

Environmental Geophysics for Sustainable Earth Management and Pollution Risk Mitigation

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DESCRIPTION

Environmental geophysics is a specialized subfield of geophysics focused on the application of non-invasive physical methods to investigate and monitor the Earth's near-surface environment. Unlike traditional geophysical applications that target deep subsurface exploration for oil, gas, or minerals, environmental geophysics addresses critical issues related to soil, water, waste, and contamination. It plays a vital role in environmental assessment, remediation, land-use planning, and natural resource protection by providing detailed subsurface information without the need for extensive drilling or excavation.

The essence of environmental geophysics lies in its ability to reveal what lies beneath the surface of the Earth using indirect measurements. By interpreting the physical properties of rocks, soils, and fluids—such as electrical conductivity, magnetic susceptibility, seismic velocity, and density—geophysicists can detect anomalies, delineate underground structures, and monitor environmental changes over time. These insights are essential for understanding contamination pathways, identifying buried waste, mapping groundwater resources, and assessing geohazards like sinkholes or landslides.

One of the most commonly used techniques in environmental geophysics is electrical resistivity. This method involves injecting electrical current into the ground through electrodes and measuring the resulting voltage differences. Different materials conduct electricity differently; contaminated soil and groundwater, for example, typically show lower resistivity than clean, dry soil. Electrical Resistivity Tomography (ERT) provides two- or three-dimensional images of the subsurface and is widely used to map leachate plumes from landfills, locate saline intrusions in aquifers, and monitor changes in moisture content related to seasonal variations or climate impacts.

Ground-Penetrating Radar (GPR) is another valuable tool in environmental geophysics. GPR sends high-frequency electromagnetic waves into the ground and records the signals that reflect off subsurface objects or interfaces. It is particularly effective in identifying buried objects, such as underground storage tanks, pipes, or construction debris. GPR is also used in

archaeology, utility mapping, and the inspection of infrastructure like roads and bridges. Its high resolution makes it ideal for shallow investigations, although its effectiveness decreases in highly conductive or clay-rich soils.

Seismic methods, commonly associated with earthquake studies and petroleum exploration, are also applied in environmental geophysics. Seismic refraction and reflection techniques use controlled sources to generate seismic waves and record how they travel through different subsurface materials. These methods are useful for identifying stratigraphic layers, detecting voids or fractures, and assessing soil stiffness for construction planning. In contaminated sites, seismic techniques can help determine the depth of the water table or locate interfaces between clean and polluted zones.

Electromagnetic (EM) methods are widely used for environmental and engineering investigations. These techniques measure the response of the subsurface to electromagnetic fields, providing information about conductivity variations. EM surveys are fast and efficient, making them suitable for mapping large areas such as industrial sites, agricultural lands, or reclaimed mining zones. EM methods are also used in detecting metal contaminants, saline water intrusion, and buried waste, supporting environmental monitoring and remediation planning.

Magnetic surveys, though more commonly used in mineral exploration, have important environmental applications as well. They detect variations in the Earth's magnetic field caused by subsurface features, including metallic waste, drums, or buried infrastructure. Magnetic methods are particularly useful in preliminary site assessments where potential environmental hazards may be present but not well documented. When combined with other geophysical techniques, magnetic surveys contribute to a more complete picture of subsurface conditions.

One of the most significant applications of environmental geophysics is in groundwater studies. Freshwater is a precious and limited resource, and understanding how it flows through and is stored in the subsurface is crucial for its sustainable management. Geophysical surveys help locate aquifers,

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determine their extent and depth, identify recharge zones, and monitor seasonal fluctuations in the water table. In areas affected by overuse or contamination, geophysics provides the data needed to manage resources effectively and protect public health.

Environmental geophysics also supports brownfield redevelopment and site remediation efforts. Before construction can begin on previously developed or contaminated land, thorough investigations must be conducted to identify environmental risks. Geophysical methods offer a cost-effective, non-destructive way to detect contaminants, evaluate the integrity of containment structures, and monitor the success of cleanup activities. These techniques help reduce uncertainty, lower project costs, and ensure compliance with environmental regulations.

As climate change and urbanization continue to reshape the planet, the importance of environmental geophysics is growing. Rising sea levels, increased flooding, and more intense weather events pose new challenges for land-use planning and disaster preparedness. Geophysical methods can assess soil stability, monitor levees and dams, evaluate erosion risks, and provide early warning of geohazards. This information is essential for building resilient communities and protecting ecosystems under changing environmental conditions.

The integration of environmental geophysics with Geographic Information Systems (GIS), remote sensing, and real-time monitoring networks further enhances its capabilities. Combining spatial data with geophysical results allows for comprehensive environmental modeling and decision-making. Additionally, advances in data processing, inversion techniques, and machine learning are making geophysical analysis faster, more accurate, and more accessible to engineers, planners, and environmental scientists.

CONCLUSION

In conclusion, environmental geophysics is an indispensable tool for understanding and managing the Earth's near-surface environment. Its ability to provide high-resolution, non-invasive subsurface information makes it essential for addressing today's environmental challenges from groundwater protection and contamination cleanup to sustainable development and disaster mitigation. As the demand for safe, clean, and resilient environments increases, environmental geophysics will continue to play a key role in guiding responsible and informed decision-making for the benefit of people and the planet.