

GPH414

ENVIRONMENTAL GEOPHYSICS



Download on the
App Store



GET IT ON
Google Play

Course video is available on our app

lanetonline.com

COURSE CODE:GPH 414

COURSE TITLE: Environmental Geophysics

COURSE UNIT LOAD (2 Units C: LH 30)

- Foundations of Environmental Geophysics and Earth Science Concepts.
- Geophysical Techniques in Environmental Pollution Studies.
- Saline Water Intrusion and Groundwater Quality Mapping.
- Geophysical Investigation of Chemical Pollution and Industrial Contamination.
- Oil Spillage, Pollution Delineation, and Environmental Mapping.

Part 1.1 Environmental geophysics within earth science.

- Core earth science concepts relevant to environmental studies
- Scope and definition of environmental geophysics
- Relevance of geophysics to environmental problem-solving

Part 1.2 Environmental processes and pollution pathways.

- Natural and anthropogenic environmental processes
- Types and sources of environmental pollution
- Behaviour and movement of contaminants in the subsurface

Part 1.3 Role of geophysical techniques in environmental investigations.

- Physical principles underlying geophysical methods
- Relationship between subsurface properties and environmental conditions
- Overview of geophysical applications in environmental studies

Introduction

Environmental geophysics is an applied branch of geophysics that uses earth science principles and geophysical techniques to investigate environmental problems affecting the subsurface. These problems include pollution arising from human activities and natural processes that impact soil, groundwater, and near-surface geological materials. Because many environmental hazards are hidden beneath the ground surface, indirect geophysical methods provide valuable information for understanding subsurface conditions without extensive excavation or disturbance.

The aim of this Series is to introduce you to the foundations of environmental geophysics and the essential earth science concepts that support its application to environmental investigations.

We shall commence this Series by examining the place of environmental geophysics within the broader field of earth science, focusing on its definition, scope, and relevance to environmental problem-solving. We will then consider key environmental processes and pollution pathways, highlighting how contaminants are introduced into the environment and how they move through the subsurface. Finally, the Series will provide an overview of the role of geophysical techniques in environmental investigations, emphasising how variations in subsurface physical properties are used to detect and assess environmental conditions related to pollution and groundwater quality.

Series learning outcomes



Upon completing this Series, you should be able to:

- **SLO 1.1** explain the scope of environmental geophysics within the context of earth science and environmental studies.
- **SLO 1.2** describe key environmental processes and identify major types and sources of environmental pollution affecting the subsurface.
- **SLO 1.3** analyse how contaminants move through soil and groundwater systems using earth science principles.
- **SLO 1.4** explain the role of geophysical techniques in detecting, assessing, and monitoring environmental conditions related to pollution and groundwater quality.

1.1 Environmental Geophysics within Earth Science

1.1.1 Core earth science concepts relevant to environmental studies

Earth science refers to the group of scientific disciplines that study the Earth as a system, including its physical structure, materials, processes, and interactions with the environment. In environmental studies, earth science concepts help explain how natural systems operate and how human activities disturb these systems, particularly in the near-surface environment.

Key earth science concepts relevant to environmental geophysics include the nature of soils and rocks, groundwater systems, and surface–subsurface interactions. These elements control how contaminants enter the ground and how they are stored or transported underground. For example, porous soils allow fluids to move more easily than compact rocks, influencing the spread of pollutants.

Understanding these basic earth science principles provides the foundation for applying geophysical techniques to environmental problems.

Fill in the blank: Earth science provides the basic understanding of how the _____ system operates and responds to natural and human influences.

[Insert figure here]

Short description: Earth systems relevant to environmental studies

Figure 1.1: Major components of the Earth system relevant to environmental geophysics

Suggested AI prompt: *Create a simple diagram showing soil, rock, groundwater, and human activities interacting within the Earth system*

1.1.2 Scope and definition of environmental geophysics

Environmental geophysics is the application of geophysical methods to investigate environmental problems, particularly those related to pollution, groundwater quality, and near-surface contamination. It focuses on detecting and characterising subsurface features that may pose risks to human health or the environment.

The scope of environmental geophysics includes mapping contaminated zones, identifying saline water intrusion, locating chemical pollution at industrial sites, delineating pollutant plumes, and assessing groundwater quality. Unlike traditional exploration geophysics, which often targets deep structures, environmental geophysics concentrates on the shallow subsurface where environmental hazards are most likely to occur.



