



REVIEW ON ASSESSING GROUNDWATER CONTAMINATION USING GEOPHYSICAL TECHNIQUES AND SUBSEQUENT REMEDICATION

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Abstract : As groundwater contamination remains a global concern, this review study seeks to provide insights into the use of geophysical techniques for evaluation and remediation in the context of electrical resistivity measurements using the Wenner array. Specifically, the research investigates the principles and benefits of the Wenner array electrical resistivity approach, which involves measuring subsurface electrical conductivity. The Wenner array can detect changes in subsurface resistivity caused by contaminants and geology variables. Particularly emphasizes the importance of RES2DINV, a software tool for inversion modelling and resistivity data interpretation, in improving the accuracy and efficiency of subsurface characterization. The research also looks at a variety of remedial treatments, such as in-situ bioremediation, pump-and-treat systems, and novel methods like phytoremediation. Finally, the study emphasizes the value of the Wenner array approach and RES2DINV software in addressing groundwater contamination, as well as the importance of integrating them to achieve more exact evaluations and effective remediation efforts. As civilizations place greater demands on water resources, the integration of geophysical evaluation and remediation techniques offers a viable way to protecting groundwater quality and guaranteeing sustainable water management.

IndexTerms – Groundwater Contamination, Geophysical Technique, Wenner Array Method, RES2DINV Software, Remediation Techniques.

I. INTRODUCTION

Groundwater, a vital natural resource, sustains ecosystems and provides drinking water to a significant portion of the global population. However, this precious resource is under constant threat from contamination. Solid waste is inevitable because all human activity naturally produces some solid waste. As the pollution grows, as well the rate at which solid garbage is produced. The issue of population expansion in metropolitan centers in developing countries seems to be a topic of much discussion. Multiple research studies confirmed that, among other things, the main reason why more people are moving to cities is their desire for a greater standard of life. Solid waste management (SWM) in developing countries is facing a number of environmental difficulties as a result of the rapid development of cities. The amount and variety of solid waste generated by household, cultural and industrial activities is expanding due to population growth, rising living standards in the majority of African countries, and technological advancements. The well-known term Solid waste management refers to a wide range of actions and procedures that represent the undesirable leftovers and this waste causes as well as harm to plants, animals and ecosystems.

Therefore, proper implementation of a careful SWM will limit the harm done to the environment. Groundwater contamination can originate from various sources, both natural and human-induced. These sources can introduce a wide range of contaminants into the subsurface, compromising the quality of groundwater. Groundwater contamination is an alarming environmental issue that demands rigorous assessment and effective remediation to safeguard both human health and the integrity of ecosystems. The significance of assessing contaminated groundwater and applying suitable remediation strategies cannot be overstated, especially in a world where clean and safe water resources are becoming increasingly scarce. Waste disposal is a significant and ongoing environmental issue. This is an extreme danger to the ecosystem and one of the main causes of groundwater contamination. This project presents a resistivity survey in which CSTs were performed to detect and delineate possible leachate infiltration into the aquifer matrix, as well as to probe the geological setting of the study area using 2-D Resistivity data, with the goal of mapping out potential areas for groundwater development that will not be polluted.

