3D AQUIFER MODELLING USING BOREHOLE DATA

A PROJECT REPORT
(GI5712-PROJECT I)

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BONAFIDE CERTIFICATE

Certified that this Project Report titled "3D AQUIFER MODELLING USING BOREHOLE DATA" is the Bonafide work of MOHAMMED IBRAHIM S (2021107310), DEEPAK T (2021107312), THARUN KL (2021107316) who carried out the work under my supervision.

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ABSTRACT

The accurate representation of subsurface aquifer systems is crucial for effective groundwater management, environmental studies, and resource allocation. This project focuses on developing a 3D aquifer model using borehole data to visualize and analyze groundwater reservoirs in detail. Borehole data, including lithological logs, stratigraphic information, and hydrogeological parameters, will be the primary input to create a realistic aquifer system model. By integrating geostatistical methods and 3D modelling software, the project aims to map aquifers' spatial distribution, thickness, and hydraulic properties. The model will enhance understanding of aquifer geometry, water-bearing formations, and their interconnections, enabling better groundwater flow and storage capacity predictions. Additionally, this approach will provide insights into the impacts of external factors such as climate change and human activities on aquifer dynamics. In this model, the water level is displayed for the user's input geographical location. The model is created using HTML as a website. The 3D aquifer model will serve as a valuable tool for water resource planners, researchers, and policymakers, offering a visual and quantitative framework for sustainable groundwater management, land use planning, and environmental protection.

KEYWORDS: Borehole data, 3D aquifer model, Hydrogeological parameters, Website Design

CHAPTER 1

INTRODUCTION

1.1 GENERAL

3D aquifer modeling, utilizing borehole data, is crucial for effective groundwater management and understanding aquifer dynamics. Unlike traditional 2D models, 3D representations capture the complexities of subsurface environments by integrating detailed information on lithology, hydraulic conductivity, and porosity from boreholes. This comprehensive approach allows researchers and water resource managers to visualize the spatial distribution of water, assess groundwater flow, and simulate various scenarios, such as changes in land use or climate conditions. By providing insights into potential contamination pathways and the effects of over-extraction, 3D models facilitate informed decision-making and strategic planning. As advancements in computational tools and geospatial technologies continue to evolve, 3D aquifer modeling is becoming more accessible, making it an indispensable tool for sustainable water resource management in the face of growing challenges like water scarcity and environmental degradation.

1.2 NEED FOR THE STUDY

- To Predict the groundwater levels using borehole data
- Study how investors use 3D aquifer models to mitigate risks associated with groundwater availability.

1.3 OBJECTIVES:

- To measure and predict the water level using borehole data with interpolation method.
- To predict and display the water level for the Geographic location from the user-given input with our own created website

CHAPTER 2
LITERATURE STUDY

2.1 GENERAL

3D modelling of aquifers using borehole data is a critical approach in hydrogeology for visualizing and managing groundwater systems. Borehole data provides detailed subsurface information, including lithology and hydrogeological properties like porosity and permeability. This data is integrated into 3D models using arc scene and Inverse Distance Weighting (IDW) interpolation and numerical simulations Challenges include data sparsity, aquifer heterogeneity, and handling uncertainties in interpolation between boreholes. Despite these, 3D aquifer models have wide applications in groundwater management, environmental assessments, and understanding the impacts of climate change, making them essential tools for sustainable water resource planning

2.2 LITERATURE REVIEW

2.2.1 Studies Related to 3D aquifer Model:

A comprehensive literature review on 3D aquifer modelling up to 2024 reveals significant advancements in methods, applications, and tools for visualizing and managing groundwater systems. This review encompasses developments from early works in the late 20th century to cutting-edge research in recent years, highlighting key studies, methodologies, and future directions.

Initial Developments and Foundations:

Early research in groundwater modelling, such as that by Freeze and Cherry (1979), established the importance of spatial variability in aquifers, initially focusing on 2D models. As computing technologies improved, the transition to 3D aquifer models became feasible, offering more accurate and detailed representations of subsurface hydrology. Numerical methods for simulating groundwater flow were further advanced by Bear and Verruijt (1987), laying a theoretical framework that supported the evolution of 3D modelling.

Numerical Models and Geo statistics in 3D Aquifer Modelling:

With the development of tools like MODFLOW (Harbaugh et al., 2000), researchers began adopting3Dnumerical modelling for simulating aquifer behaviour. MODFLOW, widely regarded as a standard tool for groundwater modelling, facilitated the representation of complex subsurface conditions by integrating multiple layers of geological and hydrological data. Journel and Huijbregts (1978) introduced geostatistical techniques, particularly Kriging, which became a cornerstone for spatial interpolation between boreholes in 3D aquifer models. Recent studies such as Liu et al. (2021) emphasize the continued importance of geo statistics in improving the accuracy of 3D models, especially when borehole data is sparse or unevenly distributed.

