CHAPTER-1

INTRODUCTION

1.1 Geophysical Inverse Problems and Genetic Algorithm (GA)

1.1.1 Geophysical Inverse Problem

Generally, all geophysical inverse problems are nonlinear in nature (Sen and Stoffa, 1995). So it may be more beneficial to use nonlinear techniques for solving nonlinear problems. Especially, the inversion of DC resistivity sounding is complex and nonlinear in nature. In this problem, the subsurface layer parameters, resistivity, and thickness of layers are obtained from an apparent resistivity data set measured on the surface of the earth. This is obtained in two steps. The first step is to establish a clear and appropriate mathematical relationship between apparent resistivity and subsurface layer parameters. This is called forward modeling. In the second step, an appropriate technique is used to obtain subsurface parameters from apparent resistivity data by using developed mathematical formulae in step-1. This is called inverse modeling. There are two broadly used methods to perform inverse modeling. One is the indirect method and the other is the direct method. The indirect method consists of curve matching methods such as partial curve matching etc. But due to less reliable results, time taking procedures, user bias, and other problems, this method is not used in practice nowadays. Direct methods use minimization of misfit error between observed VES data and synthetic VES data. This method consists of quasilinear techniques, nonlinear global optimization techniques (i.e. Simulated Annealing and Genetic Algorithms, etc.), and artificial neural networks (Jha et al., 2008).

In quasilinear inversion techniques, one problem is to guess good initial solutions which should be close to the actual solution and another problem is the amplification of noise in data. So, nonlinear global optimization techniques may be used to avoid these problems. Noise amplification is removed in nonlinear techniques but simulated annealing still requires a suitable initial guess solution otherwise the possibility of trapping in local optima increases. So Genetic Algorithm may be a better option to choose as a nonlinear inversion technique that works with a population of models (some possible solutions) choosing randomly from search space (model space consisting of all possible solutions).

1.1.2 Genetic Algorithm (GA)

Genetic algorithm (GA) is a powerful computational technique that is based on principles of natural selection proposed by Darwin to solve a wide variety of problems. In general, an arbitrarily generated initial population of chromosomes (each chromosome corresponds to a set of model parameters) competes through an objective function for the estimation of reproduction slots in the subsequent generation. Then crossover and 'mutation operators are performed to the fittest strings (the fittest strings represent the models, that give the least misfit between synthetic and real data) to "mix" the characters of the best models and find an adequate set of model parameters. The early establishment of the genetic algorithm is attributed to John Holland (1975), and his research team at the University of Michigan. The early objective of Holland's study was oriented more toward the modeling of natural systems rather than problem-solving, and his work has brought a new indulgence of natural selection from an artificial point of view.

Genetic Algorithms (GAs) belong to a broader family of algorithms known as evolutionary algorithms, which also include evolutionary programming (Fogel, 1962; Back, 1996; De Groot-Hedlin and Vernon, 1998) and evolutionary Strategy. The notable distinctions between genetic algorithms and their related methods are as follows:

1. Instead of using a real-valued representation, GAs employs a binary representation.
2. GAs utilizes crossover-based recombination.
3. GAs does not possess self-adaptation.

The binary representation enables the use of binary operators such as simple crossover, inversion, and bitwise mutation. Due to the absence of self-adaptation, GAs align more closely with evolutionary algorithms that follow Darwinian evolution, while other methods embrace the Lamarckian proposed evolution hypothesis.

Genetic algorithms can be applied to solve various problems, but they particularly excel in tackling complex nonlinear problems. Three commonly employed methods for solving such problems are Quasi-Newton (calculus-based) methods that utilize gradient information, grid search methods that thoroughly explore the solution space, and stochastic search methods. Similar to simulated annealing algorithms, genetic algorithms fall into the category of stochastic or "randomized" search (Aarts, 1989; Kirkpatrick, 1998). Genetic algorithms are highly exploitative, leveraging a significant amount of comparable information to optimize their search more efficiently. However, unlike calculus-based algorithms that are "greedy," genetic algorithms are capable of finding the global optimum even in the presence of local optima, discontinuities, and noise. This represents a significant advantage of genetic algorithms for geophysical problems. When dealing with nonlinear inverse problems, there is always a trade-off between efficiency and exploration in finding solutions. Genetic algorithms strike a compromise that applies to a wide range of problems.

Details of the implementation of Genetic algorithms for the inversion of 1-D Geoelectrical data have been described in chapter-5.

1.2 Global Water Scenario

The most essential and widely-distributed element in nature is water. It comes in various forms, including snow, moisture in the air, surface water, and underground water. Water's characteristics vary depending on where it occurs. Gleick discussed global water distribution on Earth in 1993. Figure 1.1 shows the percentages of all the different types of water that are present on Earth. According to the first bar diagram in Figure 1.1, just 2.5% of the water on Earth is freshwater, and only 1.2% of that freshwater is available as surface water (as shown in the middle bar diagram of Figure 1.1). About 69% of fresh water is trapped in permafrost and ice, while another 20.9% is found in lakes and 0.49% is present as rivers (as depicted in the last bar diagram of Figure 1.1.).