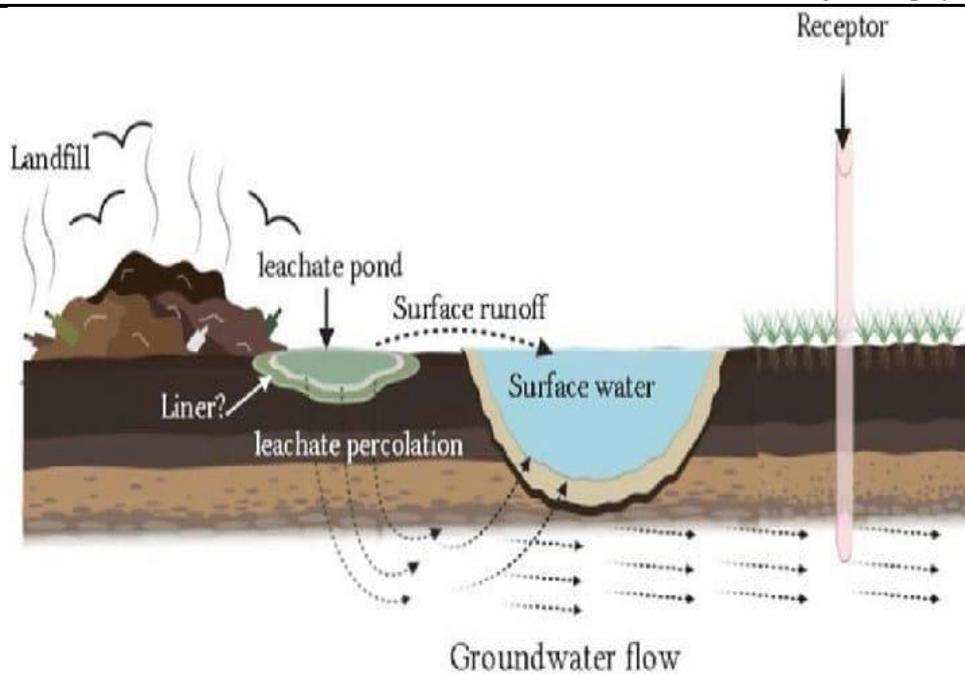


Fig. 1 Leachate affecting Groundwater

Geophysical technologies, particularly electrical resistivity, have developed as effective instruments for describing subsurface conditions, detecting contaminants, and directing remediation activities. This review paper examines the assessment of polluted groundwater, with a special emphasis on the use of electrical resistivity measurements with the Wenner array method and the integration of RES2DINV software. The Wenner array electrical resistivity approach, when combined with the RES2DINV software, provides a non-invasive and reliable way to attain this goal. This approach detects and characterizes contaminated plumes while also delineating subsurface geology features that may impact contamination migration. RES2DINV, a specialist software application, is essential for processing and interpreting electrical resistivity data, allowing for more accurate and detailed subsurface imaging. Throughout this paper, we will look at the principles that underpin the Wenner array approach, as well as analyze its benefits, limitations, and practical applications. In addition, we will offer practical examples of how this method has been successfully applied in real-world circumstances, emphasizing its effectiveness in finding pollution sources and defining subsurface conditions. These examples will demonstrate the method's capacity to identify pollution sources, describe subsurface conditions, and track changes over time. The review article also considers the broader context of groundwater remediation, both in situ and conventional. The kind and concentration of pollutants, site specific circumstances, and implementation feasibility all influence the remedial strategy selected. As groundwater contamination remains a global concern and the demand for clean and safe water supplies grows, it is critical to understand and apply modern techniques like electrical resistivity and RES2DINV software. This review article aims to educate researchers, environmental professionals, and policymakers with useful insights and practical knowledge to help them improve their efforts to protect groundwater quality and ensure sustainable water resource management.

II. STUDY AREA

The Moshi, which has a pin code of 412105 and is located in the Pune district of Maharashtra, between latitudes $18^{\circ}39'23''\text{N}$ and a longitude of $73^{\circ}51'24''$, would be the study's location. For the past thirty years, the Moshi garbage depot, a historically significant 81-acre plot of land on the Pune Nashik highway on the outstroke of the city, has been used by the Pimpri-Chinchwad municipal corporation (PCMC) as a dump for municipal waste. According to the administrators, there is no longer every space in the Moshi dump to accept more waste. The 45-acre PCMC Moshi garbage depot is a disposal facility situated in Pimpri Chinchwad, Pune. However, there is a lack of space and unhygienic conditions near the site as a result of inadequate treatment and inefficient land use practices.

The mixed-waste landfill, spanning more than 80 acres, is located at the garbage depot. Vermicomposting and mechanical composting have been used by PCMC to handle organic trash that was deposited at the depot. The company has removed waste occupied land by scientific capping, but it worries it may soon run out of room. People are also against more dumping on the property and at the planned Poonawale depot. As a result, PCMC has opened bids for the green project.

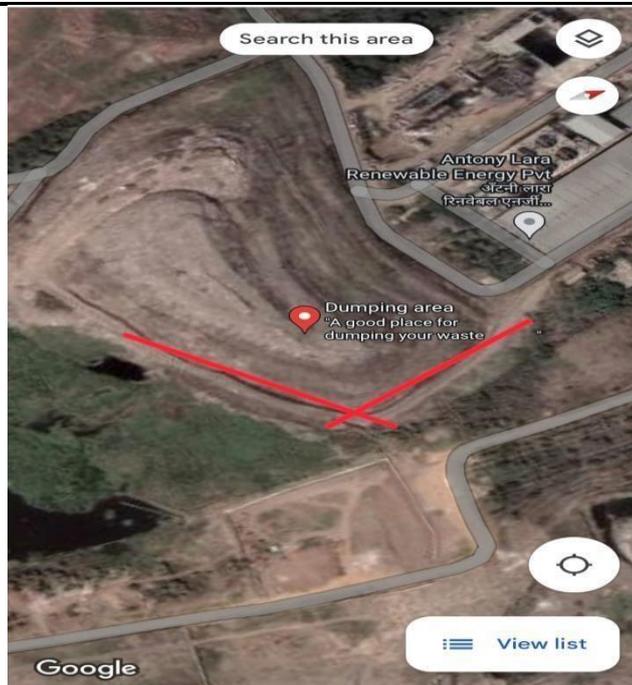


Fig. 2 Study Area

III. METHODOLOGY

3.1 Geophysical Method

Indirect techniques for examining subsurface structures through the collection and analysis of instrumental data are known as geophysical techniques, and they are classified as non-invasive or non-destructive techniques. By comparing the physical characteristics of the underlying materials—such as conductivity or resistivity, dielectric permittivity, magnetism, density, etc.—this technology makes it possible to assess the local geological conditions. They may or may not have their basis in lithological variations and other natural heterogeneities.