Key Case Studies and Applications:

Numerous case studies have applied 3D aquifer models to various geological settings, addressing issues such as groundwater management, contamination, and resource planning. Notable examples include:

- Anderson et al. (2015), who used 3D models to assess groundwater depletion in the arid regions of the U.S. Southwest.
- Yang et al. (2018), who investigated seawater intrusion in coastal aquifers in China using 3D modelling to predict future impacts of excessive groundwater extraction.
- Ala-aho et al. (2017), who modelled aquifers in northern Europe to assess climate change impacts on groundwater recharge, showcasing the utility of 3D models in climate adaptation strategies.

In addition, studies such as Khaki et al. (2022) have demonstrated the integration of 3D models with real-time monitoring data, enabling dynamic management of aquifer systems in regions prone to groundwater stress.

Challenges and Limitations in 3D Aquifer Modelling:

While 3D modelling has become a powerful tool, several challenges remain. A common issue is data sparsity, as boreholes are often widely spaced, particularly in rural or undeveloped areas. Pouladi et al. (2019) highlighted difficulties in model calibration due to limited borehole data and emphasized the need for robust methods of data interpolation. Another significant challenge is geological heterogeneity, where aquifer properties (e.g., porosity, permeability) vary greatly over short distances. Carrera et al. (2005) emphasized the importance of sensitivity and uncertainty analysis in 3D models to account for these variations and improve model reliability.

Recent Innovations and Future Directions (2020–2024):

Recent studies have focused on integrating machine learning (ML) and artificial intelligence (AI) with traditional 3D modelling techniques. For example, Zhao et al. (2021) demonstrated the use of AI in automating data interpolation, significantly enhancing the accuracy of 3D models where borehole data is sparse. These models can now predict missing data more effectively and provide higher-resolution representations of aquifer structures. The coupling of 3D models with real-time monitoring systems has also become a major trend. Fienen et al. (2020) showcased the use of sensor data integrated with 3D models for adaptive groundwater management, allowing authorities to respond quickly to changes in aquifer conditions, such as sudden drops in groundwater levels. Studies up to 2024, such as Rahman et al. (2023), have focused on sustainable groundwater management by using 3D models to evaluate the long-term impacts of water extraction, agricultural practices, and climate variability. These models are increasingly used for policy development and environmental impact assessments, particularly in water scarcity regions. Moreover, advances in cloud computing and data integration platforms have made 3D aquifer models more accessible and scalable. Tools like Leapfrog, GOCAD, and Petrel now offer cloud-based modelling environments, enabling large-scale, collaborative groundwater studies.

2.2.2 Studies related to water Aquifer Web Application:

Studies related to 3D aquifer web applications focus on developing user-friendly platforms that integrate real-time data and 3D modeling for groundwater management and analysis. Recent advancements emphasize the use of web applications to provide access to aquifer data for decision-makers, researchers, and the public. For example, Fienen et al. (2020) demonstrated web apps that connect to real-time groundwater monitoring systems, allowing users to visualize 3D aquifer models, track water levels, and predict future changes. Other studies, such as Rahman et al. (2023), explored the use of cloud-based platforms integrated with mobile applications to support field data collection, model simulations, and water resource management in remote areas, particularly where access to traditional desktop-based modeling tools is limited. These web applications are increasingly used to facilitate data sharing, enhance groundwater management strategies, and improve public awareness of water resources.

2.3 OBSERVATIONS FROM LITERATURE SURVEY:

- Borehole data remains the primary source for subsurface geological information, including lithology, porosity, permeability, and groundwater levels. It is critical for constructing accurate 3D aquifer models.

- Geostatistical methods like Kriging, Co-Kriging, and Inverse Distance Weighting (IDW) are commonly used to interpolate data between boreholes, which are often spaced widely apart. This improves the spatial resolution of the 3D models.

- Software tools such as MODFLOW, GMS, Leapfrog, and Petrel are widely employed in creating 3D models of aquifers. These tools integrate borehole data with geological and hydrological information to simulate groundwater flow and predict future conditions.

- One of the key challenges observed in the literature is the sparse distribution of boreholes, which limits the accuracy of the models, especially in rural and less-developed areas. This necessitates advanced interpolation and uncertainty analysis techniques.

- Geological heterogeneity, where aquifer properties (e.g., porosity, permeability) vary over short distances, makes 3D modeling challenging. Proper representation of such complexity requires robust data and modeling techniques.

