Studies on land disturbances due to soil piping affecting the critical zones in Western Ghats of Kerala

(A project funded by the Kerala State Disaster Management Authority)

Final Report

Submitted to

State Disaster Management Authority

Government of Kerala

ESSO-**National Centre for Earth Science Studies**

(Ministry of Earth Sciences, Govt. of India)

Thiruvananthapuram 695011

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Project team

G. Sankar	Senior Consultant
Dr. D. S. Suresh Babu	Principal Investigator
Midhun T. M.	Project Scientist (2017-19)
Sarath Kumar	Project Scientist (2016)

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6. ABSTRACT

Western Ghats often experiences flooding, mass-movements in the form of landslides and land-subsidence. Studies conducted by NCESS revealed that land subsidence is often due to a process occurring in the subsurface known as soil piping or tunnel erosion. Land disturbances due to soil piping are noticed in all districts in Kerala except Kollam and Alappuzha. In 2016 NCESS in collaboration with SEOC has completed a 3 years long study funded by the NDMA, GoI on soil piping related problems in the State. This study has been carried out as a follow up of the NDMA funded programme. NCESS has identified more than 139 regions in the Western Ghats severely affected by soil piping. A detailed field related study to demarcate areas affected was needed to know the extent of damages occurred due to soil piping. This project was taken up to fulfill some of the missing aspects in the NDMA funded programme.

The critical zone in the Western Ghats which is the permeable near surface layer from the top of the trees to the bottom of the saturated zone is a very important layer where various geo environmental parameters interact. This zone is very often subjected to changes by many processes such as anthropological activities, neo-tectonic activities, natural hazards etc. during high rainfall seasons like monsoons.

It is recommended that site-specific and detailed studies are required to understand the soil piping affected areas in the state for proposing mitigation plans at each affected location. In the affected areas the laterite mining should be discouraged or the depth of the mine to be restricted 1m above the lithomarge clay. In no case the clay should be mined or exposed. It is recommended that usage of hydrated Lime along with the fertilizers should be encouraged to neutralise dispersive sodium in the clay at the already affected localities. Major developmental projects should be taken up in highlands only after proper geologic / geophysical studies to rule out existence of subsurface tunnels. The soil survey department may take proper initiatives to determine the areas where dispersive soils are present in the State. 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, the location should be supervised carefully for any possible soil piping erosion. Dewatering is the best method to deescalate the formation of soil pipes. Overland flow may be diverted to a nearby nala / stream without allowing to infiltrate the affected zone will reduce pipe development.

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G Sankar
Senior Consultant (2016-18)
For the Project Team

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Problem Statement

Background

Even though our state is bestowed with natural beauty and natural and human resources it is also experiences the wrath of a multitude of natural and manmade disasters. The high population density of the state makes even a small incident vulnerable to a larger society. Being a maritime state and its location in the humid tropics has made Kerala state a multi hazard prone region. Hazards typical to seasons prominent in the monsoon and non-monsoon periods of the state. Droughts and forest fires are common during non-monsoon seasons whereas rain induced floods and landslides dominate the monsoon season. During the last decade, apart from landslides, land-subsidence has also become common in the Western Ghats. Even though the causes for occurrence of the landslides and land subsidence differ, they occur during monsoon times. Whereas the landslides are the different types of movement of earth material down the slope under the influence of gravity and the land subsidence is the result of roof collapse of the subsurface tunnel / cavity formed due to a soil erosion process called “soil piping or tunnel erosion”. In the Western Ghats, soil piping problems are reported from all localities except in the Alappuzha and Kollam districts.

Subsidence is caused generally by naturally and or manmade causes. In most cases these are combined together. Land subsidence can be caused by many ways. Geothermal: Withdrawal of steam for geothermal purposes has been reported as a cause of subsidence. Freezing – thawing: Effects of temperature on shear strength, volume change and settlement of surrounding soils freezing and thawing cycles will cause reduction of soil strength. Other causes are dissolution of lime stones, Mining, Extraction of natural gas, earthquake, ground water elated subsidence, faulting induced, isostatic subsidence and soil piping. In Kerala absence of big lime stone terrains and absence of underground mining rules out the first two possibilities. Same is case with natural gas. Large earthquakes have not occurred so far in Kerala. Tropical wet climate, high weathering, monsoon rains etc makes Kerala an ideal location for subsurface erosion or Soil piping.

Soil piping

Soil piping is a type of soil erosion occurring in the critical zone of the earth crust. The "Soil piping", also called 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 process results in the formation of subsurface voids / cavities / tunnels due to subsurface soil erosion. 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. 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 unsuitable for cultivation and constructions. The materials most subject to piping include fine- grained alluvium or colluvium, and some rocks (especially clay stone, mudstone and siltstone etc.). The piping process involves a relatively weak, incoherent layer that becomes saturated and conducts water to a face which transects this layer. This face could be the head of a gully, the head cut of a landslide, or a manmade excavation.

Soil piping is caused by internal erosion of soils which leads to the formation of tunnel like structure below ground level. Internal erosion of soil is the main reason for piping formation. Soil piping or Tunnel erosion is defined as the hydraulic removal of subsurface soil, causing the formation of underground channels and cavities (Boucher 1995).

Soil piping is one among the reasons which causes land subsidence. Land subsidence due to soil piping has been noticed in high land area of Kerala, especially places near to Western Ghats. This phenomenon is subsurface erosion of soils, since it is very difficult to predict and identify earlier it can be assumed as a disaster. Not much of research has gone in to piping process. Piping erosion is the 'neglected' erosional process because for many years, research on soil erosion was mainly focusing on sediment detachment and transport in overland flow while subsurface flow erosion was regarded as a process of limited importance restricted to certain materials (Bryan and Jones, 1997). Later increasing reports of subsurface erosion features in many different materials and climatic zones led to an increasing interest in subsurface flow and related soil erosion processes (Bryan and Jones, 1997)

This is a mechanical movement of soil aided by certain chemical process, which allows finer sediments and forms soil pipes. Soil particles moves with water to downstream level and it burst to outside with the formation of a pipe.

Internal erosion of soil is dangerous because there may be no external evidence or only subtle evidence is shown. It happens in a way that surface was harder to see 'piping' within the soil profile. Soil erosion happening under our feet and out of view, can be difficult to imagine, and even more difficult to study. Soil pipes underground are shaped and sculpted by the water that runs through them. Dispersive soils, those that are easily eroded, are ideal for soil pipe formation since water travelling through such soils can detach particles with little effort.

Water itself can initiate a soil pipe in some soils, if there is a crack in the soil or may be just a spot where it got a little bit less resistance. Water will then start moving through that pathway, the surrounding water will then follow that way, and a soil pipe can be created just by the action of water.

Fig 1.1 Land subsidence occurred due to soil piping in Kottaykkal, klari in 2018

Fig 1.2 Land subsidence occurred due to soil piping in Chattivayal in 2005

In other cases, as plants die or trees get uprooted, their roots leave openings in the soil, wild fires can burn up roots leaving holes behind. Animals can also help create soil pipes by burrowing and tunnelling in the soil. These voids provide an opening for moving water and create ideal situation for soil pipe formation. Soil pipe start down from very small pores, but over time can become big tunnel like structure.

Fig 1.3 inside view of a pipe formed at Kottathalachimala near Cheupuzha

Water restrictive soil layers can also facilitate soil pipe formation. Soil horizons (clay layers or bed rock) blocks the vertical movement of water through the soil profile and force it to move laterally. By forcing water in a specific direction, it is more likely that internal erosion will occur and a soil pipe will form. Likewise, restrictive soil layers also restrict the growth of plant roots causing the roots to extend laterally. When the roots die, the path left behind are primed for water movement and pipe formation.

Soil pipes can cause numerous problems. While they start from very small pores, they can cause large failures of soil structure and of engineered structure, such as dams and buildings. Water erodes through the soil out of the pipes, the soil above the pipe is not supported. The pipes can then collapse, leading to gullies, landslides, or stream bank failure.

Literature survey

Soil piping is much neglected process since it is one of the major factors causing landslide. Soil piping or Tunnel erosion is defined as the hydraulic removal of subsurface soil, causing the formation of underground channels and cavities (Boucher 1995). Piping has been observed in both natural and anthropogenic landscapes, in a wide range of climatological, geomorphological and pedological settings (Bryan and Johnes, 1997). Earth bank failures and Subsequent gully formation due to piping are one of the most reported problems (e.g.: Poesen et al., 1996). As this phenomenon is the subsurface erosion of soil, it is very difficult to identify and predict.

In the region of Western Ghats of Kerala soil piping events are observed by NCESS, from a disaster point of view the study was first initiated by (G. Sankar et al) in Kerala. The first incidence was reported by NCESS (Thampi et al at 1992) in 1992 when a semicircular depression covering an area of about 30sq.m and a depth of 2 meters was noted at the Carmel UP school in Palakkayam in the Mannarghat Taluk of Palakkad district of Kerala. Now total 18 piping affected areas have been identified at different locations in different places in the State.

Very few studies have conducted on piping process. Studies have been made in Australia, New Zealand, China, and Canada and in India to understand the geomorphic significance and other causative factors of this process. In highlands of Kerala during monsoon season soil piping or tunnel erosion become a regular phenomenon and most of these incidents are getting unnoticed. The general concept was that land subsidence was associated with mass movement of debris, like landslides. The chances of formation of pipes occurs during monsoon season because water enters through the pores and cavities followed by subsurface channels, the soil get saturated with this water and moves along with it towards the outlet and large pipes are formed.

Piping erosion is the 'neglected' erosional process because for many years, research on soil erosion was mainly focusing on sediment detachment and transport in overland flow while subsurface flow erosion was regarded as a process of limited importance restricted to certain materials (Bryan and Jones, 1997). Later increasing reports of subsurface erosion features in many different materials and climatic zones led to an increasing interest in subsurface flow and related soil erosion processes (Bryan and Jones, 1997).

Fig 1.4 Land subsidence occurred due to piping

Fig 1.5 Soil pipe formed at Kottathalachi Mala

The Process of Soil piping

Piping or tunnel erosion is a process involving the hydraulic removal of subsurface Soil, causing the formation of underground channels in the natural landscape (Boucher, 1990). 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 Boucher (1990) and Vacher et al. (2004b).

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. 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.

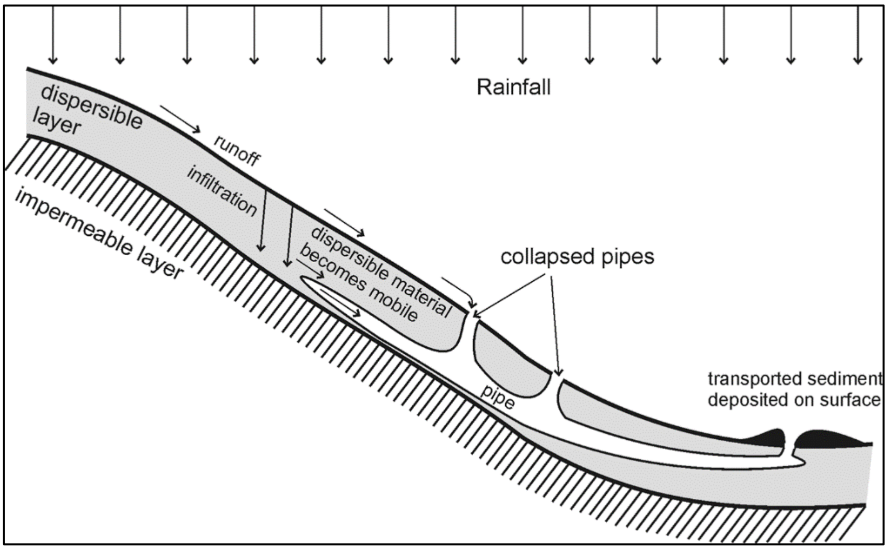


Fig 1.6 Diagram illustrating the process of piping (Boucher, 1990).

In the initial stage, flowing water causes particles to detach from the soil matrix. Two Types of subsurface erosion can cause this. The first occurs when water seeping Through a porous soil has a sufficient drag force to entrain material through Liquefaction or Coulomb failure, often referred to as spring sapping or *true piping* (Dunne, 1990) in the engineering sense. It can produce a subsurface conduit that Works back from the outlet, often developing a complex branched network (Terzaghi And Peck, 1966). The second process involves expansion of an existing conduit or macropore due to the shear stress exerted by flowing water, including the Enlargement of animal burrows, root channels or soil cracks. This process has often Been distinguished as *tunnel erosion* or *tunnelling*, although it is also referred to as Piping in much of the literature. Bryan (2000) acknowledges that piping and tunnelling represent distinct erosional mechanisms but notes that both processes are often functionally indistinguishable and generally grouped under the term piping. This will Be done in this study as well. According to Bryan and Jones (1997), the main Distinction between piping and tunnelling is that tunnel erosion features do not Necessarily develop from the outlet and they do not necessarily involve high seepage Pressures. In the second, more advanced, stage, soil particles are transported to an exit point of the tunnel where a sediment fan can be formed (Vacher et al., 2004b). This requires A sufficient slope gradient to develop a hydraulic head to drive water through the soil and to cause failure of the soil matrix. The third and last phase of pipe development involves the ultimate collapse of the Soil, forming sinkholes (Boucher, 1990). Pipe flow can occur at more than one level and often follows three-dimensional Interconnecting networks (Zhu, 1997; Holden and Burt, 2002). The networks may Have more in common with a sponge than a river network and the active network can Be very different in individual flow events, often because of temporary blockages (Zhu, 1997).

Piping Characteristics

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, on the crowns and the sides of miniature Badlands Mountains, and in badland 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.

Forms of piping

Soil piping takes place mainly three forms (Ritchie, 1963).

(i) Field tunneling,
(ii) tunneling in earthworks i.e. ‘piping’ in dams, and
(iii) Tunneling in strongly self- mulching clays.

The first 2 forms of tunneling are regarded as ‘true’ tunneling, which result from the dispersion of sodic sub soils, while the third form of tunneling 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.

Conditions for the formation of Soil Piping

Soil piping / Tunnel erosion may be initiated by a range processes like wilting of tap roots of large trees, burrowing of animals, and presence of large fractures in the upper slopes etc. which in turn generate large subsurface runoff which leads to the formation of subsurface pathways by eroding softer soil materials. Overland flow with low electrolyte concentration enters the soil via suitable conduits resulting in the dispersion of sodic clay subsoil, provided the soil matrix has sufficient permeability to minimize pore blockages and dispersed soil material moves down slope through soil cracks, leaving behind a small tunnel or cavity. 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. Tunnel expansion enables flowing water to scour the base and undercut sidewalls, resulting in tunnel expansion through mass wasting. Eventually undermining reaches an extent where complete roof collapse occurs and gullies form. 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.

Soil piping is not an instant or a sudden process; it takes years depending upon the area and type of soils present over there. The Physical properties which favours for the cause of Piping are Slope, Elevation, Rate of flow of underground water, Structure, texture, Porosity, Permeability of erodible material, Chemical properties of soil like, clay mineralogy, pH, Sodic soils, Electrical conductivity of soils. Until and unless these factors are not favourable, the soil may not be eroded and piping may not occur.

Hydrological factors

Obviously copious supply of water is needed for piping erosion, although its origin can vary. Some authors pointed to rainfall with a high variability in intensity (e.g. Gibbs, 1945;

Farifteh and Soeters, 1999). Jones (1981) stated that for piping to occur, both periods of desiccation and periods of intense rainfall are needed. In a climate with distinct seasonality of rainfall, wetting and drying cycles have an important effect on the soil structure by structural collapse of soil exposed to evaporative drying and the formation of shrinkage cracks (Vacher et al., 2004b). These shrinkage cracks provide inlet areas for concentrated runoff flows through the surface soil horizon and expose dispersive subsurface clays to water, which can initiate pipe formation (Vacher et al., 2004b; Faulkner, 2006).

It is also generally accepted that there must be an outlet for drainage (Fletcher et al., 1954; Parker, 1963; Jones, 1981), located close to surface drainage networks (Farifteh and Soeters, 1999). The pipes require a suitable exit so that mobilised sediment can continue to be removed from the pipe (Vacher et al., 2004b). Water emerging from the exit of pipes is typically turbid, with a high suspended load which may be transported to local water courses, or can form a sedimentation zone downstream due to settling of the eroded material (Boucher, 1990; Vacher et al., 2004b). Pipe outlets mainly occur at gully and river banks, road cuts or at foot slopes.

Topography

Furthermore, a sufficient hydraulic gradient within the soil is required (e.g. Fletcher et al., 1954; Parker, 1963; Jones, 1981; Bryan and Yair, 1982; Farifteh and Soeters, 1999; Vacher et al., 2004b). For piping to occur on low slopes there must be either a plentiful supply of water, possibly seasonally, steep hydraulic gradients, which can be caused by an adjacent free-face or gully wall, or very favourable soil profiles (Jones, 1981). Although a considerable relative relief is necessary, the hydraulic gradient and not the surface slope gradient controls pipe development (e.g. Jones, 1971; Baillie et al., 1986). Where flow converges to a suitable lower hydraulic outfall, macro pores are enlarged by subsurface erosion and will act as drains (Faulkner, 2006). If a landscape has sufficient relative relief for hydraulic gradients to be maintained as Piping erosion proceeds, the enlargement of pipes can be rapid (Naidu et al., 1995; Sherard and Decker, 1976; Sumner and Stewart, 1982; Faulkner, 2006).

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. deflocculation) (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 macropores, 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.

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).

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

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.

Soil salinity

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).

Sodic soils

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.

- Tunnel erosion results from a combination of both chemical dispersion and physical transport of dispersed clay particles.
- Soils with greater than 6% exchangeable sodium are prone to dispersion.

Global distribution of piping

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 beof greatest geomorphological and hydrological significance in three environments: in organic soils on humid uplands, in badland 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 (Fig. 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 occurrence of piping in the semiarid and temperate marine environments (Bryan and Jones, 1997).

NCESS-NDMA-SDMA studies on soil piping

Western Ghats often experiences flooding, mass-movements in the form of landslides and land-subsidence. Studies conducted by NCESS revealed that land subsidences are due to a process occurring in the subsurface known as soil piping or tunnel erosion. Land disturbances due to soil piping are noticed in all districts in Kerala except Kollam and Alappuzha. In 2016 NCESS in collaboration with SEOC has completed a 3 years long study funded by the NDMA on soil piping related problems in the State. This study was a follow up of the NDMA funded programme.

The critical zone in the Western Ghats which is the permeable near surface layer from the top of the trees to the bottom of the saturated zone is a very important layer where various geo environmental parameters interact. This zone is very often subjected to changes by many processes such as anthropological activities, neo-tectonic activities, natural hazards etc. during high rainfall seasons like monsoons Western Ghats often experiences flooding, mass-movements in the form of landslides and recently land-subsidence. NCESS has found out that land subsidence is due to a process occurring in the subsurface known as soil piping or Tunnel erosion. NCESS has identified more than 139 such regions in the Western Ghats severely affected by soil piping. Considering the seriousness of the problem the National Disaster Management authority has funded a research programme to NCESS-SEOC to study the problem from a hazard point of view. This was the first time such a study was taken up from a hazard point. This 3-year programme was started in 2012 and will conclude in 2016 May. Even though the study could bring out details of the affected areas, type of surveys to be conducted to delineate the subsurface tunnels, factors encouraging the formation of cavities and tunnels, types of tunnels formed in the Western Ghats etc. so far, we have only locational data of areas affected by soil piping. But in reality, there are vast areas affected by this process. A detailed field related study to demarcate areas affected was needed to know the extent of damages occurred due to soil piping. This project was taken up to fulfil the missing aspects in the NDMA funded programme.

Chapter 2
Objectives and methodology

Objectives

This project is a follow up of the research programme taken up by NCESS in collaboration with NDMA and SDMA. There were many questions regarding the areal extent of the soil piping affected localities in the state? One of the aims of this project is to "collect data of new incidents of soil piping affected localities". Based on the data collected a susceptibility map will be prepared, also soil [piping has affected many public and private infrastructures in the state. Here an attempt has been made to identify the infrastructures affected by soil piping in the state. Apart from studying few critically affected localities this project also aims to study the causative factors of this process.

Since this project is funded by SDMA this report is structured with district wise details for the use of SDMA and DDMA rather than thematic detailing. Geotechnical studies, geochemical studies and geophysical studies conducted were explained in respective districts where these were conducted. Also, mitigation studies conducted in few places were also discussed in respective district chapters.

Methodology

Primary and secondary data will be collected and analysed for this study. Extensive field data regarding the occurrence of soil pipes will be collected.

The secondary data will be collected from the inputs from village offices, taluk offices, new paper reports, SDMA and field surveys etc. will be the basis for data base upgradation. GIS data will be used to demarcate the infrastructure like roads, public buildings, etc affected by soil piping. Field inspection will be conducted at all such localities. Site specific mitigation studies of selected sites will be carried out based on chemical / dispersion studies of the samples also dewatering designs will be made for the selected areas where detailed studies are done. Geotechnical inputs from civil engineering colleges collaborating with this programme will be utilised for mitigation studies.

In order to delineate piping affected / prone areas field surveys were carried out to identify various types pipes, pipe outlet with deposits, water sprouts, land disturbances due to land subsidence reflected as ground and wall fissures etc. Chemical analysis of soil and XRD of Clay will help to pin point more accurately the areas with dispersive soils. Geophysical methods such as multi rod electrical resistivity surveys and ground penetrating radar will help to delineate already occurring subsurface tunnels and cavities. But here such surveys were carried out only a few selected sites. For delineating the prone areas larges field surveys and secondary data sets were used.

Field surveys conducted across the state were intended to map the areas with different types of pipes. The occurrence of pipes will indicate the severity of soil piping the area. Field surveys mainly looked for various types of pipes in the laterite cuttings, well sections, pipe out lets in the valleys in the form of springs, occurrence of caves and tunnels beneath the ground, indications of land subsidence etc. In the NDMA funded project a classification scheme of pipes was attempted. The study had brought out four stages of formation of pipe based on the size of the pipe. The following classification by Sankar et al 2016. The NDMA study have identified four different types of pipes commonly occurring in Kerala.

Classification of soil pipes

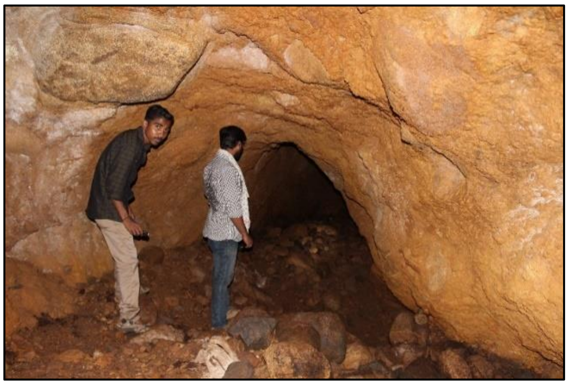
Juvenile pipes: are micro pipes**.** These pipes are indicators of soil piping activity in an area. Usually juvenile pipes are seen in the road and railway cuttings especially laterite cuttings. Presence of juvenile pipes could be used as one criterion of identifying a region as prone to piping. Many topple occurring in the laterite road/rail cuttings are caused by water saturation by the juvenile pipes. Micro pipes or juvenile pipe {figure} are the initial stage of piping. The diameter of pipe is ranges from few mm to 5cm. Clayey and lateritic soils are favourable for the formation of juvenile pipes.

Figure 2.1 Micro (Juvenile) pipe.

Younger pipes: are small pipes. Small pipes (Figure) are the second stage of development of the soil pipe. This type of pipes is seen in the laterite road / rail cuttings. Conducts water and there by saturates the laterite cutting there by promoting toppling. Presence of small pipes in road cuttings promote toppling in the lateritic area after being saturated during monsoon rains. The small pipes in an area also indicates that the soil is prone to soil piping. The diameter of small pipes ranges from >5cm to 30cm, it may combine together or individually developed as the formation of small pipe. This type of pipe is seen nearby Banasurasagar dam in figure b, is indicative of the dispersive soils occur in that area.

Figure 2.2 Small (Younger) pipe

Typical pipes: are mature pipes. Mature pipe (Figure 2.3) 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 types of pipes are common in the affected localities. In Kerala Kottathalachimala (Kannur), Iritty, Tattekanni (Idukki) are typical examples.



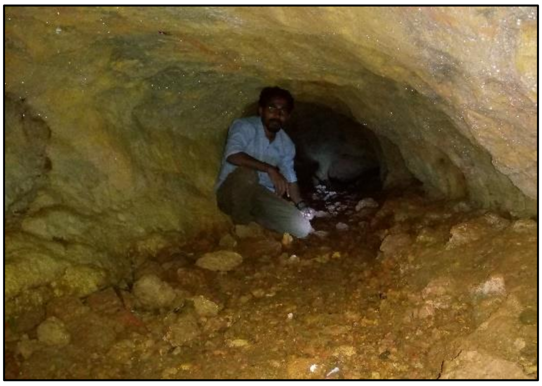


Figure 2.3 (Typical pipes (mature pipe)

Oversized pipes: are huge pipes. It is the final stage of pipe after development of a typical pipe. The diameter of huge pipe (Figure 2.4) 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 where hard duricrust is developed in deep lateritic terrains. Usually oversized pipes occur where the thickness of the lithomarge clay is high.

Figure 2.4 Over sized pipes (huge pipes)

For zoning an area in terms of soil piping susceptibility the following aspects were considered

Affected and probable areas

1. For classifying areas as "Affected areas"

lateritic terrains with dispersible clay at the bottom are ideal location for the development of soil pipes. Areas developed with tunnelling and related roof collapse, out let in the form of water sprouts, development of ground fissures on ground and walls etc are classified as affected areas. From selected areas clay samples taken from these areas will show dispersion when water is added. Two or three types of pipes are usually seen in critically affected regions. For example, Juvenile pipes, younger pipes with occur along with typical or huge pipes. These areas will have water sprouts in the valleys with sufficient sediment discharge.

In the critically affected areas infrastructure such as roads, buildings etc will be affected. Restrictions on high rise buildings or detailed surveys before the construction id needed. A proper water management plan should be developed for restricting the spread of soil piping. Geophysical surveys are suggested for locating large and typical pipes**. Laterite mining the**

depth must restricted well above (at least 1m) the lithomarge clay layer is recommended. In no case clay layer should be exposed for water to infiltrate.

2. For classifying areas as "Probable areas"

These are areas prone to soil piping or mildly affected regions. In these areas juvenile and younger pipes are developed as an indicator of soil piping processes happening there. In such places well sections and laterite cutting are to be examined in detail for pipes and caves. Geophysical surveys may not help in identifying juvenile and younger pipes as they are smaller in size. Water management practices and usage of lime powder in the soil will retard the soil piping activities.

3. Non-Affected areas

Topographically low areas, mainly non-lateritic areas like coastal plains and areas where no significant development of clay layers in the soil profile. Least probable areas. Areas where no history of pipe development. Unsuitable topography for creating a hydraulic head in connection with a clay layer etc. Coastal planes, laterites in the southern districts are generally not much prone to soil piping

Study Area

The studies conducted by NCESS (Sankar et al 2016) revealed that the Western Ghats and its foot hills are prone to soil piping. As a follow up the NCESS study this study also covered the Western Ghats and its foot hills area falling in the state of Kerala. In Kerala except the coastal district of Alappuzha all the other 13 districts have a portion Western Ghats on theeastern border. (figure 2.5) in this study apart from Western Ghats, its foot hills, midland lateritic plateaus etc were also considered for study. The districts which are affected by soil piping, the entire district was subjected to study

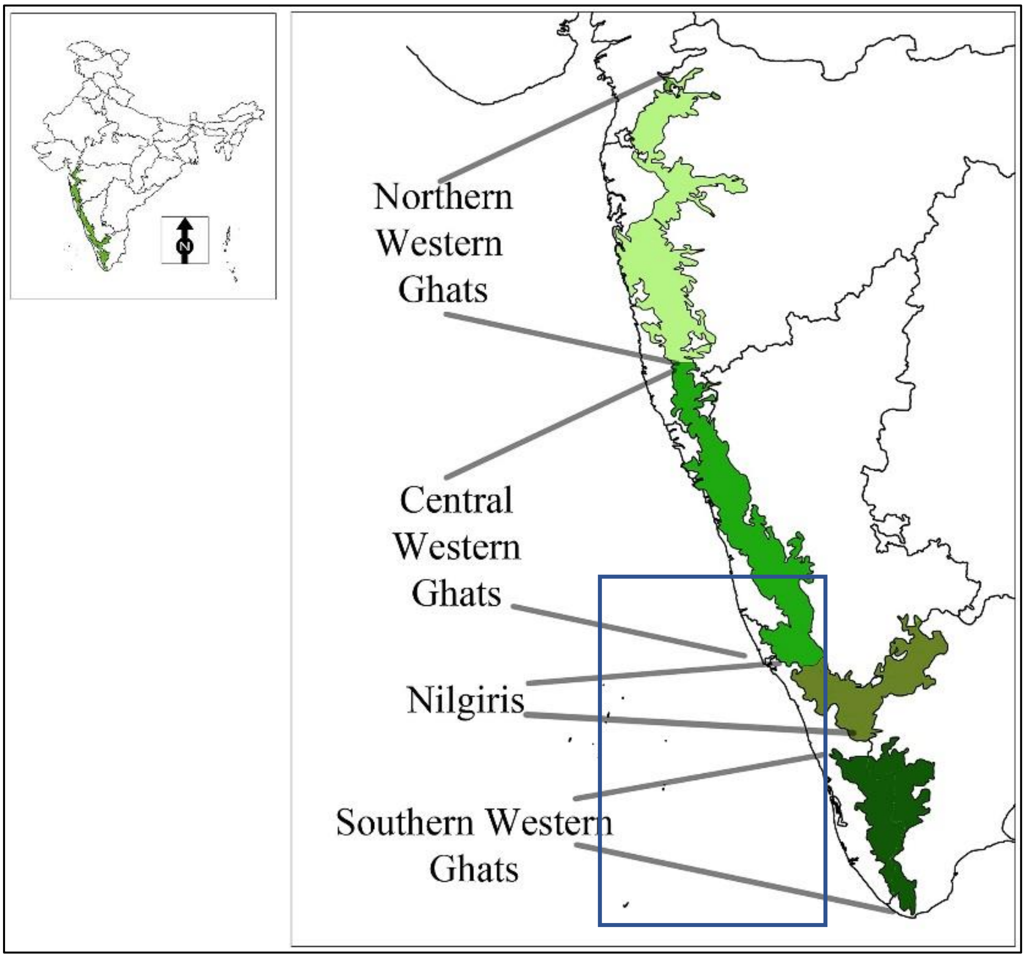


Figure 2.5 Study Area map

In this study, apart from state wise details district wise details also data presented. This will help the SDMA and DDMA for taking actions for preventing problems related to soil piping.

Chapter 3
Soil Piping affected areas in Kerala

Introduction

Soil piping is prominent in the highlands and foothills of the state.it rarely occurs in the plains. i.e it occurs mainly in the Western Ghats However it will occur in other places also if the conducive geo environmental – climatic factors exists. It is also more dominant in the lateritic areas. In 2005 NCESS (then CESS) has investigated (Sankar 2005) a major land- subsidence reported in the Chattivayal locality of Thirumeni village, Kannur, Kerala. It was found out to be due to soil piping. At that time, it was believed that it may be an isolated incidence. But subsequently many such incidences were reported from other localities in Kerala. Soil piping related land subsidence incidences were reported from all districts of Kerala except Aalapuzha, and Kollam. Major and minor incidences were reported from Kasaragod (Nelliyadukkam, Kolichal, Kuttikol), In Kannur, Chattivayal, Kottathalachimala, Cherupuzha, Iritty), Pasukkadavu (Kozhikode), Padinjarethara, Tavinjal and Kunnamangalam Vayal (Wayanad), Venniyani mala, Peringasseri, Tattekkani and Karuppilangad, Udayagiri, Upputhara (Idukki) and Pampa valley (Pathanamthitta), Perumannaaklari, Pandikadu, Irumbuzhi (Malappuram). There are minor incidents reported from Palakkayam (Palakkad), Mulanthuruthi (Ernakulam), Pasukasdavu (Kozhikode), Talanad (Kottayam). Among the districts in Kerala Kasaragod, Kannur and Malappuram are severely affected by soil piping (Table 3.1 and 3.2). whereas Wayand, Idukki Kozhikode and Thrissur have wide spread occurrences. There are many incidents of land subsidence have occurred in these districts. Topographical disposition, meteorological inputs, soil properties and landuse etc are factors favouring pipe development. Districts such as Palakkad, Pathananthitta, Ernakulam, and Thiruvananthapuram have few incidents. No major incidents are reported from Kottayam, Kollam or Alappuzha districts. The incidents that have occurred in the state have indicated in the geological map of Kerala (fig 1). The map shows the dominance of incidences in the northern part of the state where laterite is well developed.

The following chapters describe the piping incidences in different districts of the state in detail. The table and map (fig3.1) indicate that the northern districts are more severely affected by soil piping compared to the southern districts. The prominence of lateritic mesa / plateaus in the north Kerala may be one of the reasons for the high occurrence of such incidences. Apart from the occurrence of lateritic mesas these areas receive high rainfall also in comparison with the southern districts.

Table 3.1 Soil piping affected Districts in Kerala

Sl.no	Districts	Soil piping related land degradation	Remarks
1	Kasaragod	Affected by (OS/MP/SP/JP)	Severe
2	Kannur	Affected (OS/MP/SP/JP)	Severe
3	Malappuram	Affected (OS/MP/SP/JP)	Severe
4	Wayanad	Affected (MP/SP/JP)	Wide spread
5	Idukki	Affected (MP/SP/JP)	Wide spread
6	Thrissur	Affected (/SP/JP)	Wide spread
7	Kozhikode	Affected (SP/JP)	Wide spread
8	**Palakkad**	**Affected (SP)**	**Sporadic**
9	**Pathanamthitta**	**Affected (MP)**	**Sporadic**
10	**Ernakulam**	**Affected (JP)**	**Sporadic**
11	**Thiruvananthapuram**	**Affected (MP/SP)**	**Sporadic**
12	**Kottayam**	**Affected (JP)**	**Least**
13	**Kollam**	**No reports**	**No incidents**
14	**Alappuzha**	**No Reports**	**No incidents**

OS: Oversized pipes, MP: Mature pipes, SP: Small pipes, JP Juvenile pipes

(Based on data available up to DEC 2019)

The area is also dominated by the presence of a number of laterite quarries which in olden times used to mine up to the lithomarge there by exposing the clay layer. The rainwater collected in the quarry pits gets easy access to the clay layer which will in turn make path ways for water under the influence of hydraulic head due to water collected in the quarry pits.

Soil piping is wide spread in the northern districts of the state where as it is not that significantly developed in the southern districts. Since soil piping is clay mineralogy and soil chemistry rather than lithological aspects these soil pipes are developed irrespective of the basement lithology. However, in the south of Achankovil shear where Khondalatic rocks are predominant the soil piping incidences are less (fig 3.2). In Thiruvananthapuram district only one major piping related subsidence is reported. Incidences are more where ever the laterite capping are well developed. That may be the reason for the increased number of incidences in the north. In the coastal district of Aalappuzha where the coastal tertiaries are developed the incidences are not reported.

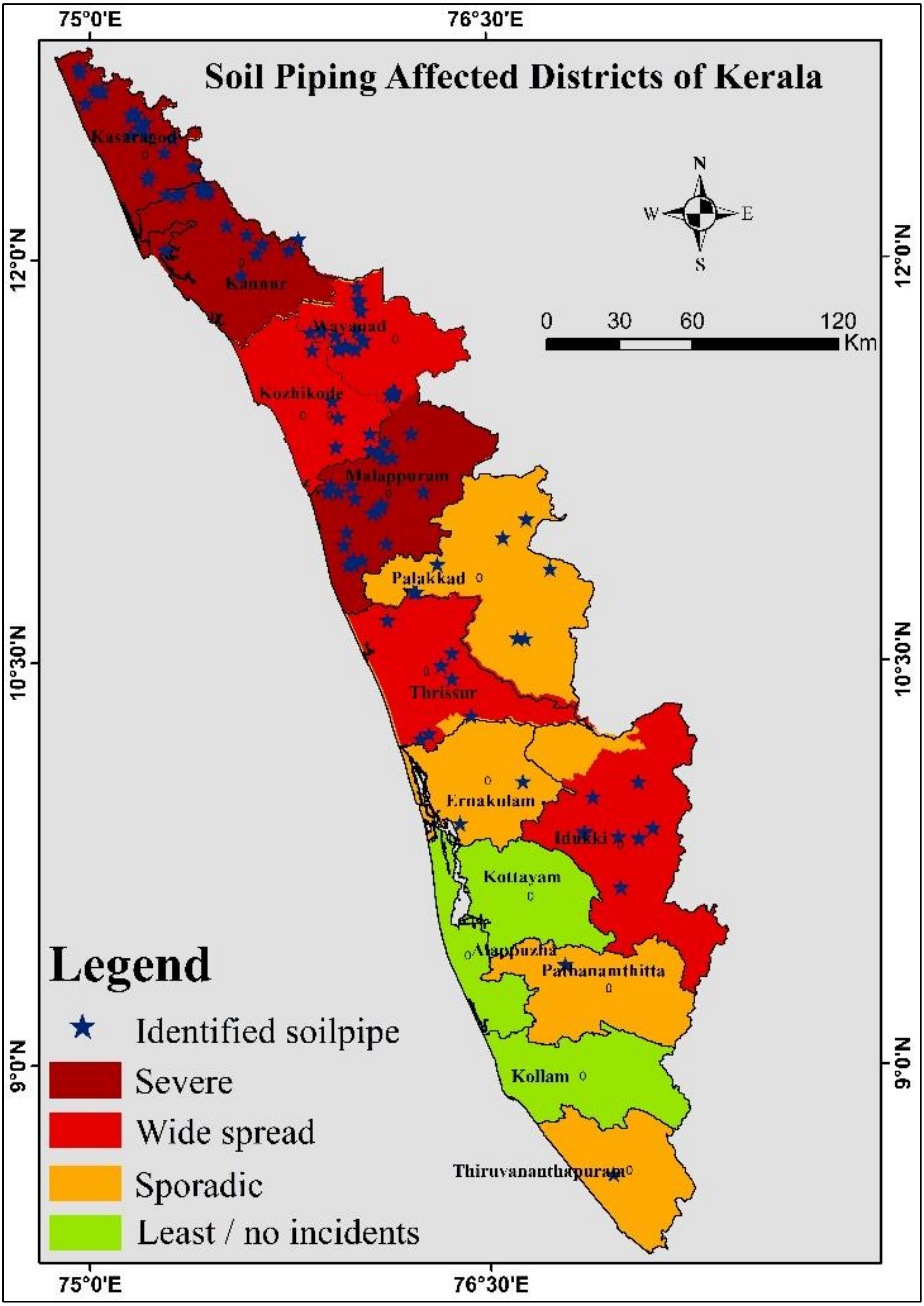


Figure 3.1**:** District map of Kerala with identified piping locations

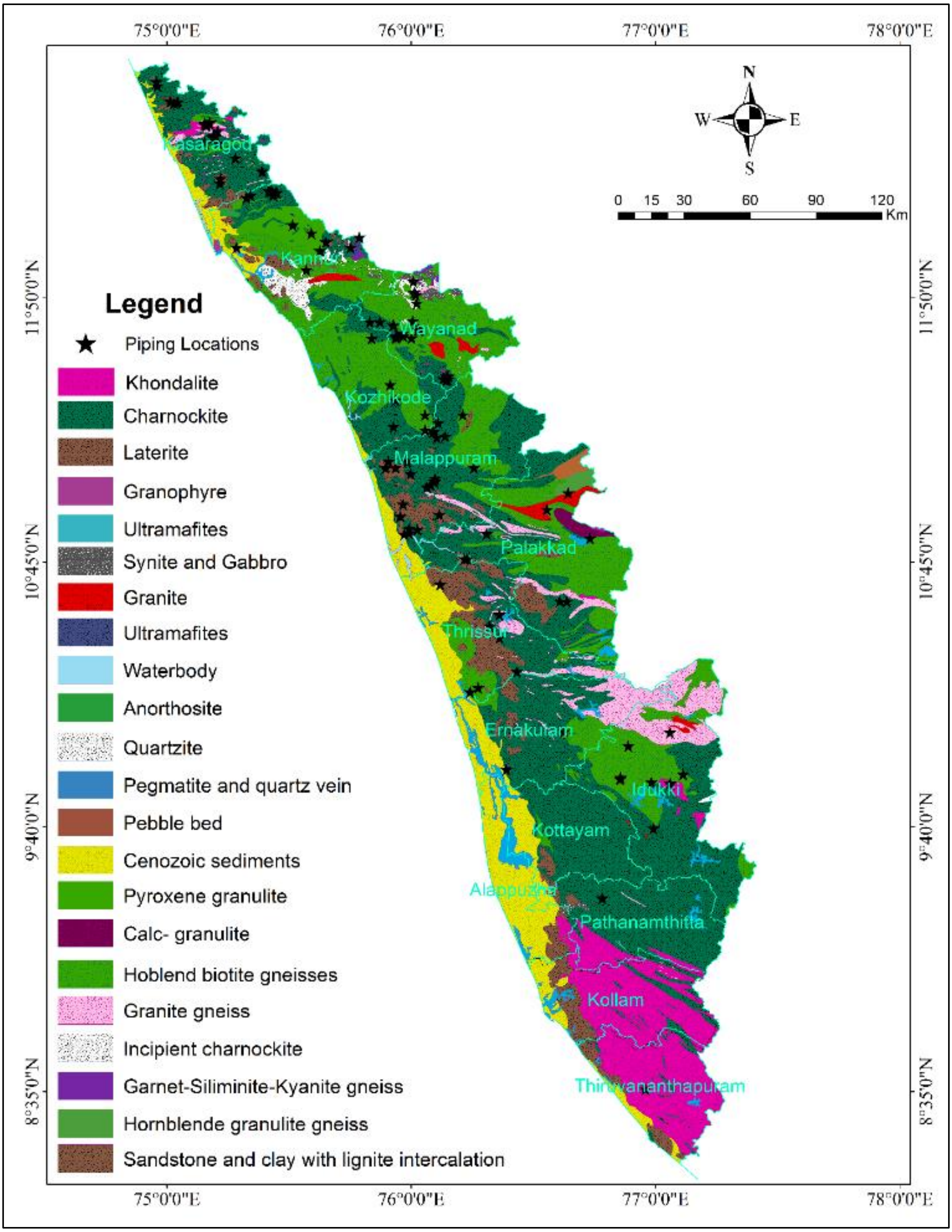


Figure 3.2: Geology map of Kerala with identified piping locations

(Based on data available up to DEC 2019) (geology map modified after Geological Survey of India)

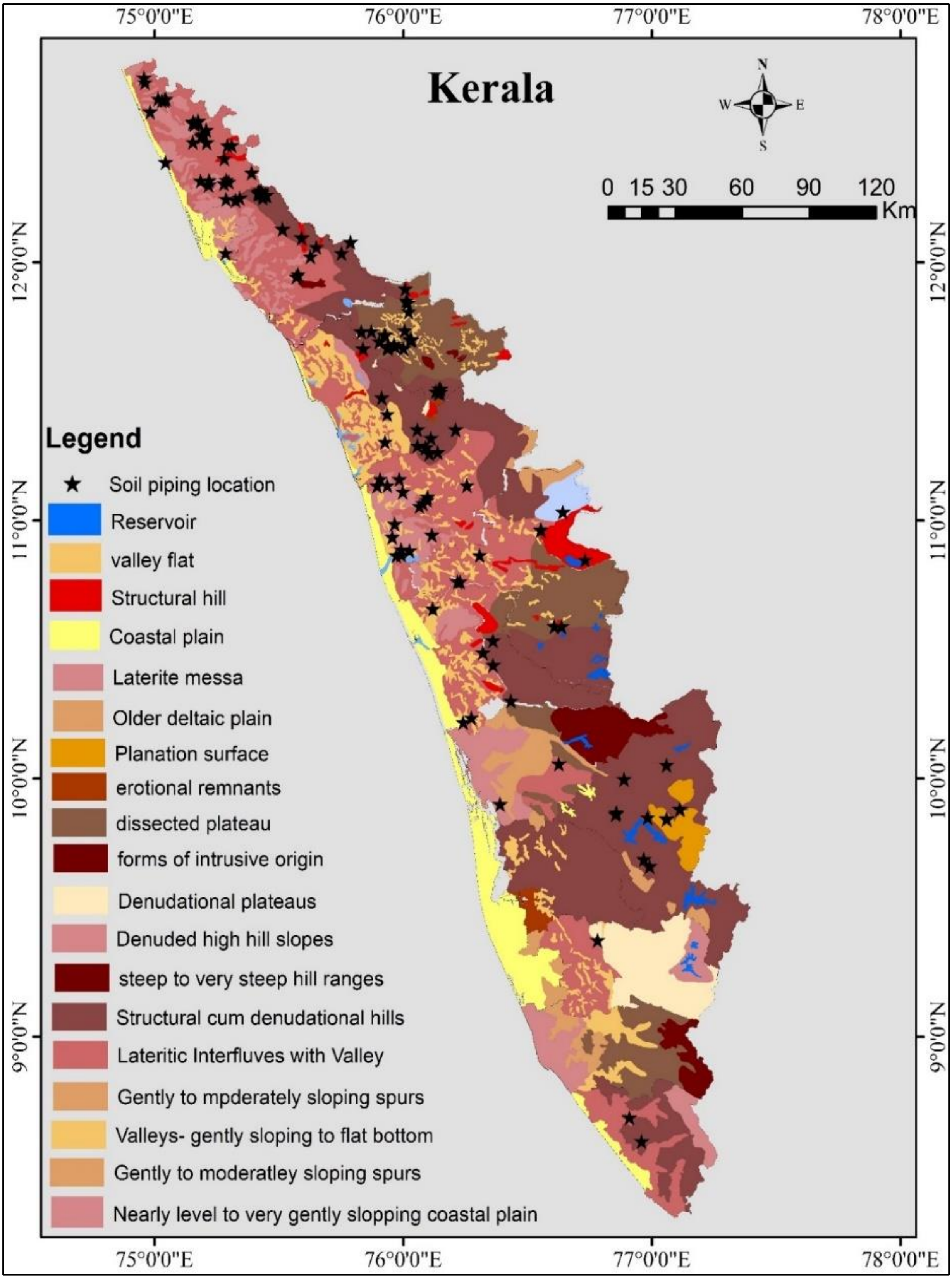


Figure 3.3: Geomorphology map of Kerala with identified piping locations

(Based on data available up to 2019) (Geomorphology map modified after Geological Survey of India)

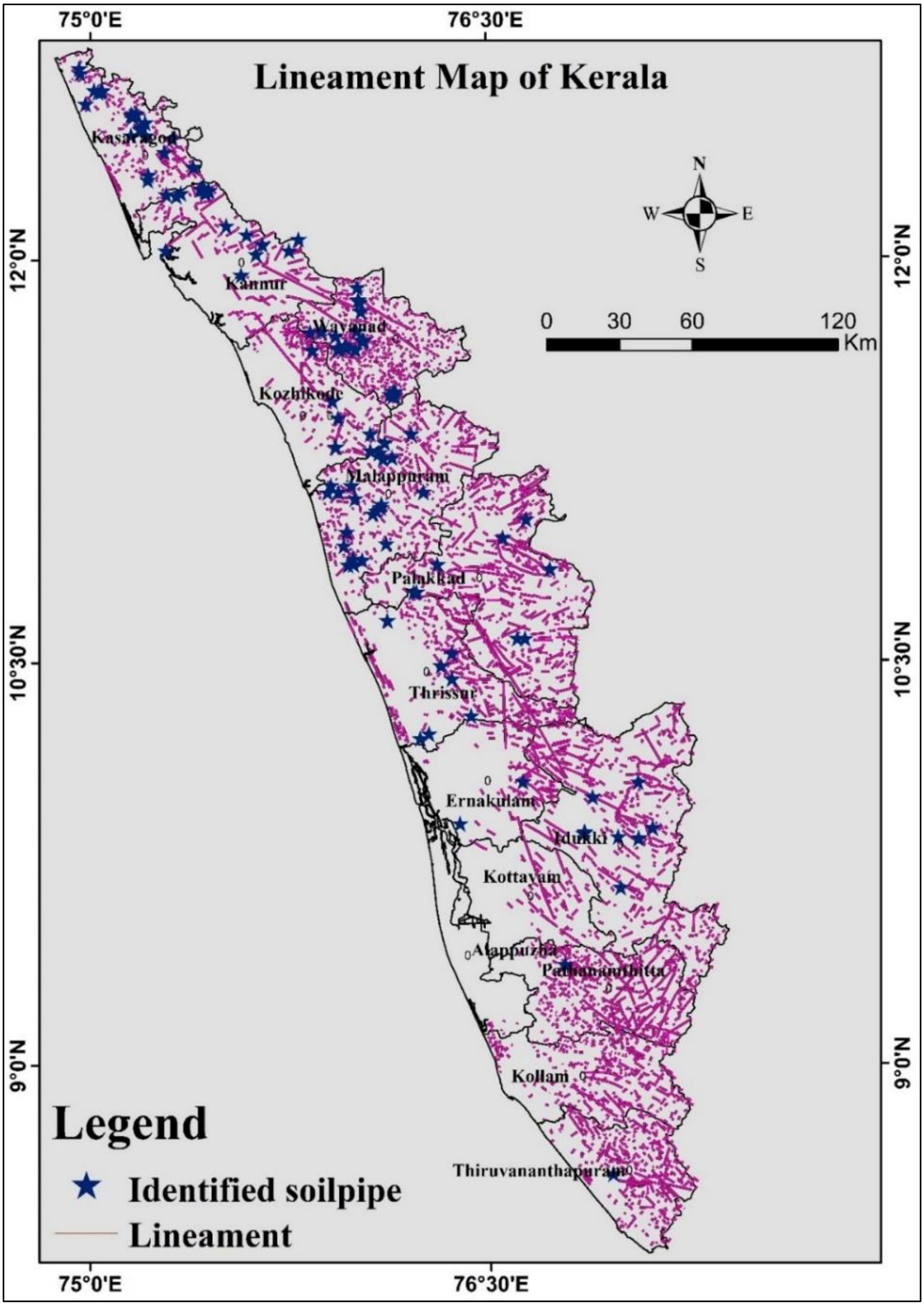


Figure 3.4**:** Lineament map of Kerala and piping locations

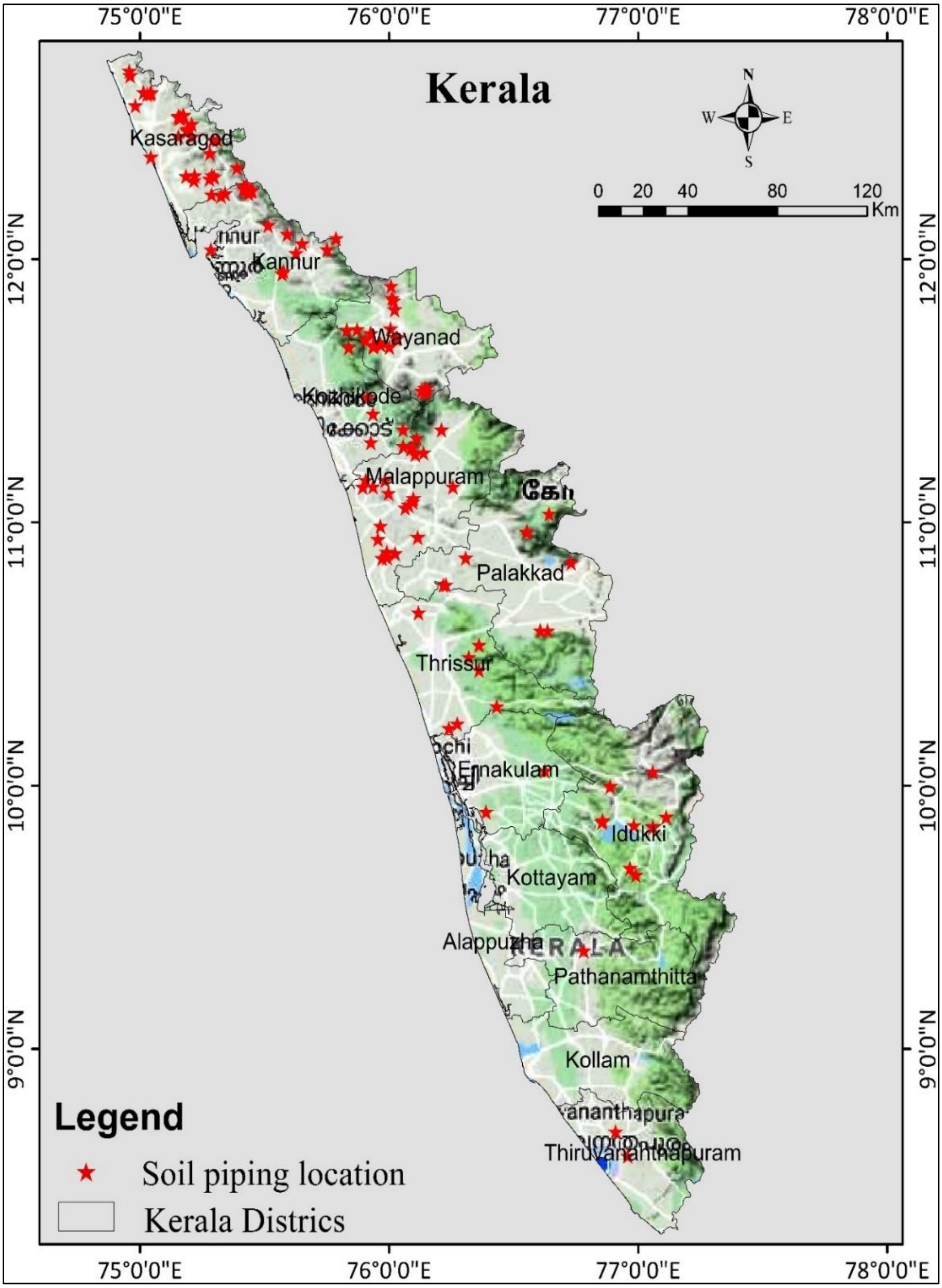


Figure 3.5: Terrain map of Kerala with identified piping locations

As mentioned before soil piping is more common in Lateritic terrains as indicated in the fig 3.3. Incidences are very less in structural hills and coastal plains. Subsidences are common where the break in the slope is observed. Pipe outlets are observed in the laterite interfluve with valley. Piping related subsidence are common in lateritic mesas (Kasargod / Kannur/Malppuram districts). There were many debates and discussion about the role of recent tectonics or neo-tectonics in the formation of soil pipes. A correlation was made by plotting the piping locations with lineament map of the state. A clear-cut influence of these structural aspects with soil pipes are observed (fig 3.4).

Terrain map derived from google map was also corelated with the piping incidences (fig 3.5). As mentioned earlier there is a definite correlation between the terrain and the piping incidences. The laterite mesa or table top topography is more prone to subsidence due to soil piping. The pipe out let is usually observed in the valleys or slopes. Water under high hydraulic pressure in contact with lithomarge clay beneath the lateritic column is an ideal locus for the development of soil pipes.

A compilation of the soil piping incidences reported from various places in the state up to December 2019 was made by this team is presented below in Table 3.2. There are 139 locations identified as soil piping related feature and studies were conducted at critical locations. SEOC in collaboration with the Department of Mining and geology and Soil conservation department were instrumental in collecting data during 2018 and 2019 extreme rainfall events in the state.

Table 3.2: Location details of the soil pipes reported up to December 2019

Sl. No	Place	District	Location	
			Longitude	Latitude
1	Mali Cave	Kasaragod	75.15997222	12.53541667
2	Poovadukka	Kasaragod	75.16333333	12.53730556
3	Mudamkulam	Kasaragod	75.15433333	12.53919444
4	Adukkam	Kasaragod	75.15527778	12.54408333
5	Parthakochi	Kasaragod	75.17558611	12.54713889
6	Parthakochi-B	Kasaragod	75.172675	12.54369722
7	Bethurpara-Ama	Kasaragod	75.19025	12.48647222
8	Bethurpara	Kasaragod	75.19025	12.48688889
9	Bethurpara	Kasaragod	75.19033333	12.48708333
10	Bethurpara	Kasaragod	75.19144444	12.48711111
11	Bethurpara-Komali	Kasaragod	75.19425	12.49522222
12	Bethurpara-Komali	Kasaragod	75.18947222	12.4905
13	Kalakkara	Kasaragod	75.20961111	12.46452778
14	Kalakkara	Kasaragod	75.20825	12.51275
15	Theerthakkara	Kasaragod	75.15455556	12.46586111
16	Ananthapura Temple	Kasaragod	75.98194444	12.58316667
17	Mundayatheduka	Kasaragod	75.0455	12.63322222
18	Mundayatheduka-padjate	Kasaragod	75.04077778	12.62797222
19	Mundayatheduka	Kasaragod	75.02925	12.62708333

20	Angadi mugor	Kasaragod	75.01455556	12.63377778
21	Meenja	Kasaragod	74.95744444	12.71472222
22	Kedengod	Kasaragod	74.96133333	12.69705556
23	Poossadi Gumpe	Kasaragod	74.02633333	12.67155556
24	Kizhakanodi	Kasaragod	75.21980556	12.31769444
25	Nelliyadukkam	Kasaragod	75.21736111	12.29944444
26	Pallikara	Kasaragod	75.04422222	12.03772222
27	Erinjilakodu	Kasaragod	75.28544444	12.03591667
28	Mattankadavu	Kasaragod	75.39022222	12.34736111
29	Balal	Kasaragod	75.281092	12.402252
30	Kottathalachimala	Kannur	75.43575	12.2500
31	Kottathalachimala	Kannur	75.43022222	12.26666667
32	Kottathalachimala	Kannur	75.42272222	12.26666667
33	Kottathalachimala	Kannur	75.41727778	12.26666667
34	Chattivayal	Kannur	75.43575	12.25947222
35	Tabore	Kannur	75.45005556	12.26052778
36	Thirumeni	Kannur	75.44602778	12.2600
37	Padiyottuchal	Kannur	75.34269444	12.24978056
38	Vayakkara	Kannur	75.78775	12.24502778
39	Ummrampoyil	Kannur	75.326	12.23991667
40	Niranganpara	Kannur	75.75199722	12.03594167
41	Thermala*	Kannur	75.62704	12.02237
42	Ayyanmada	Kannur	75.514977	12.12856
43	Manippara	Kannur	75.651073	12.05879
44	Ettupara	Kannur	75.591884	12.09484
45	Muttannur	Kannur	75.570688	11.94443
46	Vayakkara	Kannur	75.78775	12.07836
47	Pasukadavu	Kozhikode	75.83833333	11.66472222
48	Cheerankunnu*	Kozhikode	76.057522	11.289625
49	Paloramala*	Kozhikode	75.892176	11 354301
50	Muthuplav*	Kozhikode	75.936	11.4115
51	Poyilamchal*	Kozhikode	11.42443	75.43556
52	Kandirathukkal*	Kozhikode	75.914116	11.47512
53	Kakkadampoyil*	Kozhikode	76.111471	11.31902
54	Kannappankundu*	Kozhikode	75.927	11.3037
55	Panakkachal*	Kozhikode	76.056762	11.351953
56	Kozhikode*	Kozhikode	75.5615	11.2751
57	Padinjarethara	Wayanad	75.967737	11.673986
58	Valamthode	Wayanad	75.83131	11.73136
59	Wayanad	Wayanad	75.963315	11.682935
60	Wayanad	Wayanad	76.01892	11.84256
61	Wayanad	Wayanad	75.963315	11.682935
62	Wayanad	Wayanad	76.018.1	11.5033
63	Ambedkar colony*	Wayanad	76.148507	11.496003
64	Elavayal*	Wayanad	76.151082	11.509125
65	Kasmeeram*	Wayanad	76.144534	11.50927
66	Pachakkad*	Wayanad	76.131099	11.499148
67	Padavettikunnu*	Wayanad	76.14303056	11.49323056
68	Vaipadi*	Wayanad	76.001802	11.666087
69	Kappikkalam karakkozhuppil*	Wayanad	75.93725	11.67327778
70	Kappikkalam mangothukunnu*	Wayanad	75.94030556	11.67408333
71	Kappikkalam*	Wayanad	75.93819444	11.6665
72	Kappikkalam kuttiyamvayal-1*	Wayanad	75.93730556	11.67063889
73	Manthanamkunnu*	Wayanad	76.008716	11.897404
74	Thacharakolly-2*	Wayanad	76.012756	11.851537
75	Varadimoola-2*	Wayanad	76.02259	11.808366
76	Arimandhamkunnu colony*	Wayanad	76.00659	11.735431

77	Kurumbalakotta kurushsumala thazhe colony*	Wayanad	76.029347	11.698171
78	Kurumbalakotta-Josheph mangudiyil veedu bagam*	Wayanad	76.029119	11.702382
79	Kurumbalakotta-KWA water house west*	Wayanad	76.034564	11.700274
80	Mangalasserymukku-Pulinjan nellikkayal*	Wayanad	75.92585	11.717585
81	Mangalassery pulinjan enallikkaichal nellanikott (mathayi area) *	Wayanad	75.928206	11.718232
82	Challi meenmutty 1*	Wayanad	75.872726	11.732883
83	Irubuzhi	Malappuram	76.09625	11.07777778
84	Manjeri	Malappuram	76.09811111	11.09044444
85	Chembrasserri	Malappuram	76.25683333	11.13527778
86	Kottaykkal	Malappuram	75.96616667	10.98608333
87	thehnipalam, calicut university	Malappuram	75.8953	11.1340
88	Alathurpadi	Malappuram	76.079435	11.065311
89	Changili mada	Malappuram	76.02536111	10.88236111
90	Nava mugundha HSS	Malappuram	75.99147222	10.86769444
91	Nava mugundha HSS	Malappuram	75.99277778	10.86711111
92	Kodakkal	Malappuram	75.97222222	10.86372222
93	Iringavur	Malappuram	75.95613889	10.93569444
94	Chembrassery	Malappuram	76.25675	11.13519444
95	Mutiyel	Malappuram	76.21122222	11.35205556
96	ekkaparamb	Malappuram	75.98444444	11.15944444
97	pang	Malappuram	76.11536667	10.94355
98	alappara mala	Malappuram	76.08916667	11.28277778
99	malappuram	Malappuram	75.99186	10.88703
100	Chekkunnu mala, Chairangad colony area*	Malappuram	76.104833	11.258639
101	East chathallur (Cholara colony Kappakallu) *	Malappuram	76.139027	11.264022
102	Alappura*	Malappuram	76.090463	11.28113
103	Valiyangadi*	Malappuram	76.065249	11.054877
104	NH colony*	Malappuram	75.99828	11.110805
105	Vettilpurayil*	Malappuram	75.936208	11.135492
106	Karaparambil Ward 2*	Malappuram	75.90748	11.16041
107	palakkayam	Palakkad	76.554994	10.964245
108	Kottakunnu*	Palakkad	76.307887	10.864883
109	Parachathi*	Palakkad	76.731817	10.846688
110	Kuruvanpady*	Palakkad	76.642977	11.032135
111	Eyyal caves	Thrissur	76.118952	10.65724
112	Ettamkallu	Thrissur	76.32075	10.48758333
113	varandharapilly panchayat	Thrissur	76.36152778	10.43891667
114	pattilamkuzhi	Thrissur	76.36138889	10.53391667
115	Thumburmuzhi	Thrissur	76.43308333	10.30091667
116	Chira colony Kizhakkemadam (Ravi, Radhakrishnan’s houses) *	Thrissur	76.22916667	10.76263889
117	Sambava colony*	Thrissur	76.219	10.76247222
118	Thazhvaram road*	Thrissur	76.24116667	10.21716667
119	Vattakotta*	Thrissur	76.27441667	10.23483333
120	Balan peedika-kodassery*	Thrissur	76.60798611	10.588825
121	Chandanakunnu Kodassery*	Thrissur	76.63700833	10.588425
122	Kothamangalam	Eranakulam	76.626265	10.05612
123	Mulanthuruthy	Eranakulam	76.389911	9.900003
124	Mavadi	Idukki	77.11286111	9.880638889
125	Mavadi	Idukki	77.11302778	9.881166667
126	Mavadi	Idukki	77.11322222	9.881333333
127	Peringassery	Idukki	76.85788889	9.867472222

128	Thattekanni	Idukki	76.88841667	9.9970
129	Venniyani Mala	Idukki	76.85466667	9.860916667
130	Mariyapuram	Idukki	76.98325	9.848683333
131	Udayagiri	Idukki	77.06019444	9.84425
132	Udayagiri	Idukki	77.05958333	9.842138889
133	Udayagiri	Idukki	77.06008333	9.841888889
134	Udayagiri	Idukki	77.05991667	9.842138889
135	Nalaam Mile	Idukki	76.9915	9.659444444
136	Pampa valley	Idukki	76.782	9.3730
137	Powerhouse division*	Idukki	77.0593	10.0517
138	Ranni	Pathanamthitta	76.782	9.373
139	Venjaramood	Thiruvanathapuram	76.95888889	8.59302778

* Data courtesy: SEOC-SDMA

The above incidences were co-related with different geo data sets to understand their influence on the soil piping process. The occurrence data was plotted against the data sets such as geological data, geomorphological data, terrain data, lineament data etc. The lithological map (fig 3.2) indicates that the soil piping and laterites have closely associated so their occurrence is more in areas where laterites are well developed. The northern districts where the duricrust / laterite with hard iron encrustations, laterites mesas (3.3) indicated higher incidence of soil piping. Southern districts in the Khondalites, garnet sillimanite gneiss, hornblende -sillimanite-kyanite gneiss and the Cenozoic sediments there were very few incidents. There was no correlation between the lineaments (fig 3.4) and the incidence of piping ruling out any control of tectonics in the formation of soil pipes. All these indicates that for soil piping to occur topographical disposition is very important. That may be the reason for the higher number of incidences in the laterite mesas. Incidences in the structural hills are very few. This may be due to the lack of sufficient over burden material in the highly sloping structural hills. The following chapters describe the piping incidences in different districts of the state in detail.