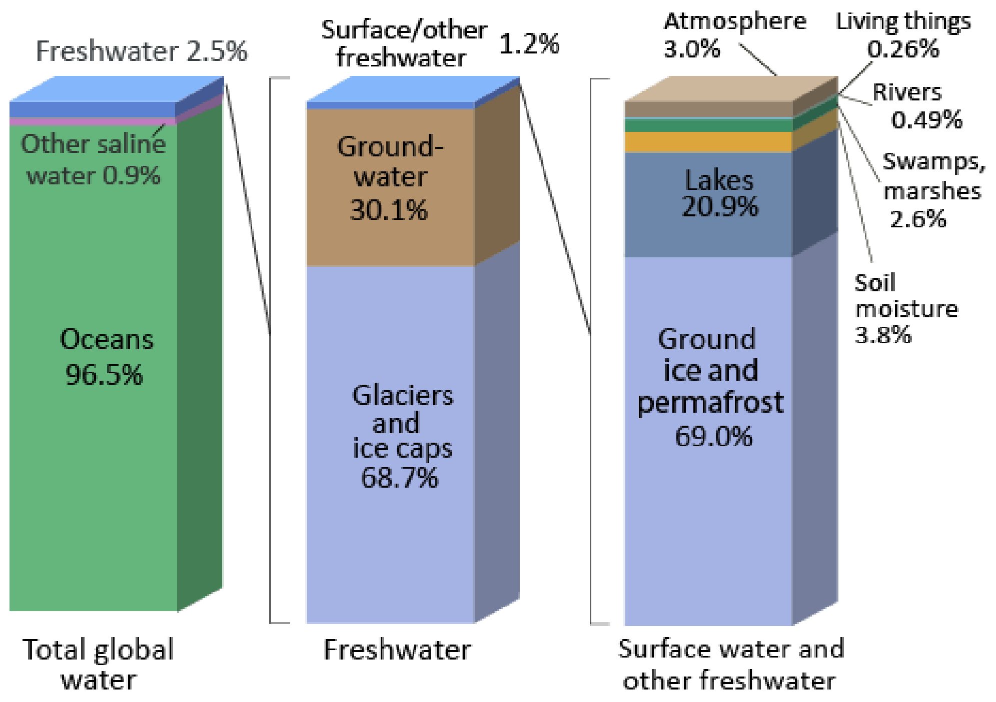


Figure 1.1 Distribution of Earth's water (Gleick, 1993).

Only 3% of the world's water, which is used for human activities, is freshwater, and two-thirds of that is frozen into polar ice caps, glaciers, and icebergs. The remaining 1% of the world's water supply is fresh water available as either surface water or groundwater. Nowadays water contamination is enhanced due to increasing population and rapid industrialization, which has two adverse effects. First, the need for water treatment before use, because contamination restricts water use for various purposes and drives up costs. Secondly, the biological lives, dependent on water, are infected by various diseases requiring expensive treatment. In most cases, groundwater is safer and more reliable than surface water. This is partly because surface water is more frequently exposed to industrial pollution than groundwater. Groundwater contamination is not frequent, but once it is polluted removing contamination from groundwater is a costly process. Groundwater contaminants might be any easily soluble chemicals that penetrate the soil.

1.3 Groundwater Occurrence

Bowen (1928); explained the occurrence of groundwater in the geological formation. Igneous and metamorphic rocks underlie about 20% of the globe's land surface. The rest is sedimentary rocks, as shown in Figure 1.2. The groundwater occurs in the form of aquifers, the geological formation which can collect, store and transmit a significant amount of groundwater, e.g., sands, pebbles, gravels, fractures in hard rocks, and cavernous in limestone are good aquifers. Aquicludes are the geological formation that contain some groundwater but cannot transmit it, e.g., clay and shale, and aquifuges, is the formation that neither transmit nor store ground water, e.g., massive granites. The aquifer is of two types confined and unconfined. The confined aquifer is separated from the atmosphere by an impermeable layer as the unconfined one is in direct contact with the atmosphere through open spaces in the porous material. Krishnamurthy et al. (2008); described the distribution of hard rock on the earth's crust. A formation having no primary or negligible porosity and predominantly secondary porosity is referred to as hard rock. Hard rock terrain comprises a great variety of igneous and metamorphic rocks. Consolidated sedimentary rocks like sandstone and dense limestone are also called hard rocks. Hard rock covers about two-thirds of the earth's crust.

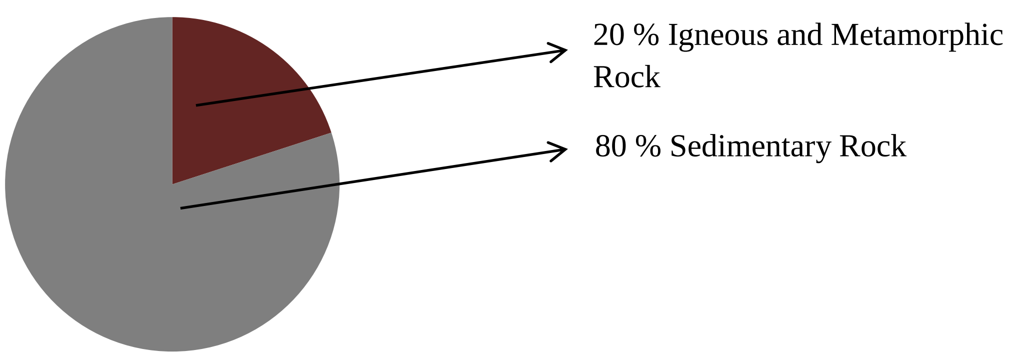


Figure 1.2 Distribution of groundwater (Bowen, 1928)

The typical geological structure found in hard rock regions is characterized by the presence of a hard rock bedrock or basement covered by a weathered overburden of varying thickness. The weathered material that makes up the overburden is very porous and holds a significant amount of water. Due to its comparatively large clay content, it also has limited permeability (Baker, 2001).

