CHAPTER-2

LITERATURE REVIEW

Several works have been reported in the literature for the implementation of genetic algorithms, assessment of groundwater levels, identification of sub-surface lithology, and characterization of aquifers. The following is a brief review of the work reported in the context.

2.1 Studies on the Implementation of Genetic Algorithms(GA)

Sen and Stoffa (1991) implemented Genetic algorithm(GA) for the inversion of the seismic reflection waveform. Since many geophysical problems have been identified as nonlinear multiparameter optimization problems, including seismic waveform inversion. Local linearization methods fail when the model corresponding to set of initial set of parameters is too far away from the actual model. This paper examined the application of Genetic Algorithms(GA) for the inversion of plane-wave seismograms. Genetic algorithms, like simulated annealing, employ a random walk in model space and a transition probability criterion to guide their search. In contrast to a simulated annealing run, genetic algorithms search from a randomly generated population of models (strings) and use binary coding of the model parameter set. The search in genetic algorithms is not directionless compared to a pure random search, such as in a "Monte Carlo" technique. Selection, crossover, and mutation are the three basic processes of genetic algorithms, which entail random number generation, string copies, and certain partial string exchanges. The initial population and the probabilities of crossover and mutation are critical for the algorithm's practical implementation. They investigated how these characteristics affected the inversion of

plane-wave seismograms using a normalized cross-correlation function as the objective or fitness function (E). To control the effect of past generations, they introduced the idea of "update" probability. The combination of a low mutation probability (0.01), a moderate crossover probability (0.6), and a high update probability (0.9) is found to be best for algorithm convergence. Furthermore, they also demonstrated that concepts from simulated annealing may be used to stretch the fitness function effectively, helping the algorithm's convergence. As a result, they proposed exp (E/T) rather than E as the fitness function, where T(analogous to temperature in simulated annealing) is an appropriately determined parameter that can vary slowly with each generation.

Sambridge and Drijkoningen (1992) presented a Genetic algorithm(GA) for the inversion of marine seismic refraction waveform. The field of artificial intelligence has recently seen a lot of interest in a new family of techniques for solving non-linear optimization issues. These techniques also referred to as genetic algorithms, belong to global optimization techniques, including Monte Carlo and Simulated Annealing techniques, and can solve highly non-linear and non-local optimization problems. Contrary to local techniques like damped least squares or conjugate gradients, genetic algorithms completely disregard any curvature information on the objective function. Because they don't need any derivative information, any misfit function may be used with them. Most iterative approaches use a single model and identify improvements by in some way perturbing it. However, genetic algorithms operate with several models simultaneously and employ stochastic processes to direct the search for the best solution. The genetic algorithm and Simulated Annealing are both imitations of natural optimization systems. While

genetic algorithms are compared to biological evolution, Simulated Annealing uses the thermodynamics analogy. In addition to allowing the algorithm to quickly assimilate and utilize the knowledge acquired to identify better data-fitting models, this evolution results in an efficient exchange of information amongst all models encountered.

To showcase the advantages of genetic algorithms over Monte Carlo methods, the researchers employed a straightforward multidimensional quadratic optimization problem. Their findings indicated a substantial increase in relative efficiency as the number of unknown variables grew. In addition, this paper explores the application of genetic algorithms to the non-linear inversion of marine seismic refraction waveforms, utilizing real-world data. The results demonstrate that genetic algorithms offer inherent superiority compared to random search strategies and outperform iterative matrix inversion, which relies on a robust model corresponding to set of initial set of parameters. This advantage stems from the genetic algorithm's ability to integrate both local and global search techniques into a single efficient approach. Given that many geophysical problems involve optimization challenges in both forward and inverse modeling, the researchers believe that genetic algorithms have the potential for wider applications in various geophysical tasks, including seismic ray tracing, earthquake location, non-linear data fitting, and even seismic tomography.

Paul Bradley Parker (1999) earned Ph.D. on Genetic Algorithms(GA) and their use in Geophysical problems. According to him, the development of genetic algorithms is well suited to the global optimization techniques that mimic Darwinian nonlinear inverse geophysical problems. A standard genetic algorithm selects the "fittest" or best models from a "population". It then uses operators like crossover and

mutation to combine the best traits of each model to generate fitter models. Although more advanced operators have been developed, a reliable and effective search is often provided by the conventional GA. Although the type of problem being solved may significantly impact the choice of parameter settings like crossover and mutation rate, several studies demonstrate that particular parameter settings yield the best performance for various problems and difficulties. A low mutation rate (about half of the inverse of the population size) is essential for the best outcomes. However, the choice of crossover technique and the rate does not affect performance significantly. The optimum efficiency is often reached with lower populations (<50). Finally, tournament selection seems to be the best option among selection techniques due to its simplicity and auto-scaling capabilities. However, fitness scaling is essential for optimal performance when a proportional selection technique, like roulette, is utilized, and a high scaling factor (> 2.0) should be chosen.

In this research work, three cases were studied where crustal characteristics are inverted using genetic algorithms. The first uses gravity data to invert the basement depth at Yucca Mountain, the second uses receiver functions derived from teleseismic events to invert the crustal velocities beneath the Mendocino Triple Junction in Northern California, and the third uses a similar receiver function to invert the crustal velocities beneath the south island of New Zealand. The inversions show that genetic algorithms can solve problems with many free parameters and computationally intensive computations for objective functions.

For specific cases, more complex approaches are offered. To identify various solutions to the nonunique issues frequently encountered in geophysics, niching, and

island model techniques are proposed. Finally, hybrid algorithms are investigated to enhance the regular genetic algorithm's effectiveness.

Ramillien (2001) attempted a new method for inverting many geophysical parameters from altimeter and sea data simultaneously using Genetic Algorithms (GA). These innovative optimization techniques, which operate on non-deterministic principles, emulate the evolution of a population of potential solutions aimed at minimizing a given objective function. These methods offer a more resilient and cost-effective alternative to gradient-based approaches for nonlinear parameter inversion. In this study, genetic algorithms were employed to solve a discrete gravity problem related to underwater topography. The objective was to simultaneously retrieve seven parameters: elastic thickness, mean ocean depth, seamount location (longitude/latitude), seamount amplitude, radius, and density, based on their observed gravity/geoid signatures. The same methodology was successfully applied to adjust lithosphere parameters in the Rarotonga seamount within the Southern Cook Islands region. The genetic algorithm simulations produced reliable estimates for all seven parameters, highlighting the effectiveness of this approach.