One of the primary advantages of using geophysical techniques over traditional subsurface investigation methods, such as surveys, is the ability to evaluate huge areas quickly and at a low cost. Furthermore, geophysical surveys give continuous running profiles, which allow for more exact identification of lateral lithological alterations caused by or deriving from changes in groundwater pollution.

There are two types of geophysical method which are mentioned as follows –

- a. Seismic Refraction Method
- b. Electrical Resistivity Method

Seismic Refraction Method

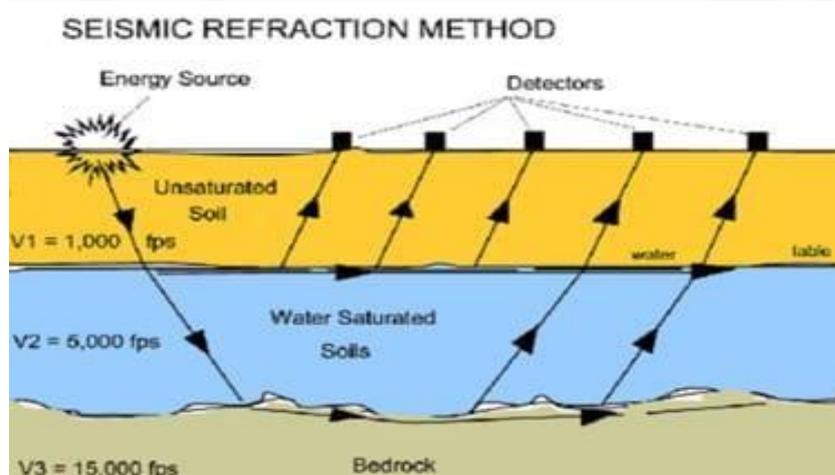


Fig. 3 Seismic Refraction Method

The refraction method is often used to determine groundwater depth. Especially, in porous soils, the unsaturated vs saturated interface is a refracting surface, which is successfully found by the aforementioned method. The seismic-refraction method determines how long it takes a seismic-energy pulse to travel from a source point to multiple receivers after being redirected by one or more subsurface interfaces. Data-based seismic-velocity discontinuities and magnitudes can be used to determine hydrogeologic contact depths and geologic material types. refraction method is widely used for the characterization of groundwater

depth. In particular, in porous soils, the unsaturated vs saturated interface, is arefracting surface, efficaciously detected by the afore- mentioned exploration method.

3.2 Electrical Resistivity Method

The electrical resistivity method is the most extensively employed, and it has proven particularly useful in groundwater research since several geological formation features, including as porosity and permeability, are important in hydrogeology and may be connected with electrical conductivity signatures. This approach is also generally regarded for its portability of equipment, ease of operation, applicability, and efficiency in drilling operations. As a result this job is carried out using the Electrical resistivity method.

Electrical resistivity methods evaluate the ability of an electrical current to pass through the subsurface. Thus, resistivity methods require an electrical connection (i.e., galvanic coupling) with the ground, which is achieved by the use of metal electrodes. Direct current (DC) is usually provided between two chosen current electrodes that are implanted in the ground using a battery- operated power source. The transmitted current and the voltage generated across the potential electrodes are recorded for every resistivity measurement. The data is often collected by a resistivity meter, also known as a combination ammeter- voltmeter, which then displays the computed output as the ratio of observed voltage to induced current.

