GOVERNMENT OF ANDHRA PRADESH

ANDHRA PRADESH CAPITAL REGION DEVELOPMENT AUTHORITY

Report on

HYDROGEOMORPHOLOGICAL STUDIES OF AMARAVATI CAPITAL CITY (TO PLAN TO CONSERVE WATER RESOURCES AND REGULATE CITY DEVELOPMENT), ANDHRA PRADESH

By

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STATEMENT OF AUTHENTICITY

*I/We hereby declare that the work presented in this report entitled **"HYDROGEOMORPHOLOGICAL STUDIES OF AMARAVATI CAPITAL CITY (TO PLAN TO CONSERVE WATER RESOURCES AND REGULATE CITY DEVELOPMENT), ANDHRA PRADESH"** is the result of independent investigation carried out by **BlueEnergy Build Private Limited**.*

The data, analyses, interpretations, and conclusions contained in this report are original and have been prepared using scientific methods and reliable sources to the best of our knowledge. Any material taken from other sources has been duly acknowledged and referenced.

This report has not been submitted, in whole or in part, to any other organization or institution for any purpose.

Signed,

Dr. P. Lakshminarayana

Managing Director, BlueEnergy Build Private Limited

Date: ___________
Place: __________

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EXECUTIVE SUMMARY

BlueEnergy Build Private Limited, under agreement with the Andhra Pradesh Capital Region Development Authority (APCRDA), conducted Hydrogeomorphological Studies for the Amaravati Capital City area of 217.23 km^2 to support sustainable water resource management and urban development.

The study integrated high-resolution satellite imagery, digital elevation models, field-based geophysical surveys (Vertical Electrical Soundings and Magnetic Surveys), hydrological modelling (HEC-HMS & HEC-RAS), pumping tests, and water quality analysis to map geomorphic features, aquifer systems, and flood-prone zones.

Findings indicate:

Geomorphology: Dominance of flood plains, pediplains, valley fills, and structurally controlled uplands, with NNE–SSW trending shear zones serving as key groundwater conduits.

Groundwater: Multi-aquifer systems with varying yields; high potential in alluvial zones, moderate to low in crystalline formations; water table depths ranging from <2 m near Krishna River to >10 m in uplands.

Hydrological Modelling: Identified basin-wise runoff volumes, peak flood discharges, and optimal locations for water retention structures to reduce flood duration to <24 hours under 1-in-100-year events.

Water Quality: Generally suitable for drinking/irrigation but localized brackish zones require targeted recharge and quality improvement measures.

Key Recommendations include scientific siting of recharge wells and water harvesting systems, preservation of natural flood retention zones, phased drainage and pumping infrastructure, and integration of groundwater sustainability measures into the Amaravati Master Plan.

The study delivers a comprehensive spatial and analytical baseline enabling APCRDA to plan resilient infrastructure, safeguard water resources, and ensure long-term water security for the capital city.

List of Abbreviations / Acronyms

APCRDA	Andhra Pradesh Capital Region Development Authority
BEBPL	BlueEnergy Build Private Limited
CDT	Constant Discharge Test
CGWB	Central Ground Water Board
CHIRPS	Climate Hazards Group InfraRed Precipitation with Station data
CWC FER	Central Water Commission Flood Estimation Report
D/S	Downstream
DEM	Digital Elevation Model
DPR	Detailed Project Report
EC	Electrical conductivity
EW	Exploratory Wells
GEV	Generalized extreme value distribution
GOI	Government of India
GPS	Global Positioning System
GSI	Geological Survey of India
HEC-HMS	Hydrologic Engineering Centre- Hydrologic Modeling System
HEC-RAS	Hydrologic Engineering Centre- River Analysis System
HFL	High Flood Level
IGRF	International Geomagnetic Reference Field
IIIT	International Institute of Information Technology
IIT	Indian Institute of Technology
IMD	Indian Meteorological Department
IRS	Indian Remote Sensing Satellite
KV	Kondaveeti Vagu
LULC	Land Use / Land Cover
AMSL	Above Mean Sea Level
NAQUIM	National Aquifer Mapping and Management Programme
NGT	National Green Tribunal
NIT	National Institute of Technology
NRSC	National Remote Sensing Centre
OW	Observation Wells
R2A L4FX	Resource sat 2A Liss
SDT	Step Drawdown Test
SOI	Survey of India
SR	Southern Region
SRTM	Shuttle Radar Topography Mission
SSR-MP-ATS	Resistivity Meter Model
TDS	Total Dissolved Solids
TF	Total Field (Magnetic Survey)
U/S	Upstream

VES	Vertical Electrical Sounding
VGTM	Vijayawada-Guntur-Tenali-Mangalagiri
VIT	Vellore Institute of Technology
WQI	Water Quality Index

CHAPTER 1: INTRODUCTION

1.0. GENERAL

The Andhra Pradesh Capital Region Development Authority (APCRDA) has commissioned BlueEnergy Build Private Limited to undertake comprehensive hydrogeomorphological studies within the Amaravati Capital City area, which encompasses 217.23 km^2. This initiative is a critical part of an integrated approach to sustainable water resource management and urban planning. The primary aim of the study is to assess, conserve, and enhance the region's natural hydrological systems, ensuring alignment with the master plan for the capital city.

Vision for Amaravati Capital City

Amaravati is envisioned as a world-class, sustainable, and livable capital for the State of Andhra Pradesh. The city is strategically situated between Vijayawada and Guntur, along the southern bank of the Krishna River. Spanning approximately 217.23 km^2, Amaravati encompasses 25 villages located in the Thulluru, Mangalagiri, and Tadepalli Mandals of Guntur District. The region exhibits a varied geomorphic landscape that includes alluvial plains, residual hillocks, riverine formations, and a complex network of drainage channels. This diversity underscores the importance of hydrogeomorphological assessment in supporting sustainable urban planning and effective groundwater management.

Purpose and Scope of the Study

The hydrogeomorphological studies aim to delineate both surface and subsurface geomorphic features that influence groundwater occurrence, movement, recharge potential, and surface-water interaction within Amaravati's proposed city limits. These studies are integral to the broader environmental and hydrological framework established for the capital region by APCRDA. The city's development plan emphasizes a "Green and Blue City" concept, integrating natural drainage networks, waterbodies, and green corridors. Understanding the area's hydrogeomorphological characteristics is central to this vision, as it ensures effective groundwater recharge, flood mitigation, stormwater management, and the sustainability of water resources.

1.1. OBJECTIVES

- Assess and map the geomorphological features and hydrological systems that influence surface water and groundwater behavior.

- Identify and prioritize potential zones for constructing water retention structures, recharge wells, and implementing rainwater harvesting interventions.
- Integrate hydrological, hydrogeological, and geophysical datasets to evaluate groundwater availability, quality, and sustainability.
- Provide actionable recommendations for stormwater drainage planning and flood risk reduction in accordance with the Amaravati master plan.

1.2. SCOPE OF WORK

- Detailed hydrogeomorphological mapping through the interpretation of satellite imagery, field verification, and geospatial analysis.
- Execution of geophysical surveys to delineate subsurface lithological and aquifer characteristics.
- Compilation and assessment of hydrological and hydrogeological data, including rainfall, runoff, infiltration, and recharge potential.
- Preparation of integrated water resource management strategies, supported by thematic maps, cross-sections, and 3D visualizations.
- Submission of a comprehensive report containing spatial datasets to support planning, design, and decision-making processes.

Significance of the Study

This hydrogeomorphological study provides a critical scientific baseline for the sustainable management of water resources in Amaravati Capital City. It ensures that urban development is supported by resilient hydrological systems and safeguards the ecological balance of the city.

1.3. LOCATION AND ACCESSIBILITY

The Amaravati Capital City, the administrative capital of Andhra Pradesh, is strategically located between Vijayawada and Guntur on the right bank of the Krishna River within Guntur District, covering an area of about 217.23 km^2 comprising 25 villages across Thulluru, Mangalagiri, and Tadepalli Mandals. Geographically, the city lies between latitudes 16°24'30"N to 16°31'00"N and longitudes 80°22'30"E to 80°37'00"E, with elevation ranging from 18 m to 260 m above mean sea level. The terrain is characterized by a combination of alluvial plains, residual hillocks, pediplains, and floodplains influenced by the Krishna River, Kondaveeti Vagu, and Paleru Vagu, which form the main drainage systems governing runoff and recharge patterns. The Krishna River defines the northern boundary of the city, while the south eastern portion is bordered by undulating hillocks near Tadepalli and Velagapudi.

Amaravati is well connected through multiple transport networks—NH-16 (Chennai–Kolkata) and NH-65 (Hyderabad–Machilipatnam) provide regional road connectivity, the Vijayawada Railway Junction and K.C. Canal Station near Tadepalli offer rail access, and the Gannavaram International Airport located about 22 km northeast ensures air connectivity. The physiography of the region, encompassing alluvial plains, residual hills, pediment zones, and valley fills, plays a vital role in controlling groundwater occurrence, infiltration potential, and surface drainage. Its strategic location and excellent accessibility make Amaravati a favorable site for sustainable urban development and integrated hydrogeomorphological planning. The location map of Amaravati Capita City is shown in Figure 1

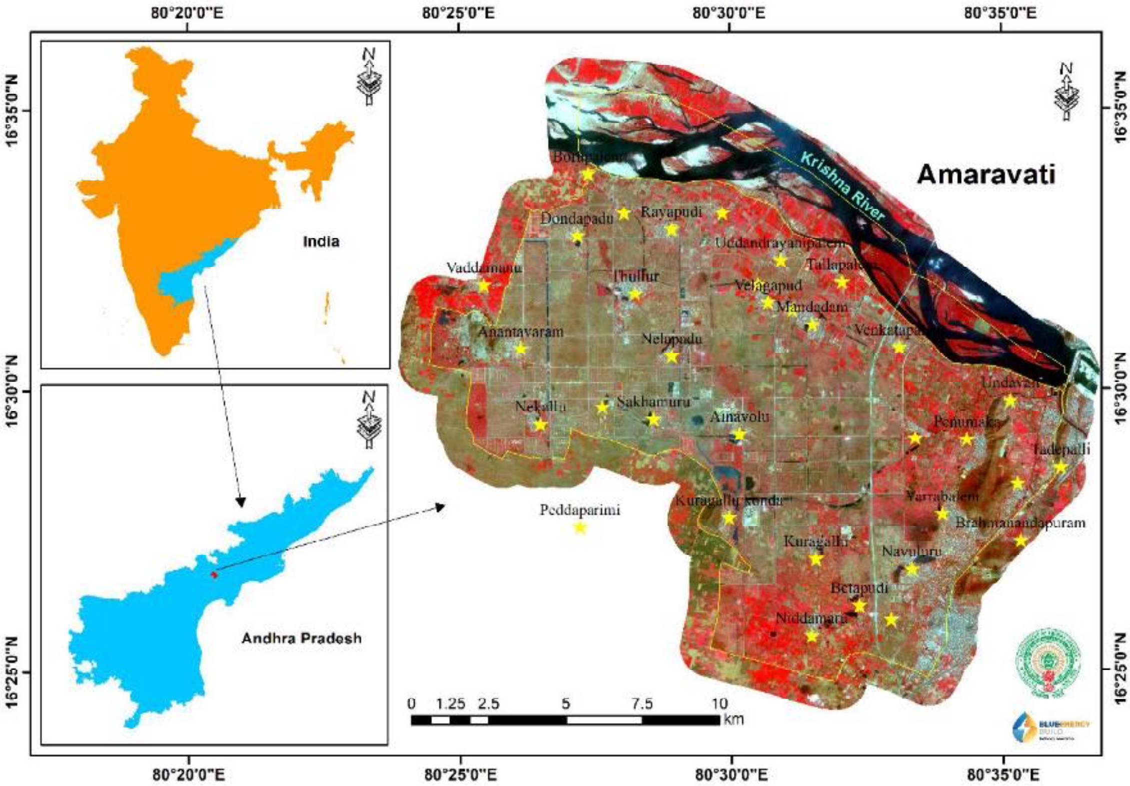


Figure 1:Location map of Amaravati Capital City

Master Plan of Amaravati Capital City

Figure 2 presents the master plan of Amaravati Capital City, as obtained from the Andhra Pradesh Capital Region Development Authority (APCRDA). This master plan has served as the foundational reference for conducting comprehensive hydrogeomorphological studies within the area. The use of the official master plan ensures that all assessments and analyses are aligned with the planned urban layout and development framework, enabling accurate integration of scientific findings into the broader context of city planning and resource management.

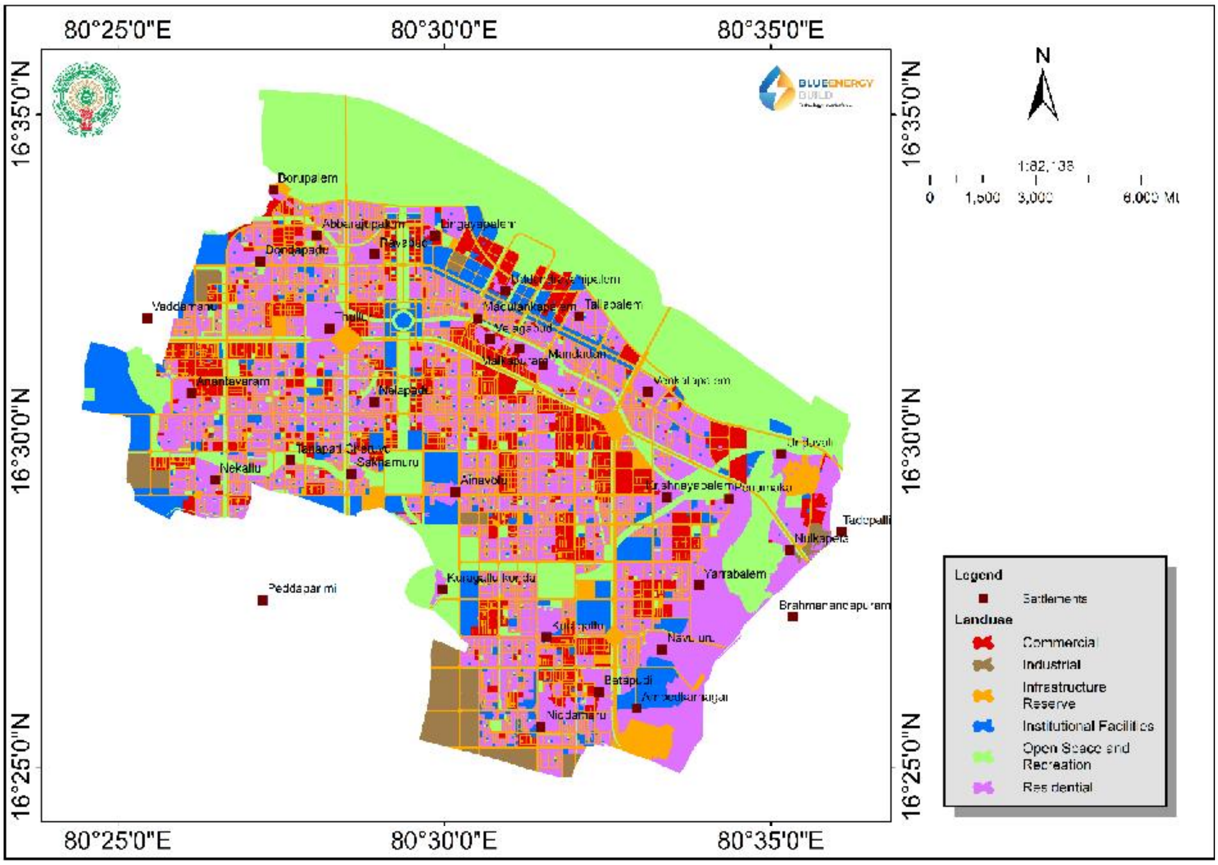


Figure 2: Master Plan of Amaravati Capital City (Source: APCRDA)

1.4. DATA COLLECTION

The primary objective of the data collection phase is to acquire and process essential geospatial datasets necessary for conducting comprehensive, village-level microplanning within the project area. These datasets form the foundation for detailed analyses and integration with ground-based surveys, supporting effective planning for water resources, infrastructure development, land use, and environmental sustainability. The data collection process is categorized into Primary Data and Secondary Data.

Secondary Data Collection

- Toposheets and Village Boundaries: This involves gathering 1:50,000 scale toposheet maps, specifically sheets numbered 65D6, 65D7, 65D10, and 65D11 from the Survey of India (SOI). Additionally, village boundary maps are collected to accurately delineate administrative and planning units within the study area.

- High-Resolution Satellite Imagery: Recent, cloud-free satellite imagery is procured from various sources, including the National Remote Sensing Centre (NRSC), Sentinel satellites, and Google Earth. The imagery undergoes radiometric and geometric corrections to ensure accuracy and reliability for further analysis.
- Digital Elevation Model (DEM): High-resolution elevation data with a 2-meter pixel size is acquired from the Amaravati Capital Region Development Authority (APCRDA), complemented by 30-meter pixel data from the Shuttle Radar Topography Mission (SRTM). These datasets facilitate detailed terrain and hydrological modeling.
- Literature and Map Collection: Spatial maps of the capital city and its master plan are collected from APCRDA. Additional documentation includes geotechnical investigation reports, flood study and management reports, rainfall datasets, and National Green Tribunal (NGT) reports from APCRDA. Reports from the Central Ground Water Board (CGWB) and the Geological Survey of India (GSI) are also incorporated. Furthermore, relevant research publications from institutions such as IIIT, IIT, NIT, and other universities and research organizations are reviewed. Water quality and supply reports are obtained from the Rural Development and Irrigation Departments.

Primary Data Collection (Field Level Data)

- Geophysical Surveys: Field investigations include resistivity surveys using Vertical Electrical Soundings conducted at 651 locations and magnetic surveys conducted at 650 locations. These surveys help characterize subsurface conditions relevant to water resource management.
- Hydrogeological Survey and Geological Mapping: Comprehensive surveys and mapping activities are undertaken to document the hydrogeological and geological attributes of the area.
- Palaeoflood Survey and Sampling: Investigations are carried out to gather evidence of historic flood events through palaeo flood surveys and sample collection, contributing to flood risk assessment.
- Pumping Test for Aquifer Parameters: Pumping tests are performed to determine key aquifer parameters, providing critical data for groundwater resource evaluation and management.

1.5. TOPOSHEET, SATELLITE IMAGES AND DIGITAL ELEVATION MODEL

Survey of India (SOI) Toposheets

The Survey of India (SOI) toposheets, specifically sheets 65D6, 65D7, 65D10, and 65D11, form a composite mosaic (Figure 3) that serves as a foundational spatial dataset for micro-level planning within the Amaravati region. By overlaying these sheets with the Amaravati boundary and village locations, planners gain access to a highly authoritative base layer for geospatial analysis.

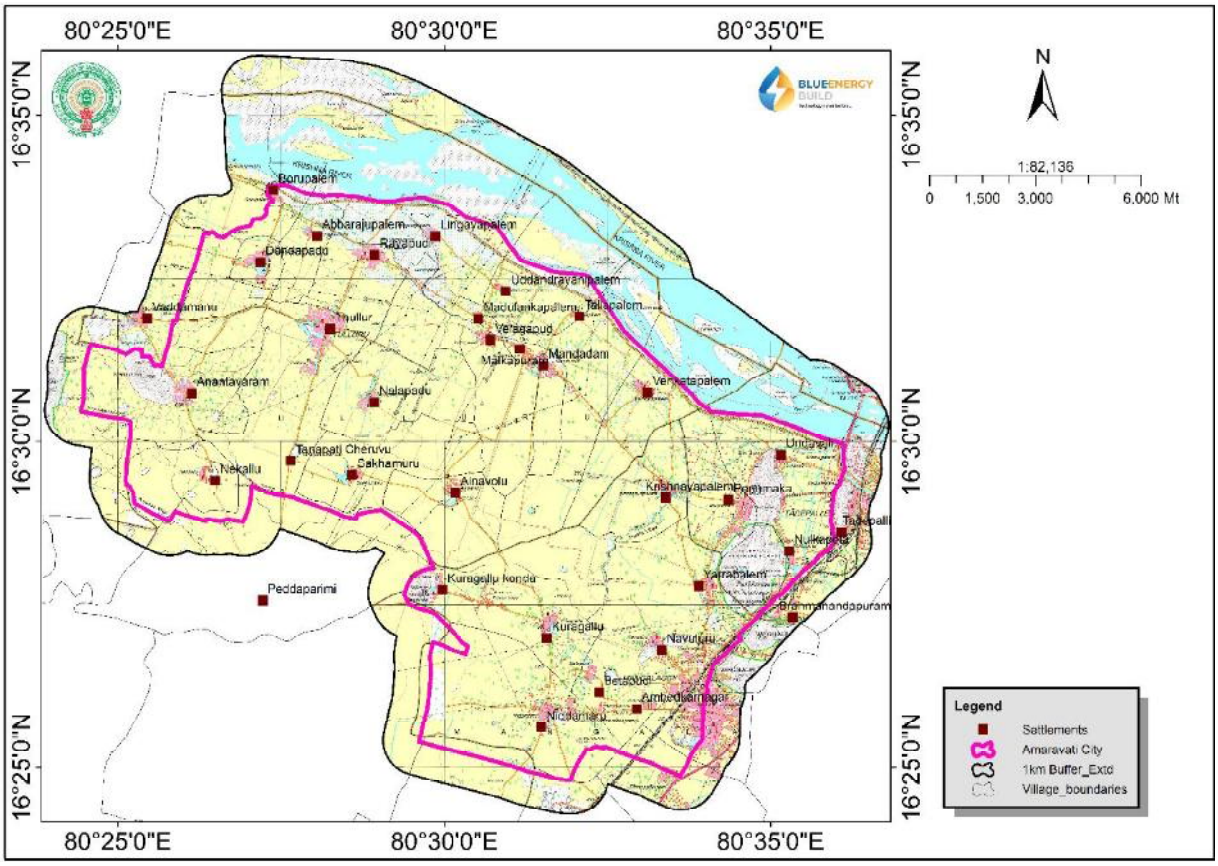


Figure 3: Toposheet map (65D6, 65D7, 65D10 and 65D11) along with Amaravati Capital City

These toposheets are characterized by detailed representations of terrain features. They include contour lines that depict elevation changes, drainage patterns that reveal the flow of surface water, and landform configurations that outline the physical structure of the landscape. Such detailed spatial information is indispensable for tasks like watershed delineation and morphometric analysis, which are commonly conducted using Geographic Information Systems (GIS) and remote sensing techniques.

Integrating SOI toposheet data into GIS platforms allows for precise overlay with other thematic layers, such as slope, land use, geology, and hydrology. This capability supports advanced multi-criteria decision support systems, aiding in infrastructure siting, water resource management, and soil-conservation planning. The detailed topographic information provided by these toposheets enhances both the spatial accuracy and hydrological integrity of micro-planning initiatives, ultimately supporting informed village-level development decisions.

Satellite Imagery

The high-resolution satellite imagery, dated 02/19/2025, obtained from the IRS-R2A L4FX database, provides a comprehensive and processed visual representation of Amaravati Capital City. This imagery, illustrated in Figure 4, is annotated with the names of villages and clearly demarcated by yellow boundary lines, creating a foundational geospatial dataset essential for village-level microplanning.

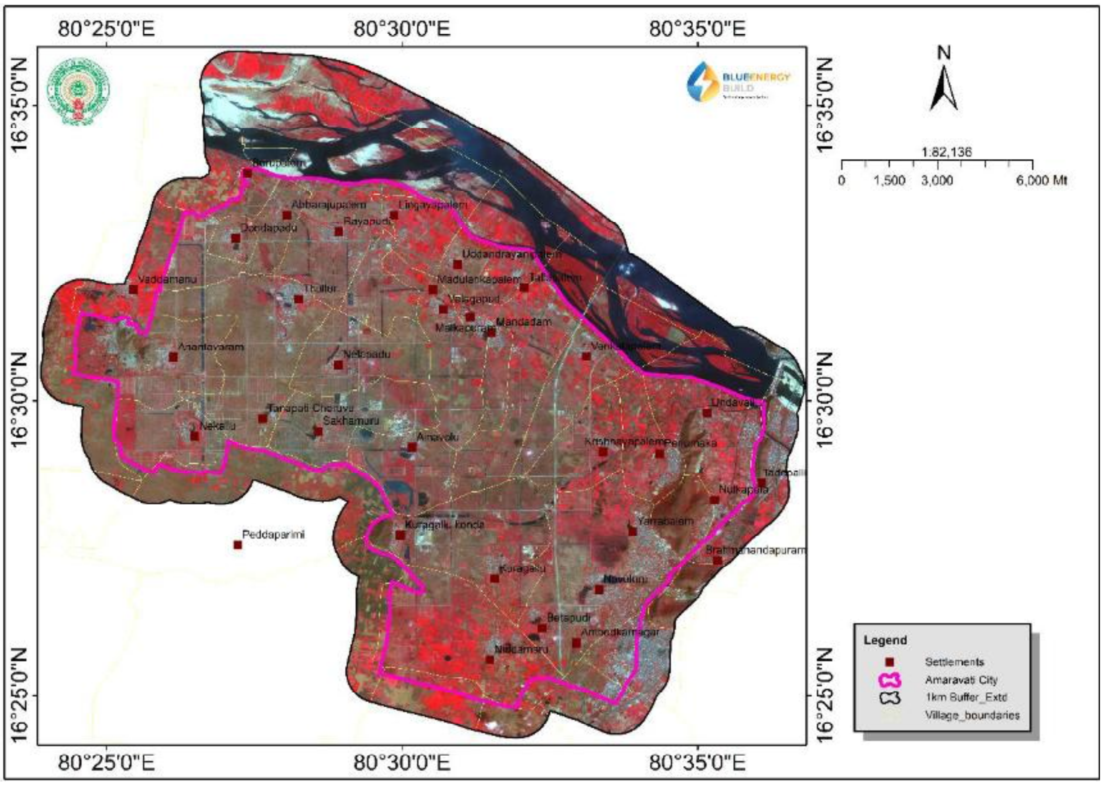


Figure 4: Satellite Image of Amaravati Capital City along with Village boundaries and Settlements

Captured at a spatial resolution of just a few meters, the satellite imagery enables precise mapping of existing land use, infrastructure, vegetation, and hydrographic features within the Amaravati region. Its high level of detail allows for accurate spatial alignment with field-based surveys, ensuring consistency and reliability in data interpretation and planning.

This detailed imagery plays a vital role in scientific micro-planning processes, as it supports the delineation of village boundaries, identification of water resources and drainage patterns, and assessment of infrastructural connectivity. By facilitating a clear understanding of the spatial layout and environmental attributes, the imagery underpins informed decision-making for development and resource management at the village level.

Digital Elevation Model (DEM)

Figure 5 presents the Digital Elevation Model (DEM) of Amaravati Capital City, captured at two distinct spatial resolutions: 30 meters and 2 meters. Both DEMs are accompanied by overlays that delineate the boundaries of villages and the Amaravati Capital City itself. The 30-meter resolution DEM offers a broad regional perspective, making it suitable for comprehensive terrain analysis. In contrast, the 2-meter resolution DEM provides a highly detailed view, allowing for the precise identification of topographical features and micro-level variations in elevation.

By integrating village boundaries and capital city limits into these models, planners and decision-makers gain valuable spatial context that is essential for effective planning across various administrative levels. The availability of DEMs at multiple resolutions supports both wide-ranging assessments and focused, localized studies. This ensures that those involved in infrastructure development, water resource management, and environmental planning have access to accurate and detailed elevation data.

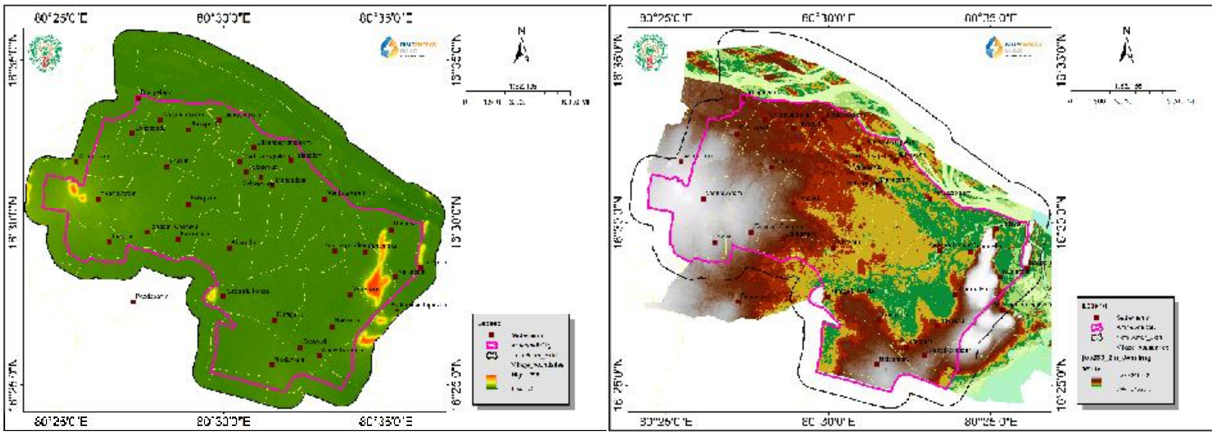


Figure 5: Digital Elevation Model (DEM) of the Amaravati region at two different spatial resolutions: (a) 30 meters (SRTM data base) and (b) 2 meters (APCRDA data base)

Utilizing this elevation data, planners and analysts are able to perform precise terrain analyses, including the evaluation of slope gradients and the determination of surface water flow direction. The DEM is instrumental in delineating watersheds, which assists in identifying areas where water naturally collects and channels. Additionally, it facilitates the detection of topographic depressions and ridges, providing critical insights into water accumulation, drainage patterns, and landform development.

Through these capabilities, the DEM supports informed decision-making in areas such as infrastructure development, water resource management, and environmental planning. By ensuring that micro-level planning efforts are grounded in accurate topographical information, the DEM contributes to the reliability and effectiveness of development and conservation initiatives within Amaravati Capital City.

1.6. PHYSIOGRAPHY

The Amaravati Capital City area exhibits a diverse and transitional physiographic setting shaped by fluvial and denudational processes. Covering an area of about 217.23 km^2, the region extends across Thulluru, Tadepalli, and Mangalagiri mandals of Guntur District, between 16°24'30"N to 16°31'00"N latitudes and 80°22'30"E to 80°37'00"E longitudes, with elevation ranging from 18 m to 260 m above mean sea level. The terrain is characterized by gently undulating topography, comprising alluvial plains, pediplains, valley fills, and isolated residual hillocks. The northern and northeastern parts, adjoining the Krishna River, form extensive alluvial and floodplains that are gently sloping and agriculturally fertile, while the central and southern zones are dominated by pediplains and denudational uplands developed over weathered crystalline rocks. The residual hillocks occurring near Tadepalli, Velagapudi, and Ananthavaram rise up to 260 m and exert a strong influence on local drainage, slope pattern, and micro-watershed development.

Physiographically, the area can be categorized into three major units — the floodplains of Krishna River, the gently undulating pediplains, and the residual hillocks of the southern uplands. The Kondaveeti Vagu and its tributaries drain the central portion of the city, forming a dendritic to sub-dendritic drainage pattern that ultimately joins the Krishna River along the northern boundary. Seasonal inundation is common in low-lying tracts, particularly in the Kondaveeti Vagu catchment, due to inadequate drainage gradients and river backflow during monsoon floods. The physiographic diversity of Amaravati provides a strong geomorphic control on groundwater occurrence, infiltration capacity, and recharge dynamics, which are crucial for sustainable urban development. The combination of fluvial plains, denudational pediplains, and residual uplands forms an integrated hydrogeomorphological framework that governs both surface and subsurface hydrological behavior within the Amaravati Capital City region.

1.7. CLIMATE

Over a span of 30 years, a time series analysis was conducted using the CHIRPS dataset (Climate Hazards Group Infra-Red Precipitation with Station data), leveraging python programming techniques to assess rainfall patterns in the Amaravati region. This analysis identified 2024 as the year with the highest recorded rainfall. Monthly rainfall data spanning the past three decades reveals that July consistently receives the greatest amount of precipitation annually. Furthermore, the most significant 24-hour rainfall event in recent years occurred at the end of August and in September 2024. A spatial map illustrating the annual rainfall distribution is available in Figure 6.

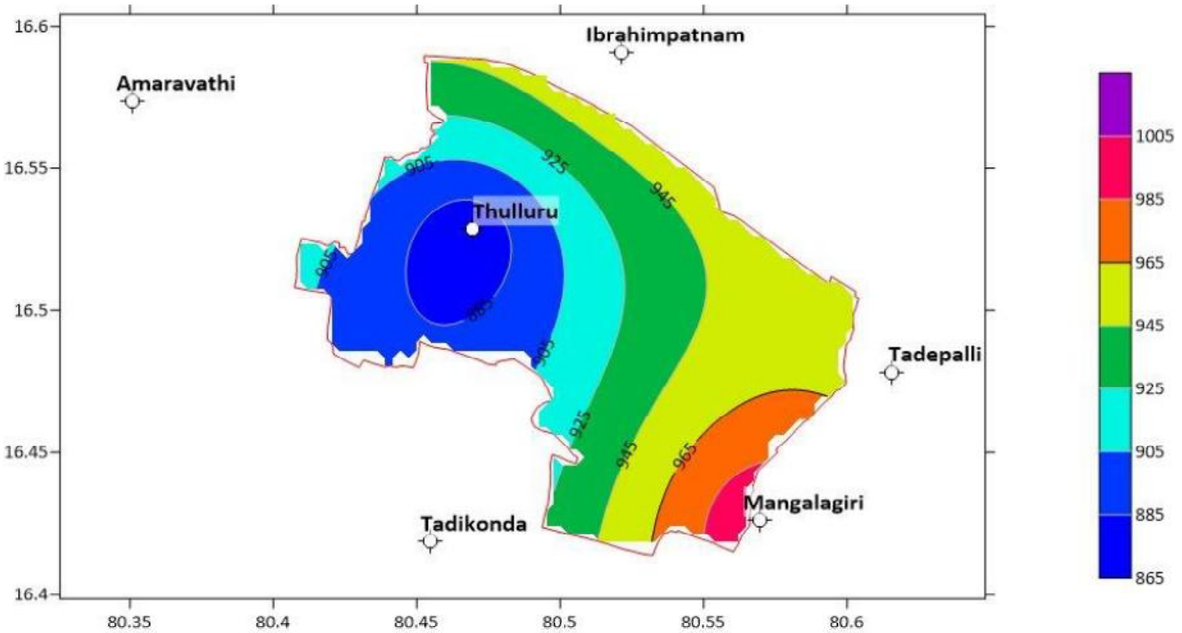


Figure 6: Average Annual Rainfall (mm) of the Study Area (1993 to 2024)

The broader Amaravati Capital City region is classified as having a tropical monsoon climate. This classification is characterized by the presence of hot summers, humid monsoon seasons, and mild winters. Situated within the Krishna River basin of Guntur District, the area is influenced by both the Southwest monsoon (occurring from June to September) and the Northeast monsoon (from October to November). The interplay of these monsoons dictates the region's rainfall distribution and shapes seasonal hydrological processes. These climatic conditions play a crucial role in regulating groundwater recharge, surface runoff, and evapotranspiration, all of which are essential considerations in hydrogeomorphological assessments.

The summer season in Amaravati extends from March to May, with maximum daily temperatures typically ranging from 38°C to 44°C, and occasionally surpassing 45°C. The monsoon season, lasting from June to October, brings approximately 850–950 mm of rainfall annually, accounting for nearly 85% of the region's total yearly precipitation. Additional rainfall from the Northeast monsoon is received during October and November. The winter season, spanning from December to February, is marked by cool and dry conditions, with average temperatures ranging from 16°C to 28°C. Relative humidity in the region fluctuates between 40% and 85%, peaking during the monsoon months (IMD, 2022; APSDMA, 2021; APCRDA, 2018; CGWB, 2020; and IMD, 2023).

The mean annual potential evapotranspiration (PET) in Amaravati is estimated to be between 1,500 and 1,800 mm, which exceeds the average annual rainfall. This disparity underscores the necessity of implementing rainwater harvesting, artificial recharge structures, and efficient stormwater management strategies in the region. Predominant wind directions are southwesterly during the summer and monsoon periods, shifting to northeasterly during the winter months. Although these climatic conditions are generally conducive to agriculture and water resource development, they highlight the importance of integrated planning to manage seasonal water scarcity and to support sustainable groundwater utilization (IMD, 2022; APSDMA, 2021; APCRDA, 2018; CGWB, 2020; and IMD, 2023).

Rainfall Trends at Monitoring Stations

The annual rainfall graphs compiled from 30 years of data across various stations in Amaravati—specifically Amaravati, Thullur, Mangalagiri, Tadepalli, Tadikonda, and Ibrahimpatnam—demonstrate a consistent decreasing trend in rainfall at each location. Despite yearly fluctuations, all stations exhibit a similar pattern in annual precipitation, indicating that rainfall amounts tend to follow the same trend across the region year after year (Figure 7).

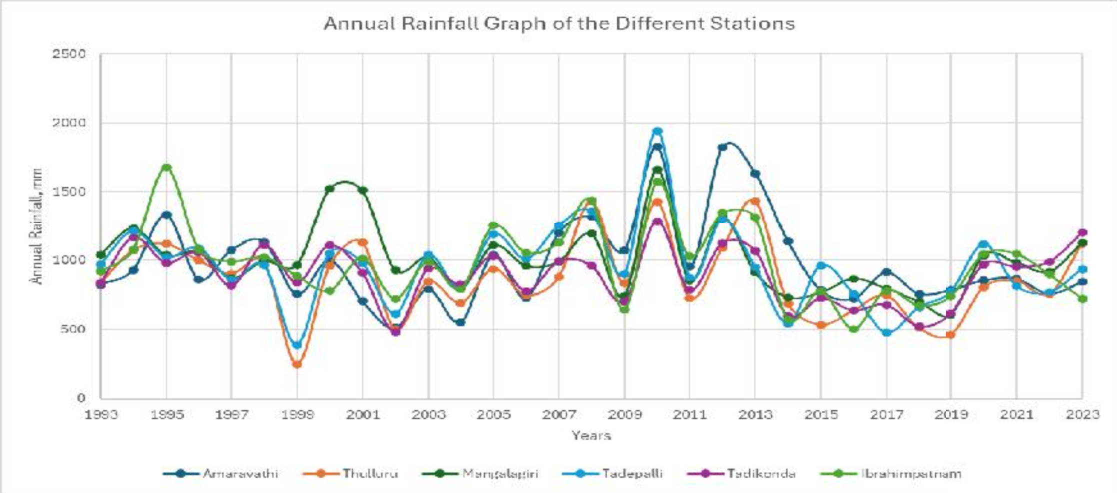


Figure 7: Annual rainfall trend of different Stations in Amaravati Area

1.8. FLORA AND FAUNA

Except for the hilly terrains, the study area lacks significant plantation cover. The Amaravati Capital City region, situated along the right bank of the Krishna River, features a diverse mosaic of natural and modified ecosystems. These ecosystems are shaped by the interplay of the riverine landscape, agricultural practices, and semi-urban development. Vegetation in the region is predominantly classified as Southern Tropical Dry Deciduous, interspersed with riverine vegetation, scrublands, and agro-ecosystems. Despite considerable alteration of the natural vegetation due to cultivation and settlement expansion, areas along riverbanks, canals, and village groves continue to support patches of native flora and habitats for local fauna (APCRDA, 2018; BSI, 2019; ZSI, 2019; APSBB,2020; IUCN, 2023).

Major Flora

The region hosts a variety of floral species, including Azadirachta indica (Neem), Ficus religiosa (Peepal), Ficus benghalensis (Banyan), Tamarindus indica (Tamarind), Albizia lebbeck, Delonix regia, Cassia fistula, and Butea monosperma. Riparian zones along the Krishna River and Kondaveeti Vagu are home to hydrophytic and semi-aquatic species such as Typha angustata, Cyperus rotundus, and Saccharum spontaneum, which play an important role in stabilizing riverbanks and filtering sediments. Agricultural lands are primarily planted with paddy, maize, and cotton, and are bordered by hedgerow vegetation and fruit-bearing trees like Mango (Mangifera indica), Guava (Psidium guajava), and Coconut (Cocos nucifera). Introduced species such as Prosopis juliflora and Leucaena leucocephala have also become established in fallow lands and along canal bunds.

Faunal Diversity

The faunal diversity in Amaravati is closely linked to its proximity to the Krishna River floodplain, supporting both terrestrial and aquatic species. Common mammals observed in the area include the Indian Hare (Lepus nigricollis), Common Mongoose (Herpestes edwardsii), Five-striped Palm Squirrel (Funambulus pennantii), and Fruit Bat (Pteropus giganteus). The region's avifauna is particularly rich, supported by wetland habitats and agricultural landscapes. Notable bird species include the Indian Pond Heron (Ardeola grayii), Little Cormorant (Microcarbo niger), various Egrets (Egretta spp.), Kingfishers (Alcedo spp.), Black Drongo (Dicrurus macrocercus), as well as weaver birds and bee-eaters. During the winter, migratory waterfowl such as Northern Pintail, Garganey, and Common Teal are occasionally spotted along the Krishna River and adjacent wetlands. Reptiles like the Garden Lizard (Calotes versicolor) and Common Rat Snake (Ptyas mucosa) are frequently encountered, while amphibians such as Bufo melanostictus are common in irrigated fields. Aquatic habitats support Indian Major Carps, Catfish, and Tilapia, contributing to local fisheries.

Conservation Status and Ecological Importance

No rare, endangered, or threatened (RET) species, as classified by the IUCN Red List or Wildlife Protection Act, 1972 (Schedules I & II), have been reported within the Amaravati Capital City boundaries. Nevertheless, the Krishna River corridor functions as a vital ecological zone for avifaunal migration and aquatic biodiversity. The maintenance of green buffers, wetland retention zones, and plantation belts along riverbanks and drainage networks is critical for preserving ecological balance in the face of rapid urbanization.

CHAPTER 2: THEMATIC MAPS OF AMARAVATI CAPITAL CITY

2.0. GENERAL

The Amaravati Capital City area was analyzed using a series of GIS-based thematic maps derived from remote sensing data, field observations, and secondary sources such as Survey of India Toposheets, GSI Geological Maps, and NRSC IRS satellite data. These thematic layers were prepared at a 1:2,000 scale and form the foundation for understanding the terrain characteristics, subsurface conditions, drainage behavior, and recharge potential of the region (APCRDA, 2018; GSI, 2019; CGWB, 2020). Integration of these maps in a GIS environment enabled delineation of hydrogeomorphological units, identification of groundwater potential zones, and preparation of a comprehensive spatial database for sustainable water management in Amaravati Capital City.

2.1. SLOPE CHARACTERISTICS

The slope map (Figure 8) of the Amaravati Capital City region reveals a diverse range of slope gradients, spanning from flat surfaces to very steep inclines, with slope angles varying from 0 degrees up to more than 55 degrees. The predominant slope direction throughout the area is towards the Northeast.

Most of the study areas feature nearly level to very gentle slopes, providing favorable conditions for infrastructure development and agriculture. However, strong to very steep slopes are distinctly observed along the eastern side of the region, as well as around isolated hills located in the west and southern portions of the area.

Slope and aspect play a significant role in shaping landforms and guiding their development. These two factors directly influence geomorphic processes such as erosion and landform degradation, thereby affecting the overall topography and landscape evolution within the Amaravati Capital City area.

2.2. DRAINAGE AND WATER BODIES

The Amaravati Capital City area is an integral part of the Krishna River Basin, located along the right bank of the Krishna River, one of India's major east-flowing rivers. The region exhibits a well-defined natural and artificial drainage network, consisting of the Kondaveeti Vagu system, its tributaries, irrigation canals, and a series of ponds and reservoirs that together form the city's blue infrastructure. The city's drainage pattern is largely dendritic to sub-dendritic, influenced by gentle topography and a network of natural streams and man-made channels. The drainage and water bodies map of Amaravati Capital City is shown in Figure 9.

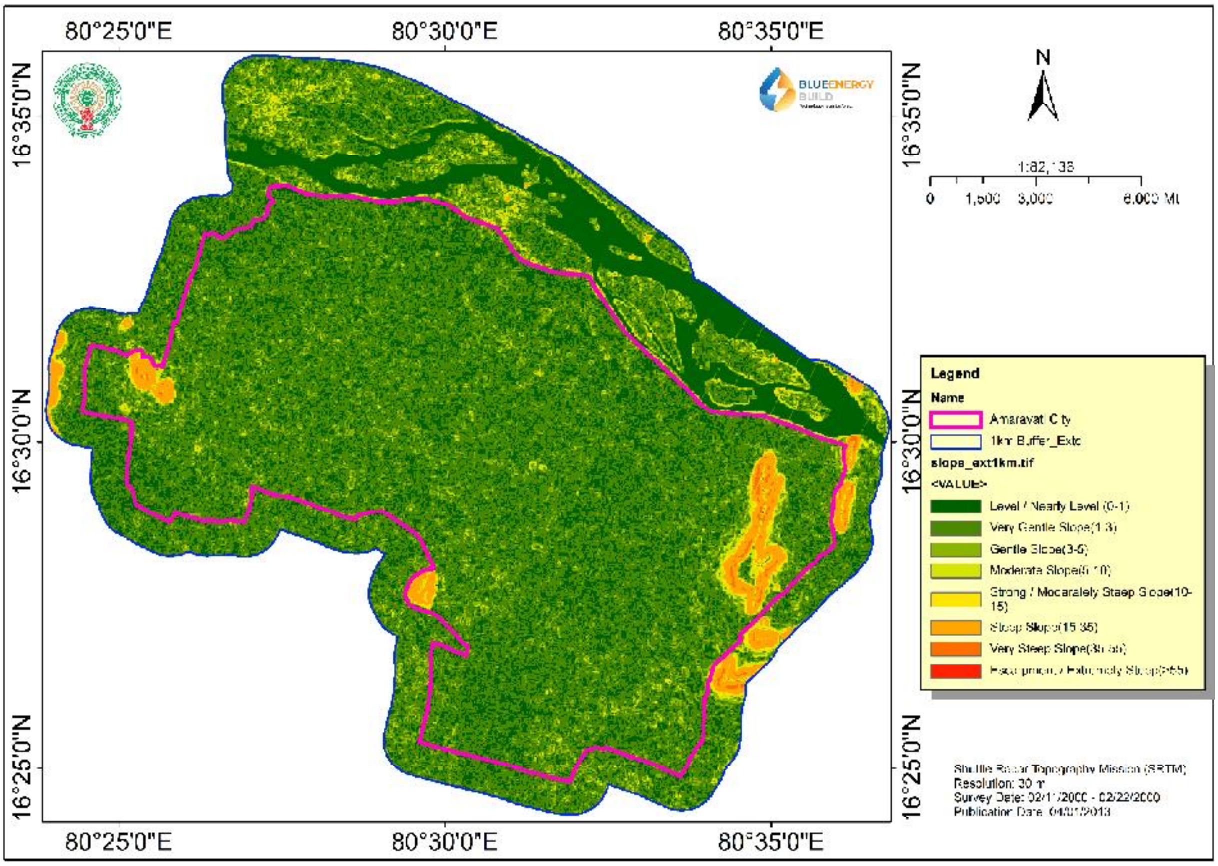


Figure 8: Slope map of the Study Area

Natural Drainage System

The Kondaveeti Vagu serves as the primary natural drainage channel within the Amaravati Capital City area. This channel originates from the Kondaveedu Hill Range and flows in a northeast direction, traversing Tadikonda, Thulluru, and Mangalagiri Mandals before joining the Krishna River near Undavalli, which is situated upstream of the Prakasam Barrage. The Kondaveeti Vagu encompasses a total catchment area estimated between 421 and 453 square kilometers, with its main channel extending approximately 31 kilometers in length.