Basokur et al.(2007) applied a hybrid Genetic Algorithm(GA) over a classical genetic algorithm. The classical genetic algorithm, which relies on natural selection, is a stochastic process capable of locating a position near the global minimum of the misfit function. However, it often proves inefficient in finding the exact solution. To address this limitation, the authors of this paper introduced a hybrid genetic algorithm that incorporates evolutionary theories. In this enhanced approach, sexual selection is integrated into the traditional genetic algorithm to simulate Darwinian evolution comprehensively. Survival advantages are given to parameters that meet specific

algebraic connections, emulating the process of sexual selection. This modification, known as the marked constraints algorithm, allows for the incorporation of geological and geophysical constraints into the problem. The algorithm gradually reduces the parameter search space across generations, introducing some determinism to the genetic algorithm. Additionally, the hybrid approach combines the damped least-squares method with the genetic algorithm, which aligns with Lamarck's evolution theory. This hybridization, referred to as Lamarckian inversion, involves several improvement procedures that decrease the mismatch between generations using a derivative-based method. By blending the Lamarckian and Darwinian evolution concepts, the solution method gains a deterministic component, leading to the Lamarckian-marked-constraint algorithm. The paper presents two examples to showcase the advantages and behaviors of these proposed algorithms. The first example focuses on a fictional scenario involving multiple minima, while the second utilizes vertical electrical-sounding data to explore the equivalence problem.

Qiu et al. (2010) proposed a Genetic Algorithm(GA) and generalized least squares (GLS) to solve geophysical optimized inversion problems. In this method nonlinear parameter estimation was computed by GA and accurate local search estimation was done by GLS. Final results were compared from GA, GLS, and proposed GA-GLS to invert the synthesized potential field. The outcomes demonstrate that GA-GLS surpasses both GA and GLS in terms of accuracy, which requires initial parameters to be known. Further, the feasibility of the method was tested on real data.

Attwa et al.(2014) used Genetic Algorithms(GA) to interpret VES data for the soil characterization in the Tenth of Ramadan City, Egypt. Most current 1D

geophysical inversion techniques rely on iterative and direct interpretation techniques. This is because these approaches have a degree of nonuniqueness and will only succeed if an initial model close to the best solution is already available. To achieve the best interpretation of the measured direct current (DC) resistivity data, the genetic algorithm (GA) approach is employed in this paper. This paper used the Tenth of Ramadan city as a case study for using GA to characterize soil utilizing resistivity measurements. Thirty-six vertical electrical soundings (VES) were collected to evaluate the subsurface soils to a depth of about 25 m. The results' reliability with the GA approach's application is validated by comparing the inversion results with lithologic and borehole information. The development of a 1D model using a GA is an accurate and rapid approach for imaging subsurface resistivity distributions; a large number of forward computations in GA enhances the likelihood of obtaining the best model correspondence to the actual geological condition. The intrinsic resistivity values are represented in maps, cross-sections, and 3D visualized models to show the nature of the shallow subsurface heterogeneity. The interpretation of DC resistivity data reveals the presence of a near-surface sandy clay barrier layer, which impacts the development plan of this significant metropolitan population. A decreasing resistivity pattern is found near oxidation ponds, suggesting wastewater percolation. Furthermore, the heterogeneity of the shallow subsurface might be regarded as the primary cause of fluid infiltration. Therefore, these reliable results are essential for further geophysical prospecting in assessing the environmental effects of oxidation ponds and the sandy clay layer close to the surface.

Maurya et al. (2019) applied a Genetic Algorithm(GA) on seismic data to characterize the reservoir using data from the Blackfoot Field, Alberta, Canada. To

fine-tune the parameters of the genetic algorithm (GA), the algorithm's effectiveness is initially assessed using artificially generated data. The evaluation involves analyzing the error between the inverted results obtained from the GA and the expected outcomes, and the algorithm demonstrates notably satisfactory performance. Subsequently, actual seismic data from the Blackfoot field is utilized for inversion purposes. The seismic data is inverted to obtain the acoustic impedance section. To further enhance the analysis, a relationship derived from the well-log data is employed to convert the seismic data into velocity and density sections.

The use of GA on post-stack seismic data is presented in this paper, demonstrating its effectiveness and capability for reservoir characterization utilizing GA-based post-stack seismic inversion without the well-log information. Both synthetic and real seismograms might be used for the analysis. The technique proved valuable for understanding subsurface properties without well-log information, even if the correlation is lower for the real data than the synthetic data. Despite having very little prior knowledge of the domain, the application of GA enabled the generation of high-resolution images of the velocity, density, and impedance models. The inversion findings on real field post-stack seismic data revealed the presence of a reservoir within a time period of 1055 and 1065 milliseconds, which was strongly supported by the other inversion results from the same region. The algorithm demonstrated average correlation coefficients of 0.94 between synthetic and modeled data and 0.89 between actual and inverted data. This makes sense given the noise in the seismic trace and the non-uniqueness of an inversion procedure. This study demonstrates that using GA on post-stack seismic data may be utilized to characterize the reservoir and for finding the best solution. In the end, it can be said that the proposed algorithm is valuable and

appropriate for searching for new prospects, such as in offshore exploration projects where data on wells logs are not available.