Because direct subsurface excavation is expensive and disruptive, environmental geophysics provides a non-invasive and cost-effective approach to environmental investigation.

Pause and reflect: Environmental geophysics focuses mainly on the _____ subsurface environment.

[Insert plate here]

Short description: Environmental geophysics applied to near-surface investigations

Plate 1.1: Use of geophysical surveys to investigate shallow environmental problems

Suggested AI prompt: *Create an illustration showing geophysical instruments investigating shallow subsurface contamination*

1.1.3 Relevance of geophysics to environmental problem-solving

Geophysical techniques are highly relevant to environmental problem-solving because many environmental hazards cannot be seen directly at the ground surface. Contaminants such as chemical plumes, saline water intrusion, and oil spills often spread underground, making detection and monitoring difficult using surface observations alone.

By measuring variations in physical properties such as electrical resistivity or conductivity, geophysical methods help identify areas affected by pollution and distinguish contaminated zones from clean subsurface materials. These methods support environmental assessment, remediation planning, and long-term monitoring of pollution impacts.

The ability of geophysics to provide continuous subsurface information over large areas makes it an essential tool in modern environmental management.

Fill in the blank: Geophysical methods assist environmental problem-solving by providing _____ information about subsurface conditions.

[Insert table here]

Table 1.1: Role of geophysical techniques in environmental investigations

[Insert table placeholder here]

Short description: Examples of environmental problems and associated geophysical approaches

Suggested AI prompt: *Generate a table linking environmental problems to geophysical investigation methods*

Pilot questions 1.1

1. What is meant by earth science in the context of environmental studies?
2. Define environmental geophysics.
3. State two environmental problems investigated using geophysical techniques.
4. Why does environmental geophysics focus mainly on the near-surface?
5. Explain one reason why geophysics is important for environmental problem-solving.

1.2 Environmental Processes and Pollution Pathways

1.2.1 Natural and anthropogenic environmental processes



Environmental processes are the physical, chemical, and biological activities that occur within the Earth system and influence the condition of the environment. These processes may be natural or human-induced. **Natural processes** include weathering of rocks, groundwater flow, erosion, and natural geochemical reactions, which operate continuously even in the absence of human activity.

Anthropogenic processes arise from human actions such as industrial operations, waste disposal, agriculture, mining, and urban development. These activities can introduce contaminants into the environment or intensify natural processes, leading to environmental degradation. For example, excavation and construction may disrupt soil structure, while industrial discharge can alter groundwater chemistry.

Distinguishing between natural and anthropogenic processes is important in environmental geophysics because it helps in identifying the origin of observed subsurface anomalies.

Fill in the blank: Environmental processes may be natural or _____, depending on whether they arise from human activity.

[Insert figure here]

Short description: Natural and anthropogenic environmental processes

Figure 1.2: Examples of natural and human-induced environmental processes affecting the subsurface

Suggested AI prompt: *Create a diagram showing natural processes such as weathering and groundwater flow alongside anthropogenic activities such as industrial discharge and waste disposal*

1.2.2 Types and sources of environmental pollution

Environmental pollution refers to the introduction of substances or energy into the environment that cause harm to ecosystems, human health, or natural resources. Pollution may occur in solid, liquid, or gaseous forms and may be introduced intentionally or unintentionally.

Common sources of environmental pollution include industrial effluents, petroleum products, agricultural chemicals, landfill leachate, and domestic waste. In the subsurface environment, pollutants frequently include hydrocarbons, heavy metals, saline water, and chemical solvents. These contaminants may enter soil and groundwater systems through leaks, spills, infiltration, or improper waste disposal practices.

Identifying the type and source of pollution is a critical step in environmental investigation because it influences the choice of geophysical techniques and the interpretation of survey results.

Pause and reflect: Industrial effluent, oil spillage, and landfill leachate are examples of _____ sources of environmental pollution.

[Insert plate here]

Short description: Common sources of environmental pollution

Plate 1.2: Major anthropogenic sources of soil and groundwater pollution

Suggested AI prompt: *Create an illustration showing industrial sites, oil spills, and landfills as sources of subsurface pollution*



1.2.3 Behaviour and movement of contaminants in the subsurface

Once pollutants enter the ground, their **subsurface behaviour** is controlled by physical, chemical, and biological interactions with soil, rock, and groundwater. Contaminants may move vertically through infiltration or laterally with groundwater flow, forming polluted zones known as plumes.