Chapter 4

Soil piping in the state-district wise analysis

4.1 Kasaragod

Kasaragod is the northernmost district of Kerala; bordering Karnataka State lies between 12º 02’- 12º 48’N latitude and 74º 51’-75º 25’E longitude with an area of1961sq.km. To its south lies Kannur District, to the South east is Kodagu district (Coorg) and to the north Dakshina Kannada district. All along its east it is walled by the Western Ghats while along the west the Laccadive Sea borders it. Kasaragod district is divided into four taluks (Kasaragod, Hosdurg, Vellarikundu and Manjeswaram) and 83 villages. The district has one revenue division, 6 Block Panchayats (Manjeshwar, Kasaragod, Kanhangad, Nileshwar, Karadka and Parappa) and 38 Grama panchayats and three Municipalities (Kasaragod, Kanhangad and Nileshwar).

Geomorphology

Physiographically the Kasaragod district have. the coastal plains to the west, the midlands and the eastern highland regions forming foothills of the Western Ghats to the east. The coastal plains with an elevation of less than 10m occur as narrow belt of alluvial deposits parallel to the coast. A number of palaeo-beach ridges are suggestive of marine regression. The coast at Bekal is rocky, whereas west of Uduma and Melparamba, it is cliffed, exposing the Warkalli Formation. To the east of coastal belt is the midland region with altitude ranging from 10 to 300 m above mean sealevel. The midland area is characterised by rugged topography formed by small hillocks separated by deep cut valleys. The terrain is characterised by flat topped or gently rolling laterite-capped upland, laterite mesas and laterite interfluves, dissection of which has led to the development of narrow flat-bottomed valleys. The midland regions show a general slope towards the western coast. The midland region is being denuded. The mesas and laterite flats are remnants of a former extensive pediplain. 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. The valley fill deposits are composed of colluvium and alluvium. To its east is the high land region. The high hills in the east are structural and denudational, with steep hills and narrow summits. The terrain in general is rugged. The high peaks in the area are situated south of Perathodi and Mozhakavalli. Chandragiri is the major river draining the district. Karyamkote River drains the southern part of the district. The area receives good rainfall, 300-350cm annually. Because of the sloping terrain and impermeable basement rocks, major part of the rainwater goes as runoff.

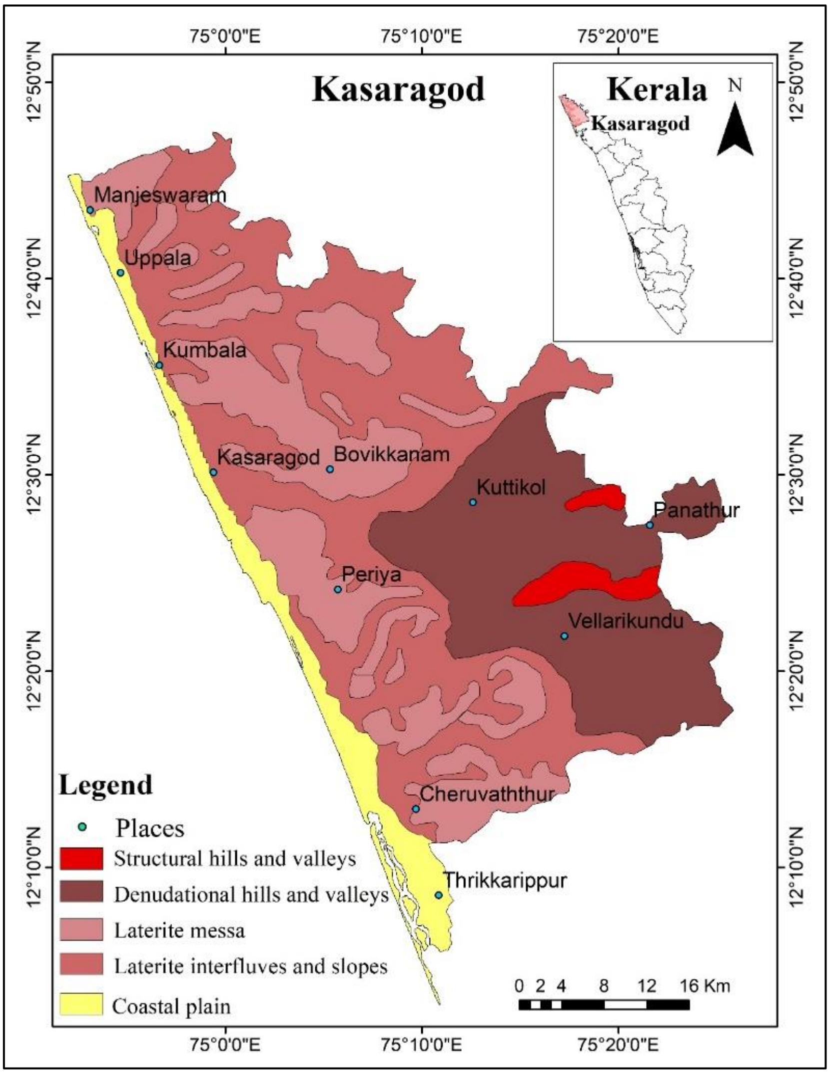


***Figure 4.1*:** Geomorphology of Kasaragod

(geomorphology map modified after District Resource map, Kasaragod district, Geological Survey of India)

Drainage

Chandragiri and Karingote Rivers are the main two river system of the district which originates from the eastern highland and flowing towards the west to join the Lakshadweep Sea. The district is drained by seven other rivers which are minor in nature. Most of the rivers have an east to west trend.

Rainfall and climate

The district receives an average of about 3500 mm rainfall annually. The major source of rainfall is southwest monsoon from June to September which contributes nearly 85.3% of the total rainfall of the year. The northeast monsoon contributes nearly 8.9% and balance of 5.8% is received during the month of January to May as pre-monsoon showers. Out of the 106 rainy days in a year, 87 rainy days occur during south west monsoon season.

The temperature is more during the months of March to May and is less during December and January. The average monthly maximum temperature ranges from 29.2 to 33.40 C and minimum temperature ranges from 19.7 to 25^0 C.

Land use

The population is mainly agrarian and the major crops raised are coconut, arecanut, cashew, rubber, paddy, pepper etc. Kasaragod district is having cash crops as its main stay compared to food crops. Coconut is the single largest crop in the district.

Geology

The Kasaragod district is broadly divisible into five geological belts. (Geological Survey of India)

1. Northern gneissic belt
2. A syenite pluton in central part,
3. Southern charnockitic rocks which extends further south
4. Isolated capping of sedimentary rocks (Warkalli Formation) confined to the coastal tract
5. Quaternary sediments of the coastal plain.

The district forms a part of the Precambrian metamorphic shield, major part of which is occupied by Archaean rocks. Along the western margin, patches and isolated cappings of Warkalli Formation and low-lying Quaternary alluvial deposits are seen. Both the Archaean and Tertiary rocks have been intensely lateritised. The important basement rocks in the area belong to Khondalite Group, Charnockite Group, Wayanad Schist Complex and Peninsular Gneissic Complex. The Khondalite Group comprises quartz-graphite schist, quartz-feldspar-garnet-sillimanite schist and associated amphibolite with abundant flakes of graphite and it occurs as bands and lenses within hornblende-biotite gneiss. The predominant rock in the south is Charnockite. The other member of Charnockite Group, namely hornblende granulite has limited outcrops near Mullaria. Quartzo-feldspathic gneiss of Peninsular Gneissic Complex is the major rock in the north and it is foliated. Along the east, rocks of Wayanad Group, comprising fuchsite quartzite, garnetiferous quartzite and quartzite are exposed. They occur as vestiges within high-grade gneiss and charnockite.

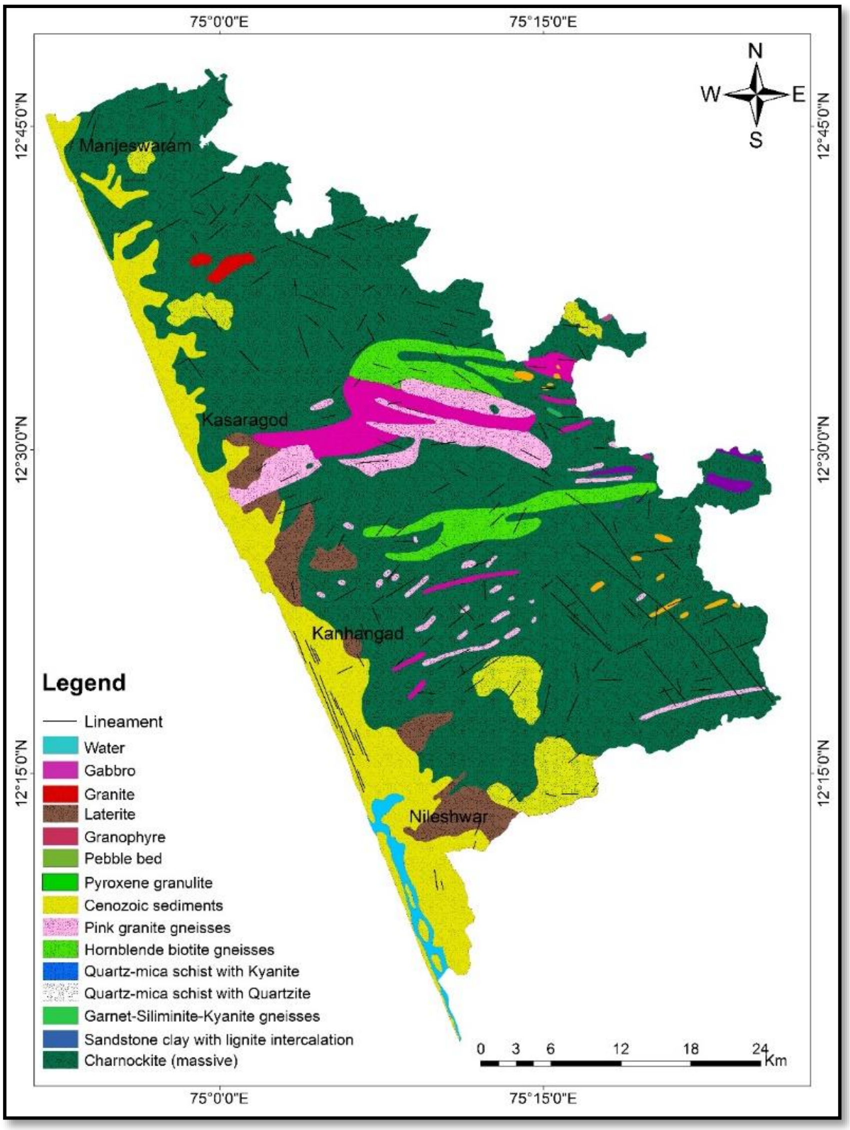


Figure 4.1**:** Geology of Kasaragod

(geology map modified after District Resource map, Kasaragod district, Geological Survey of India)

An anorthosite massif occurs along the southern border of the district, a major part of the massif is in the adjacent Kannur district. It is emplaced into pyroxene granulite/charnockite. Around Angadimogar, a large syenite pluton is emplaced, which varies in colour from pink to grey. Both varieties are medium-to coarse-grained and lack foliation. There is a granite body which is in the form of perched blocks and tors. Numerous dolerite dykes trending NNW-SSE traverse the older rocks. In the west the basement rocks are unconformably overlain by Late Tertiary (Neogene) sedimentary rocks, the Warkalli Formation, which is sporadically distributed. It comprises impersistent and alternating beds of grit, sandstone, clay and carbonaceous clay with or without lignite. Occasionally a pebble bed is also noticed. Laterite is a major litho unit of the district, covering all the rock formations except the Quaternary. It is hard, ferruginous and bauxitic at places. Its thickness varies from 5 to 15m. Unconsolidated Quaternary sediments, mostly comprising sand or admixture of sand, silt or clay occupy the coastal plain and valley floors. They have been classified into different units based on their environment of formation, morphological character and lithic content. They are palaeo-marine deposit (Guruvayur Formation), fluvial deposit (Periyar Formation), fluvio-marine deposits (Viyyam Formation) and beach and barrier beach deposits (Kadappuram Formation). **(Reference: District survey report of minor minerals by Department of Mining and Geology)**

Soil types

The soils in Kasaragod district have been classified in the following four types, based on the morphological features and physiochemical properties. (i) They are Lateritic Soil, (ii) Brown Hydromorphic Soil, (iii) Alluvial Soil and (iv) Forest Loam. The most predominant soil in the district is Lateritic soil and it occurs in the midland and hilly areas and it is derived from laterites. Brown hydromorphic soil is confined to the valleys between undulating topography in the midlands and in the low-lying areas of the coastal strip. The Brown hydromorphic soil has been formed as a result 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 with rich organic matter seen as surface layers in the eastern hilly areas of the district and are

characterised by a surface layer rich in organic matter.

Ground water scenario

Groundwater occurs under water table conditions in alluvium, laterites and weathered mantle of the crystallines, where as in the deeper fractured crystallines the groundwater occurs under semi confined to confined conditions. The physiographic set up and geological formations are same for Manjeshwar, Kasargod, Kanhangad and Nileshwar blocks, (the block area starts from the coast and ends on midland areas. The block area of Karadka and Parappa starts from midland on west and ends as hilly area on the east. Alluvium occurs as narrow strips parallel to the coast and the width increases from the northern part of Kanhangad block to southern part of Nileshwar block and around Trikaripur of Nileshwar block. In Kasargod and Manjeshwar blocks alluvium occur as isolated patches close to the coast and have limited thickness. The crystalline formations having phreatic aquifer is found mostly in Karadka and Parappa blocks.

Soil Piping in Kasaragod District

Kasaragod district has presently reported by 29 soil pipes throughout the district and in which most of them are major and oversized. Three pipes have affected the infrastructures as well as the public. The remaining located pipes also may enlarge, collapse and subsided in future. The location and details of the soil pipes are given below

Table 4.1: Piping Locations in Kasaragod District

Sl. No	Name	Location		position	Status	Remarks
		Latitude	**Longitude**			
1	Mali Cave	N12° 32'7.5''	E75° 9'35.9''	Inside Forest	Oversized pipe	
2	Poovadukka	N12° 32'14.3''	E75° 9'48.0''	Inside Forest	Matured pipe	Collapsed
3	Mudamkulam	N12° 32'21.1''	E75° 9'15.6''	Laterite quarry	Juvenile Pipes	Likely to happen
4	Adukkam	N12° 32'38.7''	E75° 9'19''	Populated region	Matured pipe	Opening filled manually
5	Parthakochi	N12° 32'49.7''	E75° 10'32.11''	Less populated region	Matured pipe	
6	Parthakochi-B	N12° 32'37.31''	E75° 10'21.63''	Less populated region	Matured pipe	Opening filled manually
7	Bethurpara-Ama	N12° 29'11.3''	E75° 11'24.9''	Populated region	Oversized pipe	
8	Bethurpara	N12° 29'12.8''	E75° 11'24.9''	Populated region	Matured pipe	Inside the well
9	Bethurpara	N12° 29'13.5''	E75° 11'25.2''	Populated region	Outlet	Active, Outflows water
10	Bethurpara	N12° 29'13.6''	E75° 11'29.2''	Populated region	Outlet	Active, Outflows water
11	Bethurpara-Komali	N12° 29'42.8''	E75° 11'39.3''	Populated region	Oversized pipe	
12	Bethurpara-Komali	N12° 29'25.8''	E75° 11'22.1''	Populated region	Oversized pipe	Active, Outflows water
13	Kalakkara	N12° 27'52.3''	E75° 12'34.6''	Populated region	Matured pipe	Mature and long tunnel
14	Kalakkara	N12° 30'45.9''	E75° 12'29.7''	Less populated region	Outlet	
15	Theerthakkara	N12° 27'57.1''	E75° 9'16.4''	Inside Forest	Matured pipe	
16	Ananthapura Temple	N12° 34'59.4''	E75° 58'55.0''	Temple	Juvenile Pipes	
17	Mundayatheduka	N12° 37'59.6''	E75° 2'43.8''	Less populated region	Matured pipe	
18	Mundayatheduka-padjate	N12° 37'40.7''	E75° 2'26.8''	Less populated region	Matured pipe	Opening collapsed
19	Mundayatheduka	N12° 37'37.5''	E75° 1'45.3''	Populated region	Matured pipe	Fully collapsed and Subsided
20	Angadi mugor	N12° 38'01.6''	E75° 00'52.4''	Less populated region	Juvenile Pipes	Likely to happen

21	Meenja	N12º 42’53’’	E74º 57’26.8’’	Less populated region	Juvenile Pipes	Likely to happen
22	Kedengod	N12º 41’49.4’’	E74º 57’40.8’’	Less populated region	Matured pipe	
23	Poossadi Gumpe	N12º 40’17.6’’	E74º 1’34.8’’	Less populated region	Matured pipe	
24	Kizhakanodi	N12º 19’3.7’’	E75º 13’11.3’’	Populated region	Oversized pipe	Tunnel crossing road
25	Nelliyadukkam	N12°17’58.0”	E75°13’02.5”	Populated region	Oversized pipe	Tunnel crossing road
26	Pallikara	N12º23'15.8"	E75º02'39.2"	Highway	Young pipe	Affected State high way in the coastal lowland
27	Erinjilakodu	N12º27'09.3	E75º17'37.6"	Less populated region	Mature pipe occurs in combination with typical and small pipes	
28	Mattankadavu	N12º20'50.5"	E75º23'24.8"	Less populated region	Mature tunnel	
29	Balal	N12º24'8.10"	E75º16'51.9"	Populated region	Matured pipe	

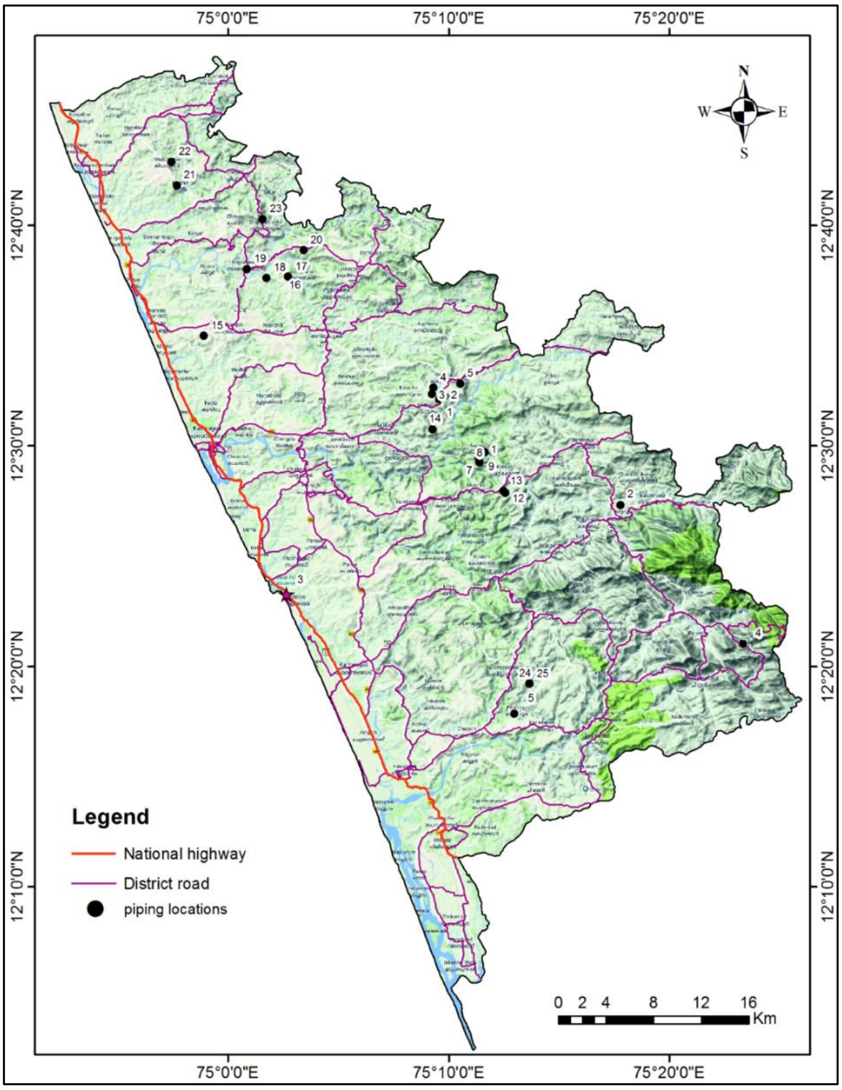


Figure 4.3**:** Identified soil pipes in Terrain map

Infrastructures affected

Kasaragod, the district on Kerala's Northern Malabar Coast, has presently reported by 26 soil pipes and in which three have affected the infrastructures as well as the public. The remaining located pipes also may enlarge, collapse and subsided in future. The location of the incidents is plotted in the District map given below.

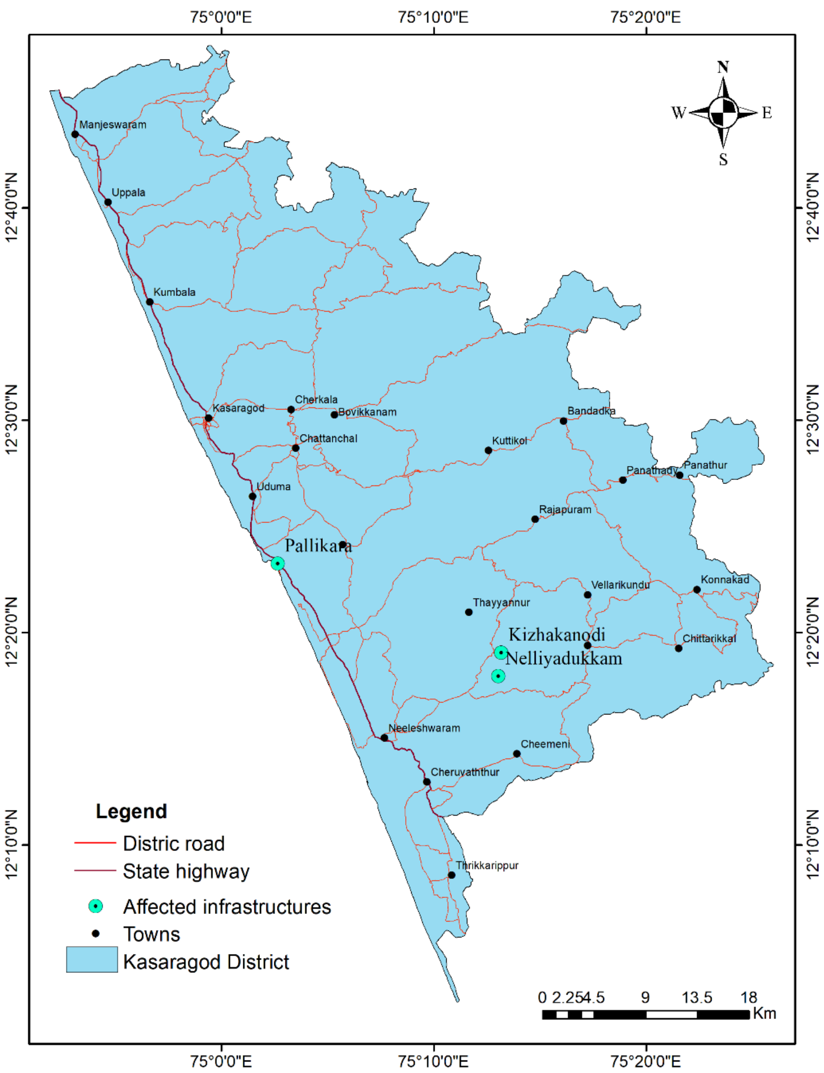


***Figure 4.4*:** Affected infrastructure location map, Kasaragod

1. Kizhakanodi, Kinanur village

A very well-developed tunnel has identified at Kizhakkanodi (N12^{0}19.226', E075^{0}13.628'), Kinanur village, Vellarikkund Taluk. The tunnel is cutting across the Kilikalam-varanjoor road with a huge cavity right below the road. The Field investigations revealed that the cavity formed is about 8-meter height and 10-meter width. The outlet of the tunnel is located 200 meters away from the inlet due south (N12^{0}19.204', E075^{0}13.680'), at the edge of a plot which belongs to Mr Gopakumar, vengayil house, chedikkundu. Presently the road is having 2m thickness above the tunnel and it may collapse at any time.

A follow up study was taken up by Alka Gond et al 2018. The following the extracts of the investigations carried out by the team

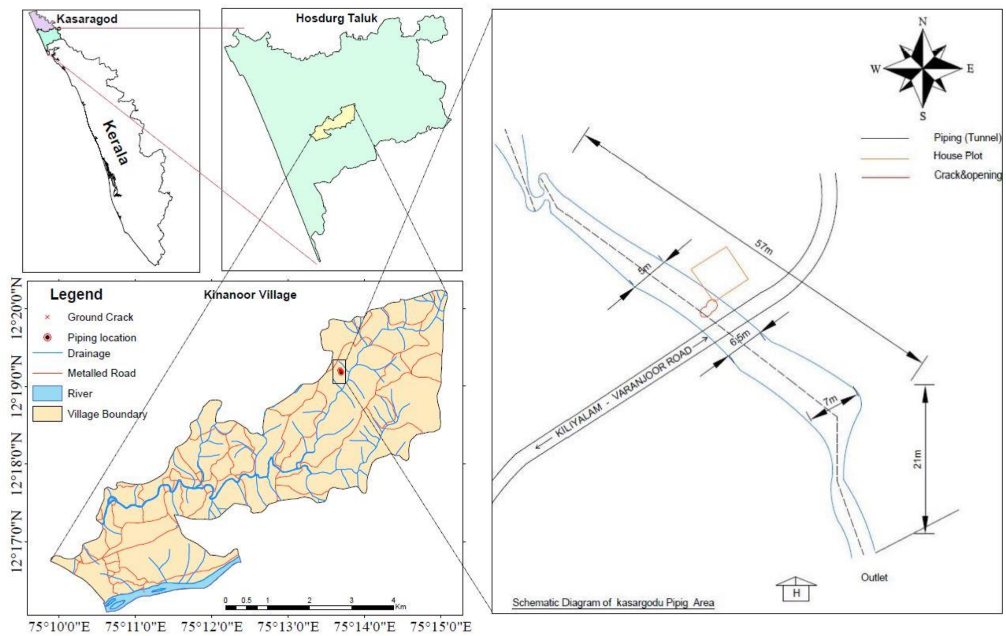


Figure 4.5**:** Location map and schematic diagram of piping.

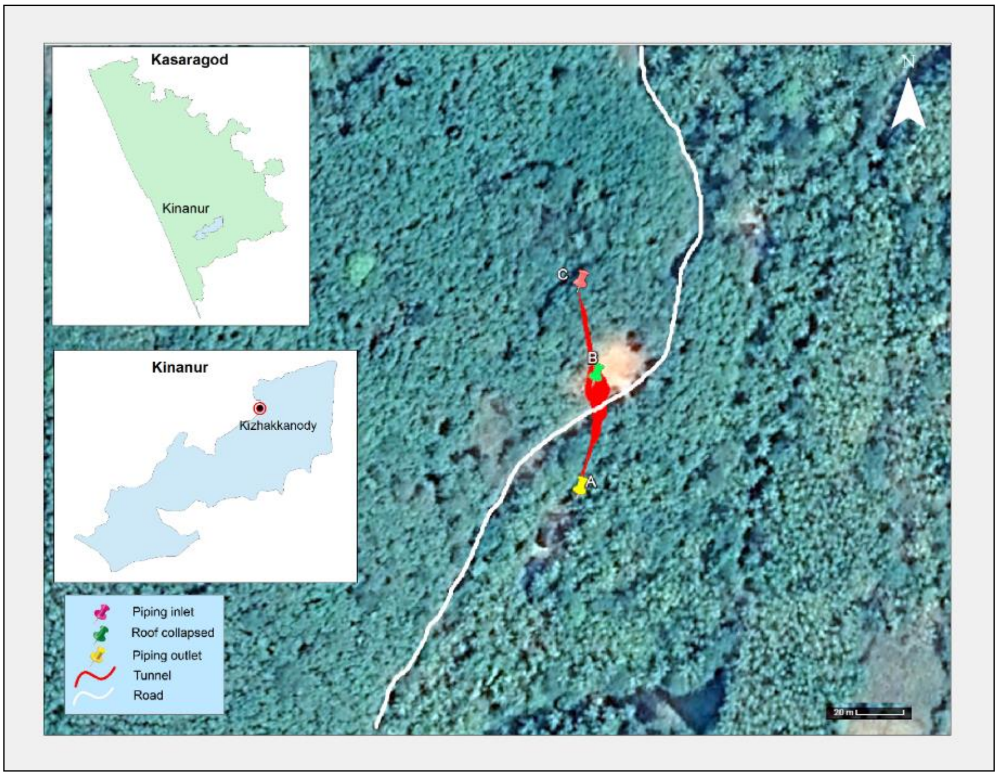


Figure 4.6**:** Identified tunnel at Kizhakanodi

The affected locality is situated in the midland region, having a variable elevation (20 m to 80 m). The upper slope is characterized by high slopes (+25°) whereas the lower slopes are about 19°. As this site is located in the fringe slope, numerous first order streams originate from the upslope. The area is characterized mostly by radial drainage, Kiliyilam chal a third order stream and its tributaries drain through the locality. Here the upslope side is occupied mostly by rubber plantations whereas the downslope is mixed tree crops. The rubber plantation and other introduced agricultural changes were observed, those are blocking the natural drainage systems. the intense rainfall accumulated in the top soil layers leading to the collapse of lands (Fig.4.7 & 4.8).

Figure 4.7: Upslope area is mostly occupied by rubber plantations.

Figure. 4.8**:** Trenches (Mazha kuzhi) made for rainwater harvesting in the rubber plantations, which facilitate percolation of water leading to the collapse of lands.

The study shows that the land subsidence was due to the soil piping. The "soil piping" or "tunnel erosion" is the subsurface erosion of soil by percolating waters to produce pipe-like conduits below the ground especially in non-lithified earth materials (Sankar et al., 2005). Subsurface tunneling is wide spread in the affected localities and their size varies from few centimeters to couple of meters. Field investigations were carried out at piping affected region of Kizhakkanodi, Kinanoor Village in Kasaragod district, during the period of 30/10/2018 to 02/11/2018. A portion of the land belongs to Sri. Gopakumar P.V, Vengayil., he was noticed a cave like feature (Fig.4). The subsidence due to piping had occurred very close (within 15m) to the house where Sri. Gopakumar P.V, Vengayil used to stay. It has been understood that the whole incident has occurred in different stages based on the information collected from the local people. The depression measured at the opening side is ~1.5mX4.2m, it partly filled by the subsided earth material. The opening portion of the tunnel has a narrow stretch, it is very difficult to move inside. After 3m from the opening, the radius of the pipe is increased to 7m. Here onwards, the width of the runnel is getting wider, two or three people can easily move through this cave upto a certain meter towards NW direction. The observed tunnel has an average length of 90m and 7-9m width lies in NW-SE direction. There is heavy discharge of water through the bottom of this cave (Fig. 4.1.9 a, b, c, d). The in-situ inspection of the site revealed that the existence of an underground channel for seepage. It is observed that the water discharge is still quite high through the cave.

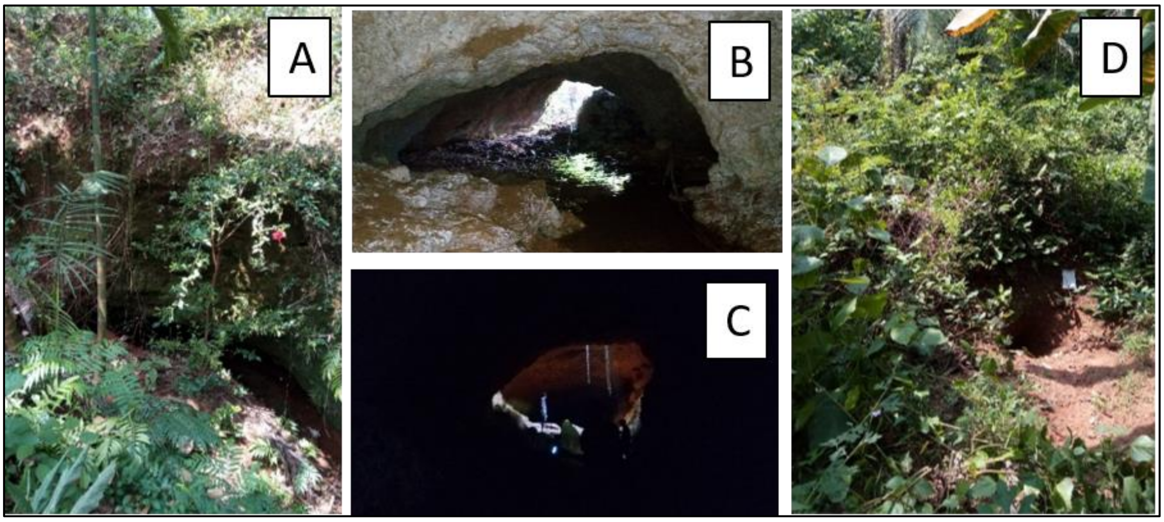


Fig. 4.9: a) Exposed tunnel opening, b&c) Inside view of the tunnel, d) Outlet of the tunnel

The discharge of ground water through the underground tunnel is located about 100 meters down-slope in a valley and then connected to a tributary stream. It is observed that the sidewall of the cave is gradually collapsing due to the erosion (flowing water). This effluent system of underground drainage causes subsurface erosion by a process known as "Piping".

Towards the upslope direction, about 150m from the house, a cave was noticed along the left-hand side of a road. According to the local people information, this cave like structure was noticed when they started constructing a house in the same plot. At this position, it is circular in shape and an average radius of 1.6m measured from the ground-level and it extends towards the bottom about 10.3m (vertical height). It is located 3m from the road towards NW direction (Fig. 4.10, 4.11). Here the soil thickness above the hollow is ~2.7m, along which Kiliyilam-Varanjoor road is passing.

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. Since the caving is still active, it shall definitely affect the stability of the house basement, which is located nearby area. Due to the heavy rainfall of this area and the piping activity will lead to the area vulnerable for further subsidence.

Figure 4.10: Collapsed roof of the tunnel along the road side

Figure. 4.11: Vertical cut slope made for house construction along the roadside where the roof of the tunnel collapsed

Field investigations were carried out at piping affected localities of Kasaragod district, during the period of 30/10/2018 to 02/11/2018. Electrical resistivity survey is carried out to understand the scenario of soil piping on the basis of subsurface electrical signatures at Kinanoor village, Kasaragod, Kerala. For this purpose, resistivity data is acquired along a 96 m long E-W traverse using two arrays. Further, the collected data is inverted to get the subsurface electrical image upto 18 m depth. The inverted models provide the detailed subsurface structures and clearly bring out the hollow beneath the surface caused due to the soil piping.

***Figure 4.12*:** Electrical resistivity survey laid across the tunnel

Electrical resisitivity surveys were conducted to locate the tunnel configuration beneath the Kilikalam-Varanjoor road (Latitude: 12.32^0 Longitude: 75.22^0 Elevation: 30 m Topography: Undulating)

ABEM Terrameter LS instrument is used to collect the resistivity values at different depth points corresponding to a specific set up of electrode configuration. In the preset study, 96 electrodes and 4 cables (with 16 take-outs in each cable) are used as 4x16 spread configuration. Both sounding and profiling are carried out to get the output with enhanced resolution in vertical and horizontal direction respectively. Schlumberger array is used for sounding and Wenner array is used for profiling in the study area. The different acquisition parameters used during the survey are

1) Unit electrode spacing: 1.5 m
2) Total spread length: 96 m
3) Number of stacking of signal: Minimum 2 to maximum 4
4) Error limit: 1.0% for repeated reading/stacking
5) Acquisition time for single measuring cycle: 0.5 S
6) Sample rate: 1000/1200 Hz
7) Range of injected current: 0.1 mA to 200 mA
8) Number of data points collected: 1307 for sounding (Schlumberger array)
   651 for profiling (Wenner array)

2D inversion:

The collected data is inverted using RES2DINV software. The 2D inversion scheme tries to reduce the misfit in a least square sense. For this purpose, the inversion program divides the subsurface into number of blocks and determines the resistivities of the blocks in an iterative manner, whose responses will agree the data. The limit up to which the measured data is agreed by the model responses of the inversion output is expressed numerically in terms of root-mean-squared (rms) error. Therefore, the rms error is an accuracy measure of the model obtained after inversion.

2D inversion for Schlumberger array

The data collected using Schlumberger array, is inverted and final model is obtained after 7 iterations. The final model yields a rms error of 0.81%. Figure 4.13 shows the inverted 2D model along the 96 m long traverse for Schlumberger array.

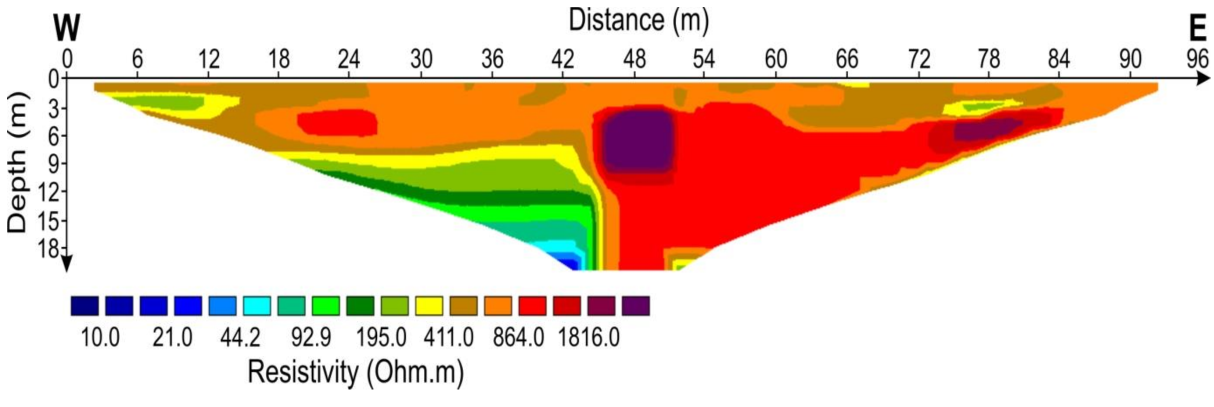


Figure 4.13: Two-dimensional inversion output for Schlumberger array.

To have a detailed view of the data misfit, the observed data and computed response at each station along the profile is plotted as a function of pseudo depth. Figure 4.14shows the pseudo sections representing the fit to the measured data.

By utilizing these data misfit pseudo sections, it is seen that data and model responses are well correlated, which establishes the reliability and accurateness of the inversion outputs along the profile.

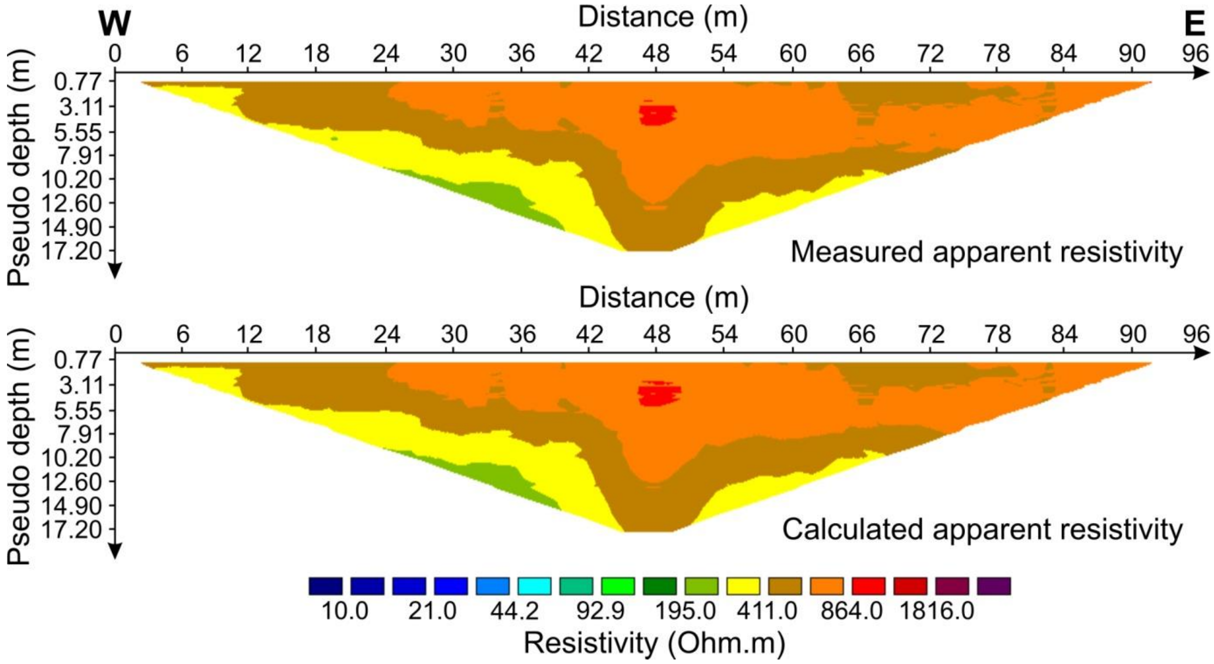


Figure 4.14: Pseudo sections representing the comparison between observed and computed resistivity sections along the profile for Schlumberger array.

2D inversion for Wenner array

The data collected using Wenner array, is inverted and final model is obtained after 10 iterations. The final model yields a rms error of 0.82%. Figure 4.15 shows the final inverted 2D model along the profile for Wenner array.

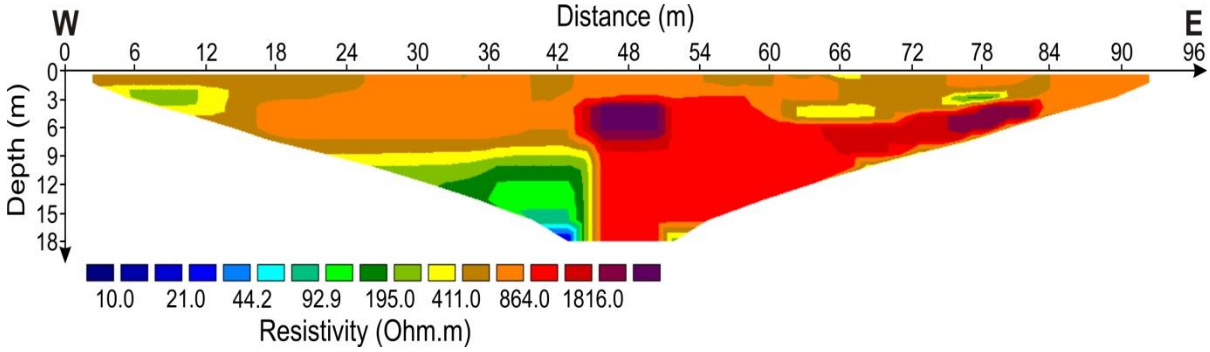


Figure 4.15: Two-dimensional inversion output for Wenner array.

The pseudo sections representing the inversion responses and the measured data are shown in Figure 4.16 to get an overview of the data misfit as a function of pseudo depth. The pseudo sections of model response and data show clear correlation, which proves the dependability of the model obtained after inversion.

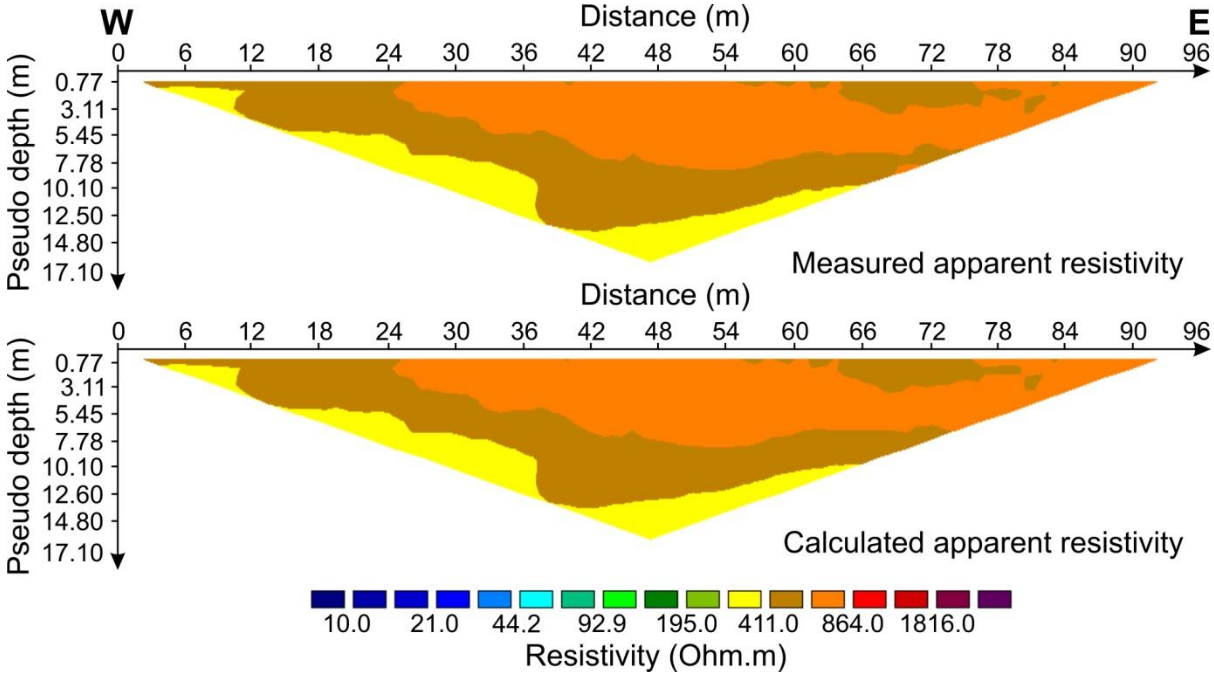


Figure 4.16: Pseudo sections representing the comparison between observed and computed resistivity sections along the profile for Wenner array.

4. Discussion:

The inversion outputs for sounding (Schlumberger array) and profiling (Wenner array) are studied together (Figure 4.17) to get the vertical and horizontal structural variations beneath the surface. From the combined analysis of sounding and profiling, the study area is divided into four distinct parts namely A, B, C and P (Figure 4.17). The top portion (A) having a resistivity of ~ 600 Ωm, represents the soil cover in the study region. The base of the soil thickness variation (black dotted line, I_1 in Figure 4.17) is demarcated from the inversion output of Schlumberger array as this array provides better vertical resolution. Basement is identified below the soil based the resistivity data. Thus, I_1 (dotted black line in Figure 4.17) represents the interface between the soil and the basement. The resistivity of the basement is not constant along the profile. That is right part (B) is more resistive (~ 1500 Ωm) than the left part (C), indicates that it is mainly composed of hard rock. The resistivity of the left side (C) varies from 20 – 200 Ωm with an average of 100-150 Ωm, this could be due to the water saturated rock or clay material. The boundary between the hard rock and the clay (black dotted line, I_2 in Figure 4.17) is demarcated from the inversion output of Wenner array as this array provides better horizontal resolution.

In both the resistivity sections (Schlumberger and Wenner), an anomalous very high resistive zone (P in Figure 4.17) is observed at the central portion of the sections. This very high resistive zone signifies the presence of a hollow structure in subsurface, which is filled with air. It is a cave like structure formed due to the soil piping and intrusion of air into it makes the hollow highly resistive in nature. The detailed configuration of the hollow structure is delineated through resistivity survey. As Schlumberger array provides better vertical resolution and Wenner array provides better horizontal resolution, therefore, vertical and horizontal configurations of the hollow structure are determined on the basis of inversion outputs (Figure 4.17). It is derived from the resistivity survey that the depth from the surface to the top of the cave is ~3 m and from the top to the bottom of the cave is ~7 m (Figure 4.17). Horizontal extent of the cave is ~6.5 m as derived from the survey (Figure 4.17). Therefore, this highly resistive zone delineated at the middle portion of the inversion sections is a hollow structure of diameter 6.5-7 m, which is situated ~3 m beneath the surface.

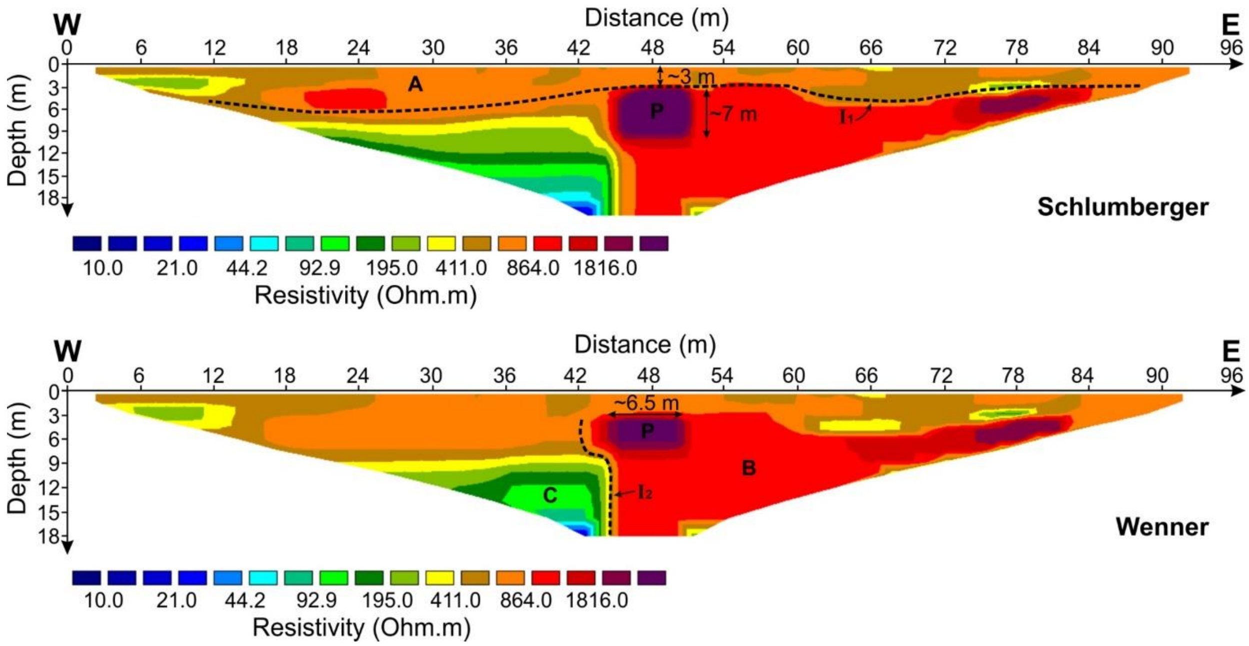


Figure 4.17: Two-dimensional resistivity sections obtained after inversion for Schlumberger and Wenner arrays

The figure (fig 4.17) shows detailed electrical signature of subsurface, based on which subsurface is divided into different parts like A, B, C and P. I1 and I2 are the interfaces between two types of formations. The anomalous very high resistive zone (P) at the central part of the sections signifies the hollow part caused due to the soil piping.

***Figure 4.18*:** Cavity formed below road at Kizhakanodi

2. Nelliyedukkam

A very well-developed tunnel has identified in Nelliyedukkam locality (N12°17’58.0”, E75°13’02.5”) in between Kinanoor and Karindalam village, Kanhangad taluk in the Kasaragod district. The pipe is well matured and diameter of the entrance is around 5m, inside diameter is in 20m. The initial investigations have established the presence of more than one subsurface erosional channel. Field investigations revealed that the entire locality is affected by soil piping. This is an example of combination of mature and huge pipes. Ground fissures indicative of ground movement are seen at few places.

Figure 4.19: Land subsidence tunnelling and affected house, Nelliyadukkam

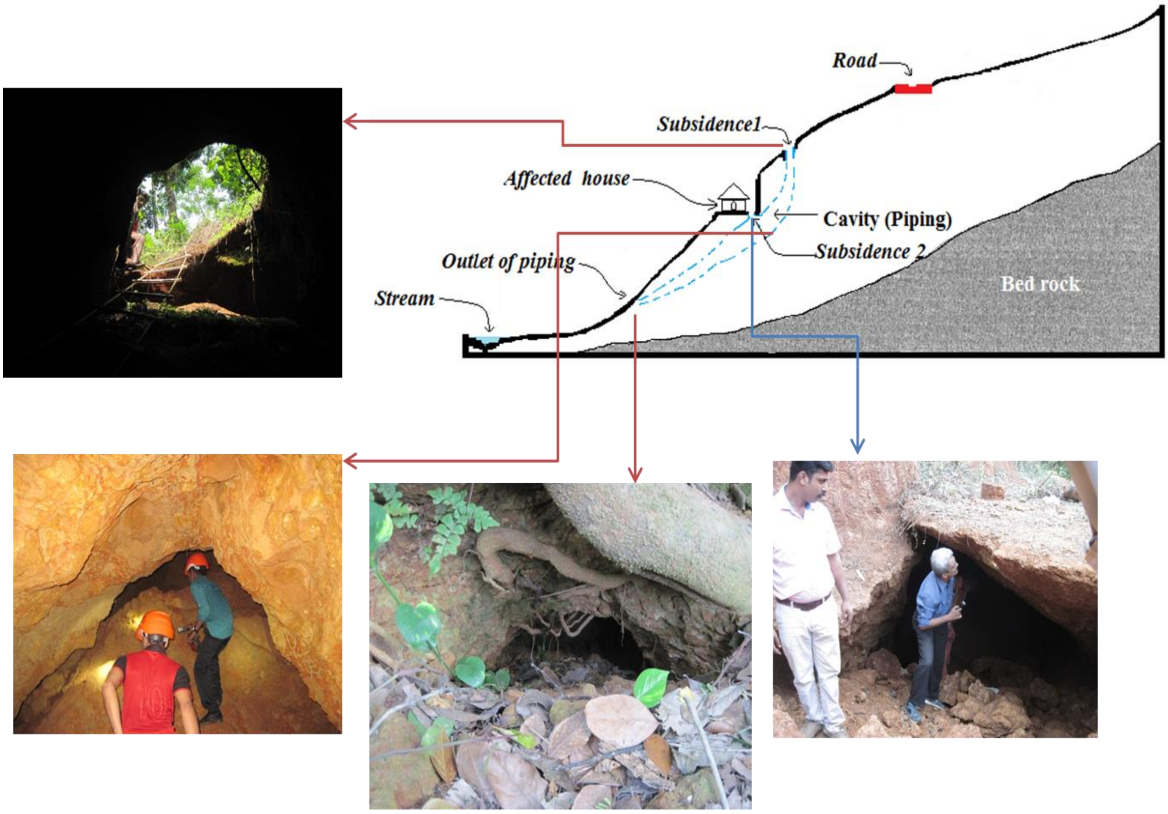
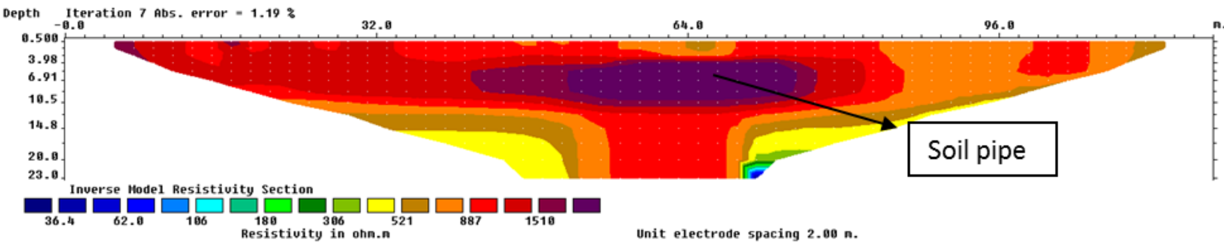


Figure 4.20: Land subsidence due to soil piping in Nelliyadukkam, Kasaragod

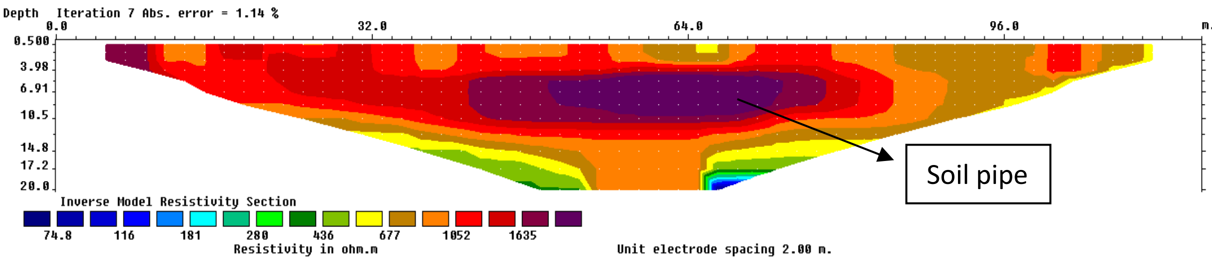
Electrical Resistivity Survey was carried out at Nelliyadukkam, Kasaragod across the alignment of a known soil pipe by using multi-function Digital DC Resistivity/IP Meter (WDJD-4), having WDZJ-4 switcher box. All survey lines are in east west direction, the suspected soil piping is in south to north direction. A total of 7 survey lines were laid, 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 center of the target (above the cavity) to arrive greater depth of penetration. S_3 and S_4 laid 15m east from the tunneling. 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 4.22 a to 4.27c).

Result and Discussion

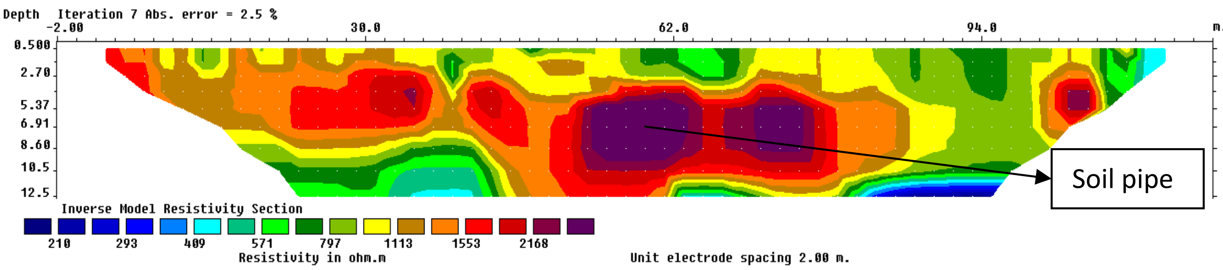
Survey line 1 (S1): The qualitative interpretation of the resistivity section indicates that the technique could delineate the conductive zones where the soil pipes were formed, evident from the profile laid at Nelliyedukkam. These profiles are directly above the pipes and the possible orientation of 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 *4.21* a) and Wenner (Figure *4.21* b) 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 *4.21c*) and Wenner array mode.



a. Schlumberger array at 1m electrode interval



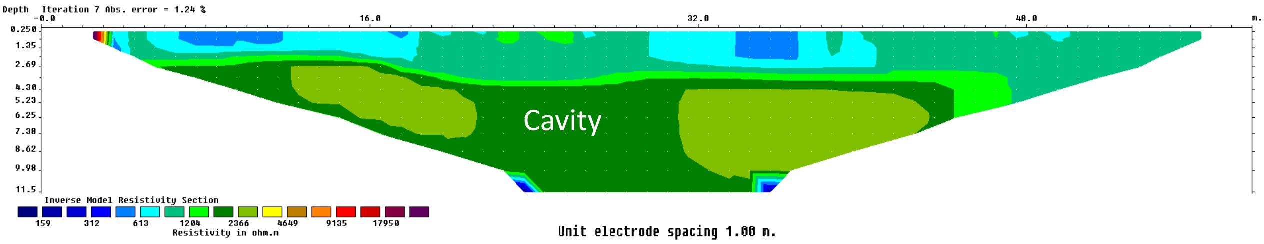
b. Wenner array at 1m electrode interval



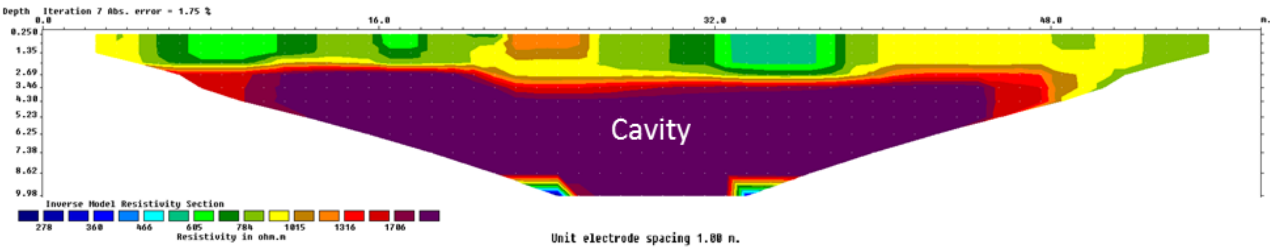
c. Dipole-dipole array at 1m electrode interval

Figure 4.21: Electrical Resistivity Tomographic section survey line 1

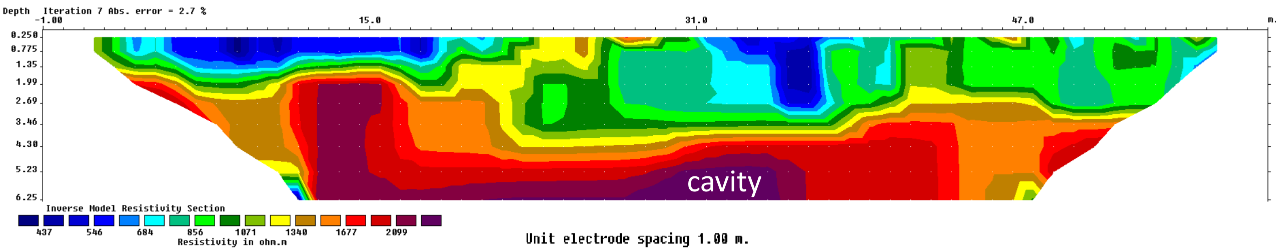
Survey line 2 (S_2): This profile was also laid at the same point of profile $S_1$with an electrode interval of 1m. Depth of information obtained was 11.5m and high resistivity value obtained was 2366 Ωm. From the schlumberger and Wenner images, a sudden increase of resistivity (~500 to 2366Ωm) was indicated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



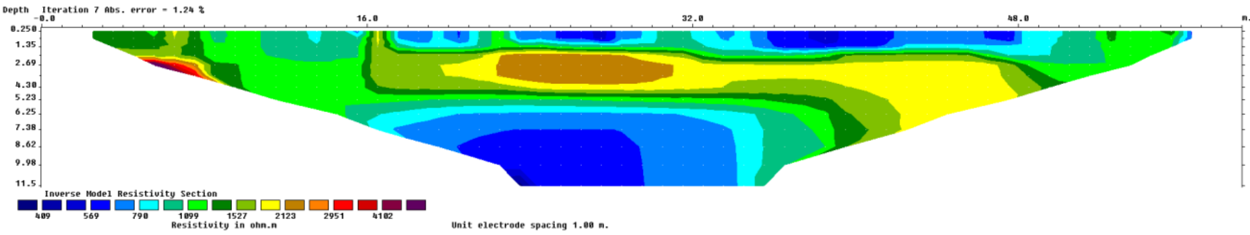
b. Wenner array at 1m electrode interval



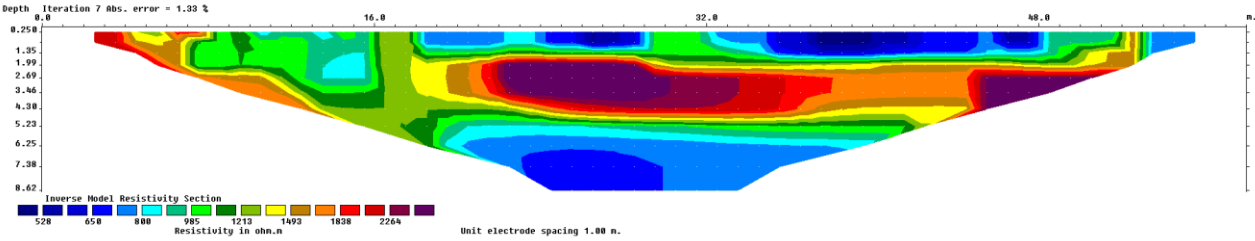
c. Dipole-dipole array at 1m electrode interval

Figure 4.22: Electrical Resistivity Tomographic section survey line 2

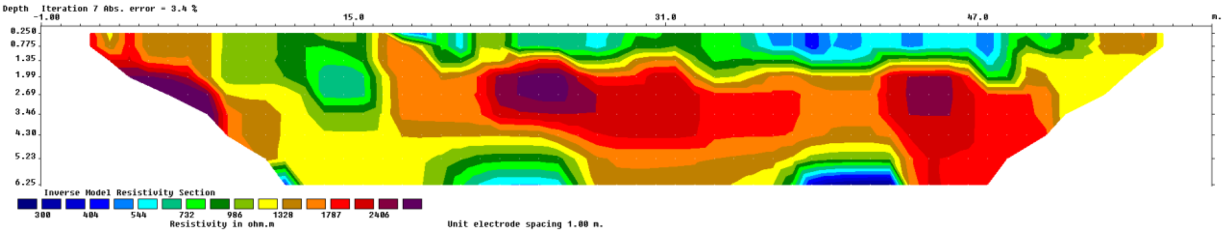
Survey line 3(S_3): This profile (S_3) was laid 15m east of the survey line S_1 at an electrode interval of 1m. From the figure *4.23* a and 4.24 b, a high resistive zone (>2264 Ωm) was seen in the middle portion in between station 22 and 33 at the depth of approximate 2m to 4.38m which is an indication 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



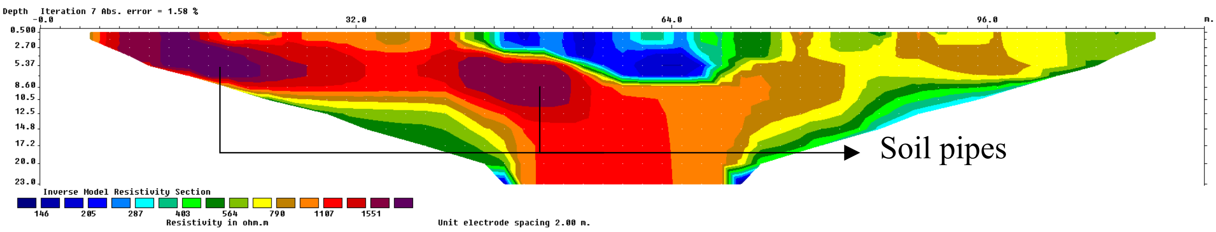
b. Wenner array at 1m electrode interval



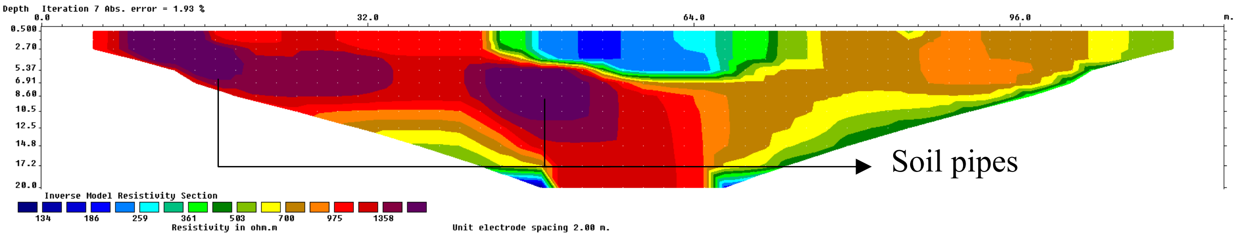
c. dipole-dipole array at 1m electrode interval

Figure 4.23: Electrical Resistivity Tomographic section survey line 3

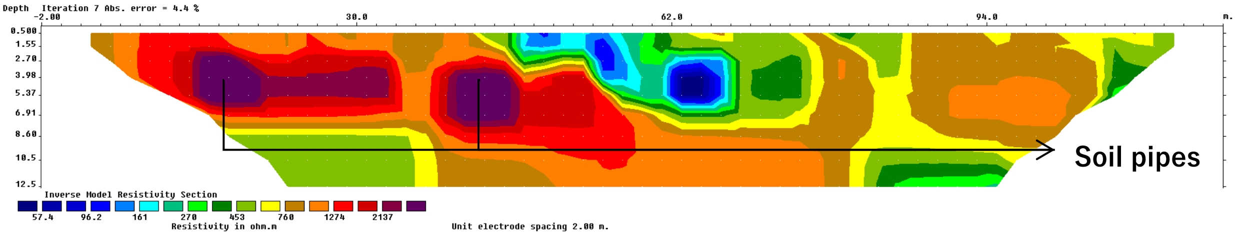
Survey line 4 (S_4): The surveyline 4 is laid across the soil pipe (east to west direction) and the mid point of the profile is 12m north of the pipe. The electrode intervel was 2m, the total distance of the profile was 120m and the maximum depth of penetration achieved was 23m. Two high resistive (>1551 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 *4.24* a, b, c) indicated branching of the pipe. In the dipole –dipole configuration it was indicated clearly.



a. Schlumberger array at 2m electrode interval.