Paloma et al. (2020) developed an efficiency-improved Genetic Algorithm (GA) on multimodal function and a 2D common reflection surface stacking problem. In this study, a novel and efficient Genetic Algorithm (eGA) is introduced as a robust global optimization algorithm that offers improved efficiency. The eGA incorporates several enhancements to address specific challenges commonly encountered in global search methods. Firstly, a modified island model is employed to enhance global search capabilities and ensure effective exploration of the solution space. Additionally, a self-adaptive differential evolution (SADE) fine-tuning scheme is implemented to achieve precise fine-tuning capabilities. Furthermore, a local exhaustive search method is integrated to mitigate premature convergence issues, which are often encountered in directed global search methods. Comparative analyses with their previously proposed advanced Genetic Algorithm (aGA) demonstrate that the eGA exhibits convergence speed improvements of over tenfold for multimodal analytical functions. When applied to a two-dimensional common reflection surface (CRS) stacking problem, the eGA achieves excellent results. Notably, the eGA requires only half the computational resources compared to the aGA while delivering nearly identical results for the 2D CRS problem. The study also discusses other aspects of the eGA, such as its application to functions with elongated or flat valleys of minima, as well as the analysis of its parallel implementation through task parallelism. Overall, the results obtained indicate that the proposed eGA holds promising potential for solving nonlinear problems in geophysical exploration.

Cheng et al.(2022) studied the Amplitude Versus Offset/Angle (AVO/AVA) inversion, which recovers the elastic characteristics of the subsurface and is an important tool in oil and gas explorations. The Zoeppritz equation is generally known for its accurate modeling of reflection coefficients. However, when it comes to amplitude inversion, the equation poses a highly nonlinear challenge, necessitating the utilization of nonlinear inversion techniques like the Genetic Algorithm (GA), which is commonly employed in seismology. An alternative version of the GA, known as the quantum genetic algorithm, utilizes qubits and the superposition of states. However, this approach has limitations in terms of convergence rate and the ability to escape local minima. To address these shortcomings, this paper proposes a hybrid quantum genetic algorithm that combines a self-adaptive rotational approach with quantum mutation and catastrophe operations. This novel hybrid algorithm aims to overcome the aforementioned drawbacks associated with the quantum genetic algorithm.

2.2 Study on Assessment of groundwater level

Duncan (1964) conducted a study examining the impact of the water table and tide cycle on the distribution of sediment in the swash-backwash zone and the development of beach profiles. The investigation focused on the deposition occurring in this zone along a sandy beach, and the findings revealed significant effects caused by the fluctuations in sea level relative to the water table level, which results from semidiurnal tide cycles. The distribution of sediment in the swash-backwash zone is influenced by the interplay of various factors, including swash deposition, swash erosion, backwash deposition, and backwash erosion. When the tide level is high and the water table on the beach is low, swash deposition and erosion play a dominant

role, leading to the formation of a thick sediment lens on the shoreward side of the swash-backwash zone and a scoured area on the side facing the breaking waves. Conversely, a relatively high water table leads to maximum backwash erosion and backwash deposition, resulting in the formation of thick sediment lenses near the boundary of the surf. Consequently, as the sea level fluctuates above and below the general water table level during the tide cycle, the zone of deposition within the swash-backwash area shifts its position, causing variations in the beach slope gradient, either increasing or decreasing it.

Ericksen (1970) conducted a study examining the changes in water table profiles caused by tides in both coarse and fine sand beaches along Pegasus Bay, Canterbury. Measurements taken along these beaches revealed a continuous exchange of water between the sea and the pores within the beach sand throughout a single semi-diurnal tidal cycle. The velocity at which water escapes from the water table during the ebbing tide does not appear to be sufficient to wash away material of silt size or larger from the beach. This lower velocity is believed to be influenced by the hydrostatic control exerted on the amplitude of the water table by the dunes located at the back of the beach. It is also noted that sources such as fresh water and wave wash play a significant role in influencing water table profiles, in addition to tidal water.

Chappell et al. (1979) conducted a study focusing on the experimental manipulation of beach face dynamics through water-table pumping. They examined how the interaction between swash and backwash processes influences the sediment budget on the intertidal portion of sandy surf beaches, which is closely linked to the behavior of the beach water table. Variations in the height of the water table are influenced by tidal movements and propagate onto the beach as a slow wave that

gradually decreases in amplitude and increases in lag. Additionally, high-frequency pulses from the incoming wave train also penetrate the beach. The study revealed that the elevation at which the water table emerges on the beach face is influenced by previous tidal and wave conditions, and this, in turn, affects the balance between sand deposition and erosion during swash and backwash processes.

Lanyon et al. (1982) conducted an investigation into the fluctuations of groundwater levels during semidiurnal spring tidal cycles on a sandy beach. They discovered that the time-series graphs depicting changes in water levels at individual wells along the beach profiles exhibit distinct asymmetry, with the amplitude of oscillation influenced by the tidal range of the beach face and its distance from the landward area. This asymmetry is attributed to filtering processes that separate the different tidal components both at the beach face and within the beach itself. The changes in groundwater induced by the tides occur on a three-dimensional water-table surface that is connected to the beach morphology and influenced by groundwater recharge from the backshore zone. As the tide rises and falls, the three-dimensional flow pattern of groundwater is elevated and lowered accordingly. The rise in groundwater begins first in shoreline embayments and then spreads landward and outward towards higher water-table surfaces near prominent shoreline areas and in the backshore zone. Consequently, the groundwater responses differ in these distinct areas, with an inland slope prevailing in embayments and a seaward slope characterizing the prominent shoreline areas.

Clarke and Eliot (1987) conducted a study on the changes in groundwater levels within a coastal dune, the fluctuations of sea levels, and the movement of the shoreline on a sandy beach. It was discovered that the groundwater situation could

contribute to low-frequency fluctuations of the shoreline with recurrence intervals ranging from 0.5 to 10 years. To investigate this proposition, a 7-year dataset of groundwater levels from coastal dune areas was compared with data on mean sea-level fluctuations and shoreline changes from the adjacent coast. In an initial analysis of records from Western Australia, it was observed that the annual cycles of sea level and shoreline change exhibited an inverse relationship, indicating that a 1.0 cm rise in sea level corresponded approximately to a 1.0 m decrease along each profile. In the present analysis, the ratio between sea level oscillations and shoreline changes ranged from 110:1 to 125:1 for annual to triennial cycles. For the 0.5-year cycle, the ratio was slightly lower at approximately 80:1. These findings closely align with the results reported in the original analysis. Notably, there was a better agreement between the time series describing groundwater and shoreline fluctuations compared to the relationship between sea level and beach change.