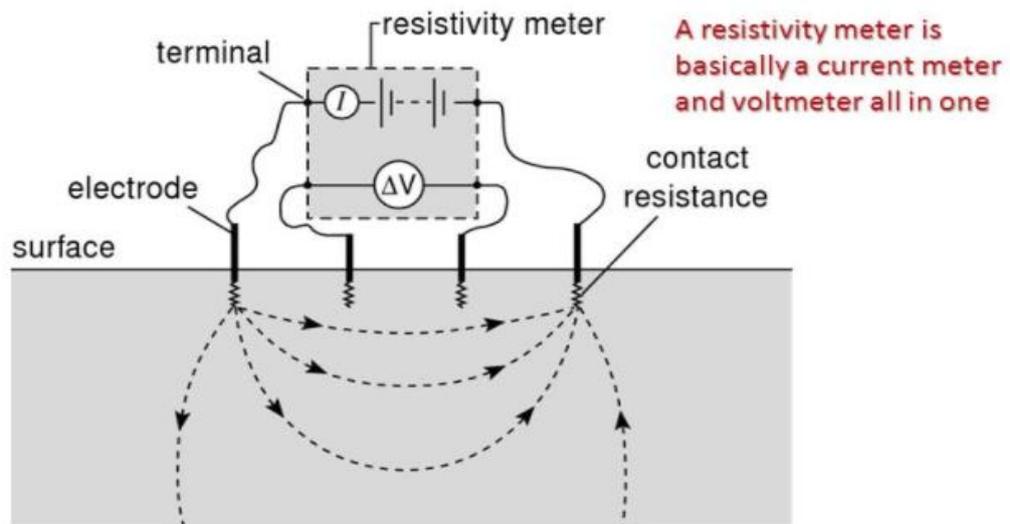


Fig. 4 Electrical Resistivity Method

There are two types of electrical resistivity

1. Wenner Array Method
2. Schlumberger Array Method

3.2.1. Wenner Array Method

It's the easiest approach. The wenner system operates on the principle that the distance between two electrodes equals the depth of examination times the separation between each electrode. For instance, we obtain the result for a depth of 50 m if the two electrodes are 50 m apart and more. Consequently, apparent resistivity contours for various electrode separations can be presented.

In this procedure, four electrodes are positioned in a line, equally spaced apart: A, P, Q, B. The two inner electrodes, P and Q, are potential, while the two outer electrodes, A and B, indicate current. The wenner array modifies the spacing between electrodes while maintaining a constant array center point to measure the resistivity of underlying layers. Electrical drilling or vertical electrical sounding (VES) are the terms used to describe this process. By moving the four electrodes across the surface while maintaining a constant electrode separation, differences in horizontal resistivity can be measured. This technique is called electrical trenching, or profiling.

Soil resistivity calculation formula Equation 1: shows the soil resistivity formula associated with the Wenner 4 Probe test method. Where,

R - is the resistance measured by the machine

a - is the spacing of the probe

$$\rho = 2\pi aR \quad (1)$$

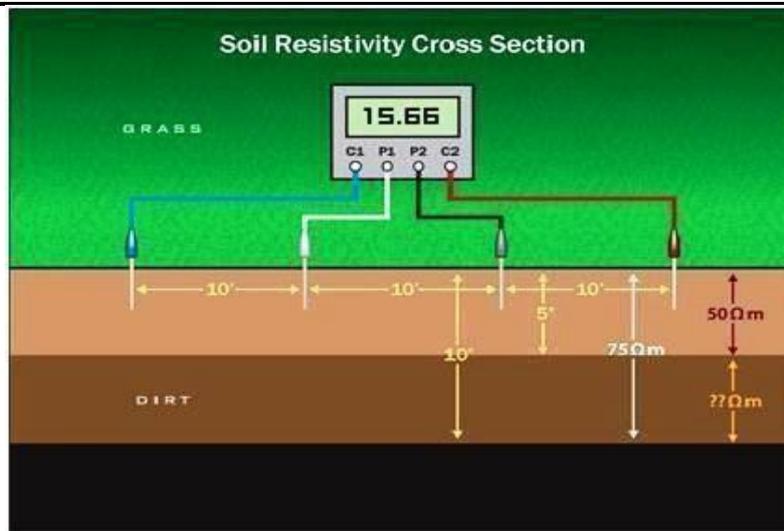


Fig. 5 Wenner Array Test

3.3 Electrical Resistivity Data Analysis

Electrical resistivity data analysis is an important process used to determine groundwater contamination. The vertical electrical soundings (VES) were geographically typical of the entire subbasin. The resistivity vs. current electrode spacing for each location was graphed using the RES2DINV Software. . These plots were used to calculate the thickness of the subsurface layers as well as their resistivity values. The resistivity obtained by the Wenner Array Test is then compared to the conventional resistivity value of various materials.

The conventional resistivity value with which the comparison of resistivity obtain by Wenner Array Test is done are mentioned in below table.