- Recent studies highlight the integration of real-time monitoring data (e.g., groundwater levels and quality) with 3D aquifer models, allowing dynamic simulations and adaptive groundwater management. This is increasingly relevant for decision-making in water-scarce regions

- 3D aquifer models are extensively used for groundwater management, contamination risk assessment, and environmental impact studies. These models aid in sustainable water extraction and in understanding the impacts of human activities like agriculture and mining.

- Recent research shows the use of AI and machine learning techniques to automate data interpolation, handle large datasets, and improve the accuracy of 3D models. These innovations help mitigate issues related to data gaps and model uncertainties.

- There is a growing trend of developing web and cloud-based applications that make 3D aquifer models more accessible to field researchers, policymakers, and the public. This helps in real-time decision-making and public awareness regarding water resources.

- The use of 3D aquifer models is increasingly linked to sustainable groundwater management practices, especially in the context of climate change and water scarcity. Studies project the continued growth of models that integrate climate data and real-time monitoring systems for improved water resource planning.

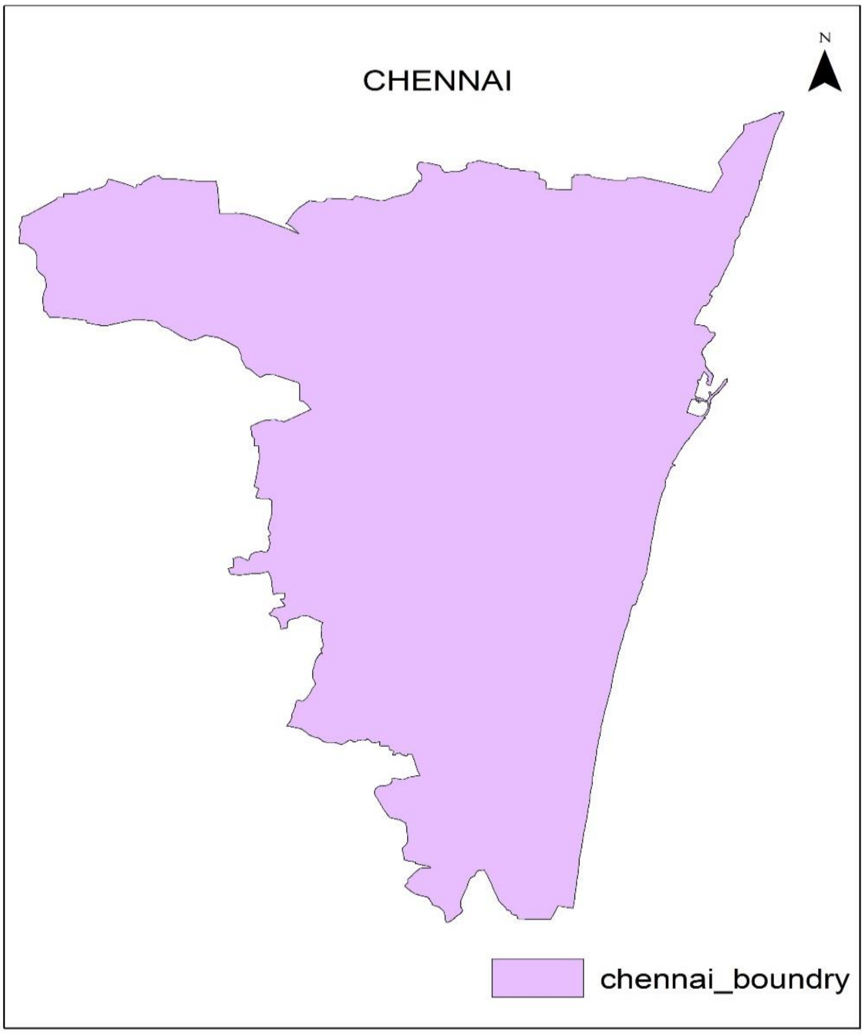
CHAPTER 3

STUDY AREA AND DATA DESCRIPTION

3.1 GENERAL

This chapter briefs about the study area, data sources and the software used.