The movement of contaminants depends on factors such as soil permeability, groundwater velocity, chemical properties of the pollutant, and the presence of confining layers. For example, saline water and dissolved chemicals can migrate easily through permeable sands, while clay layers may slow contaminant movement or cause accumulation. Some contaminants may adsorb onto soil particles or undergo chemical transformation, altering their mobility.

Understanding contaminant pathways is essential for environmental geophysics, as geophysical surveys aim to detect changes in subsurface physical properties caused by the presence and movement of pollutants.

Fill in the blank: Contaminants often migrate laterally in the subsurface along _____ flow paths.

[Insert table here]

Table 1.2: Factors influencing contaminant movement in the subsurface

[Insert table placeholder here]

Short description: Summary of processes controlling pollutant transport underground

Suggested AI prompt: *Generate a table showing how soil properties, groundwater flow, and pollutant characteristics influence subsurface contaminant movement*

Pilot questions 1.2

1. What are environmental processes?
2. Distinguish between natural and anthropogenic environmental processes.
3. State two common sources of subsurface environmental pollution.
4. Explain how pollutants enter soil and groundwater systems.
5. Why is understanding contaminant behaviour important in environmental geophysics?

1.3 Role of Geophysical Techniques in Environmental Investigations

1.3.1 Physical principles underlying geophysical methods

Geophysical techniques are based on the measurement of physical properties of the Earth that vary with subsurface conditions. These properties include electrical resistivity, conductivity, seismic velocity, density, and magnetic characteristics. Environmental investigations rely on the fact that pollution, saline water intrusion, and changes in groundwater quality often alter these physical properties relative to natural background conditions.

For example, contaminated groundwater containing dissolved chemicals generally exhibits higher electrical conductivity and lower resistivity than clean groundwater. Similarly, oil spills or chemical plumes may change the physical structure of soil and rock, producing detectable anomalies in geophysical data. By measuring such contrasts from the surface, geophysical methods provide indirect but reliable insight into subsurface environmental conditions.



Understanding these physical principles is essential for selecting appropriate geophysical techniques and interpreting survey results correctly.

Fill in the blank: Geophysical techniques detect environmental problems by measuring changes in subsurface _____ properties.

[Insert figure here]

Short description: Physical properties measured in environmental geophysics

Figure 1.3: Subsurface physical property contrasts caused by environmental contamination

Suggested AI prompt: *Create a diagram showing clean and contaminated subsurface zones with contrasting physical properties*

1.3.2 Relationship between subsurface properties and environmental conditions

Environmental conditions in the subsurface directly influence measurable physical properties.

Subsurface properties such as porosity, fluid content, salinity, and chemical composition determine how geophysical signals behave during a survey. When environmental pollution alters these properties, geophysical methods can detect the resulting changes.

For instance, saline water intrusion increases groundwater conductivity, while chemical pollution from industrial sources can reduce resistivity and modify seismic response. In oil spillage scenarios, hydrocarbons may displace groundwater and alter pore fluid composition, creating distinctive geophysical signatures. These relationships form the basis for using geophysics to assess groundwater quality and identify polluted zones.

Linking geophysical measurements to environmental conditions allows interpretation to move beyond detection toward meaningful environmental assessment and monitoring.

Pause and reflect: Changes in groundwater quality often produce detectable _____ contrasts in geophysical surveys.

[Insert plate here]

Short description: Environmental conditions influencing geophysical responses

Plate 1.3: Effect of groundwater quality and pollution on subsurface geophysical properties

Suggested AI prompt: *Create an illustration showing how polluted and unpolluted groundwater affect geophysical responses*

1.3.3 Overview of geophysical applications in environmental studies

Geophysical techniques are applied widely in environmental studies to investigate and monitor pollution and groundwater quality. Typical applications include mapping saline water intrusion in coastal areas, delineating chemical plumes at industrial sites, identifying zones affected by oil spillage, and assessing the extent of subsurface contamination.