Table 1 Resistivity of Sample Material

Sampled Material	Resistivity (Ω -m)
Leachate only	2.994
Sand saturated with leachate	4.67-5.04
Fresh waste (plant materials, rubber, strands, and) saturated with leachate	6.03-7.16
Soil saturated with leachate	3.15-4.00
Rain water only	73.88
Sand saturated with rainwater	14.36-17.50
Fresh waste (plant materials, rubber, strands, and) saturated with rainwater	19.71-22.50
Soil saturated with rain water	9.30-10.57
Clay saturated withw brackish water	0.12-0.20
Clean and saturated with sea water	1.5-3.5
Fresh sand stone	600
Phyllite	300
Hard rock	>600

3.4 Software Used

RES2DINV is one of the most widely used inversion software for calculating 2D resistivity and chargeability models. The program was developed to interpolate and analyze field data for electrical resistivity (conductivity) and induced polarization from electrical geophysical prospecting (2D sounding). Using the finite element and finite difference approaches, the resistivity and IP values are reversed by the application of the least- squares method. Any electrode array, including wenner (a, b, g), dipole-dipole, inline pole- dipole, pole-pole, wenner-Schlumberger, equatorial pole-dipole, and non-conventional arrays, can have its data processed by the software. With apparent resistivity data, the RES2DINV application uses Sasaki's smoothness-constrained least squares method inversion methodology from 1992 to create a 2D representation of the Subsurface. Since this process is fully

automated, the user need not to provide an initial model. On a Pentium- based microcomputer, the RES2DINV program automatically, while users have the option to modify them if needed. The least- squares approach is provided in three different iterations: a quick quasi- Newton Method, and a reasonably fast and precise hybrid approach. In the RES2Dinv program, resistivity differences in both vertical and horizontal directions can be emphasized by adjusting the smoothing filter. In addition, the filter can be tuned to produce models with sharp edges, like chemical plumes. Data on resistivity from boreholes and other sources to constrain the inversion process other sources might be included.

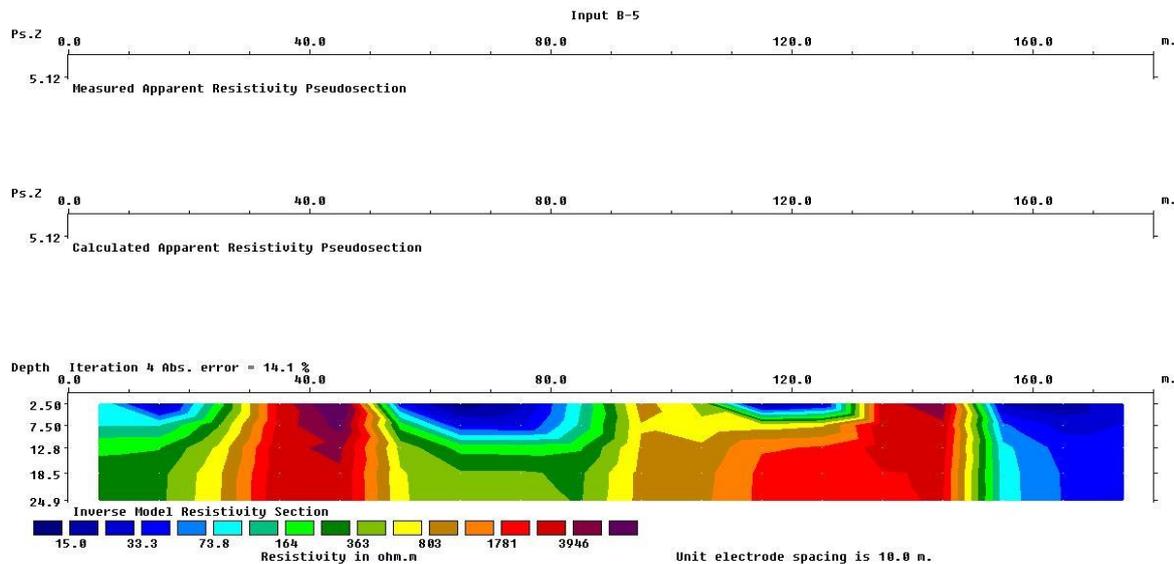


Fig. 6 Graph obtain by RES2DINV Software

IV. REMEDIATION OF GROUNDWATER POLLUTION

In addressing the issue of groundwater pollution, various remediation techniques are employed based on the nature of contaminants and site-specific conditions. The chosen remediation strategies play a pivotal role in mitigating the impact on aquifers and ensuring compliance with regulatory standards. Noteworthy approaches include pump-and-treat systems, in situ bioremediation, chemical injection, permeable reactive barriers, phytoremediation, and the extraction and treatment of contaminated soil. Each method is selected based on its effectiveness in addressing specific pollutants and the unique characteristics of the contaminated site. Furthermore, ongoing advancements in innovative technologies contribute to the evolving landscape of groundwater remediation efforts. This multifaceted approach underscores the complexity of addressing groundwater pollution and highlights the need for tailored strategies to achieve sustainable and successful outcomes. Continuous monitoring and periodic adjustments remain integral components of effective groundwater remediation practices.