Li and Jiao (2002) conducted a study on tidal groundwater fluctuations in L-shaped leaky coastal aquifer systems. This research paper introduces an analytical solution that describes the variations in groundwater levels due to tides in a coastal aquifer system with leakage, where the water-land boundaries form a right angle (referred to as L-shaped coastlines). The system comprises an unconfined aquifer, a confined aquifer, and a leaky layer positioned between them. Existing analytical solutions found in previously published works focus only on a single aquifer, which can be viewed as a specific case of the new solution when the permeability of the leaky layer approaches zero. To provide a simplified and approximate solution, an integral-free method is presented. Through error analysis and hypothetical examples, it is demonstrated that the approximate solution offers sufficient accuracy for

predicting groundwater levels and estimating parameters in an L-shaped leaky aquifer system.

Jan et al. (2007) conducted a study to examine how rainfall intensity impacts fluctuations in groundwater levels. In this research, they proposed a mathematical equation that describes the relationship between the increment in groundwater levels and the appropriate accumulated amount of rainfall. The groundwater level measurements were obtained from the Donher well station located in Central Taiwan, while rainfall data were collected from seven rain-gauge stations situated near the well station. To analyze this relationship, they initially utilized the BAYTAP-G program to eliminate the influence of non-rainfall factors on groundwater levels, such as barometric pressure and earth tide. Given that both current and preceding rainfall events can affect the increment in groundwater levels, they introduced the concept of an appropriate accumulated rainfall amount. This approach incorporated the impacts of these events using an exponential-decay weighting method. The resulting groundwater level, known as the residual groundwater level, exhibited a linear dependence on adequate accumulated rainfall. The study also revealed a strong correlation between the increment in residual groundwater level and the effective accumulated rainfall amount, which was calculated using the exponential-decay weighting method with a decay parameter of 0.25. Additionally, the researchers demonstrated that rainfall occurring outside the surface watershed surrounding the Donher well station still influenced the residual groundwater level, and they incorporated this effect into their proposed equation.

Shamsudduha et al. (2009) conducted a study to analyze recent patterns in groundwater levels within the Ganges-Brahmaputra-Meghna Delta, a highly seasonal

hydrological system. In this delta region, groundwater levels in shallow aquifers exhibit significant fluctuations corresponding to the monsoon rainfall. To distinguish between trends and seasonal variations in weekly groundwater levels in the Ganges-Brahmaputra-Meghna (GBM) Delta, the researchers employed a nonparametric seasonal trend decomposition procedure (STL) using data collected in Bangladesh from 1985 to 2005. The results indicated that seasonal variations accounted for the majority of the groundwater level variances. However, declining groundwater levels (>1 m/year) were identified in urban and peri-urban areas surrounding Dhaka, as well as in the north-central, northwestern, and southwestern regions of the country (0.1-0.5 m/year). These areas experienced intensive groundwater extraction for dry-season rice cultivation. Conversely, rising groundwater levels (0.5-2.5 cm/year) were observed in the estuarine and southern coastal regions. The application of the STL procedure in this study provided new insights into the unsustainability of irrigation practices relying on shallow aquifers in certain areas (e.g., High Barind Tract) of the GBM Delta. Additionally, it highlighted the hydrological impact of potential seawater intrusion into coastal aquifers due to rising sea levels. These findings offer valuable knowledge regarding the hydrological consequences of groundwater-fed irrigation and sea-level rise in other Asian mega-deltas where limited monitoring data are available.

Chandrashekhar Bhuiyan (2010) conducted research on the hydrogeological aspects and their correlation with seasonal fluctuations in the water table within the composite hard rock Aravalli terrain in India. The rise and fall of groundwater levels during different seasons reflect the recharge of aquifers through the process of infiltration. However, understanding the relationship between water-level fluctuations

(WLF) and various hydrogeological factors can be complex. This study employs frequency plots to analyze the variations in WLF based on different geological parameters. Statistical parameters are used to compare the seasonal fluctuations associated with these factors. Both parametric and non-parametric statistical tests are applied to determine the significance of the differences in fluctuations. The results indicate that various geological factors such as the thickness of saturated aquifers, the existence of lineaments, the intersections of lineaments, drainage patterns, as well as surface elevation and well depth play a significant role in aquifer recharge within the Aravalli terrain. The median values of these factors are combined and compared with the interpolated mean values of water level fluctuation (WLF) at hypothetical well sites.

Dong et al. (2012) conducted an analysis of groundwater-level fluctuations in a coastal confined aquifer caused by changes in sea level. The response of groundwater to tidal fluctuations in various hydrogeological scenarios has been a subject of study for many years. Previous solutions derived from assuming sinusoidal components in tides have neglected non-periodic variables, leading to inaccuracies in predicting groundwater responses to sea-level changes. In this research, the Fourier sine transform method was employed to develop an analytical solution based on the observed sea-level boundary, aiming to address this issue. A comparison was made between this solution, an analytical solution assuming sinusoidal components, and a numerical solution generated using MODFLOW. The results showed that the proposed solution significantly improved the prediction of groundwater levels in a coastal confined aquifer in Zhuhai City, China.

Chandra et al. (2015) investigated the hydrogeological factors and their association with seasonal fluctuations in the water table in Dhanbad district, Jharkhand, India. With the rapid growth of industries and population, water resources have faced significant pressure. In regions with Hardrock terrain, groundwater availability is limited to fractured and weathered zones. This study aims to establish a connection between water table fluctuations and hydrogeological factors. The considered factors include geomorphology, geological structures, geological formations, soil types, and elevation, which can impact aquifer recharge. Analysis was conducted on 65 monitoring wells, and frequency plots were utilized to assess the influence of different hydrogeological subclasses on water level fluctuations. Statistical analysis, involving mean, median, mode, and standard deviation values, was performed for all hydrogeological parameters within each subclass to specify their relative effects. The findings indicate a definite relationship between surface topography, geology, geomorphology, soil, elevation, and the recharge of aquifers based on their specific hydrogeological properties.