In groundwater quality studies, geophysical surveys help distinguish between fresh and saline groundwater and identify areas affected by chemical pollution. In industrial settings, they are used to track the spread of contaminants without disturbing the ground, supporting remediation planning.



These applications demonstrate the versatility of environmental geophysics as a diagnostic and monitoring tool.

By providing continuous subsurface coverage, geophysical methods enhance environmental decision-making and support sustainable management of land and water resources.

Fill in the blank: Environmental geophysics supports pollution assessment by mapping contaminated _____ zones.

[Insert table here]

Table 1.3: Common environmental problems and their geophysical investigation approaches

[Insert table placeholder here]

Short description: Summary of environmental applications of geophysical techniques

Suggested AI prompt: *Generate a table linking environmental problems such as pollution, saline intrusion, and oil spillage with appropriate geophysical methods*

Pilot questions 1.3

1. What physical principle makes geophysical methods useful in environmental investigations?
2. Explain how environmental pollution affects subsurface physical properties.
3. Give two examples of environmental conditions that alter geophysical responses.
4. Why is understanding subsurface property variation important for interpretation?
5. State one application of geophysical techniques in environmental studies.

Series summary

This Series introduced the **foundations of environmental geophysics** and the essential earth science concepts that underpin its application to environmental investigations. Its importance lies in establishing a clear understanding of how geophysical principles are used to study environmental problems that affect the near-surface subsurface, particularly pollution and groundwater quality issues that are not directly observable from the surface.

We began by examining environmental geophysics within the broader context of earth science, highlighting its definition, scope, and relevance to environmental problem-solving. Emphasis was placed on understanding soils, rocks, groundwater systems, and surface–subsurface interactions as fundamental components of environmental investigations. We then explored environmental processes and pollution pathways, distinguishing between natural and anthropogenic processes, identifying major sources of environmental pollution, and explaining how contaminants move through soil and groundwater. Finally, we examined the role of geophysical techniques in environmental investigations, focusing on the physical principles that govern geophysical measurements, the relationship between subsurface properties and environmental conditions, and the application of geophysical methods to problems such as pollution detection and groundwater quality assessment.

As a result of this Series, you should now be able to explain the scope of environmental geophysics, describe key environmental processes and pollution pathways, analyse contaminant behaviour in the subsurface, and explain how geophysical techniques are applied to detect and assess environmental conditions. These foundational concepts provide the basis for more detailed study of specific environmental geophysical applications in subsequent Series, in line with the Series Learning Outcomes.

Glossary of terms



- **Anthropogenic process:** An environmental process that results from human activities such as industrial operations, waste disposal, agriculture, and urban development, which may introduce pollutants into the subsurface environment.
- **Chemical plume:** A zone of subsurface contamination formed by the movement of dissolved chemicals through soil or groundwater, often originating from industrial sites or waste disposal areas.
- **Contaminant:** Any physical, chemical, or biological substance introduced into the environment that degrades soil, water, or groundwater quality and poses a risk to ecosystems or human health.
- **Earth science:** A broad field of science concerned with the study of the Earth's materials, structure, processes, and interactions with the environment, forming the scientific foundation of environmental geophysics.
- **Environmental geophysics:** The application of geophysical techniques to investigate near-surface environmental problems such as pollution, saline water intrusion, groundwater contamination, and soil degradation.
- **Environmental pollution:** The introduction of harmful substances or energy into the environment, resulting in adverse effects on soil, groundwater, ecosystems, and human well-being.
- **Geophysical techniques:** Methods used to measure physical properties of the subsurface, such as electrical resistivity or conductivity, in order to infer environmental and geological conditions.
- **Groundwater quality:** The chemical, physical, and biological condition of groundwater, which determines its suitability for domestic, agricultural, or industrial use.
- **Near-surface environment:** The shallow part of the subsurface, including soil, weathered rock, and shallow groundwater zones, where most environmental contamination occurs.
- **Natural process:** An environmental process that occurs without human intervention, such as weathering, erosion, groundwater flow, and natural geochemical reactions.
- **Oil spillage:** The accidental release of petroleum products into the environment, often leading to soil and groundwater contamination that can be investigated using geophysical methods.
- **Pollution pathway:** The route through which contaminants migrate from their source into soil, groundwater, or surface water systems.
- **Saline water intrusion:** The movement of saline water into freshwater aquifers, commonly in coastal areas, which degrades groundwater quality and can be detected using geophysical surveys.
- **Subsurface:** The region beneath the Earth's surface consisting of soil, rock, groundwater, and geological structures relevant to environmental investigations.
- **Subsurface physical property:** A measurable characteristic of subsurface materials, such as electrical resistivity or conductivity, that changes in response to contamination, salinity, or groundwater quality.