4.1. Pump and Treat Technique

The pump-and-treat technique is a widely used method for the remediation of groundwater contaminated with various pollutants. In this approach, wells are strategically placed in the contaminated area to extract groundwater. The extracted water is then brought to the surface for treatment, where various processes are employed to remove or mitigate the pollutants. Treatment methods may include filtration, chemical treatment, or other technologies depending on the nature of the contaminants. The primary goal of pump-and-treat is to prevent the further spread of contaminants and to remediate the groundwater to meet regulatory standards. This technique is particularly effective for addressing dissolved pollutants, as it involves the physical removal of water from the subsurface. Continuous monitoring of extraction rates, water quality, and periodic adjustments to the treatment processes are crucial components of successful pump-and-treat systems. While it has been a valuable remediation method, it's essential to consider site-specific conditions and the nature of the contaminants to determine the suitability and effectiveness of pump-and-treat in a given situation. This is a slow, basic process. In this procedure, contaminated groundwater is drawn out of aquifers, cleaned, and either reinjected into aquifers or discharged into a surface water body (Nwachukwu 2014). The cost of this remediation technique is high (Mackay and Cherry 1989).

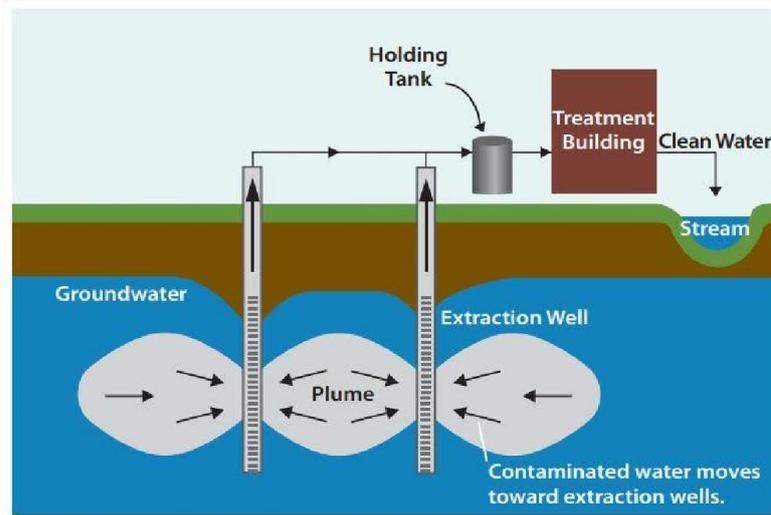


Fig. 7 Pump and treat technique

4.2. In Situ Soil Vapor Extraction Treatment Technique (SVE)

In situ soil vapor extraction (SVE) is a remediation strategy employed to address soil contamination, particularly when dealing with volatile organic compounds (VOCs). This technique aims to enrich the natural process of contaminant volatilization by injecting air or other gases into the subsurface. SVE is typically implemented by drilling extraction wells into the contaminated soil. Air or vapor is then injected into these wells, creating a pressure gradient that encourages the movement of contaminants from the soil matrix to the vapor phase. As air permeates through the soil, contaminants with high vapor pressure tend to volatilize. The vaporized contaminants are then extracted through the same wells used for injection. This process helps to reduce the concentration of contaminants in the soil. Extracted vapors are treated at the surface using technologies such as activated carbon adsorption, thermal oxidation, or other methods suitable for the specific contaminants. This ensures that pollutants are properly contained and do not re-enter the environment. In situ SVE is particularly effective for shallow contamination and is commonly used in industrial sites, landfills, and areas with subsurface pollution. The success of the technique depends on factors like soil permeability, contaminant type, and site-specific conditions. In situ SVE offers several advantages, including its ability to treat large volumes of soil, cost-effectiveness compared to excavation, and minimal surface disruption. Site characterization, monitoring, and periodic adjustments are essential for the success of in situ SVE. The effectiveness of the technique can vary based on the specific contaminants and soil conditions. Overall, in situ soil vapor extraction is a valuable remediation method, contributing to the restoration of contaminated sites while minimizing environmental impact. In-situ vapor extraction is a practical and economical approach of VOC cleanup. For the unsaturated zone, this approach is used (Reddy et al., 1995). This system includes a vacuum pump, a treatment system for vapor extraction, and one or two extraction wells (Nwachukwu 2014).