Several tributaries, including Pala Vagu, Ayanna Vagu, and Kottela Vagu, converge with Kondaveeti Vagu within the boundaries of the capital region. These tributaries, together with smaller feeder streams, play a crucial role in shaping the hydrological characteristics of the basin.

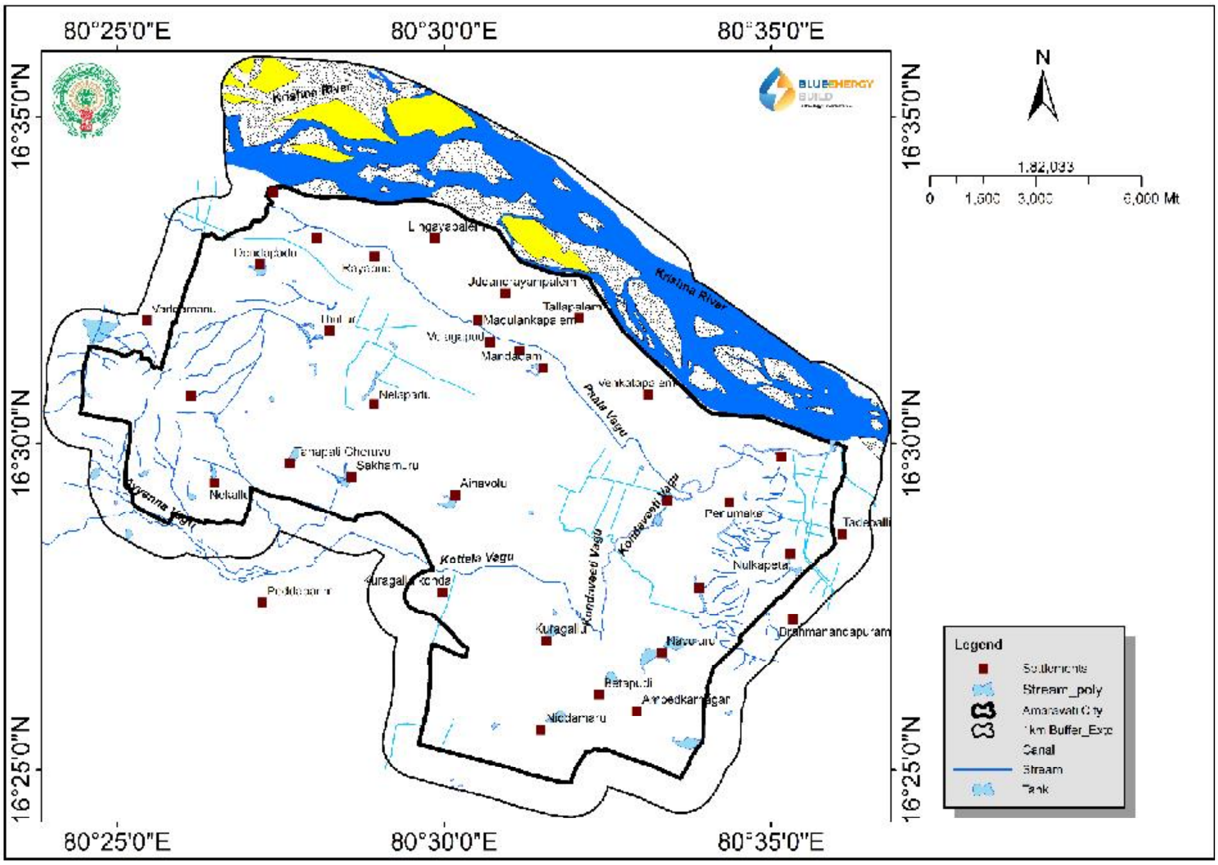


Figure 9: Stream and Water bodies map of the study area

The drainage gradient of the area generally follows a southwest to northeast direction, with elevations ranging from +260 meters in the hillocks near Tadepalli to +18 meters along the Krishna floodplain. Low-lying sections, particularly in the eastern and central portions of the city, are susceptible to seasonal flooding. This inundation occurs mainly during periods of monsoon rainfall, when elevated water levels in the Krishna River limit the outflow from Kondaveeti Vagu.

Additionally, the central part of the region displays a noticeable absence of stream networks. This may be attributed to zones with high groundwater recharge potential or significant geological variability, which influences the surface hydrology and stream formation in the area.

Water Bodies

The capital city region hosts forty-seven natural and man-made water bodies, distributed across the floodplain and low-lying terrain. These include tanks, ponds, reservoirs, and irrigation canals that support both flood management and groundwater recharge. According to the EIA and EMP Report (APCRDA, 2018), the total area under existing water bodies is approximately 2,578 hectares, including rivers, canals, reservoirs, and ponds. Notable among them are the Neerukonda, Krishnayapalem, Sakhamuru, Pedaparimi, Lam, and Vykuntapuram Reservoirs, which are key components of the flood control and water storage system proposed under the Blue and Green Plan.

All existing water bodies are proposed to be retained and enhanced, serving dual purposes of stormwater detention and ecological balance. The Green–Blue Lattice Plan integrates these water bodies into a network of linear parks, riparian buffers, and ecological corridors, ensuring that the natural hydrology is preserved. New detention ponds have been proposed at strategic low-lying junctions and stream confluences to manage urban runoff during extreme rainfall events.

2.3. GROUNDWATER HYDROLOGY

The groundwater hydrology (Figure 10) of the Amaravati Capital City region is closely influenced by the area's geological formations, geomorphological features, topographic gradient, and the hydrological connectivity within the Krishna River basin. This region contains a heterogeneous aquifer system that transitions from unconfined to semi-confined alluvial aquifers in the northern part to fractured crystalline aquifers in the southern uplands. The Kondaveeti Vagu, Krishna River, and their associated floodplains serve as important recharge and discharge systems, facilitating the interaction between surface water and groundwater regimes (CGWB, 2020; APCRDA, 2018).

Groundwater extraction in Amaravati city occurs primarily through two types of wells: tube wells and large open wells. Tube wells are indicative of the shallow water table present in the river sand beds along the southern part of the Krishna River and the linear stretches of Borupalem, Abbarajupalem, Rayapudi, Velagapudi, Malkapuram, Krishnayapalem, and Undavalli. These tube wells typically have depths of less than 100 feet, with most being less than 50 feet deep.

2.4. GEOLOGY

The Amaravati Capital City region is situated within the Krishna River Basin, part of the Eastern Peninsular Region of India. The area's geology is defined by the presence of Precambrian crystalline formations, which are overlain by Quaternary alluvial deposits (APCRDA, 2018; GSI, 2019). This region marks a transitional zone between the Eastern Ghats Mobile Belt (EGMB) and the Krishna Alluvial Plains, exhibiting a range of lithological and structural characteristics that have a direct impact on groundwater availability, drainage patterns, and the geomorphic development of the landscape (CGWB, 2020). The principle geological units of Amaravati capital City is given in Table 1. The lithological map of the study area is shown in Figure11.

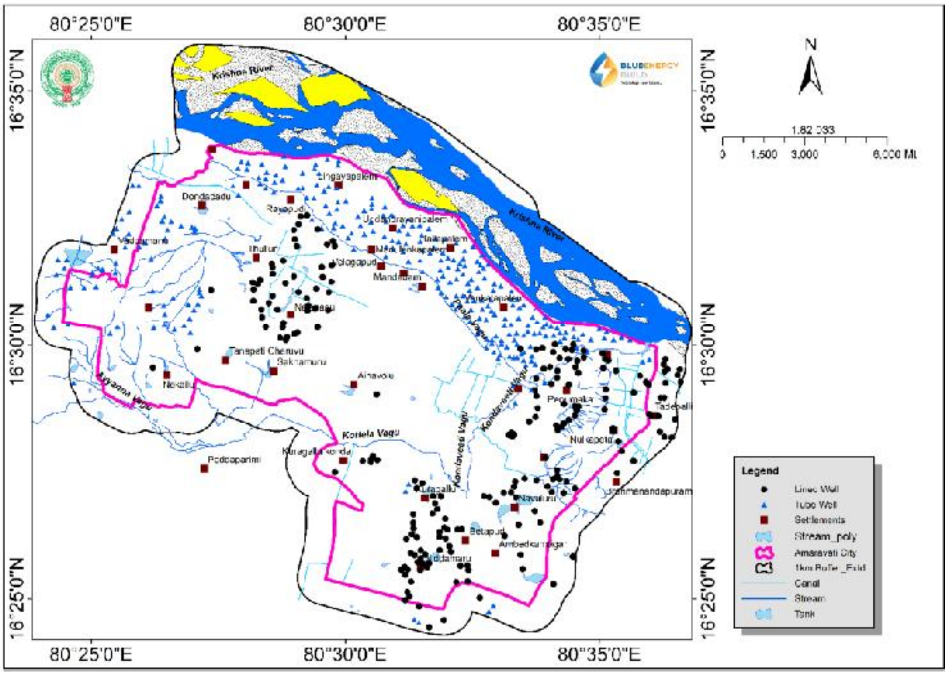


Figure 10: Groundwater hydrology of Amaravati Capital City

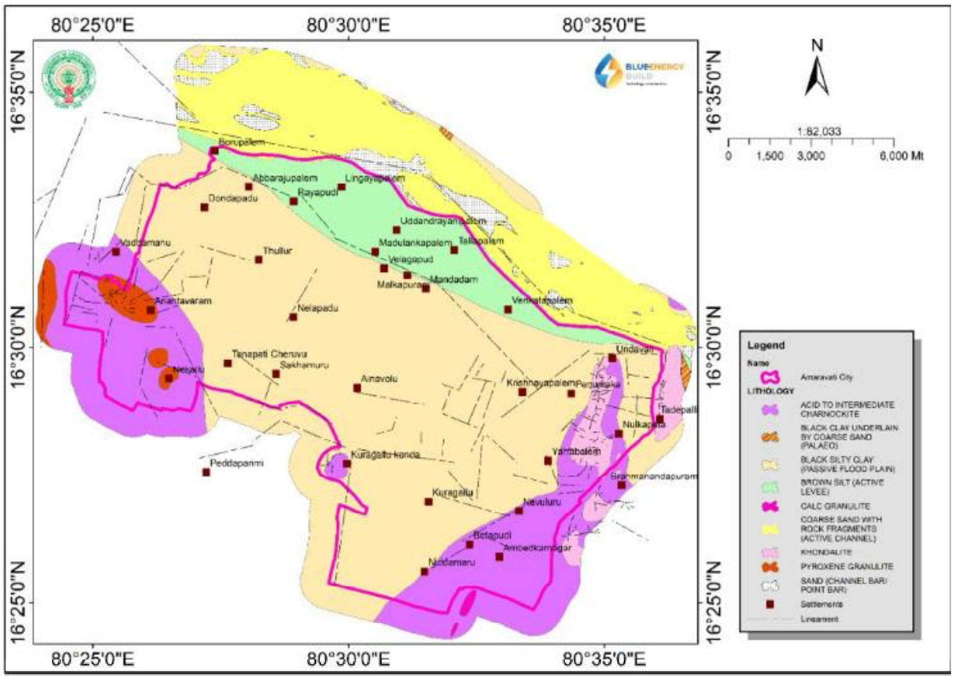


Figure11: Geological map of the study area (after GSI, 2021)

Table 1:Principal Geological Units of Amaravati Capital City

Geological Unit	Description
Acid to Intermediate Charnockite	This unit comprises hypersthene–granite gneiss and quartz–feldspathic granulites. These rocks form the basement in the southern uplands, notably near Tadepalli, Velagapudi, and Ananthavaram. They are characterized by their hard, compact, and massive nature, exhibiting low primary porosity. However, the presence of secondary fractures and joints enables localized groundwater movement(GSI, 2019; CGWB, 2020).
Black Clay underlain by Charnockite (Paleo Channel Deposits)	These deposits are found along the buried channels of ancient Krishna River courses. The black clay layers are rich in organic matter and are underlain by charnockitic bedrock, leading to poorly drained depressions with limited infiltration. These paleo-channel deposits influence subsurface hydrology and recharge gradients (APCRDA, 2018).
Black Silt Clay (Passive Flood Plain Deposits)	Formed in low-energy depositional environments along the inactive floodplain areas of the Krishna River, these fine-grained, cohesive clays are poorly drained and susceptible to seasonal waterlogging. They provide temporary storage for floodwater (CGWB, 2020).
Brown Silt (Active Levee Deposits)	Located along the current levee and meander belts of the Krishna River, these moderately permeable brown silt layers are part of the active floodplain system. They facilitate moderate infiltration and shallow aquifer recharge, supporting the most productive groundwater zones in the area (APCRDA, 2018).
Calc-Granulite	This unit consists of calc-silicate rocks and garnetiferous granulites, found as discontinuous lenses and ridges within the charnockitic terrain, particularly near the southern margins. These rocks are dense and compact, with low permeability and minimal groundwater storage potential (GSI, 2019).
Khondalite	These high-grade metamorphic rocks, formed by garnet–sillimanite–graphite gneiss, appear as linear ridges and isolated hillocks in the southwestern part of the region. Khondalite forms residual uplands with limited infiltration, but these areas contribute to runoff and serve as sources for nearby valleys (GSI, 2019; NRSC, 2020).
Pyroxene Granulite	Medium- to coarse-grained, dark hypersthene–pyroxene granulites are exposed in scattered patches south of Velagapudi and Tulluru. These massive and hard rocks create moderate topographic highs, and their fractured zones may function as secondary aquifers (CGWB, 2020).

Structural Features

The crystalline basement of the region contains a network of minor lineaments and joints, trending northeast–southwest and northwest–southeast, which align with the broader tectonic structure of the Eastern Ghats Mobile Belt (NRSC, 2020). These fractures and joints enhance secondary porosity and transmissivity in the granitic rocks, serving as preferential pathways for groundwater movement (CGWB, 2020).

Overall, the Amaravati Capital City area is defined by its transitional geology between the Eastern Ghats Mobile Belt and the Krishna Alluvial Plains. The varied lithological units and structural features control groundwater occurrence, drainage patterns, and the geomorphic evolution of the landscape.

2.5. GEOMORPHOLOGY

The Amaravati Capital City region is characterized by a diverse geomorphological framework (Figure 12) shaped by the interplay of fluvial, denudational, and anthropogenic processes. This area serves as a transitional landscape, positioned between the crystalline uplands of the Eastern Ghats in the south and the floodplains of the Krishna River in the north. The terrain exhibits a southwest-to-northeast slope gradient, guiding natural surface runoff and drainage toward the Krishna River, which forms the northern boundary of the city (APCRDA, 2018; GSI, 2019).

Geomorphological Mapping and Major Units

Comprehensive geomorphological mapping has been conducted in the Amaravati Capital Region using IRS LISS-IV satellite imagery, Digital Elevation Model (DEM) data, and field validation. This mapping has identified seven major geomorphic units within the region (Table 2). The delineation of paleo channels is based on satellite data interpretation, information from existing tube wells, and lithologs data from geotechnical reports. Together, these landforms regulate surface water flow, influence infiltration rates, support groundwater recharge, and shape the dynamics of the floodplain (NRSC, 2020; CGWB, 2020).

Table 2: Geomorphic Units of Amaravati Capital City

Sl. No.	Geomorphic Unit	Description	Hydrogeomorphological Significance
1	Anthropogenic Terrain	Man-modified terrain formed due to urban development, land levelling, embankments, and	Reduced infiltration capacity and increased surface runoff; requires

Sl. No.	Geomorphic Unit	Description	Hydrogeomorphological Significance
		infrastructure works. Natural slope and drainage altered.	stormwater control and recharge structures to restore hydrological balance.
2	Low to Moderately Dissected Hills and Valleys	Found near Anantavaram, and Peddaparimi in the southern uplands. Denudational landforms developed over Khondalite and charnockite rocks; moderate slopes (3–8%) with shallow valleys.	Runoff-dominated terrain; low infiltration but potential for check dams and contour bunds at valley bases.
3	Moderately to Highly Dissected Hills and Valleys	Confined to easter portion of the Amaravati capital city. Steep, rugged terrain with deeply incised valleys; formed due to long-term erosion and weathering of granulite and khondalite formations.	Acts as watershed divide and runoff source zone; suitable for slope stabilization and rainwater harvesting along foothills.
4	Pediment–Pediplain Complex	The largest unit, covering central and southern parts — Velagapudi, Ainavolu, Sakhamuru, Nelapadu, Tanapathi Cheruvu, and Peddaparimi. Gently undulating erosional surface developed by the coalescence of pediments over crystalline rocks; moderate slope (1–3%).	Moderate infiltration and groundwater potential; suitable for percolation ponds and recharge wells; key transition zone between uplands and floodplains.
5	Paleo Channel	The paleo channel extends between the Krishna River and a sequence of villages, namely Borupalem, Abbarajupalem, Malkapuram, Mandadam, Krishnayapalem, and Undavalli. This channel is aligned with the Kondaveeti Vagu drainage system. It represents a buried ancient course of the Krishna River, now filled with layers of black clay and sandy sediments that rest above the charnockite bedrock. The presence of these sediments marks the relict path of the Krishna River through this region.	High groundwater potential zone; ideal for recharge well networks and aquifer restoration projects.
6	Passive Flood Plain	The passive flood plain is situated along the central region, positioned between the paleo channel and the pediment–pediplain complex. This area is characterised by low-lying depositional plains predominantly made up of black silt and clay. Subject to periodic inundation	Acts as recharge–discharge interface; vital for flood moderation and wetland preservation; prone to seasonal waterlogging.

Sl. No.	Geomorphic Unit	Description	Hydrogeomorphological Significance
		during the monsoon season, these plains experience frequent flooding, which plays a significant role in shaping their physical characteristics and hydrological behaviour.	
7	Water Bodies	Scattered across the city — Sakhamuru (Tanapathi Cheruvu), Velagapudi, Ainavolu, Krishnayapalem, and the Krishna River along the north. Natural and man-made tanks, ponds, and reservoirs forming part of the Blue–Green network.	Provide local aquifer recharge, micro-climate regulation, and stormwater detention; key for flood control and ecosystem support.

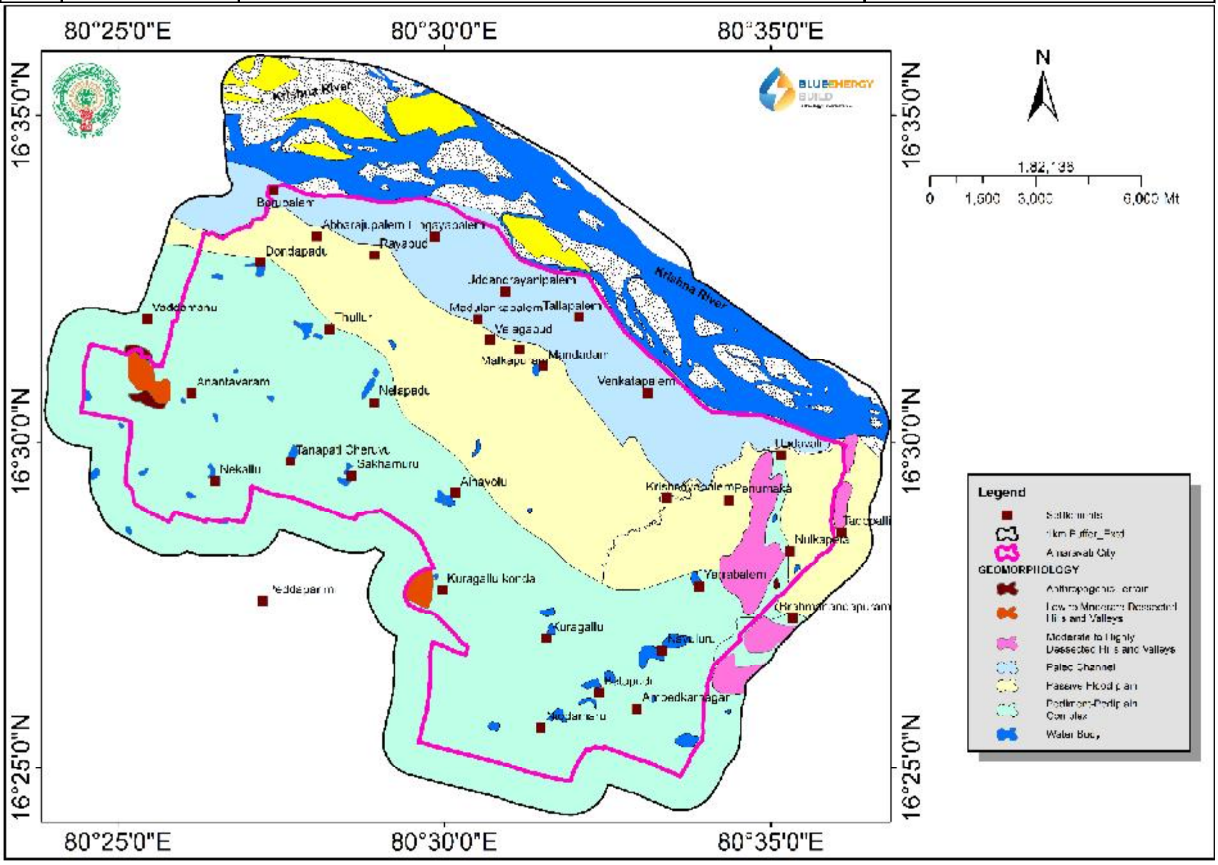


Figure 12:Geomorphological Map of the study area (after GSI, 2021)

2.6. SOIL CHARACTERISTICS

The study area features a variety of soil types, which play a significant role in determining land use and agricultural potential. The soils identified within the region include Clayey,

Clayey Calcareous, Cracking Clay Calcareous, Gravelly Loam, and Loamy Soils. Among these, Cracking Clay Calcareous and Clayey Calcareous soils are the most prevalent, covering the majority of the study area. These dominant soil types are depicted in Figure 13, which illustrates their distribution across the landscape.

SOIL ANALYSIS

Amaravati City exhibits a mix of alluvial soils and weathered residual soils, reflecting its Quaternary floodplain deposits and Eastern Ghats basement geology.

Black Clay / Black Cotton Soil

Occurrence: Peneplain between Amaravati, Errabalem, and Peddaparimi. Composition: Clay with quartz grains and rock fragments; thickness 0.5–4 m. Formation: Derived from weathering of basaltic and crystalline rocks; reworked during rainy season.

Black Silty Clay

Occurrence: Floodplain deposits along Krishna River; western and central Amaravati. Composition: Silty clay with high clay content towards the west; underlain by coarse sand in some areas.

Brown Silt

Occurrence: Intermixed with floodplain deposits, terrace fills. Composition: Fine-grained silt, sometimes with ferricrete concretions.

Reddish Brown Silt

Occurrence: Around upland areas; sometimes associated with concretions/ferricrete.

Calcareous Kankar Soil

Occurrence: SW of Amaravati and west of Nidamarru. Composition: Kankar nodules with sandy and clayey matrix; derived from underlying crystallines.

Red & Reddish-Brown Colluvial Soil (Piedmont Colluvium)

Occurrence: Around Mangalagiri hill slopes. Composition: Heterogeneous mix of clay to pebbles; derived from weathering and fluvial deposition.

Red Sandy Soil (Teri Sand)

Occurrence: Developed in Nidamarru area. Composition: Clay and sand; quartz-dominated grains, sub-angular to sub-rounded.

Grey Brown Clay Soil

Occurrence: North of Betapudi and Atmakur in small patches. Composition: Clay with quartz grains and rock fragments; resembles black cotton soil except colour.

Alkaline Soil

Occurrence: Along small streams in peneplain areas. Composition: High soluble salts; infertile without treatment.

SOIL QUALITY

Fertile Soils

Black Cotton Soil, Black Silty Clay, Brown Silt → High agricultural productivity; retain moisture; good for paddy, sugar cane, horticulture.

Moderate Fertility Soils

Reddish Brown Silt, Grey Brown Clay, Red Sandy Soil → Need organic matter and irrigation for sustained productivity.

Low Fertility / Problem Soils

Calcareous Kankar Soil → Poor water retention, high $CaCO_3$; suitable only after amendment.

Alkaline Soils → Salinity/sodicity issues; require gypsum treatment and leaching.

Piedmont Colluvium → Coarse texture, poor nutrient-holding; moderate productivity after soil improvement.

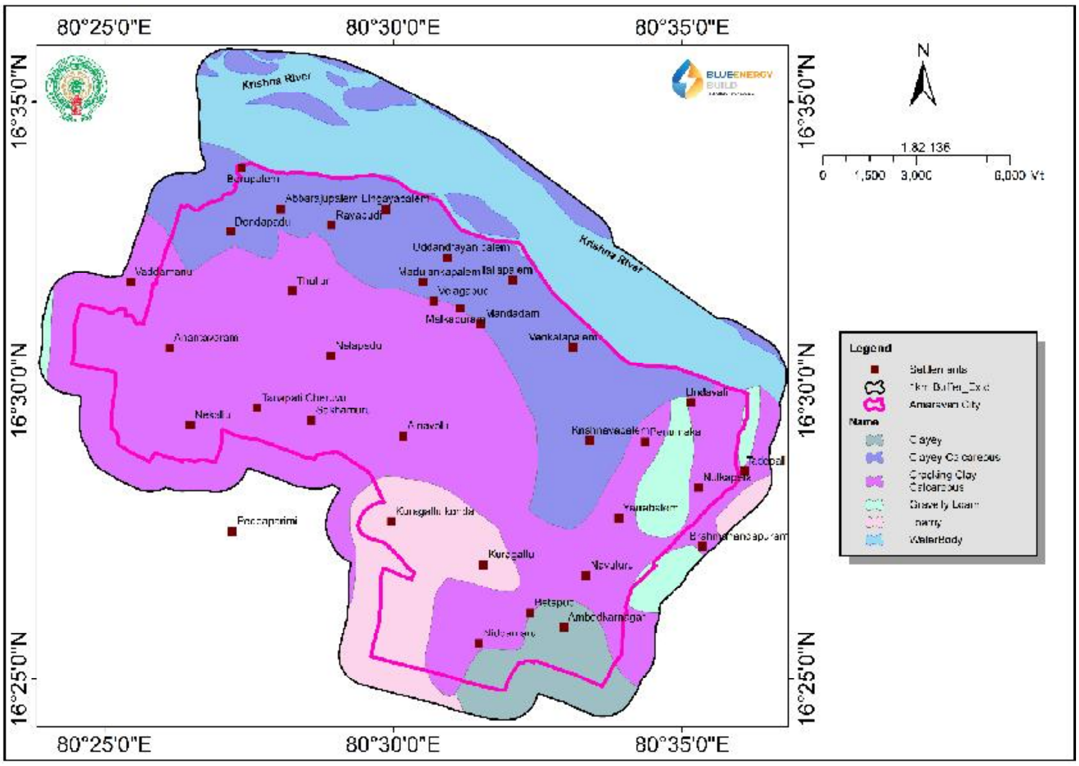


Figure 13: Soil map of Amaravati Capital City

2.7. LAND COVER AND LAND USE (LULC)

The study area encompasses five distinct categories of land use: agriculture or grassland, plantation, fallow or unused land, built-up land, and water bodies. These categories reflect the diverse utilization and management of land within the region.

Between 2002 and 2025, the extent of urban or built-up land has experienced notable growth, increasing from 8% to 15% of the total area. This change highlights the ongoing process of urbanization and expansion of infrastructure within the study zone.

To accurately map and classify the various land use and land cover types, a hybrid classification methodology was employed. This approach has enabled the identification and differentiation of the key land use categories present, as depicted in Figure 14.

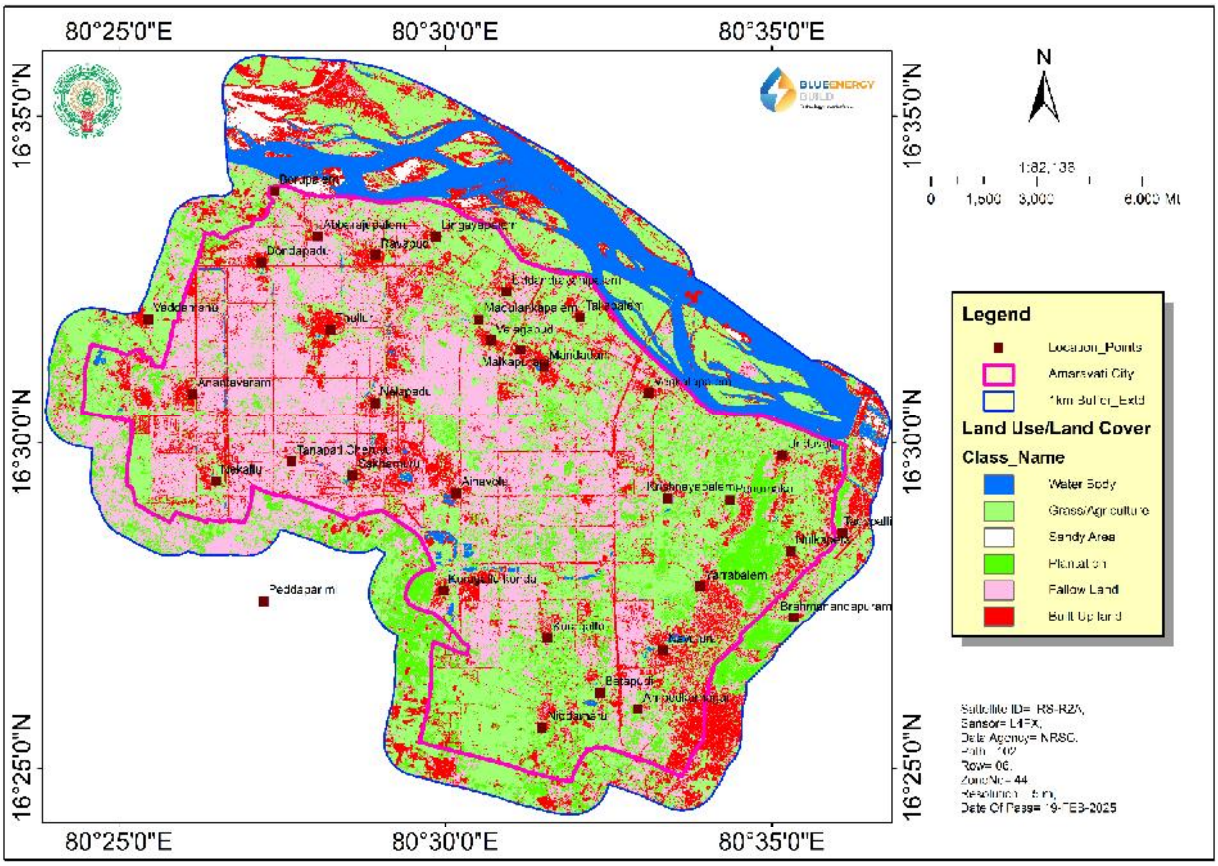


Figure 14: Land use land cover map of Amaravati Capital City

CHAPTER 3: HYDROLOGICAL MODELLING

3.0. GENERAL

Hydrological modelling using HEC-HMS model was carried out to estimate the volume of water arriving for each catchment in a year to plan the water harvesting systems at different locations of the area. The hydrological model developed by Blue Consultant and Aarvee Associates thoroughly checked for consistency and used the same model for assessing the event hydrology of the area. i.e. flood modelling study. The same model was used for annual runoff assessment with different input parameters for Loss calculation, Transforming flow and baseflow. The annual runoff available for each catchment is calculated

3.1. METHODOLOGY

Data Collection & Review

- Gathered **topographic survey data** (KV catchment DEM, cross-sections of Vagus – 2015/2016 survey).
- Collected **rainfall records** from multiple rain gauge stations (KV catchment & surrounding) up to 2024.
- Collated **reservoir, pumping station, and regulator** design data from Irrigation Department and CRDA.
- Reviewed existing **hydrological & hydraulic studies** and flood management proposals.

Rainfall–Runoff Analysis

- **Design Rainfall Estimation**:
  - Followed IS 5542:2003 – Guide for Storm Analysis.
  - Derived 1-day annual maximum rainfall series for each station.
  - Used **GEV distribution** for frequency analysis to get design rainfall for return periods (10, 25, 50, 100 years).
- **Isohyetal Mapping**: Prepared catchment-wide design rainfall maps for input to hydrological modelling.

Hydrological Modelling (HEC-HMS)

- **Basin Delineation**: KV catchment divided into multiple sub-basins.
- **Loss Method**: Initial & Constant Loss method (losses from curve number, infiltration rates from CWC FER).
- **Transform Method**: Clark Unit Hydrograph for runoff transformation.
- **Baseflow Method**: Constant monthly baseflow from empirical equations.
- **Routing Method**: Muskingum-Cunge method for channel routing using literature on surveyed cross-sections & Manning's n.

Meteorological Model Setup

- Converted 24-hr design rainfall to **hourly hyetographs** using CWC temporal distribution factors.
- Applied imperviousness values based on CRDA's phased city development plan.

Hydraulic Modelling (HEC-RAS)

- Built 1D/2D hydrodynamic model of **KV and its tributaries**.
- Incorporated **reservoirs, pumping stations, escape regulators** as hydraulic structures.
- Used **survey DEM** for terrain; refined with land-use/land-cover data.
- Defined boundary conditions from hydrological model outputs (HEC-HMS peak flows).

Scenario Simulations

- Simulated **current and future (phased) development scenarios**:
    - 2024 (existing), 2025, 2030, 2035, 2040.
- Assessed **flood immunity for 1 in 100-year event**.
- Tested **gravity diversion, pumping capacities, and reservoir storage options**.

Validation & Finalisation

- Compared results against **historic flood behaviour** and channel capacity checks.
- Verified **pumping requirements** for different development phases.

- Finalised **design cross-sections** and operational strategies for reservoirs and pumps.

This methodology ensured an **integrated hydrologic–hydraulic approach**, combining **rainfall–runoff simulation (HEC-HMS)** with **2D flood routing (HEC-RAS)** for planning and validating Amaravati's flood management measures.

3.2. KEY CONTRIBUTIONS OF THE STUDY

Peak Flood Estimates

- **Baseline (2017 DPR values) –** Derived for **1 in 100-year return period** events.
- Using **HEC-HMS hydrological modelling**, the study calculated **peak discharges** at multiple key junctions in the Kondaveeti Vagu (KV) catchment.
- At **Undavalli (main outfall)**:
  - 2024 (existing) **–** ~632 m^3/s (≈ 22,315 cusecs)
  - 2040 (fully developed city, 60% impervious) **–** ~885 m^3/s (≈ 31,249 cusecs)
- Climate Change Scenario (CCA uplift factor 20% by 2050) – Peak discharge at Undavalli could reach **~1,142 m^3/s (≈ 40,310 cusecs)**.

Flood Duration

- Hydraulic modelling (HEC-RAS 2D) showed that **without mitigation**, high flood levels (HFL) within KV and Paala Vagu would **persist for 2–3 days** in a 1 in 100-year event.
- With proposed interventions (reservoir storage, widened channels, pumping at Undavalli & Vykuntapuram), flood duration reduces to **less than 24 hours** in most areas which were already under execution phase.
- Gravity diversion channels and staged pumping help drain accumulated water faster, reducing downtime for affected infrastructure.

Impacts on Infrastructure Development

- **Road Networks** – Proposed realignment, widening, and deepening of channels reduces flood depth over key arterial roads in the capital city, allowing faster restoration of traffic after heavy rainfall.

- **Urban Land Use –** The flood immunity design allows CRDA to proceed with **60% impervious surface coverage** by 2040 without exceeding design flood levels in primary channels.
- **Reservoirs–**
    - Three key reservoirs inside Amaravati capital (Neerukonda, Krishnayapalem, Sakhamuru) and three outside (Lam, Pedaparimi, Vykuntapuram) are critical for attenuating flood peaks.
- **Floodplain Management –** Identified areas that should remain undeveloped or be used for parks/open spaces to retain temporary floodwaters.
- **Construction Phasing –** Recommendations on timing of Phase 1 & Phase 2 works to match city development pace, avoiding under- or over-design of drainage and pumping systems.

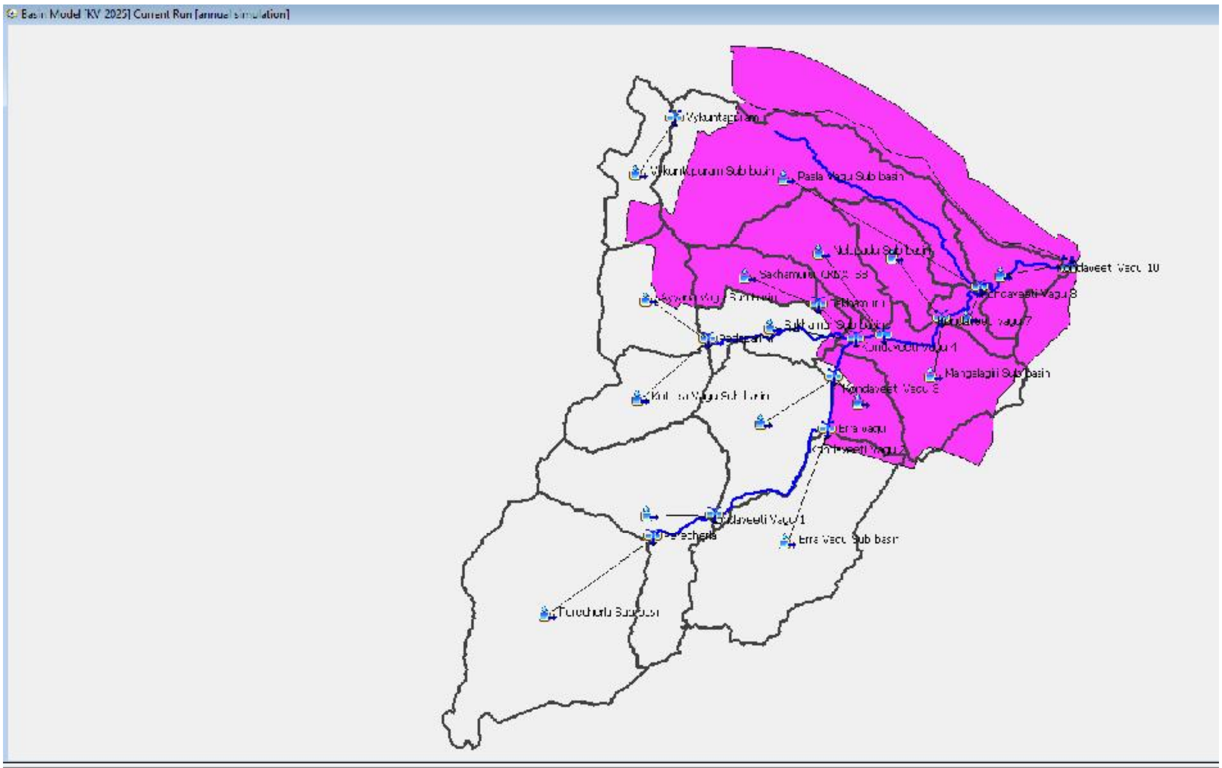


Figure 15:HEC-HMS Model for Annual Water Balance Calculation

3.3. ANNUAL AVAILABLE FLOW

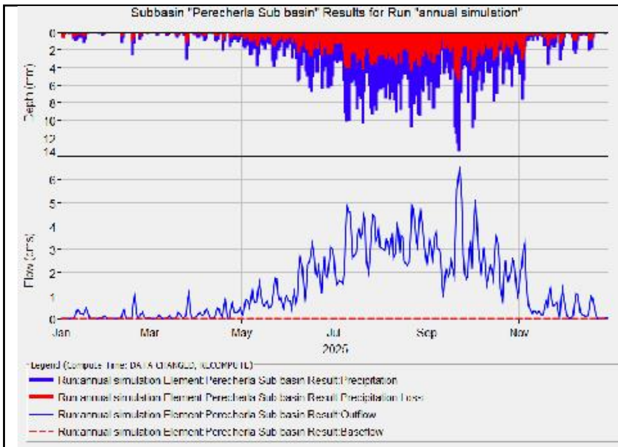
The basin wise and reach wise available annual runoff along with areas is given in Table 3. The daily average annual rainfall of 30 years was used to capture the runoff from each catchment.

Table 3: Model used Hydrological Elements, Drainage Area and Total Volume of Water Generated during a year

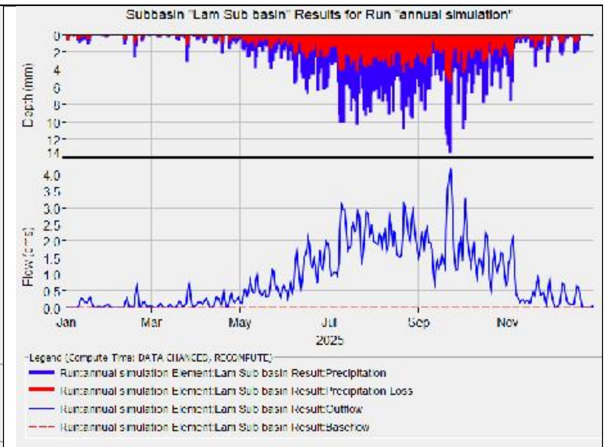
Hydrologic Element	Drainage Area (Sq. Km)	Annual Volume (1000 Cubic Meter)
Perecherla Sub basin	72.3	43394.6
Perecherla	72.3	43394.6
Kondaveeti Vagu 1	72.3	43396.4
Lam Sub basin	46.2	27739
Lam	118.6	71135.3
Kondaveeti Vagu 2	118.6	71146.7
Erra Vagu Sub basin	50.3	30198.5
Erra vagu	168.9	101345.2
Kondaveeti Vagu 3	168.9	101361.7
Tadikonda Sub basin	31.3	18793.4
Nidamarru Sub basin	12.2	7293
Nirukonda U/S	212.4	127448.1
Kondaveeti Vagu 4	212.4	127477.2
Ayyana Vagu Sub basin	22.7	13609.7
Kottela Vagu Sub basin	20.2	12116
Pedaparimi	42.9	25725.7
Kondaveeti Vagu 5	42.9	25726.9
Sakhamur Sub basin	17.2	10331
Sakhamuru_CRDA_SB	12.5	7505.1
Sakhamuru	12.5	7505.1
Nirukonda D/S	285	171040.1
Kondaveeti Vagu 6	285	171080.9
Nelapadu Sub basin	19.4	11631.4
Neelapadu	304.4	182712.3
Kondaveeti vagu 7	304.4	182788.8
Mangalagiri Sub basin	31.1	18657
Amaraveti Sub basin	14.3	8597.7
Krishnayyapalem U/S	349.8	210043.5
Kondaveeti Vagu 8	349.8	210117.1
Vykuntapuram Sub basin	15.1	9046.2

Vykuntapuram	15.1	9046.2
Paala Vagu Sub basin	58.6	35146.6
Kondaveeti Vagu 9	15.1	9050.3
Krishnayyapalem Sub basin	5.7	3437.6
Krishnayayapalem	429.2	257751.6
Kondaveeti Vagu 10	429.2	257839.4
Undavalli Sub basin	13.8	8256.9
Unadavalli	443	266096.3

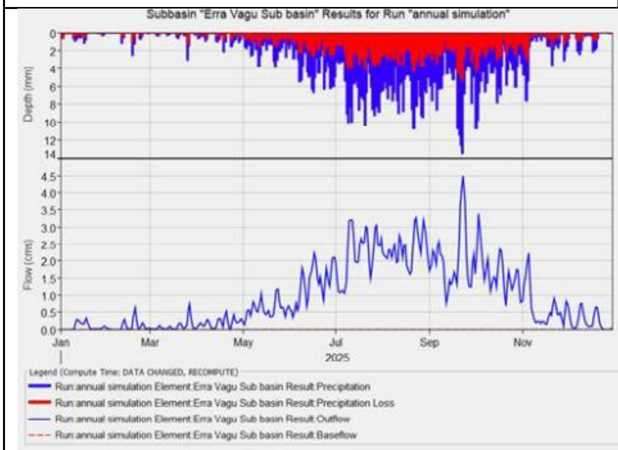
Annual Simulation (Graphs) of Rainfall Runoff in Different Sub Basins of Kondaveeti Vagu Catchment are shown in Figure 16.