Priyanka et al.(2016) studied the analysis of water level fluctuation and TDS variation in the groundwater at Mewat, District, Haryana, India. They find that groundwater is the main source for fulfilling domestic and agricultural water needs in the district, due to this groundwater is under tremendous pressure, which combined with low rainfall and variable geographic conditions, causes water levels to decline. In this paper, forty dug wells were monitored to collect the data and evaluate groundwater level and TDS (Total Dissolved Solids) during the pre-monsoon and post-monsoon seasons from 2011 to 2015. Finally, they concluded that the

groundwater level in the region is continuously declining while TDS levels have shown inconsistent trends between 2011 and 2015.

Tiwari et al. (2016) conducted a study on the evaluation of groundwater level fluctuations in the West Bokaro Coalfield, Jharkhand, India, utilizing remote sensing and GIS techniques. The West Bokaro Coalfield is primarily influenced by active mining industries and faces a severe shortage of clean surface water, resulting in heavy reliance on groundwater resources. The main objective of this research was to assess the key parameters that significantly affect groundwater level fluctuations in the West Bokaro coalfield through the integration of remote sensing, GIS, and field-based water level data collected during two seasons. To achieve this objective, thematic maps were created for parameters such as geology, drainage, soil type, slope, and elevation. These maps were developed using a digital elevation model and Survey of India Toposheet within a GIS environment. Subsequently, the thematic maps were analyzed in conjunction with field-collected groundwater level data to evaluate the overall water level conditions in the study area.

Tiwari et al. (2017) conducted a study in the Aosta Valley region, Italy, where they monitored groundwater levels in 26 observation-dug wells during the dry season (June 2013) and wet season (November 2013) to evaluate water-level fluctuations (WLF). In the dry season, the depth to the water level ranged from 3.04 to 28.70 meters below ground level (mbgl), while in the wet season, it varied from 2.92 to 25.62 mbgl. The WLF in the study area ranged from 0.01 to 6.80 mbgl, with higher fluctuations observed in the western and northwestern regions. The accuracy of the WLF map was validated through statistical analysis and comparison with elevation values in a geographic information system. The validation process confirmed the

reliability of the WLF map in the Aosta Valley. The study results indicated that the eastern region of the area could be considered a favorable and secure recharge zone for groundwater resources in the Aosta Valley. Moreover, the generated WLF map has potential applications in the management of future groundwater resources and environmental planning in the region.

Prasad and Rao (2018) conducted research in the Kandivalasa River Sub-basin near Cheepurupalli town of Vizianagaram district, Andhra Pradesh, India. They monitored groundwater levels in 41 observation wells from 2013 to 2015 and collected daily rainfall data during the same period. Throughout the study period, there was a consistent decline in groundwater levels, particularly in 2015 when there was minimal rainfall. The depletion of groundwater was predominantly observed in the Eastern and South Western parts of the basin, where there is a higher concentration of pumping wells. Based on groundwater balance studies, it was determined that the basin could sustain an annual utilization of 11.3 million cubic meters (MCM) of groundwater. However, the actual annual groundwater draft was measured at 16.6 MCM, resulting in an over-abstraction of 5.66 MCM. This excessive extraction of groundwater is identified as the primary cause of declining groundwater levels.

Abiye et al. (2018) conducted an analysis of groundwater-level fluctuations in the Johannesburg region to enhance the management of groundwater resources. Effective management of groundwater resources relies on understanding the available resources and the extent of groundwater fluctuations. Fluctuations in groundwater levels can be attributed to human activities such as excessive pumping as well as natural processes, particularly a decrease in recharge. The investigation of short-term

water-level records often falls short in uncovering the root causes behind these fluctuations. Hence, the researchers conducted a comprehensive analysis of long-term groundwater-level records in the Johannesburg region. They augmented this analysis by incorporating the results from the cumulative rainfall departure (CRD) method to gain a deeper understanding of the factors that contribute to fluctuations in groundwater levels within the mining region of Johannesburg.

The results obtained through the CRD method confirmed that groundwater levels tend to become shallower during periods of higher rainfall. Since no correlation was observed between groundwater level variation and rainfall, it was suggested that groundwater abstraction might be a potential cause for the fluctuations in groundwater levels.

Anand et al. (2020) conducted an analysis of long-term trends and spatiotemporal variations in groundwater levels in the Lower Bhavani River basin, Tamil Nadu, India, using Geographic Information System (GIS) and statistical tests. The researchers collected 32 years of groundwater-level data (1984-2015) from 57 observation wells located throughout the study area, obtained from government departments. They utilized GIS to represent the spatial patterns of groundwater level variations throughout different seasons, including the pre-monsoon (March to May), post-monsoon (January and February), southwest (SW) monsoon (June to September), and northeast (NE) monsoon (October to December) periods. To analyze the trend in groundwater levels, statistical techniques such as the Mann-Kendall test and Sen's slope estimator were applied. The study's results indicated that the average annual groundwater level experienced a decrease of over 15 meters below ground level during the monsoon seasons of 2003 and 2004, which signifies a decline in

rainfall infiltration and excessive extraction of groundwater. This has resulted in stress on the hard rock aquifer. Moreover, notable fluctuations in groundwater were observed in the southeastern and northeastern regions of the basin, while the northern and northwestern parts displayed moderate fluctuations.

Goswami and Ghosal (2022) conducted a comprehensive investigation on the spatiotemporal and seasonal fluctuations of groundwater levels in a semi-arid region in eastern India. They also explored the factors contributing to these variations in groundwater levels. To achieve their objectives, they employed a combination of statistical analysis, geographical analysis, and machine learning techniques. Their findings revealed that the southeastern part of the region, specifically Bundwan and Barabazar Blocks, along with the far western area, particularly Jhalda I and II Blocks, as well as certain eastern Blocks, are particularly susceptible to groundwater scarcity. Monitoring stations in these regions consistently displayed a declining trend in groundwater levels, as indicated by a substantial Sen's Slope value. Additionally, based on the time series predictions, it was confirmed that without implementing any measures, the average groundwater level is projected to decrease by 2.5 meters by the year 2030.

