the type of fertilizer use in the highlands needs further studies
- The ground water storage and the vegetation is also seriously affected in the localities affected by soil piping
- Multi-electrode resistivity surveys helps in identifying typical and huge tunnels. However it is difficult to identify small and Juvenile tunnels using these surveys.
- Even though it is a very slow process usage of Gypsum and lime helps to retard the soil piping activity
- As immediate remedial measure it is better to adopt dewatering techniques using some engineering measures like diversion of under ground flow channels and construction of underground barriers etc.

8.1.2 Data bank:

- The data on the affected sites indicate that the soil piping problem is spreading to many areas in the highlands
- Data of the affected sites indicate that they are confined to the shoulder slope break of the highlands.
- The worst affected districts are Kasaragod , Kannur and Idukki
- The so far the no incidents were reported from Thiruvananthapuram, Alappuzha and Kollam districts of Kerala

8.1.3 Geophysical investigations

- Multi electrode electrical resistivity surveys are best suited to identify the sub surface tunnels and voids formed by the soil piping. However with this technique it is able to map the Juvenile and small voids/tunnels which are less than 5m in diameter.

8.1.4 Geochemical Studies

- The Kaolinite clay with gibbsite present in the saprolite layer beneath the laterite bordering the impermeable bedrock is the vulnerable to soil piping. These clays are always containing dispersible Na with quantities more than 5% are ideal for soil piping erosion.

8.1.5 Geotechnical studies

- The areas subjected to piping erosion were found to be laterite soils.
- Field investigation and laboratory results show that the visual classification, Atterberg's limits and particle size analysis do not provide sufficient basis to differentiate between dispersive clays and ordinary erosion resistant clays.
- The soils at both piping and non-piping region were found to be well graded soils, which show that the particle size distribution is not the factor which makes the soil unstable.

- Presence of high dispersible sodium content makes the soil erodible and for such soils the plasticity index found to be high. Here the plasticity index of the piping region was high and which proves this positive correlation of plasticity index and presence of sodium content.
- At the piping region as the permeability of the top strata was high and decreased with bottom, it results in the accumulation of water at the bottom layers and leads to lateral subsurface flows.
- Water is found to be playing the main role in the piping erosion phenomena. The properties of soil were almost same in all regions but the soil at piping region becomes dispersible at presence of water.
- The mitigation works suggested in the area are proper dewatering technique along with renovation of damaged foundation by underpinning using polyurethane resins.

8.1.6 Mitigation

- Chemical amelioration and dewatering are found be the appropriate methods for controlling soil piping.
- Though it is a slow process, application of lime and gypsum to neutralise the dispersive nature of the soil is a good method to slow down the process.
- For immediate results it is better to adopt dewatering techniques, such as construction of subsurface barriers to divert the flow, construction of surface drains to divert the surface flow and reduce the infiltration, seal all the water intake features in the affected slope etc.
- The mitigation works suggested in the area are proper dewatering technique along with renovation of damaged foundation by underpinning using polyurethane resins.

8.2 Recommendations

- It is recommended that studies are required to understand the soilpiping affected areas in adjoining Karnataka districts
- It is recommended that usage of Lime and gypsum should be encouraged in the already affected localities.

- It is recommended that a state wise survey in the village level should be conducted to fully map the affected localities
- It is recommended that major developmental projects should be taken up in the highlands only after determining the quality (depressiveness) of the soil
- It is recommended that the Government should take immediate steps to determine the areas where dispersive soils are present. The soil survey department should take proper initiatives
- The areas where earth dams are present in the state should be watched closely to rule out the presence of dispersive soils. Since dispersive soils are located nearby the Banasurasagar Dam in the Wayanad district should be supervised carefully for any possible soil piping erosion.
- The National Centre for Earth Science Studies, Department of Earth Sciences, and Thiruvananthapuram should be made the nodal agency for handling any soil piping related matters in the country.
- It is recommended that more focussed research on soil piping should be taken up to understand complexity of the processes occurring in the piping affected localities. Also mitigation specific studies should be undertaken in critically affected localities such as major roads, earthen dams surroundings and civil structures etc..
- It is recommended that the State Executive Committee of the Kerala State Disaster Management Authority may consider declaring soilpiping and consequent damages to life and property as a state specific calamity under the provisions of ltr No 3207/20014-NDM-1 dated 8.04-2015 from the Disaster Management Division , Ministry of home Affairs, Govt. of India.

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ADDENDUM

Addendum to Project report on the “Studies on the Soil piping in the highlands and foot hills of Kerala to avoid the disaster” submitted to the National Disaster Management Authority in 2016 (report number NCESS-PR-02-2016)

Why this addendum : After the submission of the above report to the National Disaster Management Authority, it was brought to the attention of the authors that some observations need more clarification and need for the correction of inadvertent errors. The authors have decided to include this Addendum to rectify the omissions and errors.