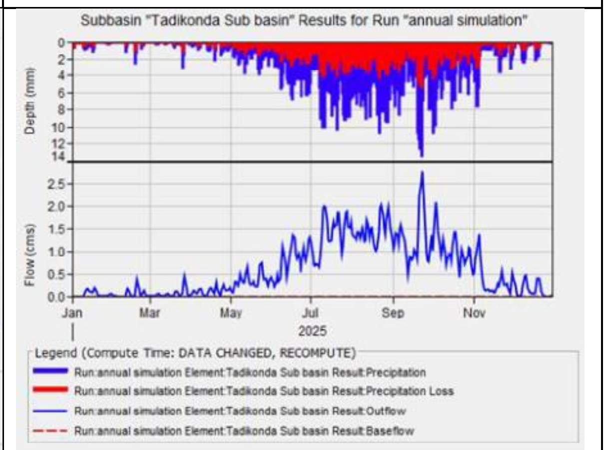
Perecherla Sub-Basin



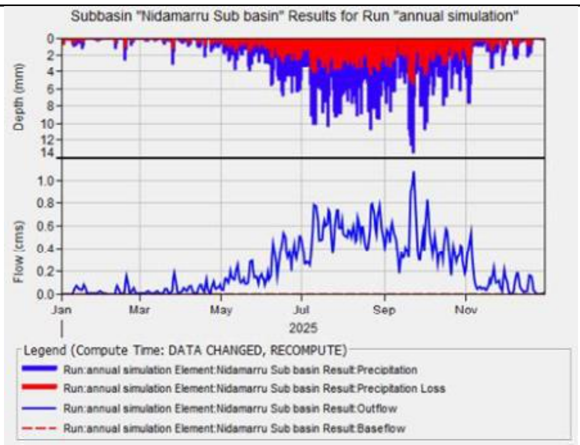
Lam Sub-Basin



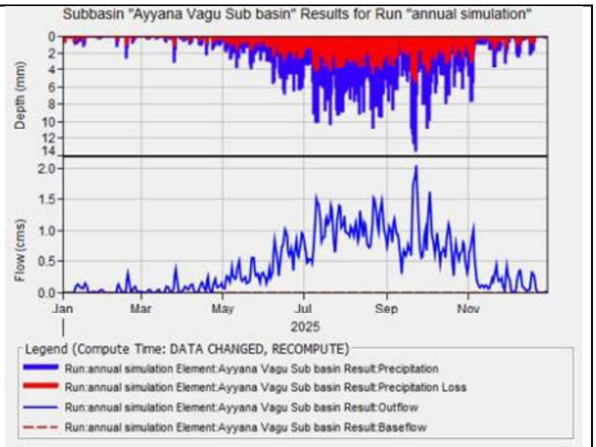
Erra Vagu Sub-Basin



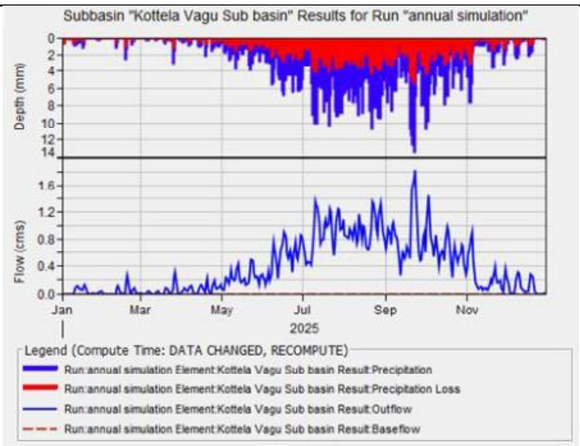
Tadikonda Sub-Basin



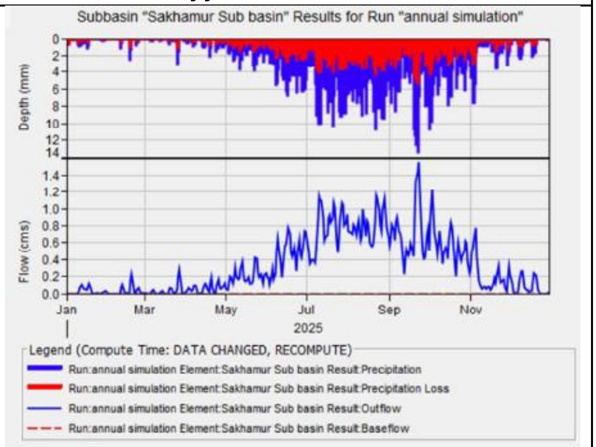
Nidamarru Sub-Basin



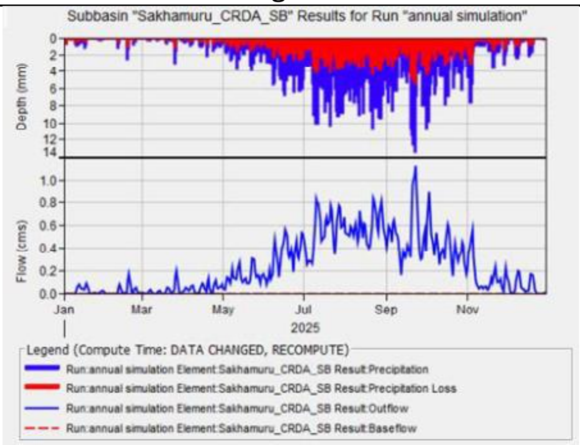
Ayyana Sub-Basin



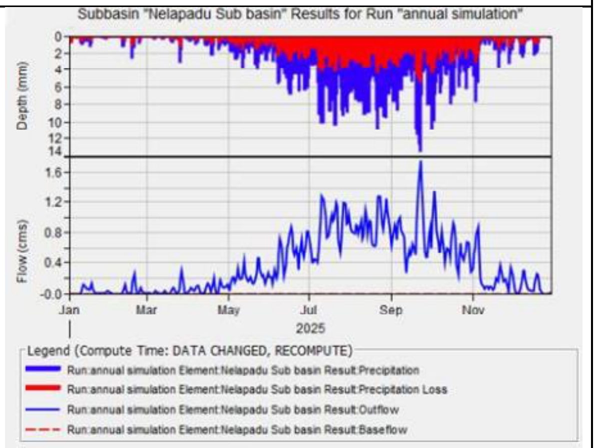
Kottela Vagu Sub-Basin



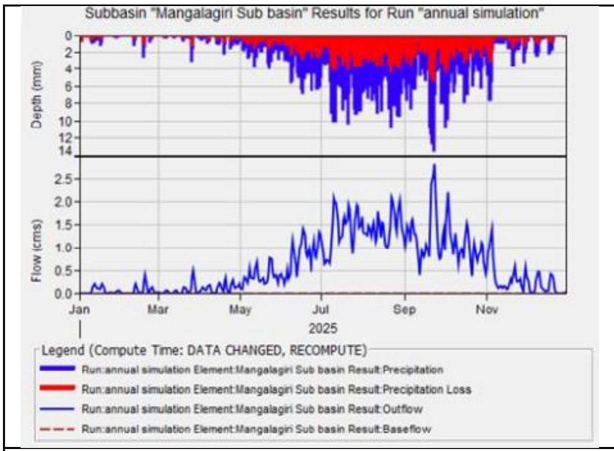
Sakhamur Sub-Basin



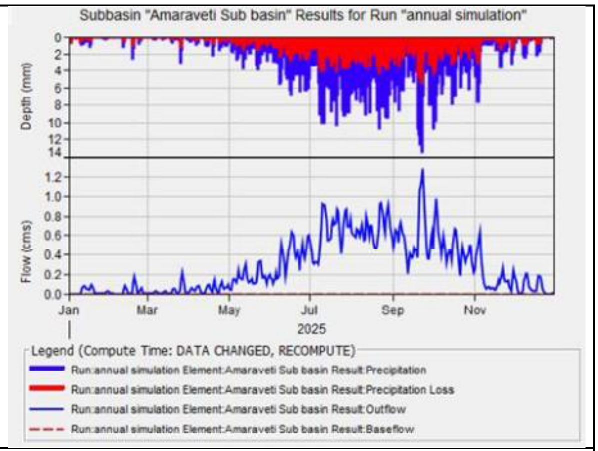
Sakhamur CRDA Sub-Basin



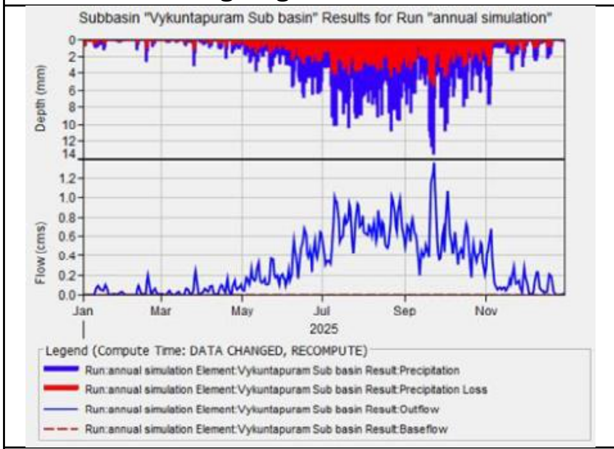
Nelapadu Sub-Basin



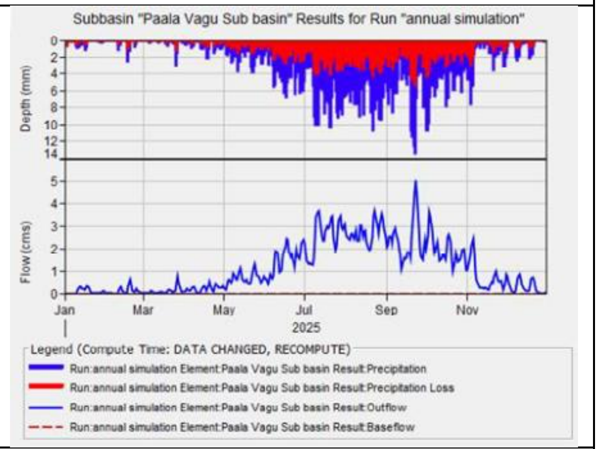
Mangalagiri Sub-Basin



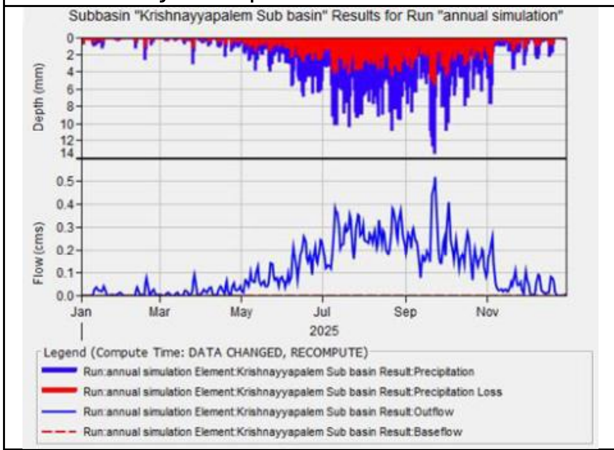
Amaravati Sub-Basin



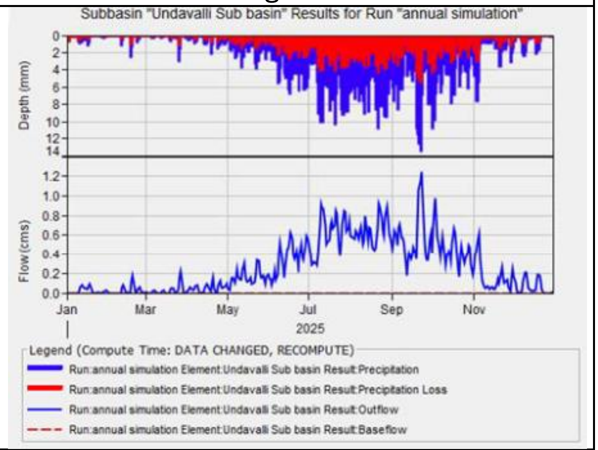
Vykuntapuram Sub-Basin



Paala Vagu Sub-Basin



Krishnayyapalem Vagu Sub-Basin



Undavalli Vagu Sub-Basin

Figure 16: Annual Simulation (Graphs) of Rainfall Runoff in Different Sub Basins of Kondaveeti Vagu Catchment

CHAPTER 4: GEOPHYSICAL INVESTIGATIONS

4.0. GENERAL

Ground geophysical techniques were systematically implemented in Amaravati City, which falls under the jurisdiction of the Andhra Pradesh Capital Region Development Authority (APCRDA), to carry out an in-depth investigation of the subsurface structure and the complex basement configuration. The basement in this region displays a stratigraphic sequence consisting of multiple layers and diverse geological features.

A comprehensive approach was adopted by integrating geological, hydrological, and geophysical datasets. This integration enabled the reconstruction of the multi-layered sedimentary system and facilitated both the electrical characterization and geometric identification of the various aquifer systems underlying Amaravati. The investigations involved the execution of Vertical Electrical Resistivity Soundings (VES) using the Schlumberger configuration, along with Magnetic (Total Field) surveys performed at closely spaced intervals. In addition to these primary surveys, secondary gravity data from the Geological Survey of India (GSI, 2006) was used to further elucidate the composition, arrangement, and tectonic framework of the sediments and basement beneath the proposed Capital City in Guntur district. These activities spanned from May 5 to June 30, 2025.

The core objective of these geophysical studies was to analyze the nature and dynamic behavior of subsurface formations, paying particular attention to detailed characterization of soil profiles and aquifer conditions. The analysis focused on identifying favorable groundwater zones that could support both domestic and industrial needs, as well as detecting any hidden structural features present in the area. Furthermore, these studies aimed to provide a deeper understanding of the basement configuration, evaluating its stability and strength, especially in the context of natural disasters such as floods and earthquakes.

The investigations were marked by the systematic application and integration of geological, geomorphological, and hydrological analyses tailored to the specific conditions of Amaravati City. This thorough methodology enabled the characterization of the quality, quantity, and sustainability of groundwater within different horizons. As a result, the presence of concealed aquifer systems was defined, and the findings contributed to the effective management of groundwater resources in the region.

4.1. ROLE OF GEOPHYSICAL SURVEYS IN HYDRO-GEOMORPHOLOGICAL STUDIES

Geophysical surveys are indispensable tools in hydrogeomorphological investigations, as they enable a thorough and detailed characterization of subsurface features that have a direct impact on groundwater occurrence and movement. By employing techniques such as resistivity sounding and magnetic total field surveys, these studies generate accurate, high-resolution data on the nature, thickness, and depth of soil and rock layers. This information forms the foundation for understanding the stratigraphic sequence, geological complexity, and the configuration of aquifer systems within a region.

The integration of multiple geophysical techniques allows for the delineation of aquifer horizons, mapping of basement structures, and identification of significant geological features such as faults, fractures, and lineaments. Such insights are crucial for evaluating groundwater potential, planning effective extraction strategies, and ensuring the sustainable management of water resources. Furthermore, by precisely mapping subsurface anomalies and correlating digital datasets—including geology, geomorphology, and hydrogeology—these surveys enhance the assessment of recharge zones and support effective groundwater management.

Collectively, geophysical surveys establish a robust scientific basis for hydrogeomorphological studies. They facilitate informed decision-making processes related to resource management, urban planning, and infrastructure development, as demonstrated in regions like Amaravati City.

Aquifer Mapping and Groundwater Management

The aquifer mapping undertaken through geophysical surveys has been pivotal in pinpointing regions suitable for groundwater-based water supply systems. By meticulously delineating the geometry and characteristics of aquifers, these surveys have enabled a comprehensive assessment of the sustainability of groundwater extraction, as well as the recharge and yield potential of water-bearing formations. Such data is vital for integrated groundwater recharge planning, ensuring sufficient water supply is maintained, even during prolonged drought periods.

Additionally, the results from these surveys provide guidance and advisories on the possible impacts associated with continued groundwater extraction, thereby helping to mitigate the risks of overexploitation and resource depletion. Based on the findings, targeted recommendations have been made for areas exhibiting strong groundwater prospects, supporting detailed and scientifically sound evaluations of groundwater resources.

Ultimately, these efforts contribute to the sustainable management of groundwater and the development of precise aquifer maps, as well as comprehensive groundwater management plans for the region.

Soil Profile and Structural Suitability Assessment

The information gathered from geophysical surveys has significantly enhanced the understanding of soil profiles and basement conditions at specific locations within the study area. This improved knowledge is essential for assessing the suitability of sites for heavy construction projects or other large-scale developments. In addition, these surveys facilitate the identification of potential geological hazards that could pose risks to infrastructure or public safety.

Through these comprehensive assessments, critical information is provided for informed decision-making in the development of the emerging smart city in Amaravati. This ensures that construction activities and urban planning initiatives are based on a thorough understanding of subsurface conditions, supporting the safe and sustainable growth of the region.

4.2. GEOPHYSICAL SURVEY PLANNING AND OBJECTIVES

The geophysical survey program in Amaravati City was meticulously planned to achieve a series of well-defined objectives, focusing on the accurate assessment of natural resources, their optimal utilization, effective time management, and the acquisition of high-quality data. The selection of survey techniques was guided by these objectives, ensuring that the methodologies employed would be well-suited to the unique geological context of the area.

Two primary geophysical methods were chosen for this investigation: Resistivity Sounding utilizing the Schlumberger array configuration and ground-based Magnetic (Total Field) surveys. These techniques were specifically selected because of their proven effectiveness in the region, their ability to achieve substantial penetration depths, and their capacity to generate precise detection of subsurface anomalies. The careful integration of these methods provided a robust framework for obtaining comprehensive and reliable data on the underlying geological structures and aquifer systems present in Amaravati City.

Resistivity Sounding Techniques

Resistivity sounding techniques were methodically applied throughout the survey area to obtain detailed information about concealed soil profiles. These techniques enabled the identification of the nature, thickness, and depth of subsurface layers, which are essential for understanding the stratigraphic sequence and geological complexity of the region.

The use of resistivity sounding was instrumental in delineating aquifer horizons and characterizing the basement configuration. Through this approach, the surveys were able to determine the depth to bedrock and distinguish between different types of basement formations, including weathered, fractured, hard, compact, and massive structures below ground level. This information is critical for assessing the suitability of the region for groundwater extraction and for evaluating potential construction sites.

To achieve comprehensive coverage and high-resolution mapping, approximately 651 site locations were selected for conducting Vertical Electrical Soundings (VES). The Schlumberger electrode configuration was employed, allowing for a maximum electrode separation (AB) of up to 400 meters. The surveys were systematically carried out at 500-meter intervals wherever possible, creating a grid pattern measuring 500 meters by 500 meters. This design ensured that data density and spatial resolution met the objectives of the investigation, providing a robust foundation for subsurface characterization and resource management.

Magnetic (Total Field) Surveys

Magnetic (Total Field) surveys were systematically carried out across Amaravati City with the primary objective of delineating concealed geological structures. These included features such as faults, fractures, shear zones, lithological contacts, and lineaments that are crucial for understanding the subsurface geology. By applying this technique, survey teams were able to effectively evaluate subsurface formations and gain insights into the configuration and depth of the basement rocks beneath the city.

The use of magnetic surveys offered a rapid and efficient approach, making it particularly well suited for geo-technical investigations within the region. This method enabled the identification and mapping of various subsurface anomalies, greatly contributing to the comprehensive understanding of Amaravati's geological framework. Such detailed knowledge is vital for informed resource evaluation and strategic development planning.

Within the Amaravati Capital Area, data was gathered from 608 magnetic survey points. This extensive data collection facilitated detailed mapping of the subsurface and enhanced the overall geophysical assessment of the region.

4.3. INTEGRATION OF DIGITAL DATA AND SURVEY ACCURACY

To enhance the effectiveness of the geophysical surveys, a comprehensive range of digital datasets was integrated with the resistivity sounding and magnetic survey data. This included information on geology, geomorphology, hydrogeology, drainage patterns, elevation and digital elevation models, as well as slope, aspect, land use, and land cover. By incorporating these diverse datasets, the survey team was able to correlate surface and subsurface characteristics, thereby facilitating the identification and delineation of concealed geological structures.

During the resistivity survey, lines were carefully laid out and measurement stacking was conducted at each Vertical Electrical Sounding (VES) location with a high degree of precision. This systematic approach ensured that the data collected was both accurate and reliable. Furthermore, the geographical positions of all VES and magnetic survey stations were determined using handheld GPS devices. This use of GPS technology played a crucial role in maintaining accuracy throughout the data collection process, supporting the overall quality and reliability of the survey results.

4.4. METHODOLOGY

To effectively characterize the subsurface geology of the Amaravati City area, both resistivity sounding and magnetic survey techniques were strategically employed. These methods were selected based on the significant contrasts in electrical resistivity, conductivity, and magnetic susceptibility observed within the subsurface sediments and geological structures. Such contrasts are particularly pronounced in features including faults, fractures, contacts, joints, and shear zones, which are often found within the compact, hard, and massive bedrock formations present in the region.

The survey area encompasses a diverse geological setting, with calc granulite and pyroxene granulites exposed in the western part, Khondalite formations in the eastern part, and charnockite rocks occupying the central portion of Amaravati City. This varied bedrock composition necessitated the use of geophysical methods to accurately delineate subsurface structures and stratigraphy. By leveraging the differences in geophysical properties, the survey team was able to identify and map critical geological features and formations, providing foundational data for subsequent analysis of groundwater potential, construction suitability, and resource management.

4.4.1. VERTICAL ELECTRICAL SOUNDINGS (VES)

Vertical Electrical Soundings (VES) were systematically performed throughout the study area at regular intervals of 500 meters, following both north-south (N-S) and east-west (E-W) alignments. The primary purpose of these soundings was to assess the characteristics, depth, and thickness of various sediment layers, including black cotton soil, clay, shale, silt, and sand. In addition, the VES technique was employed to identify the composition and depth of the underlying bedrock.

A total of approximately 651 VES points were established, ensuring comprehensive coverage of the entire Amaravati City region, which spans an area of 217.23 km^2. The soundings were laid out on a grid pattern of 500 by 500 meters, with survey lines following all accessible roads and cart tracks. This approach enabled detailed subsurface profiling across a broad geographic expanse, with data collection trending in both N-S and E-W directions. The spatial distribution of the VES locations depicted in Figure 17.

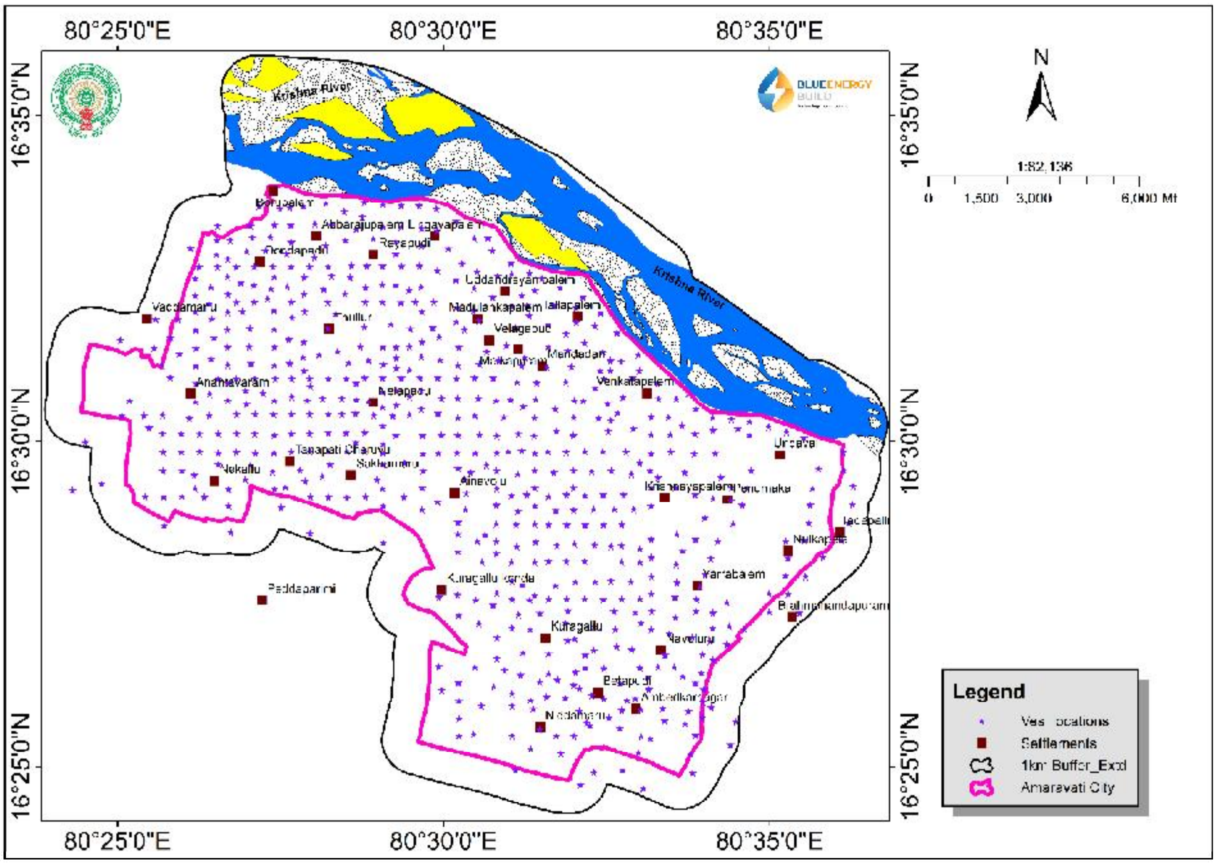


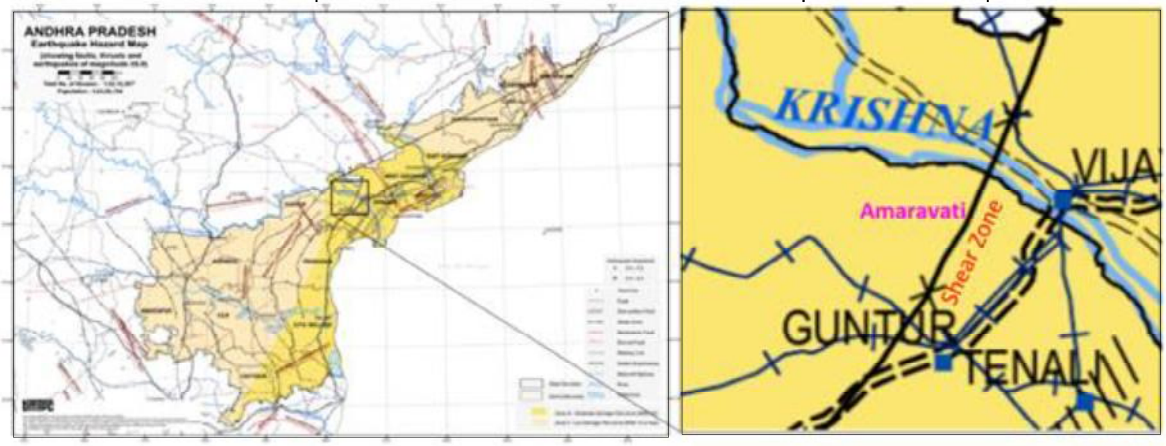
Figure 17: Spatial map of locations of Vertical Electrical Soundings (VES)

4.4.2. MAGNETIC SURVEYS

Magnetic surveys were performed using two distinct approaches: a regional mode, which encompassed the entire study area, and a confined mode, which focused specifically along the shear zone. The principal objective of these surveys was to determine the basement topography and assess variations in the thickness of the sediment layers, both of which have significant implications for groundwater potential within the region.

Analysis of the Andhra Pradesh earthquake hazard map (BMTPC, 2011) indicates that a shear zone traverses Amaravati in the NNE-SSW direction (see Figure 18). To further investigate this feature, detailed magnetic measurements were conducted along the geologically marked, concealed shear zone stretching from Uddandarayunipalem in the north to Ainavolu in the south. Nine traverses were established, each spaced 200 meters apart and trending NNE-SSW, with each traverse length extending for 1 kilometer. Along these traverses, measurement stations were set at 20-meter intervals resulting in a total of approximately 450 data points (as depicted in Figure 19). A shear zone is defined as a linear or planar region in the Earth's crust where rocks have undergone intense deformation due to differential stress. This deformation can manifest as plastic flow, fracturing, and displacement, creating a high-strain region between more rigid rock blocks. The movement within shear zones is typically ductile, occurring at depth through plastic deformation, but may also involve brittle fracturing near the surface. Such zones can range from tens to hundreds of meters in width and may extend for several kilometers.

Location map of Shear Zone from Andhra Pradesh Earthquake Hazard Map



Ref: BMTPC: Vulnrability Atlas - 3rd Edition: Peer Group, MOHUA, GOI; Map is based on degitised data of SOI; Seismic Zones of India Map IS: 1893 (Part I): 2002, BIS: Earthquake Epicentre from IMD; Seismotectonic Atlas of India and its Environs, GSI; Houses/Population as per Census 2011; Houses including vacant & locked houses; Maps are solely for thematic prepsentation.

Figure 18: Location map of Shear zone from Andhra Pradesh Earthquake Hazard Map

In addition to the targeted shear zone surveys, regional magnetic (Total Field) surveys were executed at 1-kilometer station intervals along all accessible roads and cart tracks. These regional surveys aimed to delineate concealed structural features and the configuration of the basement, which are essential for understanding the tectonic framework of the Amaravati City study area (refer to Figure 20 and Annexure-1).

All field magnetic data collected during the surveys were referenced to a local magnetic base station established near VIT College in Ainavolu village. To ensure the accuracy and consistency of the magnetic data, diurnal corrections and International Geomagnetic Reference Field (IGRF, 2005 epoch) corrections were applied using Geosoft software.

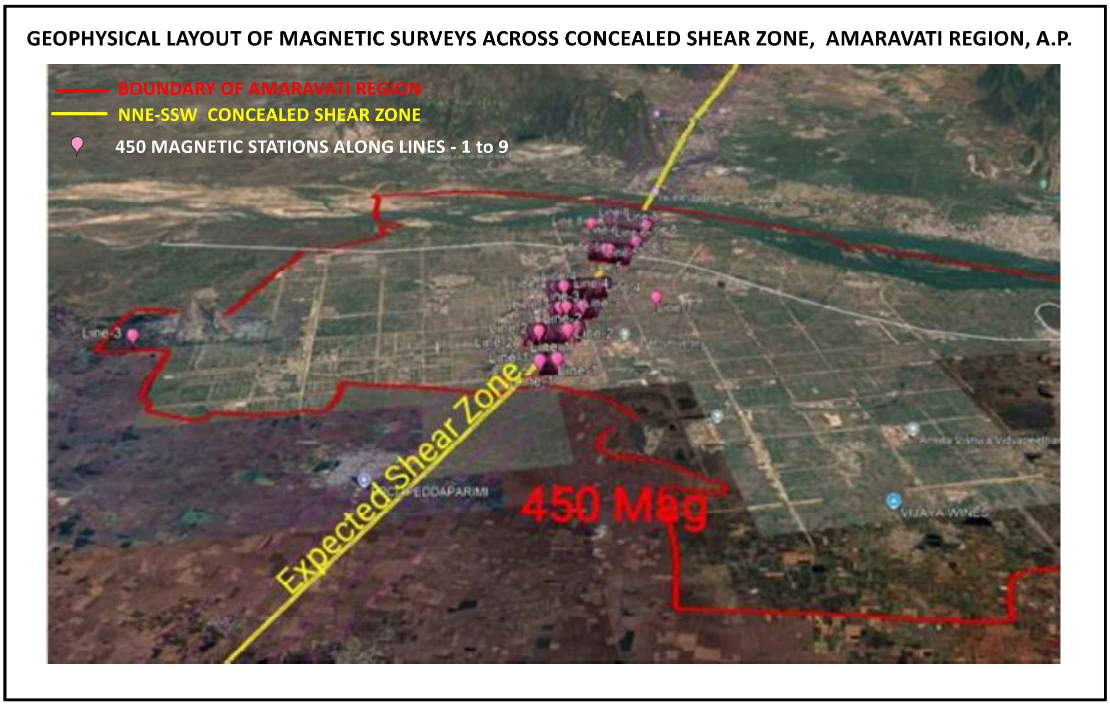


Figure 19: Layout of detailed Magnetic Survey across Shear Zone

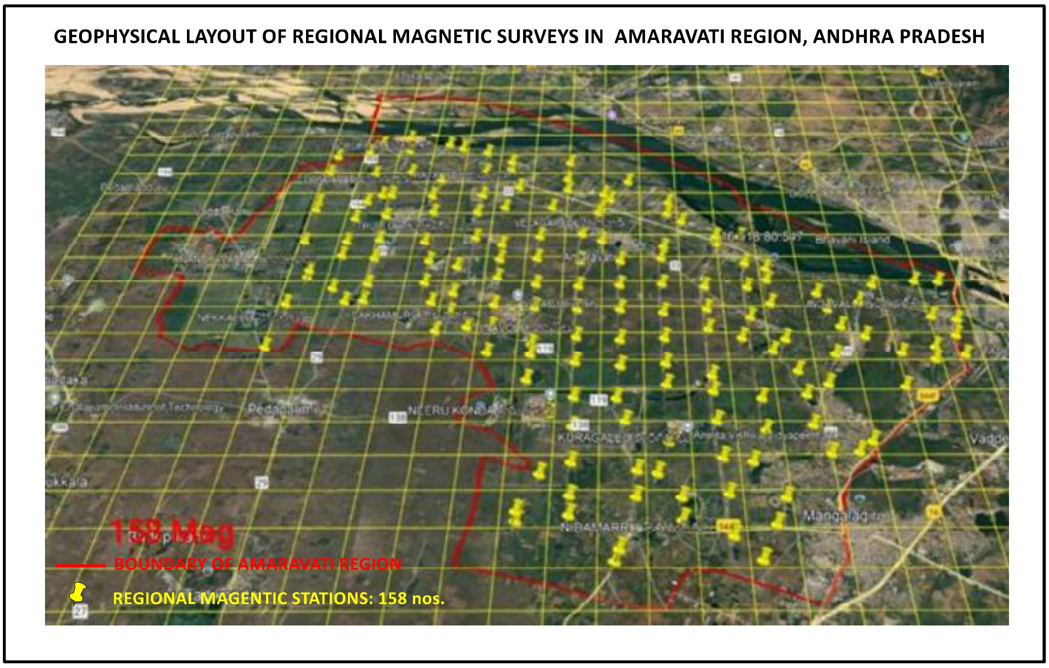


Figure 20: Layout of Regional Magnetic Surveys

Regional magnetic measurements (about 158 stations) have been made at every one kilometer along all available roads and cart tracks amounting to a station density of 1 station per 1.5 to 2.0 sq.km to cover the entire Amaravati City, shown in Figure 20.

4.5. INSTRUMENTS USED

An IGIS signal enhancement resistivity meter model 'SSR-MP-ATS' is used for resistivity sounding measurements to probe both shallow and deeper layers. Proton Precession Type Total field magneto meter of IGIS, Hyderabad was used for magnetic measurements. GPS receiver of Garmin make was used to read the coordinates (longitudes and latitudes) of the VES locations and magnetic stations with an accuracy of $\pm$ 3 m.

4.6. MAPPING OF RESISTIVITY DATA

Variation of resistivity within a rock formation is the main source of electrical anomaly and it is an important parameter for mapping different geological formations under soil cover. It is dependent on various factors like nature of formation, degree of weathering, porosity, interconnected pore space, chemical composition and compactness. In the study area, due to the presence of conductive nature and associated structures such as fracture / fault / contact / shear / joints, the resistivities obtained from the underlying and overlying formations may be altered considerably due to percolation of water and degree of weathering. Schematic Diagram of Vertical Electrical Sounding (Schlumberger Array) is shown in Figure 21.

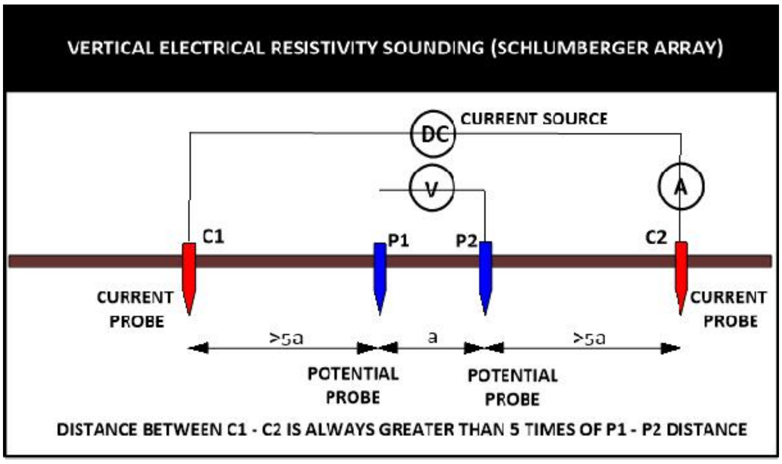


Figure 21: Schematic Diagram of Vertical Electrical Sounding (Schlumberger Array)

The database was initially prepared using MS-Excel and the data was gridded adopting kriging option using Surfer-16 software. The resulting grid was saved in ASCII format to make it suitable for further processing. The entire database of all the geological parameters was prepared VES wise to facilitate plotting of individual curves. Apparent resistivities are expressed in Ohm.m units. Resistivity sounding curves are plotted on double log graph sheets by apparent resistivity (Ohm.m) vs distance (AB/2) in meters. All multi-layered sounding curves are interpreted with partial Curve Matching Technique (Orellana and Mooney, 1966) and also using 1x1D software. Whereas profiles, sections, contour maps and images were generated using Grapher-12 , Surfer-16 and ArcMap software. The interpreted resistivity, thickness and depths of individual formations are reasonably close to the actual values.

4.7. MAPPING OF MAGNETIC DATA

Magnetic (Total Field) data collected during the survey was systematically corrected for diurnal variation to ensure accuracy. This was accomplished by repeatedly occupying the field base station throughout the magnetic survey. Additionally, corrections for standard variations were applied with reference to the IGRF-2005 epoch, utilizing each IGRF module within the Geosoft software suite.

The magnetic database was initially compiled using MS-Excel, serving as the foundation for subsequent data processing. Both Surfer and Geosoft software were employed to grid the magnetic data, facilitating advanced analysis and visualization.

Following the gridding process, various outputs were generated to interpret the magnetic data. These include profiles, sections, contour maps, images, and derivative maps such as regional and residual maps, analytical signal maps, radially averaged power spectrum, low-pass and high-pass maps, as well as low and high frequency, horizontal, and vertical derivative maps. The generation of these outputs was accomplished using ResReg, Grapher, and Geosoft software.

The characterization of magnetic anomalies, noted for their high frequency, posed challenges in interpretation. To address this, the Radially Averaged Power Spectrum was prepared for the magnetic data. This approach enabled the determination of depth variation in magnetic interfaces and facilitated the identification of magnetic responses from different sources.

4.8. INTERPRETATION OF RESISTIVITY SOUNDING CURVES

The interpretation of Vertical Electrical Sounding (VES) data was conducted using the partial Curve Matching Technique as described by Orellana and Mooney (1966). This approach was employed to determine the resistivity, thickness, and depth of each geological layer present in the study area. In addition to manual curve matching, model parameters were inferred using the 1X1D software, which provided further insight into the sub-surface characteristics.

During the course of the study, several types of resistivity sounding curves were identified. These curves varied primarily based on the number of layers beneath the surface and the contrasts in their resistivity values. The classification of these curves was based on their shapes, which are reflective of different sub-surface geological conditions.

A notable observation from the analysis is the presence of very low resistivity values over sedimentary formations in the region. This phenomenon is attributed to the existence of thick black cotton soil, which is characterized by a high clay content and elevated salinity, or by the presence of substantial alkaline salts. As a result, there is a significant overlap in resistivity values among individual sedimentary layers, such as top clayey soil, shale, silt, sand, and gravel intercalations.

Furthermore, the VES curves indicated the presence of shallow bedrock at specific locations. These occurrences are likely due to basement highs or undulations within the basement rock, which are reflected as distinct features on the sounding curves.

These curves reveal the existence of four to five multi-layered geological setups in the area (Figure 22). The identified curve types—QKA, HQA, KQA, QAA, and HKA—each correspond to particular geological scenarios and demonstrate specific geological significance within the study area.

4.9. GEO-ELECTRIC LAYER CHARACTERISTICS AND RESISTIVITY ANALYSIS

a) Black Cotton Soil / Clay Layer

The topmost layer across different locations is predominantly composed of black cotton soil or clay. Its thickness varies significantly, ranging between 0.5 meters and 17.8 meters. The resistivity of this layer is generally low, falling within the range of 1 Ω-m to 12 Ω-m. This low resistivity is indicative of high clay content and elevated salinity within the sediments.

b) Silty Clay Layer

Beneath the black cotton soil/clay layer lies the silty clay layer, which typically exhibits a thickness between 4.5 meters and 5.8 meters. The resistivity values for this layer are moderately higher, ranging from 5 Ω-m to 20 Ω-m.

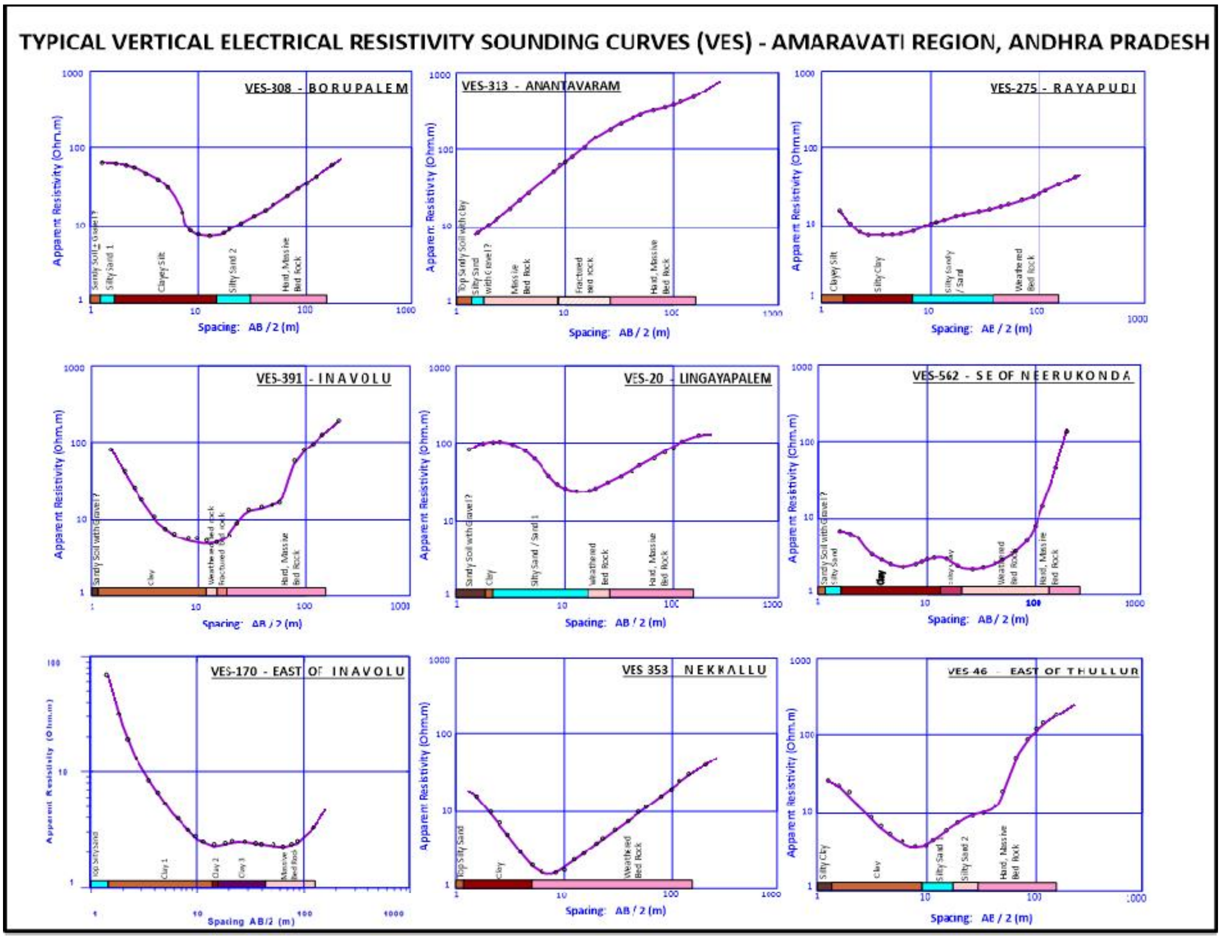


Figure 22: Typical Resistivity Sounding Curves

c) Sandy Clay Layer

The third geo-electric layer is identified as sandy clay. Its thickness is variable, extending from 8 meters to 26 meters. The resistivity of this layer ranges from 4.7 Ω-m to 12 Ω-m, reflecting the mixed nature of sand and clay within the stratum.

d) Silty Sand Layer with Gravel

Following the sandy clay layer, the fourth layer consists of silty sand, occasionally interspersed with gravel. This layer's thickness can range from 10 meters to 40 meters, and its resistivity values are observed between 10 Ω-m and 27 Ω-m.

e) Sand with Gravel

At depths between 10 meters and 40 meters, a layer characterized by sand with gravel is present. This formation is distinguished by higher resistivity values, which vary from 30 Ω-m to 170 Ω-m.

f) Weathered Basement

The presence of a weathered basement is detected at depths between 5 meters and 30 meters. The resistivity of this basement rock ranges from 10 Ω-m to 200 Ω-m, suggesting varying degrees of weathering and mineral composition.

g) Fractured Basement

In certain locations, a fractured basement is encountered at greater depths, typically between 30 meters and 100 meters. The resistivity values in this zone are observed to be between 50 Ω-m and 400 Ω-m. In some areas, the fractured basement extends further, reaching depths of up to 150 meters to 200 meters, and potentially beyond. This indicates the presence of deep-seated fracture systems.

h) Hard, Compact, and Massive Basement

Below these layers, the hard, compact, and massive basement formations—such as Charnockite, Khondalite, pyroxene granulite, or calc granulite—are encountered at depths of 60 meters and greater. These formations exhibit very high resistivity values, exceeding 400 Ω-m and, in some cases, approaching infinity.

i) Alluvium / Sand Layer in Amaravati City

In the northern part of Amaravati City, and just south of the Krishna River, the alluvium or sand layer is particularly prominent. This layer displays a thickness range of 10 meters to 51.5 meters and shows resistivity values from 9 Ω-m to 63 Ω-m. Specific resistivity and depth ranges for each formation are provided in Table 4.

Summary of VES Survey Results

The Vertical Electrical Sounding (VES) survey results demonstrate that the majority of the study area exhibits low resistivity values. These findings are attributed to the high clay content and salinity of the sediments. The depth to the weathered basement generally ranges from 10 meters to 30 meters, while the fractured basement extends from 30 meters to 100 meters, and in some places, reaches depths of 150 meters to 200 meters and beyond. This suggests that deep-seated fractures may penetrate even further into the subsurface.

Detailed analysis of aquifer characteristics, weathering, and fracture zones is presented in subsequent sections.

Table 4:Resistivity and depth range of different formations at Amaravati

Geological formation	Resistivity range (Ω-m)	Depth range (m)
Flood plain / Sand layer	9 – 63 Ω-m	10 – 51.5 m
Black Cotton Soil / Clay	1 – 12 Ω-m	0.5 – 17.8 m
Silty Clay	5 – 20 Ω-m	4.5 – 5.8 m
Sandy Clay	4.7 – 12 Ω-m	8 – 26 m
Silty Sand	10 – 27 Ω-m	12 – 40 m
Silty Sand / Sand with Gravel	30 – 170 Ω-m	10 – 40 m
Weathered Bed rock	10 – 200 Ω-m	5 – 30 m
Fractured bed rock	200 – 300 Ω-m	30 – 200 m
Semi-weathered bed rock	300 – 400 Ω-m	200 – 400 m
Hard, Massive bed rock	400 – Infinity Ω-m	400 m and above

4.10. TYPICAL VES CURVES AT DIFFERENT VILLAGES

Interpretation of VES-313 at Anantavaram

VES-313 was conducted near Anantavaram village, situated in the western part of Amaravati City. The interpretation of the field curve at this location reveals a sequence of five distinct geo-electrical layers.