2.3 Studies on identification of subsurface lithology and to locate groundwater potential zones using electrical resistivity method

Rao et al. (1987) were able to delineate potential aquifers along a lineament using the resistivity method in hard rock terrain. There are more challenges in managing groundwater resources in hard rock areas due to the enormous difficulty, uncertainty, and ambiguity in applying any geophysical method. Groundwater is

found in hard rock areas to a limited extent, primarily in secondary porosity that forms as a result of processes such as weathering, fracturing, jointing, and faulting. These structural modifications, including fractures, are not widespread and are found scattered throughout the hard rock regions. Hence, the structurally favorable zones for groundwater, i.e., lineament, faults, fractures, and joints, were identified based on aerial photographs and electrical resistivity sounding conducted in these areas. Based on the results obtained, they eventually inferred that both the resistivity profiling and soundings are essential for evaluating groundwater in regions adjoining the lineament in hard rock areas.

Al-Garni (2006) implemented an electrical resistivity method for groundwater in Wadi Lusab, Haddad Ash Sham Area, Makkah Al-Mukarramah. The Schlumberger array was employed throughout the Wadi Lusab region. The results indicated that the majority of Schlumberger-sounding curves were of high quality; however, a small number of curves were affected by lateral variations in geology and human-made objects. The analysis of the resistivity-sounding curves and cross-sections provided valuable insights into the likely position of the water table, water quality, and the potential structure of the area under investigation. Materials exhibiting resistivity values ranging from 150 to over 300 ohm-m could represent dry alluvial deposits comprising sand, gravel, and pebbles. Sedimentary deposits containing coarse sand and gravel saturated with good-quality water may exhibit resistivity values ranging from 70 to 150 ohm-m. Materials with resistivity values ranging from 30 to 70 ohm-m could indicate deposits composed of sand, gravel, and clay mixture, likely saturated with good-quality water. Lastly, resistivity values between 10 and 30 ohm-m may suggest sedimentary deposits consisting of a moderate clay content mixed with sand,

gravel, and good-quality water. The findings are further supported by three interpreted resistivity cross-sections.

In a study by Al-Garni (2009), geophysical investigations were carried out to explore groundwater in a complex subsurface terrain located in Wadi Fatima, KSA. The presence of geological contacts in such a complex subsurface terrain suggests the possibility of groundwater, especially in semiarid or arid regions. To determine the potential occurrence of groundwater in this structurally complex basement, DC resistivity profiling and sounding techniques were employed. The DC resistivity profiling technique was applied along a single profile to assess how basement structures influence the distribution of groundwater in that specific area. Additionally, Vertical Electrical Sounding (VES) was performed at chosen locations. By integrating the findings obtained from these two methods, the study successfully identified new areas, specifically VES-9 and VES-7, as suitable sites for drilling wells and extracting groundwater for water supply.

Al-Garni et al. (2011) studied the Schlumberger sounding to identify the subsurface factors controlling the groundwater flow along Wadilusab, Makkah Mukarramah, Saudi Arabia. He suggested that subsurface structures associated with hard rock are potential water-bearing zones with the metamorphic rock overlaying thick alluvium deposited in Arabian Shield.

Balakrishna et al. (2014) employed Electrical Resistivity Tomography (ERT) and Vertical Electrical Resistivity (VES) methods to investigate the presence of groundwater in a fractured aquifer formed by ophiolite in Port Blair, South Andaman Islands. The study revealed that groundwater exists in weathered formations located

in the unsaturated zone, as well as in fractured rocks found in the saturated zone. The sustainability of groundwater in the unsaturated zone is limited, while groundwater in fractured rocks can be sustainable if properly managed. However, identifying productive fractured rocks requires careful assessment and a systematic geophysical survey due to the heterogeneous nature and the occurrence of multiple episodes of magmatic and metamorphic activities. Therefore, effective planning is crucial in groundwater exploration due to the significant investments required for drilling, human resources, and time. In this study, the researchers aimed to locate fractured rocks with groundwater potential using Electrical Resistivity Tomography (ERT) and Vertical Electrical Soundings (VES). ERT was employed to determine resistivity values in both vertical and horizontal directions along various fracture orientations, while VES evaluated the conductivity or resistivity of different fractures. The researchers concluded that the 2-D Electrical Resistivity images, combined with the geoelectrical parameters obtained from VES, indicated that fractures aligned in an east-west (E-W) direction were more likely to be productive, displaying higher conductivity compared to fractures oriented northeast-southwest (NE-SW) and northwest-southeast (NW-SE). The potential of the E-W fractures was further confirmed by data collected from boreholes.

Kumar et al.(2014) applied Vertical Electrical Resistivity(VES) for geohydrological investigation at Banaras Hindu University campus, Varanasi, U.P, India. Nine Vertical Electrical Soundings (VES) using Schlumberger configurations were carried out at selected locations on the university's main campus. Both curve matching and computer-assisted automatic iterative resistivity sounding techniques were employed to analyze the sounding data. As a result, four geoelectrical cross-

sections were created, representing the profiles and incorporating the findings from the interpreted sounding data. The data interpretation unveiled the presence of four layers, with a thin top layer overlaying three thicker layers. The interpreted results were validated by comparing them with the data obtained from the boreholes. They concluded that VES results depict proper geohydrological conditions for the existence of suitable aquifers suggesting a continued supply of groundwater on the campus for an extended period.

Araffa et al.(2015) studied geophysical techniques for delineating sub-surface structures and assessing groundwater aquifers in the central part of Sinai, Egypt. In this paper geophysical method, and electrical resistivity have been applied to identify and evaluate the groundwater occurrences in the studied area. To identify the Nubian sandstone aquifer in the region, a total of 26 vertical electrical soundings (VES) stations were surveyed and analyzed. The measurements revealed that the depth of the upper surface of the aquifer differs between 483 and 1079 meters. Additionally, the resistivity values of the aquifer were found to range from 109 to 522 Ohm-m, indicating the presence of a freshwater aquifer in the studied area.

Yousuf et al.(2015) worked on delineating Geophysical methods employed to identify the areas with high potential for groundwater in the deep Midland Aquifers along the Bharathapuzha river basin in Kerala. The presence and behavior of groundwater, particularly in fractured bedrock aquifers, are influenced by various factors such as topography, lithology, geological structures, fracture density, aperture, and connectivity, as well as secondary porosity. In this research article, they analyzed Vertical Electrical Sounding (VES) data collected from 66 different sites, both qualitatively and quantitatively. The objective was to extract information about the

resistivity characteristics of layered formations and identify potential fractured zones within the deep aquifer. To aid in the analysis, thematic maps depicting drainage patterns, geology, geomorphology, slope, and lineaments were generated using toposheets and IRS P6 LISS III imagery. The slope map revealed that the southern and northeastern parts of the study area exhibited steeper slopes. The dominant drainage pattern in the area was dendritic to sub-dendritic, often influenced by lineaments and fault zones.