3.2 STUDY AREA



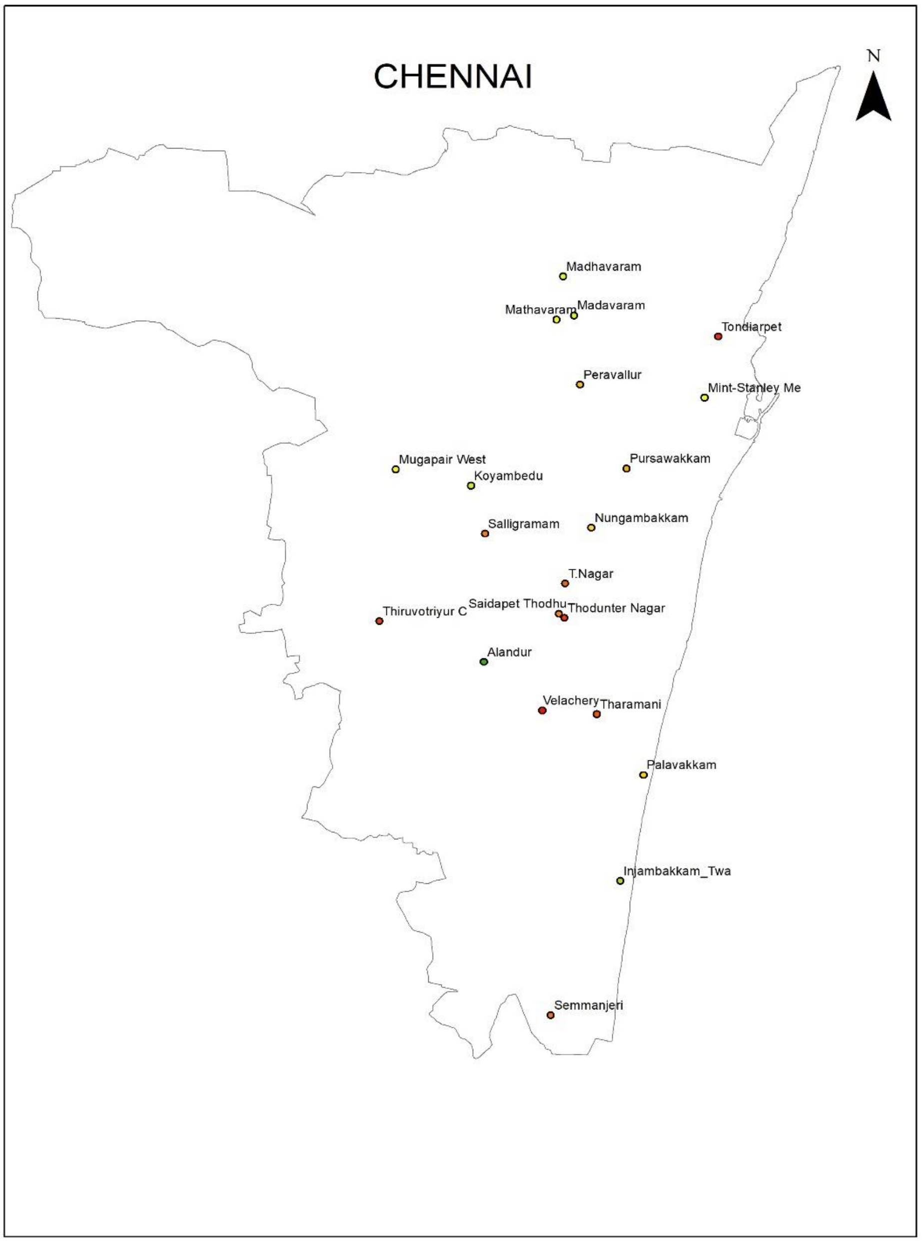
3.3 DATA SOURCE

3.3.1 DATA PROVIDER

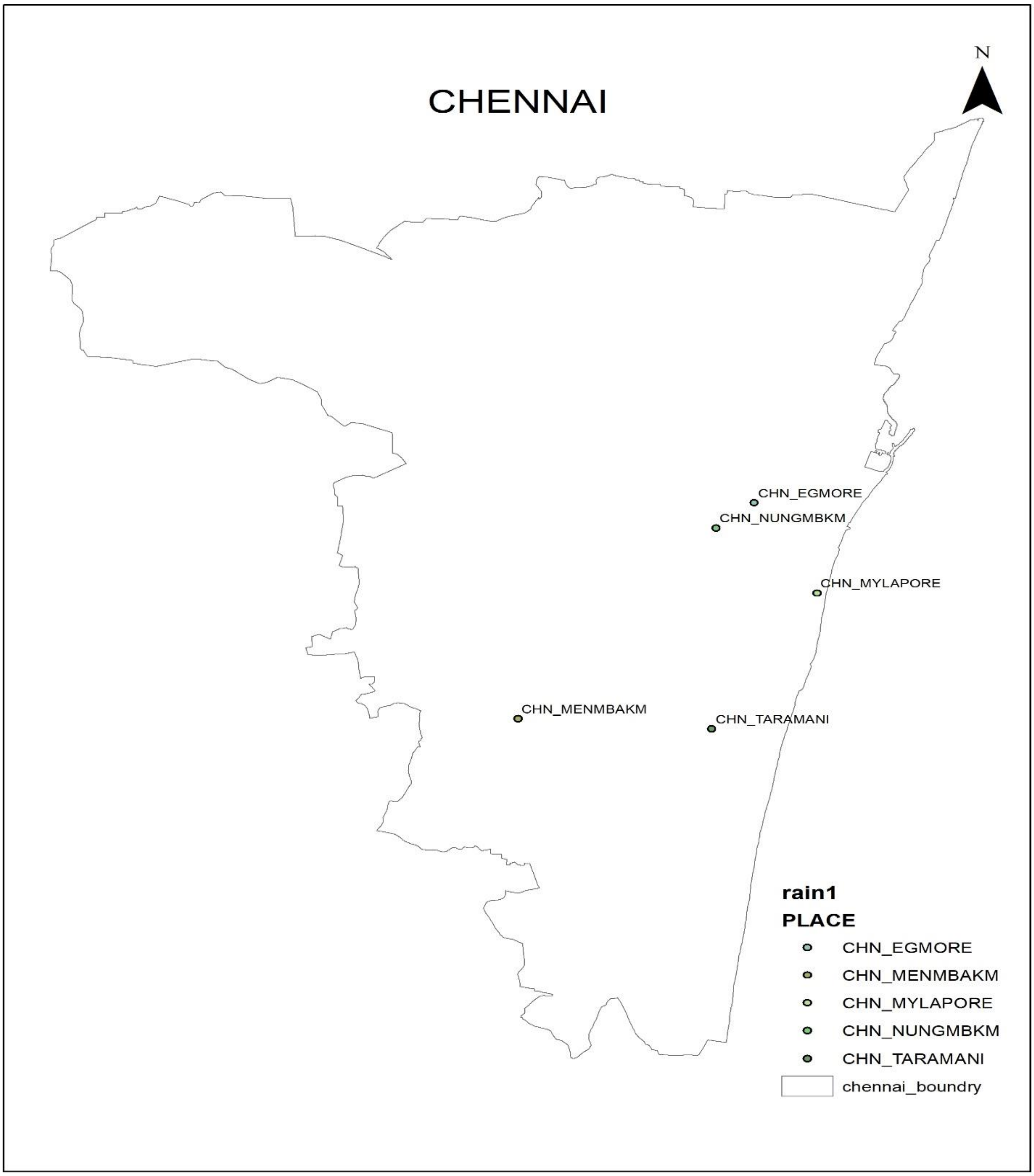
The data source for borewell data and rainfall data is obtained from the State Ground and Surface Water Resources Data Centre at Tharamani, Chennai.

The DEM data is collected for Chennai from the website of USGS Earth Explorer.

BOREHOLE DATA CHENNAI



RAINFALL DATA



3.3.2 SOFTWARE USED:

ArcGIS:

ArcGIS is a powerful geographic information system (GIS) software developed by Esri, used for creating, analyzing, and managing spatial data. It provides tools for mapping and spatial reasoning, allowing users to visualize geographic information, identify patterns, and make data-driven decisions. ArcGIS supports a variety of data types, such as satellite imagery, terrain models, and geospatial databases, making it highly versatile for applications in urban planning, environmental management, public safety, transportation, and more. Its platform includes desktop, server, and web-based versions, with capabilities for advanced spatial analysis, geocoding, and the development of interactive maps. ArcGIS integrates with other systems and supports real-time data, enabling organizations to optimize their operations using geographic insights.

VISUAL STUDIO CODE:

Visual Studio Code, also commonly referred to as VS Code, is an integrated development environment by Microsoft for Windows, Linux, macOS, and web browsers. Visual Studio Code is a free powerful

The tools in VS code are:

Editor – Where you write code

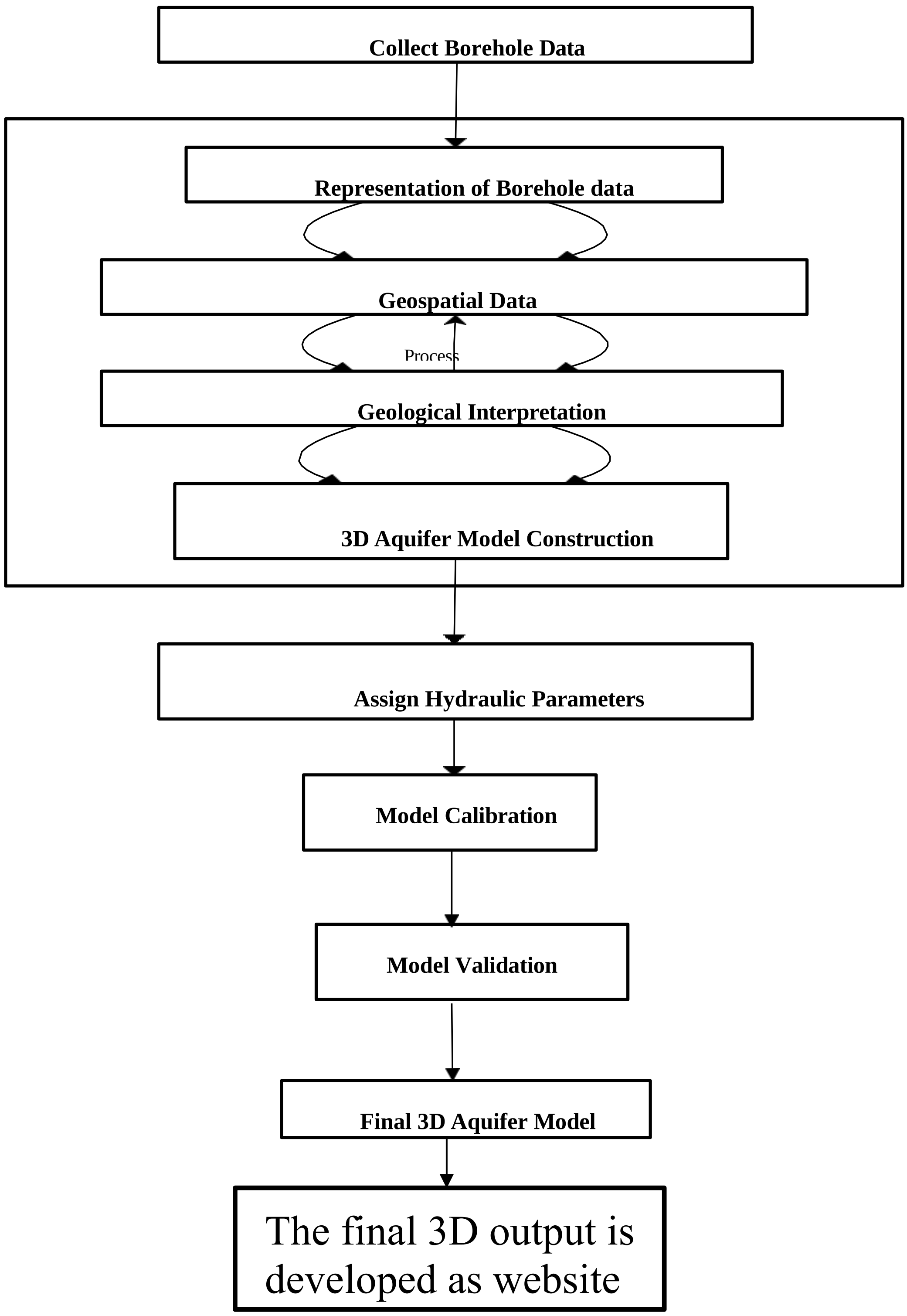
Side Bar – Navigating files and project structure