The uppermost layer consists of silty clay, which exhibits a resistivity of 10.5 Ω-m and extends down to a depth of 1.5 meters. Beneath this, the second layer comprises silty sand with gravel, characterized by a moderate resistivity of 157 Ω-m and reaching a thickness of 0.75 meters, resulting in a total depth of 2.25 meters from the surface.

The third layer, identified between depths of 5.8 meters and 8.05 meters, is a shallow, weathered, and compact basement. This layer is notable for its high resistivity value of 1920 Ω-m. Below this, the fourth layer is interpreted as a fractured basement, with a substantial thickness of 26 meters, extending down to a depth of 36 meters.

Finally, from a depth of 36 meters onwards, the fifth and bottommost layer consists of hard, massive, and compact bedrock. This layer is characterized by a very high resistivity of 4500 Ω-m, indicating the presence of competent and unweathered rock material at greater depths (as depicted in Figure 23).

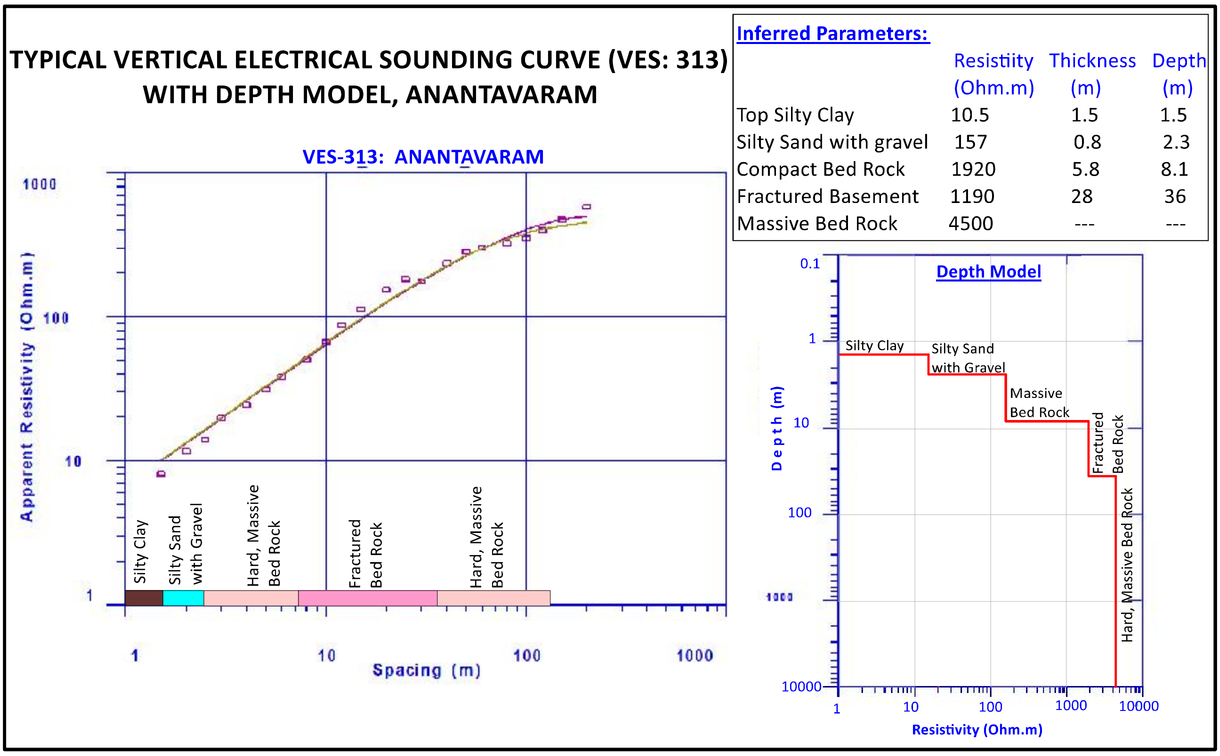


Figure 23: Typical VES curve of Anantavaram

Interpretation of VES-308 at Southwest of Dondapadu Village

Vertical Electrical Sounding (VES) number 308 was conducted at the southwest part of Dondapadu village, located in the western region of Amaravati City. The interpretation of the field curve obtained at this site identifies a sequence of five distinct geo-electrical layers, each characterized by specific resistivity values and thicknesses.

The first, or uppermost, layer consists of sandy material associated with the flood plain environment. This layer exhibits a moderate resistivity of 80 Ω-m and extends from the surface down to a depth of 1.5 meters.

Beneath the sandy surface, the second layer comprises sandy clay. This layer has a resistivity of 24 Ω-m and a thickness of 0.8 meters, reaching a total depth of 2.3 meters from the surface.

The third layer encountered is silty sand, which displays a relatively low resistivity value of 6.6 Ω-m. This layer has a substantial thickness of 9.5 meters.

The fourth layer, found between depths of 11.8 meters and 38 meters, is interpreted as sand containing gravel. It has a resistivity of 37 Ω-m and extends over a thickness of 26 meters, indicating a significant granular composition at this depth interval.

Finally, at a depth of 38 meters and beyond, the fifth and deepest layer is represented by hard, massive, and compact bedrock. This base layer is inferred to possess a very high resistivity, suggesting the presence of competent and un-weathered rock material at greater depths. The stratigraphic arrangement and resistivity profile are depicted in Figure 24.

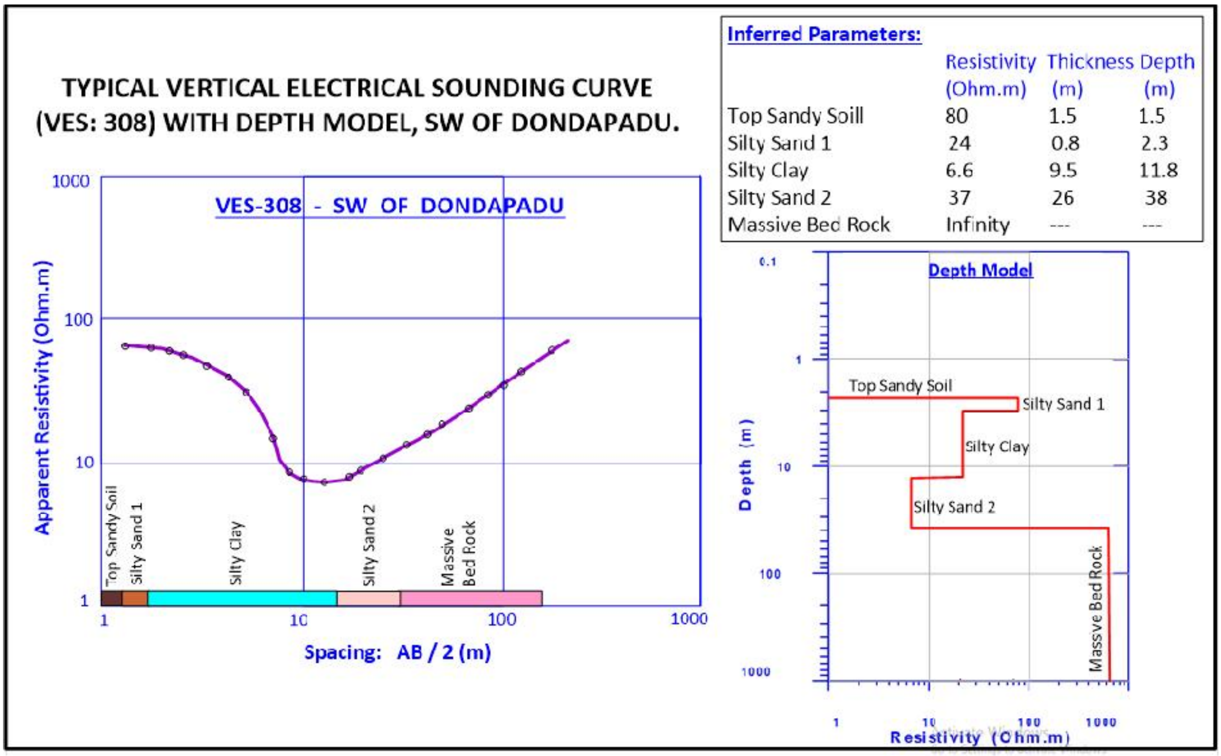


Figure 24: Typical Resistivity Curve of Dondapadu Village

Interpretation of VES-165 at Southeast of Inavolu

Vertical Electrical Sounding (VES) number 165 was conducted in the southeast region of the Inavolu area. The interpretation of the field curve obtained at this site identifies a sequence of five distinct geo-electrical layers, each with its own unique resistivity value and thickness.

The first and uppermost layer is composed of silty clay, which exhibits a resistivity of 14 Ω-m. This layer extends from the ground surface to a depth of 0.9 meters, indicating the presence of fine-grained material in the shallow subsurface.

Beneath the silty clay, the second layer consists of sandy silt with a notably low resistivity value of 2.1 Ω-m. This layer has a thickness of 4.5 meters, reaching a total depth of 5.4 meters from the surface.

The third layer encountered is made up of silty sand and is interpreted to have a thickness of 3.3 meters. The resistivity of this layer is 5.0 Ω-m, and it extends down to a depth of 8.7 meters.

Below the silty sand, a shallow fractured and weathered basement is interpreted between depths of 8.7 meters and 21.7 meters. This layer is characterized by a relatively low resistivity of 10.5 Ω-m, suggesting the presence of weathered and possibly fractured material.

Finally, at a depth of 21.7 meters and beyond, the fifth and deepest layer comprises hard, massive, and compact bedrock. This basement layer is inferred to possess a very high resistivity value, indicating the presence of competent, un-weathered rock material at greater depths. The resistivity arrangement and the stratigraphy for this site are illustrated in Figure 25.

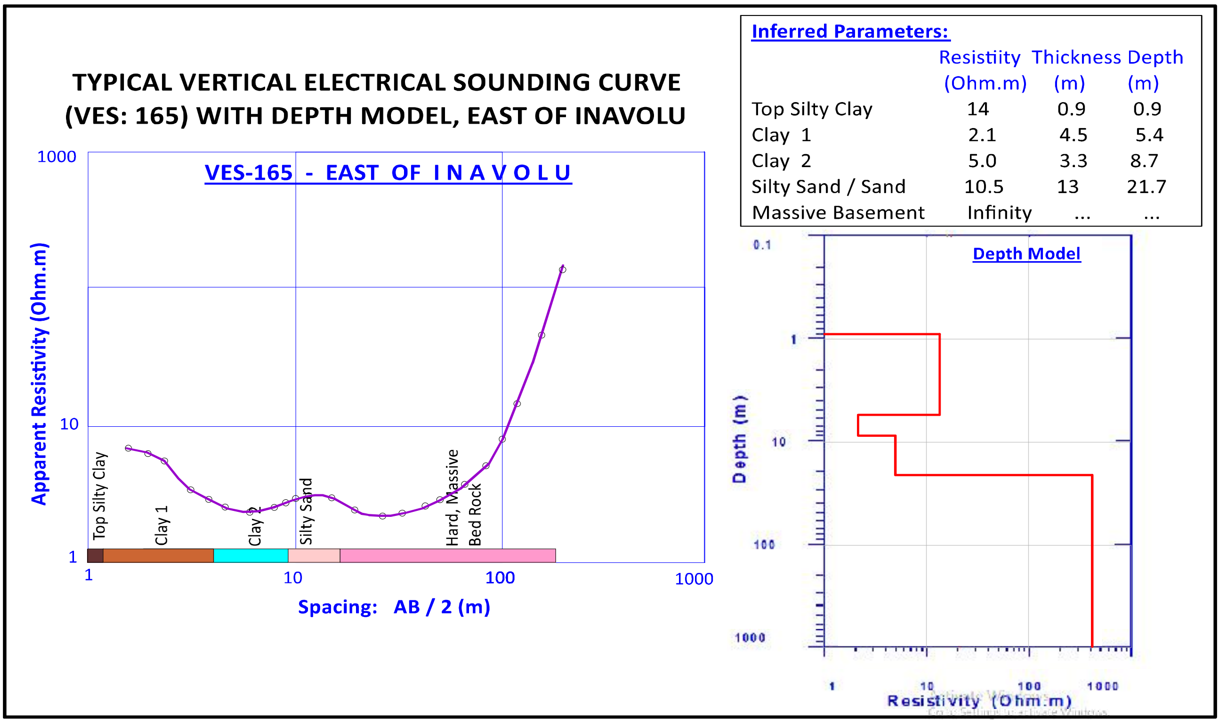


Figure 25: Typical Resistivity curve of Inavolu Village

Interpretation of VES-20 South of Lingayapalem

Vertical Electrical Sounding (VES) number 20 (Figure 26) was conducted just south of Lingayapalem village, situated within the flood plain area in the northern part of Amaravati City. The analysis of the interpreted field curve at this site reveals a sequence of five distinct geo-electrical layers.

The uppermost layer consists of flood plain sand, characterized by a relatively high resistivity of 112 Ω-m. This sand layer extends from the surface to a depth of 2.6 meters, indicating the dominance of sandy material in the shallow subsurface.

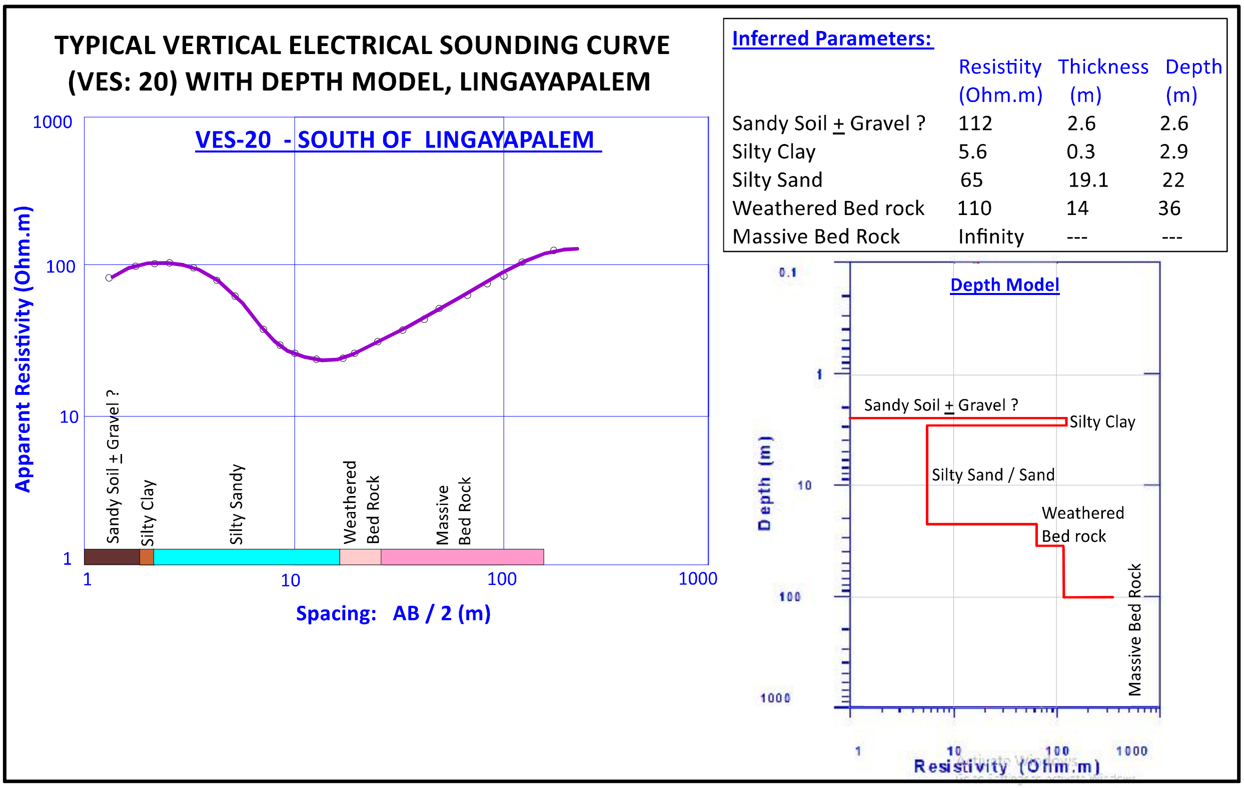


Figure 26: Typical Resistivity curve of Lingayapalem

Directly beneath the sand, the second layer is composed of sandy clay, exhibiting a significantly lower resistivity of 5.6 Ω-m. This layer is comparatively thin, with a thickness of only 0.3 meters, reaching a total depth of 2.9 meters from the surface.

The third layer encountered is silty sand, which has a thickness of 19.1 meters and a resistivity of 65 Ω-m. This substantial layer extends down to a depth of 22 meters, reflecting a major portion of the subsurface profile at this location.

Below the silty sand, a shallow weathered basement is interpreted between depths of 22 meters and 36 meters. This layer is marked by a resistivity value of 110 Ω-m, suggesting weathered and possibly fractured material at these depths.

Finally, at a depth of 36 meters and beyond, the fifth and deepest layer comprises hard, massive, and compact bedrock. This basement layer is characterized by a very high resistivity value, indicating the presence of competent, un-weathered rock material. The stratigraphic arrangement and resistivity distribution at this site are illustrated in Figure 26.

Interpretation of VES-221 at South of Nelapadu

VES-221 was carried out just near Nelapadu village, in the central part of Amaravati City. Interpreted field curve reveals essentially five geo-electrical layer setup at this location. Top black cotton of silty clay having a resistivity of 7.8 Ώ-m, up to a depth of 1.3m. Followed by sandy clay of low resistivity of 1.6 Ώ-m, having a thickness of 1.3m up to a depth of 2.6m. Silty Sand having a thickness of 5.4m with a resistivity of 3.7 Ώ-m interpreted up to a depth of 8.0m. Followed by low resistive sand with clay interpreted at a depth between 8m to 18m having a resistivity of 1.6 Ώ-m, followed by weathered bed rock encountered at a depth from 18m onwards with having a resistivity value of 112 Ώ-m (Figure 27).

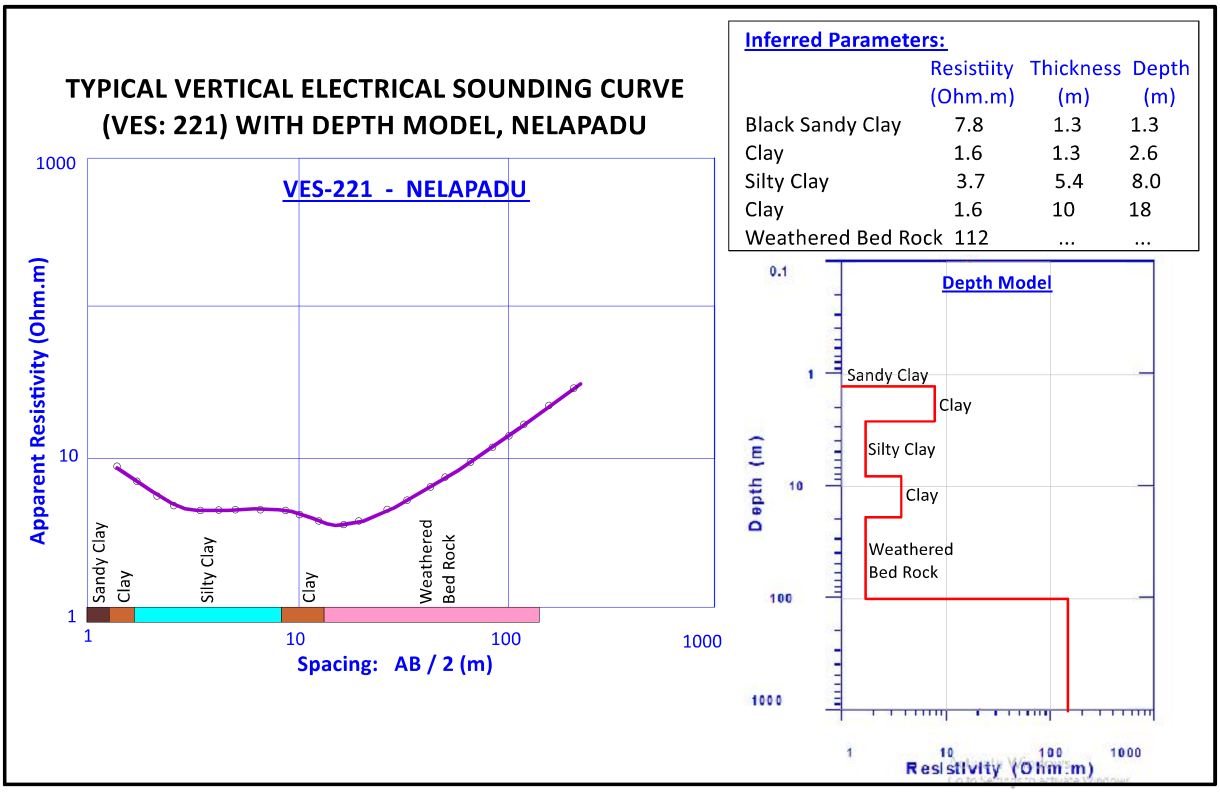


Figure 27: Typical Resistivity Curve of Nelapadu

Interpretation of VES-275 north-west of Rayapudi

VES-275 was carried out just north-west of Rayapudi village, in the north-western part of Amaravati City. Interpreted field curve reveals essentially four geo-electrical layer setup at this location. Top black silty clay having a resistivity of 7.6 Ώ-m, upto a depth of 2.5 m. Followed by sandy clay with a resistivity of 9.5 Ώ-m, having a thickness of 5.0m upto a depth of 7.5m. Silty Sand / sand layer having a thickness of 39m with a resistivity of 24 Ώ-m interpreted upto a depth of 46.5m. Followed by weathered bed rock encountered at a depth from 46.5 m onwards having a resistivity value of 95 Ώ-m (Figure 28).

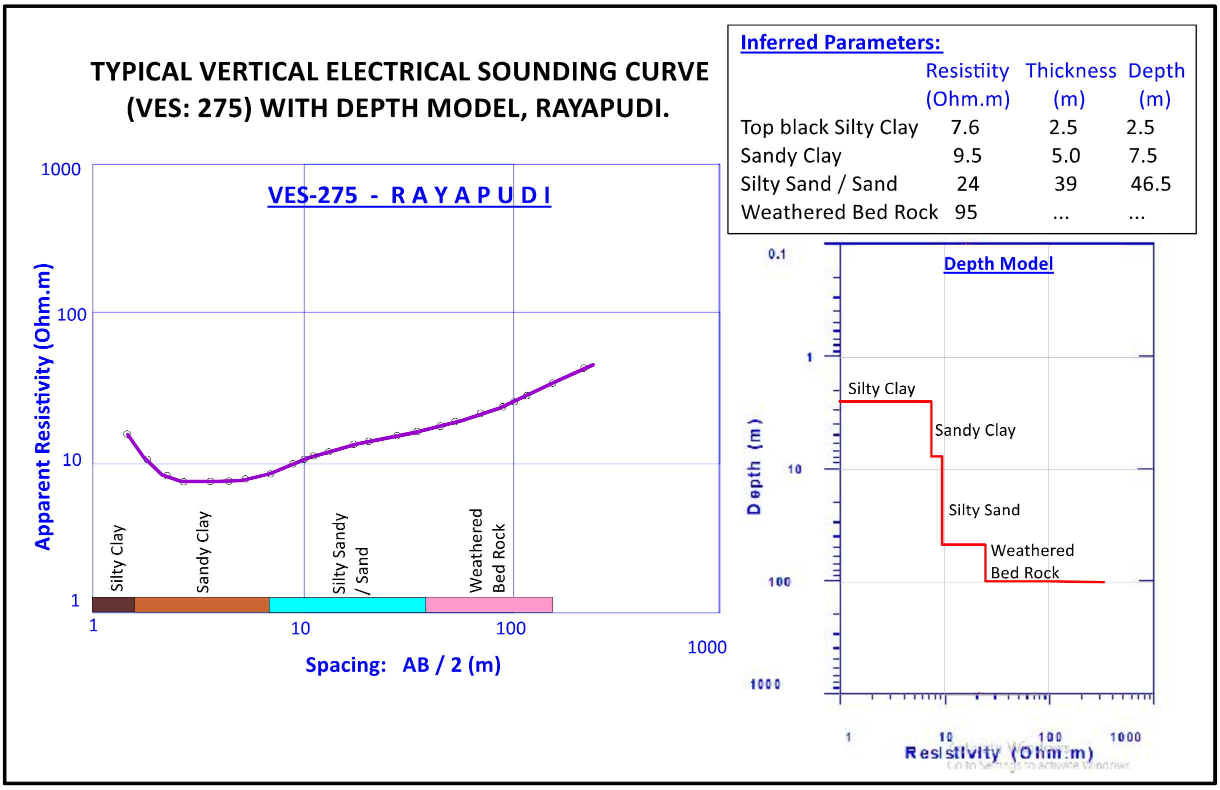


Figure 28: Typical Resistivity curve of Rayapudi Village

Interpretation of VES-341 north-west of Sakhamuru

VES-341 was carried out just north-west of Sakhamuru village, in the south-western part of Amaravati City. Interpreted field curve reveals essentially four geo-electrical layer setup at this location. Top black silty clay having a resistivity of 9.8 Ώ-m, up to a depth of 2.5m. Followed by sandy clay layer having a resistivity of 1.0 Ώ-m, having a thickness of 12.5m up to a depth of 15.0m. Followed by silty sand with gravel having a very high resistivity of 240 Ώ-m having a thickness of 1.7m up to a depth of 16.7m. Further, massive bed rock from 16.7 m onwards with very high resistivity (Figure 29).

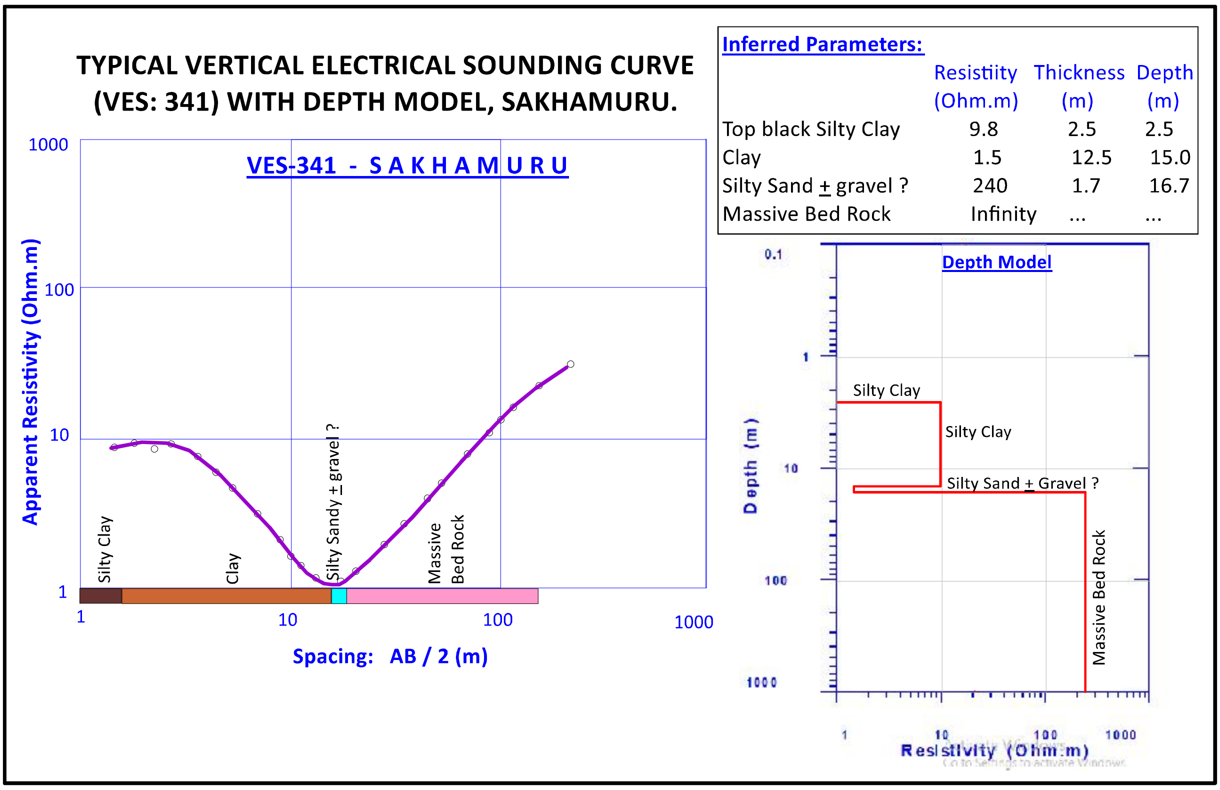


Figure 29: Typical Resistivity curve of Sakhamuru

Interpretation of VES-46 south-west of Velagapudi

VES-46 was carried out just south-west of Velagapudi village, in the central part of Amaravati City. Interpreted field curve reveals essentially five geo-electrical layer setup, consists of top black silty clay having a resistivity of 16 Ώ-m, up to a depth of 1.5m. Followed by sandy clay layer having a resistivity of 2.4 Ώ-m, having a thickness of 7.5m up to a depth of 9.0m. Followed by silty sand with gravel having a resistivity of 70 Ώ-m, having a thickness of 8.0m up to a depth of 17.0m. Weathered basement having a resistivity of 48 Ώ-m and thickness of only 3.4m interpreted upto a depth of 20.4m, followed by hard and massive bed rock with very high resistivity of 1760 Ώ-m (Figure 30).

Interpretation of VES-180 at Velagapudi

VES-180 was carried out just near Velagapudi village, in the north-western part of Amaravati City. Interpreted field curve reveals essentially five geo-electrical layer setup, consists of top black silty clay having a resistivity of 19 Ώ-m, upto a depth of 1.2m. Followed by clayey silt layer having a resistivity of 1.0 Ώ-m, having a thickness of 0.8m upto a depth of 2.0m.

Followed by clayey sand having a resistivity of 1.5 Ώ-m, having a thickness of 6.5m upto a depth of 8.5m. Silty sand layer was interpreted having a resistivity of 13.5 Ώ-m, having a thickness of 7.0m upto a depth of 15.5m. Followed by weathered bed rock with a resistivity of 70.5 Ώ-m (Figure 31).

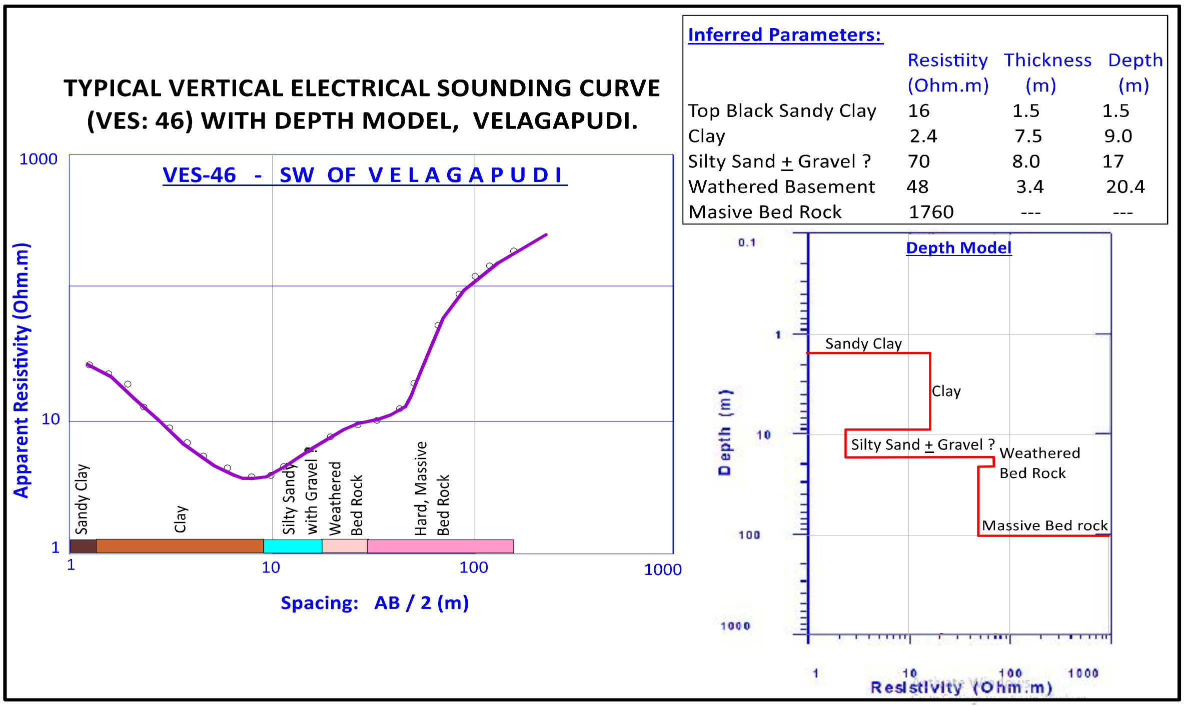


Figure 30: Typical Resistivity curve of SW of Velagapudi

Interpretation of VES-204 at Thullur

VES-204 was carried out just near Thullur village, in the north-western part of Amaravati City. Interpreted field curve reveals essentially five geo-electrical layer setup, consists of top black silty clay having a resistivity of 56 Ώ-m, upto a depth of 2.0m. Followed by sandy clay layer having a resistivity of 1.4 Ώ-m, having a thickness of 10.0m upto a depth of 12m. Followed by silty sand having a resistivity of 96 Ώ-m, having a thickness of 1.5m upto a depth of 13.5m. Followed by hard and massive bed rock with very high resistivity (Figure 32).

Interpretation of VES-562 south-east of Neerukonda

VES-562 was carried out just south-east of Neerukonda village, in the southern part of Amaravati City. Interpreted field curve reveals essentially five geo-electrical layer setup, consists of top black silty clay with gravel having a resistivity of 76 Ώ-m, upto a depth of 1.5m. Followed by silty sand layer having a resistivity of 49.4 Ώ-m, having a thickness of 0.8m up to a depth of 2.3m. Followed by sandy silt having a resistivity of 4.2 Ώ-m, having a thickness of 12m upto a depth of 14.3m. Sand layer was interpreted having a resistivity of 8.1 Ώ-m, having a thickness of 14m upto a depth of 28.3m. Followed by fractured basement with very low resistivity of 2.2 Ώ-m having a thickness of 90 m upto a depth of 118m. Then continued with massive basement with very high resistivity (Figure 33).

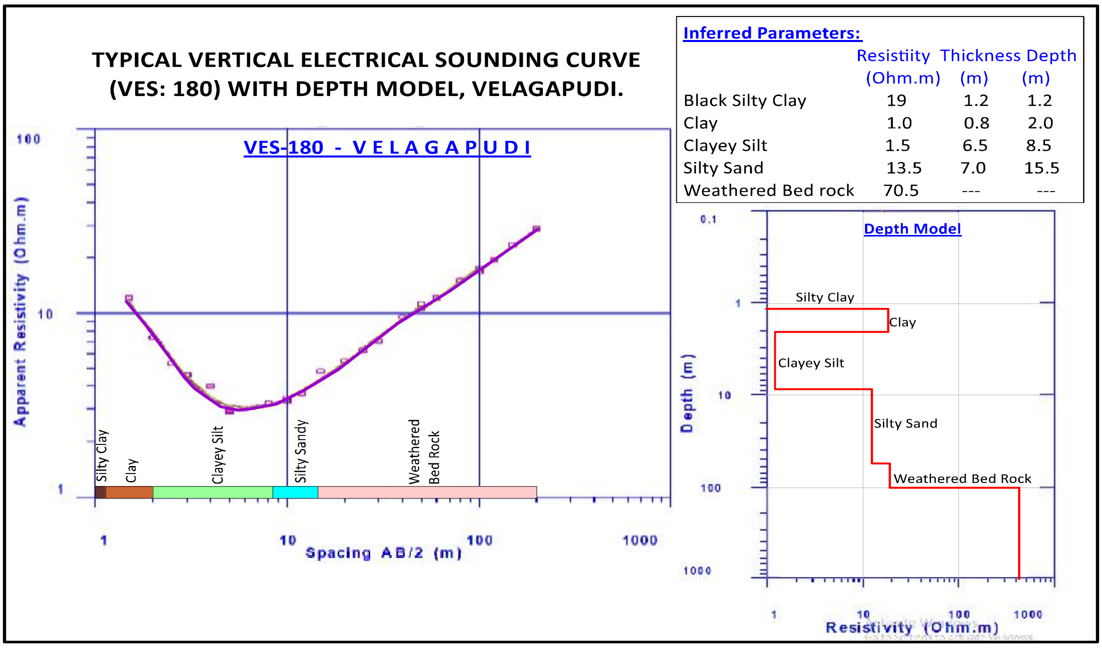


Figure 31: Typical Resistivity curve of a Velagapudi

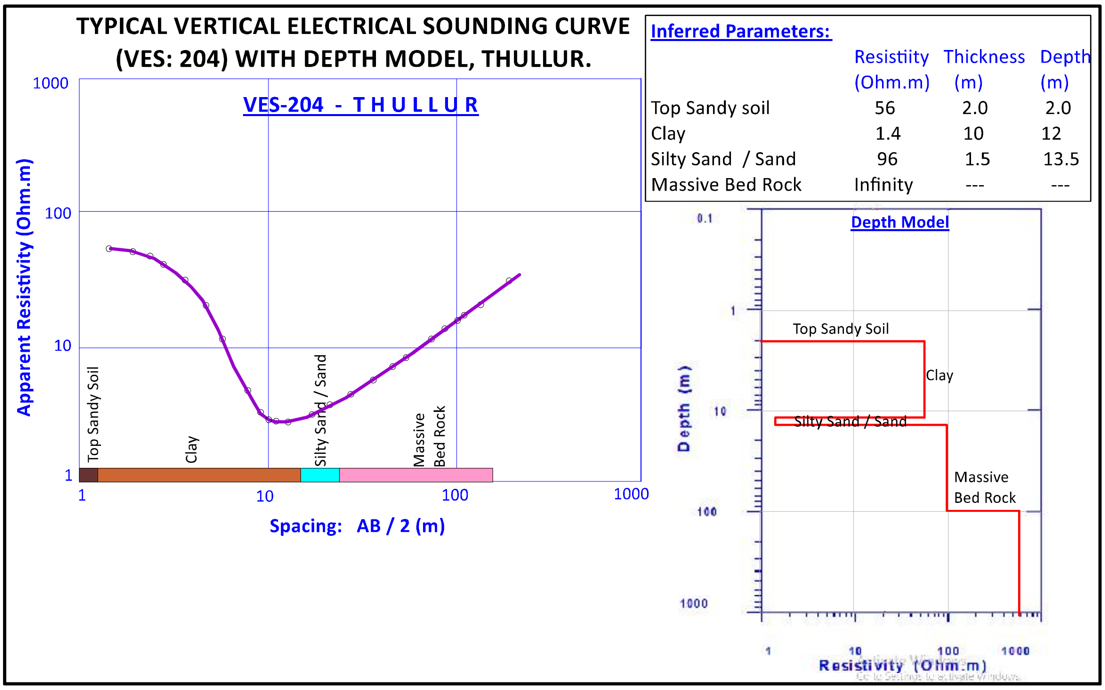


Figure 32: Typical Resistivity curve of a Thullur

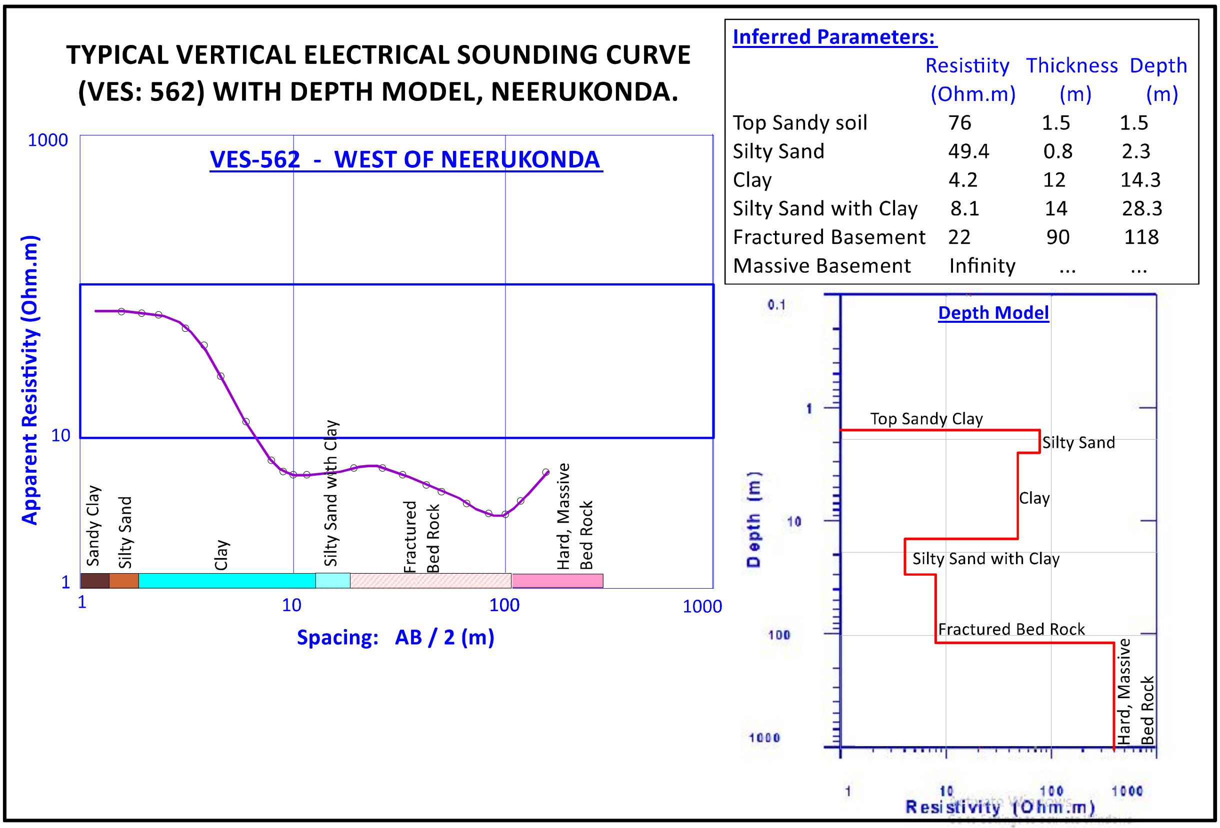


Figure 33: Typical Resistivity Curve of a Neerukonda

In general, the overburden thickness indicates overall variation in thickness from 2 to more than 30m in Amaravati City. In the eastern part of the study area from Nowluru to Mandadam (Velagapudi) the thickness varies from 10 to 30m. In south-eastern part of the area between Yerrabalam to Krishnayapalam, the overburden is thick when compared to other areas. For the resistivity soundings distributed on southern bank of Krishna River, indicating the thickness of alluvium / sand layer varies from 10 – 48m. A general observation based on the available data revealed that the bedrock is exposed as residual hills at Tadepalli and Anantavaram areas.

4.11. INFERRED GEO-ELECTRIC SECTIONS

Based on the hydro-geological conditions, low order of resistivities are attributed to the presence of clay and salinity content in the formations. A total of six geo-electric sections have been identified shown in Figure 34, to study the variations in hydro-geological and aquifer parameters, both in N-S and E-W directions. 1st to 5th geo-electric sections were chosen nearly in N-S direction to study the variations within the sediments and basement from south of Krishna River to southern part of the study area. Whereas 6th geo-electric section was chosen in WNW-ESE direction from Khondalite basement in the east at Penumaka or Tadepalli, to pyroxene / calc granulite granulite basement in the west at Anantavaram, via charnockite basement in centre.

Geo-electrical section is a perspective view or more geological cross sections in a particular direction, showing their relationship to one another. Sections-I to V were chosen in N-S direction to study the nature, resistivity, thickness and depth of sediments and underlying bed rock configuration. Whereas, section-VI was chosen in WNW-ESE direction, to study the nature of Khondalite basement in the east and to study the nature of pyroxene / calc granulite basement in the west (Figure 35 to Figure *40*). Charnockite basement occupied in the central part of the Amaravati City. The relationship in variation of resistivities, thickness with depth can be best seen in geo-electric sections, a useful way to see the multiple overlapping surfaces, such as hydro-stratigraphic data, aquifer surfaces and fracture proximities of aquifer zones.

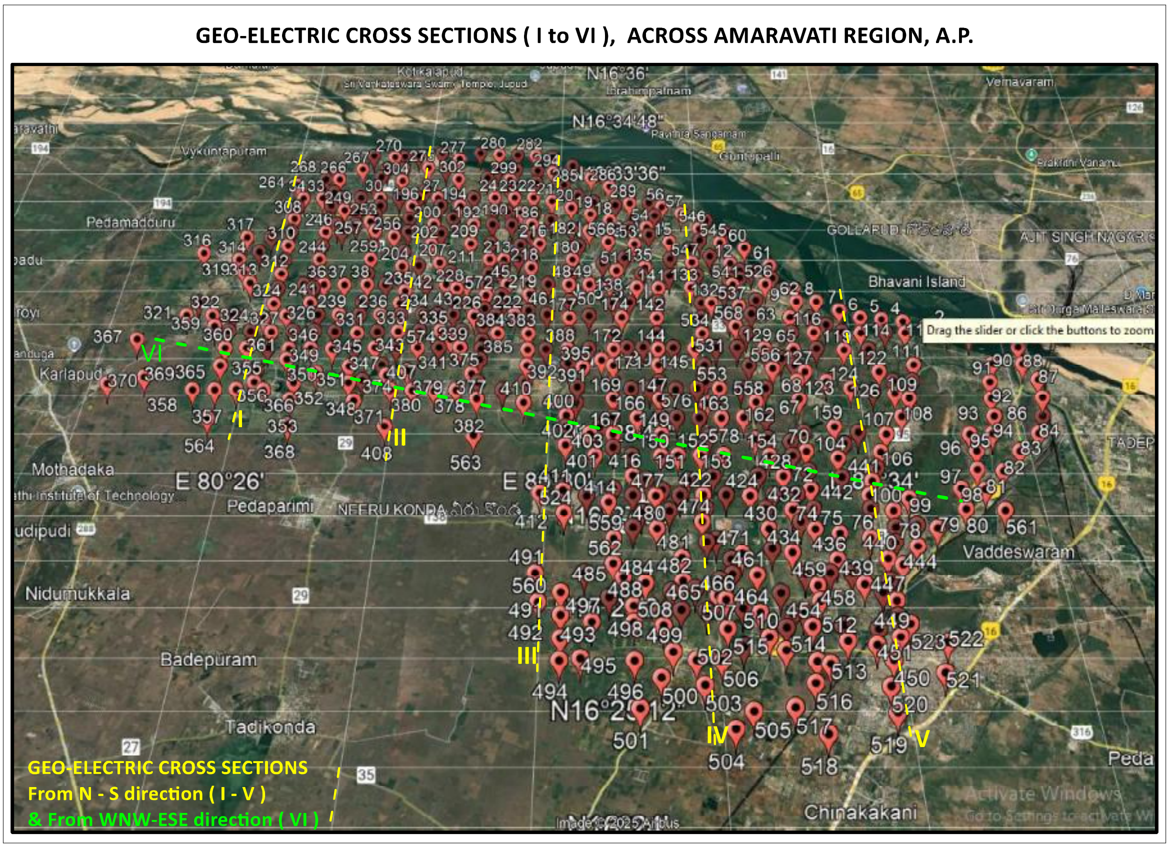


Figure 34: Google Image showing the Geo-Electric Sections from I to VI.