The qualitative interpretation of the VES data indicated the presence of multi-layered profiles in the majority of the locations, with more than four resistivity layers. After interpreting the VES data, they found that out of the 66 VES curves analyzed, 24 had five layers, 23 had six layers, 17 had seven layers, and two had four layers. The first layer exhibited resistivity values ranging from 11.9 Ωm to 8089 Ωm, with thicknesses ranging from 0.78 m to 4.79 m. The resistivity of the second layer varied from 35.3 Ωm to 11382 Ωm, with thicknesses ranging from 0.364 m to 11.3 m. Bore wells that accessed the deep aquifer zones with moderate to high yield were primarily located at the intersections of lineaments.

Olatonji et al.(2017) investigated the identification of groundwater potential by the electrical resistivity method in parts of Kwara state polytechnic, Ilorin, Nigeria. The study area, spanning approximately 1.5 square kilometers, is characterized by Precambrian basement rocks composed of migmatite gneiss. A total of fifteen Vertical Electrical Soundings (VES) were conducted using the Schlumberger electrode array configuration, with a half-current electrode separation (AB/2) of 70 meters. The acquired VES data underwent processing and interpretation using partial curve matching and computer iteration techniques. The analysis revealed the presence of

three to four geoelectric sections with varying thicknesses and resistivity values. The resistivity of the lateritic clay layer ranged from 53.1 to 302 Ωm, with corresponding thicknesses ranging from 1.9 to 8.0 meters. Similarly, the resistivity of the weathered horizon varied from 22.7 to 474.2 Ωm, with thicknesses ranging from 4.4 to 11.7 meters. On the other hand, the competent rock exhibited resistivity and thickness values greater than 220.3 Ωm and 6.1 meters, respectively. In the four-layer geoelectric section, the third layer represents the aquiferous zone, while in the three-layer geoelectric sections, the second layer serves as the aquiferous zone. Among the fifteen VES stations, only station 9 demonstrated a favorable groundwater potential based on the presence of a thick overburden and weathered layer with low resistivity. Conversely, stations 3, 4, and 13 displayed poor groundwater potential, while the remaining stations were identified as non-aquiferous.

Goel et al. (2019) presented a groundwater assessment and analyzed its quality status in Vindhyan Ganga sedimentary formation around the Mirzapur district in Uttar Pradesh(U.P), India. They examined that a clay sand-based sedimentary layer of a few meters in thickness is observed to be present beneath the topsoil layer in the study area and it is polluted with pollutants including cadmium, arsenic, lead, and iron, and not very well hydro-geological connected. They concluded that the findings of this study might contribute to the development of safe groundwater strategies, the use of aquifer management methods such as controlled aquifer recharge, and the establishment of a technical strategy for the execution of remediation programs.

Singh and Jamal (2020) utilized the Electrical resistivity method to identify areas with potential groundwater resources in Kota, Rajasthan, India. The researchers conducted twenty-one vertical electrical sounding (VES) surveys using the

Schlumberger sounding configuration. These surveys aimed to gather data on subsurface layer characteristics, including resistivities and thicknesses, in order to delineate regions with high groundwater potential. The collected VES data underwent automatic interpretation, which provided information on layer parameters such as apparent resistivities and thicknesses. These interpreted parameters were then utilized to generate geo-electrical cross-sections, representing the geological formations present in the area. The analysis of the results indicated the existence of up to five layers within the study region. Most VES curves exhibited A-type responses, including AA, HA, and HAA, suggesting the presence of progressively harder rock formations. To validate the accuracy of the VES findings, they were compared with available litho-log data, revealing a strong agreement between the sounding results and the lithology data. The study concluded that potential groundwater zones in the Sangod Block of Kota District, Rajasthan, India, are likely to be found in areas characterized by loose sand pockets and fractured or semi-fractured zones.

A hydrogeophysical study was conducted by Babatunde et al. (2022) at Lead City University in Ibadan, Oyo state, Nigeria, utilizing the electrical resistivity method. The primary aim of the investigation was to gather information about the subsurface geological structures and their hydrogeological significance through the analysis of geoelectric properties. The geoelectrical data was collected at twenty stations using the Schlumberger electrode configuration. By analyzing the geoelectric layers, they calculated the Dar-Zarrouk parameter, which enabled them to create a groundwater potential map by integrating the geoelectric parameters through the Multi-Criteria Evaluation Technique. The findings of this study suggest that the

combination of data handling methods and geophysical approaches can provide an accurate means of characterizing and assessing groundwater potentials.

2.4 Studies on aquifer characterization using Electrical resistivity method

Kelly (1977) employed geoelectric sounding to estimate the hydraulic conductivity of an aquifer in glacial outwash material. The study was conducted in Southern Rhode Island, where the electrical resistivities of the aquifer were determined using the Schlumberger electrical sounding techniques. Prior to the geoelectric sounding, pumping tests had already been conducted in the same area. The hydraulic conductivities and transmissivities derived from the pumping tests were compared with the resistivity values obtained from the electrical soundings. The findings indicate that the resistivities obtained from the soundings serve as a reliable indicator for predicting the hydraulic conductivities of the aquifer. The study also developed an empirical relationship between aquifer electrical resistivity and hydraulic conductivity, as well as a semi-empirical relationship between aquifer formation factor and hydraulic conductivity.

Niwas and Singhal (1981) conducted research on estimating aquifer transmissivity using the Dar-Zarrouk parameters in porous media. The main objective of the study was to establish a link between the aquifer parameters of porous media and the Dar-Zarrouk parameters, with a focus on estimating transmissivity based on surface resistivity measurements. By considering Darcy's law for fluid flow and Ohm's law for current flow, the researchers derived analytical relationships between transmissivity and both transverse resistance and longitudinal conductance. The study emphasized the significance of the relationship between transverse resistance and

transmissivity. In a specific geological context and within a certain range of water quality, it was found that the product of hydraulic conductivity and electrical conductivity of the aquifer can be assumed to be constant. This conclusion was supported by analyzing the data provided by Kelly.