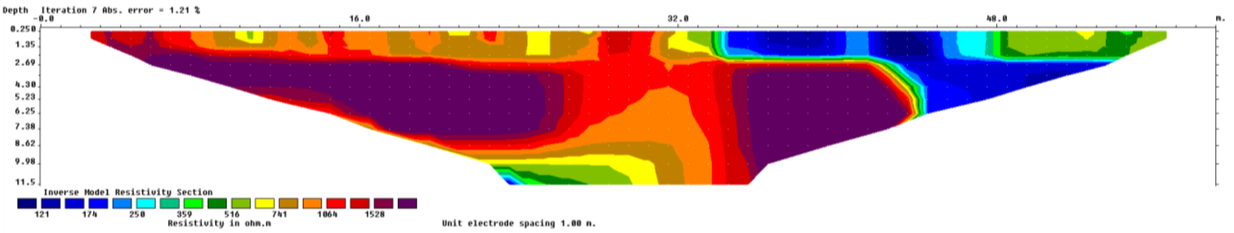
b. Wenner array 2m electrode interval



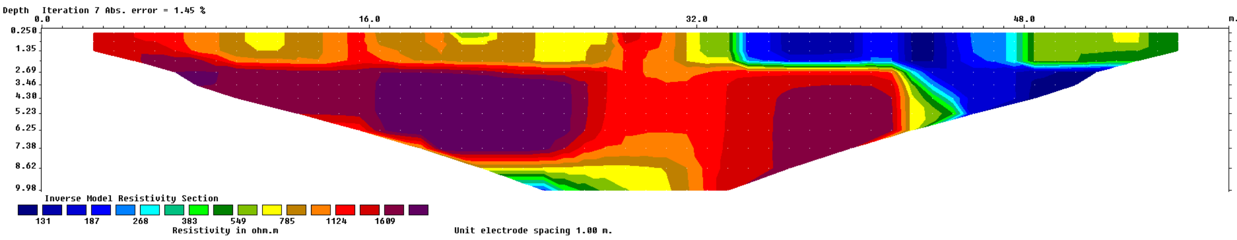
c. Dipole-dipole array 2m electrode interval

Figure 4.24: Electrical Resistivity Tomographic section survey line 4

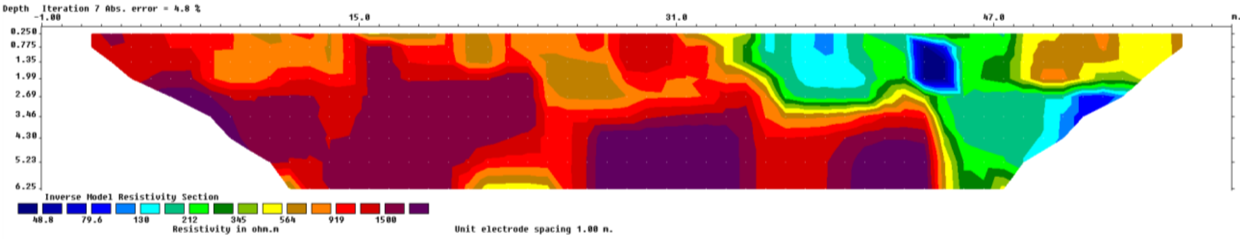
Survey line 5 (S_5): This survey line has E-W orientation and is parallel to $S_3$and has a station interval of 1m. The first electrode position was at east side. From this profile the high resistive zone with a lateral extent of almost 10m and detected at a depth of 2.69m to 7.38m may not be a pipe 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 in piping area.



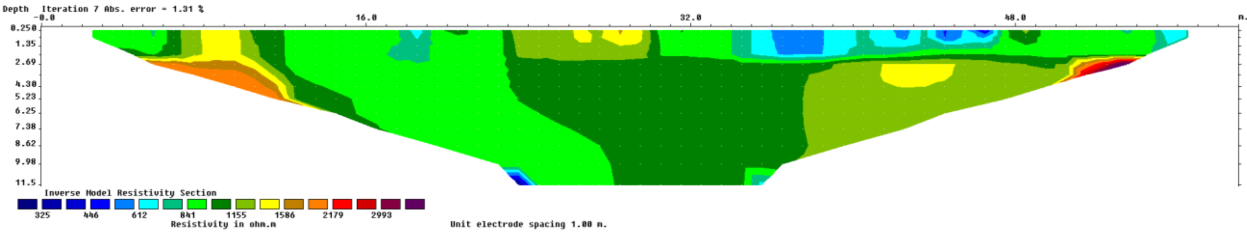
b. Wenner array in piping area



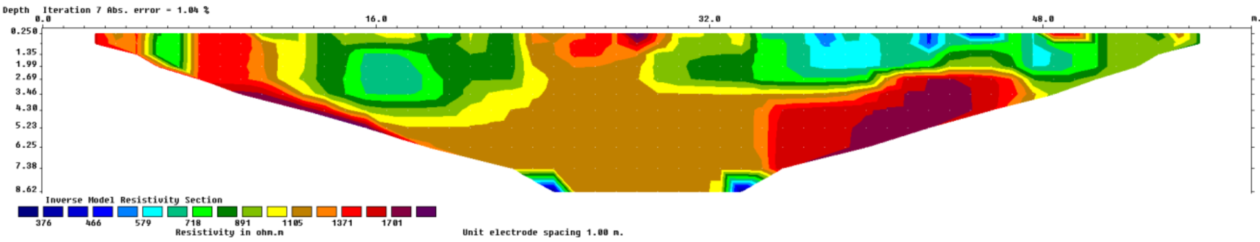
c. Dipole-dipole array at 1m electrode interval

Figure 4.25: Electrical Resistivity Tomographic section survey line 4

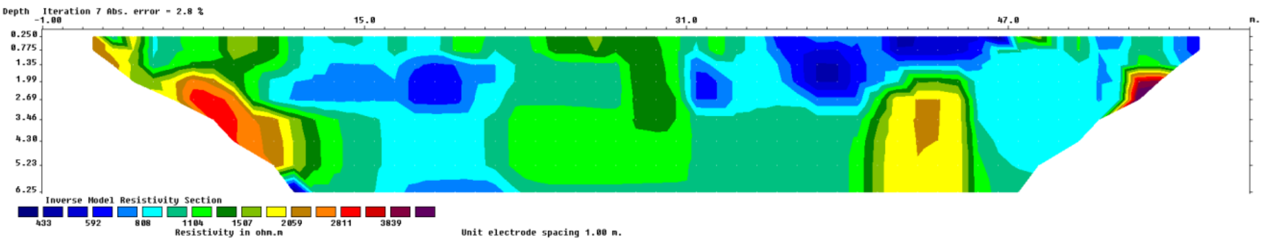
Surveyline 6 (S_6): Survey line S_6 runs in the E - W direction with midpoint placed at 10m towards north from the survey line S_3. This Profile (Figure 4.26) showed moderately low resistivity at shallow depth and relatively high resistivity at a depth of 2.62m which continued further. The same feature 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



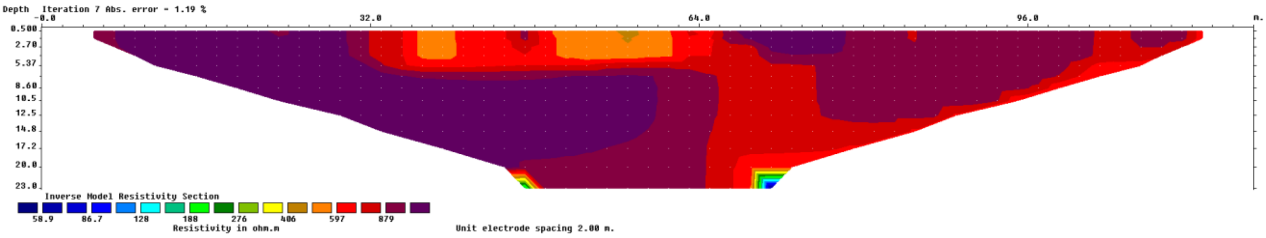
b. Wenner array at 1m electrode interval



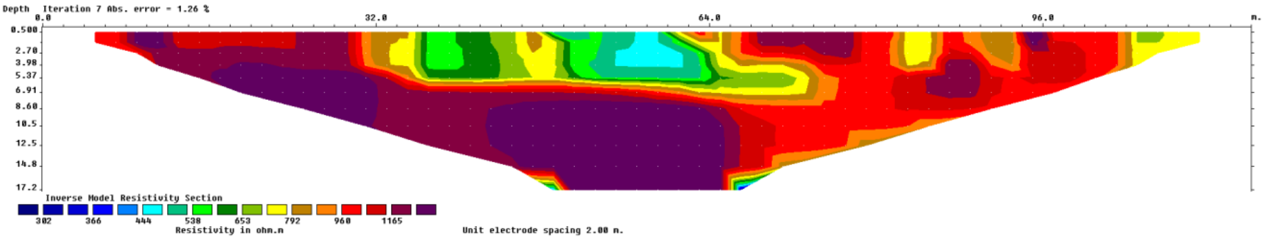
c. dipole-dipole array at 1m electrode interval

Figure 4.26: Electrical Resistivity Tomographic section survey line 4

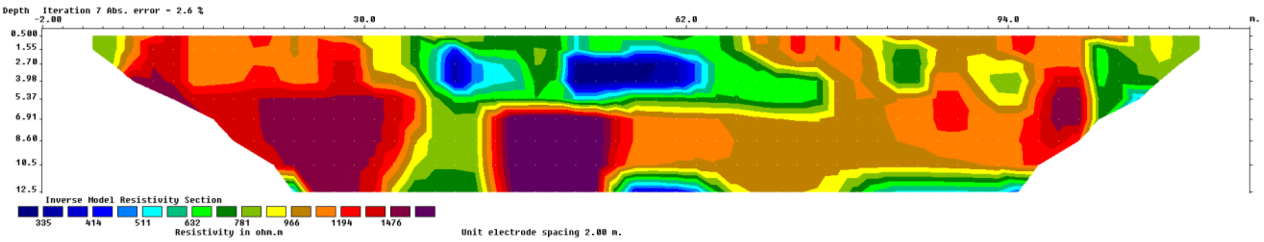
Survey line 7 (S_7): The survey was carried out on the road side; the contact resistance was relatively higher than the other profiles because of the hard nature of the road fillings. The resistivity of the top hard layer was found relatively higher and this probably represented rock-dominated top layer.



Schlumberger array in piping area.



Wenner array in piping area



Dipole-dipole array in piping area

Figure 4.27: Electrical Resistivity Tomographic section survey line 4

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 give the clear-cut picture of the cross section of pipes. It also gives the information about branching of tunnels.

3. Pallikara

A section of the road had collapsed near (Pallikara N12º23'15.8", E75º02'39.2") in 'Kanhangad-Kasaragod' State Highway. A big cavity exposed a long tunnel extending across the road at a depth is extending beneath the road. The anxiety is that pipe has recognized in a lowland area but in a lateritic terrain. The identified pipe comes under 'typical pipes category' in Kasaragod district. Since then the PWD has reclaimed the road and completely covered the cavity and passage. The measure adopted now is unsustainable and likely to collapse during course of time, geophysical survey here is recommended for designing a suitable structure here.

Figure 4.28**:** Soil piping incidence occurred in State Highway Pallikkara, Kasaragod District

Prone areas

The Kasaragod district is one of the severely prone among the fourteen other districts of Kerala regarding soil piping incidents. The field investigation has revealed more than 29 major soil pipes in the district. It is believed that there are more such pipes developed in the interior and forested areas. The district is dominated by lateritic terrain which is developed as mesa type terrain. The mesa and adjoining valley terrain set up is ideally suited for pipe development.

As the district is recognized with more than 29 number of soil pipes including minor and, major sized through stacking, scouting and geophysical investigations over the district. The geophysical, geochemical and sedimentological analyses of field data and samples collected during field investigations have given a clear idea that these pipes are occurring under certain conditions.

The geomorphological and geological features have the major hand on the piping process. The slope, drainage, soil types, vertical profile and rainfall are some of the major features that accounts on this process.

As the identified incidents are having almost similar characters and conditions in formation a zonation is possible through which the district could highlight with Critically affected, most probable zone (partially affected) and Least probable zone (less affected areas). This can help in giving awareness and management in land use in future.

Table 4.2: Areal extent of Soil piping affected regions in the district

District	Total area in sq.km	Affected area in sq.km	Probable area in sq.km	Non-affected area in sq.km	No. of soil pipes reported
Kasaragod	1,992	1018.533	713.113	260.355	29

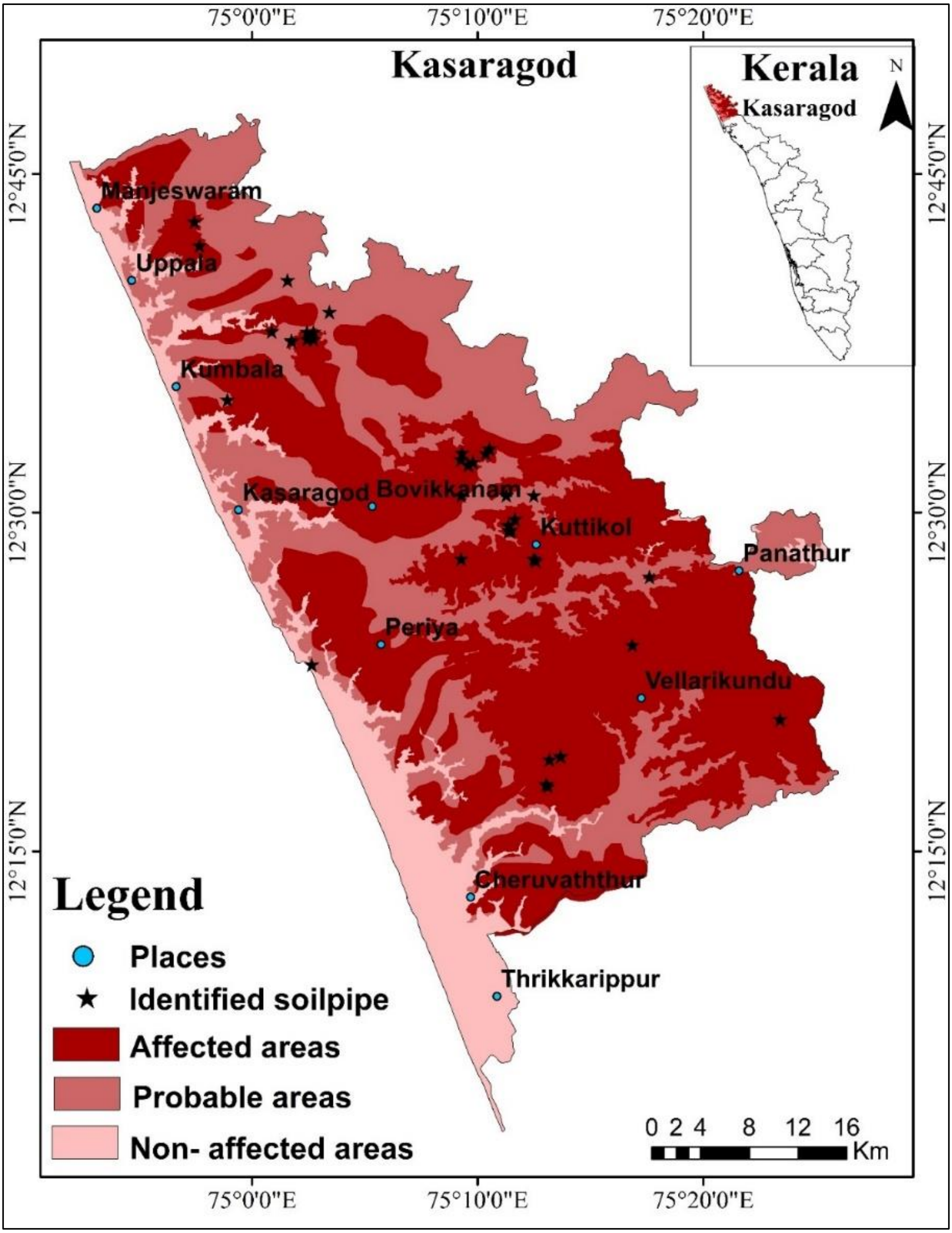


***Figure 4.29*:** Zonation map of Kasaragod District

Conclusion

The total area of the district is 1992 square kilometres in which 1018.533 km^2 is falling inside the Affected zone and 713.113 km^2 is falling inside the Probable zone which means a good portion of the district is vulnerable. The remaining 260.355 km^2 area is falling inside Non-affected zone which including coastal alluvium and hard rock exposures. Kuttikol, Panoor, Nelliyadukkam, Karadka and Paivalike are the places where the greatest number of pipes areaseen and affected severely. For zoning an area in terms of soil piping susceptibility the following aspects were considered

1. **Recommendations for the "Affected areas"**

In the critically affected areas infrastructure such as roads, buildings etc will be affected. Restrictions on high rise buildings or detailed surveys before the construction id needed. A proper water management plan should be developed for restricting the spread of soil piping. Geophysical surveys are suggested for locating large and typical pipes**. Laterite mining may be restricted in the critically affected localities or the depth must restrict well above (at least 1m) the lithomarge clay layer is recommended. In no case clay layer should be exposed for water to infiltrate.**

2. **Recommendations for "Probable areas"**

These are areas prone to soil piping or mildly affected regions. In these areas juvenile and younger pipes are developed as an indicator of soil piping processes happening there. In such places well sections and laterite cutting are to be examined in detail for pipes and caves. Geophysical surveys may not help in identifying juvenile and younger pipes as they are smaller in size. Water management practices and usage of lime powder in the soil will retard the soil piping activities. **Laterite mining the depth must restricted well above (at least 1m) the lithomarge clay layer is recommended. In no case clay layer should be exposed for water to infiltrate.**

In both areas' usage of hydrated lime along with the fertilizers should be encouraged to neutralise dispersive sodium in the clay

Dewatering is the best method to deescalate the formation of soil pipes. Overland flow may be diverted to a nearby nala without allowing to infiltrate in the affected zone will reduce pipe development.

Bethurpaera

Padiyotuchal

Kizhakanodi

Nelliyadukkam

Bethurpara-Komali

Bethurpara

Mali cave

Bethurpara

Figure 4.30**:** Field photos from Kasaragod District

4.2 Kannur

The district Kannur (Cannanore) is one of the northern districts of Kerala covers an area of 2966 sq. km bounded by North latitudes 11° 40' and 12° 48' and East longitudes 74° 52' and 75° 56'. It is bounded by Kasaragod district in the north, Kozhikode district in the south, Coorg district of Karnataka and Wayanad district in the east and the Lakshadweep Sea in the west. It is bounded by Lakshadweep Sea to the west and Karnataka state to the east. The terrain is rugged and slopes west from Western Ghats to the coast.

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.

Geomorphology

The district is divisible into three distinct geomorphological units Based on physiography.

1. The coastal plains and lowlands in the western part.

The coastal plain occurs as a narrow belt of alluvial depositional landforms running parallel to the coast with a maximum width of about 15 km. It comprises narrow beaches interrupted by cliffs, promontories and rocky beaches. Estuaries, lagoons, tidal flats, floodplain and palaeo-beach ridges are the other landforms of the area. The region has a maximum height of 7m in the east.

2. The central undulated terrain comprising the midland region.

The midland region, a relatively wide zone represents denudational landforms exhibiting laterite capped flats, mesas ridges, spurs, laterite interfluves and narrow alleviated valleys. Midland region forms a plateau land at certain places covered by a thick cover of laterite. Elevation of this region displays remnants of planation surfaces as well. Two former planation surfaces with fairly extensive remnants are characterised by laterite cappings. Vestiges of still older surfaces are identifiable at higher altitudes.

3. Eastern highland region.

The hilly region in the east is a structural cum denudational landforms, where the elevation is generally above 500m. Hills have very steep slopes. Landforms of intrusive origin are also noticed near Peralimala and Ezhimala. The hilly tract in the eastern part consists of highly rugged terrains. The Ezhimala peak 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.

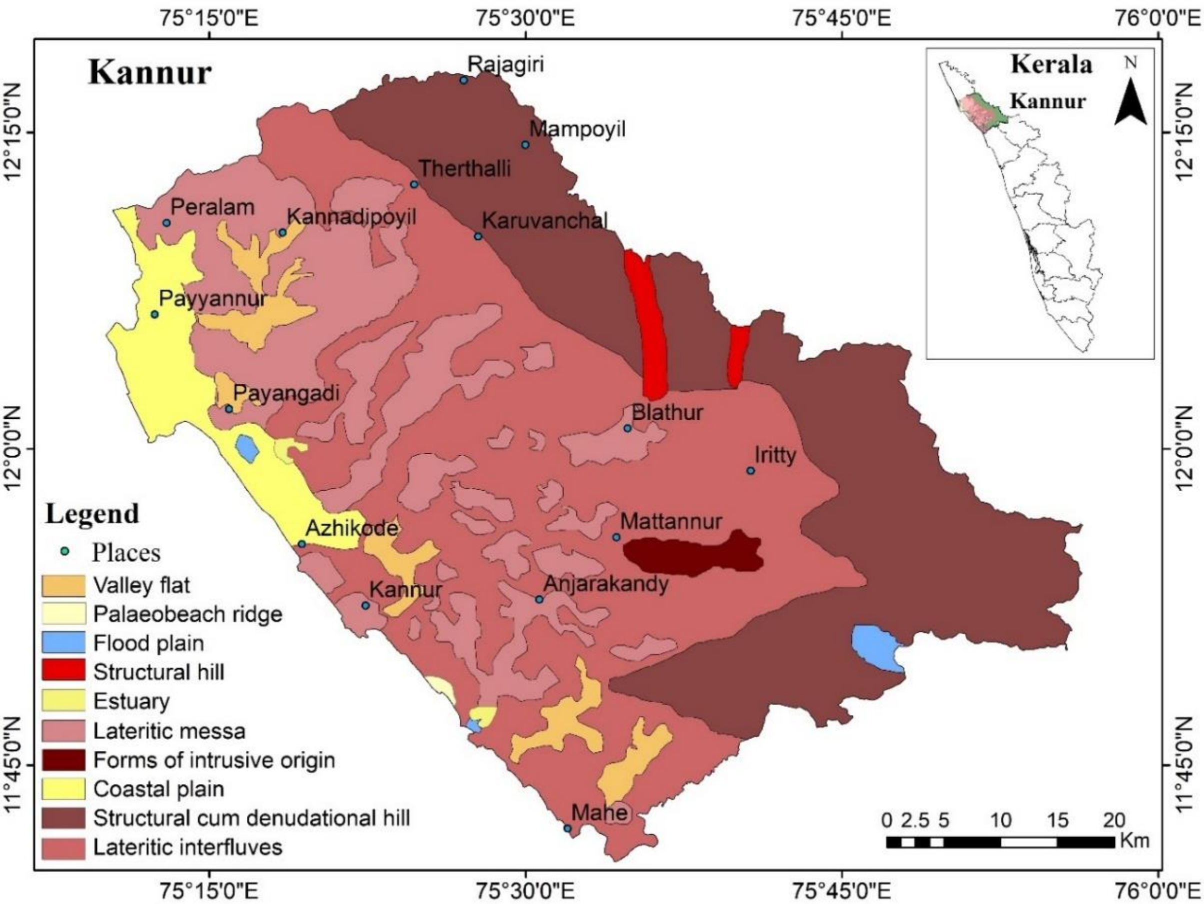


Figure 4.31: Geomorphology of Kannur District

(geomorphology map modified after District Resource map, Kannur district, Geological Survey of India)

Drainage and Irrigation

Valapattanam and Anjarakandy Rivers are the main two river system of Kannur district. The other rivers are Kuppam, Mahe, Thalasserry etc. Dendritic is the common drainage pattern. The

Valapattanam River, which is the longest in the district, originates from Brahmagiri Reserve forest in Coorg district of Karnataka.

Rainfall

Kannur district receives a total annual rainfall of around 3438 mm. District experiences heavy rainfall during the South West monsoon season followed by North East monsoon. South West monsoon during June to September contributes 70 % of the total rainfall of the year. The northeast monsoon contributes only about 30%. The year to year variability of annual rainfall is around 28.2%. In general, the rainfall increases from the coast to the eastern hilly regions. Kannur district falls under wet type of climate based on Thornthwaite's climatic classification.

Land use

The district is divisible into three different units on the basis of land usage. (1) Arable, (2) Forest land and (3) Waste land. Major part of the district is arable land which includes irrigated and unirrigated land. Forest is mostly in the east, within which some areas are developed as rubber and cashew plantations. Extensive waste land formed of hard laterite, unsuitable for cultivation lies in the midland region. Most of the area is covered by lateritic soil. Forest loam soil occurs in the east and the alluvial soil is along the coast.

Geology

The Kannur district is having much more variety of lithological units compared to the nearest districts. The lithology is varying from part to part of the district. The district is divisible mainly into seven different geological belts trending NW-SE.

1. Northern belt of Charnockite group extending further north and east to the adjacent districts
2. North central belt of Wayanad schist complex
3. Central belt of Peninsular Gneissic Complex extending to the southeast
4. South central belt of Vengad Group, equivalent to Dharwars
5. Southernmost belt of Migmatite Complex which extends further south to the adjacent district
6. Sedimentary (Warkalli Beds) in the western part near the coast
7. Quaternary sediments along the coast.

The lithology of Kannur district is grouped under Precambrian, late Tertiary and Quaternary periods and the Precambrian rocks dominate over the other two. Charnockite Group includes pyroxene granulite, charnockite (hypersthene granulite) and hornblende-diopside granulite. While hornblende granite and charnockite occupy large areas, pyroxene granulite occurs as linear bodies in the southeast. Hornblendebiotite gneiss constitutes the lithological unit of Migmatite Complex. It has a large areal extent along the coast, south of Kannur. Towards east and southeast, discrete metasedimentary and ultramafic sequences which have been designed as Wayanad Schist Complex and are considered equivalent of Sargur Group of Karnataka. They occur as isolated bands within charnockite and gneiss. Their contacts are generally discordant due to later folding, metamorphism and migmatisation. The group comprises quartzite, magnetite quartzite, garnet-kyanite-sillimanite gneiss, quart-mica-kyanite schist, quartz-sericite schist, amphibolite, kyanite-sillimanite-sericite quartzite, and metaultramafites. Garnetkyanite-sillimanite gneiss/schist is widespread in the east, whereas the other members of Wayanad Complex occur as linear bands, lensoidal bodies and vestiges to the West Peninsular Gneissic Complex, represented by hornblende-biotite gneiss comprise of a complex suite of gneisses and granites, representing the anatectic phase of migmatisation of schist complex. East of Kannur extending up to Tellichery in the south, a large body of quartz-mica schist is separated from the other schistose rocks by a conglomerate horizon extending over 8km. This lithounit is known as Vengad Formation, characterised by lack of migmatisation, presence of primary structres and absence of high-grade minerals, and is correlatable with rocks of Dharwar Super Group. Large bodies of anorthosite, gabbro, granite and granophyre from the post Vengad basic and acid intrusives. Dolerite dykes trending NW-SE represent the younger basic intrusives. Late Tertiary sedimentary rocks (Warkalli beds) occur as isolated patches along the coast near Kannur, Pazhayangadi and east of Payyannur. They comprise variegated clays and friable sandstone. At Kannur and Pazhayangadi, carbonaceous clay with thin seams of lignite is reported towards bottom of the sedimentary sequence. The Tertiaries as well as the basement rocks are extensively lateritised. The pebble bed, reported near Valapatnam along the bank of Valapatanam River, is considered to be of Quaternary age. Quaternary alluvial deposits occur along the coast and in the valleys.

(Reference: District survey report of minor minerals by Department of Mining and Geology)

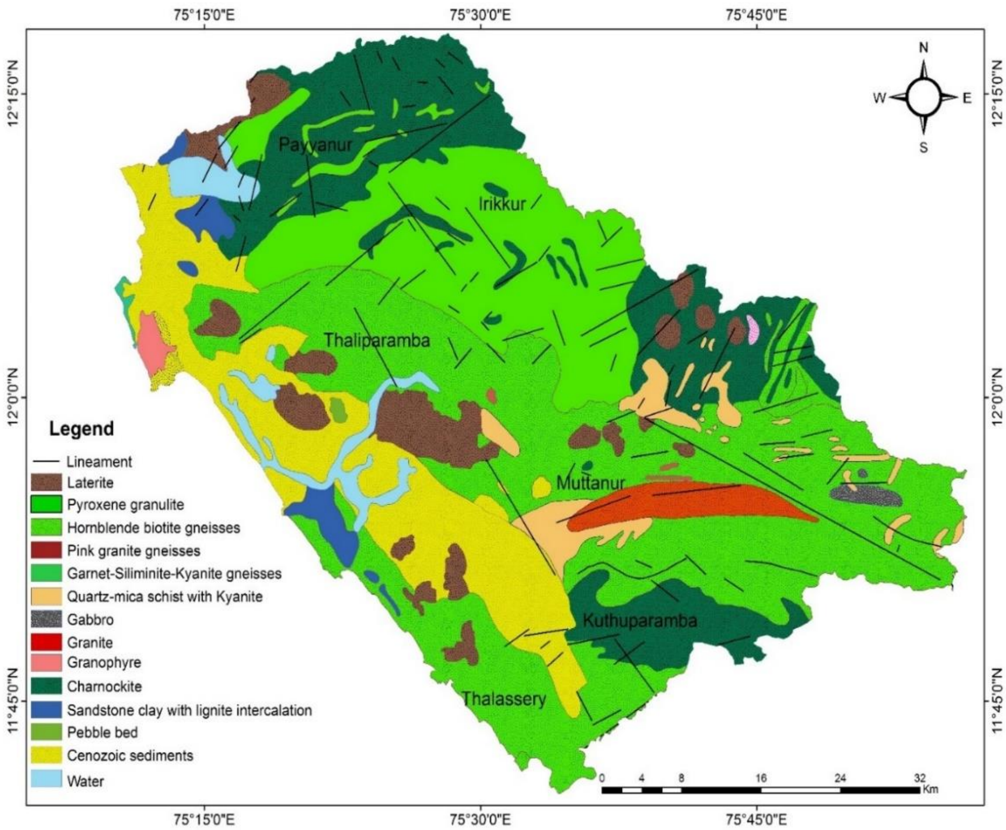


Figure 4.32**:** Geology of Kannur District

(geology map modified after District Resource map, Kannur district, Geological Survey of India)

Soil types

There are mainly four types of soil observed in the district.

1. Lateritic soil

The predominant soil in the district is lateritic soil, which is the weathered product derived under humid tropical conditions. It occurs mainly in the midland and hilly areas characterized by rugged topography. They range from sandy loam to red loam.

2. Brown hydromorphic soil

These are confined to the valleys between undulating topography in the midlands and in the low-lying areas of the coastal strip in the district. These soils are brown in colour and the surface texture varies from sandy loam to clay. They have been formed as a result of transportation and deposition of materials from adjoining hill slopes and also through deposition by rivers.

3. Coastal and river alluvium

The coastal alluvium is seen in the western coastal tract of the district. The coastal plain is characterized by secondary soils, which are sandy and sterile with poor water holding capacity. The width of the zone is more in the central part i.e., in the Kannur area and it is almost narrow in both north and southern areas of the district. The marshy soil in the coastal plain supports mangrove vegetation and is found at the estuaries and backwater extending inland along their courses. The soil is composed of recent deposits predominantly marine with some fluvial sediment along the coastline. These soils are immature with high sand content. River alluvium is found along river valleys cutting across the extensive lateritic soils. The soil is very deep with surface texture ranging from sandy loam to clay. It is fertile, having water holding capacity and plant nutrients which are regularly replenished during floods.

3. Forest Loamy soil

These soils are found in the eastern hilly areas of the district and are characterised by a surface layer rich in organic matter. They are generally acidic and are dark reddish brown to black in colour with loam to silty loam texture.

Ground water scenario

Groundwater in the district occurs under phreatic conditions in weathered mantle of the crystalline rocks, laterites and unconsolidated coastal sediments. It occurs under semi confined to confined conditions in the deep-seated fractured aquifers of the crystalline rocks and Tertiary sediments.

The 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 following.

1. Consolidated formations (weathered and fractured crystallines).

2. Semi consolidated sediments equivalent to Warkalies of Southern Kerala and laterite formations.

3. Unconsolidated formations (Recent alluvium occurring along the coast).

Kolari village, Irrtty taluk,

A subsidence has occuured in Kolari village (Latitude: N 11^0 57' 13.8" Longitude: E 75^0 34' 38.7") in the Iritty taluk in 2016. Dr Padma Rao B., Scientist B, Dr. Mayank Joshi, Project Scientist, Mr. Prasobh P Rajan, JRF and Mr. Eldhose K. technical Assistant NCESS visited the affected area on 9 September 2016 along with the village and Panchayat representative.

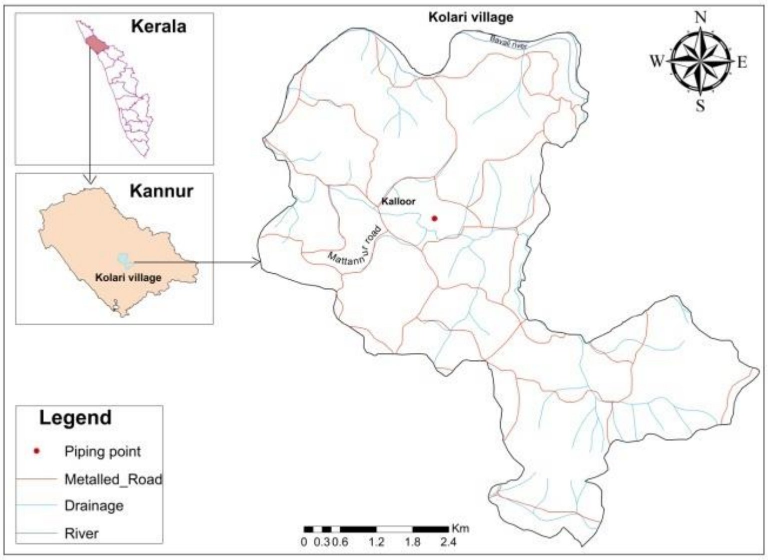


Figure 4.33: Location map of Kolari

The study shows that the land subsidence was due to the soil piping. Subsurface tunneling is wide spread in the affected localities and their size varies from few centimeters to couple of meters. The present pipe is a circular, with 1-foot radius. Electrical resistivity tomography has applied to know its extension and direction.

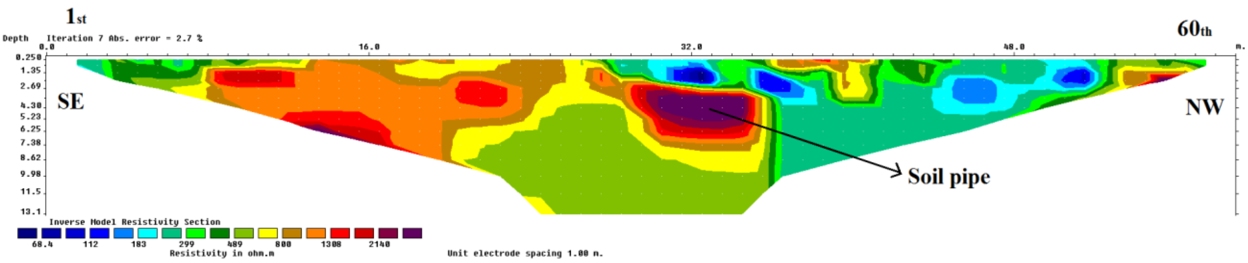


Figure 4.34**:** Inversion model of the ERT profile

The figure shows electrical resistivity tomographic sections of Schlumberger, array along the suspected area. This profile is laid near to the exposed part of the soil pipe. The survey line is oriented in the SE-NW direction and the depth resolution is ~16.9 m. The inverse model resistivity section, prima facie indicates a highly anisotropy in the entire section. A 3.5 m wide high resistivity zone present between 1.35 and 5.23m depth, near to the 32th electrode position.

The high resistivity in this region is may be due to the pipe. The moderate resistivity with lateral and vertical variation in between 1st and 30th electrode indicates hard resistive rock boulder with different layers of weathering condition.

Kottathalachimala, Cherupuzha panchayat Kannur District

The study concentrated in Kottathalachimala (Part of Western Ghats) is approximately 830m elevation. Aim of the study was to test the utility of resistivity survey to detect cavities developed due to soil piping. The work was confined to the five piping localities identified in this area.

The affected locality (Kottathalachimala) is situated in Thaliparamba taluk Kannur district comes under latitude 12°15'00''and longitude75°25'00 to 12°17'00''and 75°27'00''.The area is approachable road from Cherupuzha via Pulingom.

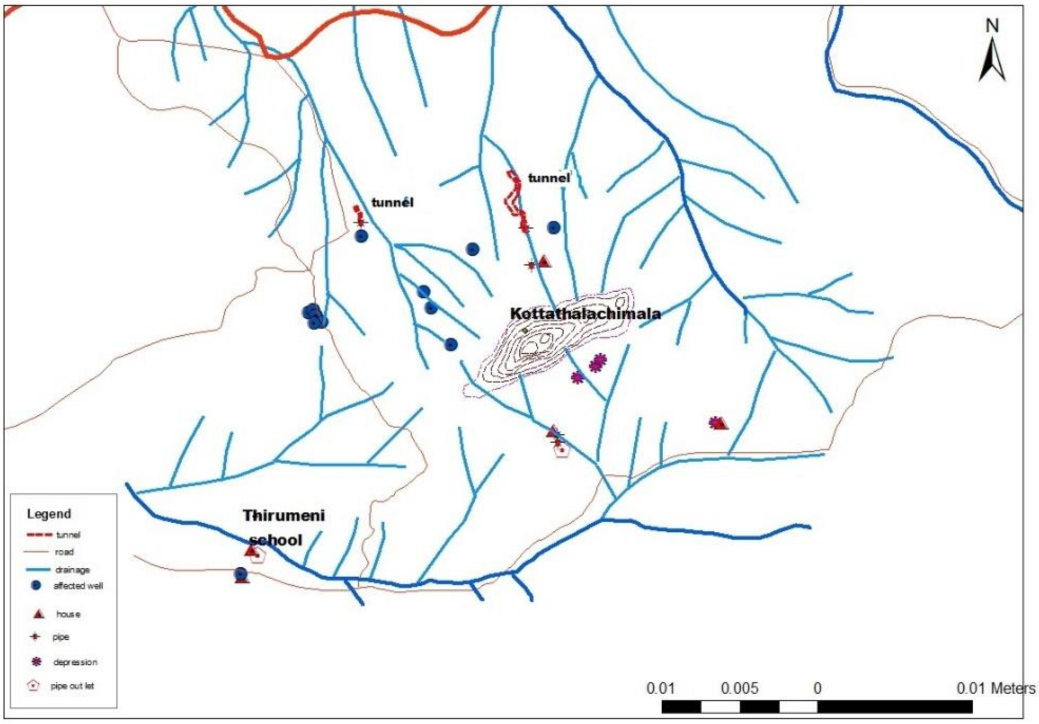


Fig.4.35: Field location

The affected area located in the highland region with elevation reaching up to 830 m. The characteristic of Kottathalachimala is its anomalous slope compared to other hills, nearby area. Upper slope is about high slope (+31°). where is the lower slops are about +24° .Kottathalachimala is characterised by radial drainage indicating it shape? Many lower order streams originated from this hill. The hill is surrounded by Pulingom River, Thirumenichal and Ponpuzha Ar.

Fig.4.36: A distinct view of Kottathalachimala

Geophysical surveys: The 2D Electrical Resistivity Imaging

Geophysical surveys were conducted in affected localities of Kottathalachimala, (fig 4.2.7) Taliparamba Taluk, Kannur to determine suitable method for delineation of pipes. Two resistivity profiles were laid across the alignment of soil pipes using the instrument WDJD4.The layout of these Electrical Resistivity Sounding (ERS) locations is given in figure1. A detailed description of the studies and their preliminary results are given here.

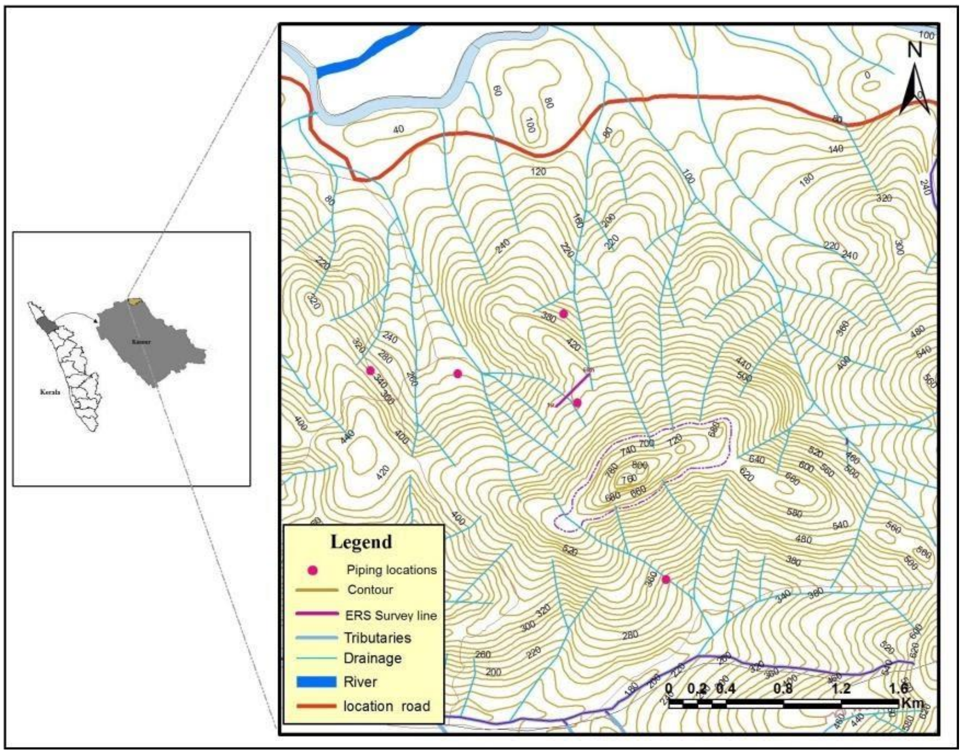


***Fig 4.37*:** The Electrical Resistivity Survey layout in Kottathalachimala

The resistivity data obtained from the ERS were retrieved to a computer and converted for interpretation by RES2DINV software (4.2.7 and 4.2.8). The interpretation of the data of each ERP carried out in specific array system provided apparent resistivity section, calculated apparent resistivity pseudo-section and inverse model resistivity section.

A profile with different electrode separation is laid across the soil pipe at 12m north of its inlet on the down slope side oriented in the EW direction. The figure 4.38 and 4.39 shows 2D electrical resistivity model of Schlumberger array with topographic correction. The corresponding resistivity with an electrode spacing of 1.5m (total profile length of 90m) and 1m (total profile length of 60m) respectively. The inverse model resistivity sections, prima-facie indicates highly anisotropic near-surface layers. There is a low resistivity zone within which a conspicuous low resistivity round-shaped feature is seen at a depth of 5m almost in the middle of the profile. Considering the apparent layout of soil pipe, resistivity values attributed to the zone and the shape of the feature, it could probably be indicative of the soil pipe.

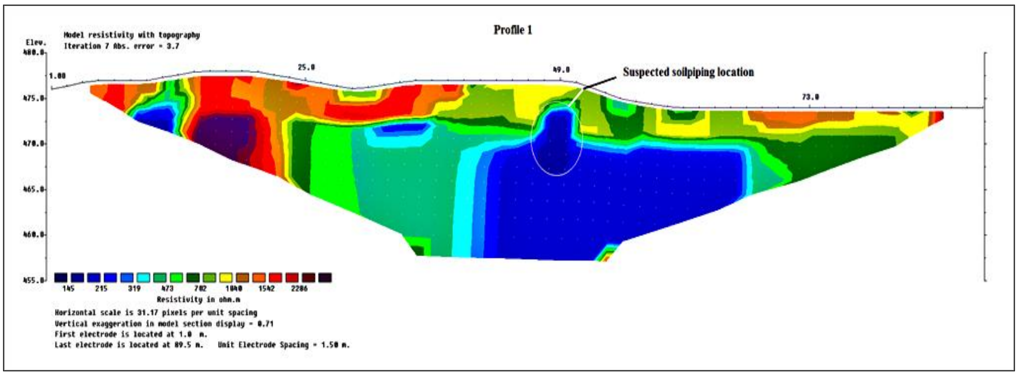


Figure 4.38: Electrical resistivity tomographic section of Schlumberger array at 1.5m electrode spacing

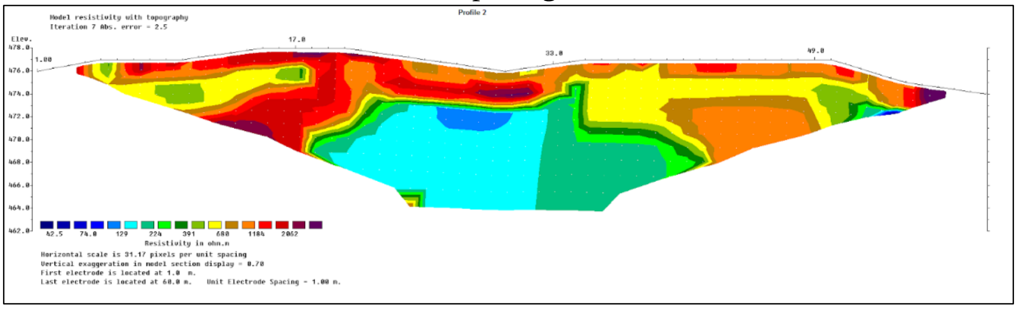


Figure 4.39**:** Electrical resistivity tomographic section of schlumberger array at 1m electrode spacing

The interpretation of the resistivity section indicates that the technique could delineate the low resistivity zones where the soil pipes are formed, subject to dimension. However, more detailed investigations with varying electrode configuration, different arrays etc. need to be attempted to get more clarity.

Table 4.3: Piping locations in Kannur District

Sl. No	Name	Location		position	Status	Remarks
		Latitude	Longitude			
1	Kottathalachimala	N 12º15'36.1”	E 75º26'08.7”	Populated area	Mature pipe, associated with small and Juvanile pipes	Typical area for soil piping
2	Kottathalachimala	N 12º16'16”	E 75º25'48.8”	Populated area	Mature pipe	Typical area for soil piping
3	Kottathalachimala	N 12º16'22.5”	E 75º25'21.8”	Populated area	Mature pipe	Typical area for soil piping
4	Kottathalachimala	N 12º16'23.2”	E 75º25'02.2”	Populated area	Mature pipe	Typical area for soil piping
5	Chattivayal	N12º15'34.1"	E75º26'08.7"	Populated area	Mature pipe	piping
6	Tabore	N12º15'37.9"	E75º27'00.2"	Populated area	Mature pipe	Medium sized tunnel affecting the foundation of house
7	Thirumeni	N 12º15'36.0”	E 75º26'45.7”	Populated area	Over size	First major occurrence reported
8	Padiyottuchal	N12º14'59.21"	E75º20'33.7"	Populated area	Mature pipe with lot of branching	Oversized tunnel
9	Vayakkara	N12º04'42.1"	E75º47'15.9"	Populated area	Over size	A complex oversized tunnelling in a habitats area
10	Ummrampoyil	N12º14'23.7"	E75º19'33.6"	Populated area	Mature pipe with lot of branching	Oversized pipe
11	Niranganpara	N12 2' 9.39"	E75 45' 7.19"	Populated area	Over size	A complex mature tunnelling beneath a well
12	Thermala*	N12.02237	E75.62704	SEOC-SDMA	SEOC-SDMA	SEOC-SDMA
13	Ayyanmada	N12.12856	E75.514977	Populated area	Mature pipe	Piping
14	Manippara	N12.05879	E75.651073	Populated area	Mature pipe	Piping
15	Ettupara	N12.09484	E75.591884	Populated area	Mature pipe	Piping
16	Muttannur	N11.94443	E75.570688	Populated area	Mature pipe	Piping
17	Vayakkara	N12.07836	E75.78775	Populated area	Mature pipe	Piping

* data from SEOC-SDMA)

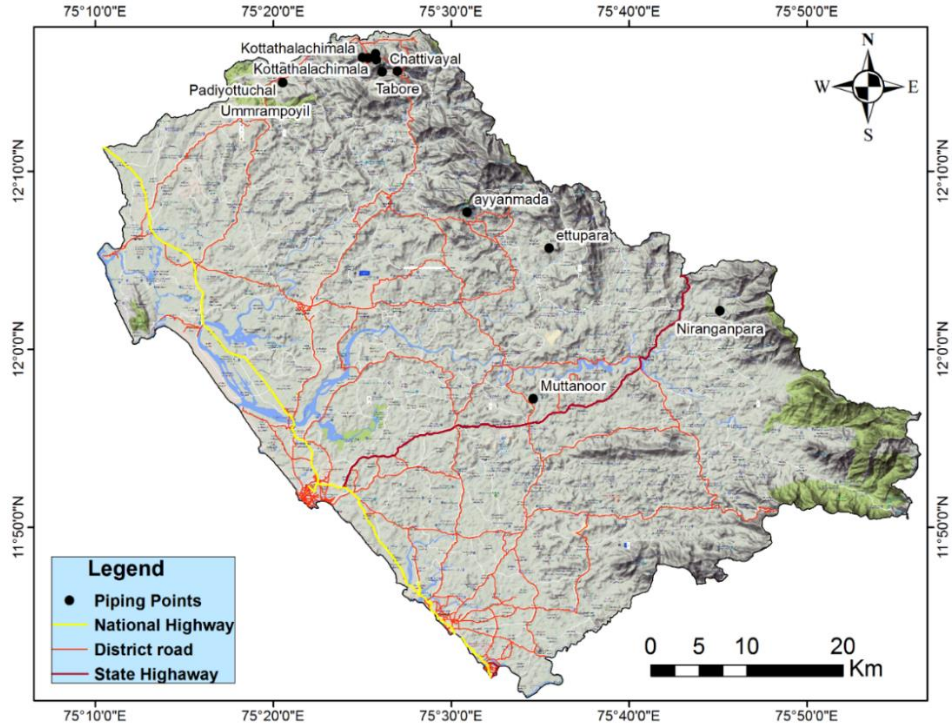


Figure 4.40**:** Piping location in Terrain map, Kannur

Prone areas

The Kannur district is prone for soil piping incidents. As the district is suspected with a total 17 number of soil pipes including minor and, major sized through stacking, scouting and geophysical investigations over the district. The geophysical, geochemical and sedimentological analyses of field data and samples collected during field investigations have given a clear idea that these pipes are occurring under certain conditions.

The Kannur district is one of the severely prone among the fourteen other districts of Kerala regarding soil piping incidents. The field investigation has revealed more than 17 major soil pipes in the district. There are chances of more such pipes developed in the interior and forested areas. The district is dominated by lateritic terrain which is developed as mesa type terrain. The mesa and adjoining valley terrain set up is ideally suited for pipe development.

As the district is recognized with more than 17 number of soil pipes including minor and, major sized through stacking, scouting and geophysical investigations over the district. The geophysical, geochemical and sedimentological analyses of field data and samples collected during field investigations have given a clear idea that these pipes are occurring mostly in the lateritic terrains affecting the lithomargic clays.

The geomorphological and geological features have the major hand on the piping process. The slope, drainage, soil types, vertical profile and rainfall are also accounting on this process.

Table 4.4: Areal extent of Soil piping affected regions in the district

District	Total area in sq.km	Affected area in sq.km	Probable area in sq.km	Non-affected area in sq.km	No. of soil pipes reported
Kannur	2,966	1224.931	993.192	777.877	17

Conclusion

The total area of the district is 2996 square kilometres in which 1224.931 km^2 is falling inside the Affected zone and 993.192 km^2 is falling inside the Probable zone which means a good portion of the district is vulnerable. The remaining 777.877 km^2 area is falling inside Non-affected zone which including coastal alluvium and hard rock exposures. Rajagiri, Mattannur, Manippara, and Iritty are the places where a greater number of pipes area seen and affected severely. Kottathalachimala is one such area severely affected by soil piping. The entire / Thirumeni Village, Cherupuzha Village and panchayat are severely affected by soil piping.

The field investigations reveal that this belt which is affected by soil piping is seen extending all directions especially in the Vellarikundu taluka of Kasaragod district and Coorge district of Karnataka where soil piping has already been reported.

1. **Recommendations for the "Affected areas"**

In the critically affected areas infrastructure such as roads, buildings etc will be affected. Restrictions on high rise buildings or detailed surveys before the construction id needed. A proper water management plan should be developed for restricting the spread of soil piping. Geophysical surveys are suggested for locating large and typical pipes**. Laterite mining may be restricted in the critically affected localities or the depth must restrict well above (at least 1m) the lithomarge clay layer is recommended. In no case clay layer should be exposed for water to infiltrate.**

2. **Recommendations for "Probable areas"**

These are areas prone to soil piping or mildly affected regions. In these areas juvenile and younger pipes are developed as an indicator of soil piping processes happening there. In such places well sections and laterite cutting are to be examined in detail for pipes and caves. Geophysical surveys may not help in identifying juvenile and younger pipes as they are smaller in size. Water management practices and usage of lime powder in the soil will retard the soil piping activities. **Laterite mining the depth must restricted well above (at least 1m) the lithomarge clay layer is recommended. In no case clay layer should be exposed for water to infiltrate.**

In both areas' usage of hydrated lime along with the fertilizers should be encouraged to neutralise dispersive sodium in the clay

Dewatering is the best method to deescalate the formation of soil pipes. Overland flow may be diverted to a nearby nala without allowing to infiltrate in the affected zone will reduce pipe development.

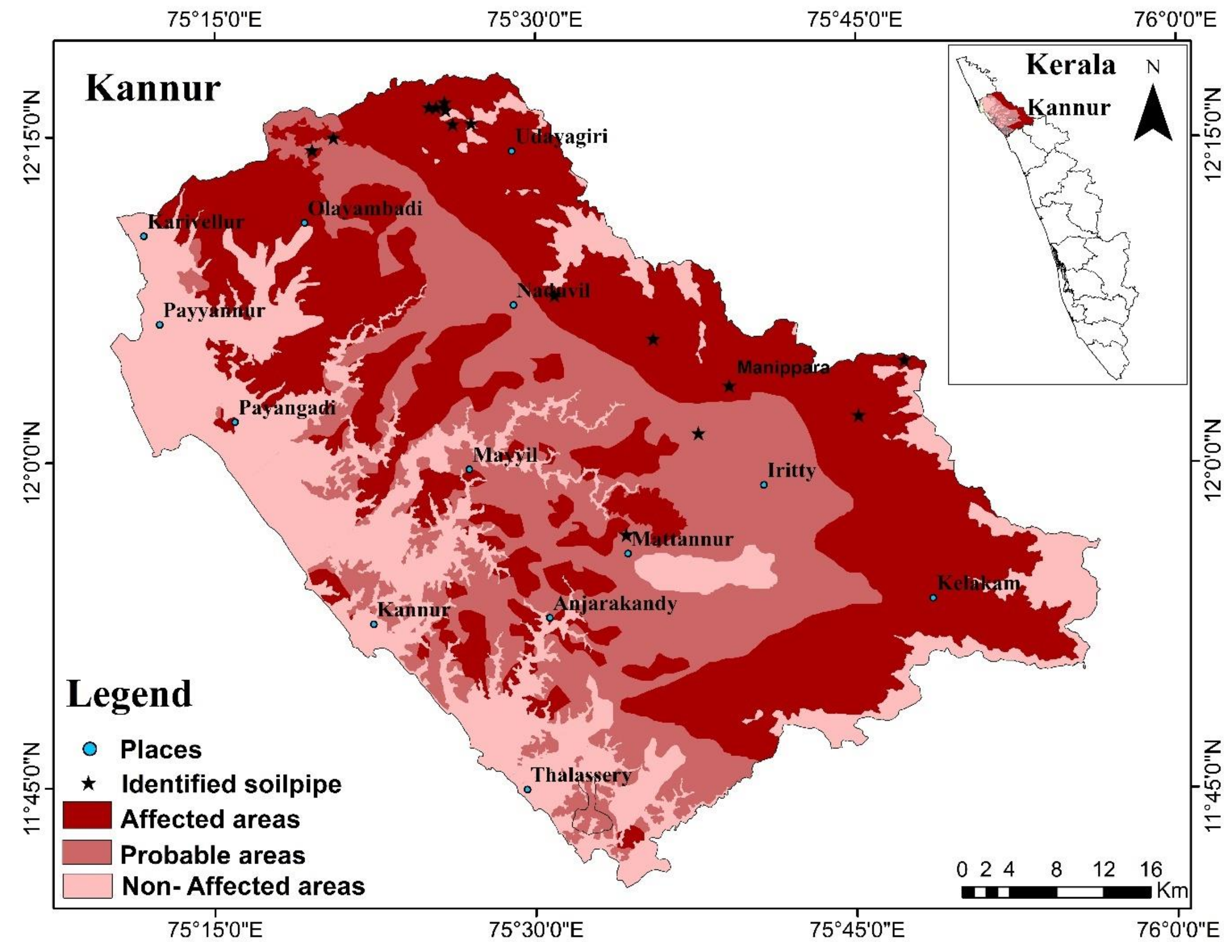


***Figure 4.41*:** Zonation map of Kannur

Kottathalachimala

Kottathalachimala

Padiyotuchal

Vayakkara

Kottathalachimala

Niranganpara

Chattivayal

***Fig 4.42*:** Field photos from Kannur district

4.3 Malappuram

The district Malappuram is one of the northern districts of Kerala lies between Latitudes: N10° 40'-N11° 32' Longitude: E75° 50' -E76° 36'. The district is bordered by Kozhikode and Wayanad districts in the north, Palaghat and Trichur districts in the south, the Nilgiris of Tamil Nadu in the east and Laksahweep Sea in the west. Malappuram district is divided into seven taluks (Ernad, Tirur, Tirurangadi, Ponnani, Perintalmanna, Nilambur and Kondoty).

Malappuram the name itself means "terraced place atop the hills", is a land of hills and valleys. The district is very important in the geological context that Angadipuram the type area for Laterite is in Malappuram.

Geomorphology

Geomorphologically the district can be divided into three physiographic units from west to east viz. coastal plain (less than 7.5 m amsl), mid land (7.5 – 75 m amsl) and highland (above 75 m amsl) or hilly terrain. The coastal plains extend as a narrow stretch of land lying along the coast from Kadalundi Nagaram in the north to Ponnani in the south. It exhibits depositional landforms of marine, fluvial and fluvio-marine origin. Palaeo-beach ridges suggestive of marine regression in the Quaternary period are well developed in the coastal tract. It becomes very narrow towards north of Tirur and the maximum width is seen along Chauravallam - Tirurangadi area. The area lying between the coastal plain in the west and the high ranges in the east is occupied by midlands. This is the most prominent physiographic unit of the district. The midland region is relatively wide with elevations ranging between 200 and 300m. It is a denudational terrain characterised by flat-topped laterite capped flats, mesas, interfluves, hills, mounds and spurs interspersed by narrow valleys as well as wide alluvial valleys and flood plain. Geomorphological studies in this region have brought out remnants of four palaeoplanation surfaces around 550m, 350-400m, 150-230m and 45-130m above msl. Of these the first two surfaces only have accordance of summits with relicts of laterite, whereas the latter two have extensive and plateau-type remnants with thick laterite profile. The hilly region in the east is more than 600m high. The terrain is characterised by hills and narrow incised valleys representing structural cum denudational landforms. This is characterized by flat topped hillock with steep 'U' shaped valleys and ridges. The valley forms potential area for agriculture including paddy, arecanut, vegetable, banana and coconut. The hill tops are generally barren and covered by thick and compact laterite. The eastern parts of the district are characterized by steep hills, gorges and escarpments. The elevation of the hill ranges goes up to 1127 m amsl. Most of the high lands are occupied by forests. Chaliyar puzha is the major river draining the northern part, Kadalundi puzha drains the central part, while the lower reaches of Ponnani puzha drain the coastal tract in the south.

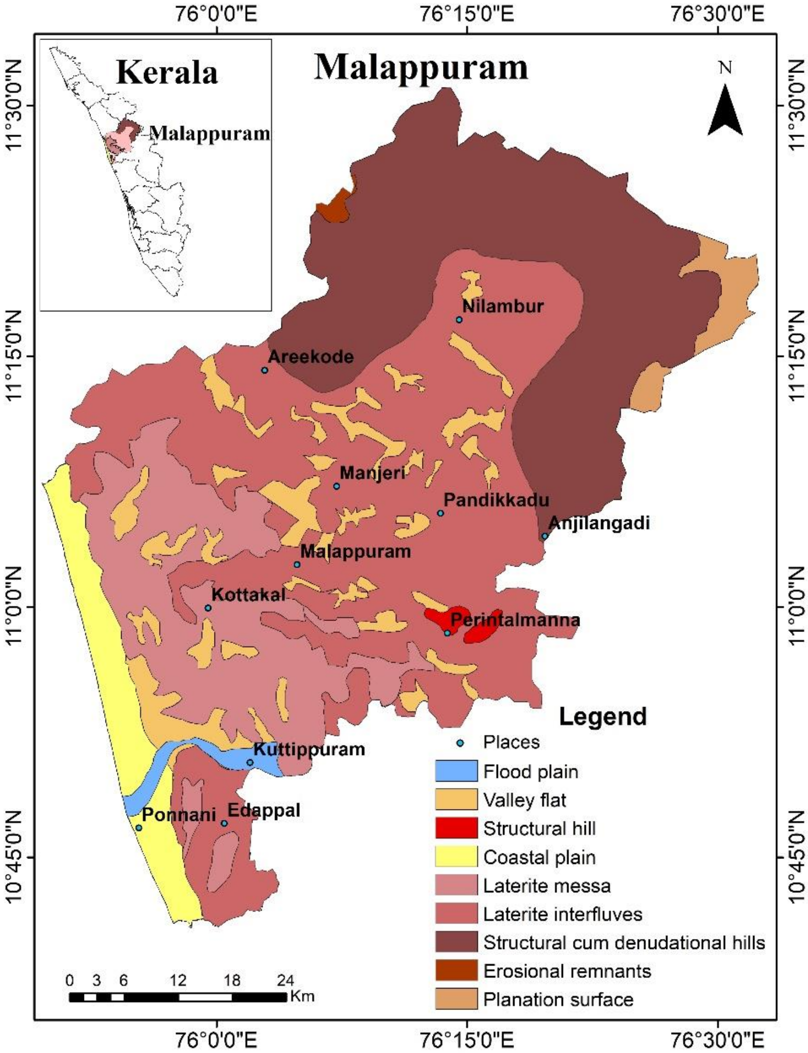


Figure 4.43: Geomorphology of Malappuram District

(geomorphology map modified after District Resource map, Malappuram district, Geological Survey of India)

Geology

The Precambrian crystallines, Tertiary and Quaternary sedimentaries constitute the geology of the district. The Precambrian crystallines includes Charnockite group of rocks covering a major part and Migmatite Complex towards the east. Wayanad group is represented by small bodies of metaultramafites (tal-tremolite schist, talc-pyroxene-garnet schist, banded magnetite quartzite) and high-grade schist and gneiss (hornblende-biotite schist and gneiss+garnet with amphibolite band). The rocks of Peninsular Gneissic Complex, represented by granite gneiss and hornblende-biotite gneiss, form the next younger sequence. A linear band of granite gneiss NE of Perinthalmanna and a large body of hornblende-biotite gneiss east of Manjeri are prominent units. Charnockite Group includes charnockite/charnockite gneiss, having the largest areal distribution, followed in decreasing order of abundance by banded magnetite quartzite, pyroxene granulite, amphibolite/hornblende granulite and pyroxenite, which occur as concordant as well as discordant bands, lenses, layers and enclaves both within charnockite as well as within gneisses of Migmatite Complex.