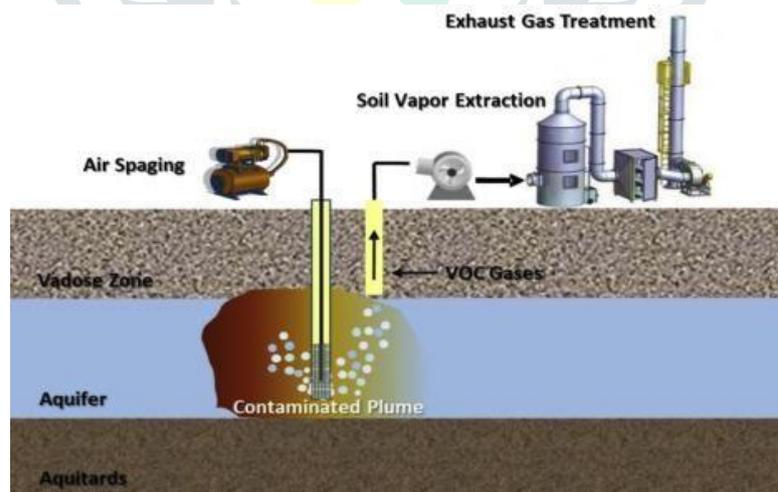


Fig. 8 In situ soil vapor extraction treatment technique

4.3. In-Situ Chemical Treatment Technique

In-situ chemical treatment is a remediation approach designed to mitigate soil and groundwater contamination by directly applying chemical agents below the ground surface. This technique aims to transform or immobilize contaminants, reducing their impact on the environment. Chemical agents, such as oxidants or reductants, are injected into the contaminated subsurface through wells or other injection points. The choice of chemical depends on the type of contaminants present. The injected chemicals react with the contaminants, initiating processes such as oxidation, reduction, or precipitation. These reactions can break down or transform the contaminants into less harmful substances. In-situ chemical treatment can involve various mechanisms, including enhanced biodegradation, chemical oxidation, or chemical reduction. For example, injecting oxidants can promote the breakdown of organic

contaminants, while reductants may reduce the mobility of heavy metals. This technique is applicable to a range of contaminants, including organic compounds and certain heavy metals. It is commonly used in areas with shallow groundwater contamination, contaminated soil, or both. In-situ chemical treatment offers advantages such as minimal surface disruption, reduced costs compared to excavation and off-site treatment, and the ability to target specific contaminants. Continuous monitoring of the remediation process is crucial for assessing effectiveness. Adjustments to the treatment parameters may be necessary based on ongoing site conditions and the progress of chemical reactions. In-situ chemical treatment is a versatile remediation technique that directly addresses subsurface contamination, offering a targeted and environmentally friendly approach to soil and groundwater restoration. Chemicals are pumped underground during this treatment to change the contaminants. This method involves putting chemicals in the head of a groundwater pollution area using a sequence of wells. According to Reddy et al. (1995), these compounds lessen pollution and change into less harmful and mobile phases. This treatment uses hydrogen peroxide, ozone, and potassium permanganate as oxidizing agents and sulfur dioxide, sulfide salts, ferrous sulphate, metallic iron, and zinc as reducing agents (Nwachukwu 2014).