- Data base: All revenue districts of Kerala except Thiruvananthapuram (Trivandrum), Kollam (Quilon) and Alapuzha (Alleppey) reported soil piping at the time of the study (2016). The study and observations have mainly focussed in the areas where this phenomenon has reached hazardous conditions, such as Idukki, Kannur, Kasaragod, Palakkad, Kozhikode, Pathanamthitta and Wayanad. This is because the districts have experienced large scale and hazardous land subsidence and tunnel formation. Whereas, in the districts such as Thrissur (Trichur), Kottayam, Ernakulum etc., soil piping was observed mainly in the form of small or juvenile pipes. In the map only locational details are specified. Spatial extent of the affected regions are not included due to time constraints. (Refer Chapter 2, section 2.3 Study area, page no. 12)
- Sample collection: Soil samples were collected from affected as well as no piping localities. Samples mentioned in Table 5.1 sample type of sample nos.1-9, 1-12, 1.13,,1-15 are from -Neendapara which is a non-piping locality. (Refer Chapter 5, section 5.1 Soil Sampling, page no. 101)
- Sample analysis: Chapter 5-pH, EC and Total Dissolved Solids (TDS) are measured with field conductivity meter (Eutech.). (Refer Chapter 5, para 1, page no. 101)
- Fig 5.3 and Table 5.11.- According to the XRD results, the sample shows Gibbsite and Kaolinite, which are more dominant. Gibbsite indicates prominent leaching material which confirms the erosional activity in that region. From the XRD result the 14Å shows vermiculite which is very much present in the soils. (Refer Chapter 5, section 5.2.7 XRD analysis, page no. 114)
- Experience in the Western Ghats indicate that multi electrode electrical resistivity surveys are ideally suited geophysical method to identify the sub surface tunnels and voids. However with this technique it is not able to map the Juvenile and small voids/tunnels which are less than 1meter in diameter. Resistivity in clayey strata is controlled by both mineralogy and cationic exchange capacity and can also be related to moisture content. This relationship was developed by Waxman and Smits (1968), the conductance of the cations (such as potassium, calcium, sodium or aluminium) is relates to the exchange capacity (CEC). For example, higher resistivity clays, such as Kaolinite have a low Cations Exchange Capacity (CEC), lower resistivity clays, such as chlorite and Illite have a medium CEC and the lowest resistivity clays like Smectite have a high CEC. In the study area highly conductive clays and weathered rock/soil surrounds very low conductive void spaces. This ground situation helps to identify the tunnels using resistivity methods. (Refer Chapter 8, section 8.1.3 Geophysical investigation, page no. 172 and Chapter 5, section 5.2.6 Determination of exchangeable sodium percentage and Ca & Mg ration, Table 5.9, page no. 113)
- Table 5.8 shows a high percentage of exchangeable sodium (up to 53.53) at Kottathalachimala, the soil samples were collected from the piping affected area. And least (9.86) in Thattekanni soil samples were collected from soil profile of the affected area. These results revealed that all the sampling area is affected by dispersive soil. (Refer Chapter 5, section 5.2.6 Determination of exchangeable sodium percentage and Ca & Mg ratio, Table 5.8, page no. 112)

Exchangeable Sodium Percentage	<6	6-10	10-15	15-25	25
Classification	Non-sodic	Sodic	Moderately Sodic	Strongly Sodic	Very strongly Sodic

Important observations

1. Soil piping (tunnel erosion) is occurring due to the subsurface erosion of lithomarge clay / non lithified earth materials.
2. Western Ghats of Kerala are the most affected locality in India
3. In Western Ghats soil piping is observed largely in the saprolite and lithomarge clay layer occurring mainly in the lateritic areas and non -lateritic localities (in central and south Kerala).
4. In soil piping affected areas usually will have outlet(s) in the downslope valley area.
5. In soil piping affected localities the water table in the open wells during rains / monsoons will be stable
6. Geophysical tools such as Electrical resisitivity mapping and Ground Penetrating Radar are suitable to map subsurface soil pipes which are more than 1 m in diameter.
7. Soil piping takes place when percolating water under very high hydraulic head comes into contact with clay or non-lithified earth materials. Laterite mining on the top of laterite mesa, rain water harvest pits, burrows, degraded deep tap root systems etc. are ideal loci for the development of soil piping.
8. Dispersible sodium present in the clay is considered to be affecting the stability of the clay structure, there by encouraging the tunnel erosion/ soil piping.
9. Soil piping triggered landslides are common in the Western Ghats
10. Dewatering of the catchment of the affected area is one method to control the erosion process
11. Chemical amelioration using hydrated lime or gypsum depending on the type of soil is also should be practiced to control soil piping.
12. Where ever the affected soils are found in strategically important locations it is better to replace the affected soil with soil from unaffected localities.