Status Bar - Displaying information like the Current Git branch

CHAPTER 4

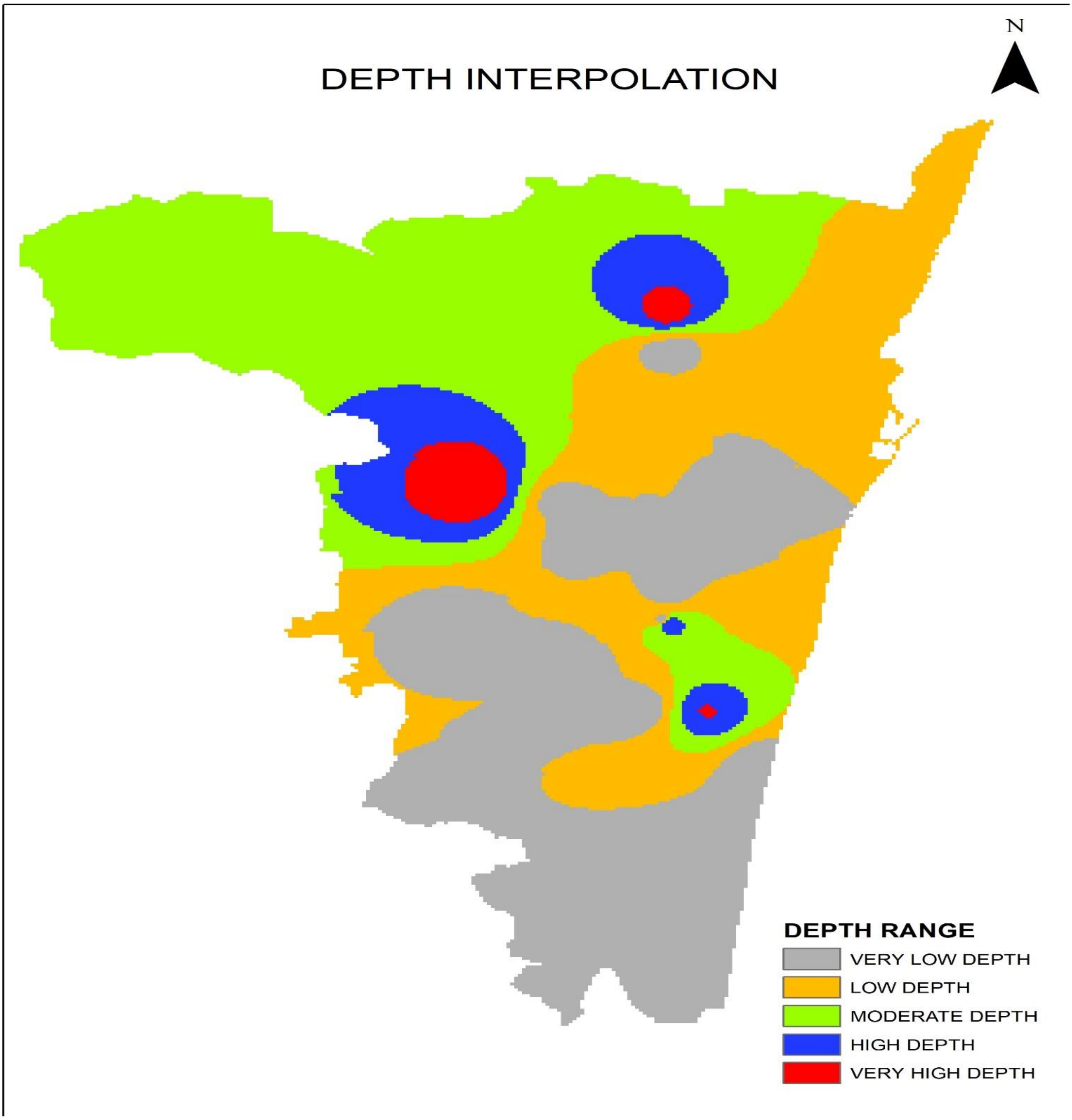
METHODOLOGY

4.1 METHODOLOGY



INVERSE DISTANCE WEIGHTING (IDW) INTERPOLATION:

Inverse distance weighting (**IDW**) is a type of deterministic method for multivariate interpolation with a known scattered set of points. The assigned values to unknown points are calculated with a weighted average of the values available at the known points.