Concept check questions 1

Objective questions

1. Environmental geophysics is best described as the application of geophysical techniques to:
 - a) Deep crustal and mantle studies
 - b) Mineral and hydrocarbon exploration only
 - c) Investigation of near-surface environmental problems
 - d) Atmospheric and climate monitoring
 (Linked to SLO 1.1)
2. Which component of the Earth system is most relevant to environmental geophysics studies?
 - a) The Earth's core
 - b) The near-surface subsurface environment



- c) The upper mantle only
 - d) The outer atmosphere
(Linked to SLO 1.1)
 - 3. Anthropogenic environmental processes are those that:
 - a) Occur naturally without human influence
 - b) Take place only in marine environments
 - c) Result from human activities
 - d) Affect only surface water
(Linked to SLO 1.2)
 - 4. Subsurface contaminant plumes usually migrate primarily through:
 - a) Solid rock matrix alone
 - b) Air-filled pores above ground
 - c) Soil and groundwater flow paths
 - d) Volcanic conduits
(Linked to SLO 1.3)
-

Short-answer questions

1. Explain why earth science concepts are important for understanding environmental pollution problems.
(Linked to SLO 1.1)
 2. State two common sources of subsurface environmental pollution.
(Linked to SLO 1.2)
 3. Why is the study of contaminant movement important in environmental geophysics?
(Linked to SLO 1.3)
 4. Explain one reason why geophysical methods are preferred for investigating environmental problems in the subsurface.
(Linked to SLO 1.4)
-

Long-answer questions

1. Describe the relationship between earth science, environmental processes, and the development of environmental pollution problems in the subsurface.
(Linked to SLO 1.1 and SLO 1.2)
2. Analyse how changes in subsurface physical properties caused by pollution make geophysical techniques useful tools in environmental investigations.
(Linked to SLO 1.3 and SLO 1.4)

Pilot questions 1.1

1. Earth science, in environmental studies, refers to the scientific understanding of the Earth's materials, structure, and processes that explain how the subsurface environment functions and responds to natural and human influences.
2. Environmental geophysics is the application of geophysical techniques to investigate near-surface environmental problems such as pollution, groundwater contamination, and saline water intrusion.
3. Examples of environmental problems investigated using geophysical techniques include chemical pollution at industrial sites and saline water intrusion into groundwater aquifers.



4. Environmental geophysics focuses mainly on the near-surface because most environmental pollution and groundwater quality problems occur within shallow soil, weathered rock, and shallow groundwater zones.
 5. Geophysics is important for environmental problem-solving because it provides non-invasive subsurface information that helps detect and map pollution that cannot be seen directly at the ground surface.
-

Pilot questions 1.2

1. Environmental processes are natural or human-induced activities that affect the condition and behaviour of the environment, including soil, rock, and groundwater systems.
 2. Natural environmental processes occur without human influence, such as weathering and groundwater flow, while anthropogenic processes result from human activities like industrial discharge and waste disposal.
 3. Common sources of subsurface environmental pollution include industrial effluents and oil spillage, or landfill leachate and agricultural chemicals.
 4. Pollutants enter soil and groundwater systems through leaks, spills, infiltration of contaminated surface water, and improper waste disposal practices.
 5. Understanding contaminant behaviour is important in environmental geophysics because geophysical surveys aim to detect changes in subsurface physical properties caused by the movement and accumulation of pollutants.
-

Pilot questions 1.3

1. Geophysical methods are useful in environmental investigations because they measure physical property contrasts created when environmental conditions such as pollution alter the subsurface.
2. Environmental pollution affects subsurface physical properties by changing fluid content, salinity, and chemical composition, which in turn alter electrical and seismic responses.
3. Examples of environmental conditions that alter geophysical responses include saline water intrusion and chemical contamination from industrial activities.
4. Understanding subsurface property variation is important because correct interpretation of geophysical data depends on linking measured anomalies to actual environmental conditions.
5. One application of geophysical techniques in environmental studies is mapping contaminated zones or delineating polluted groundwater plumes.