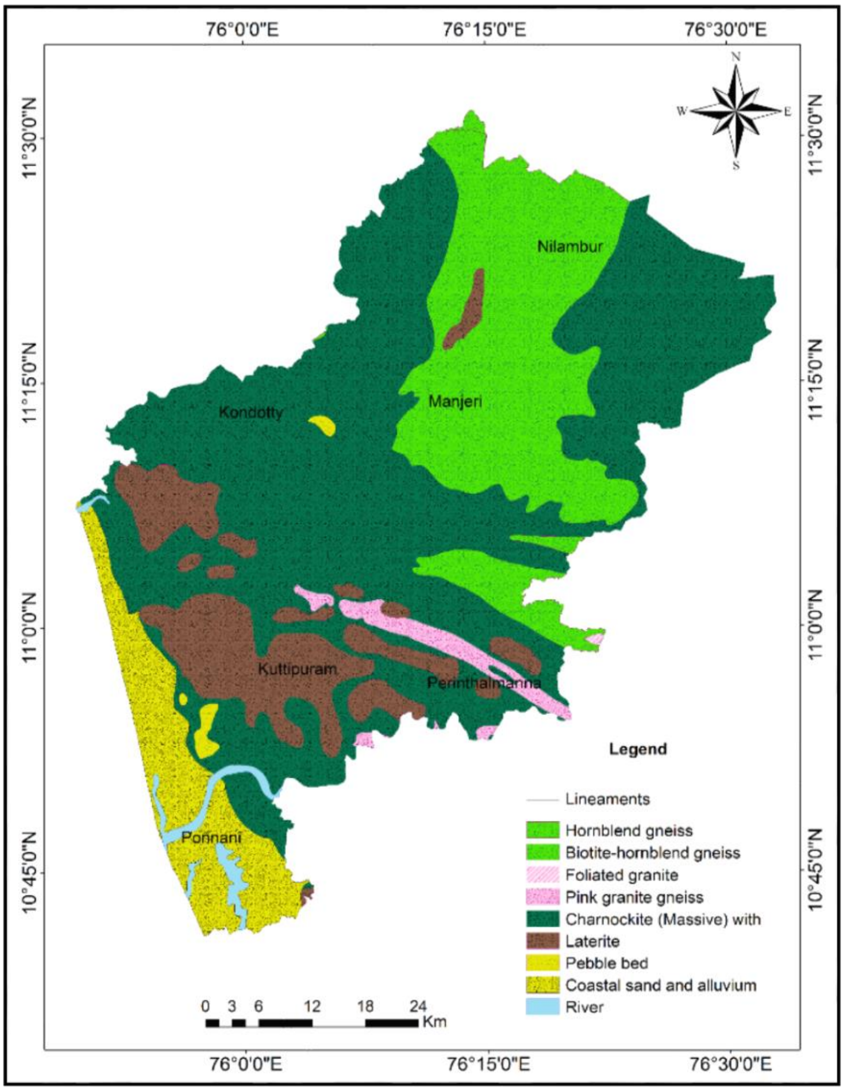


Figure 4.44: Geology map of Malappuram District

(geology map modified after District Resource map, Malappuram district, Geological Survey of India)

The Migmatite Complex is represented by biotite-hornblende gneiss (or hornblende-biotite gneiss) and quartzo-feldspathic gneiss/garnet-biotite gneiss with enclaves of garnet-sillimanite gneiss+graphite distributed mostly in the central and northeastern part. Pegmatite and quartz veins constitute the acid intrusives, whereas gabbro and dolerite are basic intrusives. Near the coast, isolated cappings of Neogene Warkalli sediments comprising grit and clay beds are noticed. Lateritisation is widespread, at places attaining a thickness of more than 10m. Extensive plateaus with laterite 'mesas' are common in the area. Angadipuram (west of Perinthalmanna) the type locality of laterite falls in this district. Quaternary unconsolidated sediments are restricted to the coastal plain.

Soil types

On the basis of morphological and physico-chemical properties, the Soil Survey Division of Department of Agriculture, Govt. of Kerala has classified the soils of the district into the following types,

- Soils of the low lands (Alluvial soil): Those are mainly seen along the coastal plains and valleys. The soils range from exclusively drained to moderately/well drained sand to sandy clay in nature.
- Soils of Mid/Up lands (Lateritic soil): These are mostly lateritic soil and is seen along the mid land portion of the district. These are deep to very deep, well drained, and gravelly to clayey.
- Soils of Central Sahyadri (Hydromorphic soil): These are deep moderate, well drained and clayey soils with high gravel content. Erosion is moderate to severe. Hard laterites with rock out crops are present.
- Soils of eastern part of Malappuram (Forest loamy soil): These soils are deep or very deep and well drained with loamy to clayey textures and having fairly high gravel content.

Drainage

The Kadalundi river, Chaliyar river and Bharathapuzha river are the major drainages draining the Malappuram district, among which Chaliyar and Baharathapuzha are perennial rivers and all the others are seasonal that they get dried up in summer making Malappuram drought prone. The Kadalundi River is 130 km long with a drainage area of 1274 sq. km. The river joins the Lakshadweep Sea at about 5 km south of the Chaliyar river mouth. The Chaliyar River, one of the major rivers of the State, originates from the Ilambalari Hills in Nilgiri district of Tamil Nadu (2066 m amsl). The river is 169 km long with a drainage area of 2535 sq. km in Kerala State. The Bharathapuzha or the Ponnani River is the second longest river of Kerala, originating from the Anamalai Hills (1964 m amsl) in the Western Ghats. The river below the confluence of

Bharathapuzha and Gayathripuzha is called the Ponnani River. It flows through the districts of Palakkad, Malappuram and Trichur and drains into the Lakshadweep Sea near Ponnani town in Malappuram district.

The three rivers generally have dentritic drainage pattern. Analysis of the drainage characteristics of the two basins reveals that Kadalundi river is a fourth order stream, the Ponnani river is fifth order stream and the Chaliyar river is a seventh order stream.

Rainfall

The district has more or less the same climatic conditions prevalent elsewhere in the state viz. dry season from December to February and hot season from March to May, the South-West monsoon from June to September and the North-East monsoon from October to December. The normal rainfall of the district is 2793.3 mm. Out of this; major rainfall contribution is from SW monsoon followed by the NE monsoon. The South West monsoon is usually very heavy and nearly 73.5% of the rainfall is received during this season. NE monsoon contributes nearly 16.4% and March to May summer rain contributes nearly 9.9% and the balance 0.2% is accounted for during January and February months.

Soil piping incidences in Malappuram

Malappuram district is one of the severely affected districts in terms of soil piping hazards. The district is bestowed with well-developed laterite mesas and duricrusts. The good quality laterite is being exploited as building material in the form of laterite bricks. Often such quarries exploit materials up to lithomarge clay present at the bottom allowing the rain water to get contact with clay. Such areas will be the initiation points of soil piping. In Malappuram district there are many areas with large stabilised tunnels and pipes. In such places field surveys should be conducted before construction civil structures. Till the end of December 2019 there are 24 well established pipe locations in the district. (table 4.3.1). One of the major incidents was the land subsidence in the Perumannaklari near Kottakkal. It is reported that many laterite quarrying localities encountered subsurface tunnels during quarrying and they cover it with local fill without reporting to the authorities. This land will be sold in real estate for housing and commercial purposes. It is better to rule out piping through field surveys before any construction or purchase of land.

Table 4.5: Piping locations in Malappuram District

Sl. No	Name	Location		position	Status	Remarks
		Latitude	Longitude			
1	Irubuzhi	N11° 04’ 40’’	E76° 05’46.5’’	Populated region	Mature pipe	
2	Manjeri	N11°05’ 25.6’’	E76° 05’53.2’’	Populated region	Mature pipe	Filled manually
3	Chembrasserri	N11° 08’ 07’’	E76° 15’24.6’’	Less populated region	Mature pipe	Stabilized
4	Kottaykkal	N10°59’09 .9”	E 75°57’ 58.2 “	Populated region	Oversized pipe	Subsided
5	Thehnipalam, calicut university	N 11° 8' 2.4"	E75°53' 43.08"	Populated region	Mature pipe	Filled
6	Melmuri-Alathurpadi	N 11° 4' 35.6"	E75°5' 5.76"	Quarry	Mature pipe	Filled manually
7	Malappuram	N 11°04'17.0"	E76°05'05.7"	Populated are	Juvenile pipe	
8	Changili mada	N 10°52' 56.5"	E76°01' 31.3"	Nonpopulated region	Oversized	Stabilized
9	Nava-Mugundha HSS	N 10°52'03.7"	E75°59'29.3"	School	Young pipe	Excavated and filled. Juveniles are
10	Kodakkal	N10°51'49.4"	E75°58'20.0"	Across road	Mature pipe	Filled by the local people
11	Iringavur	N 10°56'08.5"	E75°57'22.1"	Populated region	Mature pipe	Filled by soil for construction
12	Chembrassery	N 11°08'06.7"	E76°15'24.3"	Less populated region	Mature pipe	Stabilized
13	Mutiyel	N 11°21'07.4"	E76°12'40.4"	Populated region	Outlet	Active outlet in initial stage
14	Ekkaparamb	N 11°9'34"	E75°59'4"	Populated region	Young pipe	

15	Pang	N10°56'36.78"	E76°06'55.32"	Less populated region	Mature pipe	
16	Alappara Mala	N11°16'58"	E76°05'21"	Populated region	Young pipe	Filled manually
17	Malappuram*	N10.88703	E75.99186	populated region	Juvenile pipes	SEOC-SDMA
18	Chekkunnu mala, Chairangad colony area*	N11.258639	E76.104833	Populated region	SEOC-SDMA	SEOC-SDMA
19	East chathallur (Cholara colony Kappakallu) *	N11.264022	E76.139027	populated region	SEOC-SDMA	SEOC-SDMA
20	Alappura*	N11.28113	E76.090463	Populated region	SEOC-SDMA	SEOC-SDMA
21	Valiyangadi*	N11.054877	E76.065249	populated region	SEOC-SDMA	SEOC-SDMA
22	NH colony*	N11.110805	E75.99828	Populated region	SEOC-SDMA	SEOC-SDMA
23	Vettilpurayil*	N11.135492	E75.936208	populated region	SEOC-SDMA	SEOC-SDMA
24	Karaparambil Ward 2*	N11.16041	E75.90748	Populated region	SEOC-SDMA	SEOC-SDMA

* data from SEOC-SDMA)

Affected infrastructures

1. Kottaykkal, Perumannaklari Panchayat **Location:** N 10°59’09 .9”
E 75°57’ 58.2 “

The affected site is located about 6km from Kottakkal town in the Perumanna village. This locality is accessible by all-weather roads from the nearby towns. The land disturbances have taken place in two adjacent residential plots. One belongs to the Zainudin Paruthikunnen and the other belonging to Sri Abdul Rahim, Pottachola.

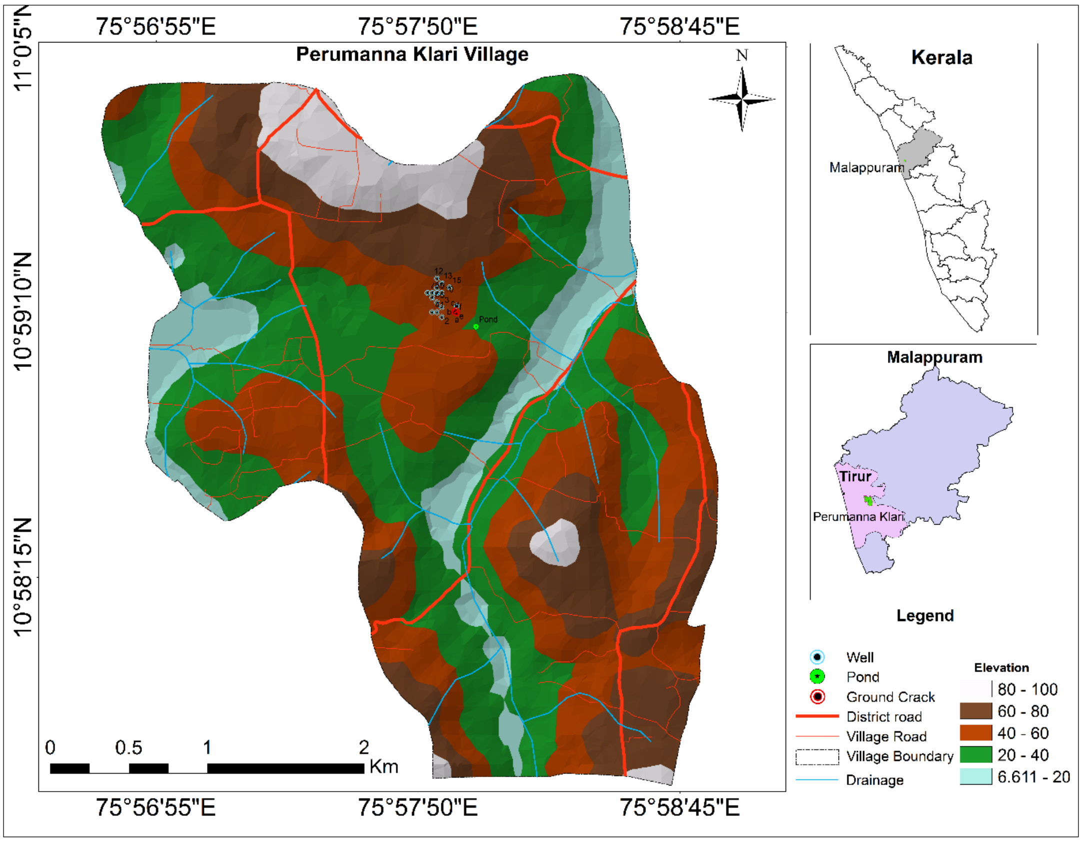


Figure 4.45: Location map of the affected site

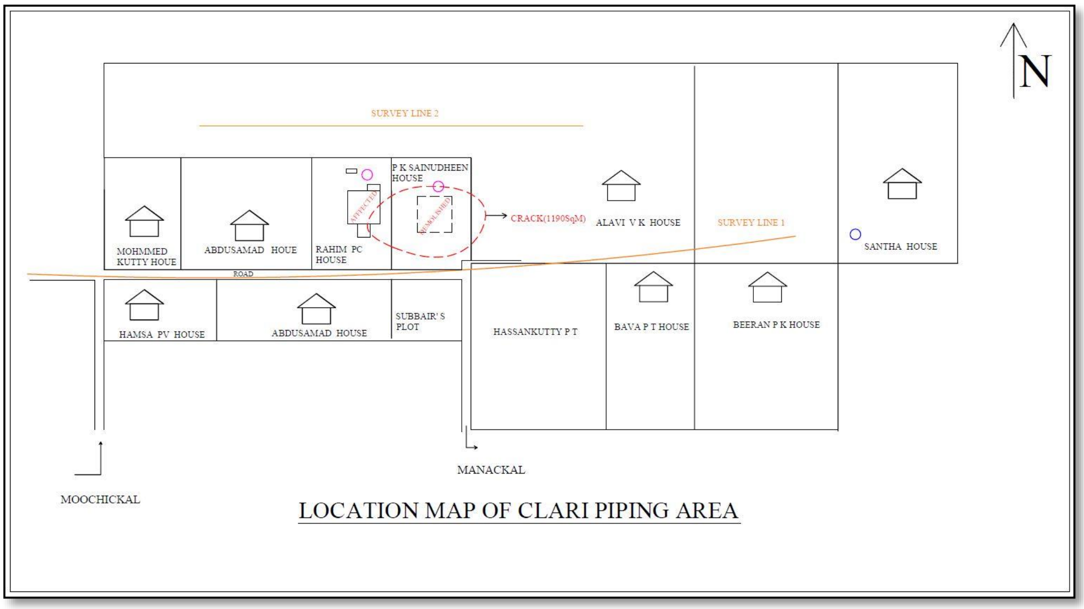


Figure 4.46**:** Showing the extent of the soil piping affected area in Perumannaklari (Klari)

<u>Zainudin Paruthikunnen house and plot:</u> In the 2013 investigation by CESS it was mentioned that "The terraced relatively new house belonging to Shri. Zainudeen, Paruthikunnen, is totally damaged with almost all the walls and floor cracked beyond repair. Sub horizontal cracks are

noticed on all the walls and basement. Plaster is peeled off exposing the bricks in many places. There is no definite pattern in the cracks. The floor tiles have been dislodged with formation of cavities below on account of ground subsidence. The basement appears to have subsided by few cms.

Figure 4.47: Showing the damaged house of Zainudin Paruthikunnen

Ground cracks are more prominent on the northern and eastern part of the building. The open well with water on the northern side of the house has developed a crack all around the circular opening at about 5 m depth with an inclination to the south. There is a visible displacement seen along the cracked surface. The crack is seen in the laterite profile below the hard-vermicular layer." At the time of this visit the house of Sri Zainudin was completely in a broken-down condition. Ground cracks have become huge. The land had subsided about 30 cm causing huge ground fissures of about 17 meters. The subsidence has taken place in an oval shape with elongation in the EW direction. The fissures have propagated to the basement of the old house there by completely destabilizing it.

Figure 4.48: Subsidence occurred at Perumanna Klari

Now only basement and remnants of the building are seen. Due to the ground subsidence the house and the plot cannot be put into any use and should be abandoned. The widened ground cracks are posing danger and it be barricade to prevent people from entering into the compound.

Here the loss is total. Repair of this house or resettlement here is ruled out due to progressive subsidence of the ground.

Figure 4.49**:** Zainuddin's house in 2013 (file photo)

Figure 4.50: Totally damaged house of Mr. Zainuddin (2018)

<u>House owned by Sri. Abdul Rahim, Pottachola:</u>

The RCC terraced house owned by Sri. Abdul Rahim, Pottachola, has been severely damaged with ground cracks extending into the basement on the South and east side. The SE corner has suffered substantial damage and developed sub-horizontal cracks below the lintel level. The floor of the house and walls are cracked in many places.

Figure 4.51**:** Cracks on the wall of affected house

The cracks are discontinuous oriented mostly in east-west direction. The horizontal separation is about 25cms. The extension of the cracks into the building resulted in the development of cracks to the floor and walls of houses. The floor of the houses appears to be tilted towards southeast. The windows and door frames have been separated from the walls with visible displacement. The house was damaged extensively and there is no scope of repair. Ground subsidence is progressing in this locality also and any scope of settlement and human activities cannot be allowed.

The affected two plots now pose extreme danger to the local community. It is reported that one goat while grazing in this area accidently fell into the crevasse formed by the ground fissures. So, it is recommended that this area should be barricaded and prevent the locals from entering into it. Local panchayat may take appropriate measure to educate the people and put informative boards in this area.

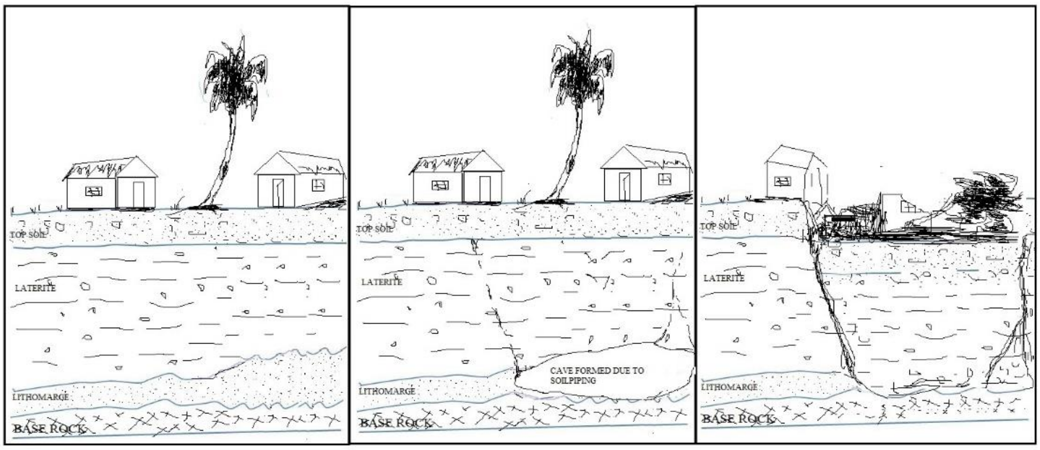


***Figure 4.52*:** Sketch showing the subsidence related to soil piping in Perumannaklari (not to scale)

Causative factors of the ground subsidence

The ground fissures in this area were first noticed by the locals in 2013. Studies were conducted by CESS (now NCESS) and GWD, Govt. of Kerala in 22.4.2013 indicated that excess draining of water from the clay substrate might have caused shrinkage with slight ground subsidence and emergence of cracks in the hard laterite cap rock. They also ruled out seismicity as a causative factor for the development of ground fissures. In that report it was mentioned that the cracks were noticed from 15.4.2013. One family had abandoned the house and the other continued to live in the dilapidated house, one day prior to this field investigation. During the course of five years, the ground fissures were enlarged and propagated as an oval shape clearly indicating a ground subsidence. Since then the ground had subsided about 30cm. The progressing nature of the ground subsidence indicated that soil erosion is active in the bottom and voids are created to accommodate the overburden. In order to understand the subsurface features two methods were employed. Observe the open wells in the area and conduct geophysical surveys. About 32 wells 7 bore holes and one pond were observed around the affected site, out of this few wells were selected for detailed studies. Multi electrode electrical resistivity surveys were carried out in the east -west direction in the northern and southern boundaries of the affected site.

Electrical Resistivity investigation : Geo-electrical surveys were conducted in affected locality to determine presence of pipes. Two resistivity profiles were laid across the alignment of suspected soil pipes that was in EW direction using the instrument ABEM Terrameter. The first electrode placed in the western side and last electrode at east of the pipe. The survey line 1 was laid near to the subsidence in the south and survey line 2 was laid about 50m north of the subsidence. A total of '64' electrodes at 2m and 3m spacing, the length of the survey line went up to 128m and 192m respectively. The survey mid points are placed at the south and north of the suspected target to get maximum depth details. The Survey was carried out with Wenner, Schlumberger & Dipole - Dipole array to study the earth resistivity responses. The data retrieved is stored in in the ABEM Terrameter and it was transferred to Laptop or PC. The 'WDAFC.EXE' data format convert software can transform data into 'RES2DINV' and measured data is processed using 'RES2DINV' Software.

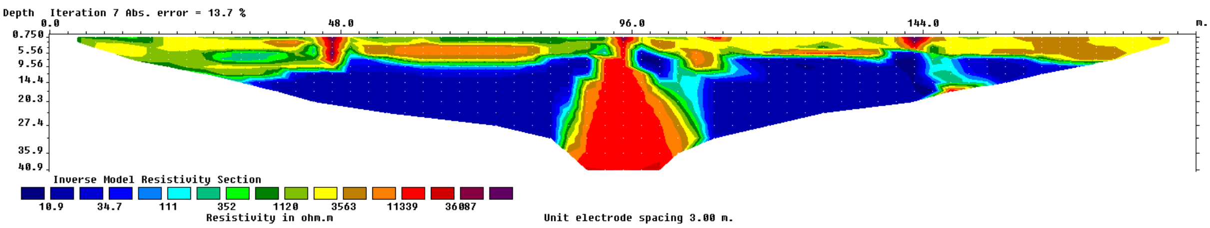


***Figure 4.53*:** ERT (Schlumberger) taken in the EW profile (survey line 1)

Profile 1 was laid with an electrode spacing of 3.0m and the mid-point of the survey line was near to the subsidence. Schlumberger (Fig **4.53**) Wenner, (Fig**4.54**) and dipole-dipole configurations have been done over the area. Among the three, Schlumberger can be most useful for mapping the tunnel cross-sections. From the section the low resistivity layer is about 6 meters in the resistivity section could be an indication of the groundwater zone. In the middle of the section a high resistivity zone separates the water saturated area is an indication of the suspected soil pipe. The configuration fails 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 array.

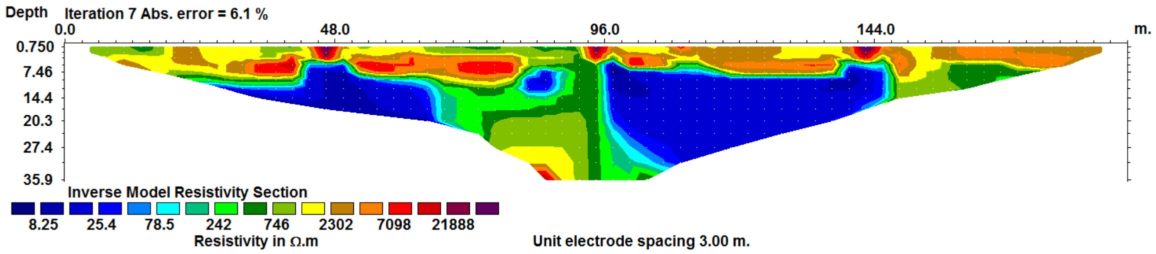


Figure 4.54: ERT (Wenner array) taken in EW direction - Survey line 1

The qualitative interpretation of the resistivity section indicates that the technique could delineate the conductive zones where the soil pipes are formed. The profile 1 has taken close to the subsidence and possible orientation of pipe at the location is 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. In profile 2 electrical resistivity survey was carried out parallel to this profile on the northern side of the affected site. Since the suspected pipe in this area is small in size it escaped detection in the survey. In this location the size of the pipe was possibly small to escape the detection from ERT

Survey line 2 was aid at 50m north of the major subsidence at an electrode spacing of 2m and the total lateral extension of 128m.The resultant data (Fig. **4.55 and 4.56**) gives a maximum depth about 16m.The resistivity tomography could not recognize any piping this locality as the suspected pipe is much smaller in size in this locality.

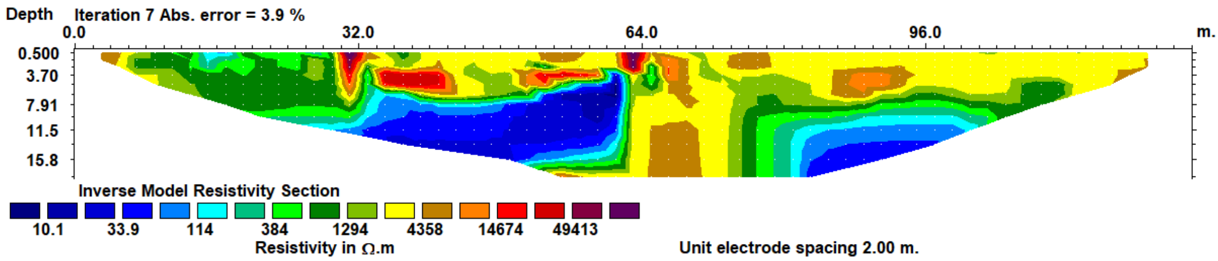


Figure 4.55: Electrical resistivity tomograph of Schlumberger array

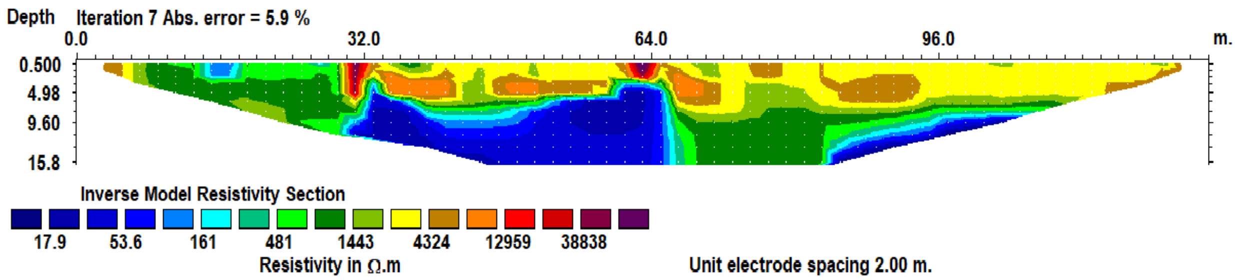


Figure 4.56: Electrical resistivity tomograph of Wenner array

Hydrogeological studies

In the Kottaykkal, Perumannaklari Panchayat total 32 wells, 7 boreholes and one pond were studied and analysed. All the studied wells are present near the affected area. The area is very gently sloping and having a surface slope of 4 o- 5o. The depth of the water level in the wells varies from ~8 m to 25 m, depending on the terrain configuration. Out of 32, 7 wells are completely dried. 24 wells show some signatures of deformation. The deformation features include cracking in wall of the well, high rate of sedimentation in well and presence of caves inside the well. The cracking in the wall is due to settlement of the land. This land settlement was due to subsurface cavity/ soil pipe. Near the affected site, well nos. 22, 27 shows a NW-SE oriented pipe which has a minimum length of 44m. The maximum depth of crack observed in the well is 12.8 m (well no 9). Below this depth some pipe features are presents in the well (well nos. 13, 14, 15,16,18,19 and 20). Some wells (nos. 14,15,17,18, 20 and 23), lying just upslope side of affected area, are presently dry. However, the area recently received good amount of water through the rain fall. In the SE direction of the affected area, four wells (nos. 29,30, 31 and 32) aligned in E-W direction contains the turbid water. However, the degree of turbidity varies in all these wells. This suggests a presence of a pipe oriented in E-W direction with at least 144 m length. The turbidity is because of the erosion and dispersion of lithomargic clay. The other wells show clear water in it. Some wells have pipe outlets. As the well 4,5,10,13,21,22 and 27 have pipe features which was covered by rings. Similarly, 4 years back (i.e. year 2014) the well 22 experienced over flow due to piping. In the well 27, one SE oriented pipe is exposed. 5 water samples were collected from different wells. The data suggests that the pH values of the well water varies from 5.26-6.25. In the pipe affected area, the TDS value is much higher (236.0 ppm) then the common surrounding values.

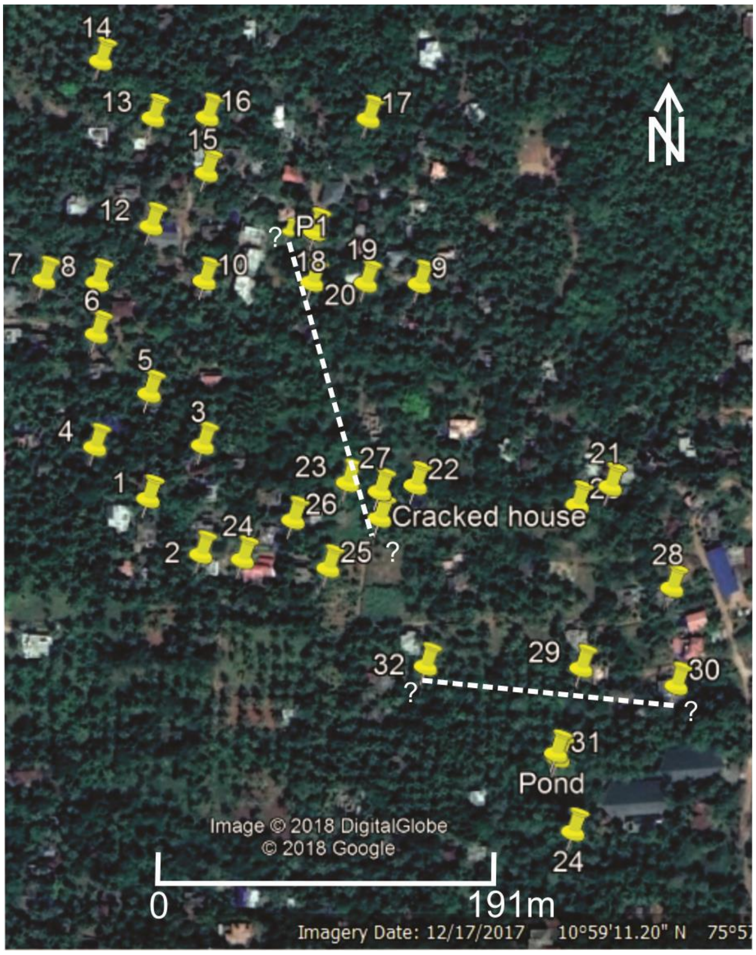


Figure *4.57:* Google Earth image showing various studied wells and location of affected house. The dotted line represents the NNW-SSE and E-W trending soil pipes.

Table 4.6: Ground investigation details, Perumannaklari, Malappuram district

Well no	Location	Water level (m)	Total depth (m)	Features	Rock type	Water quality
1	N 10o 59’ 10”, E 75 o 57’ 54’’	13.89	15.77	No crack	Laterite	
1a	N 10o 59’ 10”, E 75 o 57’ 54’’	25	-------			
2	N 10o 59’ 9”, E 75 o 57’ 55’’	13.44	---------	Crack at the depth of 8.40m	Laterite	
2a	N 10o 59’ 9”, E 75 o 57’ 55’’	16	24.38			
3	N 10o 59’ 11”, E 75 o 57’ 55’’	13.9	13.98	Crack at the depth of 12 m	Laterite	
3a	N 10o 59’ 11”, E 75 o 57’ 55’’	24	36			
4	N 10o 59’ 10”, E 75 o 57’ 53’’	14.14	26	Crack at the depth of 9.6 m. Secured covering by ring. Process started 8 year before	Laterite	

5	N 10o 59’ 12”, E 75 o 57’ 54’’	15.60	16	Crack at the depth of 9.9 m. Secured covering by ring. Process started 8 year before	Laterite	
5a	N 10o 59’ 12”, E 75 o 57’ 54’’	20	44.4			
6	N 10o 59’ 13”, E 75 o 57’ 53’’	12.9	14.10	Crack at the depth of 8.9 m.	Laterite	
6a	N 10o 59’ 13”, E 75 o 57’ 53’’	18.2	60			
7	N 10o 59’ 14”, E 75 o 57’ 52’’	15.2	16.20	Crack at the depth of 10.80 m.	Laterite	
7a	N 10o 59’ 14”, E 75 o 57’ 52’’	18	115			
8	N 10o 59’ 14”, E 75 o 57’ 53’’	16.2	19.40	Crack at the depth of 9.6 m.	Laterite	
8a	N 10o 59’ 14”, E 75 o 57’ 53’’	24	36			
9	N 10o 59’ 14”, E 75 o 57’ 59’’	12.8	14.18	Crack at the depth of 12.8 m.	Laterite	
10	N 10o 59’ 14”, E 75 o 57’ 55’’	15	17.5	Secured with ring at 10 m depth	Laterite	
11	N 10o 59’ 15”, E 75 o 57’ 54’’	15.3	16.1	No cracks	Laterite	
12	N 10o 59’ 16”, E 75 o 57’ 27’’	15.1	15.5		Laterite	
13	N 10o 59’ 17”, E 75 o 57’ 54’’	14.5	15.6	Cave starting at 7.50 m	Laterite	
14	N 10o 59’ 18”, E 75 o 57’ 53’’	--------	16.30	Crack and cave opening at 14.80	Laterite	
15	N 10o 59’ 16”, E 75 o 57’ 55’’	-------	17.8	Crack and cave opening at 16.80	Laterite	
16	N 10o 59’ 17”, E 75 o 57’ 55’’	17.10	17.40	15.5 m cave found	Laterite	
17	N 10o 59’ 17”, E 75 o 57’ 58’’	----------	15.80		Laterite	
18	N 10o 59’ 15”, E 75 o 57’ 57’’	--------	16.30	Cark and opening at 13.40	Laterite	
19	N 10o 59’ 14”, E 75 o 57’ 58’’	13.80	15.40	Cark and opening at 12.10	Laterite	Clear water
20	N 10o 59’ 14”, E 75 o 57’ 57’’		15.60	Cark and opening at 13.60	Laterite	
21	N 10o 59.172’ E 75 o 58.043’	11.75	13.21	One pipe outlet but closed with rings	Laterite	Clear water
22	N 10o 59.172’ E 75 o 57.983’	14.12	15.34	4 year back over flowed	Laterite	Clear water
23	N 10o 59.173’ E 75 o 57.962’	----------	14.59	Cracks up to 6.08 m depth	Laterite	Dry
24	N 10o 59.149’ E 75 o 57.930’	13.59	14.44	Seasonal well. Filled during rainy season only	Laterite	Clear water

25	N 10o 59.147’ E 75 o 57.956’	12.24	12.58	Cracks were present since it built	Laterite	Clear water
26	N 10o 59.147’ E 75 o 57.956’	------------	12.74	-----------------	Laterite	Dry
27	N 10o 59.170’ E 75 o 57.972’	15.11	16.89	SE oriented pipe is present, cracks are present	Laterite	Clear water
28	N 10o 59.142’ E 75 o 58.063’	11.30	12.66	----------------	Laterite	Clear water
29	N 10o 59.117’ E 75 o 58.035’	8.76	9.62	After the incidence. Seasonal well. High rate of sedimentations.	Laterite	Turbid water
30	N 10o 59.112’ E 75 o 58.065’	8.64	10.17	Lithomargic clay collapsed	Laterite	Turbid water
31	N 10o 59.09’ E 75 o 58.028’	11.20	11.78	Lithomargic clay collapsed	Laterite	Turbid water
32	N 10o 59.118’ E 75 o 57.987’	9.31	10.04	---------------	Laterite	Turbid water

Ground investigation has revealed that it is due to an underground soil erosion called “soil piping” or Tunnel erosion. The “Soil piping” (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.

In Perumnnaklari also the field studies have indicated the presence of soil pipes in this area. The geophysical survey conducted very close to the affected locality has indicated the presence of a void which extending to a depth of 26 meters. The hydrogeological studies also indicated (table 1) the presence of tunnels and caves in few wells. So, it is suspected that pipes trending in NW - SE and E-W are present in the area. A more detailed study is required map the network of soil pipes in this locality.

Prone areas

The Malappuram district is one of the severely prone among the fourteen other districts of Kerala after Kasaragod and Kannur Districts. The field investigation has revealed more than 24 major soil pipes in the district. The identified soil pipes have occurred in urban and near to urban and so there can be more such pipes developed in the remote and forested areas. The district is dominated by lateritic terrain which is developed as mesa type terrain. The mesa and adjoining valley terrain set up is ideally suited for pipe development.

As the district is recognized with more than 24 number of soil pipes including minor and, major sized through stacking, scouting and geophysical investigations over the district. The geophysical, geochemical and sedimentological analyses of field data and samples collected during field investigations have given a clear idea that these pipes are occurring under certain conditions.

The geomorphological and geological features have the major hand on the piping process. The slope, drainage, soil types, vertical profile and rainfall are some of the major features that accounts on this process.

As the identified incidents are having almost similar characters and conditions in formation a zonation is possible through which the district could highlight with Critically affected, Most probable and least probable zones. This can help in giving awareness and management in land use in future.

***Table 4.7*:** Areal extent of Soil piping affected regions in the district

District	Total area in sq.km	Affected area in sq.km	Probable area in sq.km	Non-affected area in sq.km	No. of soil pipes reported
Malappuram	3,550	867.359	1867.394	815.248	24

Out of the 3550 sqkm area of the district, about 867.35 sqkm was found to be affected by soil piping. Here many places subsidences were reported. About 1867.394 sq.km area is showing signs of initial stages of piping was classified as probable area. Since Malappuram is a laterite dominated district proper care should be taken before any activity on ground. Hydraulic head should not be created with in laterite mesas which will lead to soil piping processes.

1. **Recommendations for the "Affected areas"**

In the critically affected areas infrastructure such as roads, buildings etc will be affected. Restrictions on high rise buildings or detailed surveys before the construction id needed. A proper water management plan should be developed for restricting the spread of soil piping. Geophysical surveys are suggested for locating large and typical pipes**. Laterite mining may be restricted in the critically affected localities or the depth must restrict well above (at least 1m) the lithomarge clay layer is recommended. In no case clay layer should be exposed for water to infiltrate.**

2. **Recommendations for "Probable areas"**

These are areas prone to soil piping or mildly affected regions. In these areas juvenile and younger pipes are developed as an indicator of soil piping processes happening there. In such places well sections and laterite cutting are to be examined in detail for pipes and caves. Geophysical surveys may not help in identifying juvenile and younger pipes as they are smaller in size. Water management practices and usage of lime powder in the soil will retard the soil piping activities. **Laterite mining the depth must restricted well above (at least 1m) the lithomarge clay layer is recommended. In no case clay layer should be exposed for water to infiltrate.**

In both areas' usage of hydrated lime along with the fertilizers should be encouraged to neutralise dispersive sodium in the clay

Dewatering is the best method to deescalate the formation of soil pipes. Overland flow may be diverted to a nearby nala without allowing to infiltrate in the affected zone will reduce pipe development.

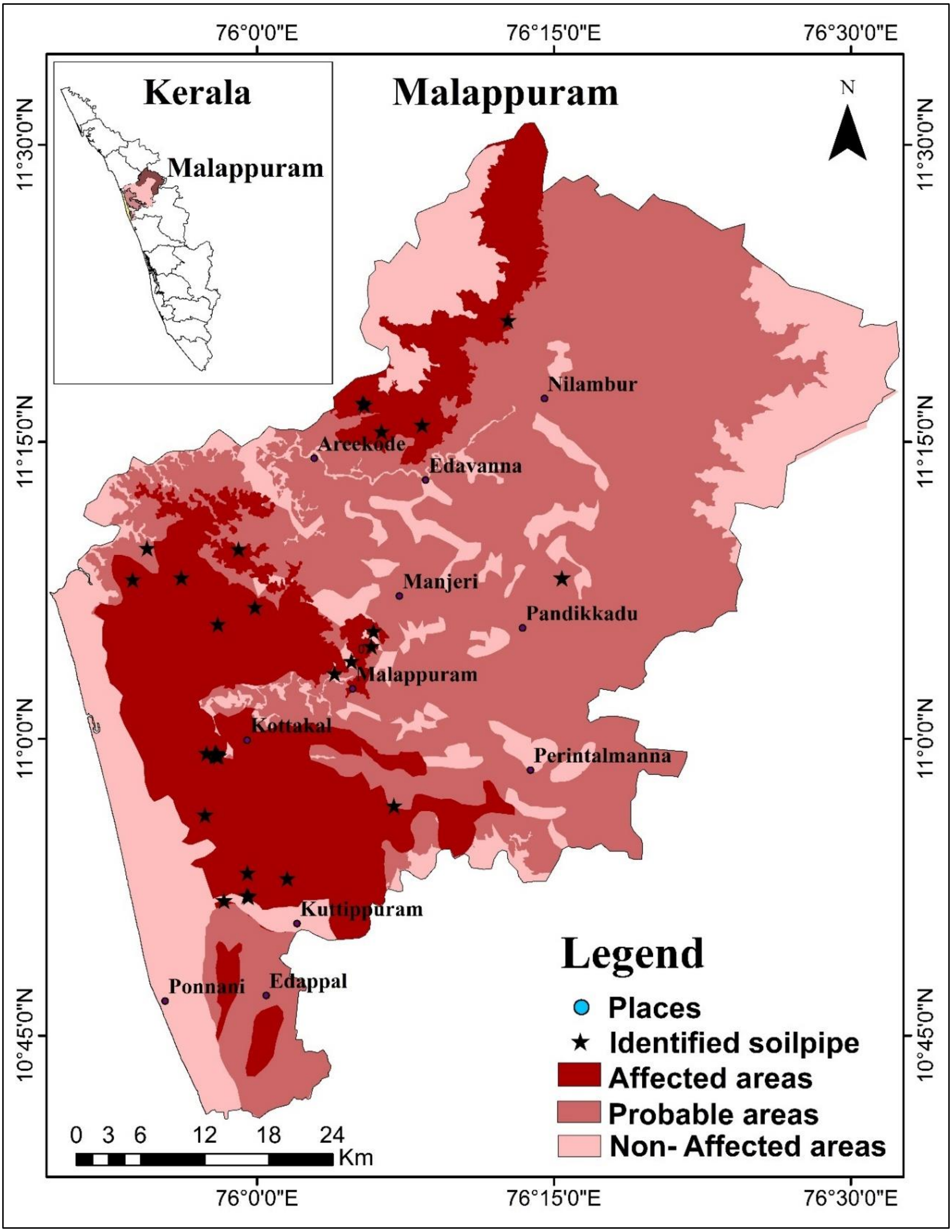


Figure 4.58: Zonation map of Malappuram

Conclusion

The total area of the district is 3550 square kilometres in which 867.359 km^2 is falling inside the Affected zone and 1867.394 km^2 is falling inside the Probable zone which means a good portion of the district is vulnerable. The remaining 815.248 km^2 area is falling inside Non-affected zone which including coastal alluvium and hard rock exposures. Kottakal, Muttiyel, Valanchery, Malappuram and its adjacent places are affected severely by soil pipes.

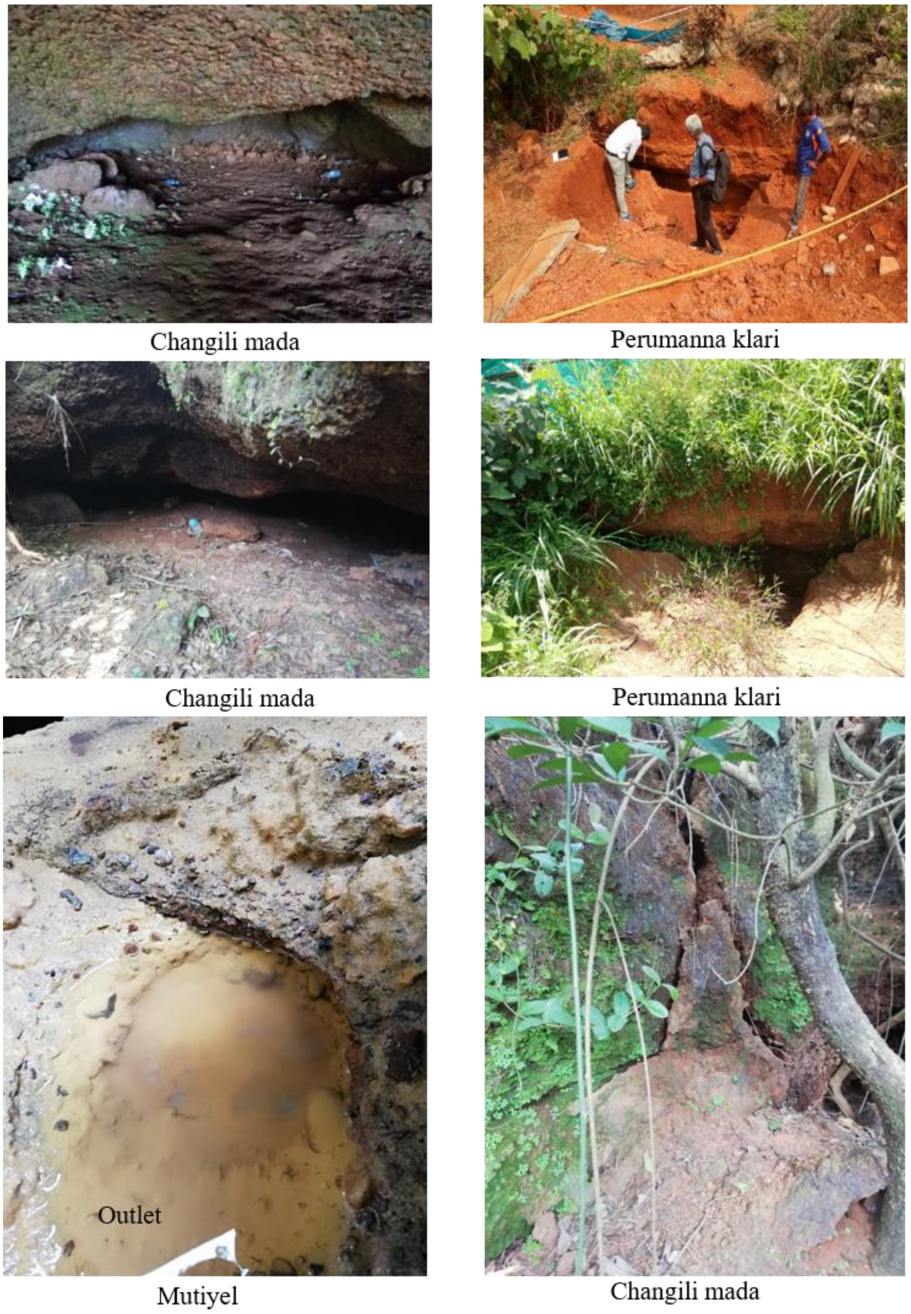


Figure 4.59**:** Field photos from Malappuram District

4.4 Wayanad

Wayanad is a land locked district in the north-east of Kerala State with an area of 2131 sqkm. It is set high on the Western Ghats with altitudes ranging from 700 to 2100 m. Wayanad district comprising of three Tehsils viz. Vythiri, Mananthawady and Sulthan's Bathery. The district is also divided into three blocks- Kalpetta, Mananthawady, and Sulthan Bathery. Recently one more block has been created in the district namely Panamaram by including 5 Panchayats i.e. Kaniambetta, Mullankoly, Panamaram, Poothadi and Pulapalli. Now the district consists of four blocks namely Kalpetta, Mananthawady, Panamaram and Sulthan Bathery. The district is having 25 grama panchayats and one municipality (Kalpetta).

Geomorphology

Physiographically the district can be divided into two units., i) a western hilly region with high ranges – Western Ghats and ii) eastern denuded plateau – Wayanad plateau. The altitudes vary from 700 to 2061m above msl. Banasuraimalai located in Vaythiri taluk has the highest peak. The Wayanad Plateau slopes towards east. The plateau is bordered on the west by structural-denudational hills whereas in the east by isolated structural hills. In contrast to the southern Kerala and unique to the Wayanad district, the major river systems flow to the east with the Kabani River, being the major east flowing river. Mananthody puzha, Karumanthodu and Panamarampuzha are tributaries to Kabani River. The west flowing rivers Valapattanam, Kuttiyadi and Chaliyar drain the western part of the district. 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, inter-montane 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 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. 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 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°) 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.

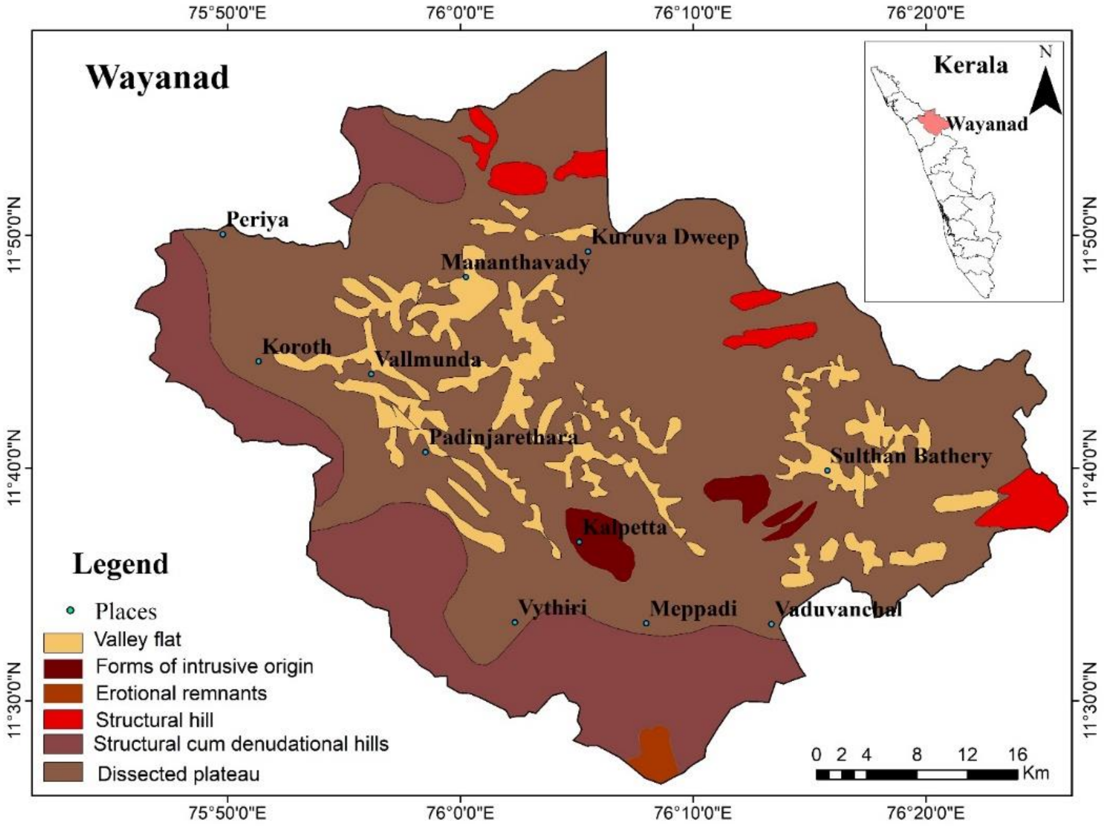


Figure 4.60: Geomorphology map of Wayanad District

(geomorphology map modified after District Resource map Wayanad district, Geological Survey of India)

Rainfall

The Wayanad district experiences salubrious climate with mean rainfall of 2786 mm. Lakkidi, Vythiri and Meppady are the high rainfall experiencing areas. It is seen that southern, southwestern and northeastern areas of the district receive more than 3000 mm of annual normal rainfall. Eastern and northeastern areas receive lesser rainfall of less than 1500 mm. Some areas bordering Karnataka state experience still lower rainfall with some areas falling under rain shadow region. An increase in rainfall is observed towards south, southwest and northeast. The SW and NE monsoons contribute rainfall in the area with 80 % of the rainfall from SW monsoon. The month of June experiences abundant rainfall and is the wettest month. The months of July, August and October also receive heavy rainfall. The climate is generally hot and humid. March and April months are the hottest and January and February months are the coldest. The maximum temperatures ranges from 28.9 to 36.2°C and the minimum temperatures range from 17.0 to 23.4°C. The temperature starts rising from January and reaches the peak in the month of March and April and then decreases during the monsoon month and again rising from September onwards.

Geology

The dominance of four types of geological units can be seen throughout the district. i) The Peninsula Gneissic Complex in the north and central part, ii) the Migmatite Complex in the southcentral part, (iii) the Charnockite Group in the south and (iv) the Wayanad Group in the north. Wayanad Group of supracrustal rocks include garnet-sillimanite-biotite gneiss with or without graphite, kyanite-fuchsite-muscovite-quarts schist, hornblende-biotiteschist and gneiss+garnet, amphibolite bands, quartz-sericite schist/quartz-mica schist and meta ultramafites, representing upper amphibolite to lower granulite facies metamorphism. These rocks are found as linear bands in the north. The main member of this group garnet-sillimanite-biotite gneiss+graphite occurs as large bodies north of Kabani River. Peninsular Gneissic Complex represented by hornblende-biotite gneiss and pink granite gneiss occupies a major part of the district. Charnockite Group comprises charnockite forming the hilly terrain in the south and southeast. Pyroxene Granulite and banded Magnetite Quartzite occur as narrow bands within charnockite. Migmatite Complex is represented by biotite-hornblende gneiss, occurring over a large area in the south-central part. The other members of this group are garnetiferous quartz-feldspathic gneiss + sillimanite occur as narrow bands within the older charnockite. In the east, large bodies of intrusive pink granite occur near Kalpetta and Sultan Battery. Pegmatite veins are also associated with the granites. Dolerite and gabbro are intrusive into the older rocks. Large lenticular bodies of gabbro/anorthosites occur northeast of Manantody and a large body of diorite occurs near the northern boundary of the district.

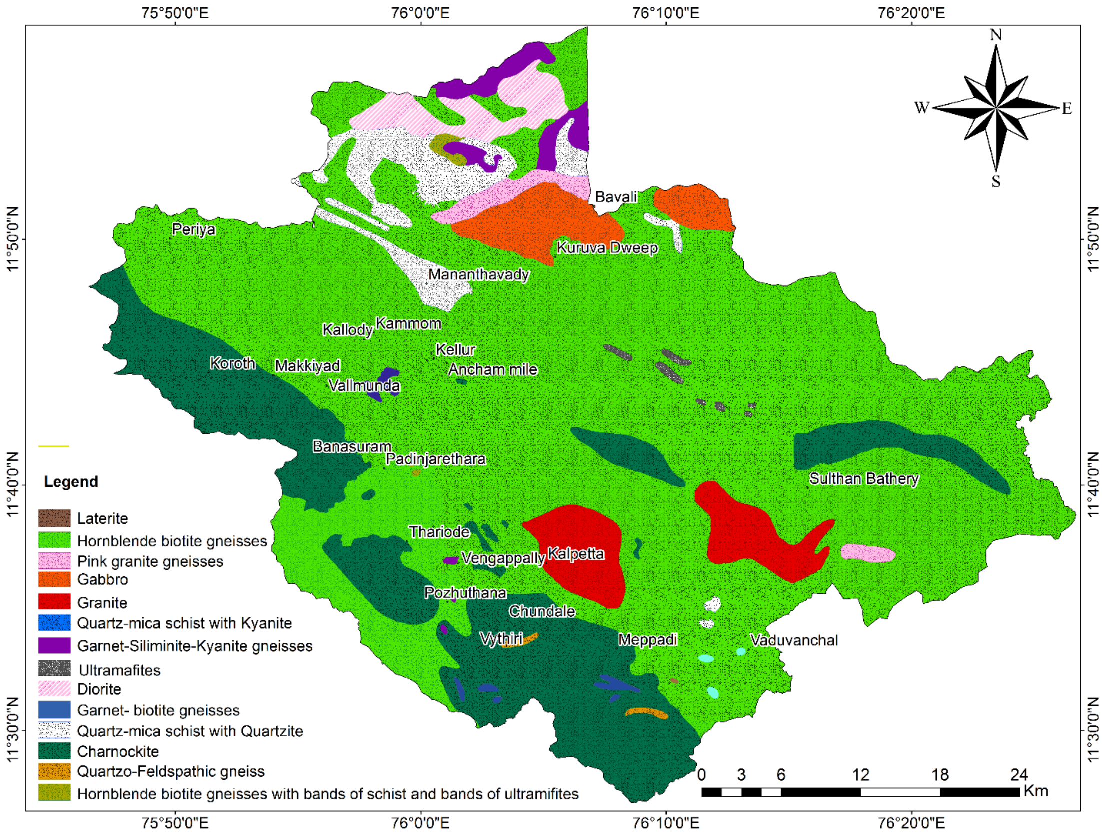


Figure 4.61: Geology of Wayanad District

(geology map modified after District Resource map, Wayanad district, Geological Survey of India)

Soil types

The Wayanad district generally consists of four types of soil. 1) Laterite soil, 2) Brown hydromorphic soil, 3) Forest loam and 4) 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 is mainly seen between undulating topography in Wayanad district. The Brown hydromorphic soil is very deep brownish in colour with sandy loam to clayey texture. The Brown hydromorphic soil 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.

Drainage and Irrigation

Almost the entire Wayanad district is drained by Kabani and its three main tributaries Panamaram, Mananthawady and Tirunelli. Other tributaries include Bavelipuzha and Noolpuzha. Kabani River is one of the three east flowing rivers in Kerala and is an important tributary of Cauvery River. Kabani and its tributaries carved the present landscape of the district. Other drainages in the district are Chaliyar and Valapattanam. Panamaram River originates from Lakkidi and its main tributaries are Kavadam puzha, Kadaman thodu, Venniyode puzha, Karapuzha and Narassipuzha. Panamaram River joins with Mananthawady rivulet originating from Thodarmudi at an elevation of 1500m amsl.

Hydrogeology

The Wayanad district is divisible into two hydrological provinces. i) The eastern Wayanad Plateau where dug wells give moderate yield and bore wells are feasible along fracture planes and ii) The western mountains, which are generally unsuitable for groundwater development but the valleys with thick alluvium sustain dug wells. All the four blocks in the district are having similar hydrogeological conditions.

The major water bearing formations in the district are weathered or fractured crystallines, alluvium and valley fills. Phreatic conditions exist in weathered formation and are mostly developed by dug wells for domestic and irrigation purposes. Semi-confined conditions exist in deep fractures and storage and movement of groundwater is mainly controlled by the fracture system.

Alluvium aquifers

Alluvium and valley fills are seen along the river courses and broad valleys. The alluvial aquifers are better represented in Kalpetta and Sulthan Bathery 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.

Groundwater occurs under phreatic condition in weathered crystallines and Semi confined to confined conditions exists in deep fracture system, which forms potential aquifers in the study area. The weathered granite and granitic gneisses in Kalpetta and Sulthan Bathery Blocks form potential phreatic aquifers along valleys and topographic lows. The weathered charnockites seen in Kalpetta block and along the hill ranges of the Western Ghats form poor aquifer system. 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 weathered gabbro and diorite rocks seen in the northern portion of Manathawady block forms moderately potential aquifers.

Table 4.8: Piping locations in Wayanad District

Sl. No	Name	Location		position	Status	Remarks
		Latitude	Longitude			
1	Padinjarethara	N11.673986	E75.967737	Populated region	Mature pipe	Suducted, filled and diverted the channel.
2	Valamthode	N11.73136	E75.83131	Populated region	Mature pipe	
3	Wayanad	N11.682935	E75.963315	Populated region	Mature pipe	
4	Wayanad	N11.84256	E76.01892	Populated region	Mature pipe	Filled manually
5	Wayanad	N11.682935	E75.963315	populated region	Mature pipe	Stabilized
6	Wayanad	N11.5033	E76.018.1	Populated region	Mature pipe	Subsided
7	Ambedkar colony*	N11.496003	E76.148507	Populated region	SEOC-SDMA	SEOC-SDMA
8	Elavayal*	N11.509125	E76.151082		SEOC-SDMA	SEOC-SDMA
9	Kasmeeram*	N11.50927	E76.144534		SEOC-SDMA	SEOC-SDMA
10	Pachakkad*	N11.499148	E76.131099	Populated region	SEOC-SDMA	SEOC-SDMA
11	Padavettikunnu*	N11.49323056	E76.14303056	Populated region	SEOC-SDMA	SEOC-SDMA

12	Vaipadi*	N11.666087	E76.001802	Populated region	SEOC-SDMA	SEOC-SDMA
13	Kappikkalam karakkozhuppil*	N11.67327778	E75.93725	Populated region	SEOC-SDMA	SEOC-SDMA
14	Kappikkalam mangothukunnu*	N11.67408333	E75.94030556	Populated region	SEOC-SDMA	SEOC-SDMA
15	Kappikkalam*	N11.6665	E75.93819444	Populated region	SEOC-SDMA	SEOC-SDMA
16	Kappikkalam kuttiyamvayal-1*	N11.67063889	E75.93730556	Populated region	SEOC-SDMA	SEOC-SDMA
17	Manthanamkunnu*	N11.897404	E76.008716	Populated region	SEOC-SDMA	SEOC-SDMA
18	Thacharakolly-2*	N11.851537	E76.012756	Populated region	SEOC-SDMA	SEOC-SDMA
19	Varadimoola-2*	N11.808366	E76.02259	populated region	SEOC-SDMA	SEOC-SDMA
20	Arimandhamkunnu colony*	N11.735431	E76.00659	Populated region	SEOC-SDMA	SEOC-SDMA
21	Kurumbalakotta kurushsumala thazhe colony*	N11.698171	E76.029347	populated region	SEOC-SDMA	SEOC-SDMA
22	Kurumbalakotta-Josheph mangudiyil veedu bagam*	N11.702382	E76.029119	Populated region	SEOC-SDMA	SEOC-SDMA
23	Kurumbalakotta-KWA water house west*	N11.700274	E76.034564	populated region	SEOC-SDMA	SEOC-SDMA
24	Mangalasserymukku-Pulinjan nellikkayal*	N11.717585	E75.92585	Populated region	SEOC-SDMA	SEOC-SDMA
25	Mangalassery pulinjan enallikkaichal *nellanikott (mathayi area) *	N11.718232	E75.928206	populated region	SEOC-SDMA	SEOC-SDMA
26	Challi meenmutty 1*	N11.732883	E75.872726	Populated region	SEOC-SDMA	SEOC-SDMA

* data from SEOC-SDMA)

Prone areas

The Wayanad district is one of the prone areas among the fourteen other districts of Kerala. The field investigation has revealed 26 soil pipes in the district including major, minor and juvenile soil pipes. The chances of occurring the event over the district are more. The land use, slope, drainage, soil types, vertical profile and rainfall of the district is very favourable to accounts on this process. The identified soil pipes have occurred in urban and near to urban and so there can be more such pipes developed in the remote and forested areas. The juvenile pipes are also noticed in adjacent to the major pipes and are noticed all over the district says that the district is favourable for the disaster.

The geophysical, geochemical and sedimentological analyses of field data and samples collected during field investigations have given a clear idea that these pipes are occurring under certain conditions. And the remedials are also studied over the identified incidents.

As the identified incidents are having almost similar characters and conditions in formation a zonation is possible through which the district could highlight in three zones. This can help in giving awareness and management in land use in future.

***Table 4.9*:** Areal extent of Soil piping affected regions in the district

District	Total area in sq.km	Affected area in sq.km	Probable area in sq.km	Non-affected area in sq.km	No. of soil pipes reported
Wayanad	2,132	948.4208	733.938	449.64123	26

Out of the total 2132sq km of the district, 948 .42 sq.km was found to be affected by soil piping. About 733.93 sq.km area is showing signs of soil piping initiation. These areas landuse should be regulated in order to minimise creation of abnormal hydrostatic pressure which will pay way for creation of soil pipes.