Fractures within a geological medium play a significant role in determining its hydrogeological properties. They have the potential to substantially increase the hydraulic conductivity of impermeable rocks or soils, particularly in the dominant directions of the fractures. Consequently, understanding the presence, extent, intensity, and orientation of fractures is crucial for any hydraulic engineering project. Boreholes that intersect fractures, without being covered by thick saturated weathered material, are not likely to yield high quantities of water in the long run. Conversely, boreholes that penetrate saturated weathered material but do not encounter fractures in the underlying bedrock are more likely to provide a sufficient water supply (Louis et al., 2002).

The bedrock itself is typically fresh but prone to frequent fracturing, resulting in high permeability. However, as fractures do not constitute a significant volume of the rock, the fractured basement exhibits low porosity. Therefore, an ideal borehole that offers sustained high yields is one that penetrates a substantial thickness of weathered overburden, which acts as a reservoir, while also intersecting fractures in the underlying bedrock. These fractures serve as efficient pathways for rapid water transport (Krishnamurthy et al., 2008).

According to NRSA (2008); India is a gigantic nation with various geology, topography, and climate. The typical rock formations range in age from Achaean to Recent, varied significantly in composition and structure, and likewise, significant variations in landforms can be observed. They range from rugged mountainous terrains to flat river valley alluvial plains, coastal regions, and aeolian deserts. Similar regional variations may be seen in the rainfall pattern. Runoff and groundwater recharge are largely controlled by topography and rainfall. Based on geology, rainfall, and geomorphology, the distribution of groundwater is not uniform throughout the country and varies significantly from place to place. The "hard rocks," or sedimentary rocks from the Precambrian period, and crystalline, volcanic, and carbonate rocks, comprise about 68 percent of India's total geographical area. Groundwater in hard rock occurs mainly at the top weathered zone and greater depths within fractures and joints.

1.4 Groundwater Scenario of India.

According to the census of India on 31st March 2011, India, which has a total area of 3,287,590 km^2, is the seventh largest country in the world and the second most populated (1,210,193,422 persons) country in the world after China (1,347,350,000 persons).In 1947, India gained independence and made its long-term objective to build its economy. At that time, agricultural development had given the highest priority, not only because food production was to be substantially increased and had to keep pace with the increasing population, but also because it was essential to build up the gross roots economy of a country because more than 80 % of whose people depend on agriculture or agricultural based activities for their livelihood and occupation. Agriculture primarily uses groundwater for their irrigation. Thus the nation's economy and its development are directly dependent on groundwater.

Over time, there has been a significant increase in the demand for freshwater resources due to factors such as rapid population growth, uneven distribution of water resources in terms of space and time, economic development, and climate change. Consequently, water scarcity has become a serious issue in many parts of the world (Selvam et al., 2015; Jasrotia et al., 2016).

In India, groundwater serves as a primary source of domestic water for 50% of the urban population and 90% of the rural population. The agricultural sector in India consumes more than 70% of the country's groundwater (GEC, 2015). Groundwater, being a dynamic resource, is influenced by various factors such as geomorphology, lithology, topography, slope, precipitation, soil, drainage pattern, land use/land cover (LULC), and hydrological conditions in a particular region (Mukherjee et al., 2009; Singh et al., 2011).In the past two decades, several regions in India have experienced a significant decline in groundwater levels. According to a report by NITI Aayog (2018), mismanagement and inadequate availability of freshwater have led to high water stress for six million people in the country.

(a) Availability of Groundwater in India

In India, groundwater recharge mainly relies on rainfall, and additional recharge occurs through surface water bodies, canals, and irrigated agricultural land. The upper unconfined aquifer, which serves as both the active recharge zone and the source of replenishable groundwater, experiences a significant portion of groundwater extraction. To estimate the country's replenishable groundwater resource within this active recharge zone, the Central Ground Water Board collaborated with State Government authorities. The assessment was conducted using Block/Mandal/Taluka/ Watershed as units and following the guidelines provided by the Ground Water Estimation Committee (GEC, 1997). According to the latest evaluation, the annual replenishable groundwater resource within this zone is 432 billion cubic meters (BCM). Out of this, 399 BCM is considered available for development across various uses, while 34 BCM has been allocated for natural discharge to maintain spring, river, and stream flows during the non-monsoon period (Central Ground Water Board, 2006).

(b) Extraction and utilization of Groundwater in India

The groundwater drafts consist of two main components: groundwater extraction for various purposes and evapotranspiration from areas with shallow water tables. The irrigation sector remains the primary user of groundwater. Based on estimates provided by the Central Ground Water Board (2006), the total groundwater draft in the country amounts to 231 BCM. Out of this, approximately 92 percent is utilized for irrigation, while the remaining 8 percent is allocated for domestic and industrial uses. Consequently, the overall stage of groundwater development, calculated by comparing groundwater drafts to the complete replenishable resources, stands at around 58 percent for the entire country. However, it's important to note that groundwater development levels vary significantly across regions, resulting in a highly uneven distribution throughout the country.