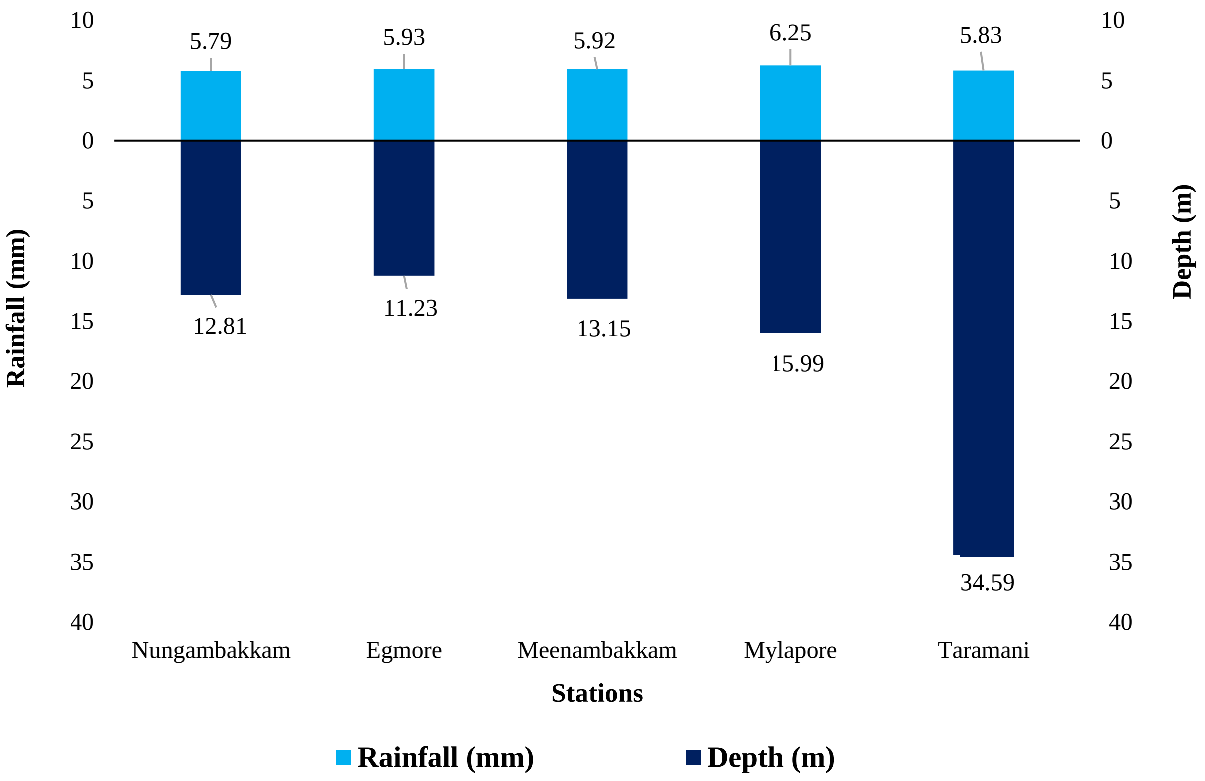


CHAPTER 5

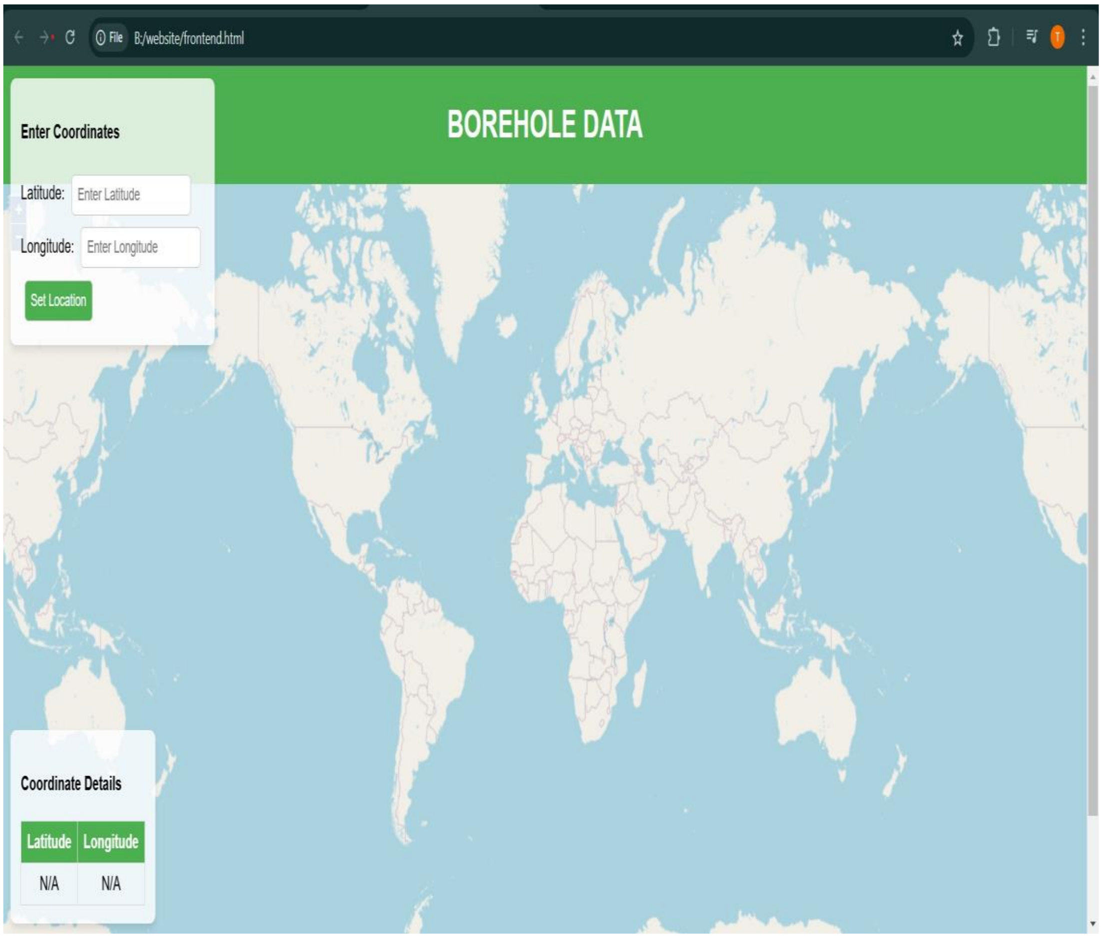
RESULTS

1) The water level for the user input geographic location is estimated and displayed using the developed 3D aquifer model mobile application.

2) The Water table depth and its presence are visualized using a 3D model and the groundwater is studied



WEBSITE MODEL



CHAPTER 6

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