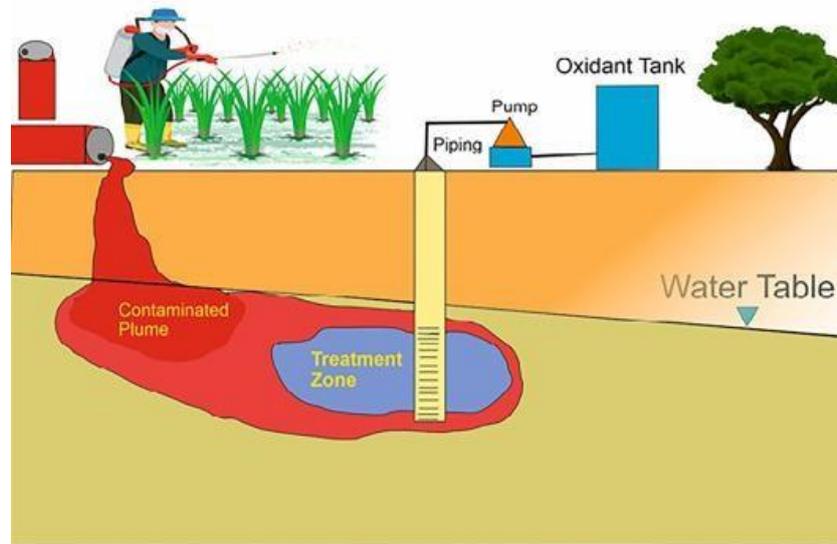


Fig. 9 In-situ chemical treatment technique

4.4. In-Situ Thermal Treatment Technique

In-situ thermal treatment is a remediation strategy designed to mitigate soil and groundwater contamination by applying heat directly to the subsurface. This technique aims to enhance the removal or transformation of contaminants through elevated temperatures. Heat is introduced into the subsurface using various methods, such as electrical resistance heating, steam injection, or hot air injection. This is typically done through wells strategically placed in the contaminated zone. The application of heat induces several beneficial processes, including enhanced volatilization of contaminants, increased microbial activity for biodegradation, and the promotion of chemical reactions that can break down or transform pollutants. Volatilized contaminants can be collected using vapor extraction systems, and the extracted vapor is then treated at the surface. In some cases, the heat-induced changes in contaminant properties make them more amenable to natural attenuation processes. In-situ thermal treatment is suitable for a range of contaminants, including volatile organic compounds (VOCs) and certain semi-volatile organic compounds. It is often used in areas with shallow groundwater contamination or in the vadose zone. This technique offers advantages such as the ability to target a specific area, the potential for rapid treatment, and the applicability to a variety of contaminants. Site-specific factors, including soil characteristics, hydrogeology, and the nature of contaminants, influence the success of in-situ thermal treatment. Comprehensive site characterization is crucial for designing an effective and efficient treatment plan. With this method, we raise the subsurface temperature. As a result, organic contaminants will mobilize more quickly owing to improved volatilization, soil desorption, greater water solubility, and higher fluid flow rates (Nwachukwu 2014).

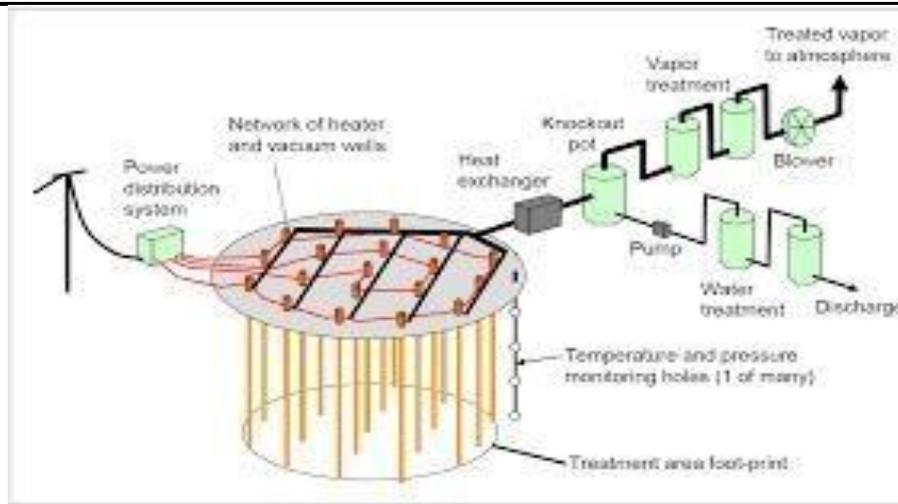


Fig. 10 In situ thermal treatment technique

4.5. Nano Treatment Technique

Reactive nanoparticles are employed in this technique to convert and detoxify pollutants. Nanoparticles can minimize the pollutants of concern through both chemical reduction and catalysis. Pumping out groundwater and moving soil are not necessary in nano remediation (Otta et al., 2008 and Nwachukwu 2014). Nanoparticles have a diameter of between 10 and 100 nm. One application for iron powder is as a nanoparticle. Chlorine is efficiently reduced by Fe reacting with a chlorinated solution. A lab test demonstrated that 99% of as were removed by a Fe particle with a diameter of 12 nm (Rickerby and Morrison 2007). An effective strategy for environmental cleanup is nanotechnology.



Fig. 11 Nano treatment technique

V. RESULTS AND DISCUSSION

After a thorough analysis of the previous research conducted by the mentioned authors, it is observed that interpreting geophysical data can help to determine lithology, stratigraphy, water table depth, foundation depth, and other geological properties of importance. Geophysical methods are used to analyze the existence of contamination in depth, with a particular focus on the location of waste canals. The use of two or more distinct geophysical approaches improves interpretation accuracy and identifies the nature of the contamination. Geophysical survey results are valuable not only for finding monitoring wells, but also for providing estimates of area and volume for contaminated soil removal and remediation efforts. Furthermore, they can be used to lessen the risk of drilling waste-filled tanks and buried drums, as well as pipelines and subterranean galleries.

Electrical Resistivity Surveys were conducted to determine the conductivity and resistivity qualities of rocks and soil near a reclaimed dumpsite. The purpose of this investigation is to determine Ground Water Contamination. The goal of this research is to provide a better solution in the form of ground profile locating areas in contaminated water zones and remedial procedures. To enable PCMC or the client to use project data in future decision-making. The goal of this research was not only to uncover groundwater contamination, but also to provide a solution to PCMC.

VI. ACKNOWLEDGMENT

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