(c) Categorization of Ground Water Assessment Units in India

Based on the guidelines provided by the Groundwater Estimation Committee (GEC), the assessment units have been categorized based on the stage of groundwater development and the long-term declining trend of groundwater levels. The assessment reveals that out of the 5723 units assessed nationwide, 839 units (14.7%) have been classified as "Overexploited." This categorization is assigned to units where groundwater development has been observed to exceed 100% of the natural replenishment.

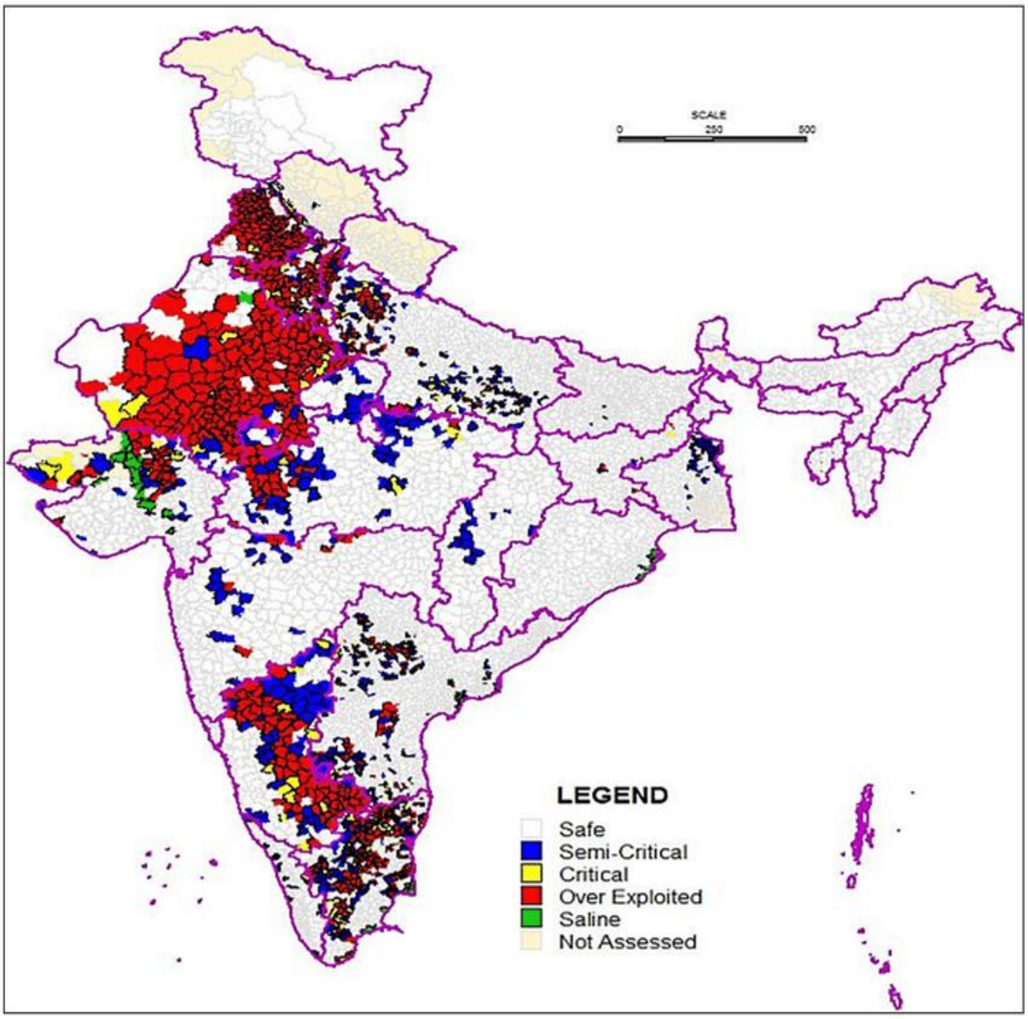


Figure 1.3 Geographical distributions of the various categories of assessment units. (Source: Groundwater scenario in India, CGWB-2014)

Two hundred twenty-six assessment units (3.9%) were classified as "Critical" because groundwater development in these units was between 90 to 100% of the usable resources. Five hundred fifty assessment units have been labeled "Semi-Critical" because they exhibit long-term declines in water levels during the pre- or post-monsoon season and the groundwater development stage varies between 70 and 100% and Four thousand seventy-eight assessment units have been labeled "Safe" because the groundwater development stage is less than 70%. Due to the salinity of the groundwater in the aquifers in the replenishable zone, Thirty assessment units have been excluded from the assessment. The geographic distribution of various assessment units in India is shown in Figure 1.3.

1.5 Groundwater Scenario of Singrauli District

Groundwater serves as the main source of irrigation in the district. The subsurface of the district contains both hard rocks and alluvium. The presence of different types of rocks influences the availability and movement of groundwater in different formations. The weathered and fractured zones located at shallow depths play a significant role in facilitating the movement and storage of groundwater.