References and attributions 1

Department-approved course outline and instructional materials for **GPH 414: Environmental Geophysics**, used as the primary institutional reference for earth science concepts, environmental processes, pollution pathways, and introductory applications of geophysical techniques in environmental studies.

Kearey, P., Brooks, M., & Hill, I. (2002). *An introduction to geophysical exploration* (3rd ed.). Oxford: Blackwell Science.

Reynolds, J. M. (2011). *An introduction to applied and environmental geophysics* (2nd ed.). Chichester: Wiley-Blackwell.



Burger, H. R., Sheehan, A. F., & Jones, C. H. (2006). *Introduction to applied geophysics: Exploring the shallow subsurface*. New York: W. W. Norton & Company.

Illustrations, figures, plates, and tables

- **Figure 1.1:** Major components of the Earth system relevant to environmental geophysics. AI-generated using the instructional prompt provided in Part 1.1.
- **Plate 1.1:** Use of geophysical surveys to investigate shallow environmental problems. Intended to be sourced from open educational repositories or generated using the suggested AI prompt.
- **Figure 1.2:** Examples of natural and human-induced environmental processes affecting the subsurface. AI-generated illustration based on the prompt embedded in Part 1.2.
- **Plate 1.2:** Major anthropogenic sources of soil and groundwater pollution. Intended to be sourced from open educational resources or generated using an AI prompt.
- **Figure 1.3:** Subsurface physical property contrasts caused by environmental contamination. AI-generated using the instructional prompt provided in Part 1.3.
- **Plate 1.3:** Effect of groundwater quality and pollution on subsurface geophysical properties. Intended to be sourced from open educational repositories or generated using the suggested AI prompt.
- **Table 1.1:** Role of geophysical techniques in environmental investigations.
- **Table 1.2:** Factors influencing contaminant movement in the subsurface.
- **Table 1.3:** Common environmental problems and their geophysical investigation approaches.

COURSE CODE:GPH 414

COURSE TITLE: Environmental Geophysics

COURSE UNIT LOAD (2 Units C: LH 30)

- Foundations of Environmental Geophysics and Earth Science Concepts.
- Geophysical Techniques in Environmental Pollution Studies.
- Saline Water Intrusion and Groundwater Quality Mapping.
- Geophysical Investigation of Chemical Pollution and Industrial Contamination.
- Oil Spillage, Pollution Delineation, and Environmental Mapping.

Part 2.1 Overview of geophysical techniques used in environmental studies.

- Basic classification of geophysical techniques for environmental applications
- Shallow subsurface investigation methods
- Suitability of geophysical techniques for pollution studies

Part 2.2 Application of geophysical techniques to environmental pollution.

- Use of geophysical methods in soil and groundwater contamination studies



- Mapping polluted zones using subsurface physical property contrasts
- Advantages and limitations of geophysical techniques in pollution assessment

Part 2.3 Interpretation of geophysical data in environmental investigations.

- Linking geophysical anomalies to pollution indicators
- Distinguishing polluted and unpolluted subsurface zones
- Reliability and challenges of geophysical interpretation in environmental studies

Introduction

Geophysical techniques play a vital role in environmental pollution studies because they provide effective means of investigating subsurface contamination without disturbing the ground. Environmental pollution problems such as soil contamination, chemical leakage, saline water intrusion, and oil spillage often occur below the surface and cannot be identified accurately through visual inspection alone. By measuring variations in subsurface physical properties, geophysical methods offer valuable insight into the presence, extent, and behaviour of pollutants within soil and groundwater systems.

The aim of this Series is to introduce you to the geophysical techniques commonly applied in environmental pollution studies and to explain how these techniques are used to detect, map, and assess subsurface contamination.

We shall commence this Series by examining the main geophysical techniques used in environmental studies, with emphasis on their classification, principles, and suitability for shallow subsurface investigations. We will then explore how these techniques are applied specifically to environmental pollution problems, focusing on soil and groundwater contamination and the mapping of polluted zones. Finally, the Series will address the interpretation of geophysical data in environmental investigations, highlighting how geophysical anomalies are linked to pollution indicators, the challenges involved in distinguishing polluted from unpolluted zones, and the reliability of geophysical interpretation in environmental assessments.