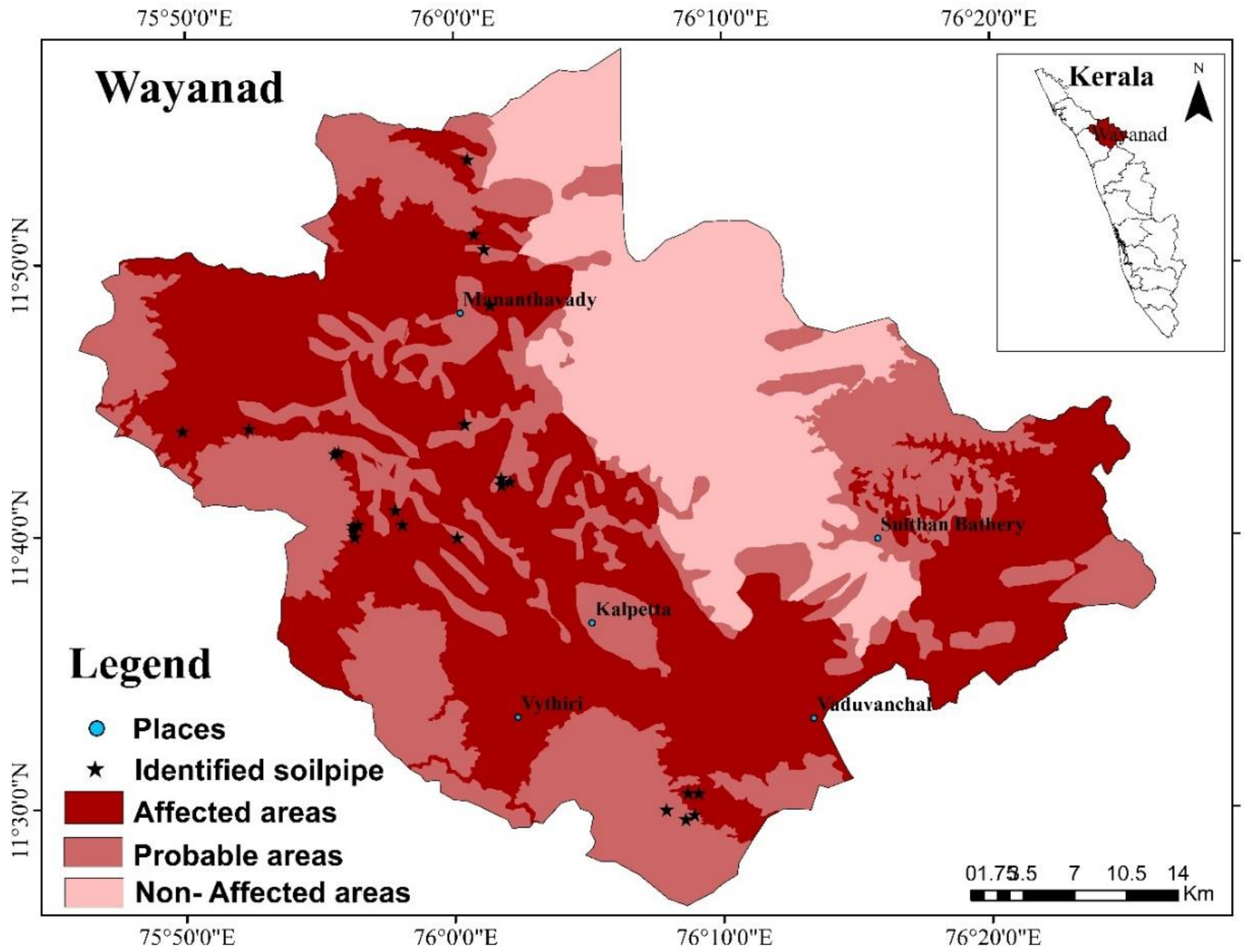


Figure 4.62: Zonation map of Wayanad District

Conclusion

The total area of the district is 2132 square kilometres in which 949.4208 square kilometres is falling in Affected zone and 1398.062 km^2 is falling inside the Probable zone which means a good portion of the district is vulnerable. The remaining 733.938 km^2 area is falling inside Non-affected zone which including coastal alluvium and hard rock exposures. Padinjarethara, Valamthode, koroth, regions and its adjacent places are the most affected and these are the regions to be studied geotechnically before new construction.

1. Recommendations for the "Affected areas"

In the critically affected areas infrastructure such as roads, buildings etc will be affected. Restrictions on high rise buildings or detailed surveys before the construction id needed. A proper water management plan should be developed for restricting the spread of soil piping. Geophysical surveys are suggested for locating large and typical pipes**.** Before any construction, proper ground surveys should be conducted to detect subsurface cavities if any. Geophysical surveys will help in identifying mature and large pipes. Water management practices and usage of lime powder in the soil will retard the soil piping activities.

2. **Recommendations for “Probable areas”**

These are areas prone to soil piping or mildly affected regions. In these areas juvenile and younger pipes are developed as an indicator of soil piping processes happening there. In such places well sections and laterite cutting are to be examined in detail for pipes and caves. Geophysical surveys may not help in identifying juvenile and younger pipes as they are smaller in size. Water management practices and usage of lime powder in the soil will retard the soil piping activities.

In both areas’ usage of hydrated lime along with the fertilizers should be encouraged to neutralise dispersive sodium in the clay

Dewatering is the best method to deescalate the formation of soil pipes. Overland flow may be diverted to a nearby nalo without allowing to infiltrate in the affected zone will reduce pipe development.

4.5 Idukki

The district Idukki is one of the Southern districts of Kerala lies between Latitudes: N09° 16’ 30’’ and N10° 21’ 00’’ and Longitudes: E76° 38’ 00’’ and E77° 24’ 30’’. Longitudes: E76° 38’ 00’’ and E77° 24’ 30’’. Idukki district is having a geographical area of 4476sq km. It is bordered by Ernakulum district in the northwest, Kottayam district in the west, Pathanamthitta district in the south and Tamil Nadu in the east. Anamudi, the highest peak in South India is in Idukki district and is also having 13 other peaks with height more than 2,000m. About 50% of the district is covered by forest. Periyar, the largest river in Kerala drains almost 80% of the district. Cardamom, Tea, Rubber and Coffee account for more than 50% of the total cropped area and pepper occupies about 25% area.

Geomorphology

The hill ranges of Western Ghats constitute the major part of Idukki district while Thodupuzha block and western part of Elamdesam block falling 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 characterized by rugged topography formed by small hillocks separated by deep valleys. The general slope of the area is towards 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. The elevation 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 characterized by 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 falls 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 characterized by high mountains with elevation more than 1500 m amsl.

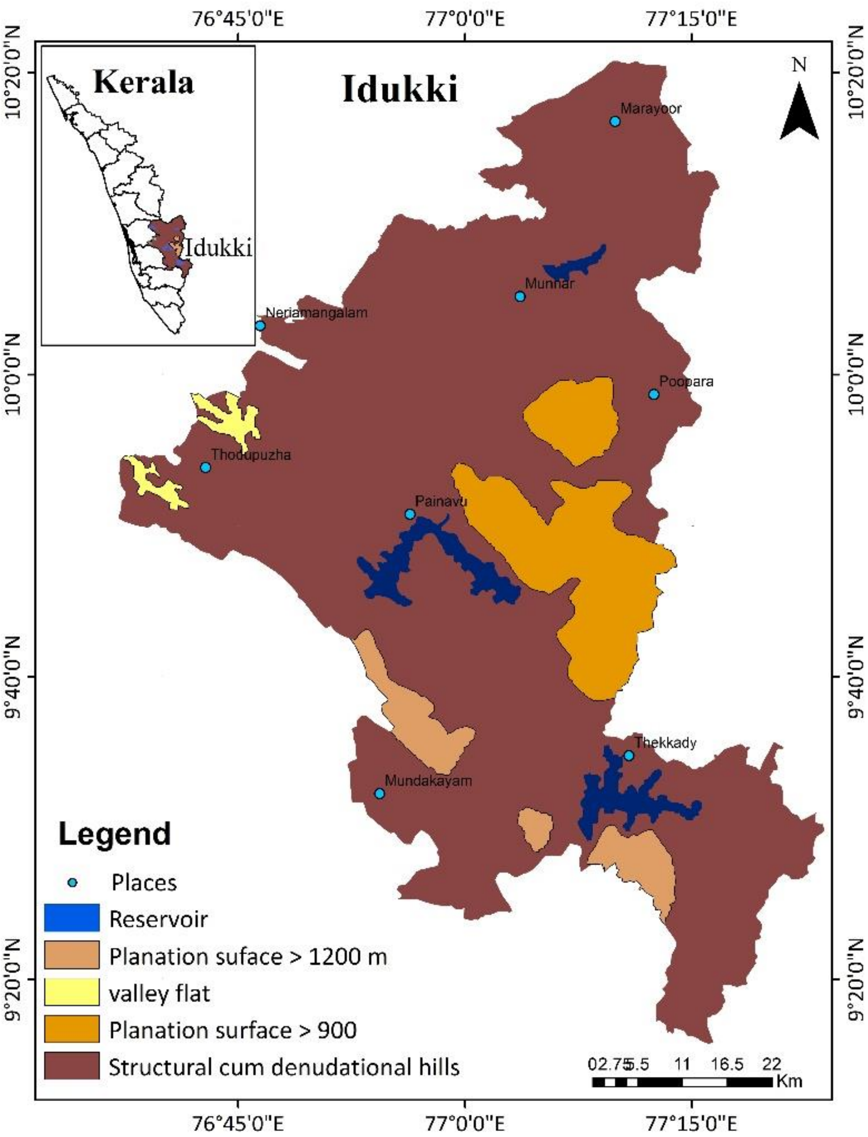


Figure 4.63: **Geomorphology of Idukki District**

(geomorphology map modified after District Resource map, Wayanad district, Geological Survey of India)

Geology

Geologically the district can be divided into three major belts in a north-south direction – (i) Peninsular Gneissic Complex in the north and (ii) Charnockite Group of rocks in the south and (iii) Migmatitic Complex in between.

The oldest rock representation from the area is the granite gneiss of Peninsular Gneissic Complex. The rocks are well foliated and show regional folding as well. Khondalite group is represented by calc- granulite and quartzite. These rocks are seen as linear bands, lenticular bodies or enclaves, mostly within the gneissic terrain. The Charnockitic Group comprises of pyroxene granulite, magnetite quartzite and charnockite among which the charnockite is dominant and widespread. Pyroxene granulite and magnetite quartzite occur as linear bands of a few metres' width and a few tens of metres in length within the gneissic terrain. They are aligned generally parallel to the trend of foliation. Charnockite occurs as continuous rock unit covering the hilly region in the south and northwest. It is mostly massive but gneissic varieties are also seen, with intermediate to acidic in composition. Central, northeast and southeast parts of the district are dominated by rocks of migmatitic complex comprising of biotite gneiss and hornblende-biotite gneiss (composite gneiss). While the south-central part around Pynavu and Thodupuzha is occupied by biotite gneiss, the north eastern and south eastern parts are covered by hornblende biotite gneiss.

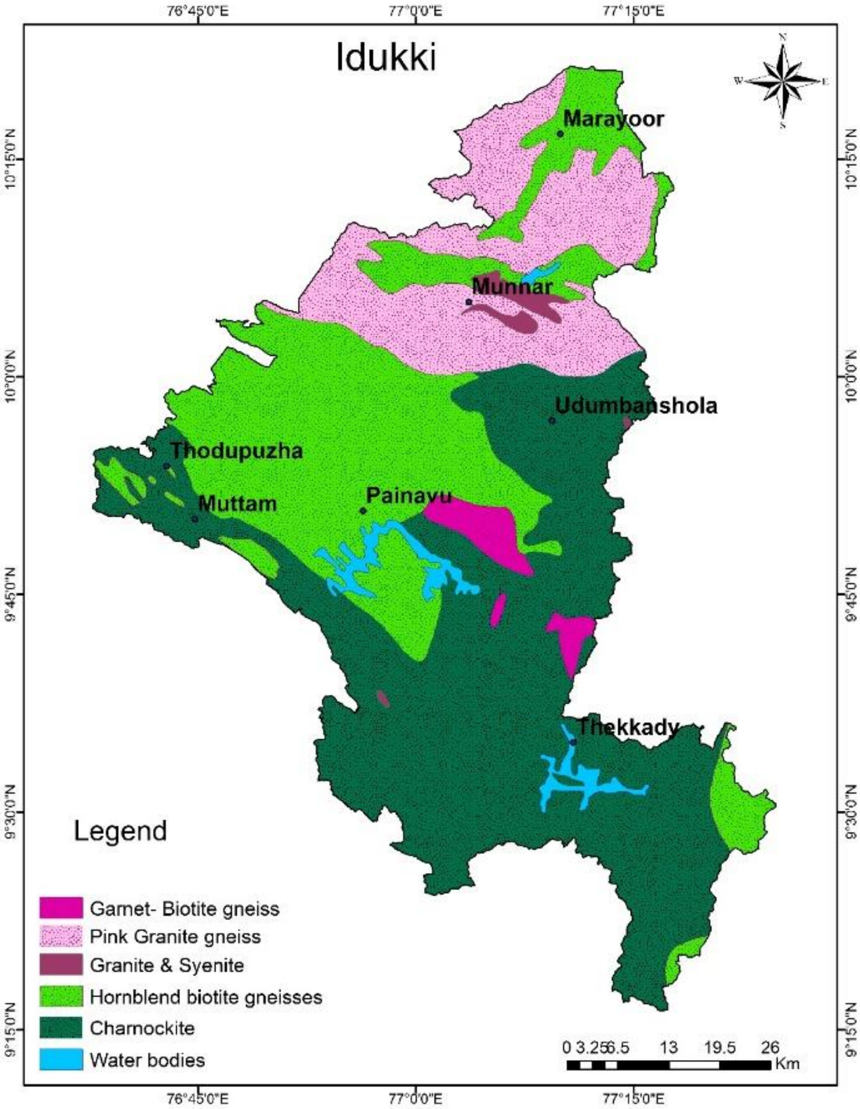


Figure 4.64: Geology of Idukki District

(geology map modified after District Resource map, Wayanad district, Geological Survey of India)

The biotite gneiss has plenty of restites of older Khondalite and Charnockite Groups of rocks occurring as lensoidal and linear bodies, conformable with the trend of foliation. Granite emplacement is seen around Munnar, Devikolam and along the eastern boundary. Both pink and grey varieties are observed. The older rocks are traversed by pegmatites and quartz veins and basic intrusive (dolerite and gabbro).

Soil types

Forest loams, lateritic soils, brown hydromorphic soils and alluvial soils constitute the main four soil types in the district. Among the four soil types, forest loams cover 60% of the district 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. 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' ranges from sandy loam to clay and they are fertile.

Rainfall

The district receives an average annual rainfall of about 3677mm, ranging from less than 1000 (Marayoor, Kanthaloor, Chinnar areas and the areas north east of Anamudi) to around 5000 mm (Peerumedu, Neriyamangalam etc). The rainfall increases from east to west. Eastern part of the district lies in the rain shadow region of the Western Ghats. The major rainfall contribution is from South West monsoon from June to September which contributes about 60% of the total annual rainfall. The North East monsoon from October to December contributes 24% of the annual rainfall and the balance during the period January to May. The climatic conditions in the mid lands, plateau regions and hill ranges of the district have wide variations.

Soil piping in the district

The Idukki district is one of the severely prone among the fourteen other districts of Kerala. A very good portion of the district is well affected by soilpiping is noticed through field investigation. The district has revealed more than 13 major soil pipes in the district. The identified soil pipes have occurred in urban and near to urban and so there can be more such pipes developed in the remote and forested areas.

As the district is recognized with more than 13 number of soil pipes including minor and, major sized through stacking, scouting and geophysical investigations over the district. The geophysical, geochemical and sedimentological analyses of field data and samples collected during field investigations have given a clear idea that these pipes are occurring under certain conditions.

The geomorphological and geological features have the major hand on the piping process. The slope, drainage, soil types, vertical profile and rainfall are some of the major features that accounts on this process.

As the identified incidents are having almost similar characters and conditions in formation this can be happened in the similar other areas with same favourable conditions and so a zonation is possible through which the district could highlight with three zones. This can help in giving awareness and management in land use in future.

Table 4.10: Piping Locations in Idukki district

Sl. No	**Name**	**Location**		**position**	**Status**	**Remarks**
		Latitude	**Longitude**			
1.	Peringassery	N 9º52'02.9”	E 76º51'28.4”	Less populated region	Well like subsidence	tunnel across the state highway
2.	Thattekanni	N 9º59'49.2”	E 76º53'18.3”	Less populated region	Mature tunnelling	across the state highway
3.	Venniyani Mala	N 9º51'39.3”	E 76º51'16.8”	Less populated region	Mature tunnelling	Stabilized pipe
4.	Mariyapuram	N 9°50'55.2"	E 76°58'59.7"	Less populated region	Well like subsidence	Occurred in Loose soil
5.	Udayagiri	N 9º50'39.3”	E 77º03'36.7”	Less populated region	Mature pipe	Widespread occurrence
6.	Udayagiri	N 9º50'31.7”	E 77º03'34.5”	Less populated region	Mature pipe	Widespread occurrence
7.	Udayagiri	N 9º50'30.8”	E 77º03'36.7”	Less populated region	Mature pipe	Widespread occurrence

8.	Udayagiri	N 9º50'31.7”	E 77º03'35.7”	Less populated region	Mature pipe	Widespread occurrence
9.	Nalaam Mile	N 9º39'34"	E 76º59'29.4"	Less populated region	Well like subsidence	Loose soil, Rubber plantation
10.	Mavadi	N9º52'50.3"	E77º06'46.3"	Less populated region	Young pipe	Loose soil, Rubber plantation
11.	Mavadi	N9º52'52.2"	E77º06'46.9"	Less populated region	Young pipe	Loose soil, Rubber plantation
12.	Mavadi	N9º52'52.8"	E77º06'47.6"	Less populated region	Young pipe	Loose soil, Rubber plantation
13.	Powerhouse division*	N10.0517	E77.0593	Less populated region		

* data from SEOC-SDMA)

Electrical resistivity surveys conducted

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 fig 4.5.3 and 4.5.4

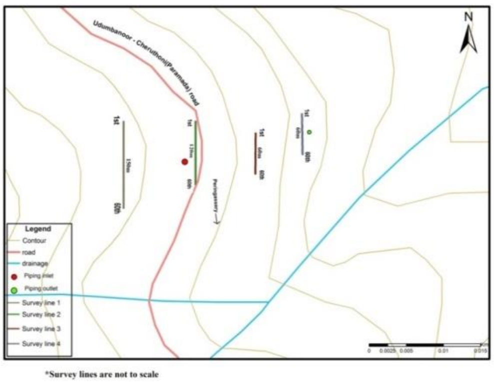


Fig.4.65: Survey layout in Peringassery

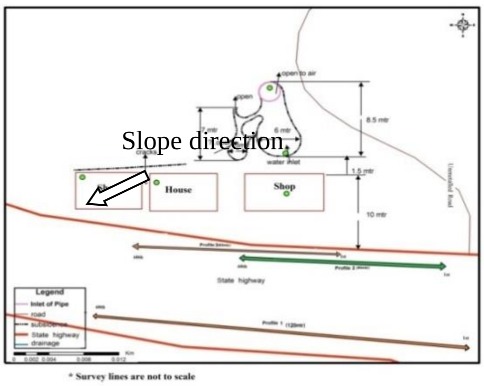


Fig.4.66: Survey layout in Peringassery

The resistivity data obtained (Fig 4.65 and 4.66) 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.

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 4.67a, b, c, d and e respectively. The resistivity inverse model sections so deduced are qualitatively interpreted as follows.

Profile 1

The figure (fig 4.67a) 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.

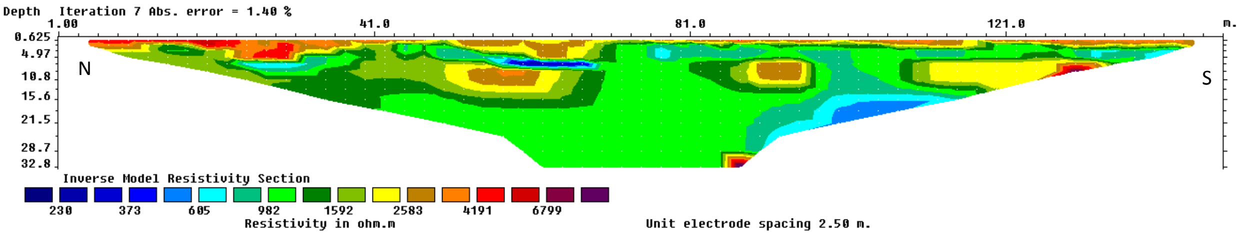


Fig.4.67a: Profile 1 Schlumberger array at Peringassery

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 (fig. **4.67** b) with an electrode spacing of 2m (Profile length 120m) and the second (fig. **4.67** b c) 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.

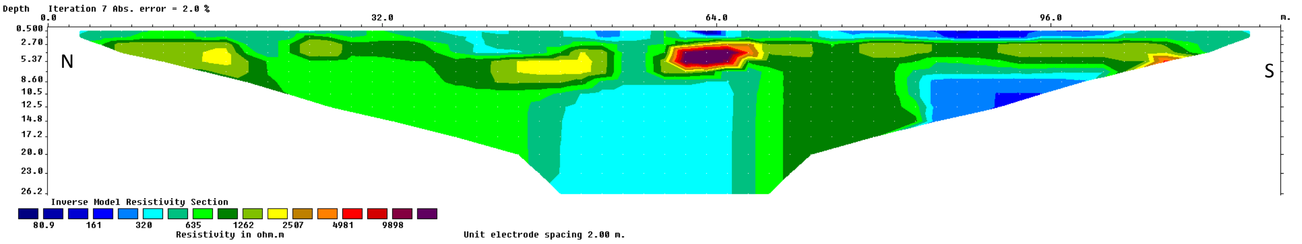


Fig.4.67b: Profile 2 Schlumberger arrays (120m stretch) at Peringassery

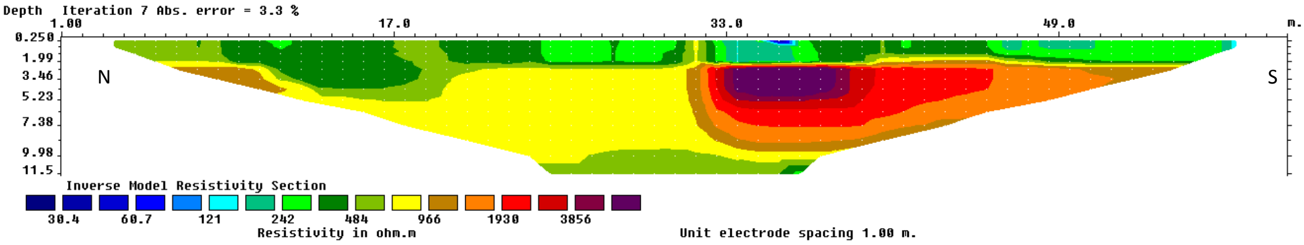


Fig.4.67 c: Profile 3, Schlumberger arrays (60m stretch) at Peringassery

Profile 4

This profile was of length 60m and electrode spacing of 1m was laid parallel to the Profile 2&3 and 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.

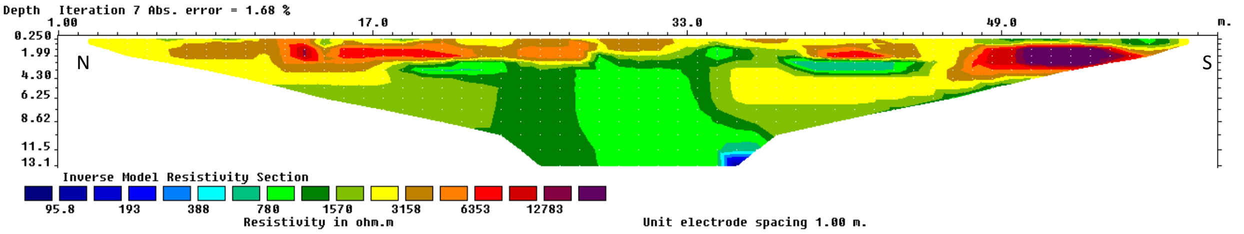


Fig.4.67 d: Profile 4, Schlumberger array at Peringassery

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.

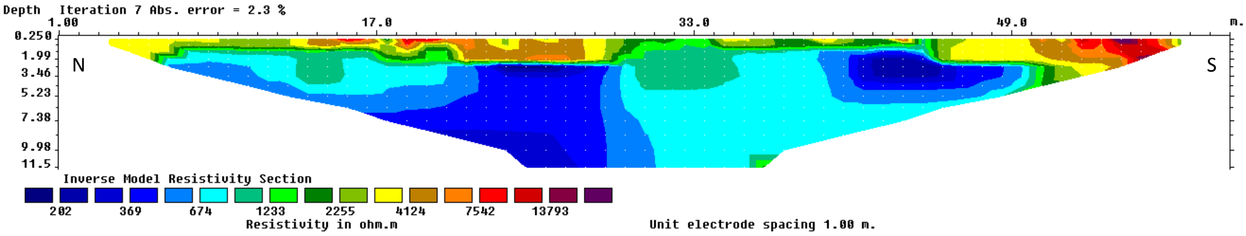


Fig.4.67e: Profile 5, Schlumberger array at Peringassery

ERP Survey at Thattekanni

Profile 6

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 using Schlumberger array are given as Figure.4. 68 a. The resistivity sections so deduced are qualitatively interpreted as follows.

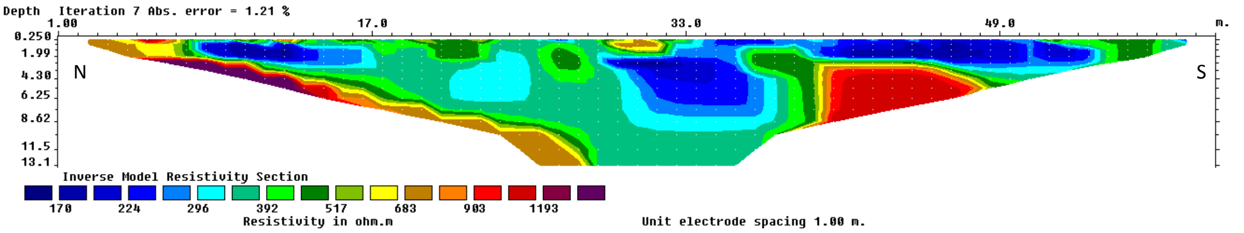


***Fig.4.68 a*:** Profile 6, Schlumberger array at Thattekanni

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 (fig 4.68 b)

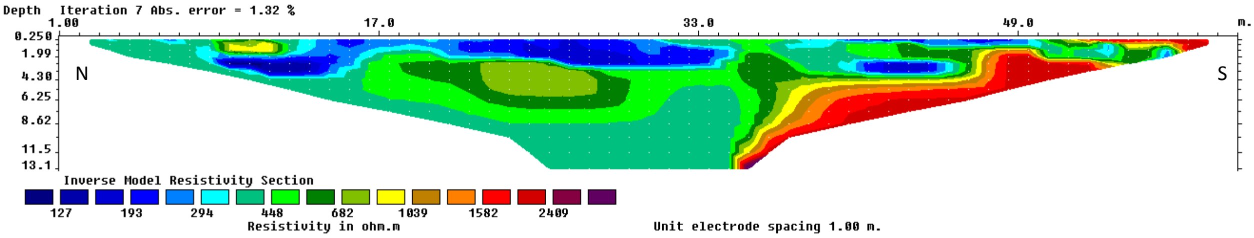


***Fig.4.68 b*:** Profile 7 Schlumberger array at Thattekanni

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 profile2 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.

Analytical report

Table4.11: Analytical report of soil samples from Idukki locations

SL.NO	Sample location	Sample No.	pH	Electrical Conductivity (µs/m)	Total Dissolved Solids (ppm)
1		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	Piping Area	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.4.5.2) 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.4.5.2) The maximum of values EC and TDS is at 13.22µs/m and 9.38ppm is respectively from the samples I17 collecting from Upputhara.

XRF Analysis

Table.4.12: Major element data of the samples from piping affected locations in Idukki

Sl. No	SiO_2	TiO_2	Al_2O_3	MnO	Fe_2O_3	CaO	MgO	Na_2O	K_2O	P_2O_5	CIA
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

Exchangeable sodium percentage and Ca & Mg ratio

***Table.4.13*:** Exchangeable sodium, calcium, magnesium of piping locations in Idukki

Sample Id	Exchangeable Na (cmol/kg)	Exchangeable K (cmol/kg)	Exchangeable Mg (cmol/kg)	Exchangeable Ca (cmol/kg)	ESP (%)	CEC (cmol /kg)
14/TK-C1	2.03	0.31	6.38	4.40	15.47	13.12
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/PRY-E	0.95	0.001	5.18	0.40	14.54	6.53

XRD Analysis

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. Muscovite, Vermiculite, Montmorillonite, Kaolinite 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.

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.4.14: 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

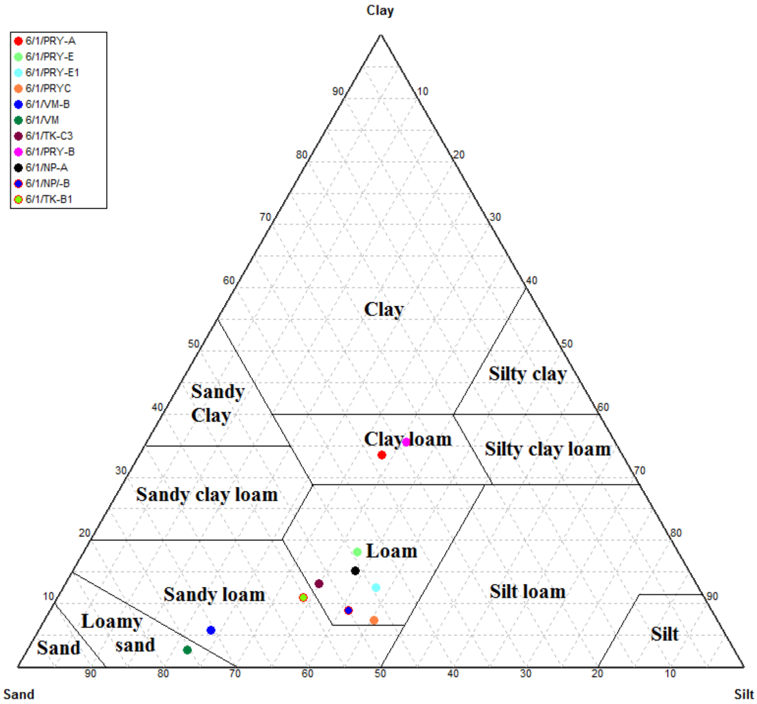


Fig.69: Textural diagram of soil sample in the piping and non-piping area

The textural analysis of the samples from the affected area shows (table.6) all sample 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.

Geochemical Investigations

X-ray diffraction analysis

X-ray diffraction (**XRD**) is a rapid analytical technique, by way of the study of the crystal structure, is used to identify the crystalline phases present in a material and thereby reveal chemical composition information. Identification of phases is achieved by comparison of the acquired data to that in reference databases. 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.

The sample 1A collected from Kaithapathal-mettumbhagam road, upputhara, Idukki district. The incident reported on 2015 has surveyed and recognized as land subsidence due to soil piping. The major rock type of the area is weathered charnockite and gneiss and the top soil is Lateritic and forest loam. The Sample collected from the bottom of subsided area is rich in clay content.

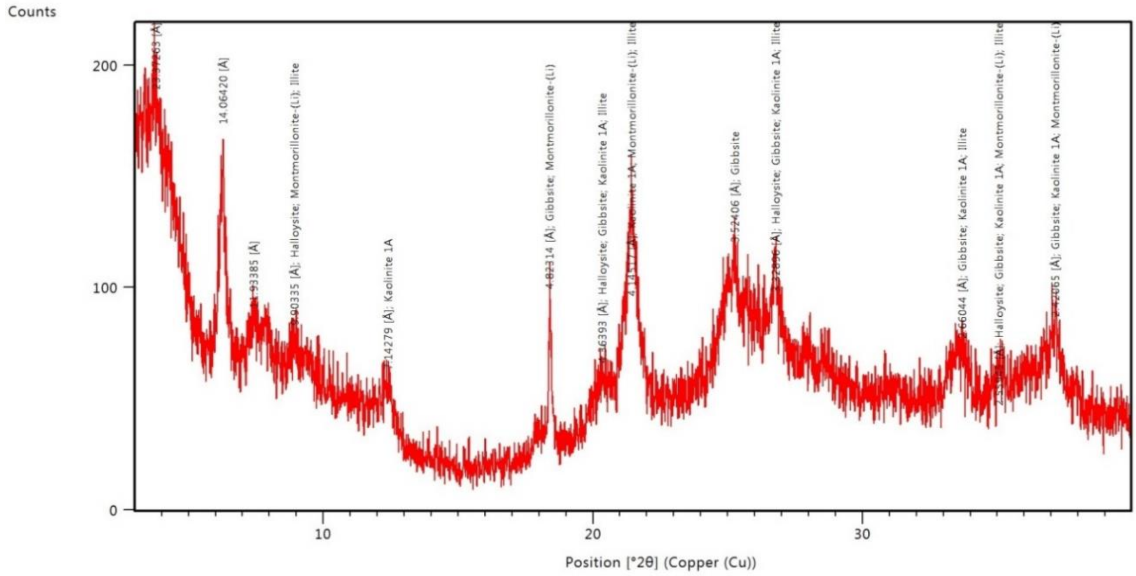


Figure 4.70**:** X-ray diffract gram of soil samples 1A

Table 4.15: Peak List of Soil sample 1A

Pos. [°2θ]	**Height [cts]**	**FWHM Left [°2θ]**	**d-spacing [Å]**	**Rel. Int. [%]**
3.7804	39.80	0.1889	23.37263	39.30
6.2845	101.28	0.0472	14.06421	100.00
7.4079	24.55	0.7557	11.93385	24.24
8.9295	19.59	0.3779	9.90335	19.34
12.3923	21.68	0.3779	7.14279	21.41
18.3954	67.32	0.0945	4.82314	66.47
20.3507	22.77	0.3779	4.36393	22.48
21.4371	100.87	0.1574	4.14517	99.60
25.2729	53.15	0.2519	3.52406	52.48
26.7808	52.90	0.1102	3.32896	52.23
33.6893	21.05	0.6298	2.66044	20.78
35.0609	10.97	0.3779	2.55945	10.83
37.1425	35.45	0.2519	2.42065	35.01

The sample 2A collected from udayagiri, Idukki district. The subsidence occurred in a laterite terrain over the Gneissic basement.

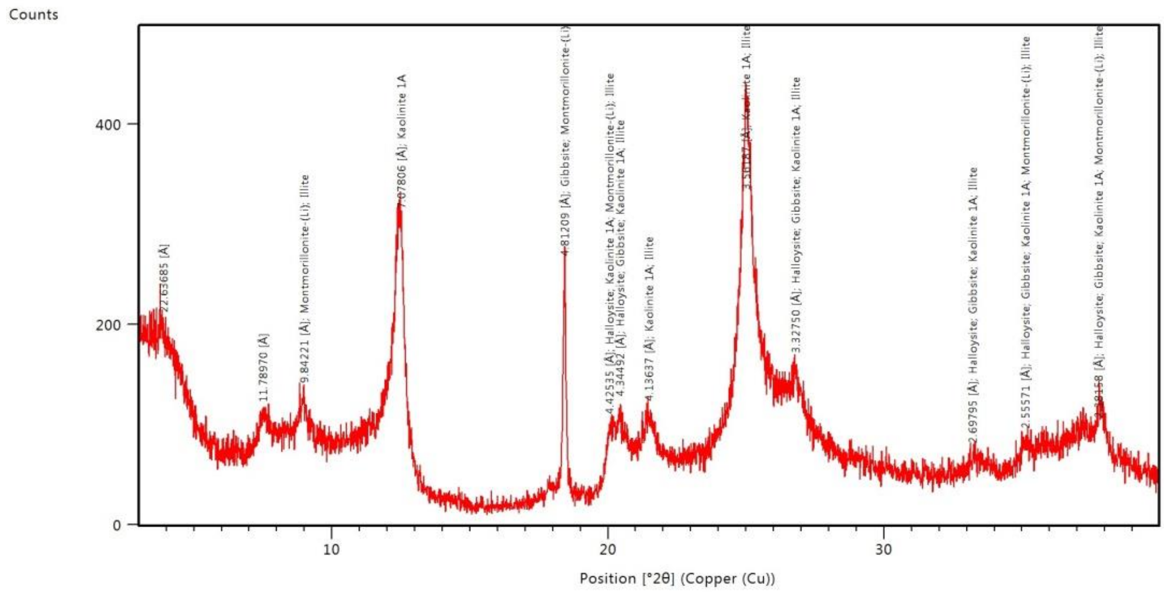


Figure 4.71**:** X-ray diffract gram of soil samples 2A

Table 4.16**:** Peak List of Soil sample 2A

Pos. [°2θ]	Height [cts]	FWHM Left [°2θ]	d-spacing [Å]	Rel. Int. [%]
3.9034	49.74	0.5038	22.63685	14.25
7.4986	32.49	0.3149	11.78970	9.31
8.9851	45.70	0.1889	9.84221	13.09
12.5060	249.52	0.1102	7.07806	71.47
18.4380	248.81	0.0472	4.81209	71.27
20.0653	51.54	0.1889	4.42535	14.76
20.4407	63.86	0.0945	4.34492	18.29
21.4832	48.79	0.4408	4.13637	13.98
25.0003	349.13	0.0787	3.56187	100.00
26.7928	76.55	0.1889	3.32750	21.93
33.2072	17.20	0.3149	2.69795	4.93
35.1138	23.64	0.2519	2.55571	6.77
37.7746	57.92	0.1574	2.38158	16.59

The sample 4A collected from Peringassery, Idukki district. Soil collected from the wall of the subsidence. Soil was rich in clay.

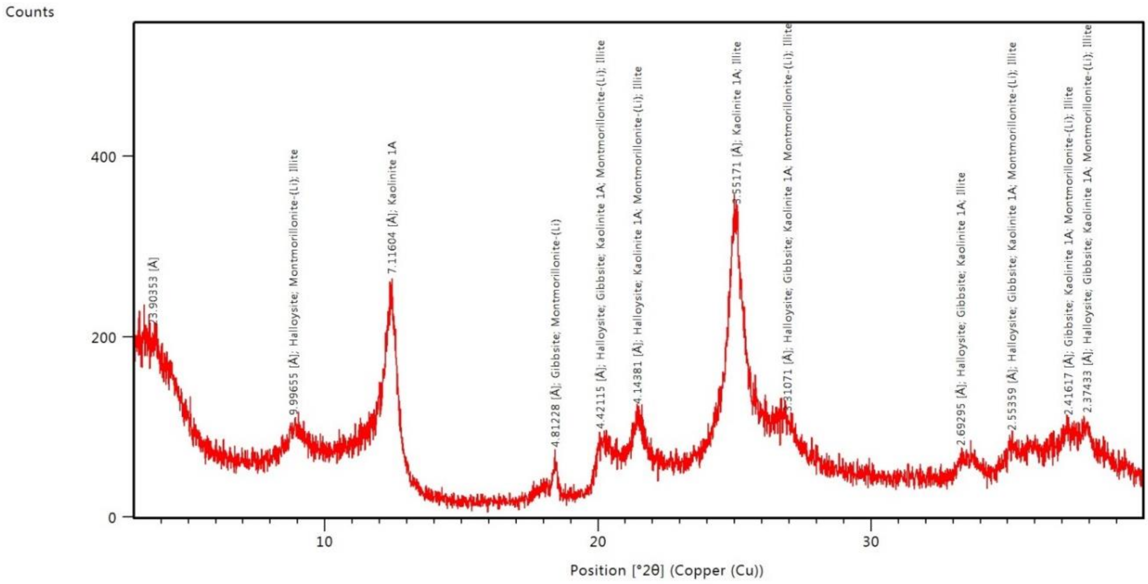


Figure 4.72: X-ray diffract gram of soil samples 4A

Table 4.17: Peak List of Soil sample 4A

Pos. [°2θ]	**Height [cts]**	**FWHM Left [°2θ]**	**d-spacing [Å]**	**Rel. Int. [%]**
3.6964	33.71	0.5038	23.90353	12.91
8.8461	35.00	0.4408	9.99655	13.40
12.4390	212.52	0.1889	7.11604	81.39
18.4372	38.66	0.1260	4.81228	14.81
20.0846	45.27	0.3149	4.42115	17.34
21.4442	56.70	0.3149	4.14381	21.71
25.0729	261.12	0.3149	3.55171	100.00
26.9312	43.89	0.5038	3.31071	16.81
33.2707	17.32	0.3779	2.69295	6.63
35.1439	21.08	0.2519	2.55359	8.07
37.2138	31.35	0.2519	2.41617	12.00
37.8944	35.82	0.2519	2.37433	13.72

The samples 5A, 5B, 5C, 5D and 5E collected from a land subsidence noticed on 28/11/2017 moolakkad, Idukki district. The samples are taken from a vertical column of different layers inside the pipe from bottom to top 5c, 5d, 5e and 5a respectively.

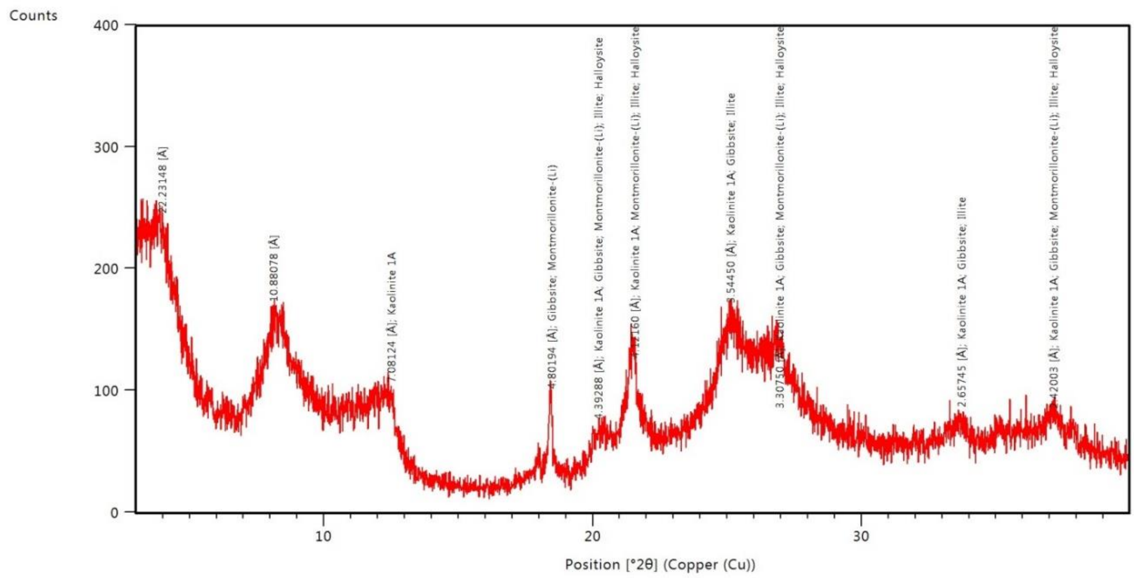


Figure 4.73: X-ray diffract gram of soil samples 5A

Table 4.18: Peak List of Soil sample 5A

Pos. [°2θ]	**Height [cts]**	**FWHM Left [°2θ]**	**d-spacing [Å]**	**Rel. Int. [%]**
3.9746	67.84	0.4408	22.23148	75.07
8.1260	87.15	0.3149	10.88078	96.43
12.5004	48.81	0.3779	7.08124	54.01
18.4773	59.85	0.1102	4.80194	66.23
20.2152	24.62	0.5038	4.39288	27.25
21.5611	81.34	0.2204	4.12160	90.01
25.1247	90.37	0.3779	3.54450	100.00
26.9578	65.34	0.3149	3.30750	72.30
33.7284	16.37	0.6298	2.65745	18.11
37.1524	26.86	0.3779	2.42003	29.72

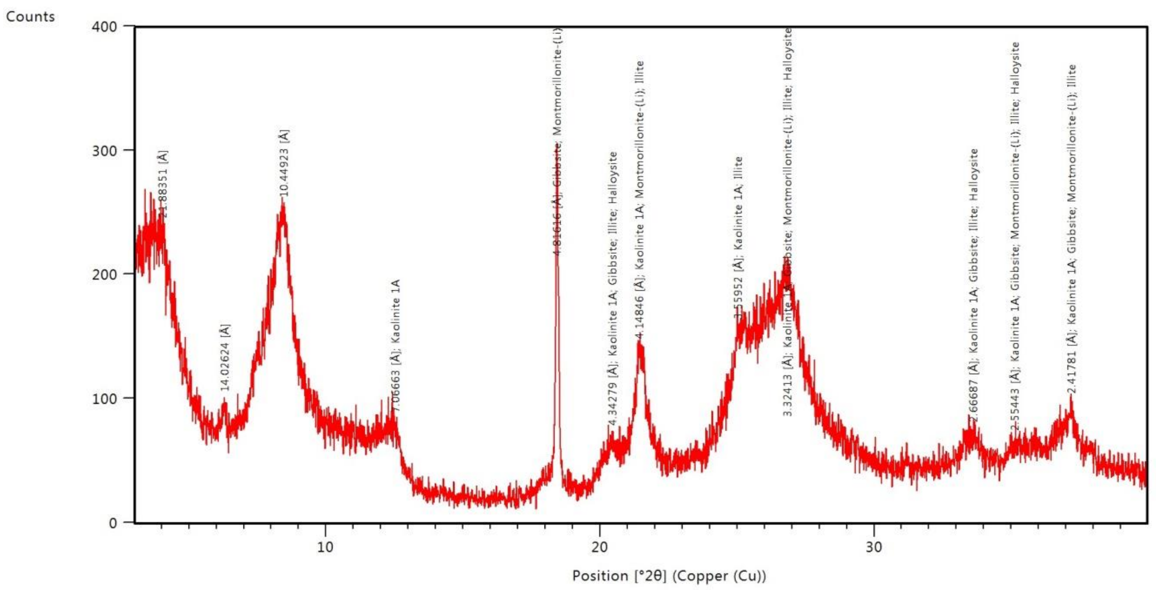


Figure 4.74**:** X-ray diffract gram of soil samples 5B

Table 4.19**:** Peak List of Soil sample 5B

Pos. [°2θ]	**Height [cts]**	**FWHM Left [°2θ]**	**d-spacing [Å]**	**Rel. Int. [%]**
4.0378	83.66	0.1889	21.88351	30.19
6.3016	24.75	0.0945	14.02624	8.93
8.4622	179.66	0.5038	10.44924	64.82
12.5263	36.83	0.3779	7.06663	13.29
18.4223	277.17	0.0787	4.81616	100.00
20.4508	28.90	0.1889	4.34279	10.43
21.4199	93.48	0.1889	4.14846	33.73
25.0170	91.40	0.4408	3.55952	32.98
26.8205	136.41	0.3149	3.32413	49.21
33.6057	22.20	0.3779	2.66687	8.01
35.1320	10.99	0.3779	2.55443	3.97
37.1876	41.74	0.2519	2.41781	15.06

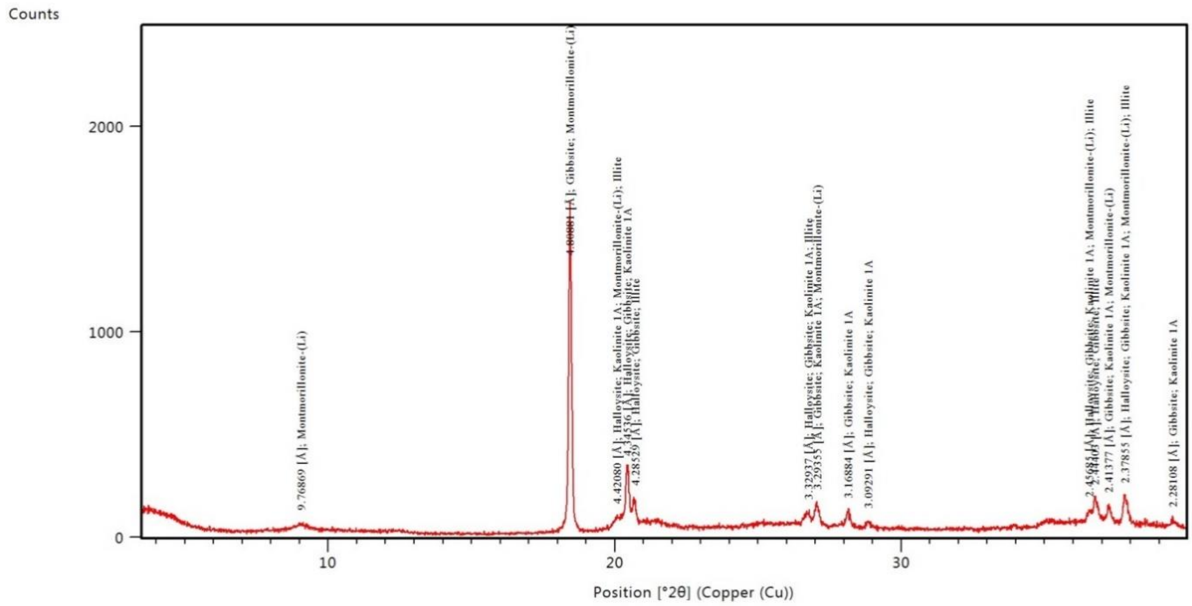


Figure 4.75: X-ray diffract gram of soil samples 5C

Table 4.20: Peak List of Soil sample 5C

Pos. [°2θ]	Height [cts]	FWHM Left [°2θ]	d-spacing [Å]	Rel. Int. [%]
4.4961	19.51	0.5038	19.65400	1.22
9.0529	24.97	0.3149	9.76870	1.56
12.3734	8.94	0.5038	7.15366	0.56
18.4353	1597.26	0.0576	4.80881	100.00
18.4777	1214.84	0.0480	4.80977	76.06
20.0694	45.54	0.2304	4.42080	2.85
20.4215	273.07	0.0672	4.34536	17.10
20.7109	122.77	0.1152	4.28529	7.69
21.4424	21.79	0.2304	4.14073	1.36
25.1510	10.95	0.4608	3.53793	0.69
26.7549	58.40	0.2688	3.32937	3.66
27.0514	105.06	0.0960	3.29355	6.58
28.1375	71.79	0.1344	3.16884	4.49
28.8430	29.34	0.1536	3.09291	1.84
33.9623	10.16	0.2304	2.63750	0.64
35.0949	17.31	0.6144	2.55493	1.08
36.5444	52.61	0.1152	2.45685	3.29
36.7429	112.39	0.0672	2.44403	7.04
37.2203	76.08	0.1344	2.41377	4.76
37.7921	129.73	0.0960	2.37855	8.12
39.4724	27.08	0.1536	2.28108	1.70

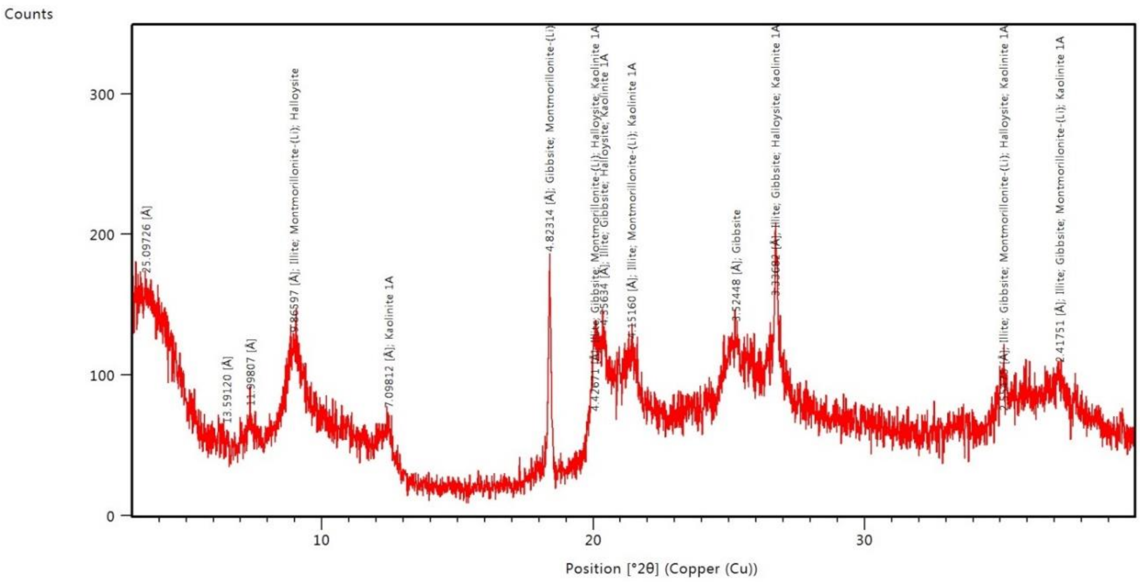


Figure 4.76**:** X-ray diffract gram of soil samples 5D

Table 4.21**:** Peak List of Soil sample 5D

Pos. [°2θ]	Height [cts]	FWHM Left [°2θ]	d-spacing [Å]	Rel. Int. [%]
3.5206	28.93	0.7557	25.09726	18.41
6.5035	8.29	0.0945	13.59120	5.28
7.3682	18.39	0.3779	11.99807	11.70
8.9634	70.05	0.4408	9.86597	44.56
12.4706	35.14	0.2204	7.09812	22.36
18.3954	157.19	0.0315	4.82314	100.00
20.0591	85.06	0.1260	4.42671	54.11
20.3865	80.55	0.1574	4.35634	51.25
21.4035	62.38	0.3779	4.15160	39.68
25.2698	53.88	0.3779	3.52448	34.27
26.7166	125.91	0.1102	3.33682	80.10
35.1275	35.60	0.2519	2.55475	22.65
37.1924	32.11	0.3779	2.41751	20.43

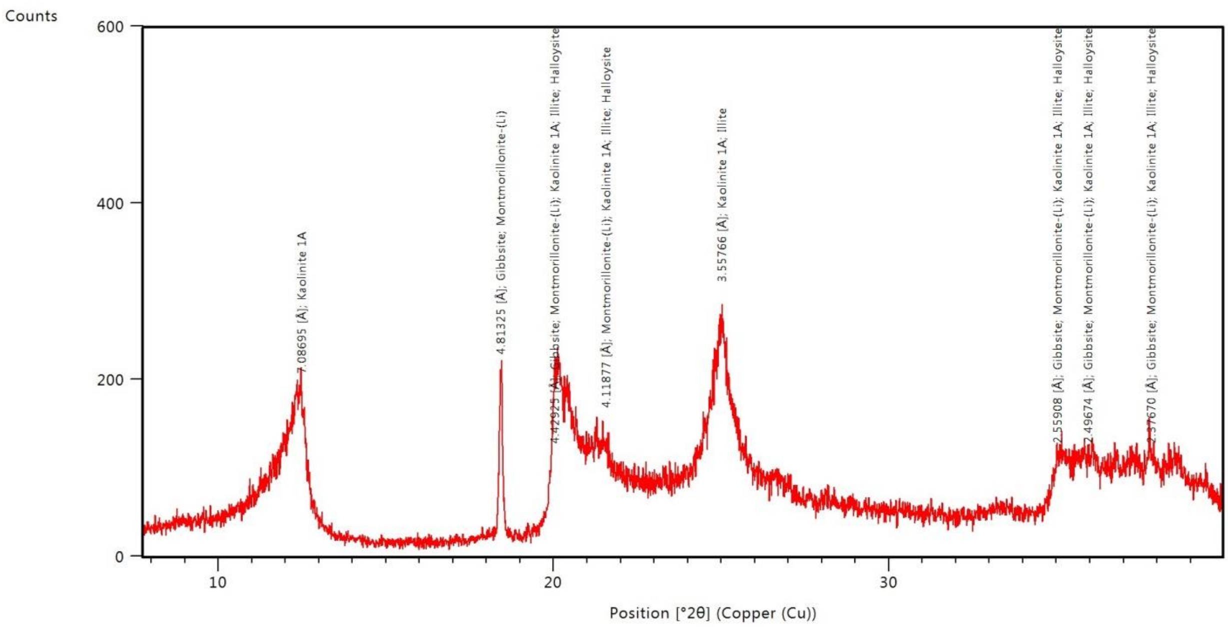


***Figure 4.77*:** X-ray diffract gram of soil samples 5E

***Table 4.22*:** Peak List of Soil sample 5E

Pos. [°2θ]	Height [cts]	FWHM Left [°2θ]	d-spacing [Å]	Rel. Int. [%]
12.4903	158.22	0.1889	7.08695	71.46
18.4181	190.38	0.0480	4.81325	85.98
18.4645	168.44	0.0384	4.81320	76.08
20.0307	177.24	0.1920	4.42925	80.05
21.5581	95.44	0.5376	4.11877	43.10
25.0092	221.42	0.1920	3.55766	100.00
26.8192	41.66	0.6144	3.32153	18.81
33.3189	9.83	0.7680	2.68694	4.44
35.0362	71.97	0.1920	2.55908	32.50
35.9404	68.84	0.4608	2.49674	31.09
36.7785	63.04	0.2304	2.44175	28.47
37.8226	75.40	0.3072	2.37670	34.05
38.5672	65.40	0.3072	2.33251	29.54
39.4361	39.16	0.4608	2.28310	17.69

The XRD results reveals that most of the soil samples collected from the study location are rich in clay minerals like Gibbsite, Kaolinite, Illite and Montmorillonite. Clay minerals are generally resulting of continuous hydrolysis of feldspar minerals and indicate a tropical humid climatic regime. The major rock type of the area being charnockite and gneiss on intense weathering results in a laterite profile with clay rich zones. These minerals indicate prominence of leaching material which leads to the erosional activity 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 & Bitar, 1966). The XRD results shows that the presence of Gibbsite and Kaolinite. 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 activity in that region. Presence of these clay minerals gives clear indication of soil piping in the affected area.

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 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 4.23**:** Estimation of major elements by XRF and Calculated CIA

Sample	SiO2	TiO2	Al2O3	MnO	Fe2O3	CaO	MgO	Na2O	K2O	P2O5	LOI	CIA	IOL
1A	42.04	0.472	33.195	0.01	3.786	0.108	0.381	0.038	0.921	0.087	18.1	96.4	46.8
1B	54.767	0.751	22.595	0.027	5.181	0.265	0.242	0.248	2.039	0.164	13.1	89.3	33.7
2A	43.721	0.792	27.15	0.016	7.927	0.293	1.094	0.197	1.425	0.149	16.97	93.0	44.5
4A	36.082	0.746	29.839	0.018	8.011	0.084	1.109	0.109	2.066	0.085	21.15	92.1	51.2
5A	35.892	2.65	16.74	0.268	19.018	0.621	7.993	0.137	3.505	0.194	12.55	78.1	49.9
5C	49.915	0.609	26.62	0.054	4.738	1.264	3.408	1.082	1.361	0.1	10.22	83.4	38.6
5D	47.115	0.357	28.25	0.015	4.354	0.635	0.847	0.482	0.702	0.034	16.77	91.5	40.9
5E	34.412	1.224	13.011	0.824	27.432	3.206	5.265	0.235	0.861	0.112	12.82	65.4	54.0

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

$$\mathrm{CIA} = \frac{\mathrm{Al2O}}{(\mathrm{Al2O3} + \mathrm{Na2O} + \mathrm{K2O} + \mathrm{CaO}*)} \mathrm{x}100$$

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 (Al_2O_3– CaO^*+Na_2O – K_2O) ternary diagrams. The combination of these features makes the CIA the presently preferred weathering index (Nesbitt and Young, 1982; Fedo et al., 1995).

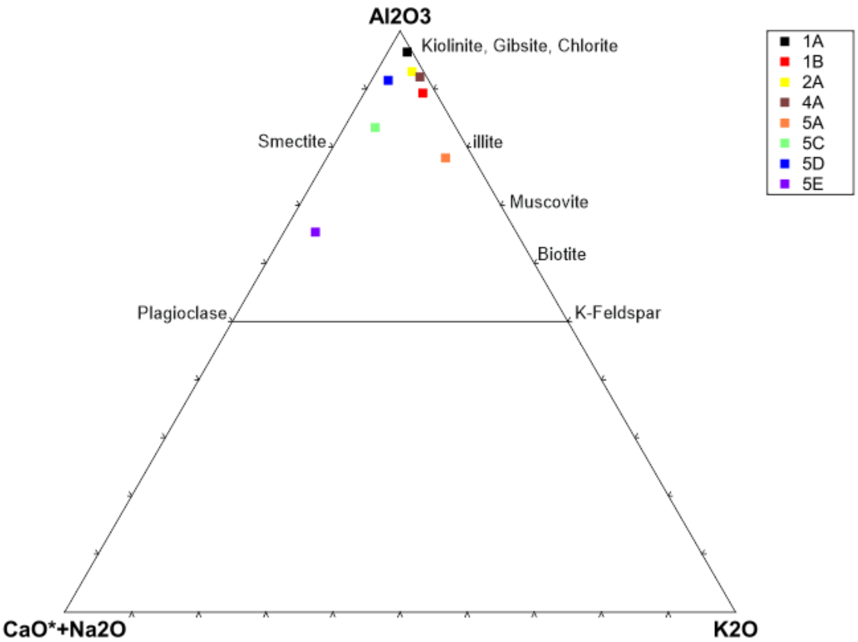


Figure 4.78 Al_2O_3– (CaO^*+ Na_2O)–K_2O (A–CN–K) diagram for the investigated soil

(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_2O_3 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.

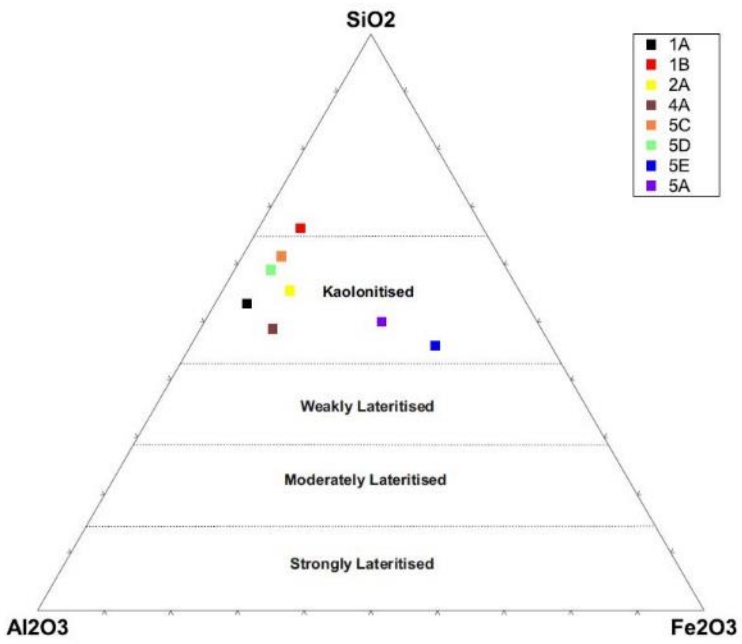


Figure 4.79 SAF diagram for the investigated soil, Idukki District

- The CIA (chemical index of alteration) value shows moderate to intense weathering.
- The samples fall in the Kaolonitised field in SAF diagram.

The intensity of laterisation calculated using the XRF data indicates that the samples collected are in the kaolinitised stage. Generally, the soil samples collected from the soil piping region are falls in Laterised zone (Babechuk 2014) and thus the tunnelling process is happening easily with the help of duricrust. The abundance of clay minerals and as the samples collected are falling in kaolinitised stage in IOL diagram revels that the areas subjected to form the piping process are weak and thus the subsidence is happening.

Prone areas

Field surveys were conducted across the district to delineate the areas susceptible for soil piping. Based on the number of occurrences of land subsidence and tunnel formation etc the area was classified as affected localities and areas with juvenile pipes and fewer incidents was classified as probable localities.

Table 4.24: Areal extent of Soil piping affected regions in the district

District	Total area in sq.km	Affected area in sq.km	Probable area in sq.km	Non-affected area in sq.km	No. of soil pipes reported
Idukki	4,358	955.995	2,831.934	570.072	13

The total area of the district is 4358 square kilometres in which 955.995 km^2 is falling inside the Affected zone and 2831.934 km^2 is falling inside the Probable zone which means a good portion of the district is vulnerable. The remaining 570.072 km^2 area is falling inside Non-affected zone which including coastal alluvium and hard rock exposures.

1. **Recommendations for the "Affected areas"**

In the critically affected areas infrastructure such as roads, buildings etc will be affected. Restrictions on high rise buildings or detailed surveys before the construction id needed. A proper water management plan should be developed for restricting the spread of soil piping. Geophysical surveys are suggested for locating large and typical pipes**. Activities that may store water in large quantity with any protection like earth removal / mining, may be restricted in the critically affected localities or the depth must restrict well above (at least 1m) the lithomarge clay layer is recommended. In no case clay layer should be exposed for water to infiltrate.**

2. **Recommendations for "Probable areas"**

These are areas prone to soil piping or mildly affected regions. In these areas juvenile and younger pipes are developed as an indicator of soil piping processes happening there. In such places well sections and laterite cutting are to be examined in detail for pipes and caves. Geophysical surveys may not help in identifying juvenile and younger pipes as they are smaller in size. Water management practices and usage of lime powder in the soil will retard the soil piping activities. **Earth removal / mining, the depth must restrict well above (at least 1m) the lithomarge clay layer is recommended. In no case clay layer should be exposed for water to infiltrate.**

In both areas' usage of hydrated lime along with the fertilizers should be encouraged to neutralise dispersive sodium in the clay

Dewatering is the best method to deescalate the formation of soil pipes. Overland flow may be diverted to a nearby nala without allowing to infiltrate in the affected zone will reduce pipe development.