Groundwater in Archaean rocks is found in joints, fractured planes, and primarily within the weathered zone beneath the water table. The occurrence and movement of groundwater are influenced by the degree of weathering and the size and connectivity of the joints. Tube wells can be effectively maintained, especially in areas where there is extensive fracturing and weathering. The shallow weathered, jointed, and fractured zones of these rock types exhibit groundwater under phreatic conditions. The thickness of the weathered zone typically ranges from 7 to 18 meters below ground level (mbgl) in the region occupied by Archaean rocks, which include granite, schist, phyllites, gneisses, and quartzites. Dug wells in the area have varying depths, ranging from 3 to 21 mbgl, and the water levels in these wells vary from 2.41 to 16.70 mbgl (CGWB North Central Region Bhopal, 2013).

In the region characterized by Archean formation, dug wells can be constructed with significant dimensions, typically ranging from several decimeters in width and penetrating the entire depth of the fractured and weathered zone within the formation. These wells can reach depths varying from 6 to 9 meters and 15 to 20 meters, effectively accessing the complete thickness of the fractured and weathered zone (CGWB North Central Region Bhopal, 2013).

Within the Vindhyan formation, the presence of sandstone and limestone at lower elevations and with well-established joints results in the availability of groundwater in varying quantities. The limestone found in the Semri group exhibits interconnected solution openings, contributing to the occurrence of groundwater in limited space. Dug wells in the region have depths ranging from 3.72 to 21.50 meters below ground level (mbgl), while the water level typically falls within the range of 6 to 24 mbgl (CGWB North Central Region Bhopal, 2013).

In the northern part of the district, within the lower Gondwana Formation, the Talchir Formation is present. Wells drilled in these formations penetrate the Talchir Sandstone, and their yields range from 200 to 400 cubic meters per day (CGWB North Central Region Bhopal, 2013).

Moving to the southern section of the area, the upper Gondwana formations consist mainly of sandstones and clays, creating a hilly terrain. In these upper

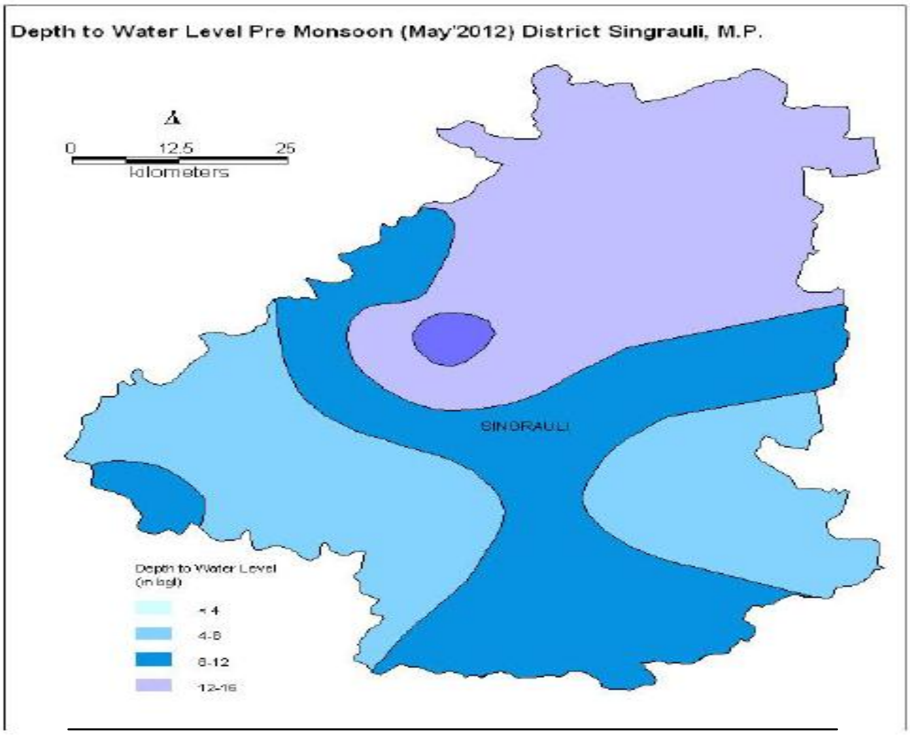
Gondwana formations, the depth of the water table ranges from 3.15 to 11.32 meters below ground level (mbgl). During the summer, wells in this formation yield a satisfactory discharge of 100 to 150 cubic meters per day. To achieve this, wells with a larger diameter between 5 to 10 meters and a depth of 15 to 20 meters are constructed, that fully penetrate the weathered, jointed, and fractured zones.

The Alluvium formation which is primarily composed of fine sands with pebbles and clay, is found in a small patch in the northern part of the district. Groundwater in the Alluvium occurs under water table conditions. The depth of wells in this area varies between 10 to 25 meters. Due to its abundance, the water table slopes towards the Son River and its tributaries.