The layer parameters and their corresponding lithology mentioned in the geo-electric sections and typical sounding curves, led to the understanding of the sub-surface nature

(Table 4). Based on geo-electric sections, two types of aquifers are inferred in the study area, (1). Top shallow aquifer (silty sand / sand layer) within the sediments (unconfined), extends to the average depth of 30m and form the shallow or unconfined aquifer, and (2). Highly weathered basement associated with sheared / faulted / fractured elements lies at moderate depths in the form of confined aquifer within the basement, inferred at shallow levels in the eastern part and slightly deeper depths between 30 - 100m in the western part, which are favorable loci for possible occurrence of groundwater. From the analysis, few basement highs are inferred at a shallow depth which correlate well with magnetic and gravity data of Amaravati City. Details of the geo-electric sections are given below in Table 5.

Table 5: Details of Geoelectric Section

Section No.	Geo-electric section from - to	Direction	Length
I	Borupalem – Anantavaram - Nekkallu	N - S	9.30 km
II	Rayapudi – Thullur - Sakhamuru	N - S	10.4 km
III	Lingayapalem – Velagapudi - Inavolu	N - S	14.8 km
IV	Udandrayunipalem–Mandadam-Nidamarru	N - S	14.0 km
V	Undavalli – Penumaka - Mangalagiri	N - S	10.0 km
VI	S of Anantavaram - Ainvolu – Penumaka	WNW- ESE	14 km

Borupalem-Anantavaram-Nekkallu Geo-electric Section (I)

Ten resistivity soundings were chosen along this N-S section (VES-266, 34, 308, 310, 312, 327, 324, 361, 353 and VES-368) from Borupalem in the NW to Nekkallu in the SW. The length of the traverse is about 9.30km and soundings were selected between 500 - 1000m distance approximately (Figure 35). The resistivity sounding curves are multi-layered and can be categorised under QKA, HQA, KQA and QKA types. In all the soundings a conductive layer (clay) with resistivity of 0.2 – 9.8 Ώ-m is traced. The estimated depth to the bed rock varies from 6.9 m to 45 m. The order of resisivities vary from 0.2 Ώ-m to 80 Ώ-m over the sediments clay, silt, sand with gravel. A thick layer of sand with gravel having a thickness of 37.5 m having a resistivity range of 63 Ώ-m just above the bed rock is traced from VES-308, 310, 312 and 327, which may be a good aquifer favourable for groundwater, yield of groundwater in this section is likely to be good. But the quality of water may not be good, because of high salinity and TDS content in the north-western part of Amaravati City.

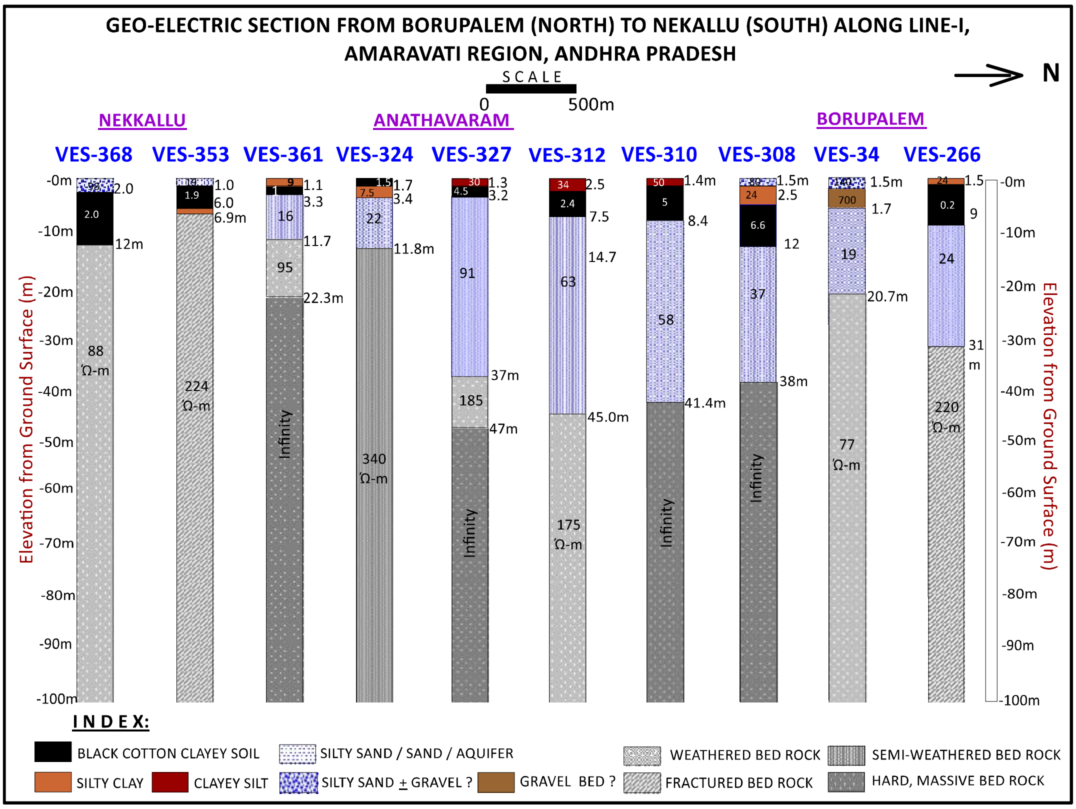


Figure 35: Geoelectric Section from Borupalem to Nekkallu

Rayapudi-Thullur-Sakhamuru Geo-electric Section (II)

Nine resistivity soundings were chosen on this N-S section (VES-374, 341, 334, 194, 205, 204, 28, 303 and VES-275) from Rayapudi in the north to Sakhamuru in the south, via Thullur. The length of the traverse is about 10.4km and soundings are selected between 500 - 1000m length approximately (Figure 36). The resistivity sounding curves are multi-layered and can be categorised under QKA, QAA and HKA types. In all the soundings a conductive layer of clay with resistivity of 0.1 – 5.7 Ώ-m is traced. The estimated depth to the bed rock varies from 13.5 m to 60 m in this section. The order of resisivities vary from 0.1 Ώ-m to 100 Ώ-m over the sediments viz., clay, silt, sand with gravel. A thick layer of sand with gravel having a thickness varies from 11.5m – 39m, with a resistivity range of 24 - 100 Ώ-m is traced from VES-374, 204, 28 and 275, which may be a good aquifer, favorable for groundwater and yield of groundwater in this section is likely to be good. But quality of water may not be good, because of high salinity with high TDS content, in the NW part of Amaravati City.

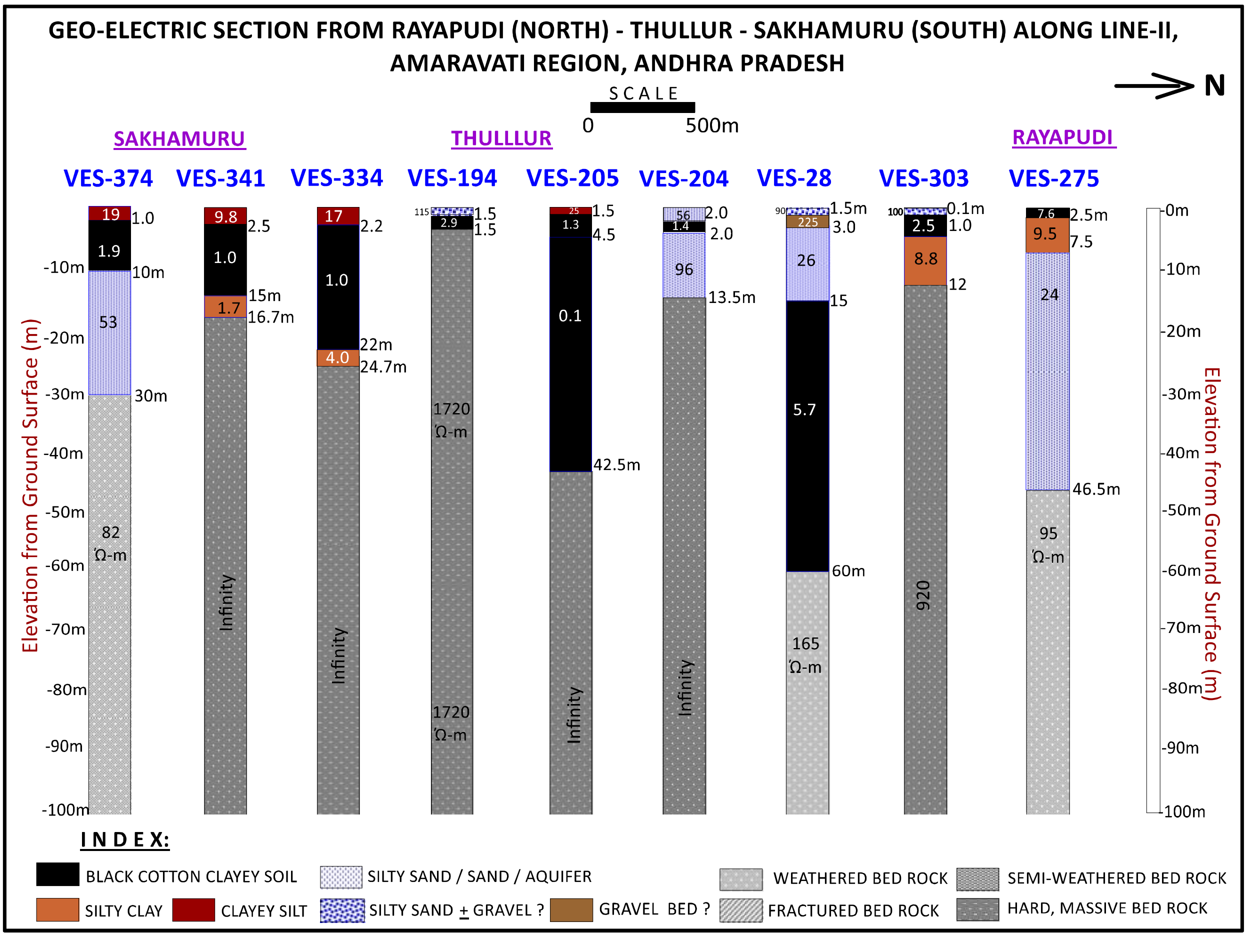


Figure 36: Geo-electric section (N-S) of Rayapudi to Sakhamuru

Lingyapalem-Velagapudi-Ainavolu-Neerukonda Geo-electric Section (III)

Ten resistivity soundings were chosen on this N-S section (VES-501, 497, 403, 411, 221, 49, 181, 183, 19 and 293) from Lingayapalem in the northern part to Ainavolu in the southern part, via Velagapudi and Neerukonda (Figure 37). The length of the traverse was 14.8km and soundings selected between 500 - 1000m. The resistivity sounding curves are multi-layered and can be categorised under QKA, QAA and HKA types. In all the soundings a conductive layer with resistivity of 0.5 – 10.4 Ω-m (clay) is traced. The estimated depth to the bed rock varies from 2.5m to 56.4m. The order of resisivities vary from 0.5 to 56 Ω-m over the sediments.

A thick layer of sand with gravel with a thickness of 6m to 48m having a resistivity range of 6.8 - 98 Ω-m just above the bed rock is traced from VES-501 to VES-411, VES-49 to VES-293, which may be good aquifer, favourable for groundwater. The quality and yield of groundwater in this section is likely to be good, as the section falls close to the NNE-SSW trending shear zone from Uddandarayunipalem to Ainavolu.

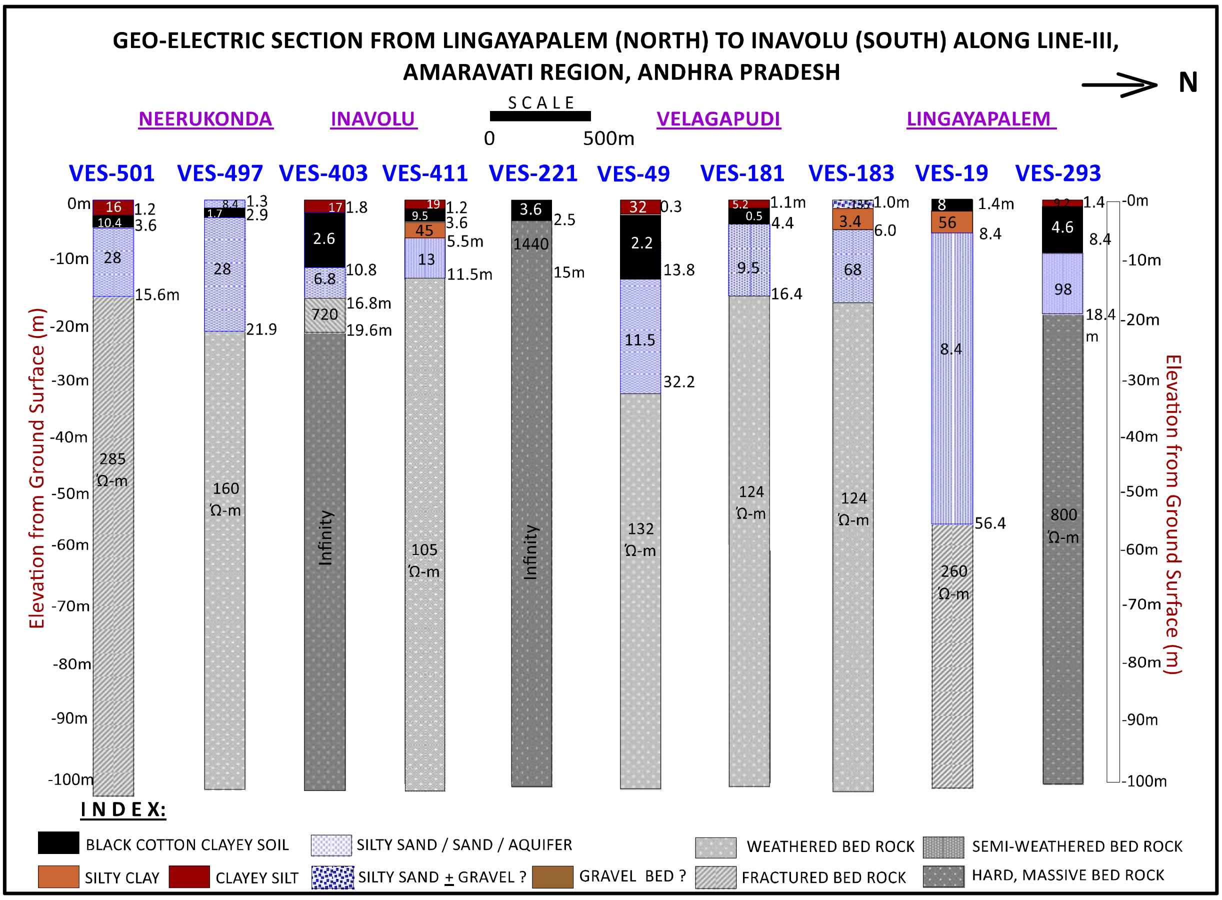


Figure 37: Geoelectric Section from Lingayapalem to Neerukonda

Uddandarayunipalem – Mandadam – Karugallu - Nidamarru Geo-electric Section (IV)

Ten resistivity soundings were chosen on this N-S section (VES-499, 483, 476, 419, 150, 146, 144, 140, 15, and 288) from Uddandarayunipalem in the north-east to Nidamarru in the south-east. The length of the traverse was 14 km and soundings were selected approximately at 500 - 1000m distance apart (Figure 38).

The resistivity sounding curves are multi-layered and can be categorized under QAA and QHA type. In all the soundings a conductive layer with resistivity of 1.2 to 8.4 Ώ-m (black clay) is traced. The estimated depth to the bed rock varies from 10m to 56m. The order of resistivities vary from 1.2 to 180 Ώ-m over the sediments viz., black cotton soil / clay, silty, silty sand, sandy silt with gravel etc. A thick layer of sand with gravel with a thickness of 25m having a resistivity range of 9.5 Ώ-m to 66 Ώ-m just above the bed rock is traced over VES-150, 144 and VES-15, which may be good aquifer, favourable for groundwater. The quality and yield of groundwater in this section is likely to be good, correlating well with the TDS data.

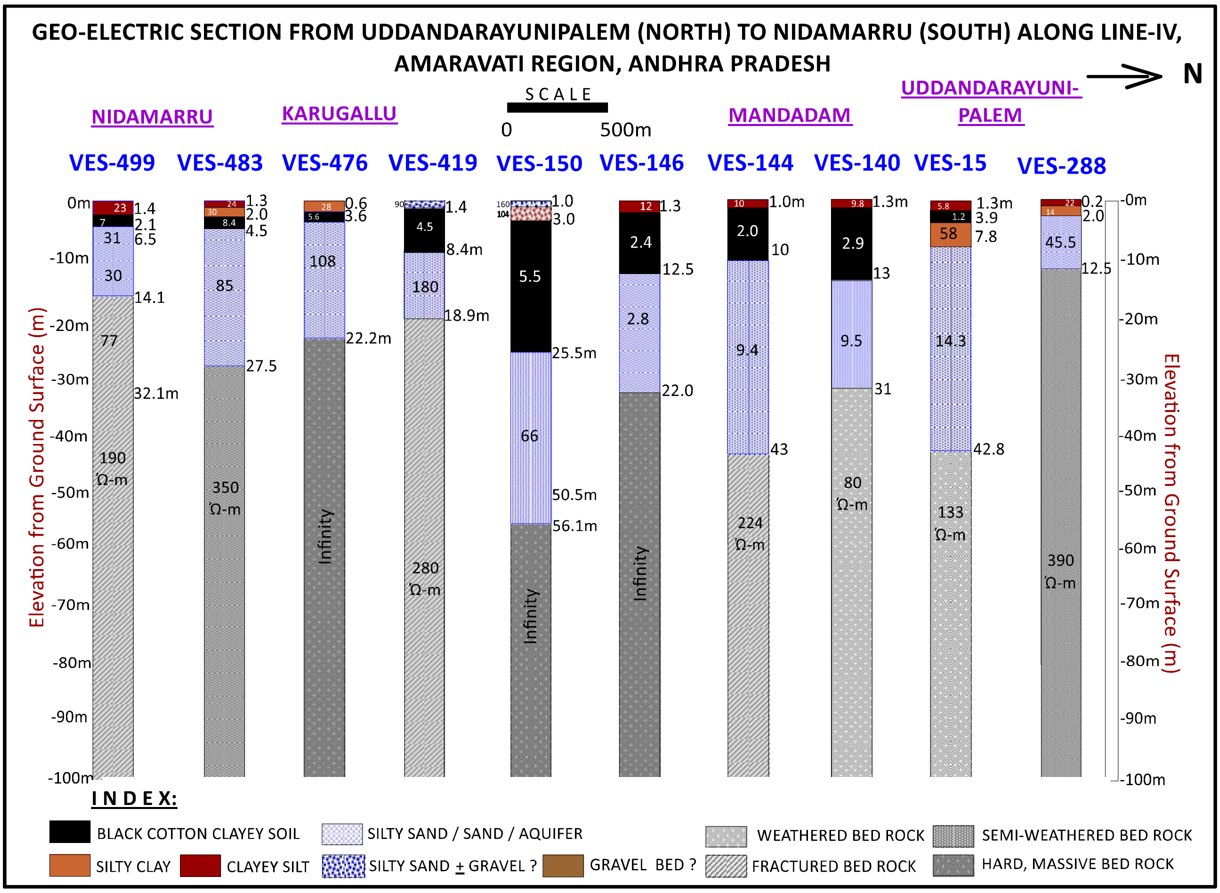


Figure 38: Geo-electric section (N-S) of Uddandarayunipalem to Nidamarru

Undavalli-Penumaka-Mangalagiri Geo-electric Section (V)

Nine resistivity soundings were chosen on this N-S section (VES-452, 76, 442, 106, 107, 125, 122, 120 and 8) from Undavalli in the northeast to Mangalagiri in the south-east (Figure 39). The length of the traverse was 10 km and soundings are selected approximately 500 - 1000m distance apart. The resistivity sounding curves are multi-layered and can be categorized under QKA and HKA type. In all the soundings a conductive layer with resistivity of 1.5 to 9 Ώ-m (black clay) is traced. The estimated depth to the bed rock varies from 24m to 54m. The order of resisivities vary from 1.5 to 120 Ώ-m over the sediments viz., black cotton soil / clay / silt / clayey silt / silt sand with gravel. A thick layer of sand with gravel with a thickness of 20 – 45m having a resistivity range of 3.5 to 38.5 Ώ-m just above the bed rock is traced in

VES-8, 120, 122, 106, 76 and 452, which may be good aquifer, favorable for groundwater. The quality and yield of groundwater in this section is likely to be good, based on less TDS content.

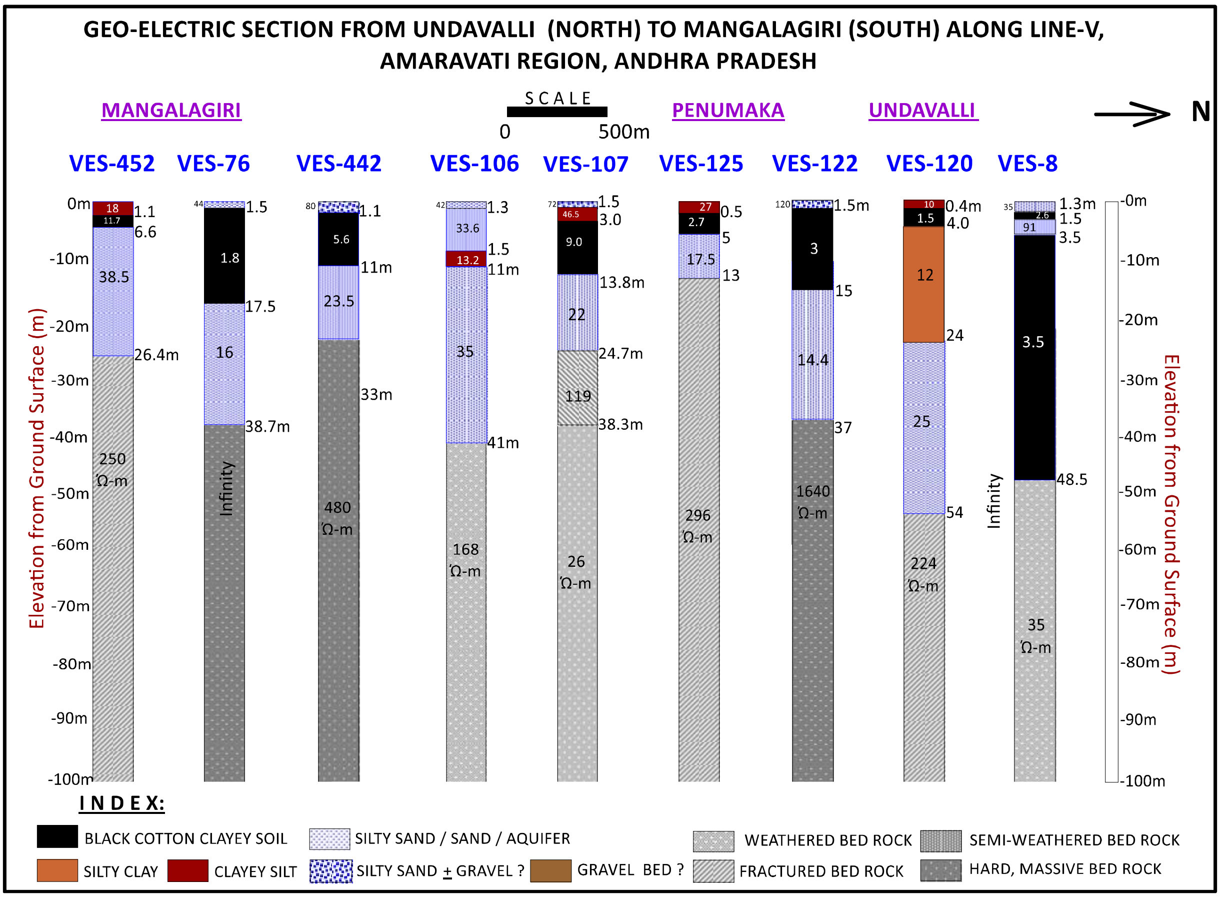


Figure 39: Geo-electric section (N-S) of Undavalli to Mangalagiri

South of Anantavaram to Southeast of Penumaka Geo-electric Section (VI)

Twelve resistivity soundings were chosen on this WNW-SES section (VES-122, 106, 146, 146, 395, 409, 221, 341, 237, 240, 204, 361 and 359) from SE of Penumaka to South of Anantavaram, via Inavolu (Figure 40). This section was chosen in WNW-ESE direction from Khondalite basement in the east at Tadepalli to pyroxene / calc granulite basement in the west at Anantavaram, via charnockite basement in the central part. The length of the traverse is about 14 km and soundings selected at every 500 - 1000m distance apart approximately.

The resistivity sounding curves are multi-layered and can be categorised under QKA, HQA, KQA and QKA types. In all the soundings a conductive layer with resistivity of 1.0 to 9.5 Ω-m (black clay) is traced. The estimated depth to the bed rock varies from 6.9m to 45m indicating the presence of basement undulations. The order of resisivities vary from 1.0 to 120 Ω-m over the sediments viz, black cotton soil, clay, silt, sand, silty clay, clayey silt, silty sand with gravel etc,.

A thick layer of sand with gravel with a thickness of 22m to 30m having a resistivity range of 14.4 to 35 Ω-m just above the bed rock is traced from VES-240, 106 and 122, which may be good aquifer, may be favorable for groundwater. The quality and yield of groundwater in the eastern part is potable with less TDS, whereas, in the western part there having more TDS.

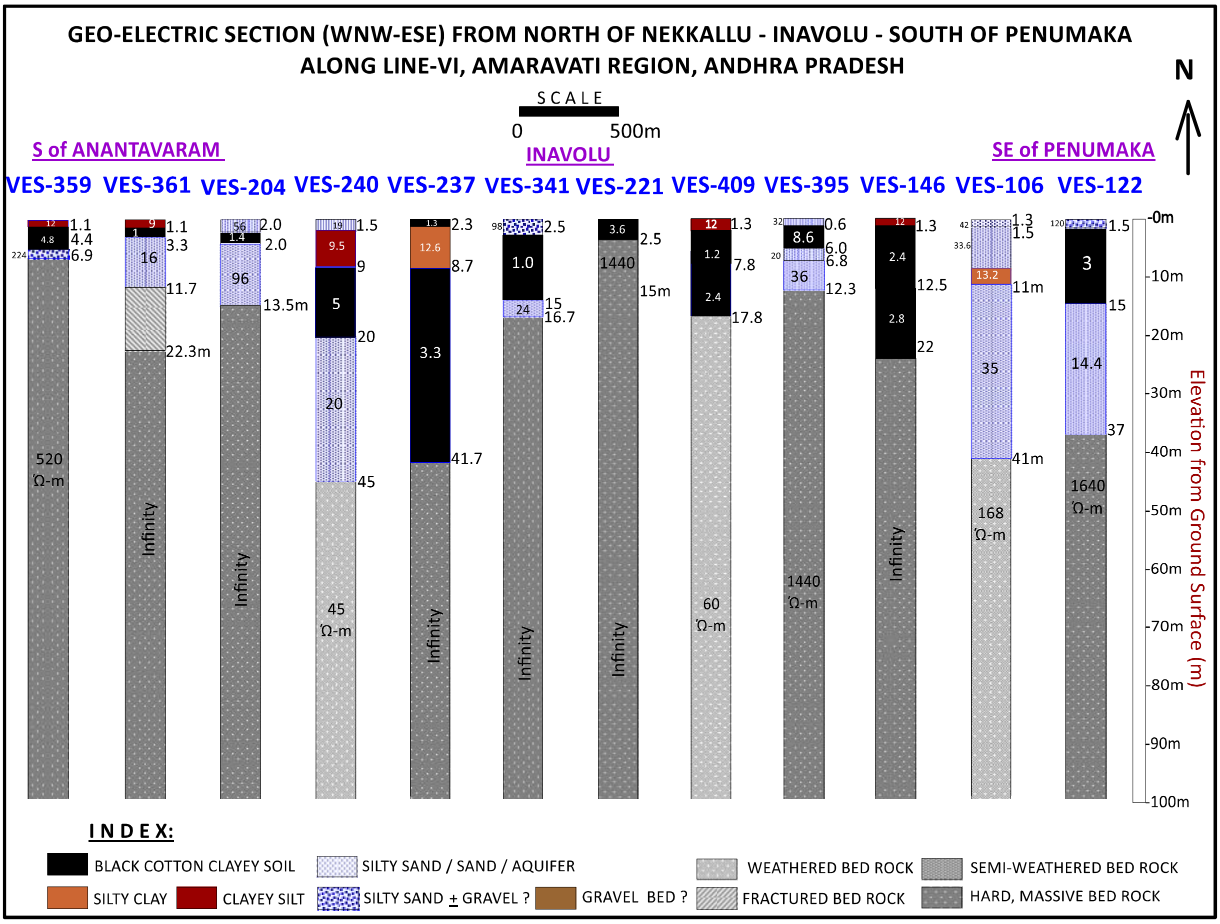


Figure 40: Geo-electric section of South of Anantavaram to South-east of Penumaka

4.12. INFERRED RESISTIVITY IMAGES AT VARIOUS DEPTHS FROM SOUNDINGS (VES)

Resistivity images delineated at different levels, derived from electrical resistivity soundings provide a valuable tool for visualizing subsurface resistivity variations with depth. These sections are created by analyzing data collected from resistivity surveys where electrode spacing is systematically increased to probe deeper levels.

Iso Resistivity depth images were delineated using IDW method in ArcGIS. Iso resistivity maps at various levels i.e., 1m, 2m, 5m, 8m, 10m, 17m, 20m, 53m, 80m and 100 m depths have been generated with increase of AB/2(m) vs apparent resistivity (Ohm.m) helps in nature and depth continuity of different lithological/structural units in Amaravati City.

At 1m depth, very low to low resistivities are recorded over black cotton soil (yellow) indicating its distribution as a background. Slightly moderate resistivities (brown) noticed between Krishnayapalem and Navuluru in the southeast and between Thullur and Dondapadu in the Northwest part (Figure 41).

At 2m depth, very low resistivities are recorded over clayey silt indicating its distribution (green) noticed between Nekkalu and Sakhamuru in the west, around Mandadam in the NE and Penumaka in the east (Figure 42).

At 5m and 8m depths, moderate resistivities recorded over silty clay indicating its distribution (yellow) between Krishnarayapalem and Navuluru in South East, Nidamarru - Kuragalu in south, between Anantavaram and Nekkalu in the west, and around Mandadam and North East of Thullur (Figure 43 & Figure 44).

At 10m depth, moderate and isolated resistivities are recorded over clayey silty indicating its distribution (yellow) noticed between Thullur-Nelapadu, Ainavolu, Mandadam, Navuluru, Kurugallu and Nidamarru (Figure 45).

At 17m depth, isolated moderate to high resistivities are recorded over sandy silt, indicating its distribution (brown) noticed at Nekkallu, east of Mandadam & Nidamarru. Whereas, moderate values over silty sand at Thullur, Ainavolu, Mandadam, Navuluru, Kurugallu area (Figure 46).

At 20m depth, high isolated resistivities are recorded over sand / silty sand indicating its distribution (brown) noticed at Navuluru, Kurugallu. Moderate values noticed at Nekkallu, Mandadam, Ainavolu & Anantavaram areas. Whereas low values observed over remaining part of area (Figure 47).

At 53m depth, isolated high resistivities are recorded over weathered bed rock indicating its distribution (brown) noticed at Navuluru, Kurugallu, Nidamarru, south of Krishnayapakem & Nekkallu. Moderate values noticed at Nelapadu, Ainavolu & Krishnayapalem. Low values are observed over remaining part of study area (Figure 48).

At 80m depth, isolated high resistivities are recorded over weathered to semi-weathered bed rock (brown) noticed at south of Anantavaram, and north of Navuluru, moderate values noticed at South of Vaddamanu, Nelapadu, North of Ainavolu and south-eastern parts (Figure 49).

At 100m depth, isolated high resistivities are recorded over semi-wathered to massive bed rock noticed around Anantavaram, North of Navaluru, Nidamarru and Undavalli areas (Figure 50).