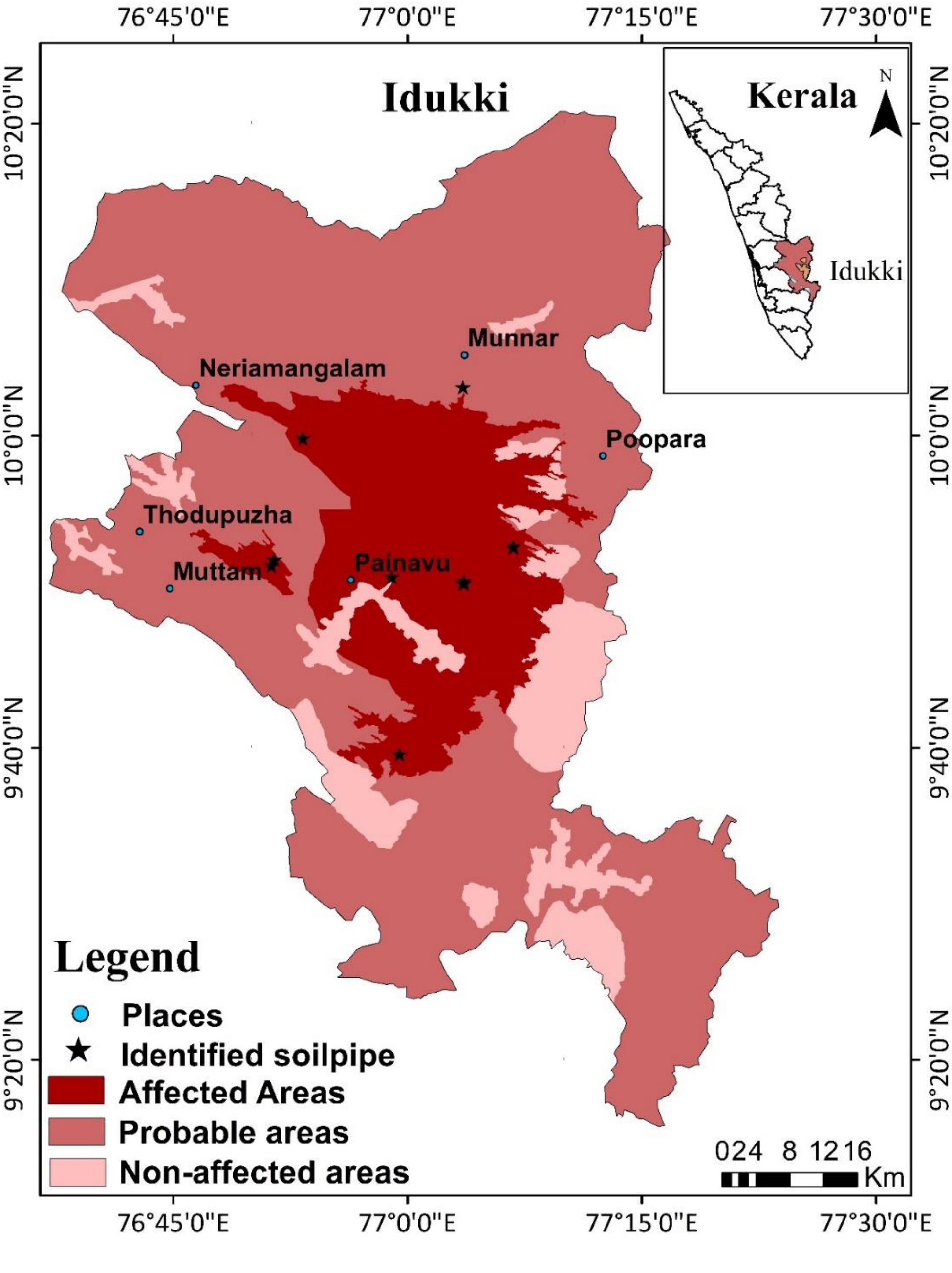


Figure 4.80: Zonation map of Idukki District

Conclusion

The total area of the district is 4358 square kilometres in which 955.995 km^2 is falling inside the Affected zone and 2831.934 km^2 is falling inside the Probable zone which means a good portion of the district is vulnerable. The remaining 570.072 km^2 area is falling inside Non-affected zone which including coastal alluvium and hard rock exposures. Peringassery, Thattekanni, Udayagiri, Nalaam Mile, Mavadi and its adjacent places are where pipes area seen and affected severely and the adjacent places are also noticed by juvenile pipes. Construction activities and new projects has to be permitted only after detailed geological / geotechnical studies.

4.6 Thrissur

Thrissur is one of the important historical cities of Kerala, which is known as the cultural capital of Kerala. The district has an area of 3032 sq.km and is located in the south-western India, lies between North latitudes 100 10' 22'' and 100 46' 54''; and East longitudes 750 57' 20'' and 760 54' 23'' (The Survey of India- Toposheet No. 58 B and 49 N). It is bounded on the north by Malappuram district, northeast by Palakkad district and south by Ernakulam and Idukki districts, touching western part of Tamil Nadu on the east and Lakshadweep Sea on the west. Thrissur district accounts for 7.8% of the area of the state. The district has five taluks viz. Chavakkad, Talappilli, Thrissur, Kodungallur and Mukundapuram which comprises 17 blocks spread over a total of 97 panchayath and 7 municipalities.

Geomorphology

According to geomorphology the district can be divided into three sections. 1. Coastal plain, 2.mid lands and 3. high lands.

The coastal plain with an average width of 7 km have elevation ranging from 1m below mean sea level to as much as 7.6 m above mean sea level. This coastal belt consists of number of beach ridges. The Kole land, which has elevations in the range of 1-2 m above mean sea level and water logged for 5-6 months in a year due to tidal effects.

The Midland region marks the two geomorphic zones. These are the flat-topped landform covered by a thick blanket of laterite, which is immediately to the east of coastal plain and rises up to 20 m above mean sea level. The laterite is quite thick and, in some places, attains thickness up to 25 m. The mounds occur all along the midland portion, occasionally rising to 70 m above mean sea level. The second geomorphic zone is represented by in filled valleys, which occur between lateritic mounts and varying in length from 100m to 3.5 km comprising alluvial sediments and are intensively cultivated and get flooded during the monsoon periods.

The High lands the hill ranges along the eastern part constitute the rugged terrains of Western Ghats. The eastern high lands exhibit a typical topography with a steep hill dissected by deep 'V' shaped valleys drained by youthful rivers.

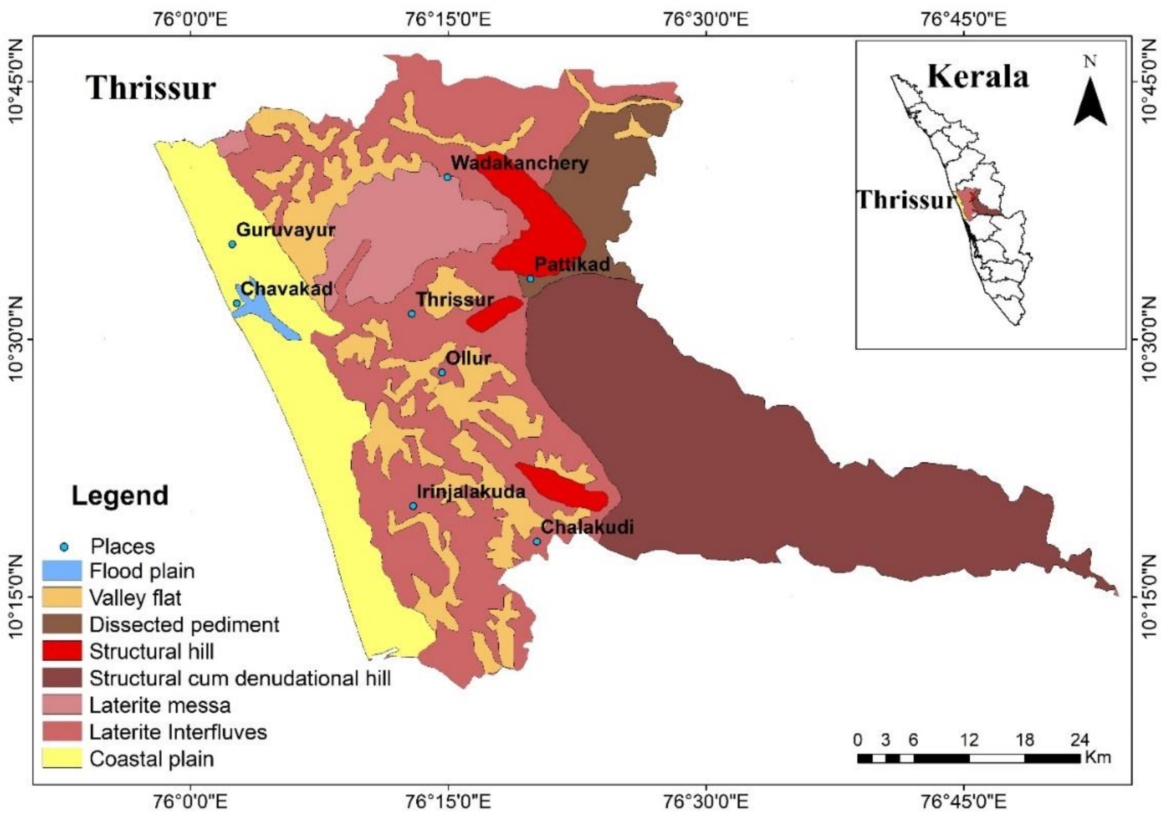


***Figure 4.81*: Geomorphology of Thrissur District**

(geomorphology map modified after District Resource map, Wayanad district, Geological Survey of India)

Drainage

The Periyar, the Chalakudy, the Karuvannur, the Kurumali River (main tributary of the Karuvannur River) and the Ponnani (Bharatha Puzha) are the main river systems in the district. They take their origin from the mountains on the east, and flow westward and discharge into the Arabian Sea. There are a number of tributaries also joining these main rivers. There are waterfalls such as Athirappilly Falls which is widely known as the "Indian Niagara" nowadays. This is the only district in Kerala with the presence of both Periyar and Bharathappuzha, though they flow only a small distance through the district. In the western part of the district where lagoons and back water channels are prominent.

Rainfall

The district has a tropical humid climate with an oppressive hot season and plentiful and seasonal rainfall. The average annual rainfall ranges between 2310.1 and 3955.3 mm in the district with mean annual rainfall of 3198.133 mm. The hot season from March to May is followed by the South West Monsoon season from June to September (72%). The period from December to February is the North East Monsoon season. However, the rain stops by the end of December and the rest of the period is generally dry. The month of July experiences abundant rainfall and is the wettest month.

The maximum temperature ranges from 29.3 to 36.20C whereas the minimum from 22.1 to 24.90C. The average annual maximum temperature is 32.300C and minimum temperature 23.30C. Generally, March and April months are the hottest and November, December, January and February months are the coldest.

Geology

Geologically the area is composed mostly of four types of lithological units:- (i) Charnockite belt which is widespread and most prominent in the district; (ii) Gneissic belt represented by biotite gneiss, hornblende-biotite gneiss and quartzo-feldspathic gneiss, (iii) Granitic gneiss (PGC) restricted to the south eastern part and (iv) the Quaternaries of the coastal tract. Pink granite (granite gneiss) of Peninsular Gneissic Complex is seen along the south eastern border, the major part of which extends to the adjacent Idukki district in the east. The rock is seen to occur interbanded with the associated rocks. It consists of varying proportions of orthoclase, plagioclase, quartz, green hornblende and brown biotite. Calc-silicate rock belonging to the Khondalite group occurs as small outcrops near Vadakkethara in the north eastern part of the district. The distribution in the area is very limited and it occurs as thin bands within the charnockite. Charnockite is generally massive but when foliated has a gneissic look. Varieties like medium- and coarse-grained, highly feldspathic and migmatitic are also not rare. Pyroxene granulite, a member of the Charnockite Group, occurs as thin bands enclosed by charnockite and/or biotite gneiss. Biotite gneiss of Migmatite Complex is next to charnockite in abundance. This is the major rock in the western part extending from Thrissur in the north to Kottapuram in the south. Small lenticular bodies of biotite gneiss are seen within the charnockite terrain as well. The rock is well foliated and is characterised by banding, rich in biotite and quartzo-feldspathic material. In places they tend to become massive and granitic. The other members of the Migmatite Group namely quartzo-feldspathic gneiss and hornblende biotite gneiss have restricted distributions. Fairly large area around Vellani Mala and Peechi are occupied by hornblende-biotite gneiss. The major part of the quartzo-feldspathic gneisses seen as linear band in the north eastern part is extending to adjacent Palakkad district in the east. Linear bands of this rock are seen in the south eastern part also. Near Ambalapara in the south eastern part there is a quartz syenite acid intrusive body. It is leucocratic, medium- to coarse-grained, medium- to coarse-grained, composed of feldspars with rare green pyroxene. Dolerite and gabbro dykes are seen cutting across these older rocks and are generally aligned in NNW-SSE trend. Pegmatite s and quartz veins occur within the charnockite and gneisses, mostly as fracture fillings. They are of small dimension and show no concentration in specific locality. A small patch of Warkalli bed is seen near the coast in the northern part. Unconsolidated Quaternary sediments overlie these basements unconformably. The sediments are classified into different morphostratigraphic units based on their lithic content and environment of formation. Guruvayur Formation is an older marine deposit while Periyar Formation, Viyyam Formation and Kadappuram Formation are the contemporary fluvial, fluvio-marine and marine deposits.

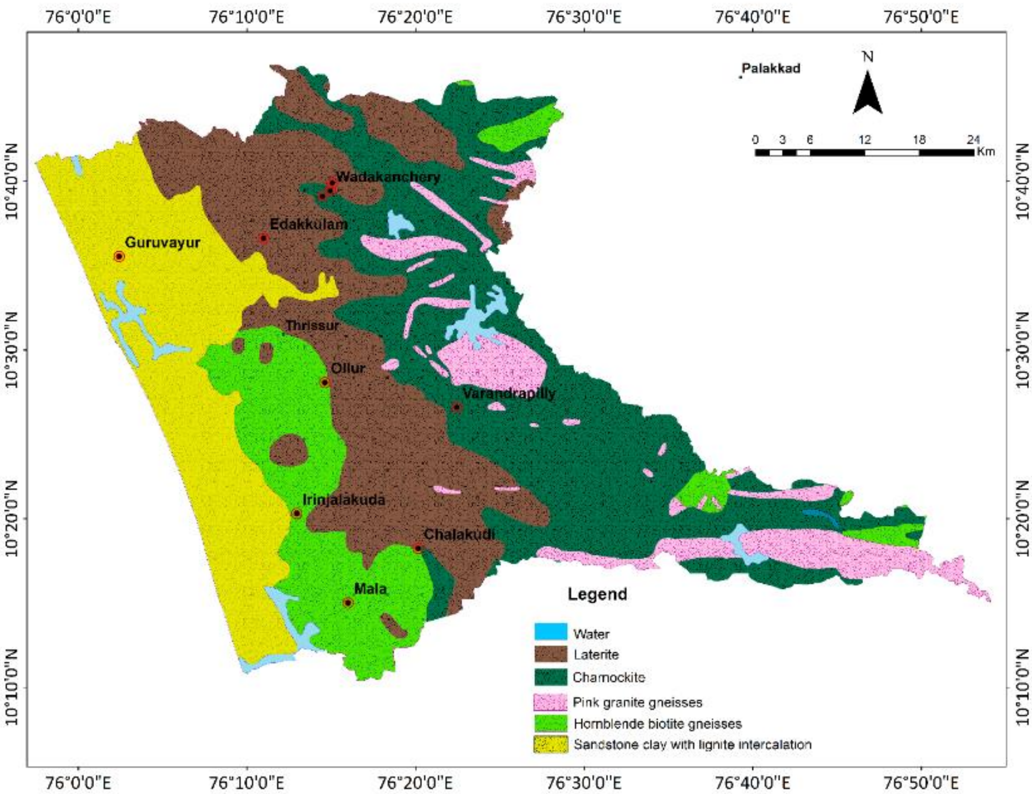


***Figure 4.82*:** Geology of Thrissur District

(geology map modified after District Resource map, Wayanad district, Geological Survey of India)

Soil Characteristics

The soils in Thrissur district have been classified in the following types, based on the morphological features and physiochemical properties.

1. The laterite Soil

the predominant soil type observed is the lateritic soil, which covers almost the entire midland areas of the district. These soils are in general well drained, low in essential plant nutrients and organic matter. They exhibit very low cation exchange capacity and are generally acidic.

2. Brown hydromorphic soils

the second prominent soil type is the brown hydromorphic soil. These are confined to the valleys between undulating topography in the midlands and in the low-lying areas of the coastal strip in the district. These have been formed as a result of transportation and sedimentations of materials from adjoining hill slopes and also by deposition from rivers. The soils are very deep and brownish in colour. The surface texture varies from sandy loam to clay.

3. Hydromorphic Saline Soils

Very small patches of hydromorphic saline soils are found in the coastal tracts of the district. They are brownish, deep and imperfectly drained, showing wide variation in texture. In the estuarine areas of the district, these soils are found with wide fluctuations in the intensity of salinity.

4. Coastal Alluvium

These soils are seen on the coastal tracts stretching from Kodungallur to Chettuvai. These have been developed from recent marine deposits with a texture dominated by partially sorted sand fraction. They are excessively drained with very rapid permeability. Water holding capacity of these soils is low.

5. Riverine Alluvium

These soils consist of moderately well drained and distributed mainly on the banks of rivers and their tributaries. They are light to medium textured with good physical properties and contain organic matter, nitrogen and potash moderately. They show wide variations in their physic-chemical properties. They are very deep soils with surface texture ranging from sandy loam to clayey loam, predominated by the fine sand fractions.

6. Forest Loamy Soil

These soils are found in the south-eastern hilly areas of the district, bordering Tamil Nadu. These are characterized by a surface layer very rich in organic matter. They are dark reddish brown to black with loam to silty loam texture. The soils are generally acidic.

Hydrogeology

Groundwater occurs under water table conditions in alluvium, laterites and weathered mantle of the crystalline, where as in the deeper fractured crystalline the groundwater occurs under semi confined to confined conditions. The hard rock and laterite aquifers constitute major aquifer system of the district while the sedimentary aquifers are seen along the coast and river courses. Groundwater occurs under phreatic, semi confined to confined conditions in the weathered and fractured portions of the crystalline formations and occurs semi-confined and confined condition in deep seated fractured and sedimentary formations. The weathered rocks form potential aquifers and the thickness of weathered portion ranges from 4.5 m to 21.0 meters. The depth to water level in the wells during pre-monsoon period varies from 1.57 to 14.42 mbgl and during post monsoon period 0.53 to 11.73 mbgl.

Soil piping in the district

The Thrissur district is one of the prone among the fourteen other districts of Kerala. A very good portion of the district is well affected by soil piping is noticed through field investigation. The district has revealed more than 11 major soil pipes in the district.

As the district is recognized with more than 11 number of soil pipes including minor and, major sized through stacking, scouting and geophysical investigations over the district. The geophysical, geochemical and sedimentological analyses of field data and samples collected during field investigations have given a clear idea that these pipes are occurring under certain conditions.

The geomorphological and geological features have the major hand on the piping process. The slope, drainage, soil types, vertical profile and rainfall are some of the major features that accounts on this process.

As the identified incidents are having almost similar characters and conditions in formation this can be happened in the similar other areas with same favourable conditions and so a zonation is possible through which the district could highlight with three zones. This can help in giving awareness and management in land use in future.

Table 4.25: Piping locations in Thrissur District

Sl. No	Name	Location		position	Status	Remarks
		Latitude	Longitude			
1	Eyyal caves	10.65724	76.118952	Populated region	Mature pipe	Very localised small & young feature
2	Ettamkallu	10.48758333	76.32075	Populated region	Young pipe	Out let is located beside a road
3	Varandharapilly Panchayat	10.43891667	76.36152778	Populated region	Juvenile pipe	Localised feature
4	Pattilamkuzhi	10.5339166	76.36138889	Populated region	Juvenile pipe	Localised feature
5	Thumburmuzhi	10.3009166	76.43308333	Non-Populated region	Small pipe	Subducted and filled
6	Chira colony Kizhakkemadam (Ravi, Radhakrishnan's houses) *	10.76263889	76.22916667	Populated region	SEOC-SDMA	SEOC-SDMA
7	Sambava colony*	10.76247222	76.219	Populated region	SEOC-SDMA	SEOC-SDMA
8	Thazhvaram road*	10.21716667	76.24116667	Populated region	SEOC-SDMA	SEOC-SDMA
9	Vattakotta*	10.23483333	76.27441667	Populated region	SEOC-SDMA	SEOC-SDMA
10	Balanpeedika-kodassery*	10.588825	76.60798611	Populated region	SEOC-SDMA	SEOC-SDMA
11	Chandanakunnu Kodassery*	10.588425	76.63700833	Populated region	SEOC-SDMA	SEOC-SDMA

* data from SEOC-SDMA)

Prone areas

The Thrissur district is identified by 11 soil pipes including minor and, major sized through stacking, scouting and geophysical investigations over the district. The geophysical, geochemical and sedimentological analyses of field data and samples collected during field investigations have given a clear idea that these pipes are occurring under certain conditions. The identified soil pipes have occurred in urban and near to urban and so there can be more such pipes developed in the remote and forested areas.

The soil pipes seen over the districts are mostly minor and juvenile type and these could develop and form major type of tunnels in future. These small size soilpipes could be the trigger for slipping of land masses where slope is favourable. As the identified incidents are having almost similar characters and conditions in formation this can be happened in the similar other areas with same favourable conditions and so a zonation is possible through which the district could highlight with Critically affected, most probable and least probable zones. This can help in giving awareness and management in land use in future.

Table 4.26**:** Areal extent of Soil piping affected regions in the district

District	Total area in sq.km	Affected area in sq.km	Probable area in sq.km	Non-affected area in sq.km	No. of soil pipes reported
Thrissur	3,032	1349.881	569.598	1112.521	11

Soil piping incidences were noticed in this district from 2018 extreme rainfall events. During this period many localities suffered landslides and floods. Many of landslides occurred in the district were associated with soil pipes. Few cases roads were affected. The fie; d surveys indicated that out of the 3032 sq km of the district about 1349 sq km area has been affected by soil piping. About 569 .59 sq.km area is probable areas where only minor initiations are noticed. There 11 identified location in the district.

1. **Recommendations for the “Affected areas”**

In the critically affected areas infrastructure such as roads, buildings etc will be affected. Restrictions on high rise buildings or detailed surveys before the construction id needed. A proper water management plan should be developed for restricting the spread of soil piping. Geophysical surveys are suggested for locating large and typical pipes**. Activities that may store water in large quantity with any protection like earth removal / mining, may be restricted in the critically affected localities or the depth must restrict well above (at least 1m) the lithomarge clay layer is recommended. In no case clay layer should be exposed for water to infiltrate.**

2. **Recommendations for “Probable areas”**

These are areas prone to soil piping or mildly affected regions. In these areas juvenile and younger pipes are developed as an indicator of soil piping processes happening there. In such places well sections and laterite cutting are to be examined in detail for pipes and caves. Geophysical surveys may not help in identifying juvenile and younger pipes as they are smaller in size. Water management practices and usage of lime powder in the soil will retard the soil piping activities. **Earth removal / mining, the depth must restrict well above (at least 1m) the lithomarge clay layer is recommended. In no case clay layer should be exposed for water to infiltrate.**

In both areas' usage of hydrated lime along with the fertilizers should be encouraged to neutralise dispersive sodium in the clay

Dewatering is the best method to deescalate the formation of soil pipes. Overland flow may be diverted to a nearby nala without allowing to infiltrate in the affected zone will reduce pipe development.

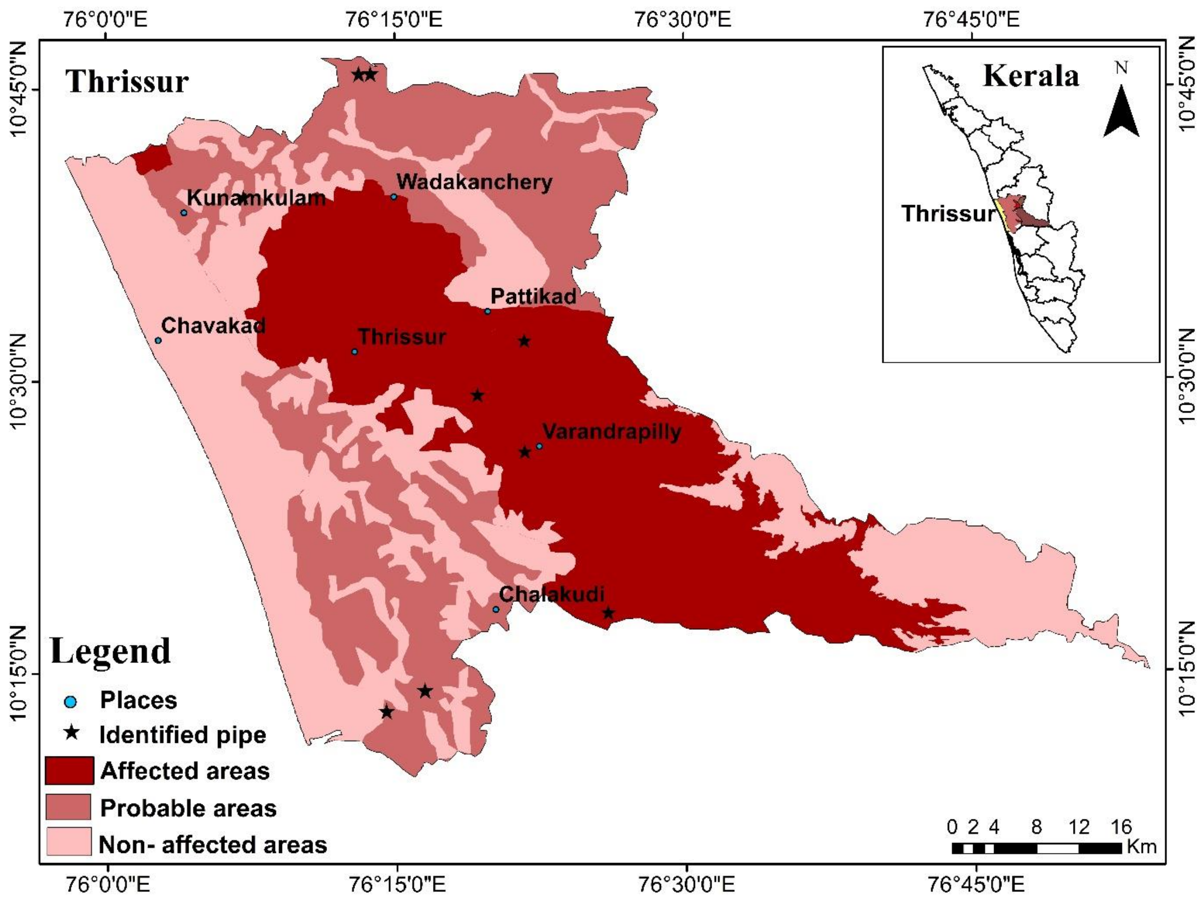


Figure 4.83: Zonation of Thrissur District

Conclusion

The total area of the district is 3032 square kilometres in which 1349.881 km^2 is falling inside the Affected zone and 569.598 km^2 is falling inside the Probable zone which means a good portion of the district is vulnerable. The remaining 1112.521 km^2 area is falling inside Non-affected zone which including coastal alluvium and hard rock exposures. Chalakkudy, Varandharapilly, Pattikkadu and its adjacent places are where constructions and new projects has to be start only after detailed geotechnical studies.

Ettamkallu

Pattilamkuzhi

Thumburmuzhi

Varandharapilly

Thumburmuzhi

***Figure 4.84*: **Filed photos of Thrissur District

4.7 Kozhikode

The Kozhikode district is one of the northern coastal districts of Kerala lies between North latitudes 11° 08’ and 11° 50’ and East longitudes 75°30’ and 76° 8’with an area of 2344 Sq. Kms. It is bounded on the north by Kannur district, on the east by Wayanad district, on the south by Malappuram district and on the west by Lakshadweep Sea. It is falling in parts of Survey of India Toposheets 58 A and 49 M.

The district is divided into 3 taluks and 12 developmental blocks and 77 panchayats for administrative purposes. The district has one corporation (Kozhikode) and two Municipalities namely Quilandy and Badagara. It has a total of 117 revenue villages.

Geomorphology

Physiographically, Kozhikode district is divided into low land, mid land and high land.

(i) Low land or coastal plain: The area with height <7.6 m amsl. The coastal plain is very narrow, 5 – 10km wide, gently sloping with a maximum height of about 10m in the east. It comprises depositional landforms of marine, fluvial and fluvio-marine origin. There is a well-developed beach all along the coast with sea cliffs and rocky beaches near Quilandy, Elattur and Kappad. The low land extends as a narrow stretch of land lying along the coast from South Kadalundi to North Mahe. The plain is interrupted by steep laterite cliffs and rock outcrops. The low land forms 6.7% of the total area of the district.

(ii) The midland: Area lies at a height between 7.6 and 76 m amsl. It may be further classified into low rolling terrain and moderately undulating terrain. The low rolling terrain has a slope of less than 15%. It consists of rolling laterite hills surrounded by valleys. The valleys are flood plain alluvium and red loamy soil. The moderately undulating terrain covering large area of the district has a slope between 15 and 25%. In addition to the agricultural crops of paddy and coconut, cash crops like rubber and arecanut are cultivated.

(iii) High land: Area with elevation above 76 m amsl is called the highland. It is in the eastern part of the district. The area is prone to landslides and land slips and comprises of steep slopes and barren rocks. The highest elevation of the district is 1935 m amsl at Nilamala in northeastern corner of the district.

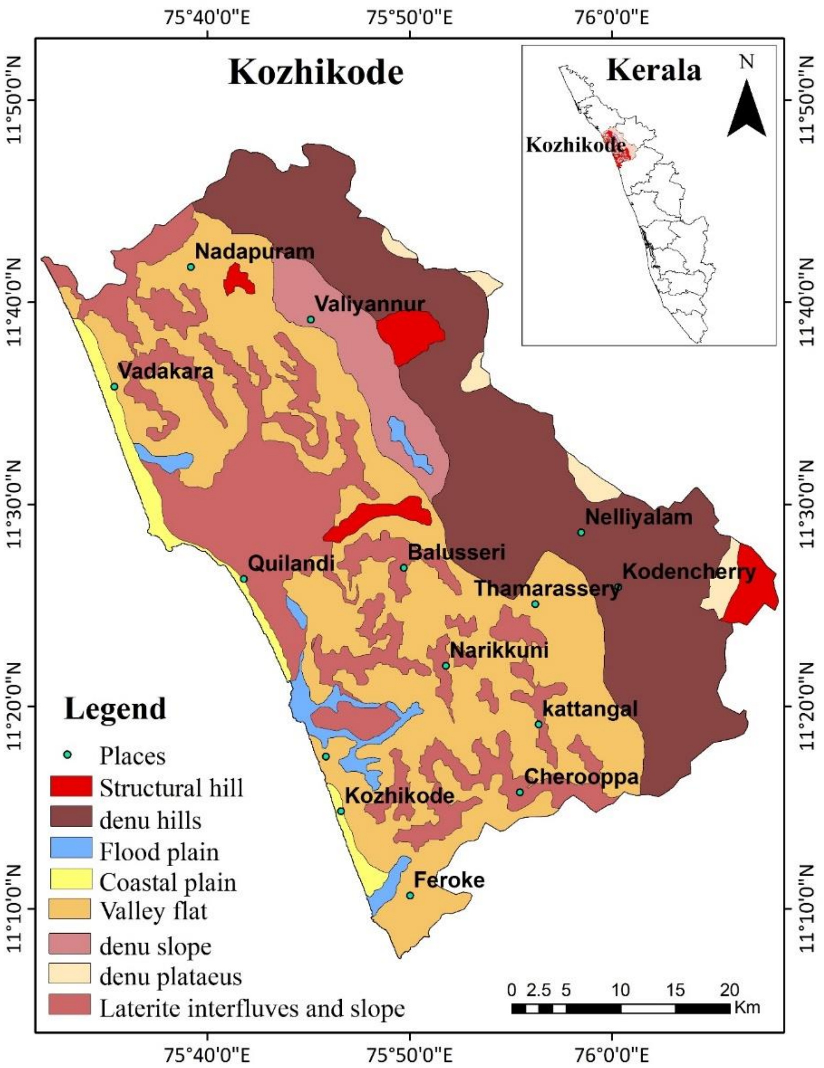


***Figure 4.85*:** Geomorphology map of Kozhikode District

(geomorphology map modified after District Resource map, Kozhikode district, Geological Survey of India)

The landform units identified in Kozhikode are alluvial plain, flood plain, valley fill, linear ridge, hillcrest, sloping terrain, rocky slope (scarp face) and hilly terrain. The flood plain and valley fill are the major fluvial landforms whereas moderately sloping terrain, highly sloping terrain, rocky slope (scarp face), linear ridge and hillcrest are major denudational landform units. The fluvial and gently sloping terrains are promising zones of groundwater. Denudational landforms are unproductive zones.

Geology

The district can be divided into three geological belts viz., (i) a linear NW-SE trending gneissic belt, along the middle extending from north to south, (ii) a charnockite belt occupying areas in the northeast and south, extending to the adjacent districts and also occurring as pockets within the gneissic terrain and (iii) a narrow coastal belt. Granite gneiss belonging to the Peninsular Gneissic Complex is the oldest unit of the area and occurs north of Alampore. Charnockite belonging to the Charnockite Group has a very wide distribution, especially in the northeast and south with variations like biotite-hypersthene gneiss, biotite-hornblende-hypersthene gneiss and hornblendehypersthene gneiss. Magnetite quartzite, another unit of this group, occurs as narrow linear bodies within charnockite.

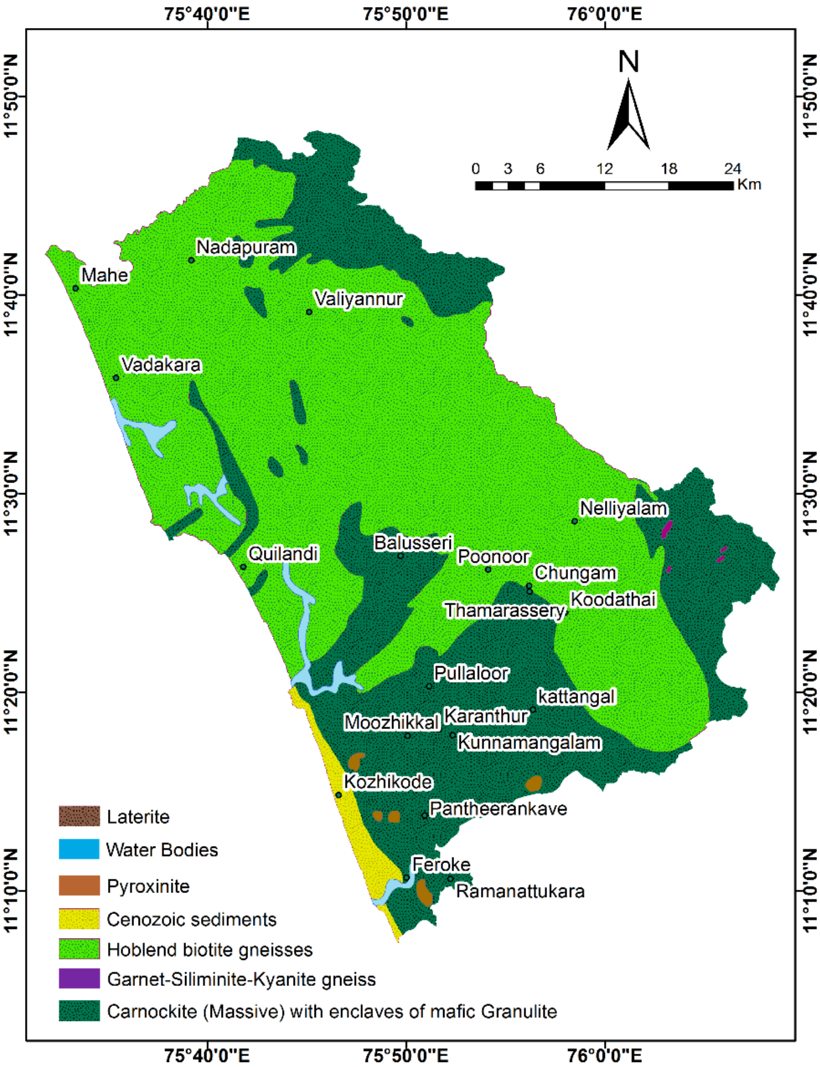


Figure 4.86: Geology map of Kozhikode District

(geology map modified after District Resource map, Kozhikode district, Geological Survey of India)

Hornblende-biotite gneiss of the Migmatite Complex extends from north to south and is well foliated. Garnetiferous quartzo-feldspathic gneiss, another member of Migmatite Complex, occurs as lenses within charnockite, in the east. NW-SE trending dolerite dykes. These dykes are 10-20m wide. Pebble beds occur on the coast and along banks of the Beypore river. The pebble bed is associated with grit and clay and it is lateritised. It comprises well rounded pebbles of quartz, granite, quartzite and granulite. It is considered to be of Pleistocene origin. Sporadic laterite is recorded from the charnockite country to the southwest. Quaternary deposits are of marine and fluvial origin. Periyar Formation is a fluvial deposit comprising an admixture of sand, silt and clay. Guruvayur Formation is a strand line deposit of palaeo-marine origin and mostly comprises medium- to fine sand. Kadappuram Formation represents contemporary marine deposits, constituting the present and barrier beach.

Soil types

The soils of the district are alluvial soil, lateritic soil and forest loam. Alluvial soil is seen mostly along the coastal plain and valley. They are coastal alluvial soil and river alluvial soils. They are excessively drained to moderately drained and are of sandy to clayey textures. Majority of the area under riverine alluvium was once occupied by paddy cultivation. But those areas are now utilised for the cultivation of various crops especially plantain. The riverine alluvium contains moderate organic matter, nitrogen, phosphorous and potash. 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. They are found mostly along the midland portion of the district. 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 loam is deep or very deep and well drained loamy to clayey textures. 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.

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Drainage and Irrigation

The district is drained by six rivers of which one is of medium nature and all others are minor ones namely Chaliyar, Kuttiyadi, Mahe, Kadalundi, Kallayi and Korapuzha. The Chaliyar River is a medium river and originates at a height of 2066 m amsl in Ilambalari hills of Western Ghats of Gudallur district, Tamil Nadu. The Chaliyar drains in to Beypore estuary. It is a sixth order stream with a length of 169 km. At its upper reaches it is formed by Punnurpuzha, Pandiyur, Karimpuzha, Cherupuzha, Kanhirampuzha, Kurumbanpuzha, Vathatpurampuzha & Iruvantipuzha. At its lower reaches near Cheruvannur, it is flowing as a broad river developing inlets. The Kuttiadi River originates at a height of 1334 m amsl on the western slopes of Wayanad plateau. The river is also known by the name of Murat River. It has a length of 75 km and flows through Badagara and Quilandy taluks. It flows in northerly direction at first then bends and takes southwesterly direction of flow. At Turaiyur it is joined by the Agalapuzha. Further it takes a "U" turn and flow northwesterly direction as the Murat River developing lagoons and joins the sea at Kottakkal near Badagara. The river is dammed at Kakkayam for the hydroelectric project and the tail end waters of the project are stored at Peruvannamamuzhi, for irrigation. The Mahe River originates at a height of 910 m amsl at Vanchimagate hills of Wayanad in Western Ghats and flows in the northeastern corner of the district. The course is forming northern boundary of the district. Near its lower reaches it bends and turns at Kariyad and flow in northwesterly direction and join the sea at Mahe. The Kadalundi River formed by the union of Olipuzha and Veliyarpuzha has a length of 130 km. It enters the district at near its mouth of flow with only 14 km length in the district. The Kallayi River has a length of 22 km. It originates at Cherukulathur, which is at a height of 45 m amsl and drains the district, joining the sea near Kozhikode. It is connected by man-made Buckingham Canal with the river Chaliyar. The Korapuzha is a small river with a length of 40 km formed by the union of Agalapuzha and Punnurpuzha. It drains into the Arabian Sea at Elathur There is only one major irrigation project in the district namely the Kuttiyadi irrigation project across the Kuttiyadi River. The Kuttiyadi irrigation project (KIP) partially completed in 1972 comprises a main dam 35.5m high across Kuttiyadi at

Peruvannamuzhi form a reservoir of storage capacity 113.28 MCM for regulating the yield from the catchment below the Kuttiyadi hydel dam and the tail waters of Kuttiyadi power station. Besides the major irrigation schemes, the district is irrigated by number of minor irrigation schemes, lift irrigation schemes, community irrigation schemes, wells and tanks.

Rainfall

Kozhikode district experienced annual rainfall of 3698 mm in the year 2006. The high rainfall areas in the district are Kakkayam dam site and Kakkayam Power House. Kakkayam dam site has been experiencing more than 4500 mm of annual rainfall since 2000. It has been noticed that rainfall displays an increasing trend towards north-eastern areas of the district. The climate of the area is divided in to four seasons – summer, South West Tropical Monsoon period, North East Tropical Monsoon period and winter. The SW and NE monsoons mainly contribute rainfall in the area with 82.77 % of the rainfall. In 2006 during winter (January to March), summer (April and May), SW tropical monsoonal (June to October) and NE tropical monsoonal seasons, Kozhikode district received 0.49%, 16.74%, 72.15% and 10.63% rainfall respectively. The month of June experiences maximum rainfall. The months of July, August and October also receive heavy rainfall. The agricultural activity of the district depends on the onset of SW tropical monsoon.

Groundwater Scenario

Groundwater occurs in the weathered, fractured, crystalline and alluvial formations in the district. Phreatic conditions exist in weathered formation and are mostly developed by dug wells for domestic and irrigation purposes. Semi-confined conditions exist in deep fractures and storage and movement of groundwater is mainly controlled by the fracture system. Deep high yielding bore wells are located along fractures / lineaments .The district is divisible into two hydrological provinces viz., (i) the eastern Wayanad Plateau where dug wells give moderate yield and bore wells are feasible along fracture planes and (ii) the western mountains, which are generally unsuitable for groundwater development but the valleys with thick alluvium sustain dug wells. 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.

***Table 4.27*:** Piping locations in Kozhikode District

Sl. No	Name	Location		position	Status	Remarks
		Latitude	**Longitude**			
1	Pasukadavu	11.66472222	75.83833333	Populated region	Young pipe	
2	Cheerankunnu*	11.289625	76.057522	Populated region	SEOC-SDMA	SEOC-SDMA
3	Paloramala*	11 354301	75.892176	Populated region	SEOC-SDMA	SEOC-SDMA
4	Muthuplav*	11.4115	75.936	Populated region	SEOC-SDMA	SEOC-SDMA
5	Poyilamchal*	11.42443	75.43556	Populated region	SEOC-SDMA	SEOC-SDMA
6	Kandirathukkal*	11.47512	75.914116	Populated region	SEOC-SDMA	SEOC-SDMA
7	Kakkadampoyil*	11.31902	76.111471	Populated region	SEOC-SDMA	SEOC-SDMA
8	Kannappankundu*	11.3037	75.927	Populated region	SEOC-SDMA	SEOC-SDMA

Prone areas

The Kozhikode district is identified by 8 soil pipes through stacking, scouting and geophysical investigations over the district. As the identified incident having some particular conditions in formation this can be happened in the similar other areas with same favourable conditions. The juvenile pipes which triggers the tunnel erosion are noticed apart from the district. The district could highlight with Probable zone and Non-affected zone. This can help in giving awareness and management in land use in future.

There 10 cases reported from Kozhikode. Laterite mesas occur in the district are prone to soil piping. so far only minor incidences are observed in the district. Juvenile other small types of pipes are observed in all these areas. In the Pasukkadavu area bigger subsidences (0.5 to 1 m dia) are seen.

Table 4.28: Areal extent of Soil piping affected regions in the district

District	Total area in sq.km	Affected area in sq.km	Probable area in sq.km	Non-affected area in sq.km	No. of soil pipes reported
Kozhikode	2,344		1479.344	864.65	8

Out of the 2344 sq.km area in the district about 1479.65 sq.km area is found to be affected or probable to soil piping. As the lithology, climate and other geo environmental features are favourable this district is likely to have larger pipes if precautions are not taken.

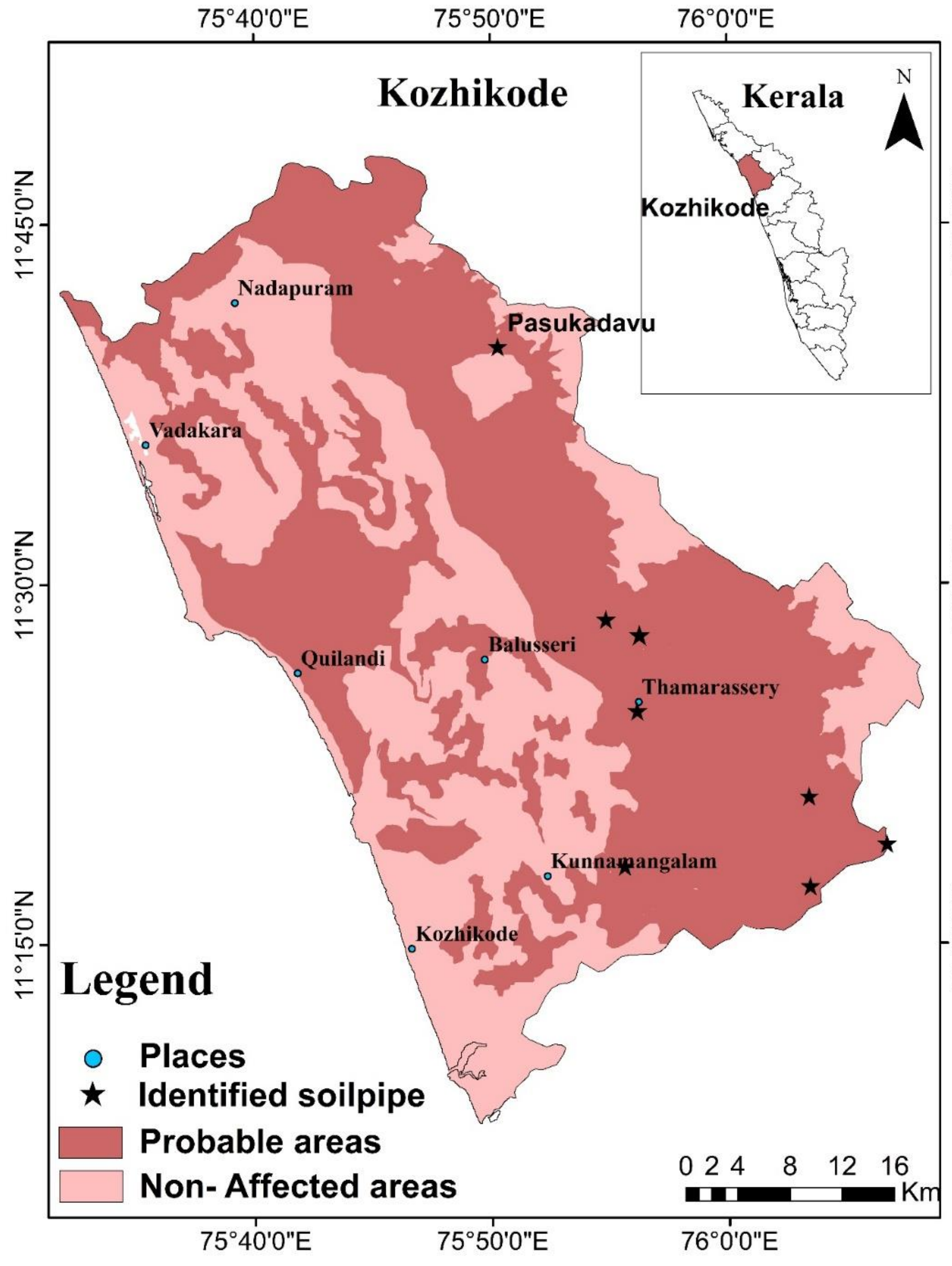

Figure 4.87: Zonation map of Kozhikode District

Recommendations for "Probable areas"

These are areas prone to soil piping or mildly affected regions. In these areas juvenile and younger pipes are developed as an indicator of soil piping processes happening there. In such places well sections and laterite cutting are to be examined in detail for pipes and caves. Geophysical surveys may not help in identifying juvenile and younger pipes as they are smaller in size. Water management practices and usage of lime powder in the soil will retard the soil piping activities. **Earth removal / mining, the depth must restrict well above (at least 1m) the lithomarge clay layer is recommended. In no case clay layer should be exposed for water to infiltrate.** Usage of hydrated lime along with the fertilizers should be encouraged to neutralise dispersive sodium in the clay. Dewatering is the best method to deescalate the formation of soil pipes. Overland flow may be diverted to a nearby nala without allowing to infiltrate in the affected zone will reduce pipe development.

Conclusion

The total area of the district is 2344 square kilometres in which 1479.344 Km^2 is falling inside the Probable zone and the remaining 864.65 km^2 is Non affected.

4.8 Palakkad

Palakkad (Palghat) is the land of Palmyrahs and Paddy fields. It is often called as the 'Gateway of Kerala'. The district has an area of 4480 sq.km and is located in the south-western India (10.775° N- 76.651° E). Palakkad is bordered on the northwest by the Malappuram District, on the southwest by the Thrissur District, on the northeast by The Nilgiris District and on the east by Coimbatore district of Tamil Nadu.

Geomorphology

Physiographically the district is divisible into two zones (i) the high hill ranges of the Western Ghats in the east (the high land) and (ii) the low-lying undulating (midland) region in the west. A conspicuous landmark of the district is the 'Palghat Gap' which is a major E-W trending break, across the NNW-SSE running hill ranges of the Western Ghats. The 'Gap' having an elevation of 70-300m above mean sea level is part of a well-defined low-level landform of the Western Ghats. The 'Gap' is bound by steeply rising Nilgiri hills in the north and Anamalai-Palani hills in the south. The width of 'Palghat Gap' is about 30km. The midland region of the district, of which the 'Palghat Gap' is also a part, represents an area of low undulating relief, with convex gently graded interstream tracts, sloping down to broad valley floors consisting of local erosional remnants. Thee erosional landforms are often seen interfingered with alluvial plains and lateritic hummocks, and the terrain as a whole represents a dissected pediment. The structural cum denudation hill ranges border the dissected pediment to its north and south. Towards west, the landform is more matured with laterite mesas and laterite interfluves separated by narrow valley flats and flood plains. Almost levelled and matured topography around 1200m above msl in the north probably represents a planation surface. The elevation of the landforms varies from 20 to 2386 m above msl.

Bharathapuzha is the major river draining the district. Gayathripuzha and Kunthi puzha are the important tributaries of the Bharathapuzha. The Attapady area is drained by Bhavani River, which unlike other rivers of Kerala is one among those three rivers that flows towards east. The district is not blessed with coastal tract and natural lakes. Ottapalam taluk lies completely in the mid land region whereas all other taluks lie both in midland and high land regions.

Morphology of the terrain has played an important role in the potential of groundwater in the district. In the 'Palghat Gap' and in the plain's further west, groundwater is available at shallow depths through open dug wells. But the hilly terrain on either side of the 'Gap' is generally unsuitable for groundwater development. The amount of rainfall received in the district is also less compared to other districts of the State because of which scarcity of water is very common and, in some parts, even drought conditions prevail during the summer months.

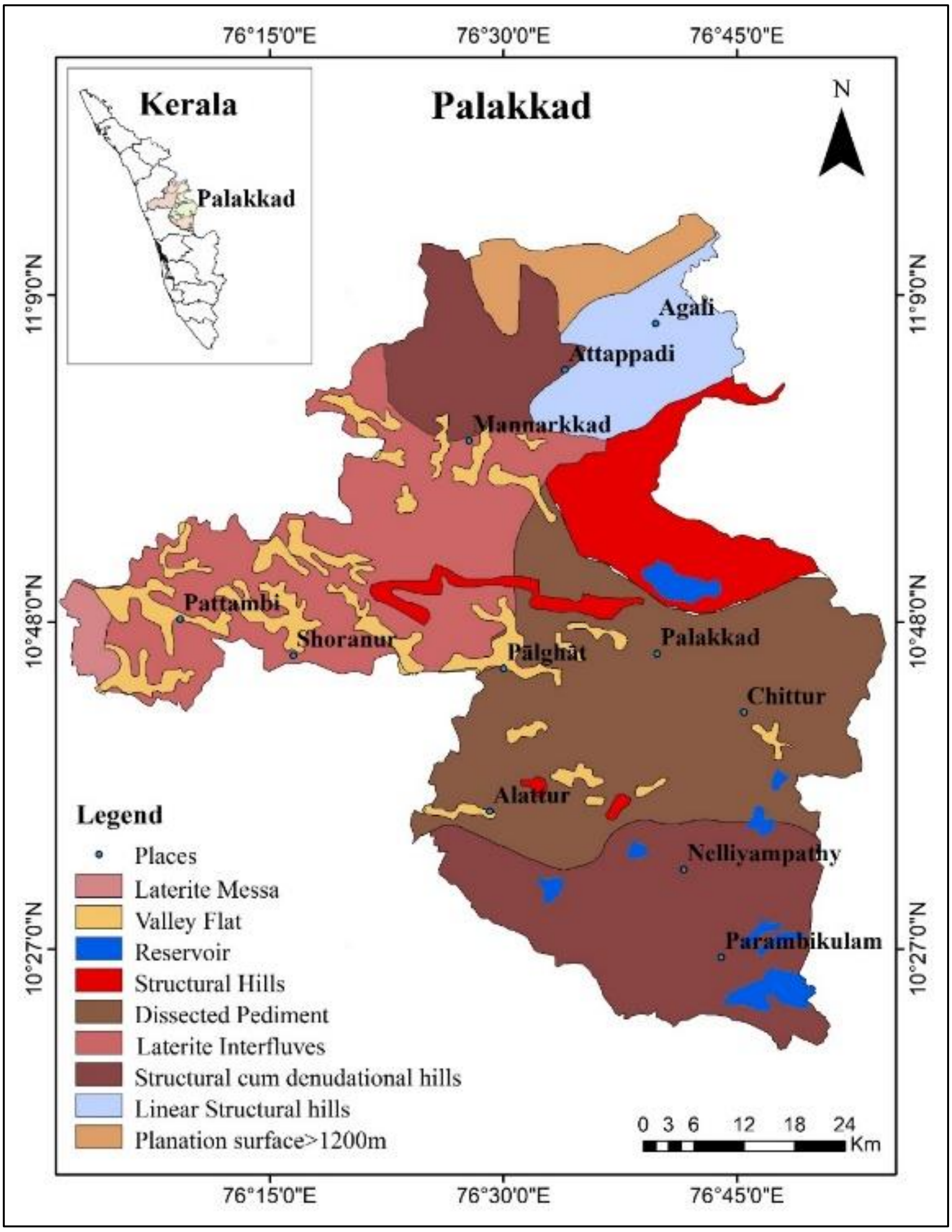

Figure 4.88: Geomorphology of Plakkad District

(geomorphology map modified after District Resource map, Palakkad district & Geological Survey of India)

Geology

The district can be divided into five geological terrains viz. i) lowland of charnockite country in the west; (ii) Migmatite Complex in the east, extending into adjacent Coimbatore district of Chennai; (iii) Khondalite Group, occurring as linear bodies in the northeast hill region; (iv) Wayanad Group, occurring as high hills in the north in Attapady area and (v) Peninsular Gneissic

Complex (PGC) confined to the north of Bharathapuzha river. The area forms a part of the Precambrian metamorphic shield having a complex geological set up. Wayanad Group is represented by rocks of upper amphibolites to lowergranulie facies metamorphism. This complex can be divided into an ultramafic dominant upper group and amphibolites dominant lower group. The ultramafic group comprises talc-chlorite schist, talc-pyroxene-garnet schist. The amphibolite group consists of hornblende-biotite schist and gneiss with amphibolites bands garnet. These rocks are exposed in the Attappadi area. Hornblende –biotite gneiss and pink granite gneiss of Peninsular Gneissic Complex are exposed in the north, especially north of Bharathapuzha river. The Khondalite group, which outcrops northeast of Malambuzha reservoir, comprises garnet-sillimanite gneiss and calc-granulite. Narrow bands of calc-granulite are exposed along the Walayar river bed. Numerous thin bands of calc-granulite associated with crystalline limestone and calciphyre have been observed in the area. Charnockite group is predominant in the west. This group comprises massive charnockite/gneissic charnockite, pyroxene granulite, pyroxenite and norite and magnetite quartzite amongst which massive charnockite/gneissic charnockite is the most widely distributed. Pyroxene granulite and magnetite quartzite occur as narrow bands. Thin impersistent segregations of pyroxenite and norite occur in the 'Palghat Gap'. The Charnockite Group is succeeded by the Migmatite Complex represented by hornblende-biotite gneiss and quartz-feldspar gneiss. These rocks occupy the eastern part and the 'Palghat Gap'. They are melanocratic and foliated. These rocks are intruded by pegmatites, quartz veins and gabbro and dolerite dykes. Basic intrusives, especially dolerite, have two distinct trends in the district; one being NW-SE, which is common throughout the State and the other NE-SW, seen in the northeastnorth of Attapady. In the westernmost part, south of Bharathapuzha, a few isolated occurrences of Warkalli sediments are noticed capping small mounds. The valleys are occupied by fluvial alluvium of Quaternary age. Lateritisation is widespread in the western region of the district.

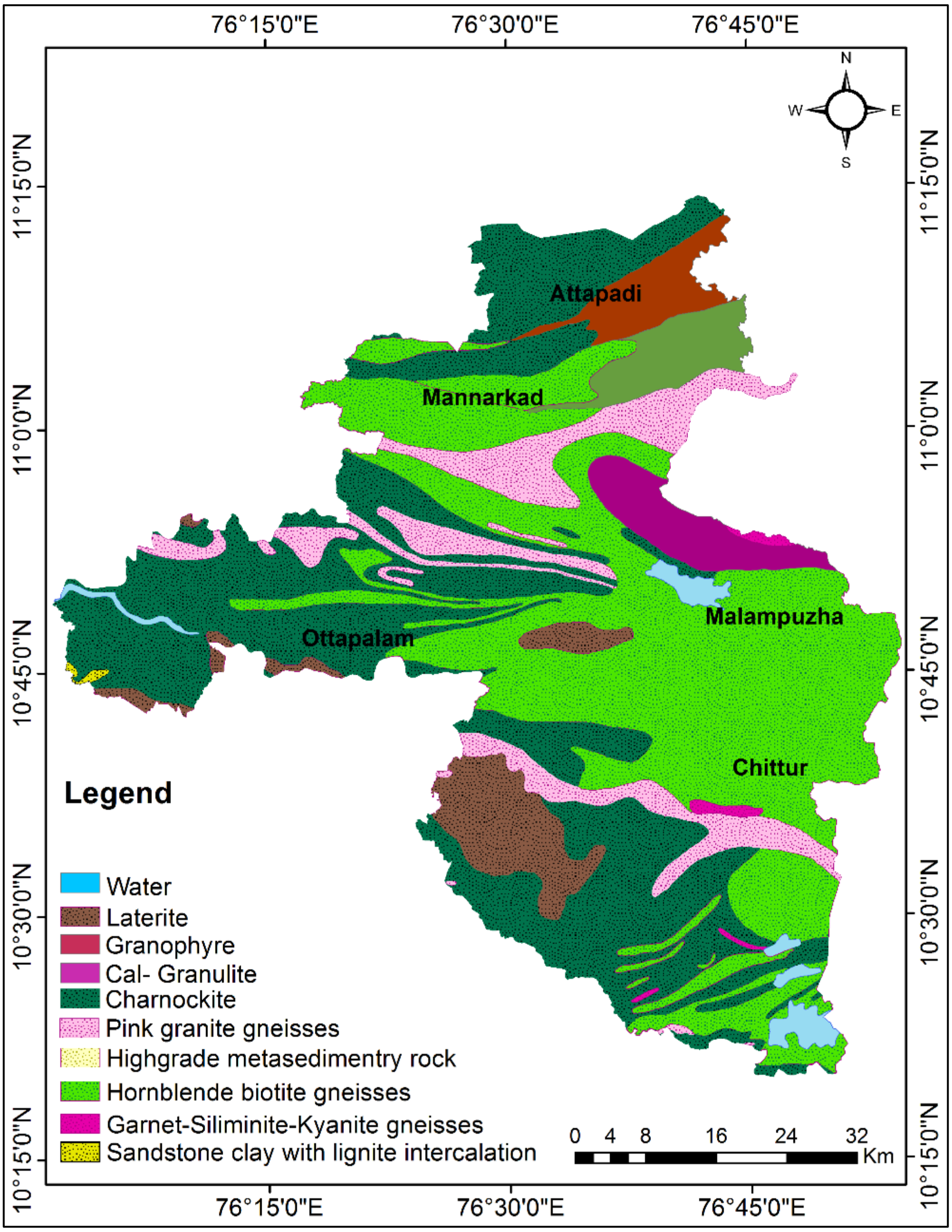

Figure 4.89: Geology of Plakkad District

(geology map modified after District Resource map, Kannur district, Geological Survey of India)

Soil types & Soil Characteristics

The soils in Palakkad district have been classified in the following types, based on the morphological features and physiochemical properties. Laterite soil, Virgin forest soil, Black cotton soil & Alluvial soil.

Laterite soil - Seen in major part of Ottappalam, Alathur, Chittur and Palakkad taluks. These are most predominant soil type in the midland and gap areas. Laterites on high grounds are more compact when compared to the low-lying areas.

Virgin Forest Soil - Seen in Mannarkad taluk and in forest areas. They are rich in humus and organic matter.

Black Cotton Soil - Seen in Chittur and Attapady Valley of the Mannarkad Taluk, which is used for the cultivation of cotton. They exhibit mud cracks and have high water retaining power.

Alluvial soils are found along the banks of Bharathapuzha and its tributaries. In the Valley portion Valley fill deposits composed of talus and scree material are observed.

Drainage and Irrigation

Bharathapuzha and Bhavani Rivers are the main two river system of the district. Of these Bhavani is east flowing and form a tributary of the Cauvery River. Bharathapuzha basin can be divided into 50 watersheds and 290 mini watersheds. Soil erosion is more in the upstream parts of the basin. Dendritic is the common drainage pattern. 75 % of the population is depending on surface water resources for their irrigation needs, mainly from Bharathapuzha, its tributaries and other water bodies. There are 12 reservoirs in the district associated with two major rivers and its tributaries viz - Parambikulam, Peruvaripallam, Thoonakadavu, Chulliyar, Pothundi, Moolathara, Meenkara, Walayar, Malampuzha, Gayathri, Kanjirapuzha and Mankulam. There are number of irrigation projects major and minor, existing in the district. The major projects are Malampuzha, Chittoorpuzha, Kuriar Kutty, Karapara, Kanjirapuzha and Attappady Valley Irrigation Project.

Hydrogeology

Groundwater occurs in all the geological formation from Archaean crystallines (hard rock) to Recent alluvium (soft rock). The entire district can be divided into three units based on hydrogeological information. 1) Valley fills/Alluvium 2) Laterite terrain and 3) Crystallines. Groundwater occurs in phreatic condition in the laterite, alluvium and weathered crystallines. It is in semi confined to confined condition in the deep fractured rocks

. Over dependence on groundwater for domestic, irrigation and industrial purposes in the district has led to the lowering of water table and water scarcity especially along the eastern parts. In most of the areas especially in eastern part of the district decline of water levels necessitates deepening of existing dug wells and putting deep bore wells thereby increasing cost of pumping and quality deterioration.

Rainfall

The district experiences humid type of climate. The district receives maximum rainfall during the south west monsoon followed by the north east monsoon. The other months receive considerably less rainfall. The temperature is pleasant from December to February. The annual rainfall varies from 1883 to 3267 mm based on long term normal. The district receives on an average 2362 mm of rainfall annually. Major rainfall is received during June to September in the southwest monsoon (71%). The western part of the district around Pattambi receives the maximum rainfall whereas in the rain shadow area of Chittur in the eastern part receives the minimum rainfall. The average annual maximum temperature is 32.30C and the average annual minimum temperature is 23.40.

Soil piping

This district has only sproradic occurrences of soil piping in the state. In fact, though minor, Palakkayam is one of the first discoveries of soil piping incident in the state. In Palakkad district majority of the area is occupied in the Palaghat Gap region where the gently planar topography with moderate rainfall conditions do not favour the formation of soil pipes. Only in areas located in the north and south borders in the Western Ghats soil piping could occur due to terrain conditions and comparatively high rain fall conditions.

Table 4.29: Piping locations in Palakkad district

Sl. No	**Name**	**Location**		**position**	**Status**	**Remarks**
		Latitude	**Longitude**			
1	Palakkayam	10.964245	76.554994	Populated region	Mature pipe	
2	Kottakunnu*	10.864883	76.307887	Populated region	Data SEOC-SDMA	Data SEOC-SDMA
3	Parachathi*	10.846688	76.731817	Populated region	Data SEOC-SDMA	Data SEOC-SDMA
4	Kuruvanpady*	11.032135	76.642977	Populated region	Data SEOC-SDMA	Data SEOC-SDMA

* data from SEOC-SDMA)

Prone areas

Only sporadic occarrances are reported from Palakkad. There four incidences reported from Palakkad district. As such there no severely affected area in the district. Whereas about 1365.36 sq.km is demarcated as probable area.

Recommendations for "Probable areas"

These are areas prone to soil piping or mildly affected regions. In these areas juvenile and younger pipes are developed as an indicator of soil piping processes happening there. In such places well sections and laterite cutting are to be examined in detail for pipes and caves. Geophysical surveys may not help in identifying juvenile and younger pipes as they are smaller in size. Water management practices and usage of lime powder in the soil will retard the soil piping activities. **Earth removal / mining, the depth must restrict well above (at least 1m) the lithomarge clay layer is recommended. In no case clay layer should be exposed for water to infiltrate.** Usage of hydrated lime along with the fertilizers should be encouraged to neutralise dispersive sodium in the clay. Dewatering is the best method to deescalate the formation of soil pipes. Overland flow may be diverted to a nearby nala without allowing to infiltrate in the affected zone will reduce pipe development.

Table 4.30: Areal extent of Soil piping affected regions in the district

District	Total area in sq.km	Affected area in sq.km	Probable area in sq.km	Non-affected area in sq.km	No. of soil pipes reported
Palakkad	4,478		1365.368	3,112.632	4

Conclusion

Only sporadic occurrances are reported from Palakkad district. There are no major incidences reported from this district. The total area of the district is 4478 square kilometres in which 1365.368 Km^2 is falling inside the Probable zone and the remaining 3112.632 km^2 is Non affected.