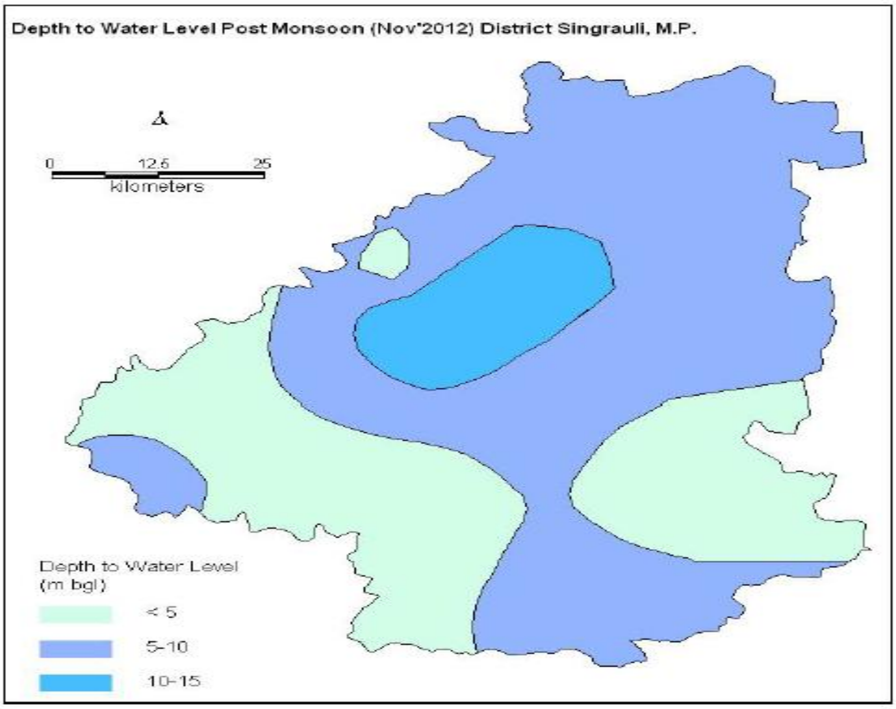
1.5.1 Depth of Groundwater level

Pre-Monsoon (May 2012) - The district's pre-monsoon water level depth ranges from 4.13 mbgl to 18.50 mbgl, as shown in Figure 1.4(CGWB NCR Bhopal, 2013). During the pre-monsoon, the majority of the district's water level is in the range of 8.12 mbgl.

Post-Monsoon (Nov.2012) - During the post-monsoon period, the water level varies from 2.94 mbgl to 15.17mbgl, as shown in Figure 1.4. In the central part of the district, the water level lies between 5 and 10 mbgl(CGWB NCR Bhopal, 2013).



(a)



(b)

Figure 1.4 Spatial distribution of depth to Groundwater level (a) During Pre-Monsoon, May 2012 (b) During Post-Monsoon, Nov 2012

(Source: District Groundwater information booklet, CGWB North Central Region Bhopal, 2013)

1.6 Controlling factors of groundwater

1.6.1 Precipitation

Todd (1980) discussed the controlling factor of groundwater related to precipitation. Groundwater is recharged through the hydrological cycle. The hydrological cycle is a simplified description of how water moves from one place to another and how much is transported. The water in the atmosphere condenses to form clouds and then falls as rain or snow. The components of the hydrological cycle can be summarized as precipitation (rainfall, snowfall, hail, dew, sleet, drizzle, fog, etc.), runoff (surface runoff, subsurface runoff, or interflow & groundwater runoff or base flow), evaporation, transpiration, infiltration, percolation, seepage, interception, depression storage and moisture storage over & below the land surface.

1.6.2 Evapotranspiration

Solar energy drives the hydrological cycle; gravity and other forces also play essential roles. Evapotranspiration is controlled by temperature, wind speed, humidity, atmospheric pressure, and vegetation. Besides the actual measurement of evapotranspiration, empirical relationships have also evolved to compute it from the constitutive parameters. These basic parameters should be quantified, to the extent possible, for a reliable estimation of the actual evapotranspiration (Rao, 1992).

1.6.3 Geological units

Rao (1992); described the controlling factor of groundwater related to geological units. The actual storage and transmission of groundwater occur in a geological formation, which should be studied to assess groundwater potential in an area. The relevant aspects are the following:

- Nature and type of rocks and their other physical characteristics, viz., extent, attitudes, structures, stratigraphy, and lithology.
- Thickness and depth range of weathered zones, aperture, density, and extent of fracture in hard rocks.
- Surface and groundwater divide.
- Recharge and discharge areas.
- Aquifer characteristics.
    - i. Boundary conditions (horizontal and vertical), magnitude, and direction of interflows between different aquifer zones (interconnections between weathered and fractured zones in hard rock formations).
    - ii. Yield ranges of the existing wells, if any present in the area.
    - iii. Characteristic hydrogeologic parameters viz., transmissivity and storativity/ specific yield.

1.6.4 Hydrogeomorphological units

According to NRSA (2008), the key factor influencing groundwater is the hydrogeomorphological units. These units consist of combined lithology, landform, structure, and recharge conditions that are distinct and unique. They are considered three-dimensional homogeneous entities with respect to hydrogeological properties and recharge conditions. Remote sensing data plays a significant role in accurately analyzing, identifying, and delineating these hydrogeomorphological features on land.

By combining remote sensing data with sufficient ground data, the hydrological characteristics of these units can be effectively deciphered

1.7 Role of Specific investigations methods for Groundwater Exploration

The primary emphasis in groundwater exploration lies in conducting specific investigations at particular sites. Exploration at each site involves multiple investigations, which can be categorized into two distinct groups as follows:

1.7.1 Detailed field investigation

NRSA (1990 & 2008) report on detailed field investigation for further study. Information on the variables, such as rock types, geological structures, landforms, and recharge conditions that govern groundwater's occurrence and distribution, can be gathered by studying existing geological, hydrological, and meteorological data. When these four parameters are adequately understood, it is possible to visualize the region's gross aquifer characteristics to understand the groundwater regime better. So further Geophysical surveys are planned based on the analysis of these data.