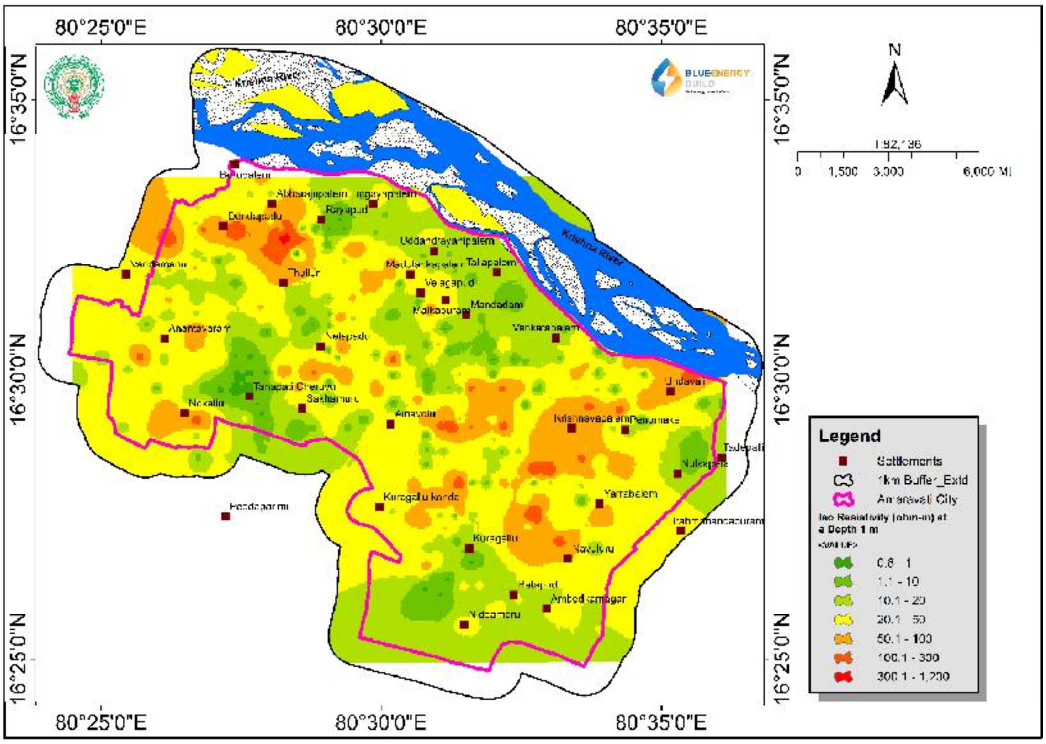


Figure 41: Iso Resistivity contour map at 1 m depth

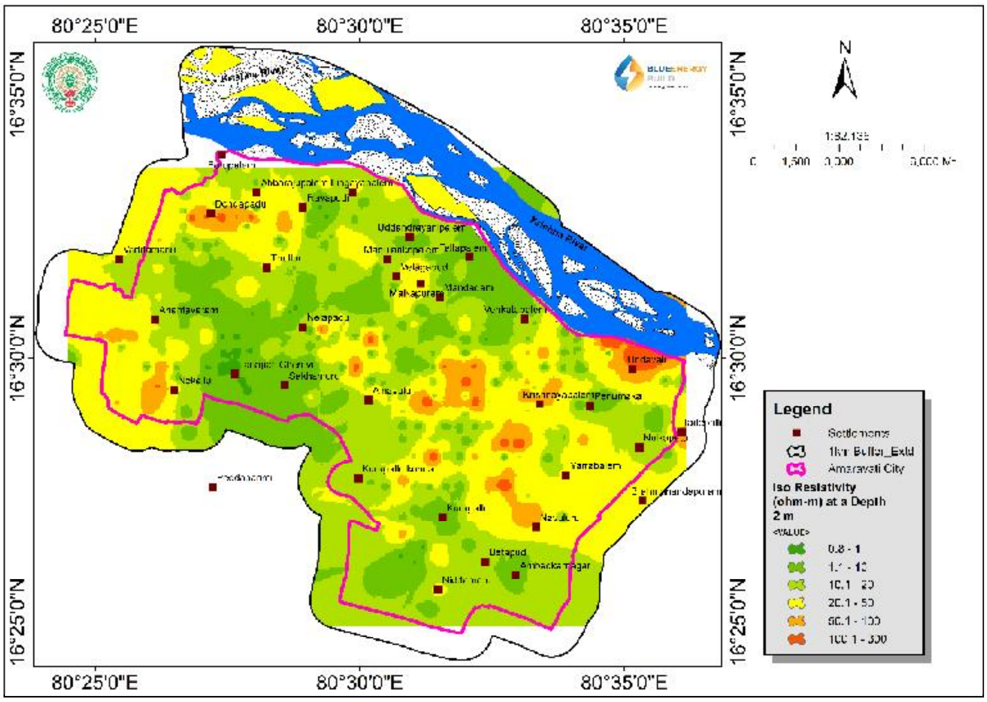


Figure 42: Iso Resistivity contour map at 2 m depth

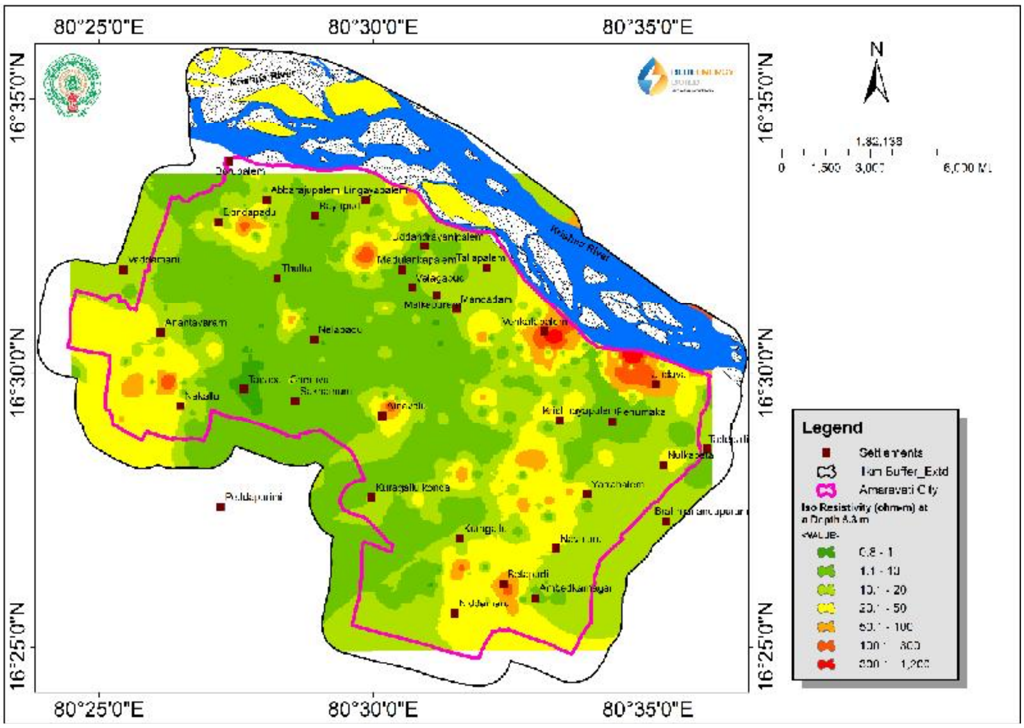


Figure 43: Iso Resistivity contour map at 5 m depth

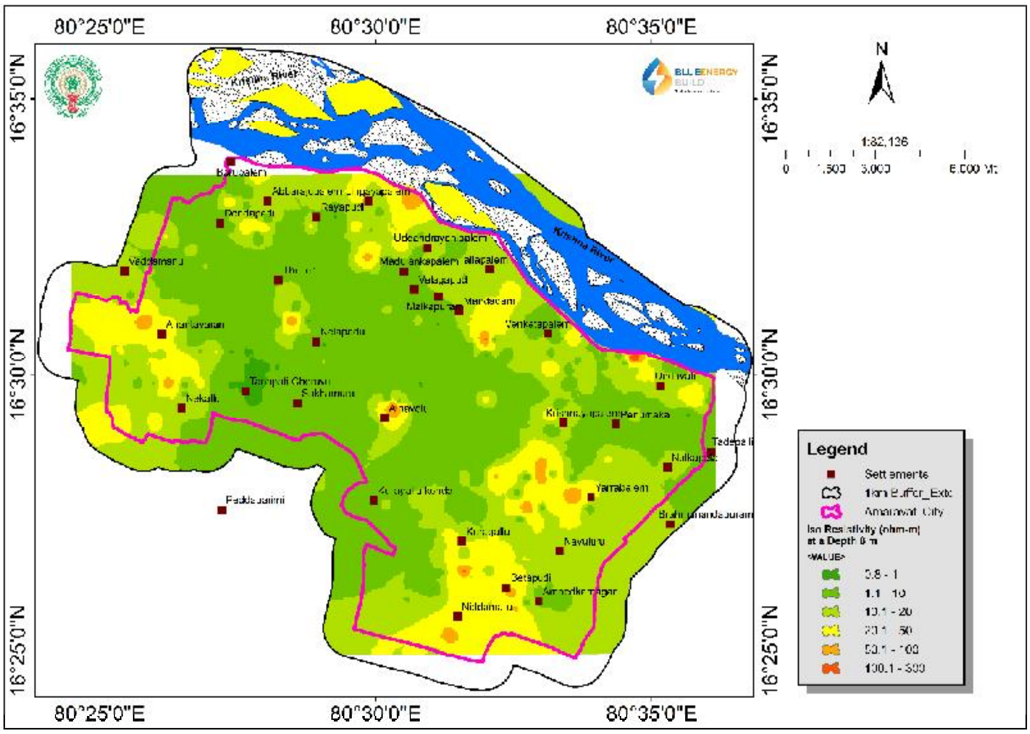


Figure 44: Iso Resistivity contour map at 8 m depth

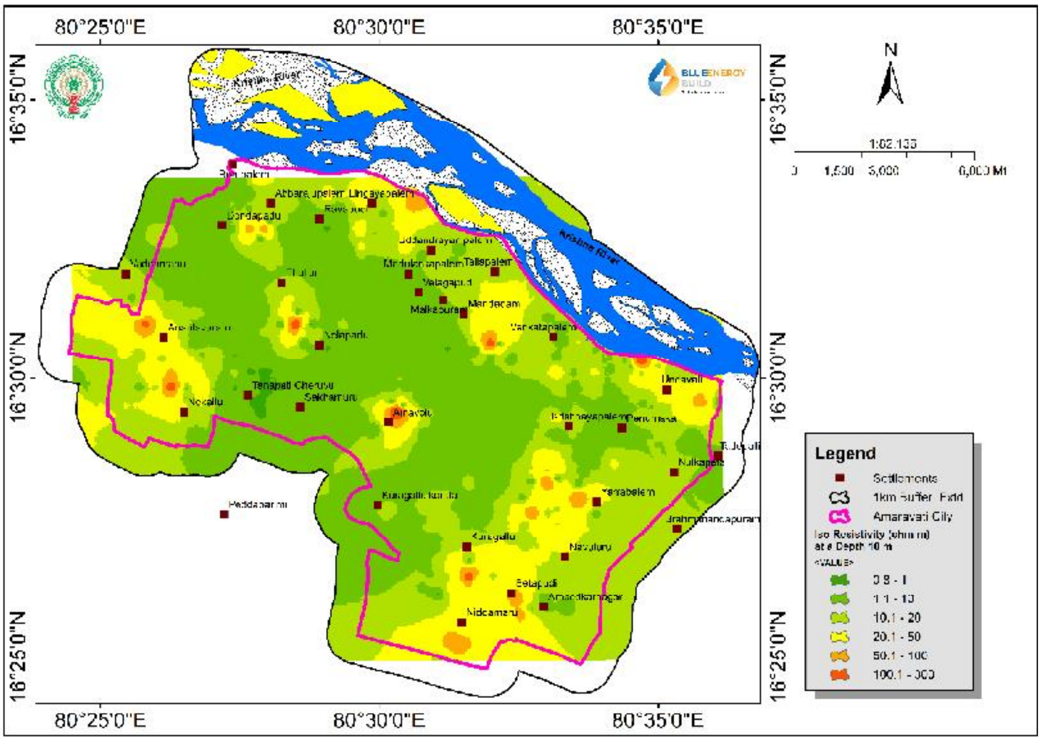


Figure 45: Iso Resistivity contour map at 10 m depth

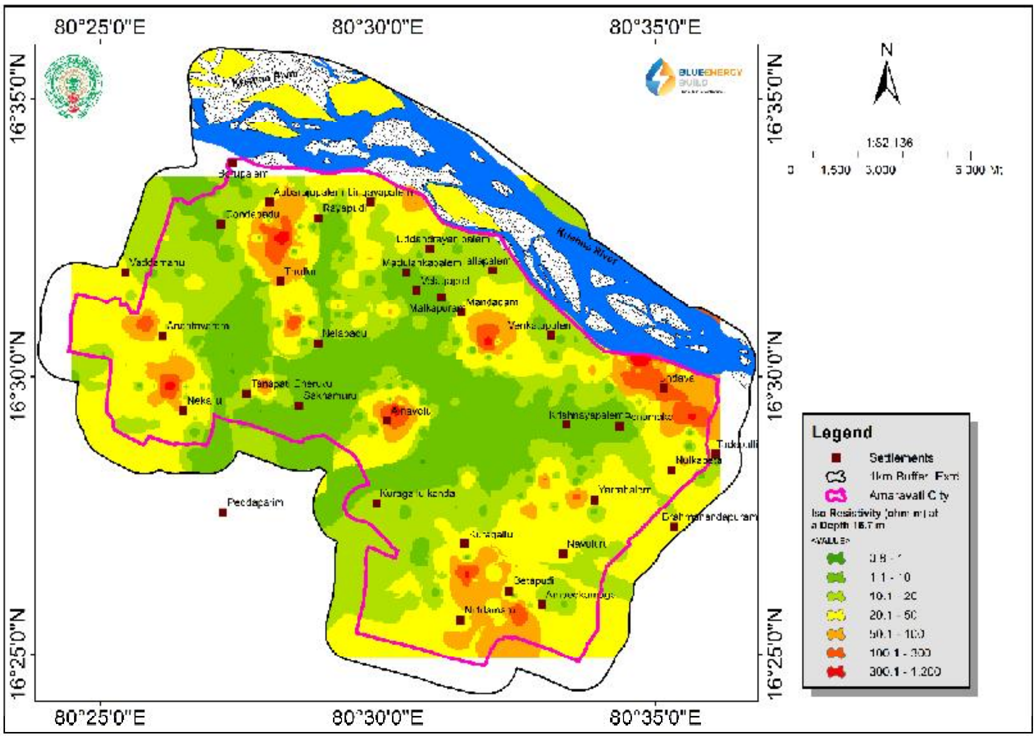


Figure 46: Iso Resistivity contour map at 17 m depth

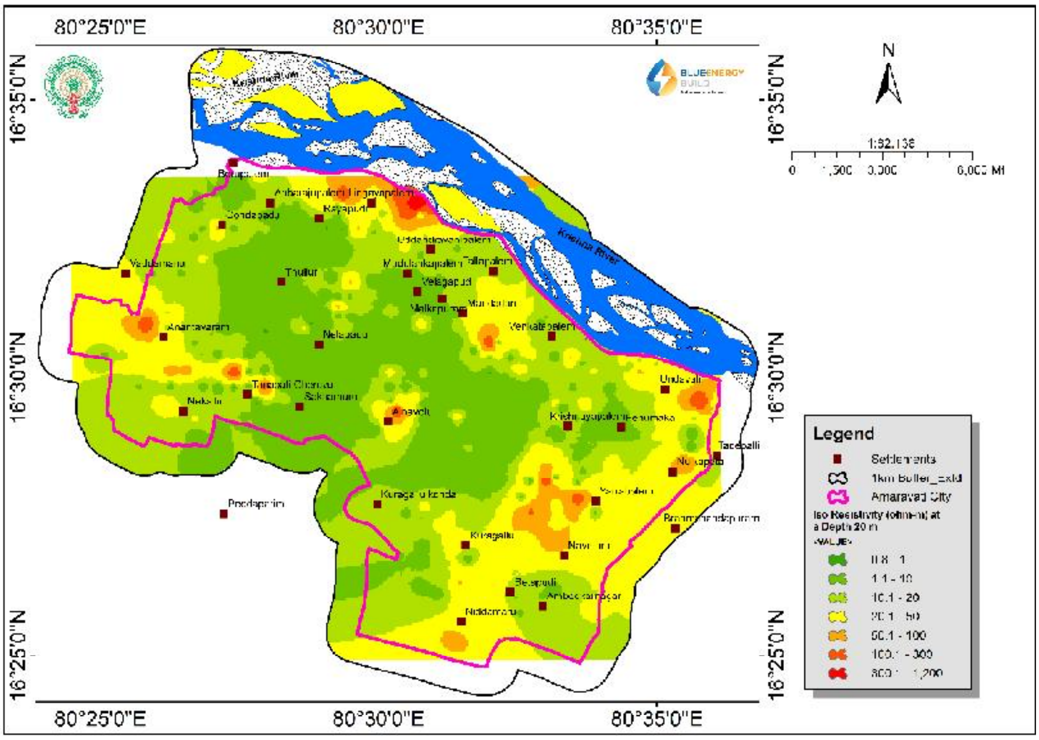


Figure 47: Iso Resistivity contour map at 20 m depth

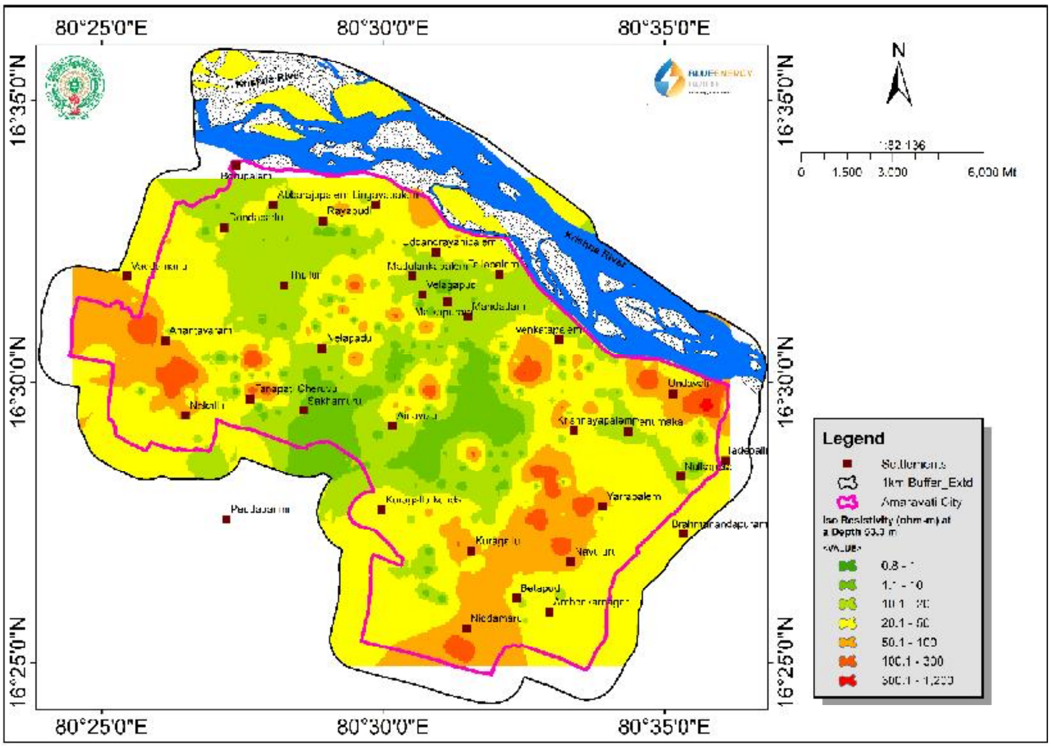


Figure 48: Iso Resistivity contour map at 53 m depth

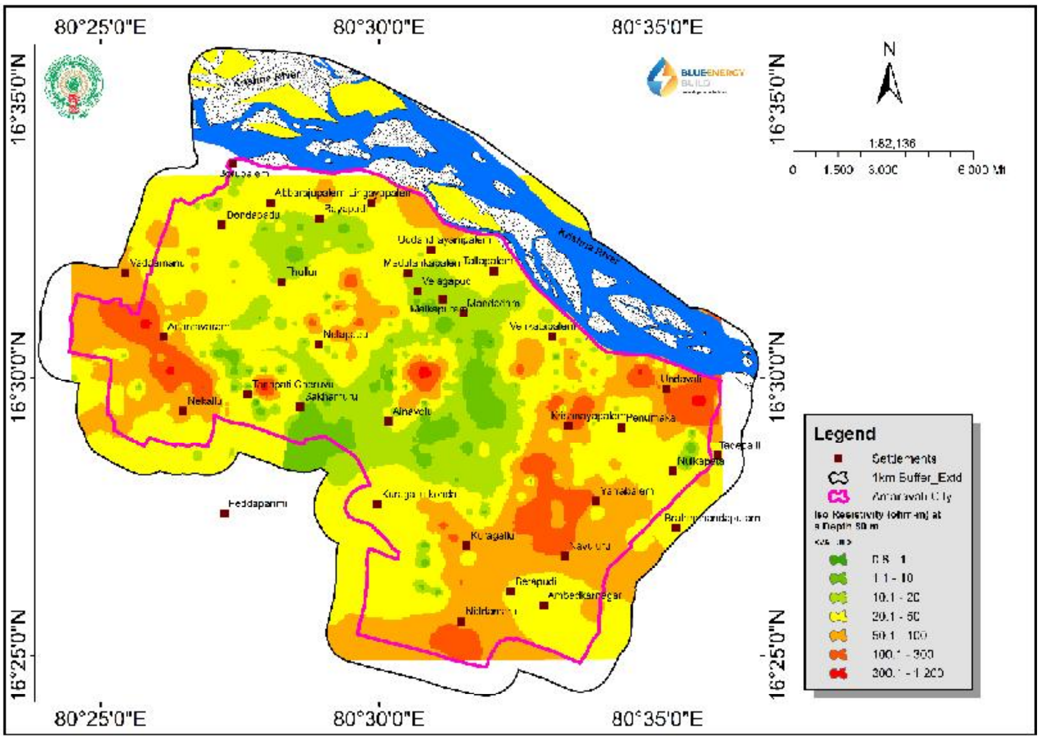


Figure 49: Iso Resistivity contour map at 80 m depth

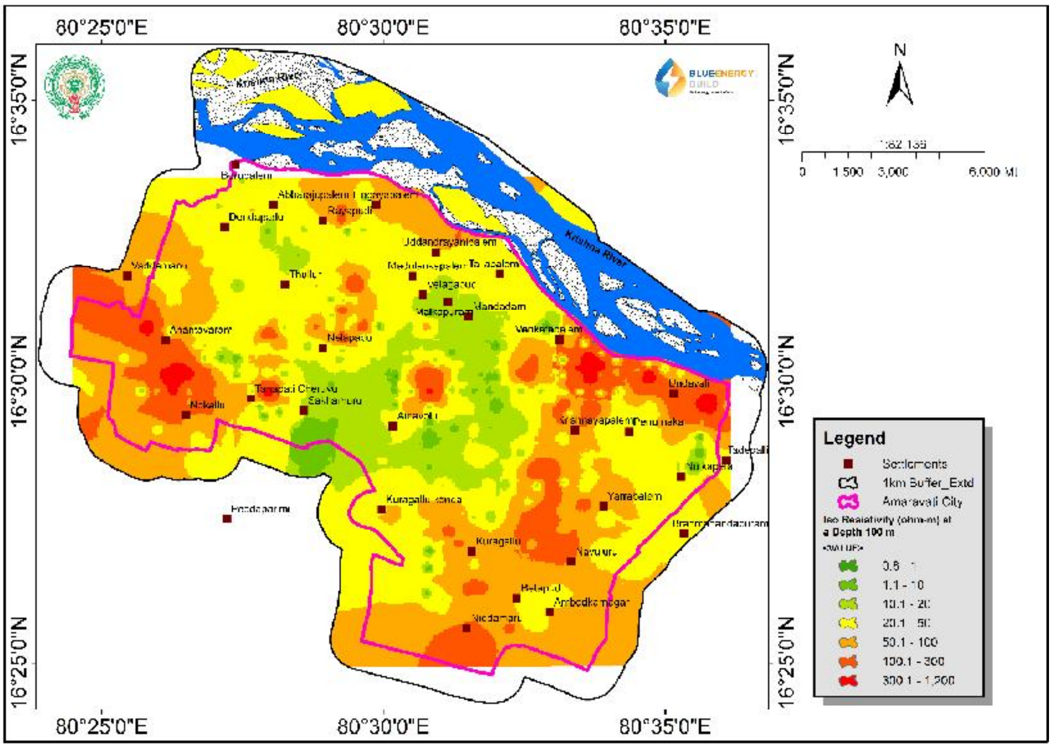


Figure 50: Iso Resistivity contour map at 100 m depth

4.13. MAGNETIC SIGNATURES OVER NNE-SSW SHEAR ZONE

Further, the NNE-SSW trending inferred and concealed shear zone from Uddandarayunipalem to Ainavolu, reflected well in the form of low dominant magnetic anomalies and moderate gravity gradients. From the magnetic anomalies, the width of the concealed shear zone may be around 400m approximately in the northern part. It seems the shear zone may be affected by strike-slip fault mechanism in the form of block movement along NNE-SSW direction, and western part may be down thrown block, as evidenced by presence of thick sediments in the western part, elevation and drainage density data.

Detailed magnetic measurements have been made across NNE-SSW trending concealed shear zone inferred from Seismic Zonation Map of India, IS: 1893 – Part-1, 2002, passing through the centre of the area between Uddandarayunipalem in the north to Ainavolu in the south and extending further in both the directions.

Nine traverses (Figure 51) were laid at 200 m interval across the shear zone, trending in WNW-ESE direction at a traverse length of 1 km each and station interval of 20m.

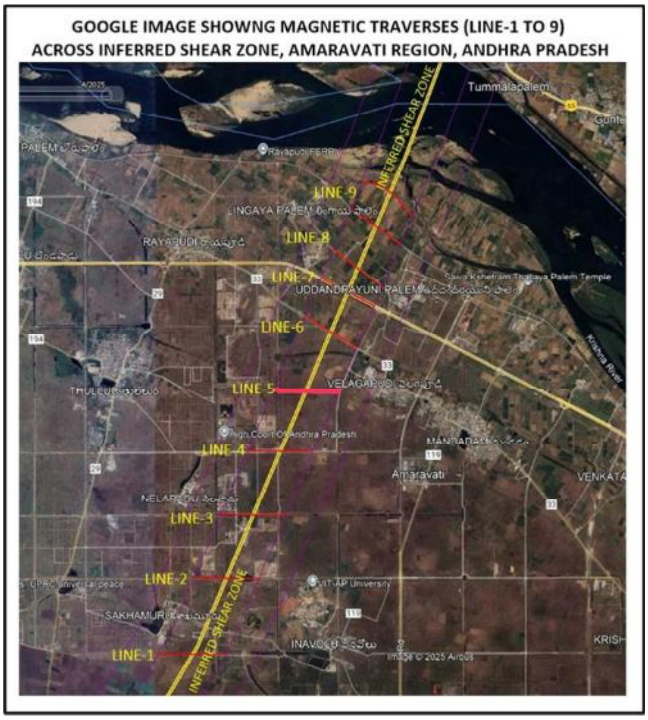


Figure 51: Geophysical Traverses across Concealed Shear Zone (Lines-1 to 9)

Magnetic Response along Line-2

Magnetic profile along Line-2 from west to east indicates an overall relief of 3957nT from +1293nT to -2664nT. In general, magnetic lows are noticed over western part, and highs are recorded in the eastern part. Whereas bipolar magnetic anomalies observed over concealed shear sone in central part, having a width of 400m (Figure 52).

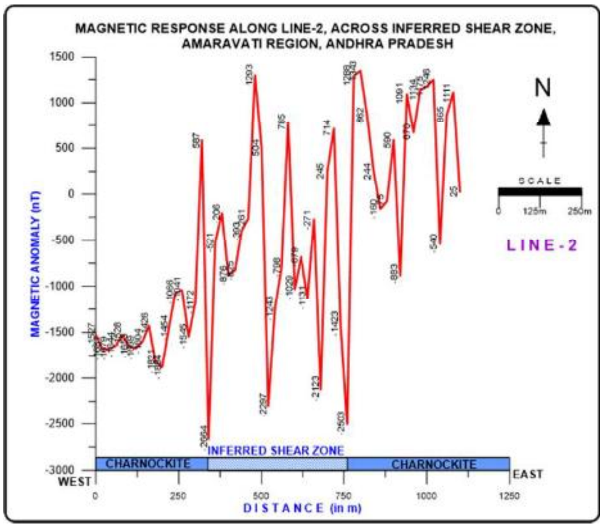


Figure 52: Magnetic Response along Line-2

Magnetic Response along Line-3

Magnetic profile along Line-3 from west to east indicates an overall relief of 5977nT from +2110nT to -3867nT. In general, magnetic lows are noticed over western part, and highs are recorded in the eastern part. Whereas bipolar magnetic anomalies observed over concealed shear sone in central part, having a width of 200m (Figure 53).

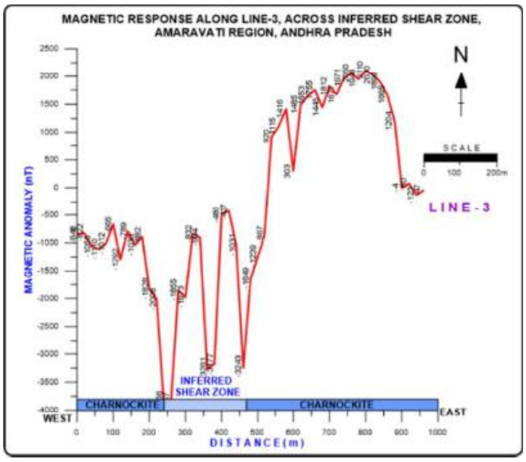


Figure 53: Magnetic Response along Line-3

Magnetic Response along Line-4

Magnetic profile along Line-4 from west to east indicates an overall relief of 2711nT from +1338nT to -1373nT. In general, magnetic lows are noticed over western part, and highs are recorded in the eastern part. Whereas bipolar magnetic anomalies observed over concealed shear sone in central part, having a width of 160m (Figure 54).

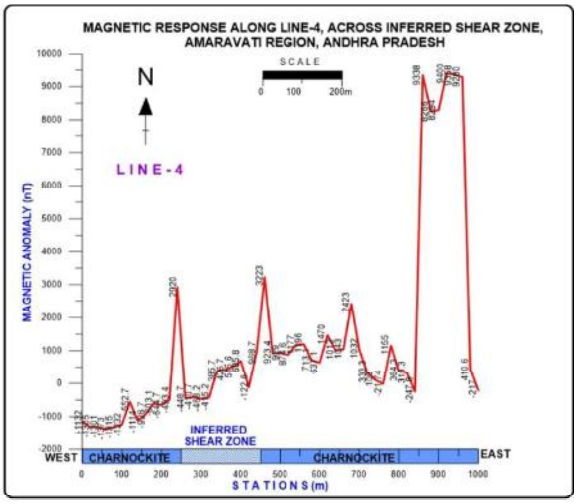


Figure 54: Magnetic Response along Line-4

Magnetic Response along Line-5

Magnetic profile along Line-5 from west to east indicates an overall relief of 3644nT from +3073nT to -571nT. In general, magnetic lows are noticed over western part, and highs are recorded in the eastern part. Whereas bipolar magnetic anomalies observed over concealed shear sone in central part, having a width of only 290 m (Figure 55).

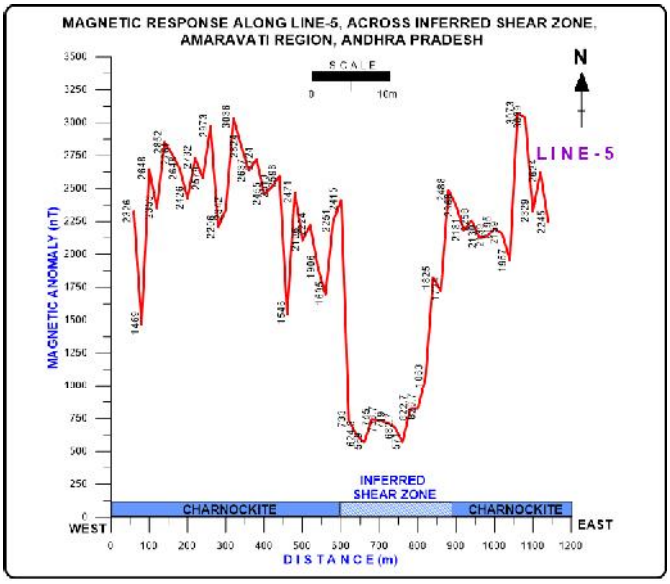


Figure 55: Magnetic Response along Line-5

Magnetic Response along Line-6

Magnetic profile along Line-6 from west to east indicates an overall relief of 3888nT from +1899nT to -1989nT. In general, magnetic lows are noticed over western part, and highs are recorded in the eastern part. Whereas bipolar magnetic anomalies observed over concealed shear sone in central part, having a width of only 200 m (Figure 56).

Magnetic Response along Line-7

Magnetic profile along Line-7 from west to east indicates an overall relief of 2470nT from +278nT to -2462nT. In general, magnetic lows are noticed over western part, and highs are recorded in the eastern part. Whereas bipolar magnetic anomalies observed over concealed shear sone in central part, having a width of only 350 m (Figure 57).

Magnetic Response along Line-9

Magnetic profile along Line-9 from west to east indicates an overall relief of 3753nT from +1204nT to -2549nT. In general, magnetic lows are noticed over western part, and highs are recorded in the eastern part. Whereas bipolar magnetic anomalies observed over concealed shear sone in central part, having a width of only 600 m (Figure 58).

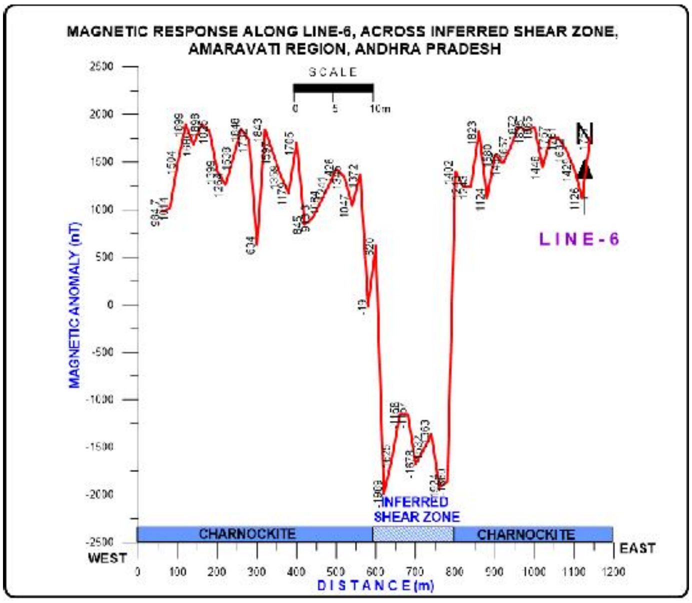


Figure 56: Magnetic Response along Line-6

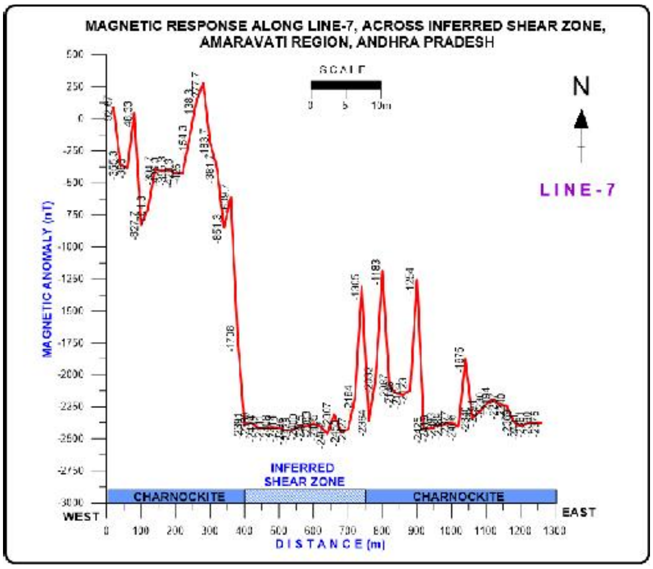


Figure 57: Magnetic Response along Line-7

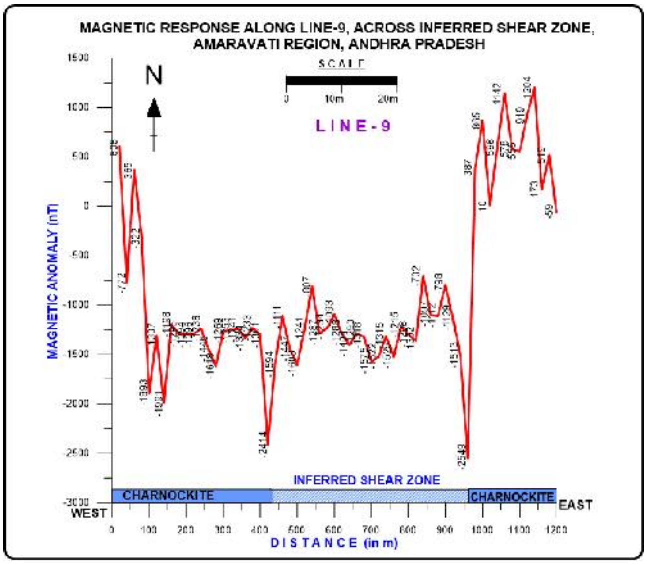


Figure 58: Magnetic Response along Line-9

Magnetic profiles from Line-1 to Line-9 indicate low magnetic signatures in the western part of shear zone, and high signatures in the eastern part of shear zone, may indicate the basement is shallow in the east and deeper in the west, may be due to fault. Strong bipolar magnetic anomalies recorded over central part of the shear zone. The width of the concealed shear zone may increase from 160 m in the south to 600m in the north.

4.14. REGIONAL MAGNETIC (TF) SURVEYS OVER AMARAVATI CITY

Carried out regional magnetic surveys at 1km station interval (approximately) at Amaravati City and generated total field magnetic Image with a contour interval of 100nT. Derivative maps viz., regional, residual, low & high frequency, analytical signal, horizontal derivative, vertical integration and directional filter maps have also been generated by applying necessary corrections. Magnetic (TF) maps are well brought out the structural fabric of Amaravati City.

Magnetic surveys can detect variations in the earth's magnetic field caused by differences in the magnetic properties of rocks. Magnetic image of Amaravati City is overlay on google image shown in Figure 59. Magnetic anomaly map (Figure 60) with 100nT contour interval has indicated an overall relief of 5923nT varying from +3100nT to -2623nT with strong bipolar magnetic signatures, trending in NNE-SSW, NE-SW, NW-SE, N-S and E-W directions in the study area.

Prominent high dominant magnetic anomaly zones trending in NNE-SSW direction is located around Krishnayapalem in the eastern part, Mangalagiri, Nidamarru and

Neerukonda areas in the southern part, between east of Vaddamanu to Nekkallu trending in N-S direction in the western part and between east of Tadepalli and Undavalli trending in N-S direction in the eastern parts. Further, moderate high dominant magnetic signatures noticed around Borupalem, west of Uddandarayunipalem, east of Thullur and Sakhamuru areas.

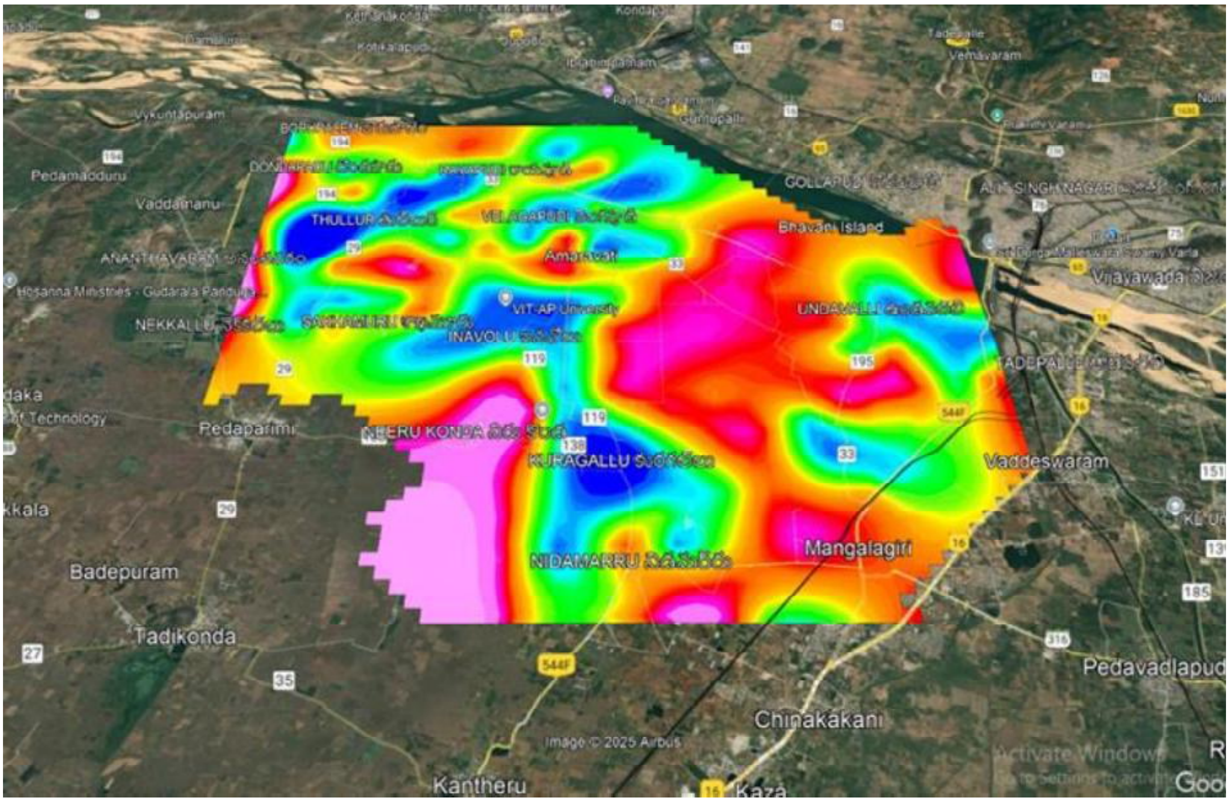


Figure 59: Magnetic Anomaly map overlay on Google Image

These high magnetic signatures may be indicating the presence of basement highs within the charnockites in the central part, khondalites in the eastern part, pyroxene/calc granulites in the western part (Figure 60).

Prominent low dominant magnetic anomaly zones trending in NNE-SSW directions around Thullur in the western part and between Uddandarayunipalem to Ainavolu in the central part, trending in NNW-SSE direction between Ainavolu to Kurugallu in the southern part, trending in NW-SE direction around Undavalli and trending E-W direction just south of Yerrabalem areas, may be due to presence of basement lows (Figure 60).

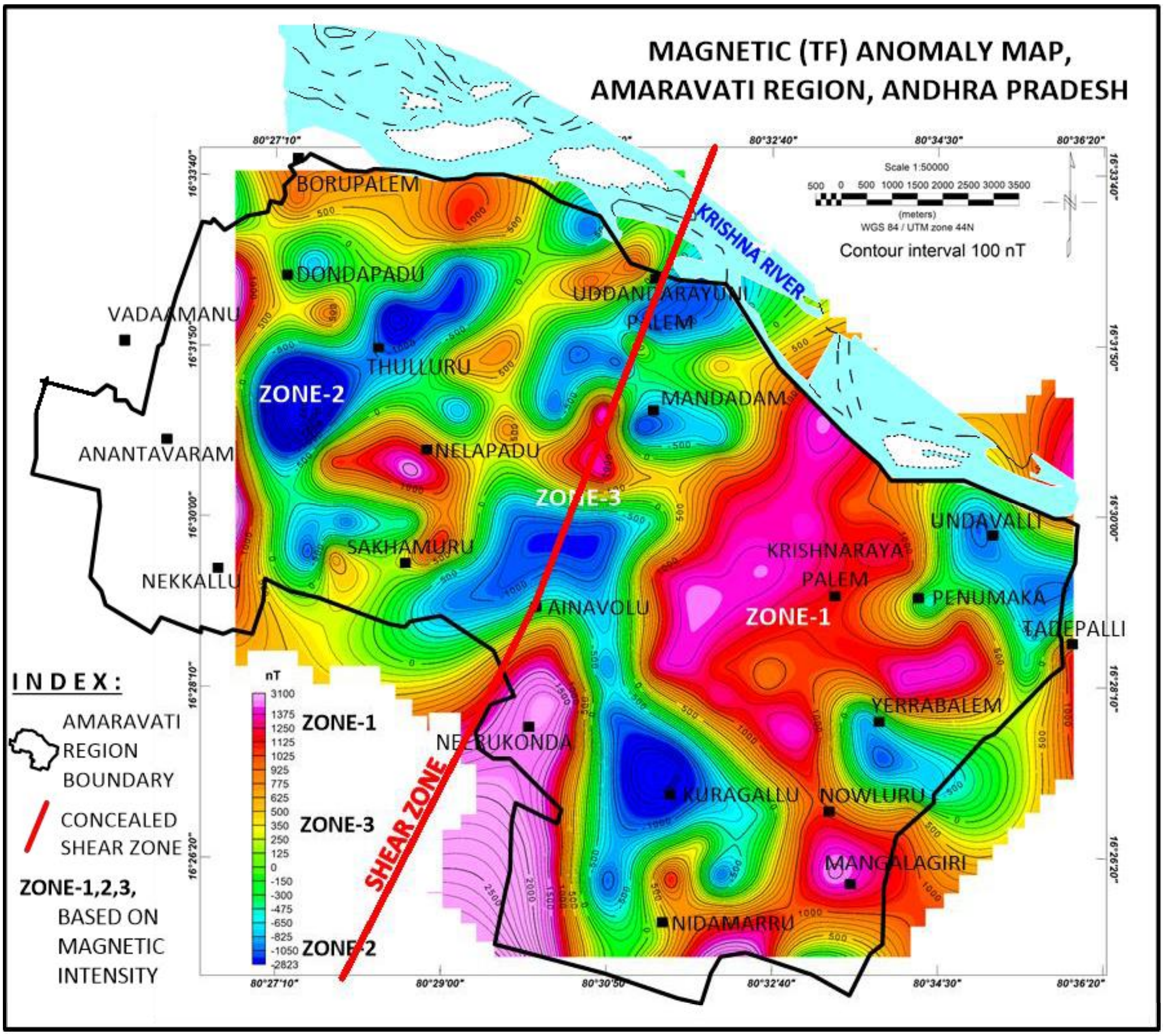


Figure 60: Magnetic (TF) Anomaly Map, Amaravati City

In addition, a number of magnetic linear features in the form of magnetic gradients trending in NNE-SSW and NNW-SSE directions on either side of Amaravati City, may indicate the presence of concealed structural features viz., fracture / fault /contact / shear zones, corroborating well with the magnetic derivative maps and gravity signatures in the form of gradients .

Geologically marked Shear zone, trending in NNE-SSW direction from Uddandarayunipalem in the north to Ainavolu in the south, adjacent to the concealed magnetic high zone, falls along the low dominant magnetic signatures associated with low resistivity anomalies and NNE-SSW trending gravity gradients. North-south trending dissected Khondalite hills near Tadepalli in the east, pyroxene granulite / calc-granulites out crops near Anantavaram in the western part are reflected well in the form of linear high dominant magnetic anomalies, on either side of the study area.

Magnetic data was further subjected to Radially Averaged Power Spectrum (RAPS) for wavelength filtering, for making derivative maps at different depths.

Residual Magnetic Anomaly Map_(Figure 61) or the high pass filter map of Amaravati City helps in enhancing the shallow and near surface geological features, such as magnetic highs may be reflected as basement highs, magnetic lows may be reflected as basement lows. In addition, near surface geological structures on either side of Amaravati City viz., concealed fault / fracture / shear / contact zones are delineated well in the form of linear magnetic anomalies.

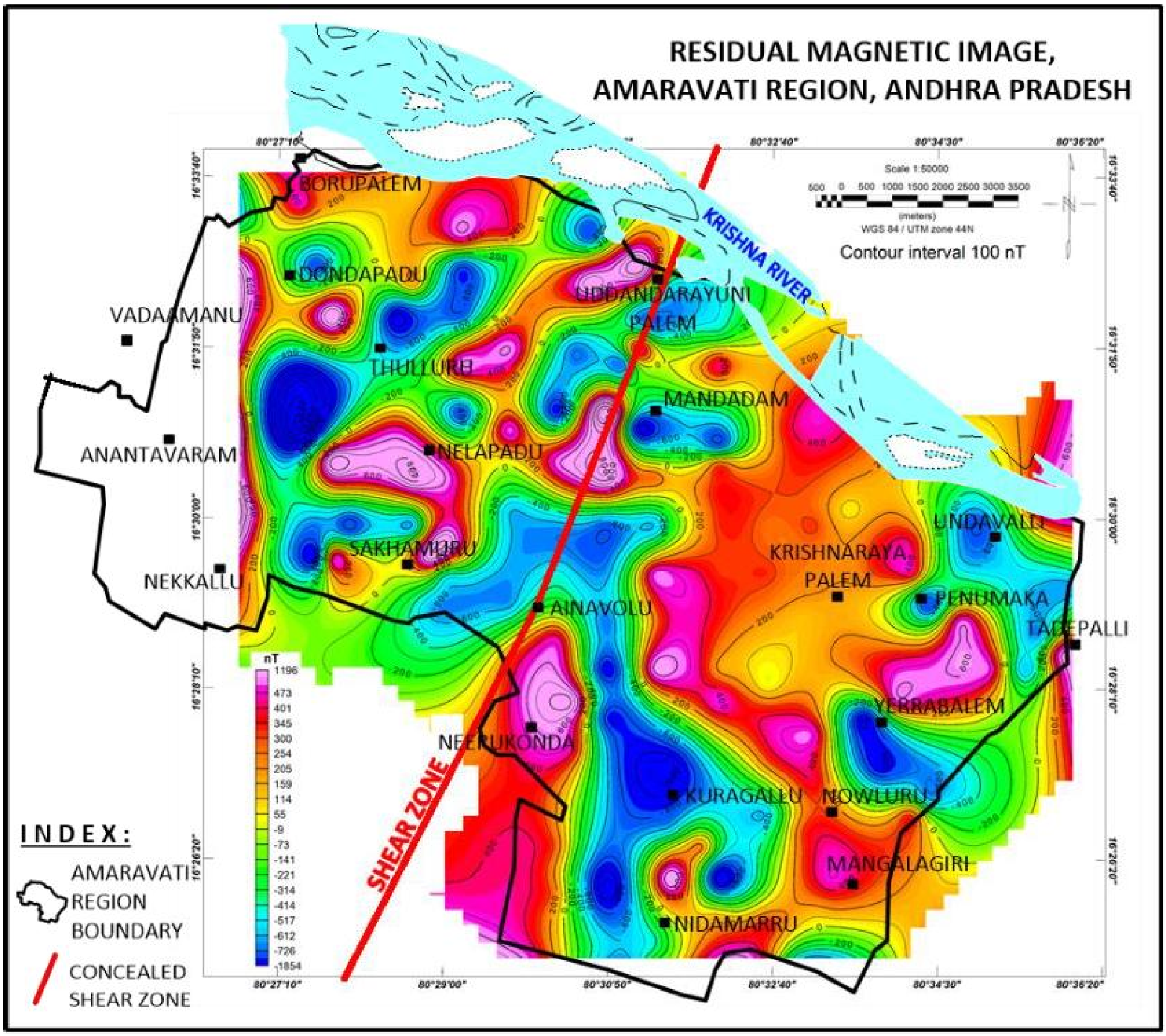


Figure 61: Magnetic Residual Map, Amaravati City

Regional Magnetic Map (Figure 62) or low pass filter map of Amaravati City, helps in understanding the tectonic history of the city by removing the shallow near surface features or high frequency anomalies and understanding the subsurface geology and deep-seated structural features. The structural features reflected in the regional magnetic map having depth continuity.

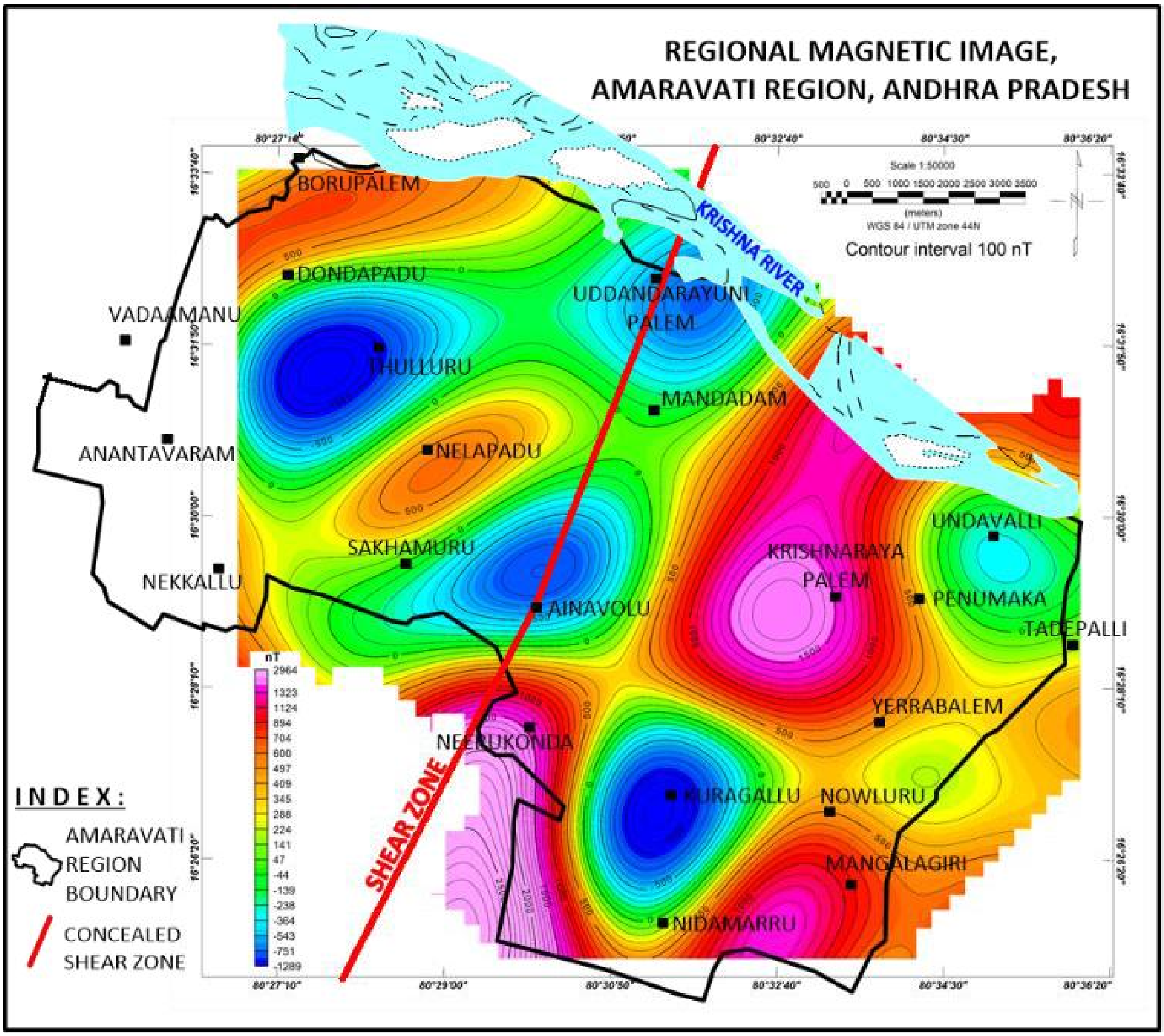


Figure 62: Magnetic Regional, Amaravati City

Analytic Signal Map (Figure 63) highlights the edge detection of magnetic sources and precise location of geological contacts / faults on either side (eastern and western parts) of Amaravati City and mapping of subsurface and concealed structures.

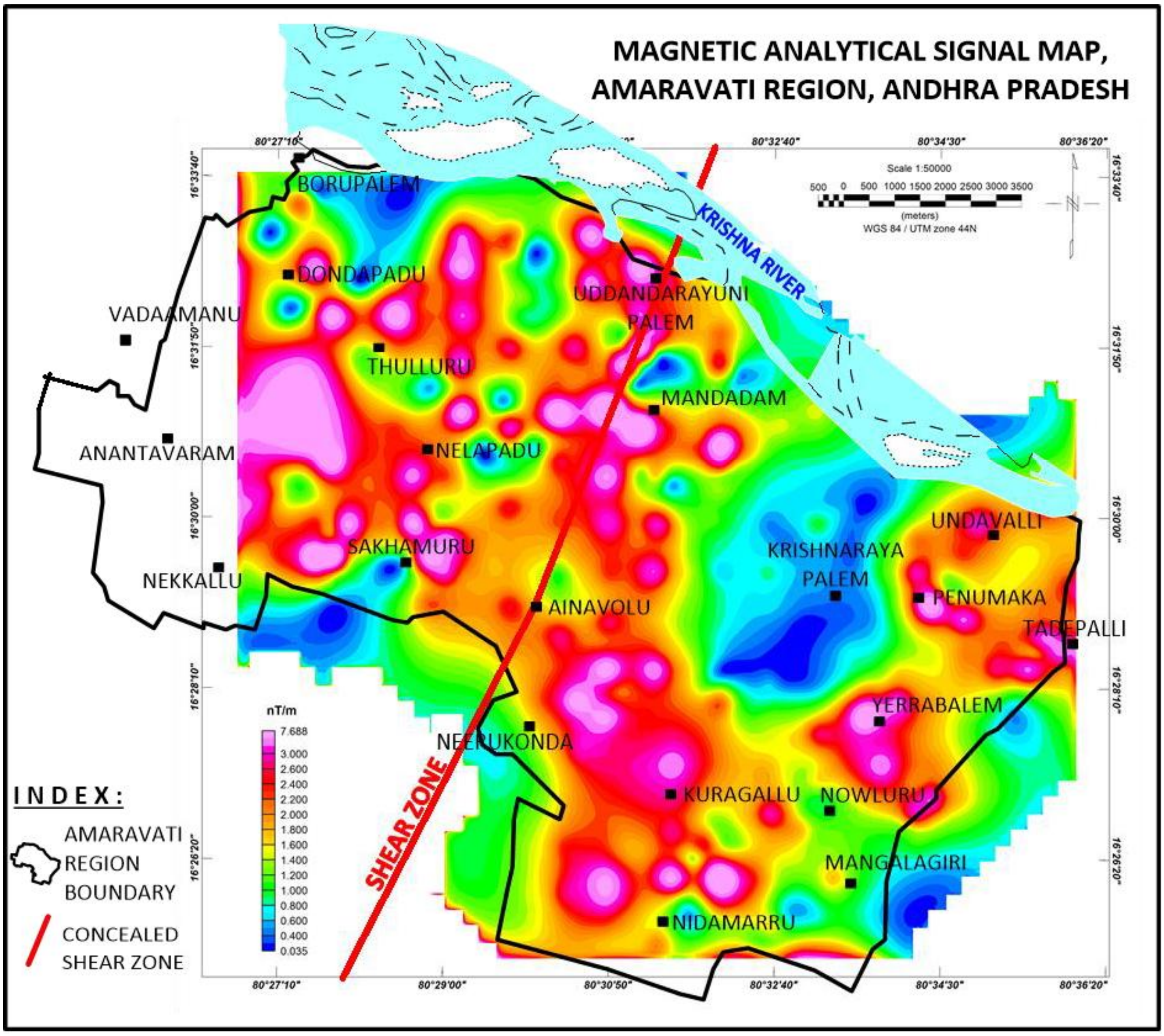


Figure 63:Magnetic Analytical Signal Map, Amaravati City

Magnetic Horizontal Derivative Map (Figure 64) of Amaravati City, particularly helps in structural mapping. They enhance the subtle anomalies, delineate geological contacts and provide insights into the continuity and geometry of subsurface structures.