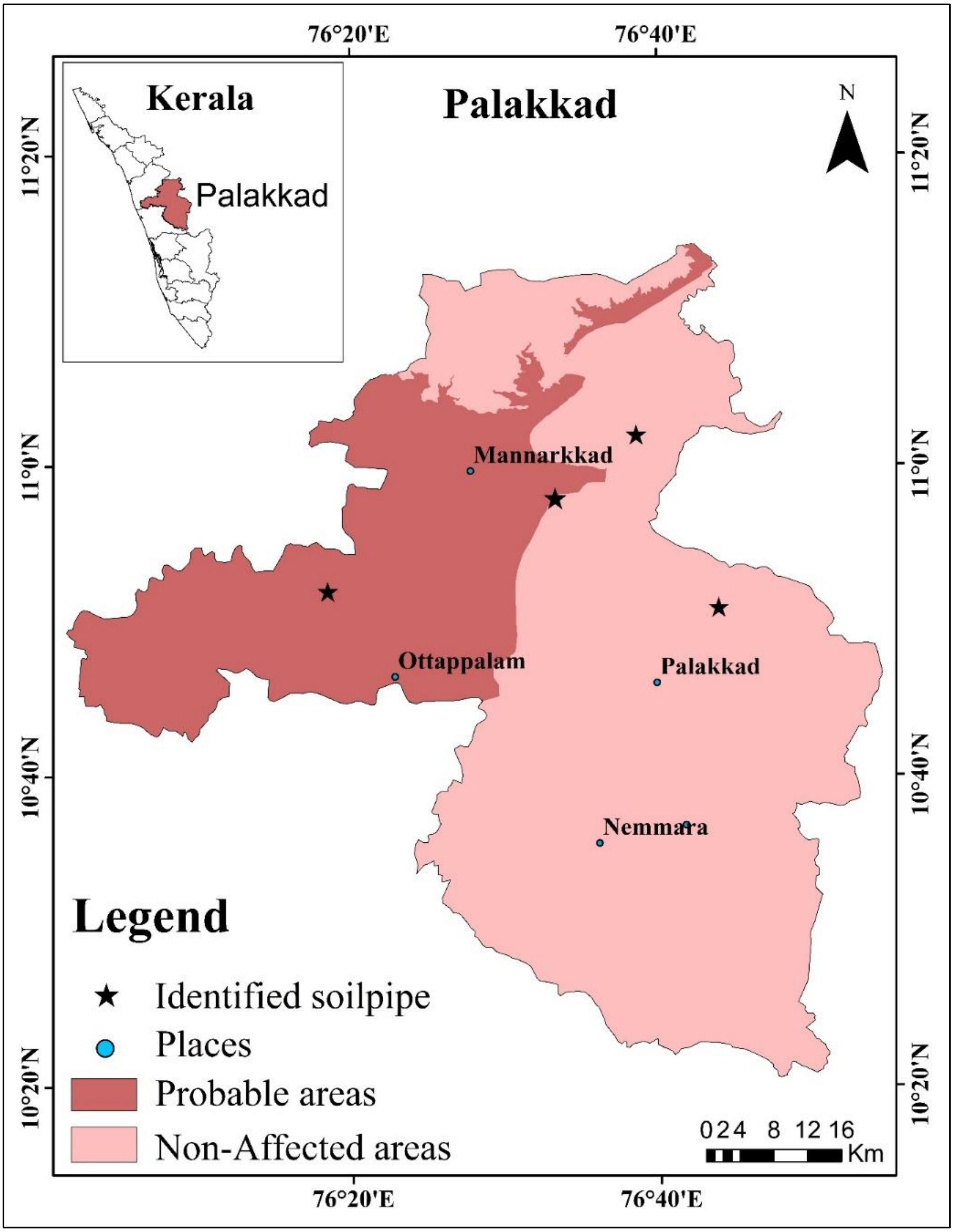

Figure 4.90: Zonation map of Palakkad District

4.9 Pathanamthitta

Pathanamthitta is a landlocked district in the southern part of Kerala, India, covering an area of 2642 sq.km located at 9°16′N 76°47′E. It is bordered by Kollam district in the south and Alappuzha in the west, Kottayam and Idukki districts in the north and Tamil Nadu state in the east and falling in parts of Survey of India degree sheet No.58 C and G. The district has two revenue divisions namely Thiruvalla and Adoor and consists of five taluks as Adoor, Kozhencherry, Thiruvalla, Mallapally and Ranni. The five taluks are having 8 blocks with only three municipalities - Pathanamthitta, Adoor and Thiruvalla. There are eight blocks viz Parakode, Pandalam, Elanthoor, Konni, Mallappally, Ranni, Koipuram and Pulikeezhum.

Geomorphology

The district is divisible into three distinct Physiographical units viz. the coastal plains in the northwest, the midland region and the high hills to the east. The coastal plain is characterised by fluvial landforms, which extend further west to Alappuzha district. The coastal plain in the western part of the area is restricted to Pulikeezh block of the district with an area of 82 sq. km. The mid land region in the western part of the district is of undulating terrain of low and broad valleys with some valleys becoming narrow close to the foothills. The major part of the area in this region is characterized by thick laterite cover. The midland region has elevations ranging from 30m to 300m. It is characterised by undulating topography with numerous small ridges, spurs and laterite interfluves, with moderate to gentle slope, intervened by narrow valleys. The hilly region to the east is relatively wide and occupies a major part of the district. The foothills of Western Ghats form the hill ranges in the eastern part of the district. The area is characterised by steep hills, narrow gorges and precipitous escarpments and is thickly forested. The hills that are either structural or denudational in origin are very steep with narrow summits. Some of the peaks in the east area are more than 150m high and form part of the Western Ghats. Devar Mala is the highest point in Pathnamthitta District.

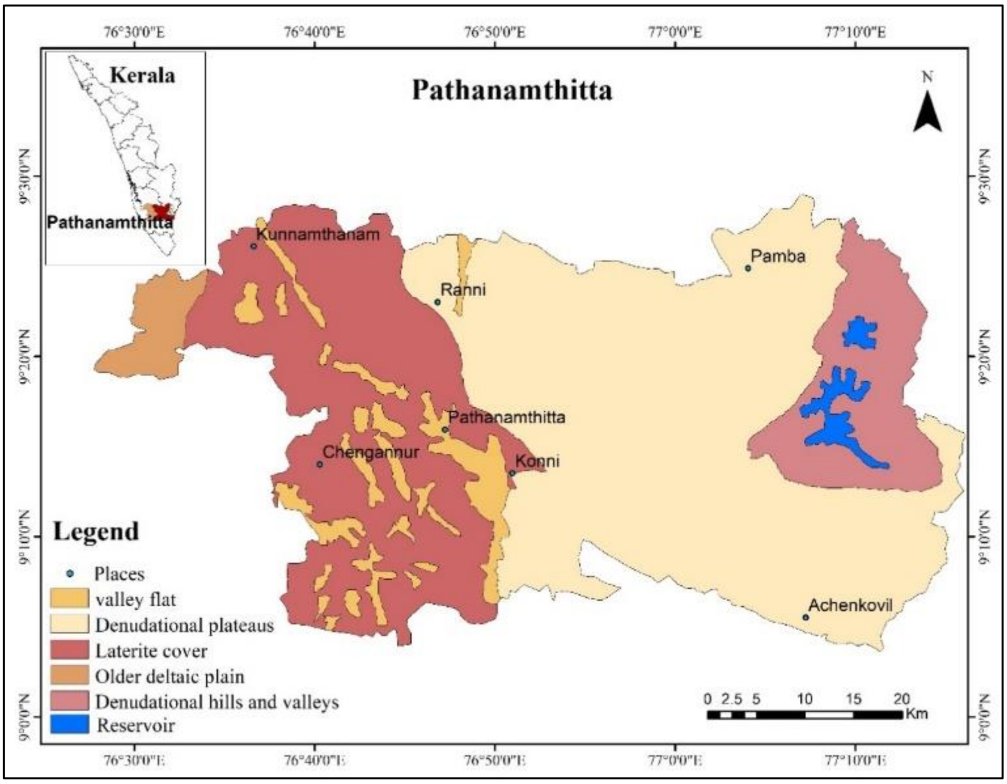

Figure 4.91: Geomorphology of Pathanamthitta District

(geomorphology map modified after District Resource map, Pathanamthitta district & Geological Survey of India)

Geology

The district forms part of the Precambrian metamorphic shield comprising mainly three geological units.

(i) Charnockite Group, Khondalite Group and Megmatite Complex of Archaean age.

(ii) Acid intrusive of Proterozoic age.

(iii) Rocks of Cenozoic age (basic intrusive, Neogene and Quaternary).

Charnockite group is the dominant formation of the area within which occur concordant, linear and lensoidal bodies of calc granulite and quartzite of Khondalite Group. The Charnockite Group comprises Charnockite (hypersthenes granite), pyroxene-granulite and cordierite gneiss. Charnockite is the dominant rock and its variants are charnockite gneiss, massive charnockite and hypersthenes-diopside gneiss. The rock is generally dark grey and crudely foliated. Cordierite gneiss occurs as impersistent bands within charnockite, while pyroxene granulite is seen as restates, mostly in the west. At places, charnockite is migmatised resulting in the formation of biotite gneiss, and garnet-biotite gneiss (Migmatite

Complex). These rocks are predominant towards south. The area witnessed a period of igneous activity during the Proterozoic as evidenced from the granite and syeno-granite (acid intrusive) bodies. Pegmaite and quartz veins traverse the older rocks parallel to the regional foliation. Basic igneous activity, probably of Late Mesozoic age, is evidenced from the dolerite and gabbro dykes cutting across the older rocks. These dykes have a general NW-SE trend. Warkalli sediment of Neogene age are exposed near Thiruvalla. Along the western margin, the basement and sedimentary rocks have been lateritised. The Quaternary sediment mostly of fluvial origin, are the v read with the “Geology of Kerala” which is given as Annexure 1 for better understanding of geological succession and stratigraphic sequence.

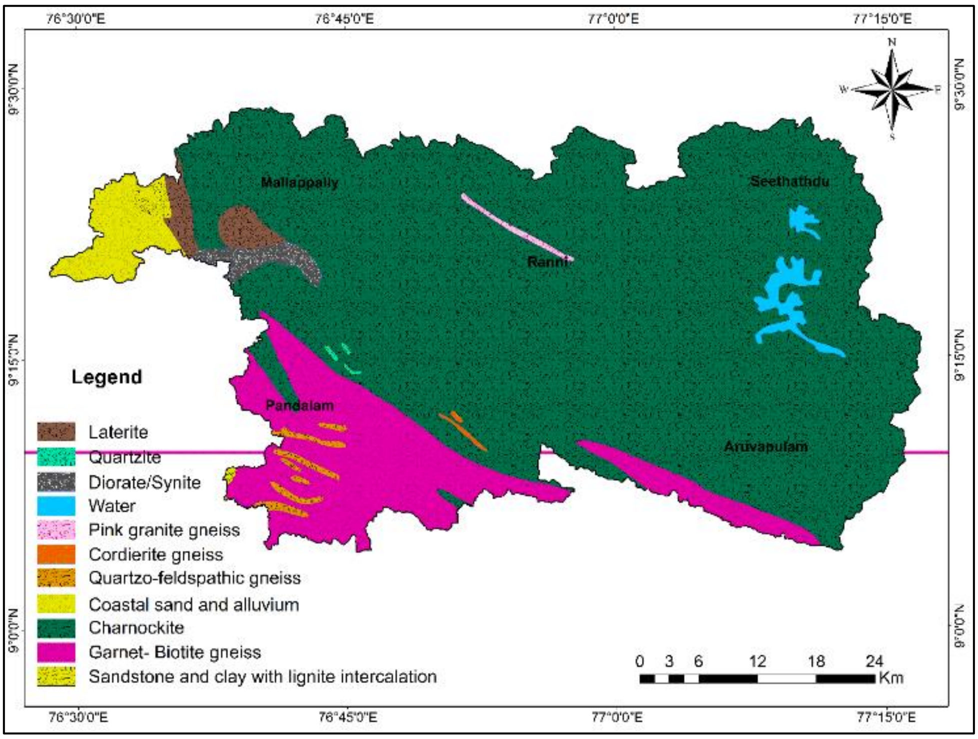

Figure 4.92: Geomorphology of Pathanamthitta Distrct

(geolmorphology map modified after District Resource map, Pathanamthitta district & Geological Survey of India)

Soil types

Based on the morphology, physical and chemical properties, the soils of the district are classified as Forest Loam, Lateritic, Brown hydromorphic, Riverine alluvium and Greyish Onattukara soils. The diversity of the parental rock, the climatic conditions and differential weathering has led to the formation of these different soil types. Forest loam is the product of weathering of the country rock under forest cover. Forest loamy soil is encountered in the eastern parts of the district, in major parts of Ranni and Konni blocks. Lateritic soil is the most widely occurring soil type in the district. This soil is the product of lateralization of the crystallines and sedimentaries under humid tropical conditions. Brown hydromorphic soil occurs mostly in valley portions in the midland area of the district. The soil is formed as a result of transportation and deposition of material from the adjoining hill slopes under impeded drainage conditions. Riverine alluvium occurs mostly along the banks of rivers and their tributaries. Greyish Onattukara soil is having very limited occurrence in the district and is restricted to the western parts of Pulikeezh block.

Drainage and Irrigation

The district is drained mainly by two rivers viz. Pamba and Kallada. The major tributaries of the Pamba River are Achenkovil, Manimala, Kakki, Arudai, Kakkad and the Kallar that drains through major part of the district. The Kallada River flows through the southern portion of the district. Both the Pamba and Kallada rivers are perennial with a drainage density of 0.30 km/sq.km and both are fifth order streams. These rivers with their tributaries exhibit a trellis pattern of drainage in the eastern portion of the hills, sub-trellis pattern in the middle and dendritic pattern in the western part of the district. Almost 57% of the district area is occupied by forest and only about 31% is the net area sown. Important crops are Coconut, Rubber, Paddy, Banana and Pepper. Though the total cropped area in the district is 1151 sq km, area sown more than once is restricted to 317 sq km. The irrigation facilities are confined to the valleys in the midland area. Only 2.2% of the district area has irrigation facilities i.e. 6119 hectares and groundwater irrigation is restricted to 1891 hectares only. A small part (600 hectares) of the command area of major irrigation project of Pamba falls in the district. The project uses the tail end water from the Sabirigiri hydroelectric project located in the upstream of Pamba River. Under minor irrigation schemes, surface water through lift irrigation and tanks and ground water through wells are utilised.

Rainfall

Wet type of climatic condition prevails in the district. The district receives an average rainfall of 3133.9 mm annually. The major rainfall contribution is from south-west monsoon season during June to September. Based on 1901-99 data, rainfall during south-west monsoon contributes nearly 56.8% to the annual rainfall. Followed by this season, the north-east monsoon season from October to December contributes about 21.7% and the balance 21.5% is received from the rainfall during January to May months. The eastern part of the district receives maximum rainfall in comparison with the western part. The area around Konni receives the highest rainfall and the area around Adoor receives the lowest.

Groundwater scenario

On the basis of groundwater potential the district is divisible into five zones: They are from east to west (i) Coastal alluvium: suitable for medium type tube wells, yield is up to 2 lps, occasionally the water is brackish; (ii) Midland: this area is underlain by thick laterite; it is suitable for dug wells; however, borewells are feasible along fractures, the yield upto 3 lps; (iii) area underlain by thin laterite/weathered zone: valleys abd topolows are good for open wells, bore wells are feasible along fracture planes; (ivA) foothills and highly undulating terrain; valleys can sustain domestic wells; fractures are potential but they are site specific and (v) mountaineous area: it is generally unsuitable for water development. Valleys where thick alluvium is seen can sustain dug wells for domestic use. Pathanamthitta district is underlain by geological formations ranging in age from Archaean to Recent. About 96% of the area of the district is underlain by crystalline rocks of Archaean age, which have under gone weathering and lateralization. The Archaean group of rocks comprises charnockites and gneisses along with minor occurrence of pyroxene granulites and are traversed by pegmatite and quartz veins. There are several basic dykes of doleritic and gabbroic composition cutting across the crystalline rocks. The crystalline rocks have undergone several phases of deformation and have suffered intensive fracturing and dislocations. The regional strike of foliation in charnockites and gneisses is generally NW – SE with variation from NNW – SSE to WNW – ESE with steep southerly dips ranging between 60o and 80o. There is one major shear zone – the Achenkovil Shear trending in NW – SE direction along which the Achenkovil River flows. The rest of the area in the north-western parts of the district is underlain by Tertiary sediments equivalent to the Cuddalore and Rajahmundry sandstones of east coast with a capping of Recent Alluvium. Lithologically these rocks are composed of carbonaceous clay with lignite, sandstone and grit with alternate lenses and beds of variegated clays.

Table 4.32: Piping locations in Pathanamthitta District

Sl. No	Name	Location		position	Status	Remarks
		Latitude	Longitude			
1	Pathanamthitta	9.373	76.782	Less populated region	Young Pipe	

Prone areas

The Pathanamthitta district is sporadically affected district in Kerala. There is one major incident occurred in the district near Pamba valley. The district could highlight with Probable zone and Non-affected zone.

Table 4.31: Areal extent of Soil piping affected regions in the district

District	Total area in sq.km	Affected area in sq.km	Probable area in sq.km	Non-affected area in sq.km	No. of soil pipes reported
Pathanamthitta	2,642		881.756663	1,760.24	1

In Pathanamthitta district there is no severely affected areas but 881.75 sq.km probable areas have been identified. This area was demarcated with help of the number of juvenile pipe formations and topography.

Recommendations for "Probable areas"

These are areas prone to soil piping or mildly affected regions. In these areas juvenile and younger pipes are developed as an indicator of soil piping processes happening there. In such places well sections and laterite cutting are to be examined in detail for pipes and caves. Geophysical surveys may not help in identifying juvenile and younger pipes as they are smaller in size. Water management practices and usage of lime powder in the soil will retard the soil piping activities. **Earth removal / mining, the depth must restrict well above (at least 1m) the lithomarge clay layer is recommended. In no case clay layer should be exposed for water to infiltrate.** Usage of hydrated lime along with the fertilizers should be encouraged to neutralise dispersive sodium in the clay. Dewatering is the best method to deescalate the formation of soil pipes. Overland flow may be diverted to a nearby nala without allowing to infiltrate in the affected zone will reduce pipe development.

Conclusion

The total area of the district is 2642 square kilometres in which 881.756663 Km^2 is falling inside the Probable zone and the remaining 1760.24 km^2 is Non affected.

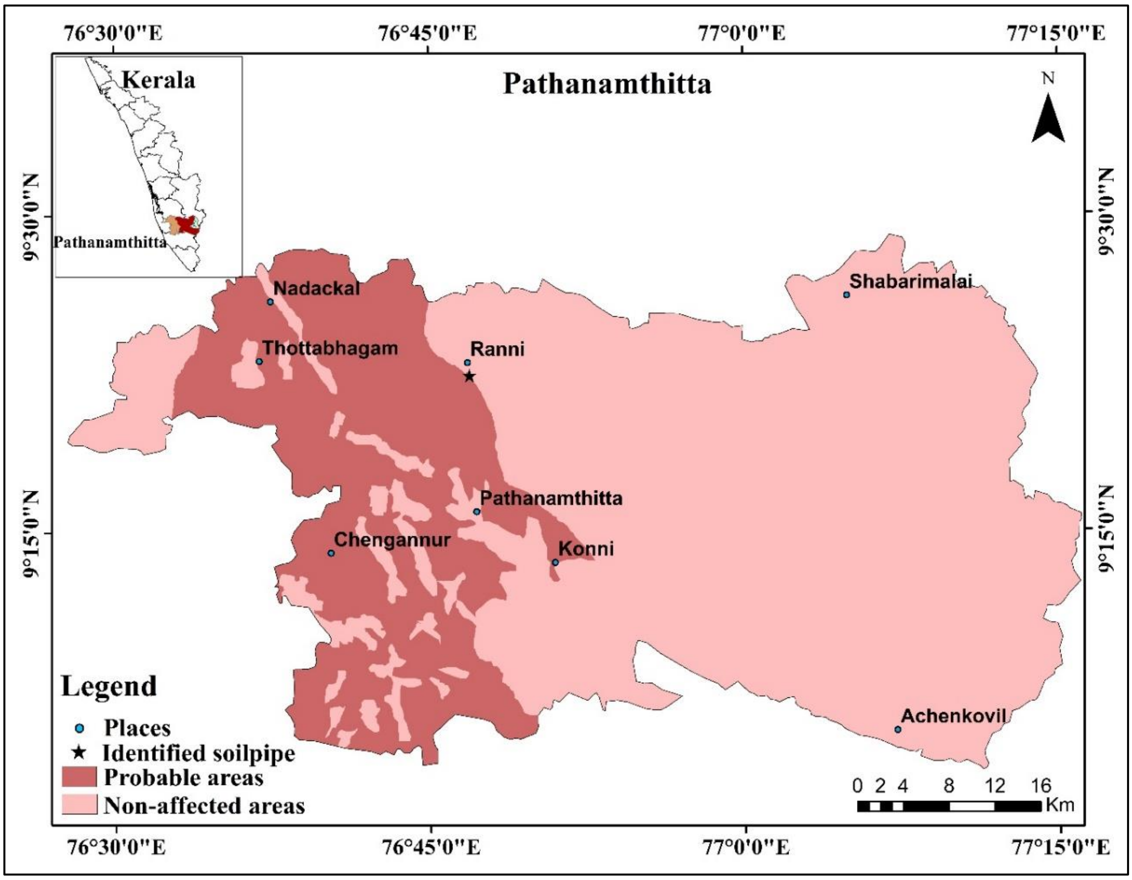

Figure 4.93: Zonation map of Palakkad District

4.10 Ernakulam

Ernakulam district occupies the Central part of Kerala state spanning an area of about 3,068 km, and is bound by Thrissur district on the north, Idukki on the east and south east, Kottayam and Alappuzha districts on the south and the Lakshadweep Sea on the west Ernakulam district lies between North latitudes 090 47' 13" and 100 10'44" and East longitudes 76^0 10' 05" and 77^0 05' 24.

For administrative purposes, the district is divided into two revenue divisions and seven taluks. Muvattupuzha revenue division with Muvattupuzha as its headquarters comprises of 43 villages belonging to Kunnathunadu, Muvattupuzha and Kothamangalam taluks, while Kochi division with its headquarters at Kochi consists of 71 villages of Aluva, Paravur, Kochi and Kanayanur taluks. There are 14 community development blocks, 88-gram panchayats, eleven municipalities and one corporation in the district.

Geomorphology

The district can be broadly divided into three physiographical units (1) the Coastal plains or low lands (2) the mid lands and (3) the high lands. The general elevation of the coast is less than 8.0 m above the mean sea level and that of the midlands is between 8.0 and 76 m above the mean sea level. The highlands are having the general elevation above 76 m with the maximum of around 504 m above the mean sea level. The entire taluks of Kochi and Paravur and major parts of Kanayannur fall under the coastal plain. The municipalities of Paravur and Tripunithura the township of Kalamasseri and the corporation of Kochi are located in the coastal plains. All the other taluks except the north-eastern parts of Kunnathunad taluk fall under the mid land area. The high land belt of the district is the Malayattoor reserve forest in Koovappady block, which covers about 9% of the area of the district.

The Coastal belt is dotted with a host of islands ranging from largest Vypin islands of length 27 km to, smaller islands like Mulavukad, Vallarpadam, and Willington Island etc. The western coast of Vypin has the longest beach in Kochi namely, the Cherai Beach. The northern tip of Vypin (Munambam) has the largest fishing harbour in Kochi namely, the Munambam Fishing Harbour. Vypin is home for harbour related industrial establishments like, the SPM project of the Kochi Refineries, and the Puthuvyp LNG Terminal.

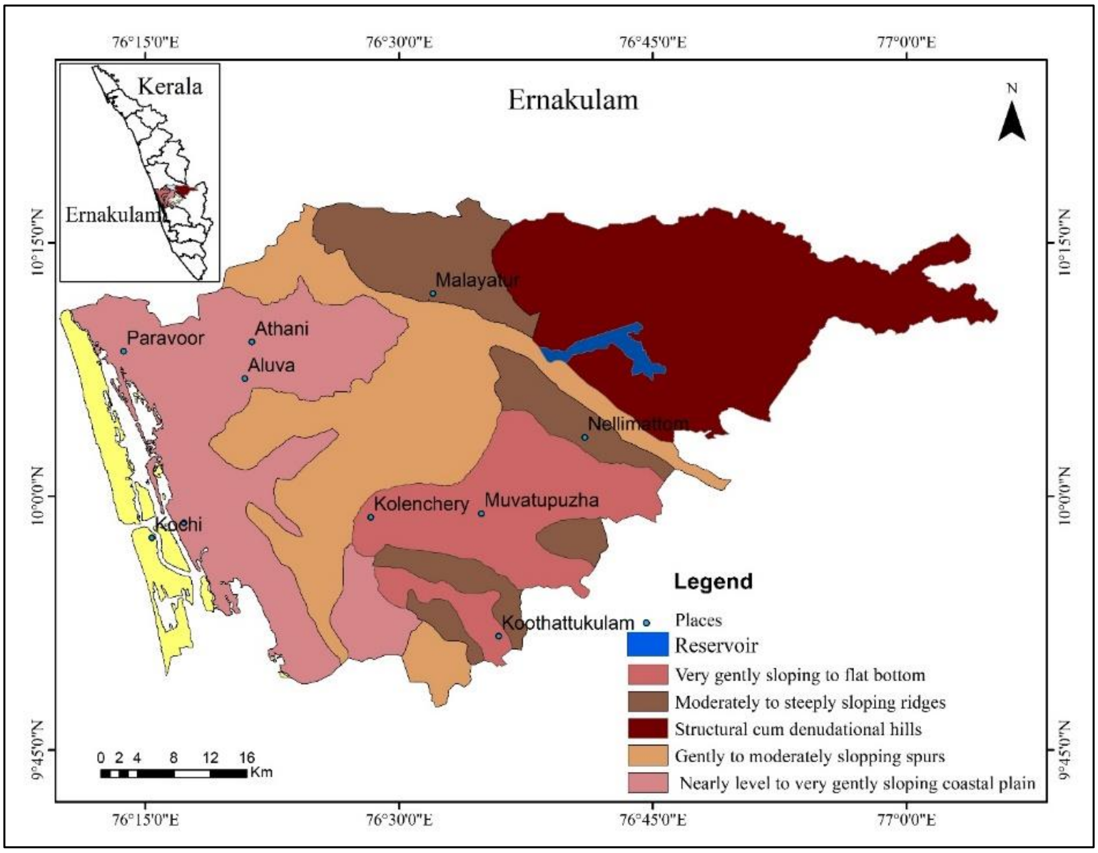

Figure 4.94: Geomorphology of Ernakulam District

(geomorphology map modified after District Resource map, Pathanamthitta district & Geological Survey of India)

Rainfall

The district experiences heavy rainfall during southwest monsoon season followed by northeast monsoon. During the other months the rainfall is considerably less. March, April and May are the hottest months. December to February is the coldest months. The district receives an average rainfall of 3359.2 mm annually. The annual rainfall ranges from 3233 to 3456 mm at different places of the district. The rainfall is less in the western part of the district and gradually increases towards the east. Maximum rainfall is received around Neriamangalam area in the eastern part where the normal annual rainfall is found to be 5883 mm, while Kochi, which is in the western part receives around 3233 mm rainfall annually. South-west monsoon season contributes nearly 67.4% of total rainfall of the year, followed by the north-east monsoon which contributes nearly 16.6% and the balance of 16% is received during the month of January to May as summer showers.

Geology

The district can be divided into two distinct lithological units are discernible in the area. The eastern part is occupied by hard rocks representing Precambrian metamorphosed rocks while the coastal tract in the west is covered by soft rock or the unconsolidated coastal alluvium. Major part of the district is occupied by charnockite and migmatite groups of rocks of Precambrian age. The charnockite group is composed of pyroxene granulite, magnetite quartzite and charnockite. Charnockite, which is very widely distributed, is coarse grained, granulitic and dark coloured. Pyroxene granulite and magnetite quartzite occur as linear bands. Calc-gneiss and quartzite of khondalite group are the oldest rocks of the area and they are seen as linear lensoidal bodies within the charnockites.

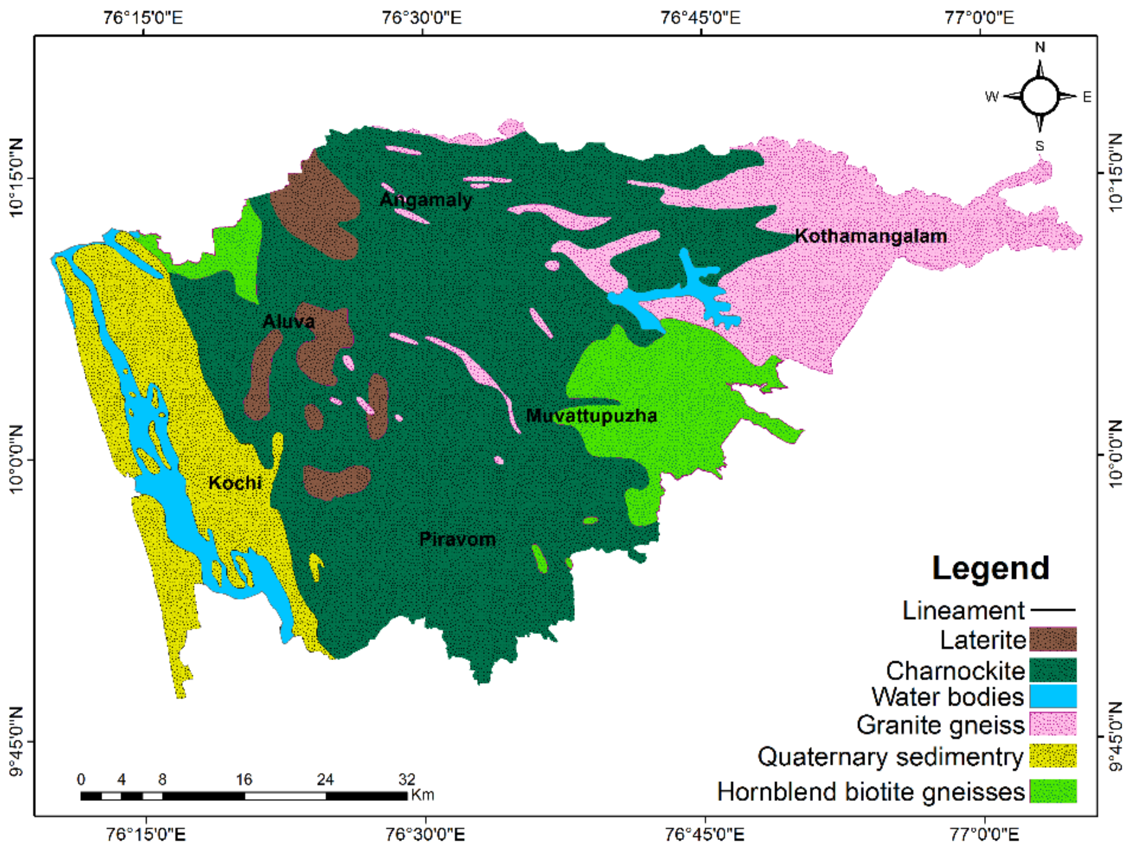

Figure 4.95: Geomorphology of Ernakulam District

(geomorphology map modified after District Resource map, Pathanamthitta district & Geological Survey of India)

The migmatite group includes biotite gneiss and quartzofeldspathic gneiss which are next to charnockite in abundance. These older rocks are intruded by both acid (syenite) and basic (gabbro and dolerite) intrusive. Patchy outcrops of Warkalli beds, consisting of pebble bed, grit, friable sandstone and variegated clay is seen in the western part around Edappalli, kalamasseri areas. Both the Warkalli beds as well as the basement rocks are subjected to intense lateritisation, which is confined to the midland region only. The coastal tract is covered by Quaternary sediments like beach sand, palaeo-beach ridge deposits (sand), flood plain deposits (sand, silt, clay) and tidal deposits (clay, mud)).

Soil types

The soils in Eranakulam district have been classified in the following types, based on the morphological features and physiochemical properties 1. Lateritic; 2. Hydromorphic saline; 3. Brown hydromorphic; 5. Riverine alluvium and 6. Coastal alluvium.

Lateritic soil is the most predominant soil type of the district. In Muvattupuzha, Kothamangalam, Kunnathunadu and parts of Aluva taluks lateritic soil is encountered. These soils are well drained, low in organic matter and plant nutrients. Small patches of hydromorphic saline soil are encountered in the coastal tracts of the district in Kanayannur and Cochin taluk. The tidal backwaters contribute to the salinity of the soil. Brown hydromorphic soil is the second most prevalent soil type of the district and they are encountered in valley bottoms. The soil is enriched in clay content and plant nutrients. Riverine alluvium is restricted to the banks of rivers and their tributaries. They are composed of sandy to clayey loam and are enriched in plant nutrients. In Cochin taluk and the western parts of Paravur and Aluva taluk coastal alluvium is encountered and is composed of sand and clay.

Drainage and Irrigation

The district is drained by the Periyar and its tributaries in the north and Muvattupuzha River in the south. Periyar, the longest river in the state with a total length of 244 km originates from the cardamom hills of the Western Ghats flows in a Northerly direction initially and then in North-west direction as it flows through Idukki district before entering Ernakulam district at Neriamangalam. In the district, the river takes almost a straight-line course roughly in a North Western direction and at near Bhuthathankettu dam, it is joined by major tributaries Cheruthoni and Idamalayar. Further downstream at Aluva, the river bifurcates into two: the Marthandavarma and the Mangalapuzha branches. The Mangalapuzha branch joins Chalakkudy river and empties into the Lakshadweep sea at Munambam, and the Marthandavarma branch flows southwards, through the Udhyogamandal area and joins the Cochin backwater system (part of Vembanad Lake) at Varapuzha. The Muvattupuzha River is formed by the confluence of Thodupuzha River, Kaliyar River and Kothamangalam River at Muvattupuzha. These rivers originate from the Thodupuzha reserve forest. The Muvattupuzha River takes a rough east-west course up to

Ramamangalam and thereafter it flows towards south leaving the districts south of Pazhur. In the upstream areas the drainage pattern in both Periyar and Muvattupuzha basin are trellis to sub-trellis. In the lower reaches dendritic pattern of drainage is observed.

Hydrogeology

Groundwater generally occurs under phreatic conditions in weathered and fractured crystalline rocks, laterites and unconsolidated coastal sediments. It occurs under semi-confined to confined conditions in the deep-seated fractured aquifer of the crystallines rocks and Tertiary sediments. The weathered zone in the crystallines below acts as good storage for groundwater. Based on nature of formation, the aquifer can be classified into hard rock aquifers and sedimentary aquifers.

Hard Crystalline Formation

Groundwater occurs under phreatic conditions in the shallow weathered portions whereas it occurs under semi confined to confined condition in the deep-seated fractures of the crystalline formation. The hard rock formations in general lack primary porosity. The water is stored in the secondary pores developed as a consequence of weathering in fractures, fissures and joints etc.

Warkali Beds

The Warkali beds of the Tertiary formation are found to constitute aquifers of semi-confined to confined aquifers. In Ernakulam district, they are least extensive and are restricted to the southern coastal belt with thickness thinning out from South to North from 106.7m at chellanum in south to less than 13 m in north at Panangad. The Warkali aquifers are essentially composed of fine to medium grained sand.

Vaikom Beds

The Vaikom beds are potential confined aquifers and are generally separated from the overlying potential Warkali formations by confining Quilon beds except in the northern portion of the district where the Vaikom beds are underlying the Coastal alluvium or Laterite. The Vaikom beds are composed of thick sequence of coarse to very coarse sand, gravel and pebble beds intercalated with ash, grey clay and carbonaceous clay. They extent North to South in the coastal belt with thickness increasing from 18 m at Panangad in north to 151 m at Chellanum in south.

Laterite

The laterite is vastly occurring in the mid land areas of the district by weathering of the crystalline formation and also at depth in the sedimentary formation in the coastal belt. Along the coastal belt, they are discontinuous and are found to be eroded at places and generally they occur as a horizon between the recent alluvium in top and Warkali beds or Vaikom beds below at depth ranging from 20 to 56 m bgl. The laterites are highly porous and permeable.

Alluvial Formations

The alluvial formations occurring in the coastal belt are constituted by sand, silt, clay of the lagoonal and back water deposits, beach deposits and the river/flood plain deposits in mid land areas. The thickness ranges from less than 1m to 54 m at Kandakadavu in south.

Table 4.33: Piping locations in Ernakulam District

Sl. No	Name	Location		Position	Status	Remarks
		Latitude	Longitude			
1	Kothamangalam	10.05612	76.626265	Populated region	Small pipe	
2	Mulanthuruthy	9.900003	76.389911	Populated region	Small pipe	

Prone areas

The Ernakulam district is identified by 2 soil pipes through stacking, scouting and geophysical investigations over the district. As the identified incident having some particular conditions in formation this can be happened in the similar other areas with same favourable conditions. The juvenile pipes which triggers the tunnel erosion are noticed apart from the district. The district could highlight with Probable zone and Non-affected zone. This can help in giving awareness and management in land use in future. Mulanthuruthy and Kothamangalam are two areas piping cound been seen. In Mulanthuruthy Juvenile pipes along the railway cutting was saturated by these juvenile pipes which lead in to collapse of the cutting in to the track. In Kothamangalam in Paingottur -Kadavur area a well-developed subsidence occurred due to soil piping. Pies could be seen at the bottom of the well-formed due to soil piping

Table 4.34: Areal extent of Soil piping affected regions in the district

District	Total area in sq.km	Affected area in sq.km	Probable area in sq.km	Non-affected area in sq.km	No. of soil pipes reported
Ernakulam	3,068		722.8555	2,345.14	2

Recommendations for "Probable areas"

These are areas prone to soil piping or mildly affected regions. In these areas juvenile and younger pipes are developed as an indicator of soil piping processes happening there. In such places well sections and laterite cutting are to be examined in detail for pipes and caves. Geophysical surveys may not help in identifying juvenile and younger pipes as they are smaller in size. Water management practices and usage of lime powder in the soil will retard the soil piping activities. **Earth removal / mining, the depth must restrict well above (at least 1m) the lithomarge clay layer is recommended. In no case clay layer should be exposed for water to infiltrate.** Usage of hydrated lime along with the fertilizers should be encouraged to neutralise dispersive sodium in the clay. Dewatering is the best method to deescalate the formation of soil pipes. Overland flow may be diverted to a nearby nala without allowing to infiltrate in the affected zone will reduce pipe development.

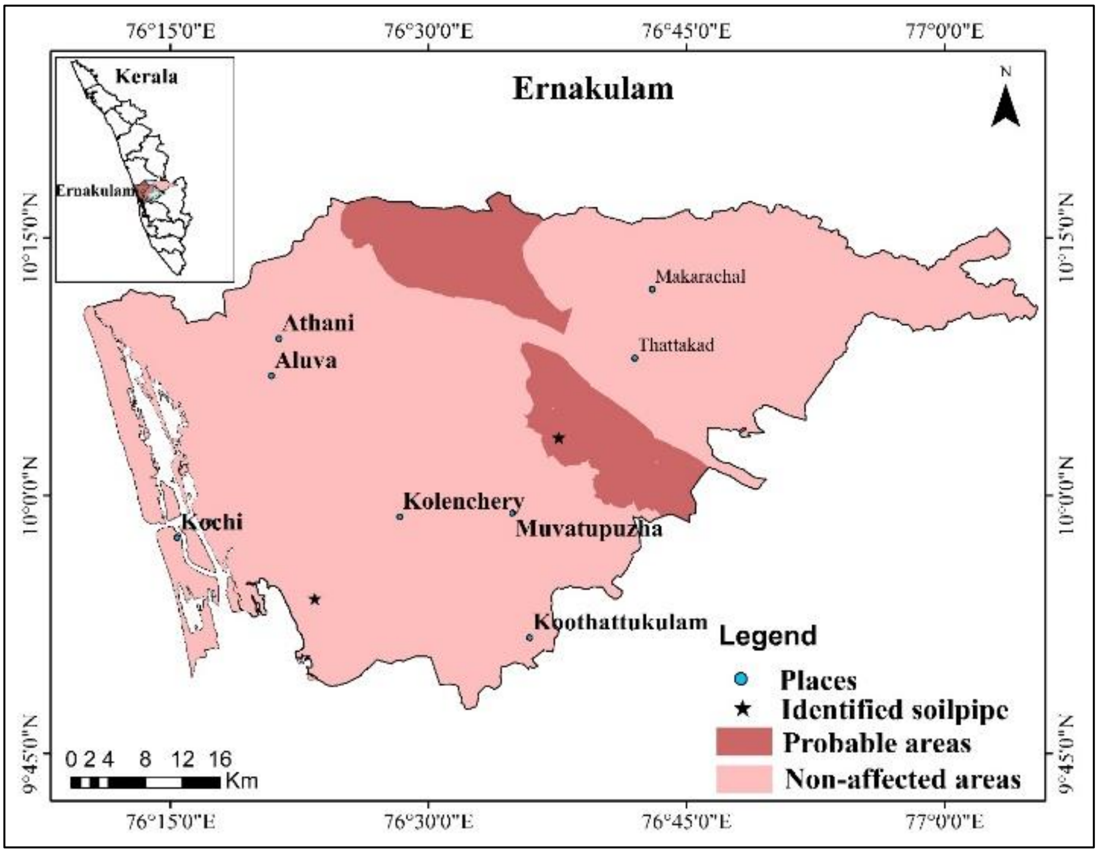

Figure 4.96: Zonation map of Ernakulam District

Conclusion

The total area of the district is 3068 square kilometres in which 722.8555Km^2 is falling inside the Probable zone and the remaining 2,345.14 km^2 is Non-affected. Mulanthuruthy and Kothamangalam are two areas where soil piping is affected.

4.11 Thiruvananthapuram

Thiruvananthapuram District is the southernmost district of the coastal state of Kerala situated between north latitudes of 8°17':8°47 and east longitudes 76°41':77°16' and covers an area of 2,192 square kilometres. The district is bounded by Kollam and Pathanamthitta districts in the north, Tirunelveli and Kanniyakumari districts in the east and south and the Arabian Sea (Lakshadweep Sea) in the west. The district falls in Survey of India degree sheets 58 D and H. The Western Ghats, which form the eastern boundary of the district as well as the State, are comparatively closer to the coast in this district, than in other parts of the State.

Administratively, the Thiruvananthapuram district can be broadly grouped into 4 taluks viz., Thiruvananthapuram, Neyyatinkara, Chirayinkil and Nedumangad consisting of 11 blocks, 84 panchayats, 4 municipalities and 1 corporation.

Geomorphology

Physiographically, the district has a very rugged topography which is present in the coastal city of Thiruvananthapuram and towns like Vizhinjam, Varkala and Edavai. Three distinctive topographic units can be identified in the district from west to east – (i) lowland (coastal plains), (ii) midlands and (iii) highlands. The low land or coastal plain are seen in areas between Thiruvananthapuram and Anjego and between Vizhinjam and Poovar. The occurrence of crystallines at Veli, Kovalam and Vizhinjam and laterite cliff sections at Poovar and Varkala are conspicuous land forms within the coastal plains which is quite narrow and the maximum width is 5 kms. 60% of the district comes under the midland unit which is occupied by valleys and hillocks making an undulating topography. The highly rugged terrain in the eastern part of the district represents the highland where the elevation goes upto 1869m above mean sea level (Agasthya mala). Among the 4 taluks, only Neyyatinkara Taluk stretches through all the three regions. Chirayankeezhu and Thiruvananthapuram taluk lies in the midland and lowland region, while the Nedumangad taluk lies in the midland and highland region. The landforms of the district are carved out by a combination of marine, fluvial and denudational processes. The landforms can be categorised into three units viz. lowlands, midlands and highlands. Lowlands are formed by a combination of marine and fluvial activities and represented all along the coastal plain, which stretches a length of 78 km, and are characterised by gently sloping terrain. The main landforms are sandy and rocky beaches, coastal cliff and sand ridges. Major portion of the district was formed by denudational activities, which includes both midlands and highlands. The area with an elevation of 7.5 to 75 m above msl with low or moderate slope (< 25%) can be categorised as midlands. The landforms formed over Tertiary sediments are generally flat toped hillocks. Terrain with basement rocks like charnockite and khondalite has an undulating to rolling topography and is characterised by gently undulating spurs. The thick coloumn of lateritic soil in this region supports growth of coconut and rubber. Landforms with steep slopes and elevation of more than 75 m above msl can be grouped under highland. This highly rugged terrain is characterised by thin veneer of forest soil mostly occupied by thick vegetation with NW- SE trending ridges, narrow valleys with steep slopes, rocky cliff and escarpments, which mainly occurs in the eastern part of the district. The area between high hills and midland is characterised by moderate to steep sloping ridges.

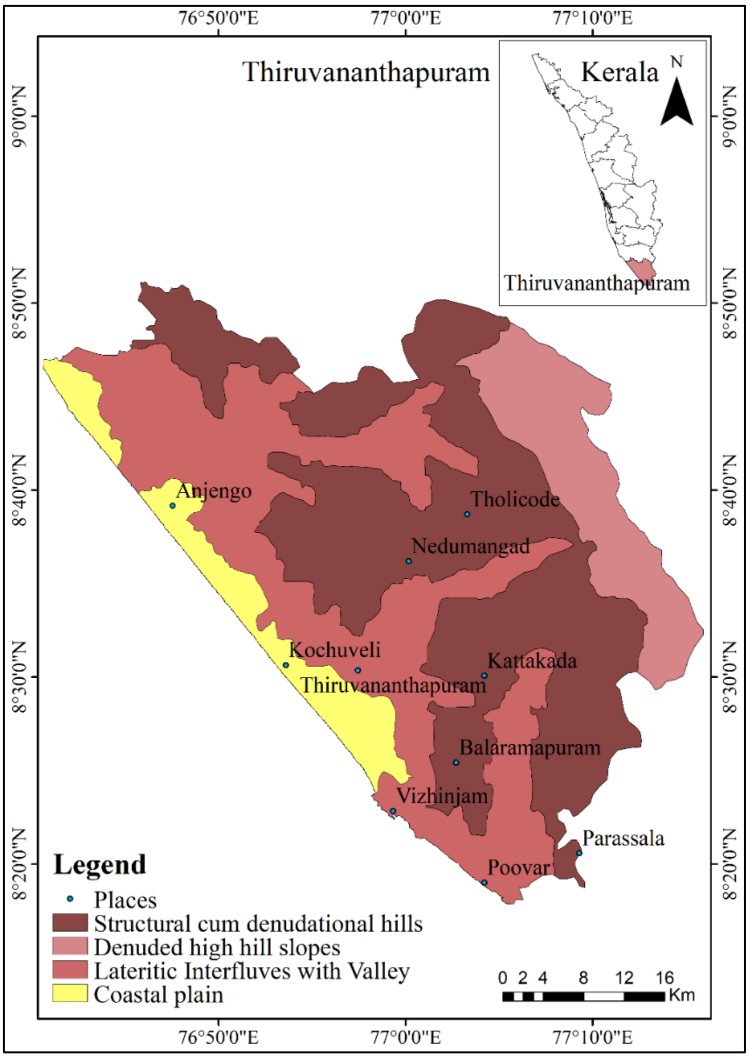

Figure 4.97: Geomorphology of Thiruvananthapuram District

(geomorphology map modified after District Resource map, Pathanamthitta district & Geological Survey of India)

Geology

The district can broadly be divided into two geological divisions viz. (i) the eastern part represented by the Archaean crystalline rocks and (ii) western coastal fringe occupied by Tertiary and Quaternary sediments (Figure 4.98). The Archaean crystalline rocks comprise Khondalite Group, Charnockite Group and Migmatite Group. Khondalite Group is composed of garnetiferous biotite-sillimanite gneiss, with occasional bands of calc-granulite and quartzite, and constitutes the major rock type. Charnockites are acidic to intermediate in composition. Irregular patches of khondalite, veins of pegmatite and quartz are seen within the charnockite. Pyroxene granulite occurs within the khondalite as thin discontinuous lenticular bands conformable to the foliation planes.

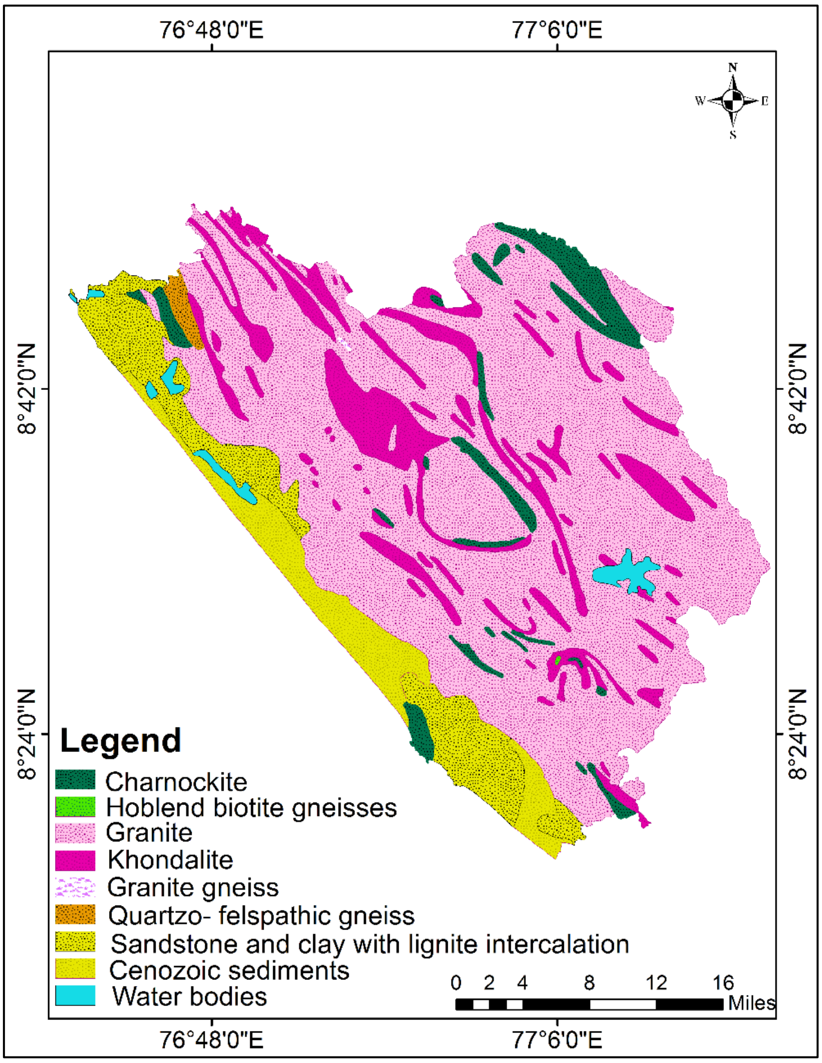

Figure 4.98: Geology of Thiruvananthapuram District

(geology map modified after District Resource map, Pathanamthitta district & Geological Survey of India)

Migmatites are evenly distributed in the central part of the district as narrow zones within garnetiferous sillimanite gneiss. All these rocks are intruded by a number of dolerite dykes, but their distribution is restricted to the midland region of the district. Thin and impersistent veins of pegmatite and quartz veins are very common, and many of the pegmatites have gained importance because of their gemstone (chrysoberyl) content. Sedimentary formation of Mio-Pliocene age (Warkalli beds) occurs as detached patches unconformably overlying the crystalline rocks, along the coastal tracts. Quaternary Formation includes pebble beds (with ferruginous sandstone and bands of clay), coastal sands and alluvium. The Tertiaries and the basement rocks of the midland are extensively lateritised

Soil types

The major types of soil found in Thiruvananthapuram district are red loams, coastal alluvium, riverine alluvium, lateritic soil, brown hydromorphic soil and forest loam. Most predominant soil in the district is lateritic soil and is mainly found along the midland, which is mostly reddish brown to yellowish red in colour. Brown hydromorphic soils are mostly confined to valley bottom in the midland and low-lying areas of coastal strip which exhibits characters like gray horizon, mottling streaks, hard, organic matter deposition, iron and manganese concretions etc. Red loamy soils are highly porous, friable and low in organic matter, which is mainly seen in southern part of the district. The lowland area is dominated by alluvium, which are sandy loam to clayey loam in texture. Coastal alluvium is mainly found along the coastline while river alluvium is found along the banks of rivers and their tributaries. The eastern part of the district is characterised by fluvial loams, which are the products of weathering of crystalline rocks. These soils are dark reddish brown to black with loam to silty loam texture. As per the recent survey by ICAR ten types of soil are present in the district. Thiruvananthapuram district has a reserve forest area of 495.145 sq. kms and vested forest area of 3.534 sq. kms spreading over three ranges, viz., the Kulathupuzha range in the north, Palode range in the middle and the Paruthipalli range in the south. These forests may be broadly classified into three categories, namely, (a) southern tropical wet ever green forests, (b) southern tropical and semi ever green forests and (c) southern tropical moist deciduous forests.

Rainfall and climate

The district has a climate that borders between tropical savanna climate and tropical monsoon climate. In a broad sense, it can be said that the district experiences a tropical monsoon climate. The annual variation of mean air temperature at Thiruvananthapuram district is from 21o C to 34oC. The humidity is high and rises about 90% during the monsoon season. The average annual rainfall of the district is 2035mm. It is significant that the district gets benefits of both monsoon – southwest monsoon and northeast monsoon. The district is characterised by very high precipitation which is spread over very few wet days and a long dry season (December- May) and a marked gradient from the eastern hilly region to the sea rapidly re-conveying the rainfall back to the sea through short, fast, west flowing rivers. Thiruvananthapuram is the first city along the path of southwest monsoon and gets its showers by end of May/beginning of June. The district also gets rain from receding northeast monsoon which hits the district by October. The southwest monsoon contributes more than the northeast monsoon to the total rainfall in the district. The dry season sets by December in the district. December, January and February are the coldest months while March, April and May are hottest. The normal rainfall of the district is 2001.6 mm.

Drainage

The important rivers draining the district are Neyyar, Karamana, Vamanapuram, Mamom and Ayirur, which form three main drainage basins such as Neyyar, Karamana and Vamanapuram basin. The Neyyar River with catchments of 497 sq. km. originates from Agasthya hills at about 1860 m above msl and joins Lakshadweep Sea near Poovar which is perennial with dendritic drainage pattern. Neyyar Irrigation Project constructed across this river irrigates southern parts of Thiruvananthapuram district and adjoining Kanyakumari district of Tamil Nadu state. The other major river of the district is Karamana River, which is also perennial in nature and exhibits dendritic pattern, which originates from Chemmunjimalai at 1717 m above msl and joins the Lakshadweep Sea near Pachallur with a total catchment area of 703 sq. km. The dam constructed across the Karamana River at Aruvikkara and Peppara provides drinking water for the Thiruvananthapuram City. Vamanapuram, Mamom and Ayirur River form the Vamanapuram drainage basin with a total catchment area of 867 sq. km. It also originates from the Chemmunji Malai at about 1860 m above mean sea level and flows in a north-westerly direction and then to south-west before emptying into the sea. A number of backwaters are seen along the western parts of the district viz. Poovar Kayal, Poonthura Kayal, Vellayani Kayal, Veli Kayal, Kadinamkulam Kayal, Anchuthengu Kayal and Edava-Nadayara Kayal. Among this only Vellayani Kayal is freshwater lake which is supplying water to major portion of Nemom block. Though the district houses the state capital, the industrial development in the area is negligible. The land use pattern shows that major portion of the area is under agriculture, which is followed by forest. 64.27% and 22.7% respectively are the distributions of agriculture land and forest in the district. Irrigation is mainly by surface water. The total area irrigated by canals is 36.31 sq.

km., which is about 53.7% of the total irrigated area. The land utilisation pattern shows that net area sown is 1338.62 sq. km. while area under forest cover is 498.61 sq. km. Agriculture constitutes the main source of economy and about 15 types of crops are being cultivated in the district. Paddy is the main dry land crop. The crop is mainly grown in rain fed condition excepting along the Ayacut area of Neyyar Irrigation project, which falls in Neyyatinkara Taluk. Coconut is one of the most important crops of the district which are mainly grown along the coastal places and the slopes of midland hills. Rubber, tea, cardamom, coffee is grown on the higher contour area of midland and Western Ghats. Other crops, which are grown in the district, are banana, pepper, cashew and arecanut.

Groundwater scenario

The drainage pattern in the gneissic country is sub-parallel to trellis. Three major westflowing rivers viz., Kallar Ar, Karamana Ar and Neyyar Ar along with their tributaries drain the area. The Neyyar Ar flows through the central part, more or less in a southerly direction. The Chit Ar, the main tributary of Neyyar joins it near Ottashekharamangalam. The Karamana Ar flows through the western part of the area with southerly course and joins sea near Pachallur. The Kallar, a major tributary of Karamana Ar flows in the southerly direction and passes through Thiruvananthapuram city. The eastern margin of the district coincides with a water divide. Thiruvananthapuram district is characterised by the outcrops of crystalline rocks of Archaean age in the eastern part and is overlain by sedimentary formations ranging in the age from Miocene to Recent along the western coast. Based on the water bearing properties, the entire district can be broadly classified into crystalline formation and sedimentary formation. The crystallines include khondalites, charnockites, migmatites and intrusives occur at shallow or deep with or without fractures. Whereas sedimentary formation comprises the (1) Recent alluvium that occur along the coastal plain and in the valleys and are mainly composed of sand and clay (2) Tertiary formation such as Warkali, Quilon and Vaikom beds and (3) laterites which occur as a capping over crystallines. Groundwater occurs under water table and semi-confined conditions. Groundwater potentiality is fairly good along the coastal tract, which is underlain by laterite, sandstone and beach ridges. The Archaean terrain acts a poor aquifer, having low to poor possibility of groundwater.

Prone areas

The Thiruvananthapuram district is identified by only 1 soil pipe through stacking, scouting and geophysical investigations over the district. As the identified incident having some particular conditions in formation this can be happened in the similar other areas with same favourable conditions. The juvenile pipes which triggers the tunnel erosion are noticed apart from the district. The total area of the district is 2,192 square kilometres in which 12.35527 acres (0.05 sq km) land at Vattapara region has been affected.

Table 4.35: Piping locations in Thiruvanathapuram District

Sl. No	**Name**	**Location**		**position**	**Status**	**Remarks**
		Latitude	**Longitude**			
1	Venjaramood	8.59302778	76.95888889	Populated region	Mature pipe	Subsidence

Remarks

Since there is only one incident occurred in the district it was not possible to zone the district in terms of soil piping vulnerability. However, the incident that has occurred in Vattappara covered an area of 0.05 sqkm.

Recommendations

Even though a major has occurred in the district there is not much concern about soil piping problems in the district.

Figure 4.99: **Soil pipe in Vattappara**

4.12 Kottayam

The district is famous for the largest inland water body in the State i.e., Vembanad lake. Panoramic backwater stretches, lush paddy fields, highlands, hills and hillocks, extensive rubber plantations, places associated with many legends and a totally literate people have given Kottayam District the enviable title: The land of letters, legends, latex and lakes. The city is an important trading center of spices and commercial crops, especially rubber. Kottayam is also called as "Akshara Nagari" which means the "city of letters" considering its contribution to print media and literature. Kottayam Town is the first town in India to have achieved 100% literacy (a remarkable feat achieved as early as in 1989). Kottayam is situated between Western Ghats and the Vembanad lake and has an area of 2208 sq. km. Ernakulam, Idukki, Alappuzha and Pathanamthitta districts lie respectively to the north, east northeast, west, southwest and south of the district. Kottayam lies between latitudes 9 ° 15’ and 10° 21’ and longitude 76° 22’ and 77° 25’. Kottayam is one of the districts in Kerala which has no sea coast. The Kottayam district is divided into two revenue divisions viz. Kottayam and Pala. There are five taluks in the district viz Kottayam, Changanacherry, Vaikom, Meenachil and Kanjirapally. There are four municipalities Kottayam, Changanacherry, Pala and Vaikom and 11 blocks namely Madapally, Pallom, Ettumanoor, Kaduthuruthy, Vaikom, Uzhavoor, Lalam, Erattupetta, Kanjirapally, Vazhoor and Pampady. The total number of grama panchayats and revenue villages are 75 and 95 respectively. In 2011, Kottayam had population of 1,979,384 of which male and female were 970,140 and 1,009,244 respectively. There was change of 1.32 percent in the population compared to population as per 2001. The total population living in rural area is 1,413,773 and urban area is 565,611 and indicates that the people living in rural population is 71.42 %. The density of the population is 896 per sq.km.

Geomorphology

The district is divided into three well defined physiographical units from west to east viz. (i) western low-lying fluvial landscape (coastal plain) followed by (ii) laterite capped midland region with moderate to gently sloping spurs towards east and (iii) the structurally controlled high hills and steep ridges in the east. A major part of the district is undulating peneplain. Because of a thick soil cover cash crops are widely cultivated. The low-lying fluvial landscape which is the flood plain of Muvattupuzha and Pamba rivers has thick fluvial sediments derived from the catchment area of these rivers. This fertile land is ideal for paddy cultivation. The high hills to the east have thin forest soil cover which supports luxuriant growth of plantation crops. The lowland is the area with an elevation of less than 7.5 m amsl which covers around 398.4 sq km and midland area having an elevation of 7.5 to 75 m amsl covers around 1287.75 sq km and the highland area with an elevation of more than 75 m amsl covers around 508.8 sq km and are mainly found in the eastern part of the district. The low lands are seen along the western portion of Vaikom, Changanassery and Kottayam taluks whereas the Meenachil and Kanjirapally taluks fall in the highlands. Major part of Kottayam, Changanassery and Vaikom taluks fall in the midland region. Around upper Kuttanad (part of Changanassery taluk) particularly Pallom, Ettumanoor and Kaduthuruthy the ground elevation is generally 1 to 1.5 m below mean sea level.

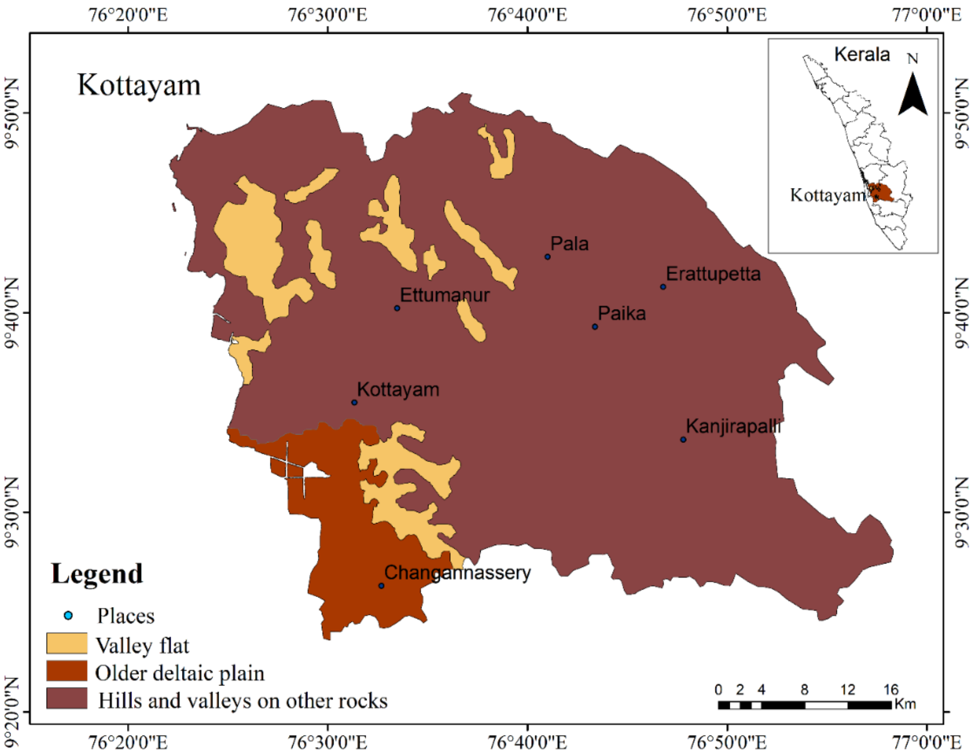

Figure 4.100: Geomorphology of Kottayam District

(geomorphology map modified after District Resource map, Pathanamthitta district & Geological Survey of India)

Geology

This area shows a very interesting correspondence between the major rock classes and their physiographic expression. The east comprises Precambrian metamorphic rocks and forms hilly ground. The central part is a low plateau, where Tertiary sediments containing lignite occur. These are followed by further west by a low plain, which is underlain by Quaternary Formations, fluvial or partly marine. The Charnockite Group dominates in areal distribution with charnockite, charnockite gneiss and diopside gneiss occupying the major part. Pyroxenen granulite (with hornblende granulite), magnetitie quartzite and cordierite gneiss occur as concordant bands within charnockite. The linear bands of quartzite (Khondalite Group) are the oldest rock of the area. Biotite geniss (composite gneiss) representing the Migmatite Complex has a limited areal extent, west of Ettumanur and along the eastern boundary. Three major granite bodies are emplaced in the district, two along the southwest and other in the east. Numerous dolerite and gabbro dykes trending NW-SE traverse the older basement rocks in the central and eastern parts. A prominent gabbro dyke extends from north to south with a NNW-SSE trend. Tertiary sediments comprising sandstone, clay with lignite intercalations are confined to the west and they occur as small patches, especially as capping on hillocks. Both the Archaean and Tertiary rocks are lateritised. Quaternary alluvial deposits occur to the west. They have been classified into various morphostratigraphic units, based on their environment of formation, as Guruvayur Formation (palaeo-marine), Periyar Formation (fluvial) and Viyyam Formation (fluvio-marine).