1.7.2 Geophysical investigation

Hubbard (2011); discussed the advantage and disadvantages of geophysical surveys. Geophysical surveys can help to identify local hydrological characteristics or determine the most suitable places to drill boreholes. Additionally, it has the benefit of providing vast amounts of spatial information on the subsurface in an invasive manner and with a higher resolution than the traditional approaches. Geophysical surveys, despite being more expensive than hydrogeological investigations, can significantly reduce much more costly infructuous drilling operations, particularly in areas of hard rock formations. However, they have the disadvantage that they provide only indirect information regarding the subsurface hydrological properties that are relevant to subsurface flow and transport.

Geophysical exploration includes the measurement and analysis of signals or data from induced or natural physical phenomena resulting from changes in one or more physical properties of a subsurface formation. These signals or data are collected from various platforms (such as from satellites and aircraft, at the earth's ground surface, and within and between boreholes). Further, these signals or data are appropriately interpreted to evaluate geological information such as sub-surface features as they may have good potential for groundwater or be a good indicator of the aquifer. Under favorable conditions, these methods have the potential to provide valuable information, although indirectly, about some characteristic parameters. This information can then assist in quantifying the groundwater potential within a survey area. Various geophysical method used in groundwater exploration relies on different physical properties such as electrical conductivity, magnetic susceptibility, density, elasticity, and radioactivity (Telford et al., 1990; Milson, 2003; Knodell et al., 2007; Lowrie, 2007).

Rao (1992); explained the geophysical survey for groundwater exploration. Frequently used geophysical surveying methods are gravimetric, magnetic, electrical, and seismic. The first two methods depend on measuring the spatial variations in the intensity and direction of natural fields of gravity and magnetism. The latter two depend on the electrical and mechanical excitations of shallow regions of the earth's crust and the measurement of spatially variant responses of subsurface materials to this excitation. The gravimetric and magnetic methods have relatively limited applicability in groundwater exploration since these methods possibly give information only in some cases about the favorable structure for groundwater accumulation and do not directly indicate groundwater occurrence. In recent years, methods based on radioactivity measurements such as helium and radon detectors have also been in vogue, particularly for the direction of fractures in hard rocks. The other exploration method that has recently found acceptance is the nuclear magnetic resonance, which is used to measure rock porosity, estimate permeability from pore size distribution, and identify pore fluid.

The gravity method uses groundwater exploration to identify favorable geological conditions. The technique is most successful in tracing the course of buried channels. The prospecting by magnetic method gives indirect information to identify the geotectonic structures like faults, dykes, etc., which show the favorable condition for groundwater occurrence (Telford et al., 1990).

To map lateral and vertical variations in conductivity, electromagnetic methods are applied with some spectacular instances of its application in groundwater investigations. Electromagnetic techniques provide several benefits that lead to higher resolution and more practical applications despite comparable results to electrical methods (Lowrie, 2007).

The resistivity method is the most popular of all the geophysical techniques concerning groundwater exploration. This method has made phenomenal progress in its utilization over the past decades. The electrical resistivity survey has become an indispensable tool for groundwater exploration because of the contrast between the physical properties between dry, non-water-bearing formations and water-saturated formations. Thus the resistivity method helps in furnishing information regarding the depth to the water-bearing zone, depth to bedrock, the existence of fissure, fracture and fault zones, the existence of aquifer in a sedimentary basin, structural and stratigraphic conditions, salt water-freshwater interface, and permeability of the aquifer and also in the estimation of hydraulic conductivity of aquifer (Yadav, 1995).

The seismic method is based on the principle that seismic waves are reflected or refracted at any interface where a change in the seismic wave velocity occurs. Generally, the various seismic methods used are based on micro delays or amplitude attenuation analysis. The seismic refraction method is used for proper shallow investigation in hard rock areas. This technique considers the velocity contrast of the acoustic waves between the water-bearing formation and the adjacent strata (Rao, 1992).

1.7.3 Subsurface investigation

As documented, NRSA (2008) also reported subsurface investigation for groundwater exploration. Even though subsurface studies are costly, they cannot be avoided if the information on groundwater quality is desired. Small diameter holes are drilled to gather data for the geological substrata and groundwater level. The outcomes of the drilling and sampling of materials enable the establishment of a litho-log with information from several strata. Additionally, groundwater samples can be collected for chemical analysis. Geophysical logs, such as spontaneous potential, resistivity, acoustic, and temperature logs, may be used depending on the geological conditions.

1.8 Scope of the present study and problem identification

Geophysical methods play a crucial role in the exploration of groundwater. The primary objective of these methods is to accurately and comprehensively understand the hidden subsurface hydrogeological conditions. The effectiveness of geophysical techniques relies on the contrast or anomaly between the physical properties of the target and the surrounding environment. A stronger contrast or anomaly results in a more pronounced geophysical response, facilitating better identification. The feasibility of utilizing geophysical methods is rooted in the fact that disintegrated zones exhibit reduced magnetic susceptibility, density, electrical resistivity, and seismic velocity compared to the massive host rocks. Consequently, the efficiency of any geophysical technique lies in its capability to detect and resolve hidden subsurface hydrogeological variations or heterogeneities. Thus, a judicious application or integration of techniques is crucial for successful groundwater exploration, both in terms of technological advancements and economic viability. While the hydrological potential of groundwater is generally assessed through macro-level studies, micro-scale investigations are particularly important for accurately pinpointing the exact location to extract groundwater using various means (Abolfazli, 1996).