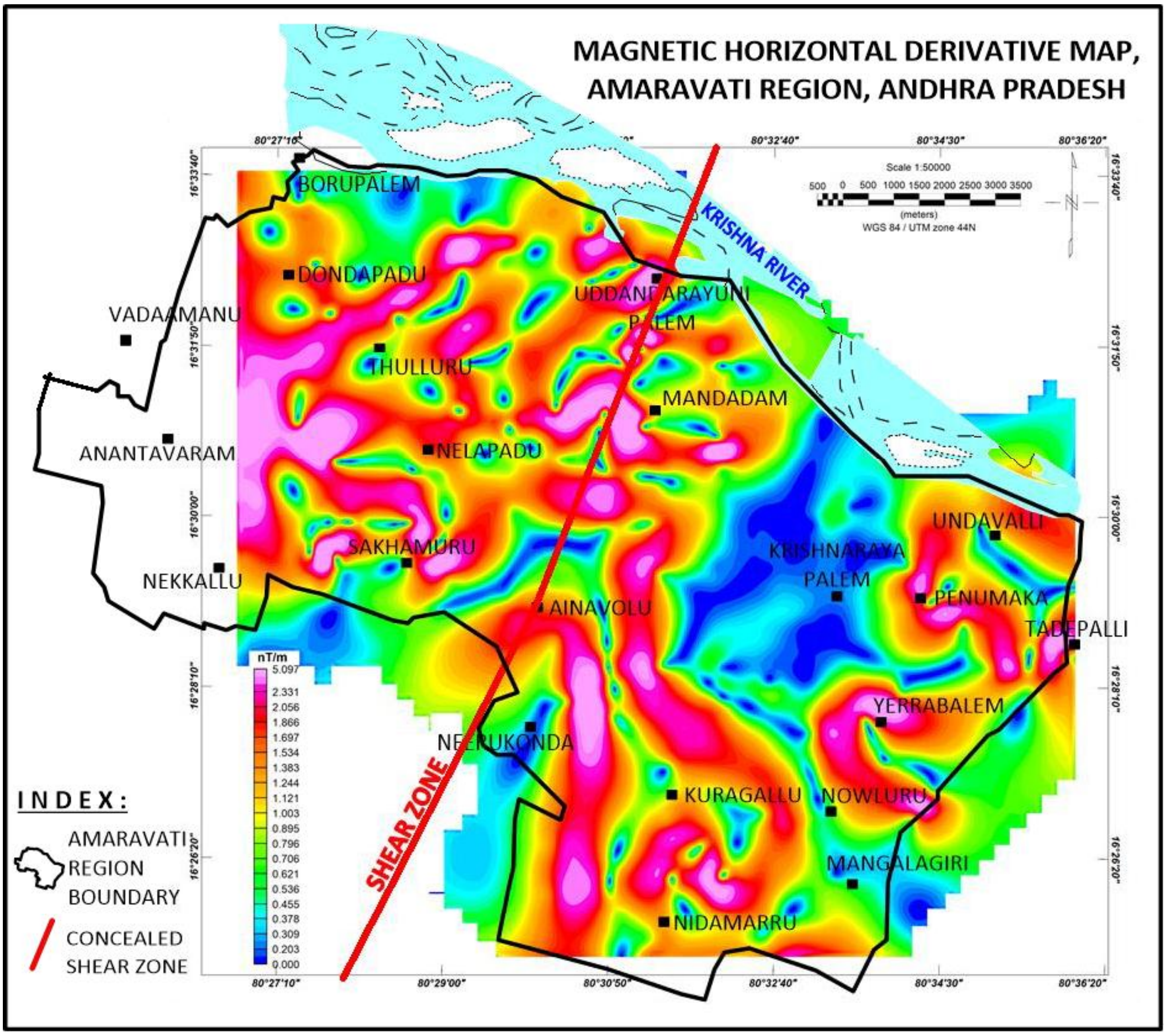


Figure 64:Magnetic Horizontal Derivative Map, Amaravati City

Magnetic Vertical Derivative map (Figure 65) and Vertical Integration map (Figure 66) visualize the vertical component of the magnetic field intensity and direction at different depths. They also help in identifying subsurface structures in the form of fault / fracture / joint / shear zones and geological formations.

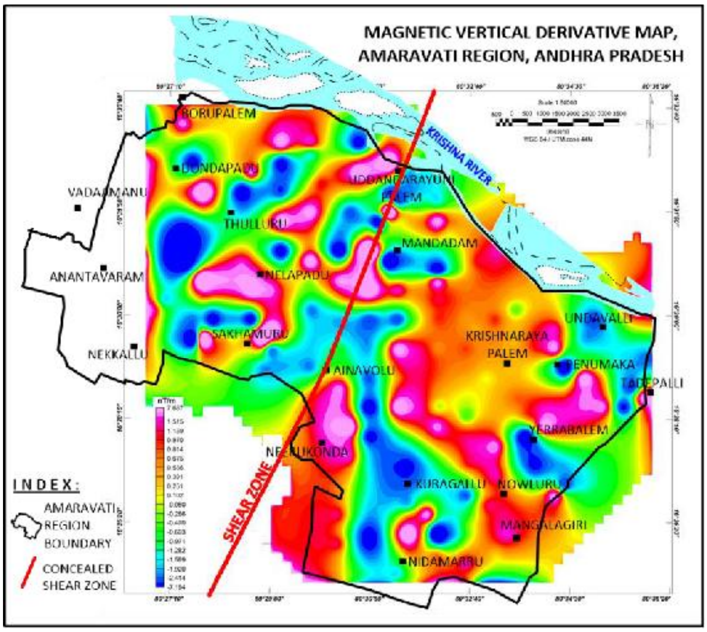


Figure 65: Magnetic Vertical Derivative Map, Amaravati City

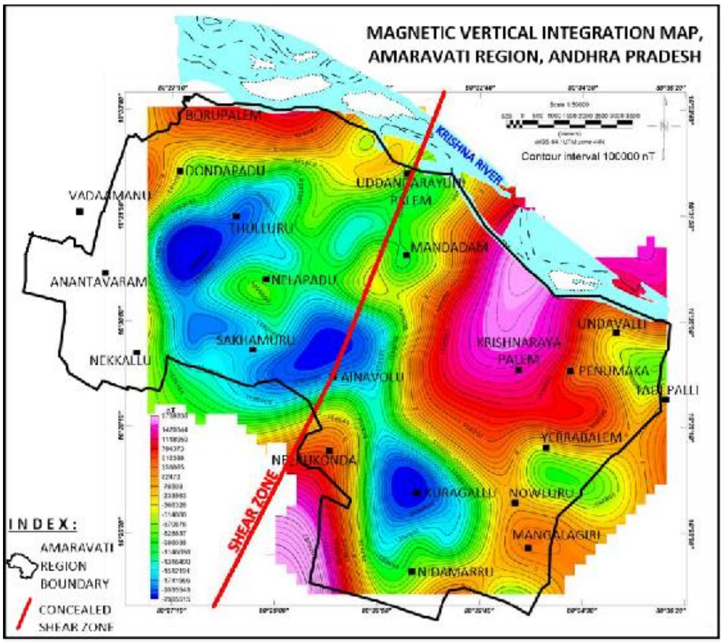


Figure 66: Magnetic Vertical Integration Map, Amaravati City

Radially Averaged Power Spectrum (Figure 67) is used primarily for analyzing spatial data, particularly to determine the depths of subsurface parameters like magnetic susceptibility by analyzing the slope of the spectrum. Based on the wavelength filtering of magnetic data, three interfaces have been identified in the study area. Top layer or weathered bed rock at an average depth of 30 - 50m, followed by intermediate layer or semi-weathered bed rock at a depth between 50 - 270m followed by third layer or hard, massive and compact bed rock up to a depth of 760m and beyond.

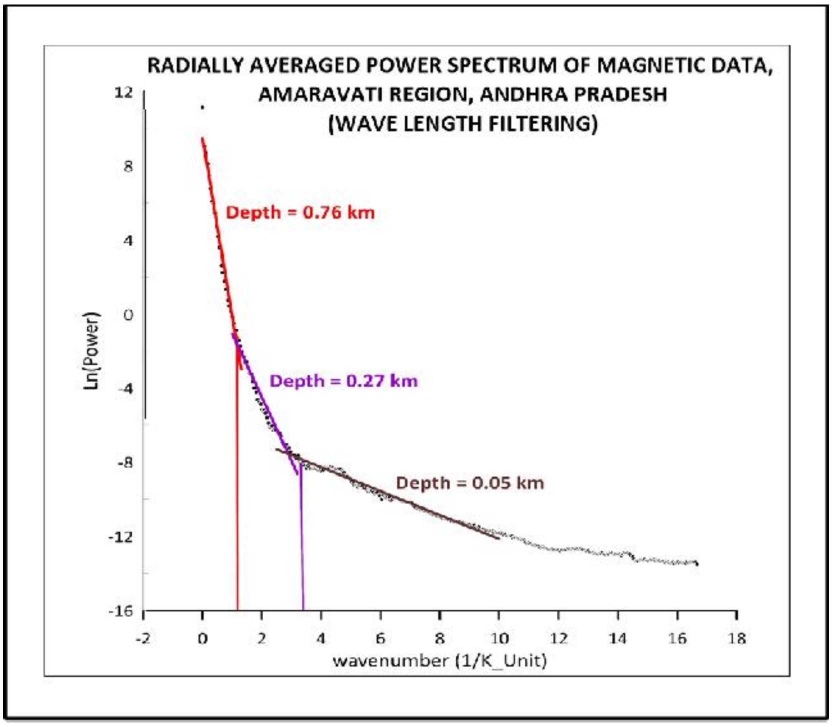


Figure 67: Radially Averaged Power Spectrum of Magnetic data

The average width of the geologically marked concealed shear zone in the central part trending NNE-SSW direction may be around 400m, inferred from detailed magnetic profiles associated with low dominant magnetic anomalies in the same direction.

Both Gravity and Magnetic signatures are well brought out the concealed structural information and correlating well with the basement highs inferred from depth sections of Vertical Electrical Resistivity Soundings (VES).

4.15. INTERPRETATION OF GRAVITY ANOMALY MAP (after GSI, 2006)

Bouguer gravity anomaly map of Amaravati City, Andhra Pradesh (secondary data) with contour interval of 1 mGal (digitized from Gravity Map of India Series – 2006, GSI) shown below (Figure 68 and Figure 69) is well brought out the structural fabric of Amaravati City, falls in parts of 65D/6, 65D/7, 65D/10 and 65D/11 toposheets. The inferred and salient features are mentioned below.

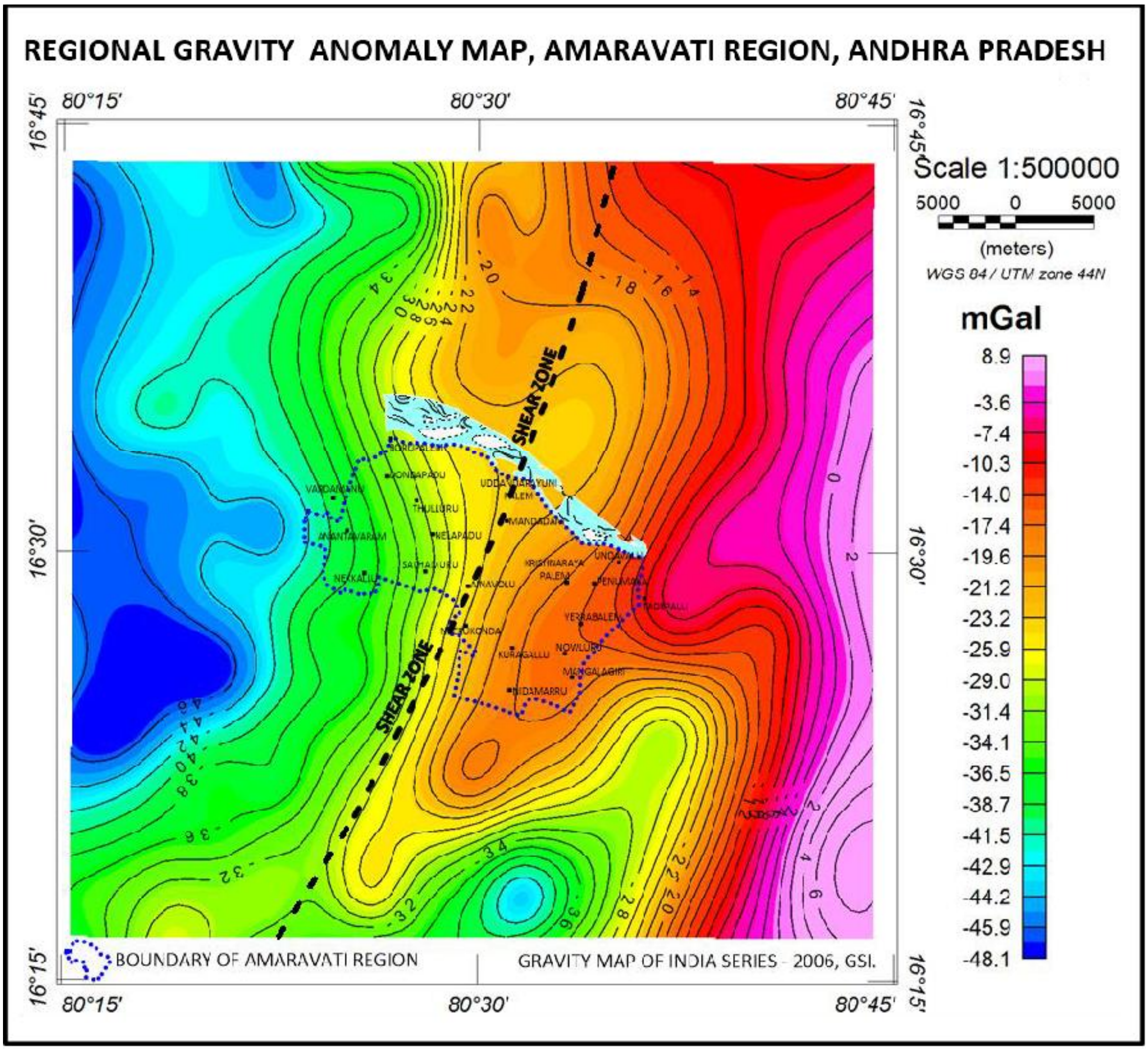


Figure 68: Regional Gravity Map of Amaravati City and adjoining areas

Gravity map has indicated an overall relief of 54 mGals from east to west, with prominent NNE-SSW trending gravity highs in the east and gravity lows in the west.

Prominent gravity high (+8 mGal) is noticed in the eastern part (around Tadepalli) and prominent lows (-46 mGal) in the western part (around Anantavaram).

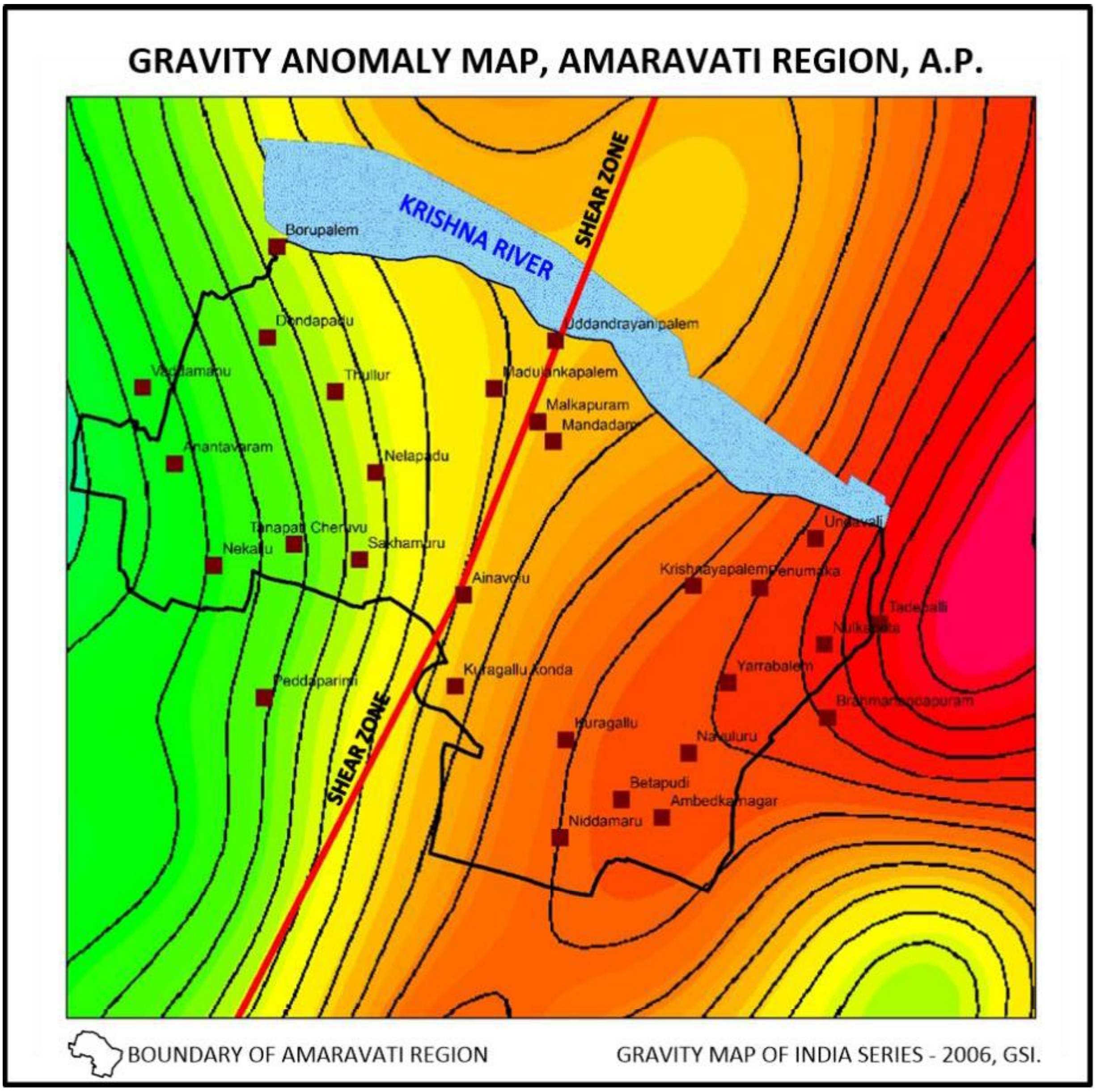


Figure 69: Gravity Anomaly Map of Amaravati City

Khondalite suite of rocks exposed in the eastern part in the form of gravity highs and pyroxene / calc granulites are exposed in the western part in the form of gravity lows. Whereas, charnockite occupied in the central part of the study area, below the sediments in the form of moderate gravity signatures.

Further, few isolated gravity high closures and high nosing's in the study area may be due to the presence of isolated basement highs.

Entire study area falls within a fault / fracture zone, in the form of NNE-SSW (eastern part) and NNW-SSE trending gravity gradients (western part) observed on either side of entire Amaravati City, may indicating a graben like structure in the center.

Further, the study area was bisected by an NNE-SSW trending geologically marked concealed shear zone, (may be a strike slip fault ?) reflected in the form of NNE-SSW trending gravity gradients and high nosing's from Uddandarayunipalem in the north to Ainavolu in the south, associated with resistivity lows and low dominant magnetic anomalies.

Based on the interpretation of gravity image and study of the inferred lineament analysis, the entire area may be affected not only by strike slip fault along NNE-SSW trending geologically marked shear zone, but also western part may be a down thrown block compared with the eastern block, as evidenced by presence of thick sediments, elevation and drainage density data.

The linear NNE-SSW gravity high nosings in the northern and southern parts associated with the NNE-SSW trending concealed shear zone, may indicating the strike slip mechanism along the shear zone. The western block may be moved further NNE direction, whereas, the eastern block may be moved towards SSW direction along the shear zone.

Krishna river is passing right angles to this shear zone, trending ENE-WSW direction, in the form of feeble gravity nosings, cutting across the regional trend.

4.16. GRAVITY, MAGNETIC & RESISTIVITY PROFILES

Regional gravity profile across Amaravati City from west to east (longitudes from 80^0 15' 00" to 80^0 45' 00") indicating an overall relief of 53mGal observed in the area. A prominent gravity high of +4mGal in the eastern part may be due to the presence of high-density rocks at shallow depth. Whereas a prominent low of -48mGal in the western part may be due to the presence of low-density material at deeper depths, occupied with thick sediments.

It is important to note that, a residual gravity low of the order of 0.5mGal identified at Tadepalli within the regional gravity profile, at the contact between Khondalite and charnockite units in the eastern part, may be due to structural disturbances in the form of fault / fracture / shear zone between the two formations.

Another residual gravity low of the order of 0.5mGal observed at Anantavaram within the regional gravity profile, at the contact between charnockite and pyroxene / calc granulite units in the western part, may be due to fault / fracture / shear zone.

In addition, another residual gravity low noticed in the central part at Uddandarayunipalem within the regional gravity profile trending in NNE-SSW direction, which continues further south-west between Ainavolu and Sakhamuru, within the charnockite basement may be due to presence of concealed shear zone, corroborating well with low magnetic and low resistivity signatures.

Regional Magnetic profile of Amaravati City from Anantavaram in the west to Tadepalli in the east, overlay on regional gravity profile shown in Figure 70. Faulted contact on either side of the Amaravati City and concealed NNE-SSW trending shear zone in the central part are reflected well in the form of strong bipolar magnetic anomalies, corroborating well with residual gravity signatures and low resistivity anomalies.

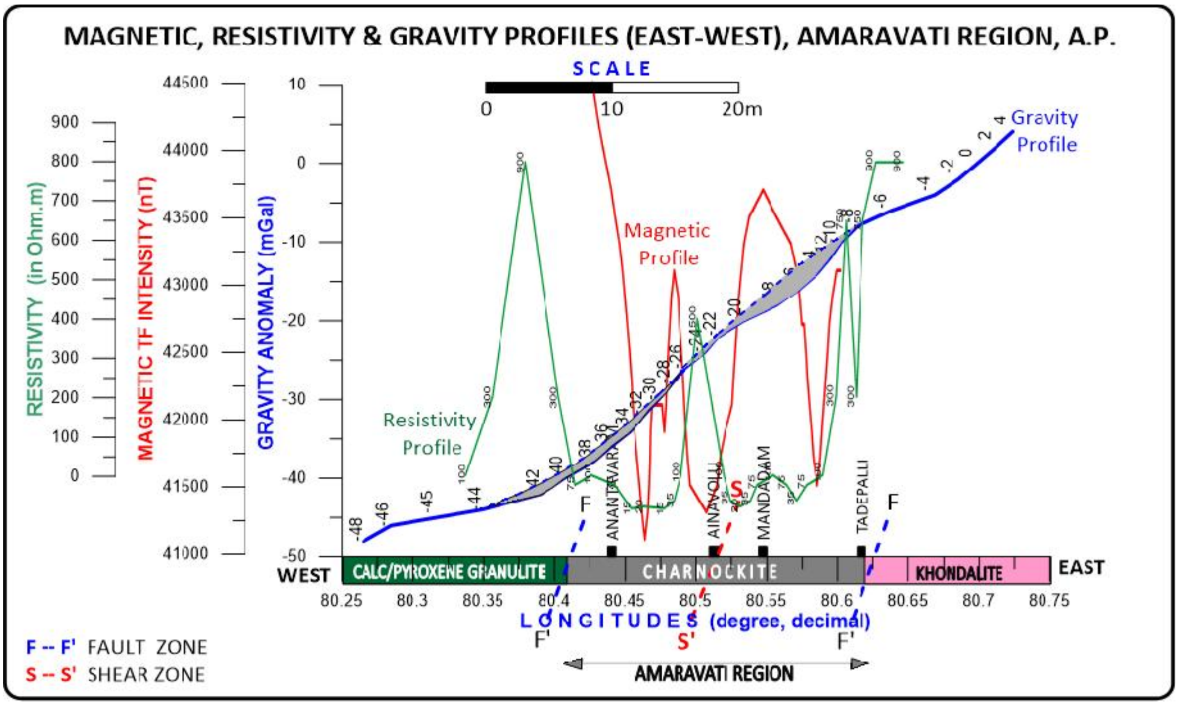


Figure 70: Gravity, Magnetic & Resistivity Profiles

4.17. LINEAMENT ANALYSIS

Lineament analysis is a powerful tool used in Amaravati City to delineate and study the concealed linear or curvilinear features from satellite imagery, gravity, magnetic and drainage density images, such as fault, fracture, shear zone, joint and geological boundaries, that indicate underlying geological and structural significance. These features, often appearing as straight or slightly curved lines, and provide valuable insights into structural / tectonic activity of Amaravati City (Figure 71a, b & c).

Lineament analysis is a method aimed at detecting, classifying, and measuring linear features in Amaravati City helps in understanding the basement configuration and structural fabric of the City. Mapping lineaments helps identify potential groundwater recharge zones and fracture systems that helps in delineation of important features for groundwater resources. Identifying lineament zones also indicate pathways for fluid migration for mineral deposits and can indicate areas prone to earthquakes and other geohazards (Figure 71).

Lineaments from Drainage Network

In the study area, lineaments identified and analyzed from drainage network aligned in NW-SE, NE-SW, NNE-SSW and E-W directions formed by streams and nalas of Kondaveeti Vagu and Kottella vagu insights into the subsurface structure and groundwater resources (Figure 71 a). The drainage pattern is sub parallel to sub-dendritic. The sub-parallel drainage in the eastern part appears to be controlled by fractures and structures possibly of tectonic origin and the dendritic pattern in the western part large controlled by erosional nature of terrain, corroborating well with the linears inferred from magnetic and gravity images.

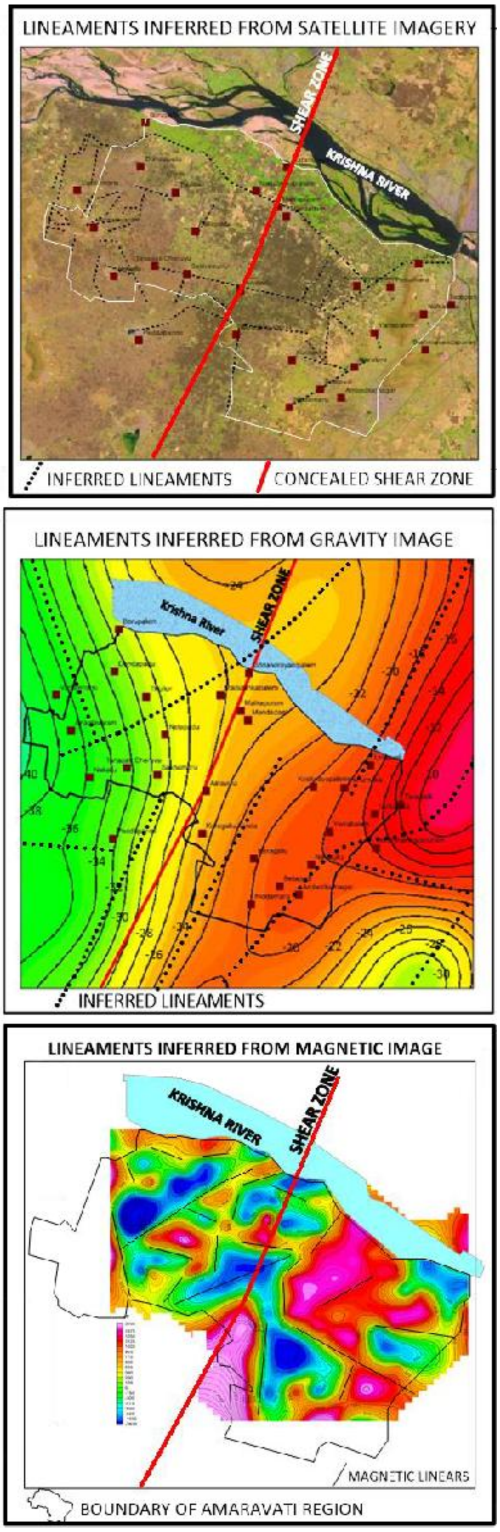


Figure 71: Inferred Lineaments from Stream Network (First Image), Gravity Map (Second image) and Magnetic Map (Third image)

Lineaments from Gravity Image

Based on analysis of gravity linears, the study area falls within a fault / fracture zone, in the form of NNE-SSW trending gravity gradients in the eastern part over Khondalite basement and NNW-SSW trending gravity gradients in the western part over calc granulite / pyroxene granulite basement, may indicating the faulted contact with charnockites in the central part (Figure 71 b). A prominent NNE-SSW trending linear with moderate gravity gradients in the central part, corresponding to presence of a concealed shear zone from Uddandarayunipalem in the north to Ainavolu in the south and it may extend further in both the directions. Krishna river is passing right angles to this shear zone, trending WNW-ESE direction, in the form of feeble gravity nosings, cutting across the regional trend. Few E-W and NE-SE trending gravity linears inferred from gravity nosings, correlating well with magnetic linears.

Lineaments from Magnetic Image

Structural / lineament analysis plays an important role in identifying the concealed movements and structural disturbances within the basement. Steep magnetic gradients, discontinuities, contacts, dilated zones, truncation, offsets and intersections of lineaments are reflected well in the form of magnetic lineaments. The structural elements inferred from gravity image are corroborating well with magnetic signatures.

The NNW-SSE trending magnetic linears in the western part over calc granulite / pyroxene granulites and NNE-SSW trending linears in the eastern part over khondalites, may indicate the faulted contact with charnockite basement in the central part. Further, a concealed NNE-SSW trending magnetic linear, falls along the low dominant magnetic anomalies in the central part of the study area, corresponding to presence of a concealed shear zone from Uddandarayunipalem in the north to Ainavolu in the south and it may extends further in both the directions (Figure 71 c).

In addition, few E-W, NW-SE and NE-SE trending magnetic linears inferred low dominant magnetic signatures, correlating well with lineaments inferred from gravity and drainage density maps.

4.18. STRUCTURAL FABRIC AND BASEMENT CONFIGURATION

To suppress the near surface high frequency anomalies and to enhance basement structures, magnetic low-pass anomaly maps are helped in delineation of basement configuration. Based on the intensity of magnetic and gravity signatures, the study area is divided into 3 zones. Zone-1 indicating high dominant magnetic and gravity anomalies in the eastern part over khondalite basement. Zone-II indicates the presence of low dominant gravity and magnetic anomalies in the western part over calc granulite / pyroxene granulite basement. Whereas Zone-III indicates moderate gravity and magnetic signatures noticed in the central part over charnockite basement (Figure 72 a & b).

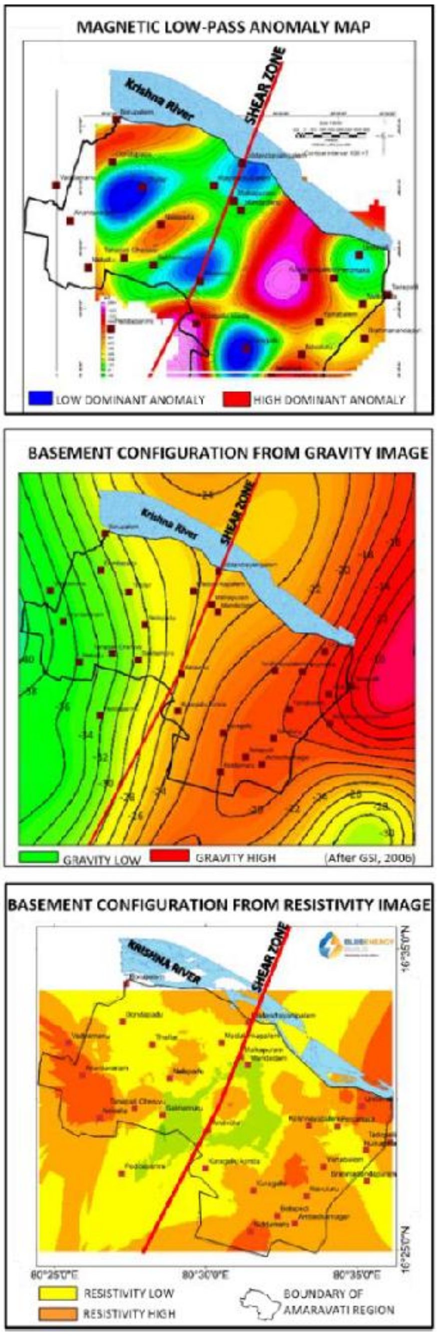


Figure 72: Inferred Basement configuration Magnetic (First Image), Gravity Map (Second image) and Resistivity Map (Third image)

These NNW-SSE trending linears in the western part may indicate faulted contact between calc granulite / pyroxene granulites with charnockites. Whereas the NNE-SSW trending linears in the eastern part may indicate the faulted contact between Khondalite with Charnockites. Gravity highs correlating with isolated magnetic high anomalies in the eastern part may indicate the basement highs at shallow depth (Figure 72 a & b). These isolated basement highs are corroborating well with magnetic highs and resistivity highs (Figure 72 a & b) confirmed by vertical electrical sounding data (Figure 72 c). Whereas gravity lows associated with low dominant magnetic anomalies in the western part may indicate the basement at deeper depths.

A concealed NNE-SSW trending moderate gravity and low magnetic signatures falls along the central part of the area, from Uddandarayunipalem in the north to Ainavolu in the south corresponding to the presence of a concealed shear zone. Based on the interpretation of lineament analysis and basement configuration, the entire NNE-SSW trending concealed shear zone, not only displaced by strike slip fault but also western part may be down thrown block (graben like structure?), as evidenced by the elevation data, drainage density map and increased thickness of sediments (Figure 72 c).

It is interesting to note that, along this concealed NNE-SSW trending geologically marked shear zone having a width of 200m to 600m. increasing the width from south to north, associated with magnetic lows and resistivity highs. Water quality along this shear zone is good and tds content is less along the shear zone, when compared to the quality of groundwater from the western or south-western parts.

Because of magnetic susceptibility, density and resistivity variations, all the inferred structural features identified from magnetic, gravity and resistivity signatures, are corelating well with the residual gravity lows, as indicated in the gravity profile.

Based on the qualitative interpretation of geophysical data consisting of gravity, magnetic and resistivity anomalies (Figure 73), structural fabric and basement configuration of Amaravati City have been delineated. Basement highs and lows in the form of gravity highs / high dominant magnetic anomalies / resistivity highs and gravity lows / low dominant magnetic anomalies / resistivity lows are shown in Figure 72, indicating the presence of basement undulations.

Structural analysis of inferred linears from potential field data and resistivity signatures may indicating the faulted contact on either side of Amaravati City between Khondalite-Charnockite in eastern part and between calc / pyroxene granulite–charnockite in the western part. Based on the anomaly pattern, the NNE-SSW trending concealed shear zone in the central part may indicate not only a strike slip fault mechanism, in the form of gravity nosing's on either side of the fault plane, but also the western part of the study area may be a down-thrown block, while compared to eastern part. These structural disturbances may be confirmed by elevation data, drainage density map and presence of thick sediments in the western part. Whereas, the eastern part may be an up-thrown block, due to shallow basement and thin sediment thickness.

Figure 73: Structural Fabric and Basement Configuration

4.19. SEISMIC HAZARD & MICROZONATION STUDIES

Amaravati City falls in the south-western fringe portion of Seismic Zone–III of the Seismic Zonation Map of India (IS: 1893 – Part 1 (2002)). The soil in general is broadly classified as sandy loamy, red loamy and black cotton.

Seismic Hazard and Microzonation studies were carried out by GSI, SR (2010) to determine the site response parameters, viz., the predominant frequencies, the amplification of the ground motion and decipher vulnerable zones of damage in case of an earthquake occurring in and around Vijayawada / Amaravati. The objective is to assess and delineate the microzones of varying seismic site response in the event of a moderate earthquake (≈ 6 magnitude) occurring in the proximal source area. Microzonation plays a vital role as a proactive strategy in cities where high seismic risk is involved. Microzonation information can be used to incorporate earthquake damage control / reduction measures in planning land-use and designing of heavy structures.

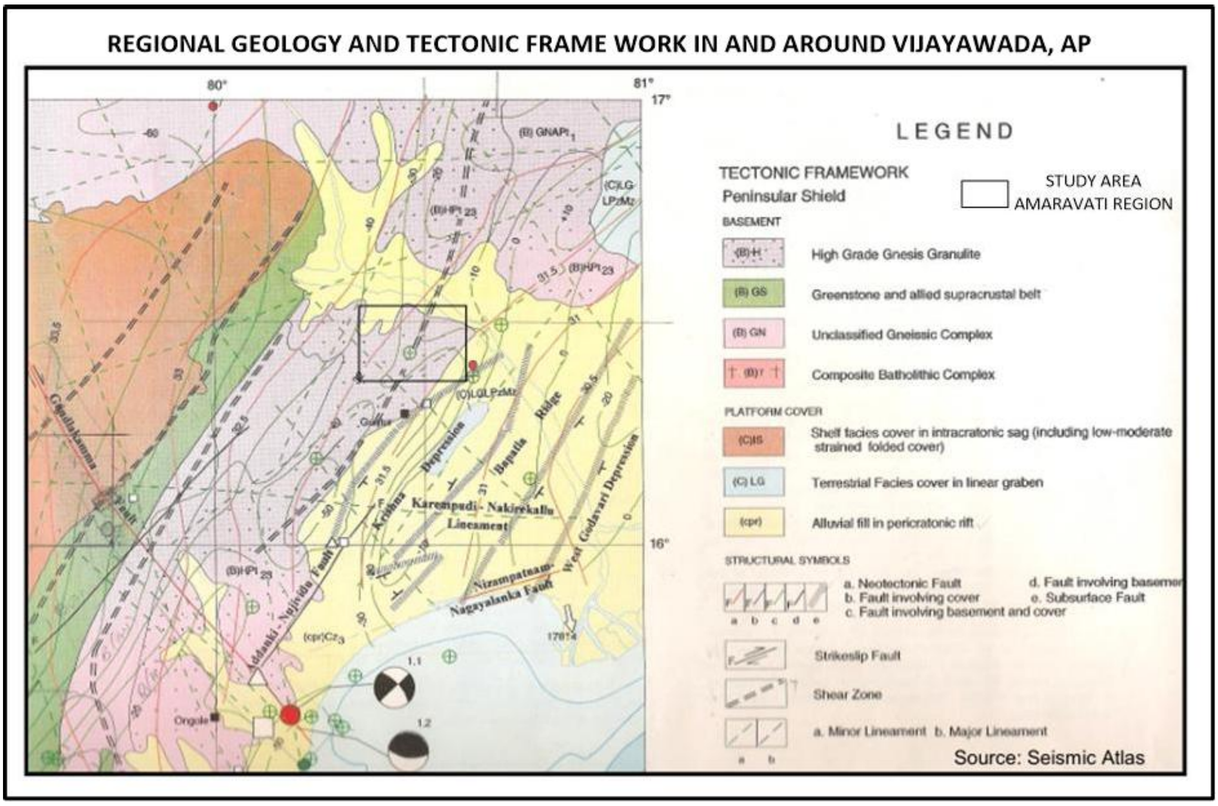


Figure 74: Regional Geology and Tectonic Framework

The City is traversed by a fairly dense network of medium and mega lineaments (Figure 74). Records of earthquake tremors / seismic events located around Mangalagiri of 3.4M, 3.2M, around Vijayawada of 3M and moderate magnitude of 5.2M with its epicentre at Ongole town indicating the occasional occurrence of seismic activity in the study area. Hence, evaluating the seismic hazard microzonation is an important input to earthquake disaster mitigation. Peak amplification image parts of Amaravati City (GSI, 2019) indicates high amplification zones around Nowluru, Yerrabalam, Krishanyapalam and Tadepalle areas, which are vulnerable for damage during an earthquake (Figure 75). This indicates near homogeneous nature of top layer. The top layer consists of clay, sandy silt, sand and silt layers with poor compactness. Thick pile of sediments is present in the area at depth with shallow groundwater conditions. The peak amplification values range from 1.5 to 4 corresponding to frequency range of 1.5 to 8 Hz indicating that the overburden is thick in the area. Due to the presence of ground water at shallow depths, in some of the areas there is more damping. Because of damping, even though there is a good acoustic impedance contrast between top layer and bottom layer at places, the peak amplification is reduced. Variation of peak frequency lies between 1.5 and 10 (Figure 76).

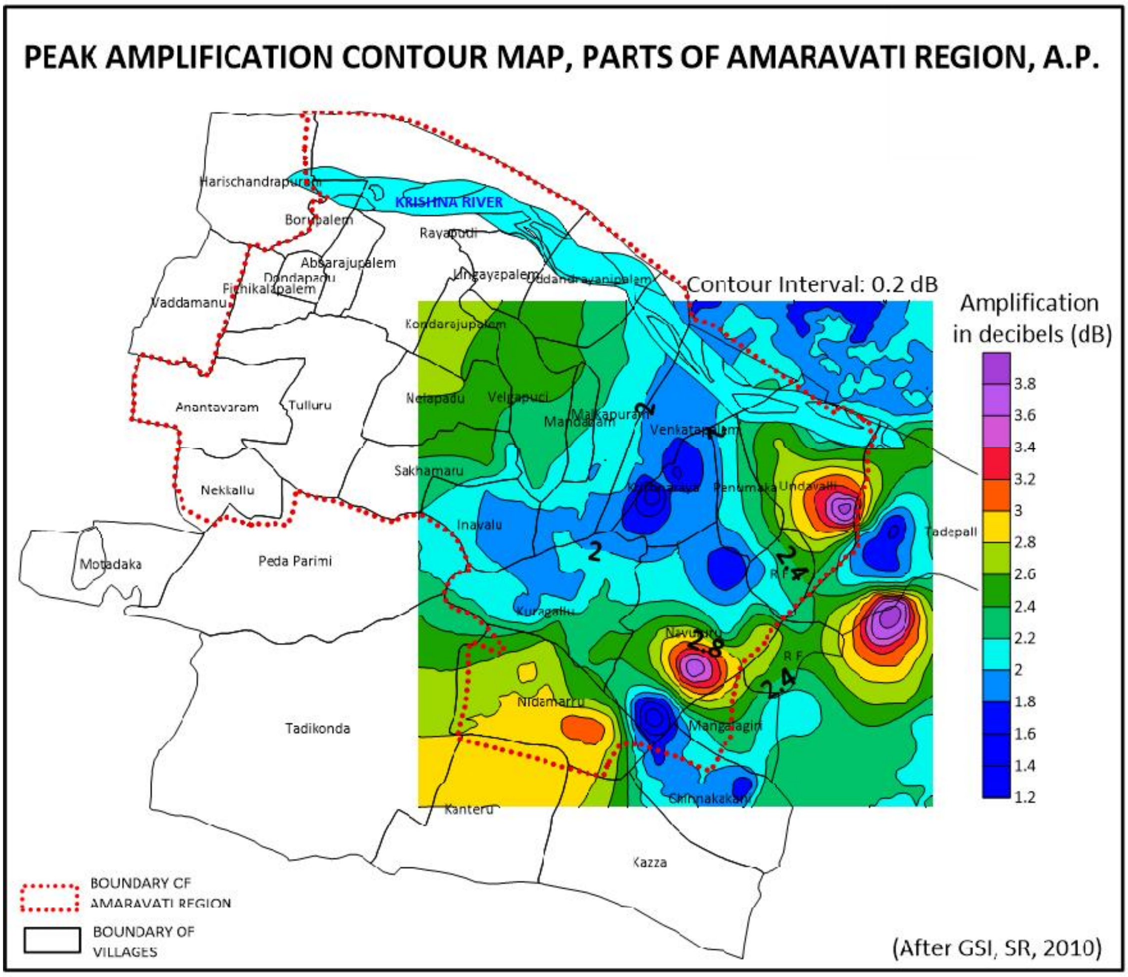


Figure 75: Peak Amplification contour map, parts of Amaravati City

The higher peak frequencies are observed over the areas having overburden is thin. Whereas, from Yerrabalam to Mandadam the thickness of the sediments is more, hence it has reflected low frequency values. From Nowluru to Nidamarru there is not much change of frequency values indicating the gentle increase of overburden above the rock (Figure 75 and

Figure 76). Rest of the area, the amplification of the order of 1.6 to 2.4 is observed indicating the presence of the semi-compact (thick) sediments. Vertical Electrical Soundings (VES) conducted in the study area confirmed the depth of sediments varying from 5m to more than 30m.

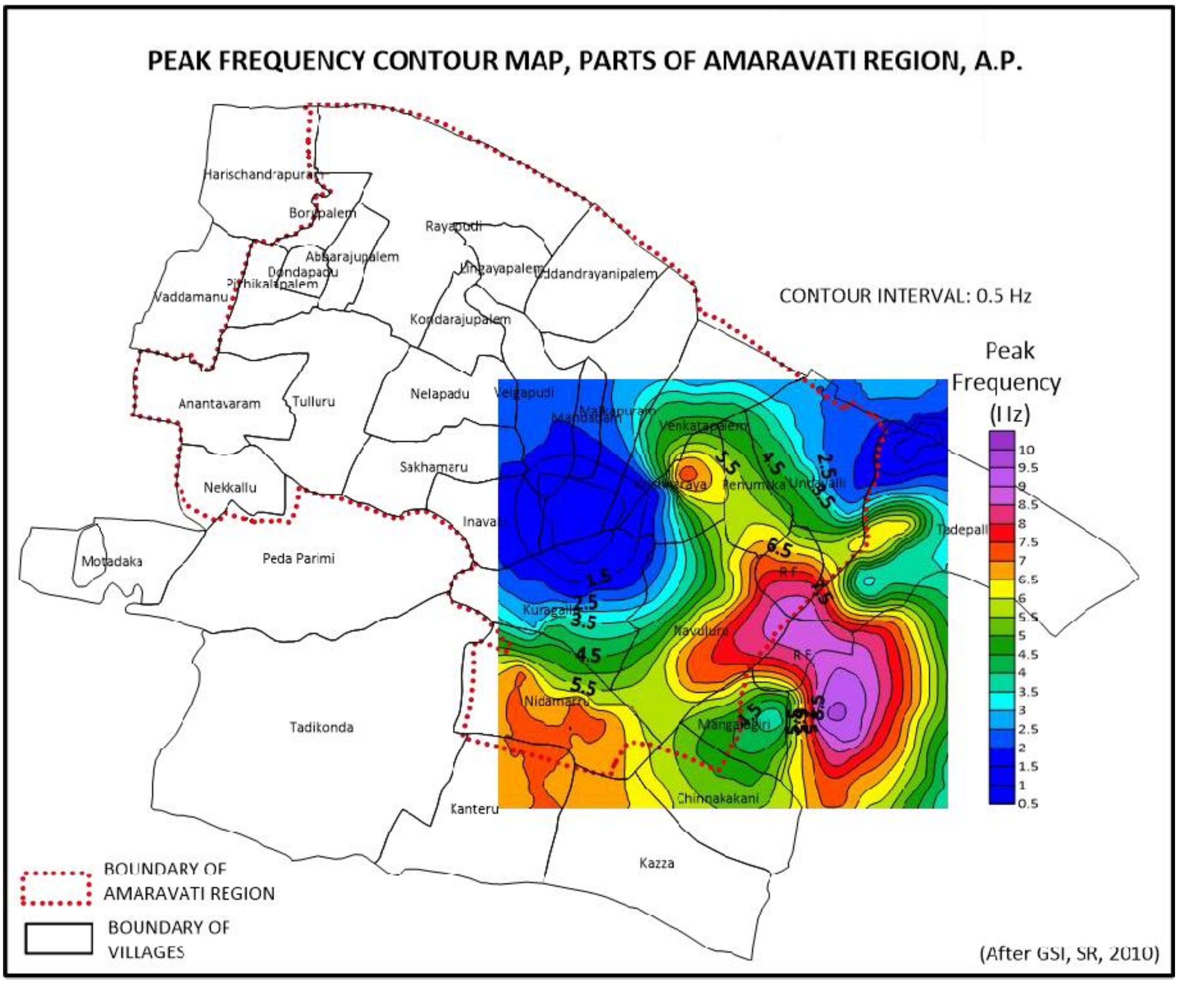


Figure 76: Peak Frequency contour map, parts of Amaravati City

Studies for site response determinations have brought out zones which could be vulnerable for major damage in case of earthquakes in the zones of influence. The peak amplification values range from 1.5 to 4, corresponding to peak frequency range of 5 to 10 Hz, indicating that the overburden thickness is large and is unconsolidated. Hence, it can be said that structures with natural frequency greater than 5Hz are safe and suitable in this area. It is interesting to note that high peak amplification values correlate well with low dominant and high peak frequency values correlate well with the high dominant magnetic anomalies.