Lima and Niwas (2000) used geoelectrical measurements to estimate shaly sandstone aquifer hydraulic parameters. The electrical and hydraulic conductivities of shaly sandstones are explained by employing a capillary approach suitable for clay-bearing granular materials. To express the hydraulic conductivity within this model, a modified version of the Kozeny-Carman equation is utilized. Furthermore, a novel semi-empirical equation establishes a relationship between the hydraulic conductivity of these rocks, their porosity, formation resistivity factor, and the electrical conductivity of their solid matrix. These collective properties are referred to as the litho-porosity factor. This new formulation allows for the straightforward determination of the involved petrophysical parameters using electrical geophysical measurements. The equation's performance was evaluated using experimental laboratory data found in the existing literature. Subsequently, the equation was applied to estimate hydraulic parameters in a shaly sandstone aquifer located in Bahia, Brazil. The estimation utilized either borehole data or geoelectrical surface data.

Soupios et al.(2007) estimated aquifer hydraulic parameters from surficial geophysical data in the Keritis basin in Chania, Greece. Understanding aquifer parameters is crucial for effectively managing groundwater resources. Traditionally, these parameters are determined by conducting pumping tests on water wells. However, due to the limited availability of boreholes and the expensive and time-consuming nature of conducting pumping tests at multiple sites, there is a need for a

more efficient and cost-effective approach. One alternative method is the integration of geophysical techniques with pumping tests, which offers a viable solution for estimating aquifer parameters in a more economical and time-efficient manner. The electrical resistivity method was employed to determine aquifer properties through pumping tests. By establishing a correlation between these parameters, they extended their findings to other locations where pumping tests were not conducted. This approach enabled the characterization of the entire study area's aquifer system.

Chandra et al.(2008) developed a theory with field application for estimating hard rock aquifer hydraulic conductivity from geoelectrical measurements. A methodology has been developed that draws upon the similarities between Darcy's law, which describes groundwater flow, and Ohm's law, which describes electric current flow. This methodology enables the estimation of hydraulic conductivity and transmissivity in hard rock granite aquifers using geoelectrical parameters. By combining these two relations with the common parameter of aquifer thickness (t), an analytical equation has been derived. They observed that a mathematical relationship exists, indicating a negative correlation between aquifer resistivity and hydraulic conductivity, as well as a positive correlation between longitudinal conductance and transmissivity. To evaluate its effectiveness, they applied this methodology to granite aquifers in India and conducted tests to validate its findings. The strong agreement between the hydraulic conductivity (K) and transmissivity (T) values derived from the resistivity sounding parameters and those obtained from pumping test analysis confirms the potential of this methodology. Surface electrical resistivity measurements were used to estimate the K and T parameters, and the results were used to create K and T maps of the Maheshwaram watershed located in a hard rock terrain in India.

Ndatuwong and Yadav (2015) assessed overburden protective capacity in part of the Sonbhadra district, Uttar Pradesh using geoelectrical methods. This research paper utilized geoelectric properties derived from the interpretation of resistivity data to obtain additional parameters known as the Dar-Zarrouk parameters. Thematic maps were created to represent various characteristics of the study area, including overburden thickness, anisotropic coefficient, transverse resistance, and longitudinal conductance. These maps were then classified, weighted, and integrated within the ArcGIS environment using the overlay weighted model. Through this process, a comprehensive map was generated that categorized the groundwater potential zones of the study area into low, moderate, and good categories. Furthermore, the researchers conducted a further evaluation of the longitudinal conductance to assess the protective capacity of the overburden material. The results indicated that the study area predominantly consists of overburden with moderate to good protective capabilities.

Sattar et al. (2016) conducted Vertical Electrical Soundings (VES) at 24 locations in Chapai-Nawabganj, located in northwest Bangladesh, with the aim of determining the transmissivity and hydraulic conductivity of the aquifer. Initially, the transmissivity (T) and hydraulic conductivity (K) were calculated using data obtained from nearby production wells that were being pumped. Subsequently, the researchers established correlations between T and geoelectrical resistance, as well as between the total resistivity of the aquifer and K. This study reveals the analogous functional relationships between geoelectrical resistance and transmissivity, as well as between total resistivity and hydraulic conductivity, in the aquifer of northwest Bangladesh.

Nwachukwu et al. (2019) conducted an assessment of aquifer properties in the southern part of Nigeria using the electrical resistivity method. The main objective of

this study was to utilize the electrical resistivity method to investigate the groundwater potential and determine the Dar-Zarrouk parameters. The evaluation of groundwater potential in the area considered several factors, including longitudinal conductance (S), transverse resistance (T), coefficient of electrical anisotropy (λ), resistivity for the formation (ρm), reflection coefficient (Rc), and resistivity contrast (Fc). The observations revealed that, in seven out of the eight Vertical Electrical Sounding (VES) measurements, there were typically four subsurface geoelectric layers. However, one VES measurement indicated the presence of only three subsurface geoelectric layers. Notably, the resistivity values for all the layers in the study area were unexpectedly high, surpassing what would be anticipated in a sedimentary basin. The results obtained from the assessment of the formation parameters indicated that the area has a favorable groundwater potential but could potentially be heavily contaminated, particularly from sources such as hydrocarbons and other human-induced pollutants.

Obasi et al. (2022) utilized the Vertical Electrical Sounding (VES) technique to characterize aquifers and assess groundwater potential in Igbo-Imabana, located in Southern Nigeria. The VES method involved conducting measurements at fifteen distinct locations using a Schlumberger array. The maximum electrode distances for potential and current were set as 20 m and 400 m, respectively. The collected VES field data were interpreted using Interpex software, which revealed the presence of three to five geo-electric layers in the study area. These layers were identified as sandstone, clay, saturated sandstone, sandy shale, clayey shale, and shale. The study concluded that the region exhibits heterogeneous lithofacies and contains both confined and unconfined aquifers at different depths.