Since the introduction of the electrical resistivity method in geophysical prospecting by Wenner (1915); and Schlumberger (1920); and its application in groundwater exploration has been increasing significantly because various hydrological problems have been solved very successfully in both soft rock and hard rock terrains. A successful example of this technique for groundwater exploration in a basement complex was shown by Reynolds (1998); in a survey of rural water supply in northern Nigeria. Previous to the Vertical Electrical Sounding (VES) usage, a failure rate of over 82% was recorded for boreholes. However, with the integrated application of geophysics, remote sensing, GIS, and a combination of geological and photogeological assessment, this was dramatically reduced to less than 20% failure.

The present research work has been carried out in and around the Singrauli Coalfields regions situated in central India Madhya Pradesh is managed by the Northern Coalfields Ltd, (NCL). It is one of the world's largest opencast coal mining complexes and produces over 14% of the coal produced in India. The presence of nearby Govind Vallabh Pant water reservoirs and the availability of power-grade coal reserves makes it an excellent location for cement, aluminum, and super thermal power plants (STPS) industries. Due to this there is a threat to the environment and ecosystem of the area, of which water pollution is a prominent one. This is caused by the large-scale mining operation combined with thermal power plants and many different types of power-based enterprises in the surrounding region of Singrauli coalfields.

Environmental parameters like water quality, groundwater level, air quality, and noise level are regularly monitored by organizations like The Central Pollution Control Board (CPCB) and Central Mine Planning & Design Institute Limited (CMPDIL) in the Singrauli coalfields regions. CMPDIL has also conducted a Geophysical study, including electrical resistivity and magnetic surveys in NCL and Non-NCL blocks for dyke delineation, groundwater study, and the identification of coal seam in-crop (CMPDIL annual reports and accounts 2019-2020).

Water is a crucial natural resource available to humankind. It is an integral component of biotic life in direct consumption and in maintaining local urbanization. Rapid industrialization, opencast mining activities, and population growth in the Singrauli Coalfield region are damaging groundwater quality along with its quantity. Due to this there is dis-equilibrium in the environmental scenario of the area and disturbs the groundwater conditions and its management in particular.

Some common statements of problem in the study are as follows:

- During the summer seasons, there is limited availability of water supply in rural areas.
- Although there is an adequate amount of rainfall in the study area, opencast mining activities have created unfavorable conditions for groundwater recharge.
- Active opencast mining resulted in the depletion of water levels, decreased soil moisture content, elevated atmospheric temperatures, and alterations in the hydrological cycle.
- The geometry of the aquifers, the flow patterns of groundwater, and the recharge and discharge processes of groundwater are disturbed by mining activities.
- Contamination occurs in both surface water and groundwater as a result of acid mine drainage.

A few researchers have studied groundwater resources in the Singrauli coalfields (Dhar et al., 1986; Choubey and Shankaranarayana, 1990; Yadav, 1993; Yadav, 1995; Khan et al., 2013; Das, 2015; Adhikari et al., 2021). However, an in-depth study on groundwater is still lacking in the Singrauli coalfields regions.

So, in this study, an attempt has been made to examine the groundwater levels, sub-surface lithology, groundwater potentials, and aquifer parameters in the Singrauli Coalfield region.

1.9 Objectives of the present study

The objectives of the present research work are following:

1. Implementation of a genetic algorithm for inversion of 1D-Geoelectrical data.
2. Preparation of various thematic maps like geomorphology, geology, slope, drainage, Land Use Land Cover (LULC), and lineament map from satellite imaginary data to get the priori information and further plan geophysical survey in the study area.
3. Evaluation of groundwater level fluctuation in the study area through selective wells during pre-monsoon, monsoon, and post-monsoon for the year 2021 using remote sensing and GIS.
4. Identification of sub-surface lithology and to locate the groundwater potential zones using the electrical resistivity method.
5. Characterization of aquifers using the electrical resistivity method.

1.10 Organization of Thesis

The thesis mainly consists of seven chapters in addition to the chapter containing references, which have been cited in the entire thesis.

- Chapter 1: Describes the introduction of research presented in this thesis. This includes a brief outline of the geophysical inverse problem, the occurrence of groundwater in rock formations, problems in the study area, the aim and objective of the study, and a brief review of the application of geophysical methods for groundwater exploration.

- Chapter 2: This chapter includes a review of previous studies concerning geophysical inverse problems, groundwater level fluctuation, and the identification and characterization of subsurface aquifers.
- Chapter 3: This chapter briefly discuss the geological tectonic setting, stratigraphic description, geomorphology, drainage, hydrology, soil, flora and fauna of the study area.
- Chapter 4: Illustrate the application of remote sensing and GIS for the assessment of groundwater level fluctuation.
- Chapter 5: This chapter explains the details of the implementation of a genetic algorithm for the inversion of 1D-Geoelectrical data.
- Chapter 6: This chapter contains the general introduction, concept, theory, methodology, and interpretation of the electrical resistivity method and the results of resistivity soundings data and their interpretation for delineating sub-surface, groundwater potential zones, and characterization of aquifers.
- Chapter 7: Reports the conclusion based on the research work. Finally, some suggestions for future work.

A detailed literature review of past studies related to the above objectives. Enlisted in the thesis is explained in the next chapter.