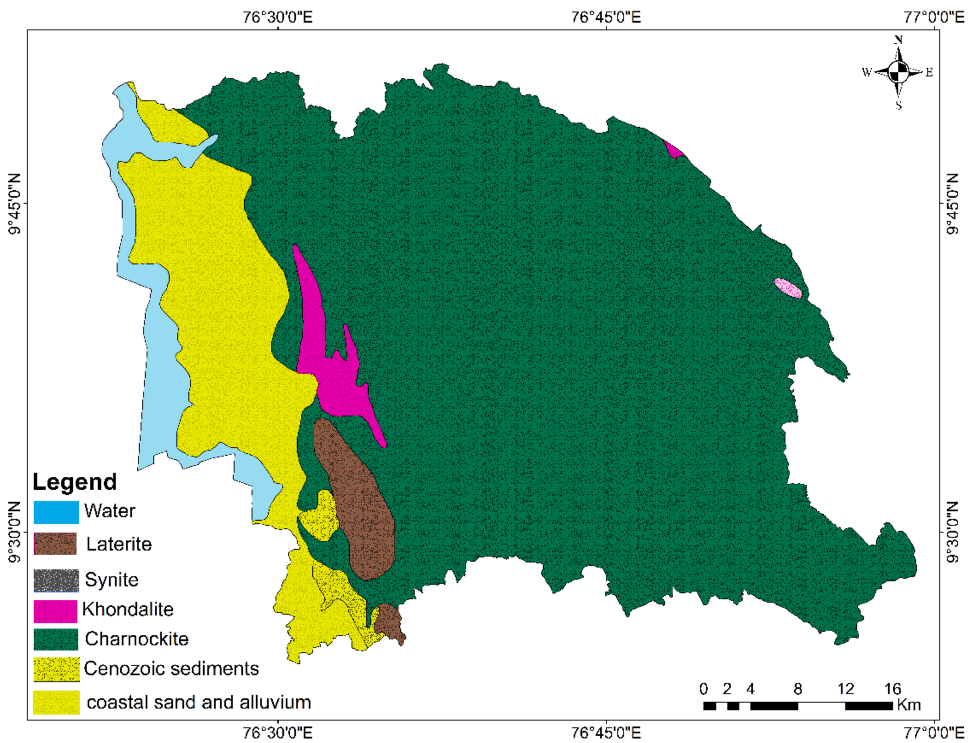

Figure 4.101: Geology of Kottayam District

(geology map modified after District Resource map, Pathanamthitta district & Geological Survey of India)

Soil types

The soil types occurring in Kottayam district can be broadly grouped into four types on the basis of their physico-chemical properties and morphological features. They are (a) Lateritic soil. (b) Riverine alluvium, (c) Brown hydromorphic, and (d) Forest loams. The lateritic soil is the predominant soil type, which covers almost the entire midland areas of the Katya district. The surface soil is mostly reddish brown to yellowish red in colour and the texture ranges from gravelly loam to gravelly clay loam. Heavy rainfall and high temperature prevalent in the area are conducive to the process of formation of this soil type. It is well drained and the presence of organic content is low. This soil is poor in nitrogen, phosphorous and potassium. It is acidic in nature with a pH value ranging from 5.0 to 6.2. Riverine alluvium the occurrence of these soils is restricted along the river courses and their tributaries. They show wide variation in their physico-chemical properties depending on the nature of the alluvium that is deposited and the characteristics of the catchments area drained by the river. They are very deep soils with surface textures ranging from sandy loam to clay loam. These soils are characterised by moderate amount of organic matter, nitrogen and potassium. Presence of mica flakes has been observed in the alluvial soils. Brown hydromorphic soil These soils are mostly confined to valley bottoms between undulating topography in the midland and in low-lying areas. They have been formed as a result of transportation and sedimentation of material from adjoining hill slopes and also through deposition by local streams. These soils are very deep and brownish in colour and exhibiting wide variation in physico-chemical properties and morphological features. The surface soil texture varies from sandy loam to clay. Their pH value ranges between 5.2 and 6.4 and are acidic in nature. Forest loam These soils are the products of weathering of crystalline rocks under forest cover. They are occurring in the eastern hilly areas. These are dark reddish brown to black in colour. The surface texture varies from loam to silt loam. They are characterised by a surface layer very rich in organic matter. Generally, they are acidic, rich in nitrogen and their pH ranging from 5.5 to 6.3.

Rainfall

The normal rainfall of the district is 2931 mm based on 1901-1999 data and the major contribution of rainfall is during South West monsoon followed by the North East monsoon. The analysis of rainfall data reveals that the distribution of rainfall increases from west to east. The highest rainfall recorded at Pala while the lowest recorded at Ettumanur. The annual rainfall ranges from 2435.9 to 3755.2 mm and the average annual rainfall of the district is 3169.28 mm. In general, the district has wet type of climate and four seasons are seen in this district.

Drainage and Irrigation

The major rivers in the district are the Meenachil River, the Muvathupuzha River and the Manimala River. The Meenachil River flows through Meenachil, Vaikom and Kottayam taluks.

The total catchment area of Meenachil River is 1272 sq km and is formed by several streams originating from the Western Ghats in Idukki district. The Poonjar river join at Erratupetta, the Chittar River join at Kondur and the Payapparathodu join at Lalam. Finally, the river confluences with Vembanad Lake. The Muvattupuzha River originates from Idukki district flowing mostly through vaikom taluk and joins with Vembanad Lake. The Manimala river flows through Kanjirapally and Chanaganacherry taluks. The Chittar joins it on its course further down the west as it flows towards Alappuzha district. There are no major irrigation projects in this district, however, the Meenachil medium irrigation project is having a net ayacut of 9960 hectares and a catchment area of 155 sq. km. The minor irrigation is by tanks, dug wells and bore wells etc.

Groundwater scenario

Geohydrologically the area is divisible into six zones based on groundwater potential. Groundwater occurs under water table conditions in alluvium, laterites and weathered mantle of the crystalline rocks whereas in the deep fractured crystalline rocks the groundwater occurs under semi confined to confined conditions.

There are four types of hydrogeological units encountered in the district viz., Crystallines (shallow & deeper), Tertiary sediments, Laterites and Alluvium.

The Kottayam district is not affected by any major soil piping incidents so far but some areas are likely to be happen in future as they are reported by juvenile type pipes. The slope and land use and other geomorphological and geological features are likely to happen in certain areas.

Soil piping

Kottayam district has not reported any major land subsidence due to soil piping. However, the areas adjacent to Idukki districts in areas of manimala and meenachilar catchments juvenile pipes are observed. At present there is no field evidence suggestive of soil piping problems in the district. Hence zonation in terms of soil ping vulnerability is not attempted here.

Conclusion

Since there are no major incidents reported the zonation of the district in terms of vunerability is not attempeted. Since the field evidences are lacking there is not much to be concerned about soil piping in this district.

(This is conclusion is based on December 2019 data set)

4.13 Kollam

Kollam or Quilon, an old sea port town on the Arabian coast, stands on the Ashtamudi lake. It lies between North latitudes 80 45’ and 90 07’ and East longitudes 760 29’ and 770 17’. It has a geographical area of 2412 sq. km. Kollam District is located on the southwest part of Kerala State and extends from Lakshadweep Sea to the Western Ghats and is bordered by Trivandrum district on the South and Alleppey and Pathanamthitta districts in the North and Tirunelveli district of Tamil Nadu State in the East and Lakshadweep Sea in the west. It has a maximum length of 75 kms in the E_W direction and maximum width of 45 kms in the N-S direction. Kollam District which is a veritable Kerala in miniature is gifted with unique representative features - sea, lakes, plains, mountains, rivers, streams, backwaters, forest, vast green fields and tropical crop of every variety both food crop and cash crop, so called 'The Gods Own Capital'. and falls in parts of Survey of India Toposheets 58C, D, G and H. The Quilon district is divided both on geographical and functional basis for purposes of general administration. Geographically it is divided into Revenue Divisions. Kollam is administratively divided into 6 taluks. They are Kollam, Karunagappally, Kunnathur, Kottarakkara, Punalur and Pathanapuram, which are subdivided into 104 villages.

Geomorphology

Physiographically, the district can be divided into three distinct units from west to east viz. the coastal plains, the midlands and the eastern highland regions. The coastal plains with an elevation ranging between 0-6 m amsl occur as narrow belt of alluvial deposits parallel to the coast. It has a maximum width of 90kms in the north and gradually narrows down to less than 0.5kms towards south. It is nearly level to very gently sloping terrain depicting depositional landforms like strandlines (palaeo-beach ridges), flood plain and tidal flats. The coastal plain has a number of back waters known as kayals in Kerala – the prominent being the Ashtamudi kayal, Paravur kayal, Panmana kayal and the Sasthamkotta kayal. Among these the last one is a fresh water lagoon, while the others are brackish. To the east of coastal belt is the midland region having a rolling topography with elevations ranging from 20m to around 300m. The midland area is characterised by rugged topography formed by gently to moderately sloping spurs, moderately to steeply sloping ridges, flat and domal hills with intervening narrow valleys and broad valley floors. The midland regions show a general slope towards the western coast. To its east is the high land region. Athe hills have steep slopes and narrow and small summits. Highest peaks along the eastern boundary are 1200 to 1500m high. Major parts of the catchment of river Kallada and Ithikara fall within this unit. This unit occupies the maximum area of the district. The

Western Ghat fringes is bounded by 300 to 600 m contours. The highest elevation is noticed at Karimalai (1758 m amsl).

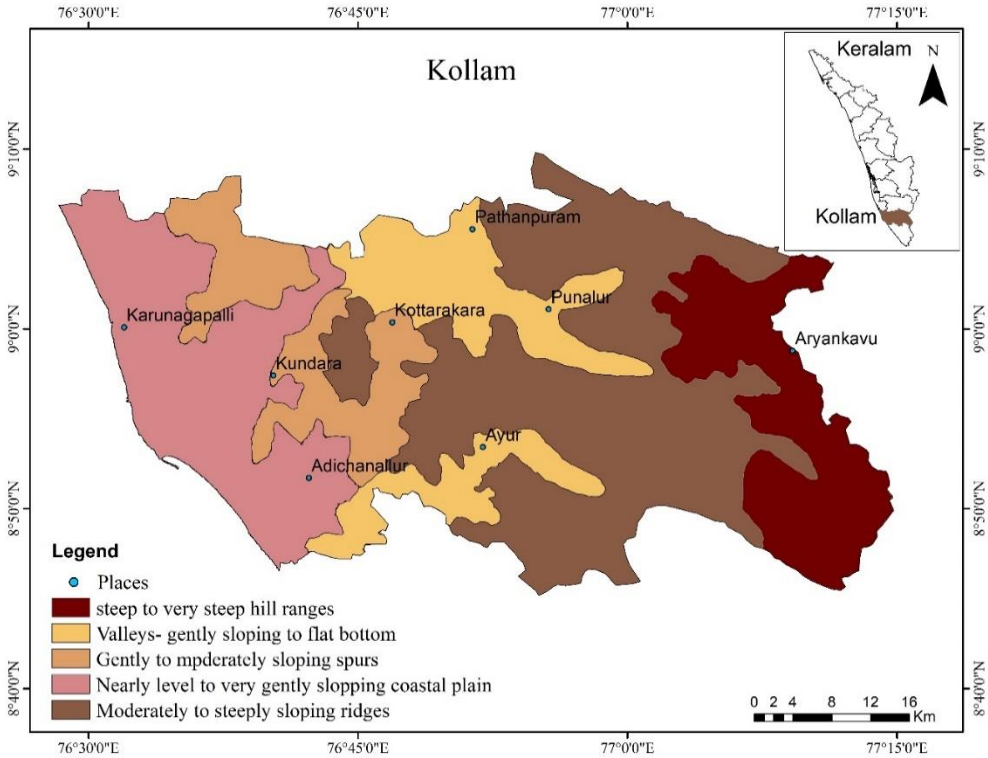

Figure 4.102: Geomorphology of Kollam District

(geomorphology map modified after District Resource map, Pathanamthitta district & Geological Survey of India)

Geology

The district can be broadly divided into three geological provinces – the westernmost Quaternary alluvial deposits followed by a narrow N-S zone of late Tertiary sediments and the easternmost Precambrian metamorphic. The Precambrian metamorphic are represented by Khondalite, Charnockite and Migmatitie groups. They are intruded by younger basic dykes and overlain by Tertiary and Quaternary sediments. High grade metamorphic rocks of Khondalite Group include calc-granulite, quartzite and garnet-biotite-sillimanite gneiss with or without graphite. Thin lenticular bands of calc-granulite occur within charnockite and migmatite. The Khondalite paragneiss tends to occur as linear bodies towards the middle and western part of the district. The Charnockite Group consists of pyroxene granulite, cordierite gneiss and hypersthenes-hornblende granite gneiss (charnockite). It mostly occurs as concordant bands and lenses of varied dimensions in Khondalite and migmatite with a diffused contact. It grades into gneiss. Generally, it is garnetiferous near the contact with the gneiss. The rock shows granoblastic texture and is mostly intermediate to acidic. Pyroxene granulite occurs as thin, discordant, lenticular patches, within migmatite, and is concordant with the para gneiss. Cordierite gneiss is found as impersistent bands and lenses within garnet-biotite gneiss and is confined to the contact with gneiss and charnockite. It displays xenoblastic gneissose texture and consists of varying proportions of cordierite, plagioclase, microperthite, quartz, biotite, hypersthenes, garnet and hornblende. Near Punalur, there is a small body of dunite. The Migmatite Complex comprising garnet-biotite gneiss and quartzo-feldspathic gneiss are the major rock units of the aea and they are traversed by the pegmatite and aplite veins.

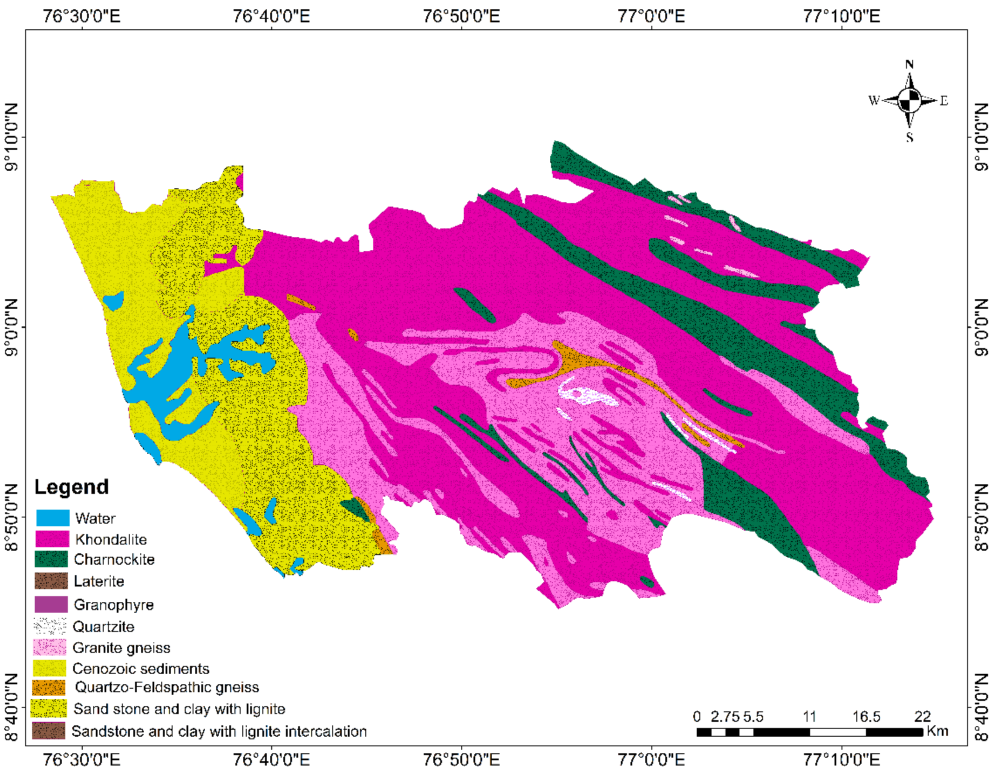

Figure 4.103: Geomorphology of Kollam District

(geology map modified after District Resource map, Pathanamthitta district & Geological Survey of India)

The rocks of the Migmatite Comples are widely distributed and interlayered with rocks of Charnockite Group. Garnet-biotite gneiss has a larger areal distribution and is characterised by the presence of biotite foliae and concentration of garnet in layers. Bands and lenses of quartzo-feldspathic gneiss occur within it. Granite gneiss of Peninsular Gneissic Complex occurs as small lenses towards the east. All the older rocks are intruded by basic intrusive of doleritic composition having a general NW-SE trend. Towards west, the rocks of Archaean age are uncoformably overlain by sedimentary rocks of Mio-Pliocene age. Two distinct sequence of sediments are noticeable. A lower marine sequence (Quilon Formation) represented by fossiliferous limestone and marl and an upper non-marine sequence of alternating beds of sandstone and clay, with carbonaceous clay and lignite seams towards the bottom (Warkalli Formation). These beds are horizontally disposed and lateritised at the top. The midland portion representing the Tertiary sedimentary terrain and the western part of the Archaean terrain is extensively lateritised and the laterite is 5 to 10m thick. The coastal plain is covered by Quarternary.

Soil types

There are five major soil types encountered in the district. They are Lateritic soils, Brown Hydromorphic soils, Greyish Onattukara soils, Riverine and Coastal Alluvium 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. Brown 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 a result 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 alluvium is characterized by secondary soils which are sandy and sterile with poor water holding capacity. Riverine alluvium is seen along the river beds. The width of the zone increases towards the southern part of the district. Greyish Onattukara soils are purely marine deposits extending to the interior and are generally coarse in texture. Forest loamy soils are found in the eastern hilly areas of the district and are characterized by a surface layer rich in organic matter.

Drainage and Irrigation

The district is drained by three west flowing rivers, viz Achenkovil, Kallada and Ithikara, originating in the eastern hilly region. These rivers together with their tributaries exhibit dendritic pattern of drainage. The Ithikara basin has its elevation north of Madathara (271 m amsl) on the eastern side and slopes down to sea level west of Mayyanad. The Ithikara river originates from the Madatharaikunnu hills, south west of Kulathupuzha and drains into the Paravoor backwaters near Meenad. Ithikara river is a fourth order stream with a slope of 8.2 m/km. The length of the river is 56 km and the drainage area are 779 km2. The Kallada river basin has its highest elevation at Karimalaikodkal (1763 m amsl) on the eastern side and reaches almost sea level west of Karunagapally. The river originating from the Western Ghats drains into Ashtamudi backwaters near Kollam. The length of the river is 121 km and drainage area are 1996 km2. Kallada river is a fifth order stream with a gradient of 12.6 m/km. The Achenkovil river originates from the Western Ghats and covers a basin area of 1484 km2 and the main channel length is 128 km. The River joins Pamba river at Veeyapuram and finally debouches into the Vembanad lake. The Achankovil river is set in a well-known shear zone demarcating the boundary between Kerala

Khondalite Belt and charnockites of Southern Granulite terrain. The district is blessed with the largest fresh water lake in the State namely the Sasthamkotta lake and is one of the resources which caters to the drinking water needs of Kollam district. The lake occupies 440 hectares and the catchment area of the lake is 1269 sq km. Other major lakes (Kayals) in the district are - Ashtamudi Kayal (6424 ha) and Paravoor Kayal (662 ha). The irrigation facilities in the district are limited. The major irrigation scheme is Kallada irrigation project and the target fixed for it was 61630 ha of land and 92806 ha of crops. There are also minor irrigation schemes through which 1500 ha of land is being irrigated. Among source of irrigation, ground water is the principal source of irrigation accounting for about 47% of the area under irrigation and the rest by lift and other methods of irrigation.

Rainfall

The district receives an annual average rainfall of about 2428 mm. The Southwest monsoon from June to September contributes nearly 55% of the total annual rainfall. The Northeast monsoon season from October to December contributes about 24% and the balance 21% is received during the month of January to May as pre-monsoon showers. Out of the total 119 rainy days, about 70 rainy days occur during the southwest monsoon season.

Groundwater scenario

Geohydrologically, the area comprises A, B and C zones with respect to groundwater potential as low to poor, moderate to low and fairly good respectively. The district is subdivided into Vamanapuram, Ayur, Itikara, Kallada, Pallikkal and achenkovil basins. Ground water occurs in the porous granular formations such as alluvium, laterite, the Tertiary sediments and weathered and decomposed crystalline rocks as well as in the fissures, joints and fractures in the fresh crystalline rocks. The aquifers in the district can be grouped into four distinct geological formations in which they occur viz alluvial aquifers, laterite aquifers, Tertiary sedimentary rock aquifers and crystalline rock aquifers

The Kollam district is not affected by any major soil piping incidents so far but some areas are likely to be happen in future as they are reported by juvenile type pipes. The slope and land use and other geomorphological and geological features are likely to happen in certain areas.

Soil piping

Kollam district has not reported any major land subsidence due to soil piping. At present there is no field evidence suggestive of soil piping problems in the district. Hence zonation in terms of soil ping vulnerability is not attempted here.

Conclusion

Since there are no major incidents reported the zonation of the district in terms of vunerability is not attempeted. Since the field evidences are lacking there is not much to be concerned about soil piping in this district.

(This is conclusion is based on December 2019 data set)

4.14 Alappuzha

Alappuzha district situated in the southwestern part of the State, bounded by the Lakshadweep Sea in the west, Kottayam and Pathanamthitta districts in the east, Ernakulam district in the north and Kollam district in the south. The district lies between North latitudes 9o 05' and 9o 54' and East longitude 76o 17' and 76o 36'. Alappuzha is one of the well-developed coastal districts in southern part of Kerala State. Alappuzha district was formed on 17th August 1957.The district is unique for its wide and lengthy coastal plain. The total area of the district is 1,414 sq.km and is the smallest district accounting 3.64% of the area of the State, out of which more than 60% constitute the coastal low and backwater bodies. Coconut palm studded sandy flats garlanded with water bodies, extensive paddy fields, canals, lakes (kayals) all together make the district one of the most picturesque and beautiful parts of the State. As considerable part of the district is occupied by water bodies, navigation is one of the most important modes of transportation in the area. It is the only district in the State where there are no reserved forests. Kuttanad, also known as the "rice bowl of Kerala" has a predominant position in the production of rice. Alappuzha is well known for its coir industry with innumerable outlets for various finished coir products. According to 2011 census, the district has a population of 2121943. Of the total population 1010252 are males and 1111691 are females. The population density is 1501 persons/sq.km, the highest among all the districts of the State. Alappuzha is the Headquarters of the district. The district has 6 taluks viz. Sherthalai, Ambalappuzha, Kuttanad, Karthikapally, Chengannur and Mavelikara which have further been subdivided into 12 Community Development Blocks and 73 Grama Panchayats. There are five municipalities namely Chengannur, Alappuzha, Kayamkulam, Mavelikara and Cherthala. The district is well connected by good roads and rail. The National Highway NH-47, the Main Central road (M.C road) and the Delhi - Mumbai - Trivandrum broad-gauge railway line is passing through this district. Alappuzha town is crisscrossed by navigable canals that are connected to Cochin in the north and other important towns in the east.

Geomorphology

A major part of the district represents coastal plain characterised by landforms of marine, fluvial and fluvio-marine origin. The general elevation of the area is less than 6 m above mean sea level with some parts of the area below mean sea level in the range of 1-2 m. The widest part of the coastal plain of Kerala is seen in this district, in the stretch between Ambalappuzha-Thiruvalla. Haripad-Chengannur sections where its width is as much as 35km. The prominent landforms of this area are the coastal geomorphic features such as beaches, shore platforms, spit and bars, beach ridges. The beach ridges are suggestive of marine regression. Beach is very narrow and straight. The absence of extensive tidal plain and the intensive coastal erosion may be indicative of neo-tectonic activity.

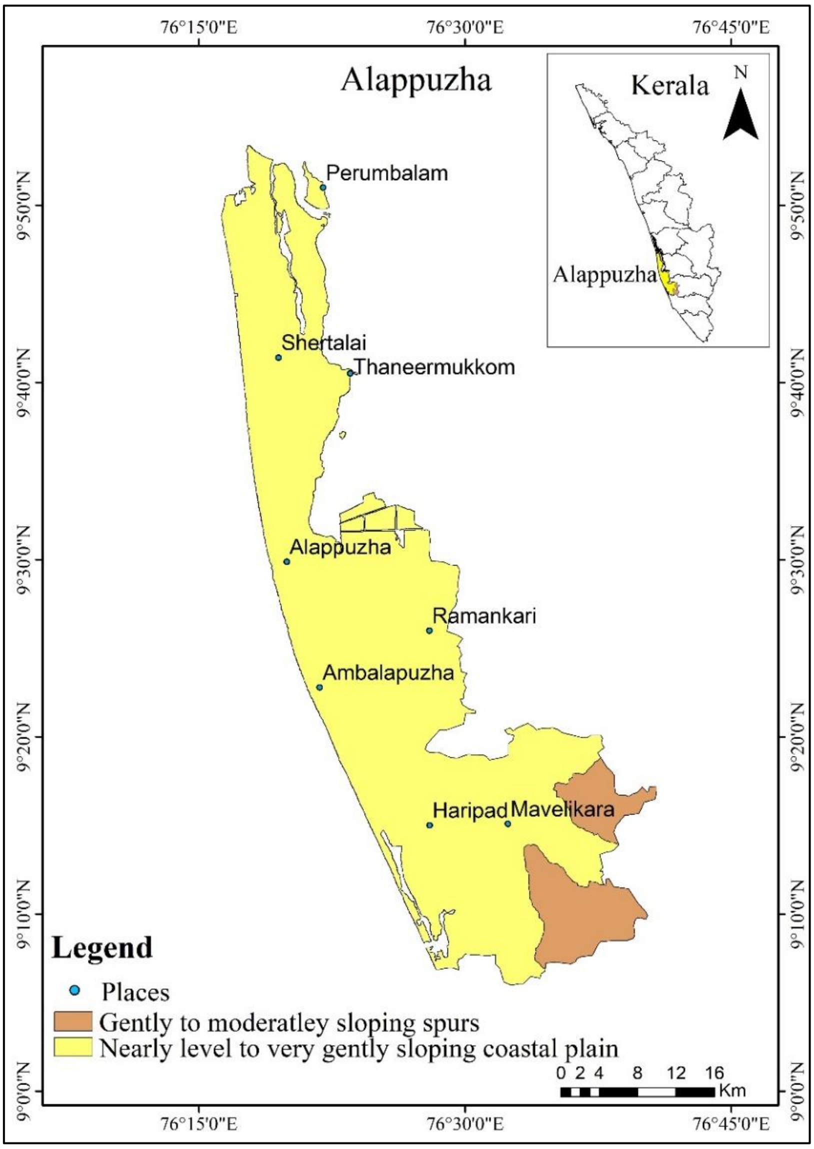

Figure 4.104: Geomorphology of Alappuzha District

(geomorphology map modified after District Resource map, Pathanamthitta district & Geological Survey of India)

The beach between Purakkad and Trikkunnappuzha is undergoing active erosion. A small part of the district in the southeast forms part of mid land hard rocks. Backwaters in the form of lagoons (kayals), canals, and distributor systems of the rivers occupy a considerable part of the coastal plain. Vembanad kayal, Karthikapally kayal, Vayalar kayal and Vatta kayal are some of the prominent back water bodies. In addition to this, there is a conspicuous low-lying area which is below the sea level (05 to 1m below msl) and is always under water logged condition. This is the Kuttanad area south of Vembanad lake i.e., the area east and southeast of Alappuzha town. It represents a low-lying deltaic region characterized by wetlands. All these water bodies are brackish during summer. The Thannermukkom barrage across Vembanad lake and the Thottappalli spillway help to a certain extent the incursion of sea water during the high tide. The low land region along the mouth of Pamba and Achenkovil rivers has helped to develop a well-marked distributor system and formation of delta. Kuttanad is also known as 'rice bowl of Kerala' as this region produces maximum paddy. Punnamada kayal, the venue of famous Nehru Trophy boat race, is also situated in Alappuzha district. Eastern part of the district is characterised by small laterite capped hillocks and narrow valleys representing the midland region.

Geology

Khondalite is the oldest rock of the area and it includes quartzites which occur as lenticular bodies and garnet-biotite-sillimanite gneiss with or without graphite. The charnockite group of rocks including acid and intermediate varieties are found in the north eastern parts. Rocks of the migmatite group reperesented by biotite gneiss (quartzo-feldspathic gneiss) is noticed as small bodies in along the eastern margin of the district. Near Chengannur, a massive granite body representing the acid intrusive occurs. Hills in the southern and western parts are capped by Tertiary sedimentary rocks (Warkalli Formations). Drilling by CGWB indicated that the Tertiary basin is deepest along the coastal plains of the district and is more than 600m deep south of Alappuzha town. The Kuttanad low land covering an area of approximately 100 sq. km. is reported to have plenty of semi-carbonised and partly decayed wood trunks, roots, branches, leaves etc. buried under a thin veneer of black carbonaceous clay. This region is locally known as Karipadams because of yielding of coal-like (carbonised wood) material from the paddy field. It is believed that this area is submerged forest of Quaternary period. The other Quaternary sediments include strand line/palaeo beach deposit (Guruvayoor Formation), fluvial deposits (Periyar Formation), tidal/mudflat deposit (Viyyam Formation) and beach deposit (Kadappuram Formation) (Figure 1). The geology of the district given above may be read with the "Geology of Kerala" which is given as Annexure 1 for better understanding of geological succession and stratigraphic sequence.

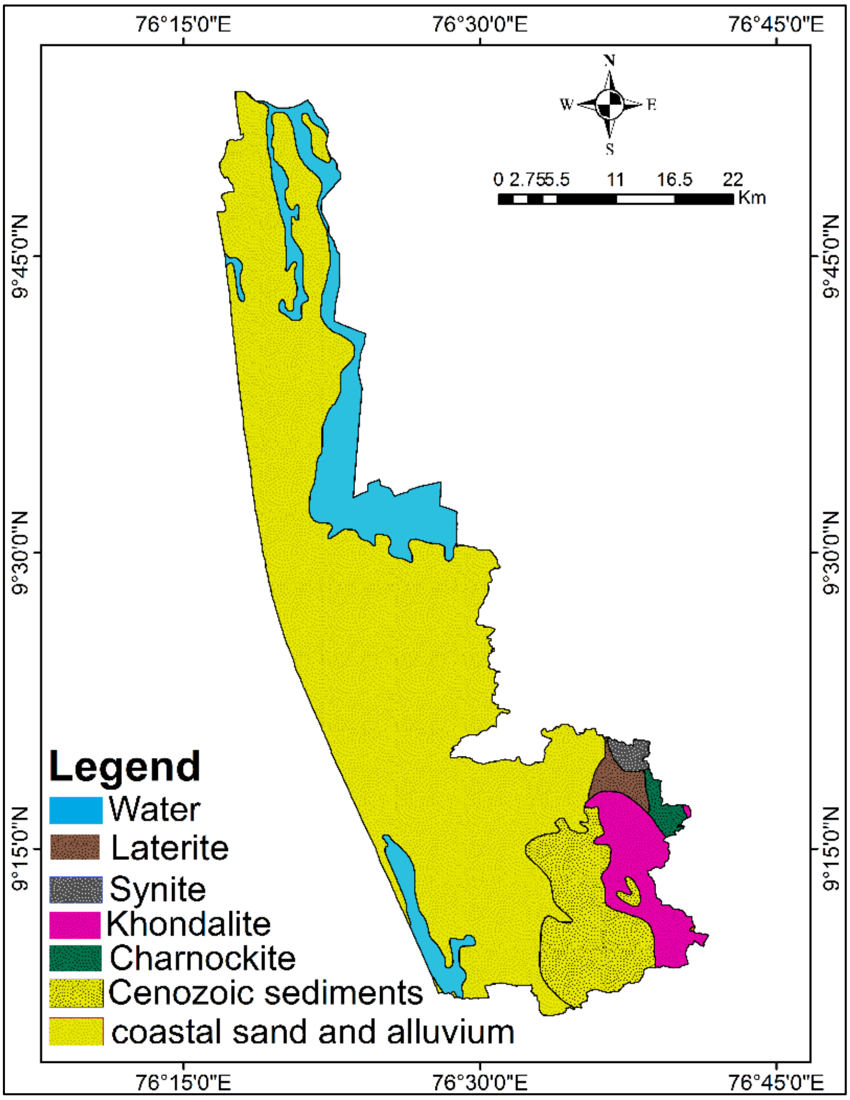

Figure 4.105: Geomorphology of Ernakulam District

(geology map modified after District Resource map, Pathanamthitta district & Geological Survey of India)

On the basis of morphological and physico-chemical properties, the Soil Survey Division of Department of Agriculture, Govt. of Kerala has classified the soils of the district into four types viz. (1) Coastal alluvium (Entisols), (2) Riverine Alluvium (Inceptisols) (3) Brown hypidimorphic soil (Alfisols) and (4) Lateritic soil (Oxisols). Coastal Alluvium (Entisols) These soils are seen along the western parts of the district all along the coast and have been developed from recent marine and estuarine deposits. The texture is dominated by sand fraction and is extensively drained with very high permeability. These soils have low content of organic matter and of low fertility level. Riverine alluvium (Inceptisols) These soils occur mostly in the central pediplains and eastern parts of the area along the banks of Pamba River and its tributaries and show wide variation in their physicochemical properties depending on the nature of alluvium that is deposited and characteristics of the catchment area through which the river flows. They are very deep soils with surface textures ranging from sandy loam to clayey loam and moderately supplied with organic matter like nitrogen and potassium. Brown hydromorphic soil (Alfisols) These are mostly confined in the western low-lying areas of the district along the coast. These soils have been formed as a result of transportation and sedimentation of material from the adjoining hill slopes and also through deposition by rivers and exhibit wide variation in their physical and chemical properties. They are moderately supplied with organic matter like nitrogen, potassium and deficient in lime and phosphate. Lateritic soil (Oxisols) The lateritic soil is the result of weathering process of Tertiary and Crystalline rocks under tropical humid conditions and is seen in the south-eastern part of the district. Heavy rainfall and temperature prevalent in the area are conducive to the process of formation of this soil type and have been formed by leaching of base and silica from the original parent rock with accumulation of oxides of iron and aluminum. They are poor in nitrogen, phosphorous, potassium and low in bases. The organic content is also low and is generally acidic with pH ranging from 5.0 to 6.0.

Drainage and Irrigation

Alappuzha district is drained mainly by Pamba River and its tributaries viz. Achankovil and Manimala Rivers. The Pamba River drains an area of 804 sq.km of the district and form a deltaic region skirting the south eastern, southern and south western fringes of Vembanad Lake. The Manimala River enters the Kuttanad area at Thondara and confluences with Pamba River at Neerettupuram. Achancovil Ar enters Kuttanad at Pandalam and joins Pamba River at Veeyapuram. Vembanad Lake, the largest back water in the State lies on the north eastern part of the district separating Alappuzha from Kottayam district.

Rainfall

The district has a tropical humid climate with an oppressive summers and plentiful seasonal rainfall. The period from March to the end of May is the hot season. This is followed by the southwest monsoon season, which continues till the end of September. During October and major part of November southwest monsoon retreats giving place to the northeast monsoon, and the rainfall up to December is associated with northeast monsoon season. The district receives an average annual rainfall of 2965.4 mm. The southwest monsoon season from June to September contributes nearly 60.3% of the annual rainfall. This is followed by the northeast monsoon season from October to December, which contributes about 20.9% of the annual rainfall, and the balance 18.8% is received during the period from January to May months.

Groundwater scenario

Alappuzha district consists of Coastal alluvium comprising sand and clay along the coastal region and flood plain deposits in Kuttanad region. Residual laterite formations are encountered in the south-eastern parts of the district and granites are encountered in and around Chengannur area. Charnockite, Khondalite and Granites form the basement. Charnockites and Khondalites are encountered at depth. They are overlain by Tertiary sedimentary formations. The laterite/alluvial sediments overlay the Tertiaries. Domestic water requirements of the district are met from groundwater source on a large scale. The area consists of two hydrological zones – (i) moderate to low permeability zone and (ii) fairly good ground water potentiality zone. The Pamba river flows in the area forms a part of the deltaic region. As most of the area is underlain by Tertiary sediments, the ground water potential is fair to good. The entire area is an arable land, except the coastal tract where coconut plantation is predominant.

The Alappuzha district is not affected by any major soil piping incidents so far but some areas are likely to be happen in future as they are reported by juvenile type pipes. The slope and land use and other geomorphological and geological features are likely to happen in certain areas.

Soil piping

Alappuzha district has not reported any major land subsidence due to soil piping. At present there is no field evidence suggestive of soil piping problems in the district. Hence zonation in terms of soil ping vulnerability is not attempted here.

Conclusion

Since there are no major incidents reported the zonation of the district in terms of vulnerability is not attempted. Since the field evidences are lacking there is not much to be concerned about soil piping in this district.

(This is conclusion is based on December 2019 data set)

4.15 Soil Piping Hazard Zonation of the State

The soil Piping or Tunnel erosion is serious issue in Kerala. These pipes area seen mainly in the western Ghats and it's foots in Kerala. The vulnerability of the incidents is in the form of Land subsidence. The phenomenon is mainly occurring in the Lateritic terrain as well as in the loam. The geophysical, geochemical and sedimentological analyses of field data and samples collected during field investigations have given a clear idea that these pipes are occurring under certain conditions and geomorphological and geological features have the major hand on the piping process.

As the identified incidents are having almost similar characters and conditions in formation a zonation is possible through which the district could highlight with Critically affected, most probable zone (partially affected) and Least probable zone (less affected areas). This can help in giving awareness and management in land use in future.

The total area of the Kerala district is approximately 38867 square kilometres, in which 6365.12 square kilometres of land is affected by soil piping. The northern districts Kasaragod, Kannur, Malappuram, Thrissur, Wayanad and Idukki in the south are severely affected by soil piping. 12158.49 square kilometres of land is falling inside Probable zones. Which are Partially affected and the probability for the formation of new incidents are more. 12068.38 square kilometres of land is falling inside the Non-affected zones. Which are the areas less affected by soil piping and probability for the formation of new incidents are less. The coastal stretch consist of alluvium sediments and hard rock terrain are coming inside this zone. The districts Kollam Kottayam and Alappuzha are not reported by any soil piping incidents so far, but all the districts except Alappuzha is likely to be happen in future.

The reported soil pipes in many areas are grown beyond mitigation. The subsided soil pipes or those which are having opening to the surface might be noted while those which are situated in the interior and forested areas cannot be identified easily. The infrastructures like roads, building have been affected by tunnel formation due to soil piping, so that systematic soil sampling, geotechnical and geophysical surveys has to be done before the new construction plans.

Table 4.36: **Areal extent of Soil piping affected regions in state**

District	Total area in sq.km	Affected area in sq.km	Probable area in sq.km	Non-affected area in sq.km	No. of soil pipes reported
Kasaragod	1,992	1018.533	713.113	260.355	29
Kannur	2,966	1224.931	993.192	777.877	17
Malappuram	3,550	867.359	1867.394	815.248	24
Wayanad	2,132	948.4208	733.938	449.64123	26
Idukki	4,358	955.995	2,831.93	570.072	13
Thrissur	3,032	1349.881	569.598	1112.521	11
Palakkad	4,478		1365.368	3,112.63	4
Pathanamthitta	2,642		881.756663	1,760.24	1
Kozhikode	2,344		1479.344	864.65	4
Ernakulam	3,068		722.8555	2,345.14	2
Thiruvananthapuram	2,192	0.05			1
Kottayam	2,208	not reported yet			
Alappuzha	1,414	not reported yet			
Kollam	2,491	not reported yet			
Total in State	**38,867**	**6365.17**	**12158.5**	**12068.37**	**132**

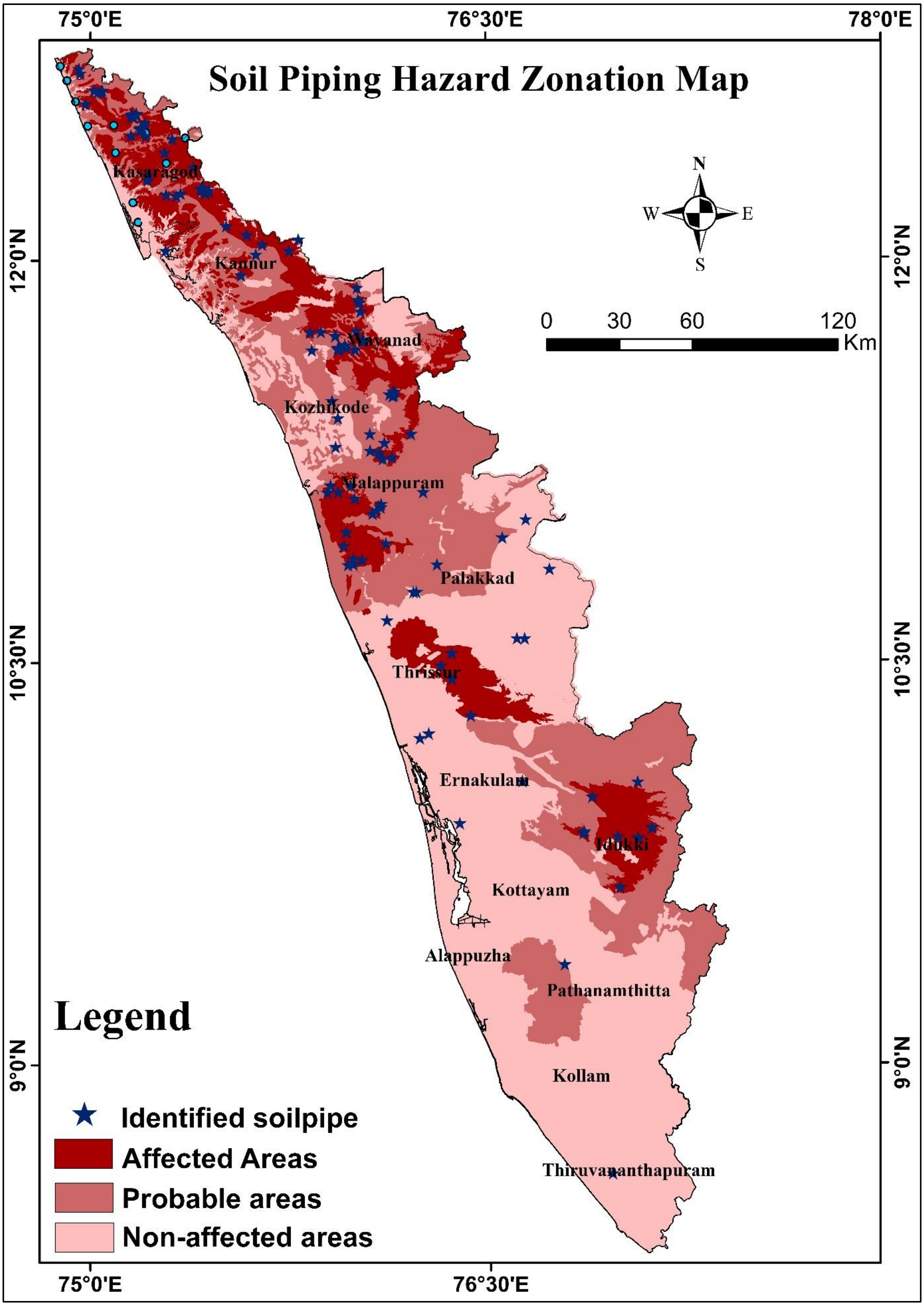

Figure 4.106: Zonation map of Kerala state

Chapter 5

Geotechnical Investigations and mitigation work in soil piping affected regions of Kerala

Panjami K. Assistant Professor, FISAT Angamali

Introduction

The word soil piping refers to the insidious and enigmatic process involving the hydraulic removal of subsurface soil, causing the formation of an underground passage in landscape (Boucher 1995). Soil piping erosion has become a serious issue from the last few years in various parts of Kerala. Even though the frequency of occurrence of this phenomenon has shown an increasing trend in the last few years in the various parts of the state, there are few works carried out on this topic to find the exact reason behind its formation. Some works had been conducted recently by various geologists to find out the physical, chemical, topographical and hydrological factors controlling the spatial distribution of soil piping. But little works had done to find out how the geotechnical properties of the soil affect this phenomenon. It still remains a mystery that why only some parts of the state are affected by this phenomenon and what is the common character of the soil in these areas.

Geochemical analysis conducted by NCESS (Sankar 2015) indicates that the presence of dispersible sodium has a main role in piping erosion to occur. A soil with more than 5% dispersible sodium is considered as dispersible soil (Sankar 2015). The high sodium content associated with the physical process of soil dispersion and clay and aggregate swelling. The reason for the above process is disruption of binding between clay particles in the presence of large sodium ions, and this separation will cause the expansion of clay particles. From certain soils in the tropical regions of Africa it was reported that hard crust will be formed due to higher sodium content in the soil column. The dispersion of soil causes clay particles to plug soil pores, resulting in the reduction of soil permeability and the repeated wetting and drying of soil and clay dispersion the strata reformed and solidified into almost cement- like soil. The soil of this type will reduce the infiltration and hydraulic conductivity and cause surface crusting. And this is the reason for the run off to find out alternative subsurface paths for the flow. The studies depict that a combination of physical, chemical, hydrological and tectonic factors that develops the soil piping in the area. The rainfall exceeding 5 cm per hour, soil matrix with high sodium content and low calcium and magnesium, soil having the cohesionless texture at sub-surface layer and area subjected to high removal of shrubs and trees, sloping terrain are found out to be the threshold factors in developing soil piping.

Analysis of Various Geotechnical Properties

The undisturbed samples from the site have to carry to the geotechnical lab and various geotechnical lab tests are to be conducted. The tests include 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 have to conduct in accordance with IS standards.

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 thereof.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).

Particle size distribution data mainly used in the classification of soils. The information obtained from the grain size analysis can be used to predict soil water movement although permeability tests are widely used for this purpose. Soil classification according to Indian Standards are preffered here.

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 permeability of the soil is the property of soil to transmit water and air. 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).

Study area

Kasaragod is one of the 14 districts of Kerala state, India situated in the northern part of Kerala with an area of 1992 km^2.It is bordered by Karnataka to the north and east, Kannur district to the south and the Arabian Sea to the west. The current study area is Nelliyadukkam locality, Karindalam panchayath, Kinanur village, Vellarikundu taluk of Kasrgod district (Figure 5.1), which is situated 12 Km east of Nileswaram town. Soil piping incident in this area has occurred in 2014 August 2, the subsided area is located adjacent to the house of Mr. Balan V.K. The foundation of the house under construction has damaged by the soil piping phenomenon (Figure 5.2).

The total area of Nelliyadukkam lies in the toposheet number 48P/3 with a latitude of 12˚15'N and longitude of 75˚0'E. The current study area, from which samples collected have the co-ordinates:12˚17.5'N and 75˚13'E. Nelliyadukkam is located 12 Km east of Nileswaram town. There is a river called Madikkal puzha flowing near to the piping area. A clay mine is present by the Kerala clays and ceramic limited in the adjacent area. Large quantities of alumina-silica rich laterites are being transported from the mine area to different cement industries.

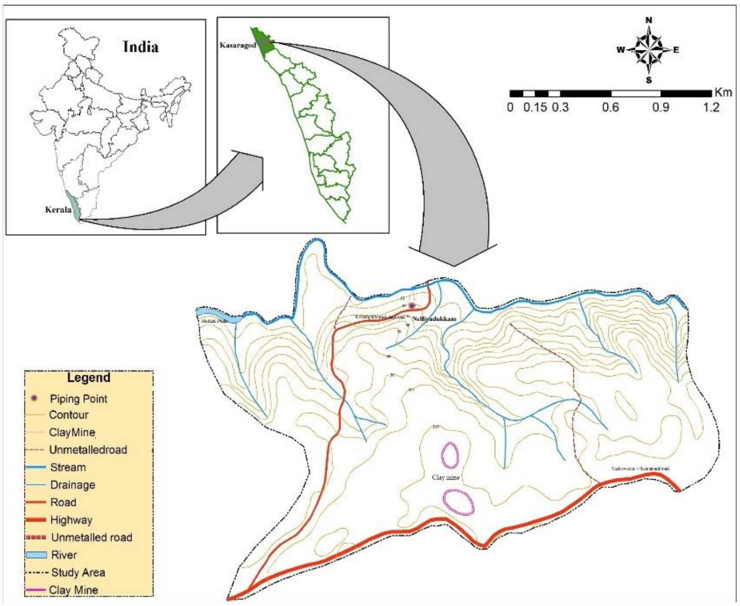

Figure 5.1: study area ***Figure 5.2*:** Damaged foundation in the study Area (Sankar 2015)

Evaluation of dispersive potential

Visual classification, Atterberg's limits and particle size analysis do not provide a basis for the differentiation between dispersive and ordinary erosion resistant clays (J K Mitchel,1993). The four special laboratory tests most popular in India and United states of America (USA), for the identification of dispersive nature of soil are Sherard's pin hole test, Crumb test, SCS double hydrometer test and chemical analysis of pore water. Studies on this various test shows that none of these tests truly identify the dispersive nature of soil. Pin hole erosion test developed by Sherard and its later modifications are to be more reliable. By taking the following factors like extent of reliability of the test, applicability of the test in field conditions and other related factors viz. soluble salts in pore water, mineralogy etc. into consideration, a realistic assessment is done in the identification of dispersive characteristics. Dispersive clays can be of any color, but black colored soils with high amount of organic content has not been found to be dispersive. From the surface, the soil might seem to be strong but at the bottom portion there are chances for dispersion to occur and if there are no excavations made in those areas there will be no evidence that the underlying soil is eroding. The areas of steep topography where dispersive soils exist are found to be having high sodium content and low amount of calcium and magnesium ions. In Kerala the XRD analysis of samples from the affected sites indicated that Kaolinite as the major clay.

Laboratory Methods to Identify Dispersive Soils

Among various tests available for finding out the dispersive nature of soils no tests satisfy under all conditions. It is suggested that, for the civil engineering works a range of chemical and physical tests to be adopted rather than relying on a single analysis. The important thing to be noted is all the specimens should be maintained and tested at their natural water content since there are chances for altering the dispersive nature characteristics of soil while drying especially oven drying. Crumb test, pin hole erosion test and double hydrometer tests are the conventional physical tests performed to determine the dispersive clays.

The crumb test (Emerson, 1967)

Crumb test is a simple test developed to identify the dispersive soils in the field. In this method cubical specimens of about 15 mm on sides are prepared at their natural water content and about equal volume. This specimen has to be carefully placed in 250 ml distilled water. Observe the cloudiness as the crumb begins to hydrate. Results interpreted at various time intervals. Potential erodibility of clay soils can be easily identified by this method however a dispersive soil sometimes gives no dispersive reaction in crumb test. The complete procedure for determining dispersive nature of soils is given in USBR 5400(Dixit M and Gupta S L,2011, Hardie M,2009).

Double hydrometer test (Volk, 1937)

Double hydrometer test also known as SCS (Soil Conservation Service) laboratory dispersion test has been identified as one of the most appropriate tests for classifying the dispersive soils.

The test is carrying out its natural water content. It evaluates the dispersibility of a soil by measuring the tendency of clay fraction to go into suspension in water. Using standard hydrometer test the particle size distribution is determined for the specimen which dispersed in distilled water with strong mechanical agitation and chemical dispersant. A parallel hydrometer test is then conducted on a duplicate soil specimen without chemical dispersant and mechanical agitation. Dispersion ratio is defined as the quantity of particles finer than 0.005 mm in the parallel test to that of standard test (Walker, 1997). Soils with greater than 50% dispersion ratio are considered as highly dispersive, between 30% and 50% are moderately dispersive, between 15% and 30% are slightly dispersive and less than 15% are non-dispersive (Elges, 1985). There are similar systems with different ranges utilized by Gerber and Hames (1987) and Walker (1997).

Pin hole test (Sherard et al, 1976)

This method was developed to directly measure the dispersivity of compacted fine soils in which water is allowed to flow through a small hole in the soil specimen. The water flow through the small hole simulates the water flow through a crack or other concentrated leakage channels through the structures other structure. Soil specimen prepared for the test is of 25 mm long and 35 mm diameter cylindrical specimen. Distilled water is allowed to flow through it under various heads. Sherard classifies the dispersive nature of soil under a flow caused by 50 mm head of distilled water. Soils erodes at a head of 50 mm or 180 mm classified as intermediate category, whereas nondispersive soils are supposed to produce no colloidal erosion under 380 mm or 1020 mm head of water. Detailed test procedure of this is outlined in USBR 5410, Determining dispersivity of clayey soils by pin hole test method. Pin hole test to be considered as the accurate method but care has to be taken to properly simulate the field conditions (J K Mitchel, 1993).

Study area

For the present study disturbed soil samples were collected from three main piping districts of Kerala including Idukki, Kannur and Wayanad. Main localities from which Samples collected are Thirumeni and Kottathalachimala localities of Kannur district, Vythiri taluk of Wayanad district, Peringassery, Thattekanni and Neendapara localities of Idukki districts.

Results obtained from the experimental investigation

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. The current study area was of sloping nature and which was situated almost middle of the hill top. The 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 at presents of water.

While comparing the results obtained from double hydrometer test on various samples, the Idukki samples were found to be having more dispersion ratio having a range of 13.11 – 27.21 %. Samples collected from the pipe wall was found to be more dispersive than that collected from the soil profile outside piping region. Expected range of dispersion ratio on the pipe wall was more than 30%. The reason for the lower value is assumed to be the loss of dispersive clay by the pipe erosion in those areas, as the samples were collected from the eroded pipe region. Samples collected from Kannur districts was found to be having dispersion ratio in the range of 8.33 – 14.43%. Since all the samples of this district collected from the pipe wall can conclude that the loss of dispersive clays can be the reason for this low value. While comparing the results of sample 8 ,9 and 10 these were samples of same region at different depths. Sample 8 was collected from a depth of 300 cm from the pipe wall, sample 9 from a depth of 400 cm from the pipe wall and sample 10 from a depth of 500 cm from the pipe wall. The test results show that at greater depth the dispersion is more and top dispersion is low. The reason behind is same as explained above that is the surface dispersive soil already eroded in presence of water. From Wayanad district samples were obtained from both pipe wall and hard surface portion of piping region. The region at this area was recently undergone high rate of piping erosion.

Mitiagtion suggested in the study area is proper dewatering technique along with renovation of damaged foundation by underpinning using polyurethane resins.

Possible mitigation

Mitigation of dispersive soils can be done in both physical and chemical aspects. Physical aspect of mitigation includes improving the texture, structure, bulk density, consistency, permeability etc., which influence the properties of slaking of soil and goes in suspension. Chemical aspect of mitigation is modifying the chemical properties like pH, cation exchange capacity, amount of exchangeable sodium etc and which is achieved by chemical amelioration. Usually using chemical for the chemical amelioration are hydrated lime (Calcium hydroxide), gypsum (calcium sulphate), and alum (aluminum sulphate). In a widely affected soil piping area chemical amelioration is found quite uneconomical. Dewatering techniques are quite suitable in those areas. If proper dewatering techniques applied on the field then the chances of soil go into suspension can be avoided as without presence of water dispersive soils are not harmful.

Mitigation works suggested for different cases of piping are explained below.

1. Piping under foundations of buildings

There are certain cases reported in Kerala where piping was observed under foundations of buildings and which cause subsidence problems for such buildings. 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. 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.

- **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 a 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. While the hydrological barrier technique has only been experimented once in Tasmania (Ducket pers. comm.) 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).

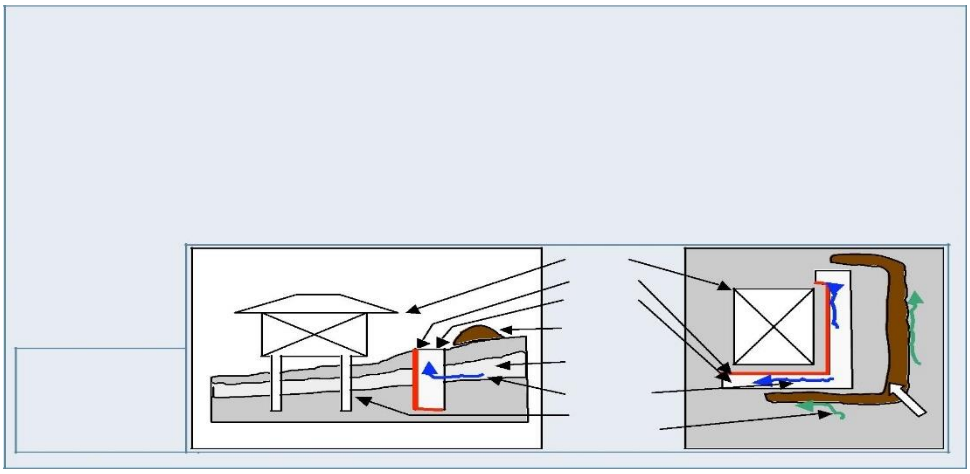

Figure 5.3: Mitigation technique Hydraulic barrier

- **French drain**

A French drain 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.

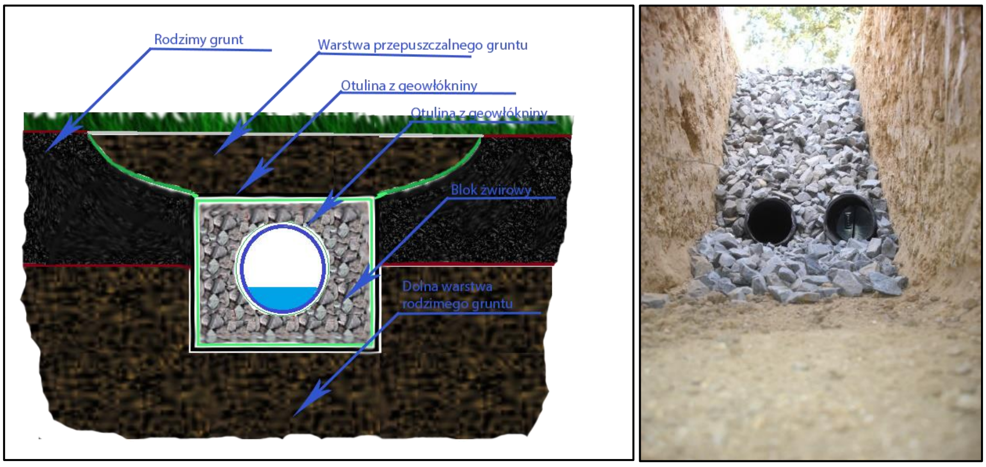

Figure 5.4: Mitigation technique Hydraulic barrier french drain

- **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 relevelled.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 waterflow 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 do not require water for the reaction. The expansion rate of hydrophobic polyuretahnes are higher than hydrophilic and it is about 20 times the original volume

2. **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.

- **Filter drains**

Filter drains 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.

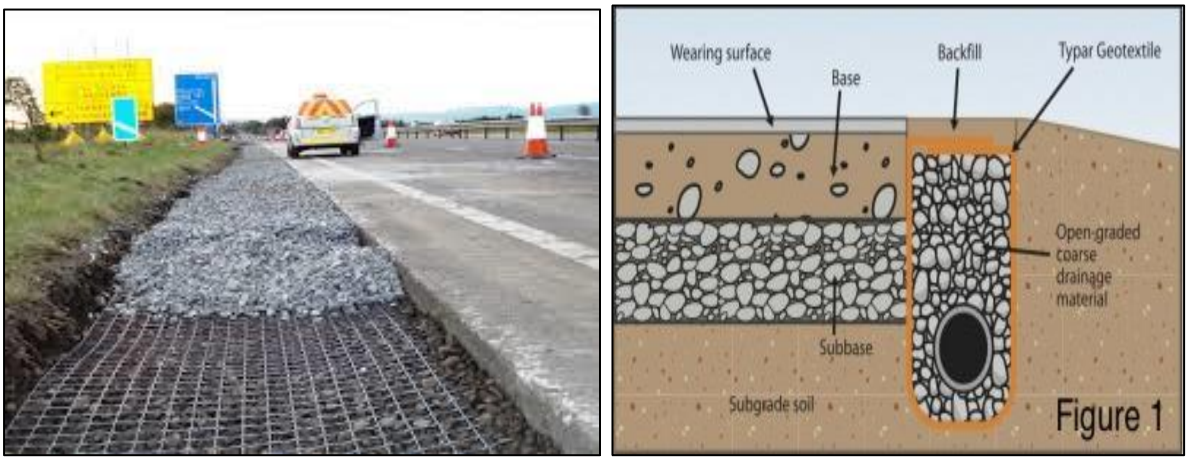

Figure 5.5: Mitigation technique filter drain

- **Application of polyurathane grout**

The use of polyurethane resins is 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.

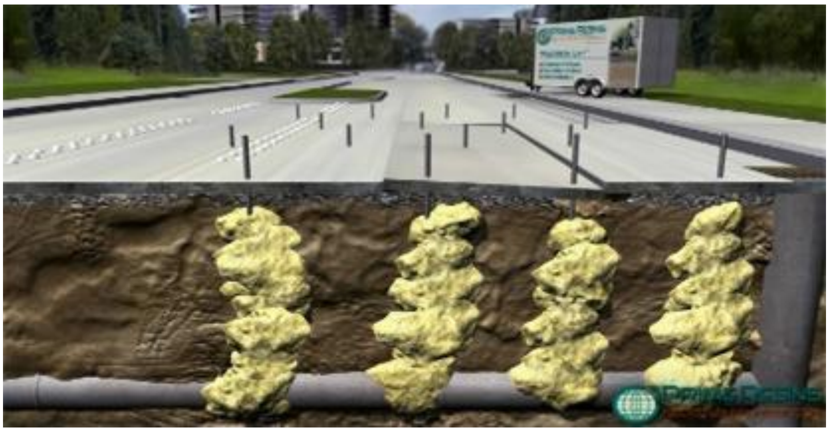

Figure 5.6: Mitigation technique by application of polyurethane grout

Chapter 6
Conclusion

6.1 General

1. The total area of the Kerala district is approximately 38867 square kilometres, in which 6365.12 square kilometres of land is affected by soil piping. The northern districts Kasaragod, Kannur, Malappuram, Thrissur, Wayanad and Idukki in the south are severely affected by soil piping. 12158.49 square kilometres of land is falling inside Probable zones. Soil piping is prevalent in the lateritic areas of the state compared to non -lateritic areas. Excepting, Kottayam and Kollam soil piping is observed / reported from all other districts in Kerala in one form or other Northern districts such as Kasaragod, Kannur and Malappuram are severely affected by soil piping. Districts like Idukki, Wayanad and Thrissur have widespread areas affected by soil piping
2. Districts such as Ernakulam, Pathanamthitta, Thiruvananthapuram, Palakkad and Kozhikode have small pockets of affected localities
3. There are no reports of soil piping from Kollam and Alappuzha districts so far. Whereas Kottayam district has shown tendency for soil piping in the highland regions in the form of juvenile and small pipes.
4. Geophysical surveys especially multi electrode electric resistivity surveys are ideal for locating subsurface tunnels and cavities formed by soil piping. However small and Juvenile pipes are extremely difficult to locate due to resolution problems.
5. Dewatering is the most quick and effective way to mitigate but for sustainable results chemical amelioration could be tried.
6. Many places the tunnel formation has grown beyond any possibilities of mitigation
7. Studies suggested that many infrastructure facilities especially communications line like roads have been affected by tunnel formation due to soil piping
8. The ground water storage and the vegetation are also seriously affected in the localities affected by soil piping
9. Multi-electrode resistivity surveys help in identifying typical and huge tunnels. However, it is difficult to identify small and Juvenile tunnels using these surveys.
10. Even though it is a very slow process usage of Gypsum and hydrated lime helps to retard the soil piping activity

11. As immediate remedial measure it is better to adopt dewatering techniques using some engineering measures like diversion of underground flow channels and construction of underground barriers etc.

6.1.1 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 Malappuram and Idukki
- The so far, the no incidents were reported from Kottayam, Alappuzha and Kollam districts of Kerala

6.1.2 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.

6.1.3 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.

6.1.4 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.

6.1.5 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.

6.2 Recommendations

- It is recommended that site specific and detailed studies are required to understand the soil piping affected areas in the state
- In the affected areas the laterite mining should be discouraged or the depth of the mine to be restricted 1m above the lithomarge clay. In no case the clay should be mined or exposed.
- It is recommended that usage of hydrated Lime should be encouraged 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 proper geologic / geophyscical studies to rule of existance of subsurface tunnels
- 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.
- 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.
- In affected areas and probable areas usage of hydrated lime along with the fertilizers should be encouraged to neutralise dispersive sodium in the clay.
- Dewatering is the best method to deescalate the formation of soil pipes. Overland flow may be diverted to a nearby nala without allowing to infiltrate in the affected zone will reduce pipe development.

NATIONAL CENTRE FOR EARTH SCIENCE STUDIES

Akkulam, Thiruvananthapuram 695011

Data Collection format of soil piping problems

Location details:

1. Station No.
2. Location Name:
3. District:
4. Taluk:
5. Village:
6. Panchayat:
7. Ward:
8. Contact person in the area (if any) name and mobile no:

Geo environmental parameters

9. Co-ordinates (a. failed area and b. out let)
   a. Latitude: Longitude:
   b. Latitude: Longitude:
10. Elevation of the failed / affected area (m)
11. Elevation of outlet (if any in m)
12. Geographical location of the failed surface (Hill crest / side slope / valley)
13. Slope amount (in degree)
14. Slope aspect
15. Slope forming material
16. Depth of the over burden (m)
17. Land use

Soil piping characteristics

18. Nature of evidence: (Subsidence / pipes inside well / sound &vibrations)
19. Date and time of occurrence (if available) (IST):
20. Type of subsidence / pipe
21. Diameter of opening (m)
22. Depth (m)
23. Type of subsurface pipes
24. Diameter of pipe (m)
25. Direction of pipe
26. Length of pipe to out let (m)
27. Description of outlet

Met.data (if available)

28. Rainfall during the incident / area (mm)
29. Rainfall intensity
30. Rainfall during season (mm)
31. Source of info:

Hydrological info:

32. Water table conditions in nearby wells: (fluctuating / not fluctuating during rains)
33. Depth to water table (m)
34. Type of soil / well wall material
35. Pipes present or not in the bottom
36. Discharge through the outlet:

Lithology / Soil

37. Rock type(s) of the area
38. Soil / laterite (profile pic)
39. Samples taken with numbers
40. Sample collection details:

Disaster management

41. Nature and types of infrastructure affected:

42. Evaluation of the site with respect to disaster proneness:

43. Any relocation of people required
44. If so, the details

45. If nearby areas affected, if so, give details

46. Mitigation suggested (use separate sheet in required)

47. Recommendations

Data collected by: on:

Signature

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