CHAPTER 5: HYDROGEOLOGICAL STUDIES

5.0. GENERAL

This chapter defines a complete hydrogeological investigation package for Amaravati city and its peri-urban area to support groundwater resource assessment, sustainable management, recharge planning, and infrastructure design. The study covers:

- aquifer characterization, groundwater occurrence and flow, water-quality status, recharge/discharge dynamics, and sustainable yield;
- inputs for the groundwater recharge plan, well siting, regulatory decisions, and monitoring.

5.1. GROUNDWATER DYNAMICS

Groundwater levels are dynamic in nature and vary from place to place based on the seasonal rainfall, usage, physiographical and geological conditions. Groundwater levels represent the vertical distance from the ground surface to the top of the saturated zone, which is called the water table in unconfined aquifers and the potentiometric surface in confined aquifers.

They are dynamic and vary with recharge, pumping, and seasonal changes, making them a critical parameter for assessing aquifer storage status, identifying recharge and discharge zones, and determining groundwater flow direction, which always occurs from areas of higher hydraulic head to lower.

Measurement is typically carried out before and after the monsoon using water level indicators. Units in fts below ground level (ft bgl) or ft above mean sea level (ft amsl), and the data is plotted to create water level contour maps, where contours connect points of equal water level elevation and help in visualizing flow patterns. Aquifer boundaries define the physical limits of an aquifer, both laterally, where permeable layers meet impermeable or low-permeability formations, and vertically, where aquifers are separated from aquitards or aquicludes. These boundaries can be identified through borehole lithologs, geophysical surveys like VES and ERT, pumping test interpretations, remote sensing analysis of geomorphic and structural features, and changes in groundwater chemistry.

Integrating groundwater level data with mapped aquifer boundaries allows the preparation of aquifer maps that depict both the spatial extent and hydraulic characteristics of each aquifer system. In multi-aquifer areas, separate maps are made for shallow, intermediate, and deep systems, and cross-sections are prepared to show aquifer thickness, disposition, and hydraulic connectivity.

Such combined mapping provides the foundation for hydrogeological planning, enabling the delineation of flow directions, recharge and discharge areas, and sustainable groundwater management strategies.

Table 6: Groundwater levels of the study area during 11th and 12th of June, 2025

Borewell No.	Latitude	Longitude	Depth to Water Table (ft)
1	16.529870	80.526360	7.26
2	16.530990	80.524070	9.80
3	16.496910	80.585880	14.03
4	16.493000	80.595700	19.54
5	16.497180	80.580810	3.60
6	16.491880	80.552780	15.02
7	16.486020	80.557190	21.02
8	16.455860	80.524530	18.94
9	16.457900	80.524710	17.03
10	16.448900	80.526670	21.19
11	16.451859	80.525565	23.86
12	16.455213	80.527375	11.78
13	16.486679	80.502118	8.58
14	16.487549	80.501779	19.83
15	16.488110	80.504444	10.86
16	16.524781	80.469004	17.33
17	16.515858	80.466336	27.00

The post-monsoon groundwater level data for the study area was obtained from the published Smart City of Amaravati report by the Geological Survey of India (GSI, 2021). This dataset, representing measurements from November 2019, was utilized to assess the prevailing groundwater conditions. The analysis indicates that groundwater levels are relatively shallow along the stretches adjoining the Krishna River, reflecting the influence of riverine recharge. Additionally, a notable shallow water table trend is observed along the North–North-East (NNE) to South–South-West (SSW) direction, coinciding with a mapped shear zone that extends from Uddandarayapalem to Sekhamuru villages. This alignment suggests that the structural features, particularly the shear zone, play a significant role in controlling groundwater occurrence and movement within the area (Figure 77).

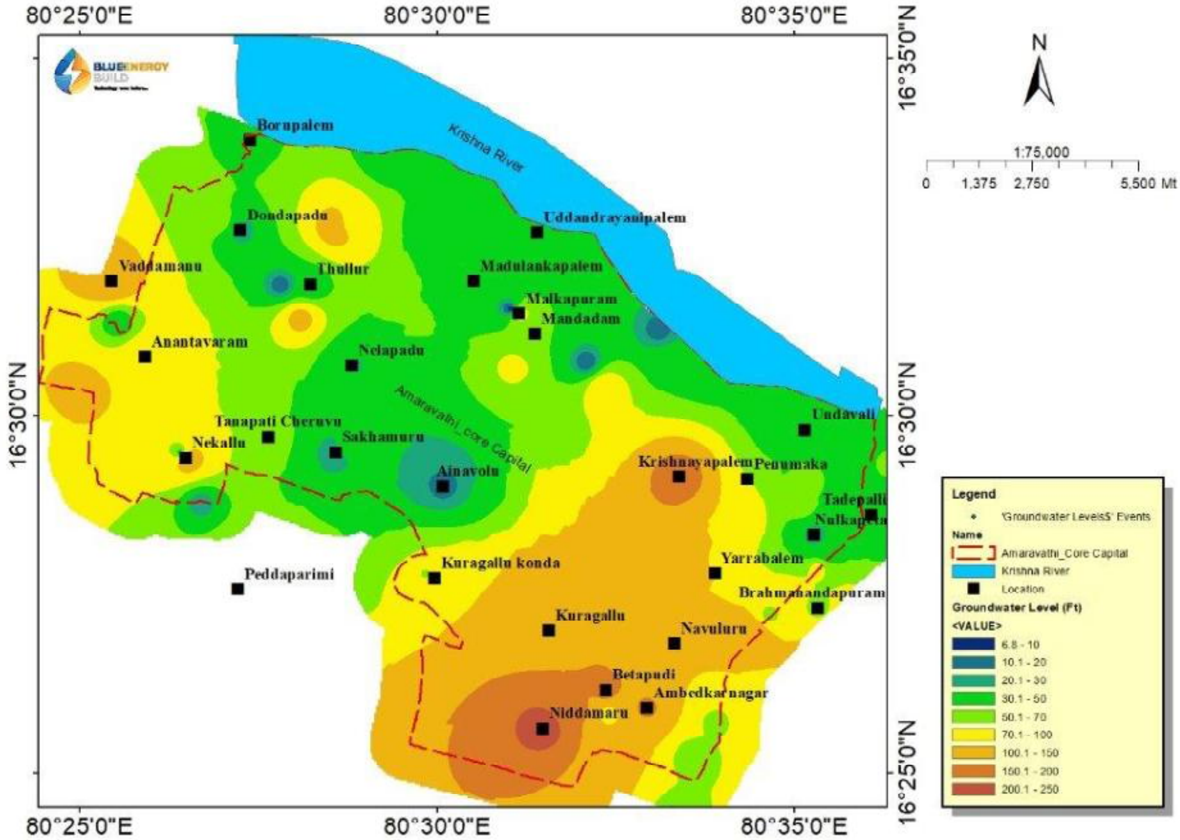


Figure 77: Water table (ft) below ground level.

5.2. PUMPING TESTS

Purpose of Pumping Tests are-

1. To determine the Aquifer hydraulic parameters, include Transmissivity (T), Storativity (S), and Specific Capacity.
2. To identify aquifer boundaries, connectivity between wells, and degree of confinement.
3. To assess well performance (safe yield) for irrigation, domestic, and industrial supply.
4. To validate aquifer layers interpreted from lithologs, resistivity surveys, and drilling data.

Pumping tests are Conducted on Exploratory Wells (EW) and Observation Wells (OW).

Step Drawdown Test (SDT) is done to determine well efficiency. Data analysed using methods like Theis, Cooper–Jacob, or Neuman (for unconfined aquifers).

Hydraulic parameters from pumping tests are plotted spatially to delineate high- and low-yield zones. Combined with geophysical, lithological, and water-level data to prepare Aquifer Management Plans.

Table 7: Aquifer parameters of different aquifer systems in Amaravati Area

Aquifer Type	Transmissivity (T) *(m^2/day)*	Storativity (S)	Yield *(lps)*	Remarks
Alluvium (sand, gravel)	200 – 1,200+	1×10^{-3} to 1×10^{-4}	5 to 15+	High potential: Krishna River floodplain shows best values
Granite / Gneiss	5 – 80	1×10^{-3} to 1×10^{-5}	1 to 5	Yield from weathered zone (8–15 m) & fracture zone (40–120 m)
Khondalite	3 – 30	1×10^{-3} to 5×10^{-5}	0.5 to 3	Low–moderate; yields improve where intersecting shear/fracture zones
Charnockite	2 – 25	1×10^{-3} to 5×10^{-5}	0.5 to 2.5	Generally low; deep fracture zones (>100 m) improve yield marginally

5.3. WATER QUALITY ANALYSIS

Based on the onsite water sample analysis methods and Smart City of Amaravati report (GSI, 2021), the water quality assessment was carried out through detailed physico-chemical analysis of 100 groundwater samples collected across the study area. The parameters measured included pH, electrical conductivity (EC), total dissolved solids (TDS), total hardness (TH), major cations (Ca^{2+}, Mg^{2+}, Na^+, K^+) and anions (HCO_3^-, Cl^-, SO_4^{2-}, NO_3^-, F^-, PO_4^{3-}, SiO_2), and the results were evaluated using BIS standards and the Water Quality Index (WQI) method.

Water Quality Status

- Most samples showed **alkaline nature**, with pH generally within permissible limits.
- TDS and hardness values in many samples indicated suitability for drinking, though **localised pockets** exhibited higher concentrations, reflecting mineral dissolution from host rocks.
- Elevated **nitrate (NO_3^-)** was recorded in about 40% of samples, exceeding permissible limits in some locations—an indicator of contamination from fertilisers, domestic wastewater, and leaching from agricultural lands.
- **Fluoride (F^-)** exceeded safe limits in about 7% of samples, most likely due to leaching from fluoride-bearing minerals in the bedrock.

- According to WQI classification, **54%** of the area falls under the “excellent” category, **19%** as “good”, **10%** as “poor”, **6%** as “very poor”, and **11%** as “unsuitable for drinking”.

Reasons for Poor Water Quality

1. **Geogenic Sources –** The lithology of the area, dominated by Eastern Ghats granulite facies rocks such as Khondalite, charnockite, and pyroxene granulite, contributes ions like sodium, potassium, calcium, and magnesium through rock–water interaction.

2. **Agricultural Activities –** Intensive irrigation and heavy use of fertilisers lead to nitrate enrichment in groundwater, particularly in shallow aquifers and areas with high infiltration rates.

3. **Urbanisation & Wastewater Disposal –** Expanding built-up areas without adequate sewage infrastructure cause local contamination from untreated domestic wastewater and solid waste dumping.

4. **Over-extraction and Reduced Recharge –** Excessive pumping in some parts has altered natural flow patterns, encouraging the ingress of poor-quality water from adjacent brackish zones, especially in the deltaic alluvium.

5. **Structural Controls –** Shear zones and fracture networks act as conduits, sometimes transmitting water from deeper layers with higher dissolved solids.

CHAPTER 6: GROUNDWATER MODELING

6.0. GENERAL

Amaravati, the planned capital city of Andhra Pradesh, lies on the right bank of the Krishna River within Guntur district. The region is under rapid urbanization, resulting in increased water demand for domestic, industrial, and institutional needs. A reliable understanding of groundwater resources is essential to ensure sustainable water supply and to minimize risks of over-extraction, waterlogging, or contamination.

Groundwater modelling provides a scientific framework to simulate aquifer behavior under different stress conditions and to evaluate the impacts of urbanization, climate variability, and recharge interventions.

6.1. AQUIFER CHARACTERISTICS INFERRED FROM RESISTIVITY SOUNDINGS

Based on the resistivity signatures from different soundings, the aquifer characteristics are classified into hydro-geological parameters and hydro-stratigraphic units, which include degree of fracturing, weathering and presence of geological structures (joint / fault / fracture / shear / contacts), that favor groundwater storage. Weathered layer forms an important zone for infiltration of water, if its thickness and holding capacity increases. Thick weathered zones with porous residual material forms in topographic lows, act as potential groundwater repository. The depth of water level is a subdued replica of the topography of the area. Shallow water level conditions are commonly observed in valley areas, topographic lows and flat terrain, whereas the deeper water table conditions noticed near water divides and the topographic highs. Hence, the depth to water levels under unconfined conditions mainly dependent on the thickness of the weathered zone, permeability, topographic set up, the nature of aquifer material and the functions of recharge and discharge.

Based on geo-electric sections, two major aquifer systems are said to exist in this terrain, which are the shallow / unconfined aquifer within the sediments, and the fractured / deeper / confined aquifer within the weathered basement. Highest groundwater yields are obtained where the overburden, weathered columns overlies the fractured zones.

On the basis of occurrence of aquifer system and movement of ground water in the study area, hard rock units are classified into three categories; Archean crystalline granitic basement underlies by charnockite in the central part, Khondalite in the eastern part and calc granulites in the western part of the Amaravati City. Weathered and fractured Archean crystalline rocks form the semi-confined / confined aquifer system. Sedimentary aquifer system (unconfined) overlies Archean crystalline rocks. The main aquifers constitute the weathered zone at the top, followed by a discrete anisotropic fractured zone at the bottom followed by semi-weathered and hard, massive, compact basement. Ground water occurs under unconfined and semi-confined conditions and flows downward from the weathered zone into the fracture zones. The aquifer units identified includes shallow aquifer and deeper aquifer.

Interpretation of resistivity vs thickness of sedimentary data of Amaravati City well brought out the disposition of concealed and unconfined aquifer geometry. In general, the trend of the shallow and unconfined aquifer system is almost parallel to the Krishna River, which is trending in WNW-ESE in the study area, associated with low resistivity values. Maximum thickness inferred for unconfined aquifer is about 60 - 70m, just southern part of Krishna River (Figure 78).

Figure 78: Thickness of concealed & unconfined aquifer zone

Figure 79: Variation of Resistivity of concealed & unconfined aquifer zone

Moderate to high resistivities noticed for unconfined aquifer around Borupalem, Lingayapalem, NE of Velagapudi, SW of Uddandarayunipalem, Venkatapalem and north of Undavalli areas. Aquifer thickness of >40m noticed around Rayapudi, south of Uddandarayunipalem, north of Velagapudi, Malkapuram, Venkatapuram and Undavalli areas. Isolated high zones (>40m) also observed around Nekkallu, south of Nelapadu and Velagapudi areas. Moderate aquifer thickness of around 15 - 35m inferred around Dondapadu, Thullur, north of Anantapuram, Krishnayapalem, Penumaka, Navaluru and Kurugallu areas. Thickness of 5 – 15m observed in the remaining part of the study area. Further, it is interesting to note that, the thickness of aquifer along the concealed NNE-SSW shear zone is >45m.

Isolated high resistivities over unconfined aquifer were noticed around Anantavaram, Thullur, Nelapadu, south of Velagapudi, Krishnayapalem, Southeast of Undavalli, around Kurugallu, north of Sakhamuru, and Nekkallu areas. Whereas aquifer zones having low resistivities identified in the remaining part of the study area (Figure 79).

In addition, a confined aquifer system also exists in the Amaravati City which has a multi-layered aquifer system layered beneath the shallow / unconfined aquifer, between 30 to 100m or upto 150m depths consist of alluvium / sand, weathered and fractured bed rock. This confined aquifer is characterized by an impermeable clay layer above and hard, compact massive bed rock below.

WEATHERED ZONE

Sounding data and available drilling data indicates that the thickness of weathered zone is in the range of 10-30m in most areas covering ~78 % of area, shallow weathering (< 10 m) occurs in 55 % of the area and deep weathering (> 20 m) occurs in rest of Amaravati City. Shallow weathering mostly seen in Khondalite rock areas in the eastern part of the area. Ground water yield from weathered charnockite aquifer varies from <100m depth are more predominant (~83 % of the area), fractures occur in ~13% of area respectively and deep fractures in the range of >150m in the central part and on either side of the Amaravati City.

FRACTURE ANALYSIS

Based on resistivity sounding data, well inventory and available drilling data up to 200m depth of Amaravati City, about ~70% of the area is covered by consolidated formation / sediments unable to demarcate any major structural features (viz., fracture, shear, folds, faults and joints) in relation with lineament study. However, based on well inventory and geophysical studies including magnetic and secondary gravity data) reveals that, the fractures are oriented in specific direction towards NNE-SSW on either side of the Amaravati City at Anantavaram in the west and Tadepalli in the eastern part. In addition, a concealed shear zone was traced, trending in NNE-SSW direction from Uddandarayunipalem in the north to Ainavolu in the south. The analysis shows that fractures having a depth range in shallow aquifers from 20m to 45m and moderate to deeper aquifer ranges from 100 to 150m depth. Fracture analysis reveals that, majority of fractures (~83 %) occur within 100m depth. Further, these fractures are mostly short distance, desecrated, disconnected and thickness in meters has led to low yield in certain parts of charnockite area.

6.2. INFERRED DEPTH SECTIONS OF ALLUVIAM / SAND LAYER FROM DRILLING DATA

Based on the geological formation, depths, fracture pattern from the geophysical surveys, well inventory and available drilling data, geo-electric cross sections were drawn along North to South (section: I to V) and East to West (section: VI) directions, covering the entire area showing aquifer / fracture delineation. Northern and north-eastern part of the area, a shallow aquifer up to the depth of 45m is more potential as it comes under alluvium formation / flood plain. The North to South geo-electric sections show aquifer and fractured delineation in between 30 m to 150m depth. In the north-western part is completely covered by Alluvium formation up to the depth of 30m, shallow depth and aquifer is in between 15 to 23m depths, whereas in south-eastern part covers completely charnockite bed rock, giving rise to very thin fractures at certain locations and it has been extended to the thicker in western part of the area. It is found that the north-eastern part shows shallow aquifer up to the depth of 45 m is more potential as it comes under Alluvium formation.

Figure 80: Locations of lithologs used for sand layer delineation

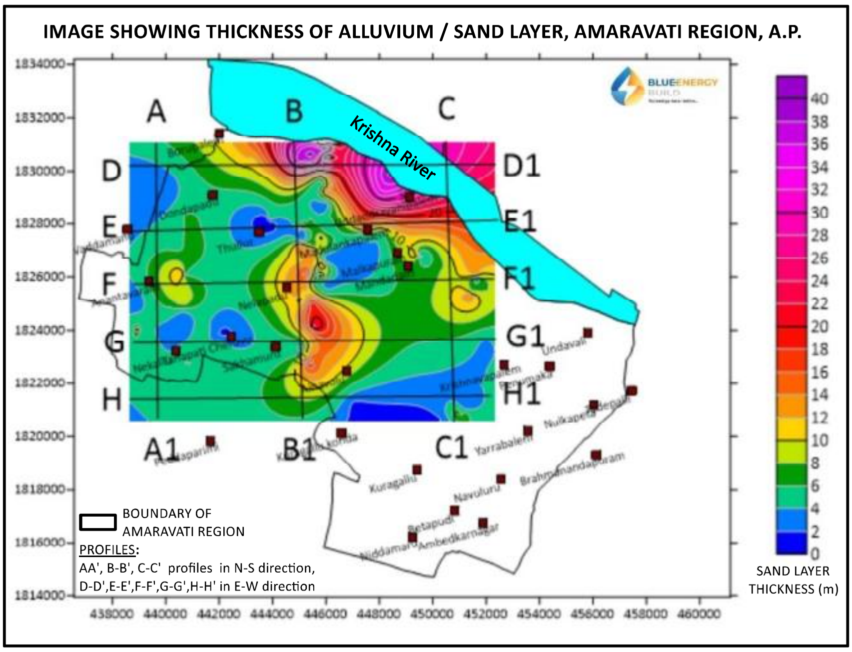


Figure 81: Contour map of Alluvium / Sand layer thickness

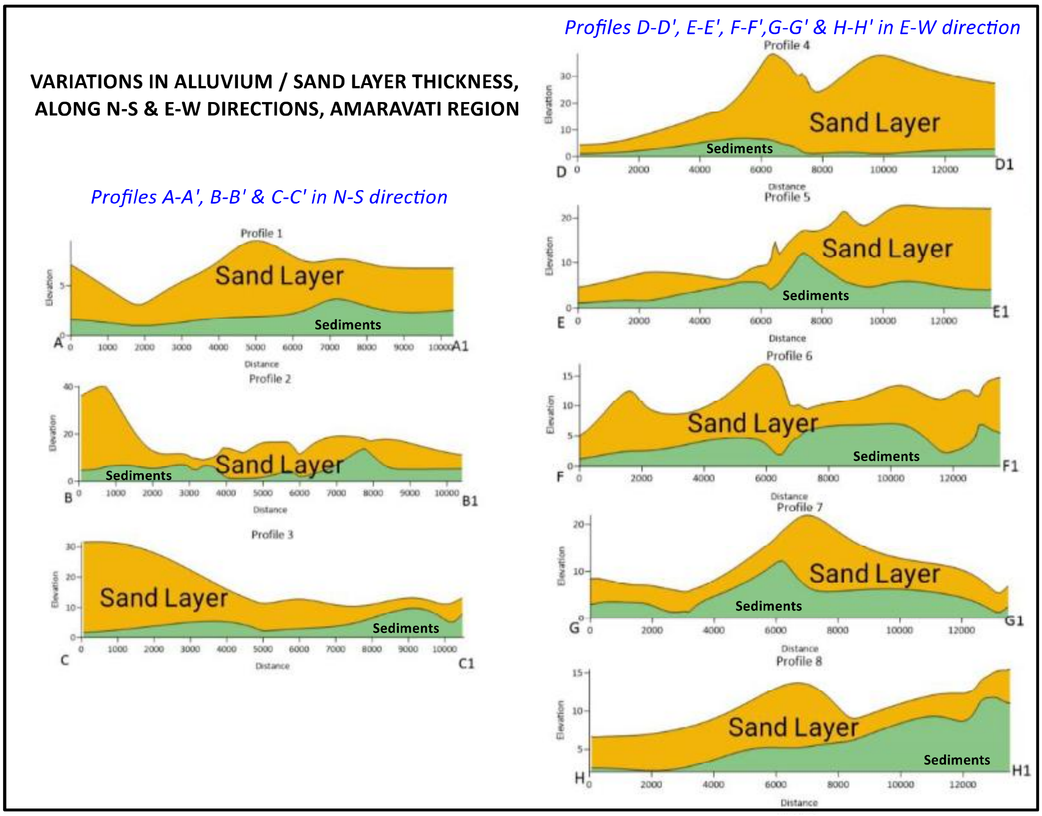


Figure 82: Inferred Sand Layer Thickness of Sections A to H

Table 8: Aquifer characteristics, its resistivity and depth range, Amaravati

	Sedimentary formations		**Crystalline basement**	
Lithology	Top black cotton soil, clay, clayey silt, silty clay, sandy clay, silty sand / sand and gravel.		Charnockite, Khondalite, Pyroxene / Calc Granulite and Granite gneiss	
Aquifer type	*Unconfined aquifer*	Weathered zone	*Confined aquifer*	Fracture zone
Thickness	1 – 30m	Upto 60m	30 – 100m	Upto 150m
Depth	30m	85% encountered within 30m	30 – 100m	85% encountered within 100m

6.3. MANDAL WISE AQUIFER DISPOSITION

Thullur Mandal

Geology & Aquifer Type: Underlain predominantly by Archaean crystalline rocks – gneisses, Khondalites, and charnockites.

Aquifer-I: Weathered zone aquifer (8–15 m bgl), tapped by dug wells; yields ~0.12–3 lps.

Aquifer-II: Fractured rock aquifer (40–120 m bgl, with deep fractures up to ~173 m bgl); yields ~1–5 lps.

Special Features: Groundwater occurs in secondary porosity; fracture density varies across Mandadam, Rayapudi, Velagapudi, Uddandarayunipalem.

Mangalagiri Mandal

Geology & Aquifer Type: Mix of crystalline rocks and minor alluvial cover along drainage zones.

Aquifer-I: Weathered zone (~10–15 m bgl) – supports irrigation through dug wells; yields up to 200 m^3/day.

Aquifer-II: Fractured aquifer at 40–100 m bgl; bore wells yield 1–3 lps generally.

Special Features: Areas like Nidamarru and Nowlur have both shallow alluvial deposits and hard rock aquifers, leading to variable yield.

Tadepalli Mandal

Geology & Aquifer Type: Located along Krishna River floodplain – dominated by alluvium (sands, clays, gravels) over crystalline basement.

Aquifer-I: Unconfined to semi-confined alluvial aquifer (5–20 m bgl); moderate to high yields (up to 10–12 lps in coarse sand/gravel zones).

Aquifer-II: Underlying weathered/fractured crystalline rocks (depth >40 m bgl); yields vary 1–5 lps.

Special Features: High recharge potential from Krishna River; better groundwater quality near riverbank filtration zones.

CHAPTER 7: RECHARGE PLAN FOR THE AMARAVATI CAPITAL CITY

7.0. GENERAL

Amaravati, the emerging capital city of Andhra Pradesh, is located on the right bank of the Krishna River and is envisioned as a modern, sustainable urban centre. With rapid urbanization and increasing water demand, groundwater has become a critical resource for domestic, industrial, and institutional sectors. However, over-dependence on borewells and limited recharge opportunities have resulted in stress on aquifers.

This chapter outlines a comprehensive **Groundwater Recharge Plan** designed to enhance aquifer sustainability, mitigate water scarcity, and support the long-term water security of Amaravati city.

7.1. OBJECTIVES

- Enhance aquifer recharge to meet future urban water demands.
- Integrate recharge measures into flood control and stormwater management.
- Improve water quality in brackish and saline-prone zones.
- Ensure long-term groundwater sustainability alongside city development.

7.2. GROUNDWATER POTENTIAL ZONES

A groundwater potential map is developed through the weighted overlay analysis (of spatial datasets, including slope, drainage density, lineament density, soil types, geology, geomorphology, and land use/land cover. Based on the weightage the groundwater potential zones classified as Very low, low, moderate, High, Very High (Figure 83).

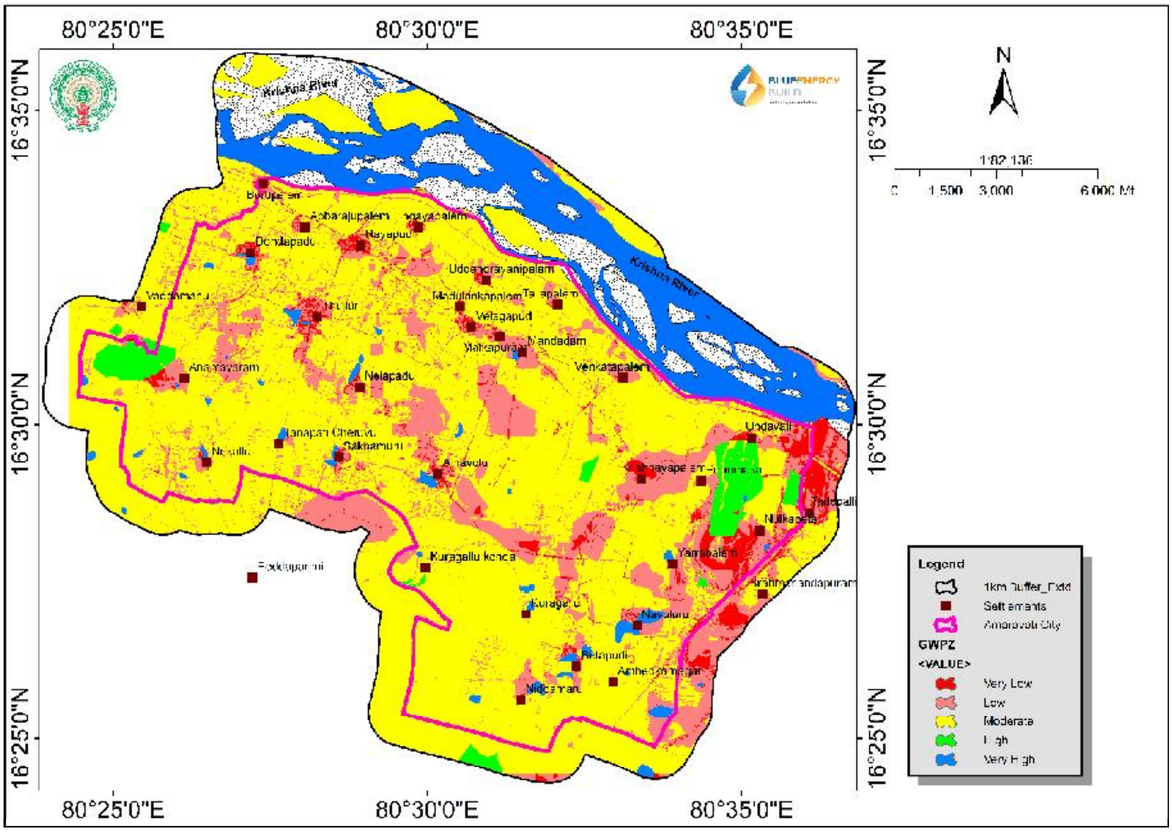


Figure 83: Groundwater Potential Zones derived from Land use land cover, Geology, Geomorphology, Drainage, Slope, Soil and Lineament Density

Table 9: Recharge zonation based on aquifer type, geomorphic setting, infiltration potential, and water quality

Zone	Key Villages	Geomorphic Setting	Aquifer Potential	Recharge Priority
High Potential Alluvial Zone	Uddandarayunipalem, Lingayapalem, Krishnayapalem, Sakhamuru	Flood plains, valley fills	Thick sand/gravel layers, shallow water table	High
Moderate Potential Pediplain Zone	Rayapudi, Velagapudi, Nelapadu, Thullur, Inavolu	Pediplains, residual soils over weathered rock	Moderate yield, deeper water table	Moderate
Structural/Shear Zone Recharge Corridor	Uddandarayunipalem–Ainavolu belt	NNE–SSW shear zone in crystalline rocks	Confined aquifer in fractured basement	High
Low Potential Rock Outcrop Zone	Mangalagiri, Anantavaram, Nidamarru	Structural hills, rocky uplands	Limited storage, fractures as recharge sites	Low–Moderate

7.3. RECOMMENDED RECHARGE STRUCTURES

Flood Plains & Valley Fill Areas (High Infiltration)

Percolation Tanks along major drainage lines (e.g., Kondaveeti vagu, Kottela vagu). Recharge Wells (30–50 m depth) to tap into shallow aquifers. Check Dams on seasonal streams to retain post-monsoon runoff.

Pediplains with Weathered Basement

Recharge Shafts (3–5 m diameter, 15–25 m deep) targeting weathered/fractured basement zones. Contour Trenches & Farm Ponds for local recharge and soil moisture retention.

Shear Zone Corridor (Uddandarayunipalem–Ainavolu)

Deep Recharge Wells (50–80 m) into fracture zones to enhance confined aquifer recharge. Injection Wells for treated stormwater to augment groundwater storage.

Rock Outcrop & Upland Areas

Rainwater Harvesting Pits in institutional/urban complexes. Roof-top to Ground Recharge Systems in built-up areas near Mangalagiri hills.

7.4. WATER QUALITY IMPROVEMENT MEASURES

Blending of poor-quality groundwater with harvested rainwater in brackish zones (e.g., Amaravati, Nekkallu). Bio-remediation trenches in recharge zones to reduce nitrate/fluoride levels.

7.5. INTEGRATION WITH FLOOD MANAGEMENT

Dual-purpose retention reservoirs at Neerukonda, Krishnayapalem, and Sakhamuru to store floodwater for controlled recharge. Staged pumping and diversion channels to recharge wells after major storm events.

7.6. IMPLEMENTATION PHASING

Phase 1 (Immediate): High-potential floodplain and shear zone recharge works before 2027.

Phase 2(Medium-term): Pediplain recharge interventions integrated with urban infrastructure rollout (2027–2032).

Phase 3 (Long-term): Low potential rocky upland recharge combined with landscaping, parks, and institutional RWH (2032 onwards).

CHAPTER 8: CONCLUSIONS

The Hydrogeomorphological studies conducted for the Amaravati Capital City area, as per the agreement with APCRDA, have successfully identified and mapped the critical geomorphological, geological, and hydrogeological characteristics influencing groundwater occurrence, recharge, and storage. The integration of field-based geophysical surveys, interpretation of satellite imagery, and analysis of existing hydrogeological data has provided a comprehensive understanding of the terrain and subsurface conditions.

Key findings indicate that the area exhibits distinct geomorphic units such as flood plains, buried pediments, valley fills, and uplands, each influencing groundwater potential differently. The shear zones trending in NNE–SSW and associated with lineaments have been identified as significant groundwater-bearing structures. The post-monsoon groundwater levels reveal shallow water tables near the Krishna River and along major structural trends, supporting higher recharge potential in these zones.

The study confirms the presence of multi-aquifer systems, with varying yield capacities depending on lithology—ranging from high-yield alluvial zones to moderate- and low-yield crystalline rock aquifers. Water quality assessments indicate that while most areas fall within permissible limits for drinking and irrigation, localized zones of poor quality require intervention through recharge enhancement and contamination control.

Recommendations from this study will aid in the scientific planning of water retention structures, recharge wells, and stormwater management systems, ensuring both flood mitigation and sustainable groundwater development. The outputs serve as a scientific baseline for APCRDA to integrate water resource management into urban planning, thereby contributing to long-term water security in the Amaravati Capital City.

Interpretation of geophysical and other data sets helped in identifying the architecture of the Amaravati City associated with structural features favorable for occurrence of groundwater aquifer system. Based on the analysis, the following have been inferred:

- In Amaravati City, delineation of aquifer system in the sediment / hard rock terrain is controlled by the nature of the weathered regolith and the fractured basement.

- Inferred hydro-geological characteristics of weathered portions and underlying bed rock depends on deep weathering and influence of structural features viz., joint / fault / fracture / shear and contacts.

- Hydrogeology of this area includes silty sand / sand layer within the sediments forming the shallow / unconfined aquifer system, weathered bed rock forms the deeper / confined aquifer system.

- Hydrogeology of this area reflects groundwater stored in the top sand layer / unconfined aquifer, whose thickness varies between 10 - 30m, weathered / fractured basement (confined), depth fluctuates between 30 - 100m.

- In Amaravati City, shallow aquifer within the sediments are characterized by low to moderate resistivities between 10–100 Ώ-m. Geo-electric characteristics depicts its nature as unconfined, vulnerable to infiltrating surface contaminants, with low groundwater potential, suitable for small community water supply projects.

- The semi-confined to confined aquifer system within the weathered / fractured basement is characterized with moderate resistivities varying from 10 to 200 Ώ-m and relatively thicker sequence of aquifer material. Groundwater potential seems to be largely moderate and aquifer is deemed suitable for industrial and irrigational purpose.

- The maximum groundwater resources in the basement complex occur along the major tectonic lineaments, mainly along NNE-SSW and E-W directions inferred from resistivity, magnetic and gravity data, which constitute the preferential flow paths for the groundwater.

- Lineament analysis from Amaravati City indicates that density of lineaments and their intersections represent higher level of fracturization, assume importance for potential zones of groundwater.

- Qualitative analysis of lineament data viz., lineament frequency, density, direction, length and their intersections vis-à-vis possible occurrence of groundwater, immensely helpful in delineating the concealed and unexplored potential zones.

- In Amaravati City, resistivity depth sections at different levels, well brought out the prominent resistivity low zones corroborating well with inferred lineaments, which are structurally favorable for presence aquifer system at different depths.

- Based on the resistivity signatures, shallow aquifers are inferred mostly from the eastern part / low lying areas and moderate aquifers are found in the south-western part having thick sediments.

- Based on the intensity of magnetic and gravity signatures, the study area is divided into: Zone-1 indicating high dominant magnetic and gravity anomalies in eastern part over Khondalites. Zone-II indicates low dominant gravity and magnetic anomalies in the western part over calc granulite / pyroxene granulite basement. Zone-III indicates moderate signatures in the central part over charnockite basement.

- Amaravati City falls within a fault / fracture zone, in the form of NNE-SSW and NNW-SSE trending steep gravity and magnetic gradients / lineaments on east and west respectively.

- A NNE-SSW trending geologically marked concealed shear zone was reflected in the form of gravity gradients and magnetic lows in the central part from Uddandarayunipalem to Ainavolu.

- Based on inferred lineament analysis, the NNE-SSW trending geologically marked concealed shear zone, may be affected not only by strike slip fault along but also western part may be down thrown block, evidenced by thick sediments, elevation and drainage map.

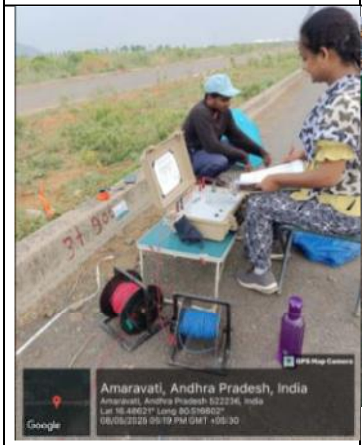
- Gravity highs correlating with isolated magnetic and resistivity highs in the eastern part may indicate the basement highs at shallow depth. Gravity lows associated with low dominant magnetic anomalies in the western part may indicate the basement at deeper depths. Isolated basement highs are corroborating well with isolated resistivity highs confirmed by VES data.

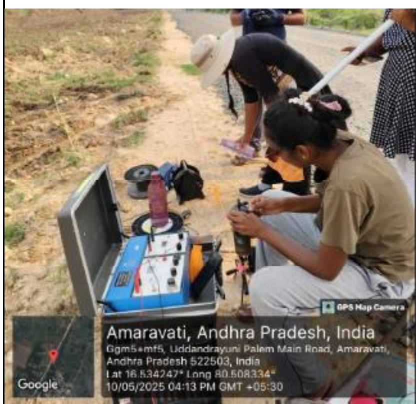
- Residual gravity lows inferred from gravity profile of the order of 0.5 mGal identified on either side of the regional gravity profile may be due to structural disturbances.

- The concealed NNE-SSW trending geologically marked shear zone having a width of 200m to 500m, increasing the width from south to north, associated with resistivity highs.

- Water quality along this shear zone is good and TDS content is less, when compared to the quality of groundwater from the SW part.

FIELD PHOTOGRAPHS



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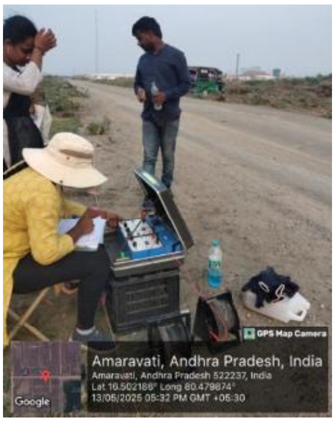
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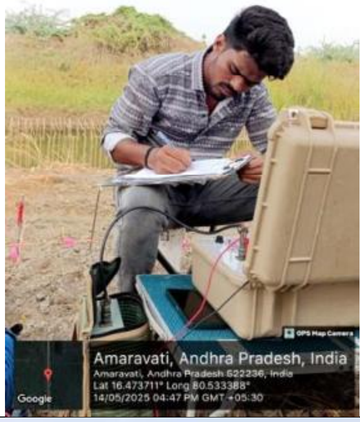
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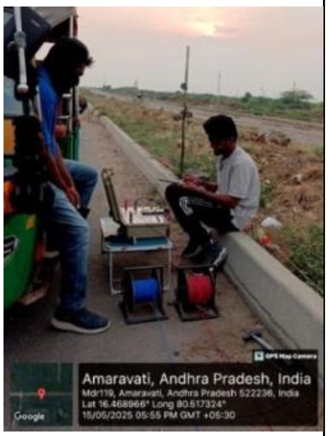
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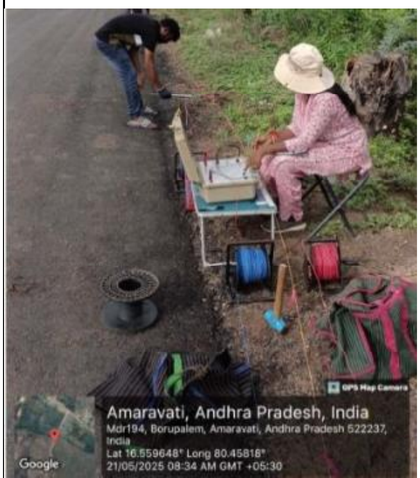
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Note: 356


Amaravati, Andhra Pradesh, India
Amaravati, Andhra Pradesh 522236, India
Lat 16.51509° Long 80.444599°
28/05/2025 05:07 PM GMT +05:30
Google


Latitude: 16.499783
Longitude: 80.408577
Elevation: 51.62±28.9 m
Accuracy: 1.7 m
Time: 28-05-2025 16:10
Note: 367


Latitude: 16.497187
Longitude: 80.542884
Elevation: 27.4±2.5 m
Accuracy: 3.79 m
Time: 06-07-2025 06:39


Latitude: 16.500968
Longitude: 80.59222
Elevation: 37.36±8.22 m
Accuracy: 25.64 m
Time: 06-09-2025 23:04
Note: 1


Latitude: 16.506697
Longitude: 80.557404
Elevation: 27.48±2.9 m
Accuracy: 3.79 m
Time: 06-09-2025 18:51
Note: 117


Latitude: 16.50636
Longitude: 80.568765
Elevation: 31.96±3.57 m
Accuracy: 3.79 m
Time: 06-10-2025 04:05
Note: 5


Latitude: 16.486667
Longitude: 80.553025
Elevation: 42.13±7.22 m
Accuracy: 3.79 m
Time: 06-10-2025 16:53
Note: 67


Latitude: 16.493126
Longitude: 80.557938
Elevation: 40.8±4.37 m
Accuracy: 5.252 m
Time: 06-10-2025 17:45
Note: 648


Latitude: 16.493126
Longitude: 80.557938
Elevation: 40.8±4.37 m
Accuracy: 5.252 m
Time: 06-10-2025 17:45
Note: 648


Latitude: 16.473396
Longitude: 80.545779
Elevation: 28.9±2.5 m
Accuracy: 3.79 m
Time: 06-13-2025 11:42
Note: 157


Latitude: 16.459348
Longitude: 80.545909
Elevation: 41.34±23.6 m
Accuracy: 3.79 m
Time: 06-13-2025 18:12
Note: 425

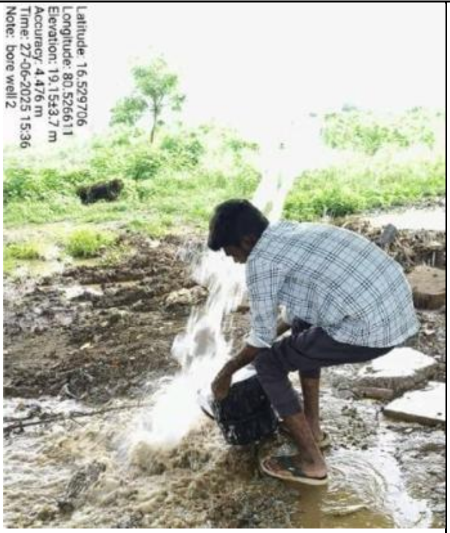

Latitude: 16.5593
Longitude: 80.498558
Elevation: 25.53±3.5 m
Accuracy: 1.3 m
Time: 24-06-2025 11:44
Note: 283


GPS Map Camer
Amaravati, Andhra Pradesh, India
F Rd, Amaravati, Andhra Pradesh 522503, India
Lat 16.516485° Long 80.496531°
09/05/2025 07:55 AM GMT +05:30
Google


477
BLUEENERGY BUILD (P)LTD
HydroGeomorphological Survey
Cell no: +91 9976854999


GPS Map Camera
Amaravati, Andhra Pradesh, India
D Rd, Amaravati, Andhra Pradesh 522503, India
Lat 16.459640° Long 80.516483°
09/05/2025 11:09 AM GMT +05:30

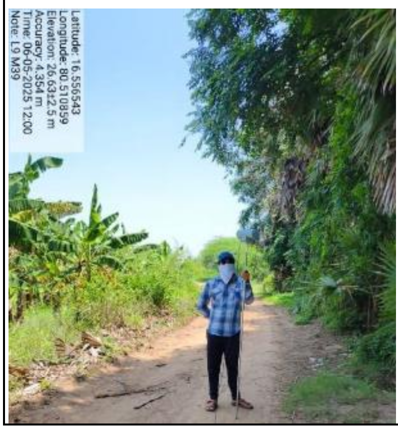
		
		
		









		GPS Map Camera Amaravati, Andhra Pradesh, India F Rd, Amaravati, Andhra Pradesh , India Lat 16.507038° Long 80.492726° 31/06/2025 04:33 PM GMT +05:30 Google
GPS Map Camera Amaravati, Andhra Pradesh, India Amaravati, Andhra Pradesh 522237, India Lat 16.507026° Long 80.491628° 31/05/2025 05:31 PM GMT +05:30 Google		
		

	Technical Discussion at Central Ground Water Board, Hyderabad with Regional Director Dr. Jyothi Kumar. Technical Secretary- Dr. Madhav and Dr. S Srinivasa Vittala, Scientist C.
	Technical Discussion at Central Ground Water Board, Hyderabad with Dr. S Srinivasa Vittala, Scientist C who worked in NAQUIM 2.0 project.

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