Series learning outcomes

Upon completing this Series, you should be able to:

- **SLO 2.1** explain the principles and classification of geophysical techniques used in environmental pollution studies.
- **SLO 2.2** describe how geophysical methods are applied to investigate soil and groundwater contamination.
- **SLO 2.3** analyse subsurface physical property variations associated with different types of environmental pollution.
- **SLO 2.4** interpret geophysical data to distinguish between polluted and unpolluted subsurface zones.
- **SLO 2.5** evaluate the advantages, limitations, and reliability of geophysical techniques in environmental pollution assessment.

2.1 Overview of Geophysical Techniques Used in Environmental Studies

2.1.1 Basic classification of geophysical techniques for environmental applications



Geophysical techniques are methods used to investigate the subsurface by measuring physical properties of earth materials from the ground surface or near-surface. In environmental studies, these techniques are classified based on the physical property they measure and their suitability for shallow investigations related to pollution and groundwater quality.

Broadly, geophysical techniques used in environmental applications include electrical methods, electromagnetic methods, seismic methods, gravity methods, and magnetic methods. Among these, electrical and electromagnetic methods are the most commonly applied because they are highly sensitive to changes in fluid content, salinity, and chemical composition of groundwater and soil. Seismic methods are also used where information on subsurface layering and structure is required.

This classification helps environmental geophysicists select appropriate techniques based on the nature of the environmental problem being investigated.

Fill in the blank: Geophysical techniques are classified according to the physical _____ they measure in the subsurface.

[Insert figure here]

Short description: Classification of geophysical techniques used in environmental studies

Figure 2.1: Classification of geophysical techniques applied in environmental investigations

Suggested AI prompt: *Create a simple diagram classifying geophysical techniques into electrical, electromagnetic, seismic, gravity, and magnetic methods*

2.1.2 Shallow subsurface investigation methods

Environmental geophysics primarily focuses on the **shallow subsurface**, where most environmental pollution problems occur. Shallow subsurface investigation methods are designed to explore soil layers, weathered rock, and shallow groundwater zones, typically within a depth range of a few metres to several tens of metres.

Electrical resistivity surveys are widely used for shallow investigations because they can detect contrasts caused by polluted groundwater, saline intrusion, or chemical contamination. Electromagnetic methods provide rapid coverage and are useful for mapping conductive zones associated with contamination. Seismic refraction methods help determine depth to bedrock and identify subsurface layering that may influence contaminant movement.

These shallow investigation methods are preferred in environmental studies because they are non-invasive, cost-effective, and capable of providing continuous subsurface information across contaminated sites.

Pause and reflect: Environmental geophysical investigations focus mainly on the _____ subsurface where pollution commonly occurs.

[Insert plate here]

Short description: Shallow subsurface investigation using geophysical methods

Plate 2.1: Application of shallow geophysical surveys in environmental site investigation

Suggested AI prompt: *Create an illustration showing shallow geophysical surveys investigating soil and groundwater contamination*



2.1.3 Suitability of geophysical techniques for pollution studies

The suitability of a geophysical technique for pollution studies depends on how sensitively it responds to changes caused by contaminants. **Pollution studies** rely on the fact that contaminants often alter the electrical, chemical, or physical properties of soil and groundwater.

Electrical and electromagnetic methods are particularly suitable because contaminated zones often show higher conductivity or lower resistivity compared with unpolluted areas. These contrasts make it possible to map pollution plumes, identify saline water intrusion, and assess groundwater quality. Seismic methods may be useful where pollution affects soil compaction or where structural control of contaminant pathways needs to be understood.

However, no single technique is universally suitable for all contamination problems. The effectiveness of a method depends on site conditions, type of pollutant, depth of contamination, and surrounding geology. Consequently, careful method selection and, where necessary, integration of multiple techniques are essential for reliable environmental assessment.

Fill in the blank: Electrical geophysical techniques are especially suitable for pollution studies because contaminants often increase subsurface _____.

[Insert table here]

Table 2.1: Geophysical techniques and their suitability for environmental pollution studies

[Insert table placeholder here]

Short description: Relationship between pollution effects and geophysical method response

Suggested AI prompt: *Generate a table linking types of environmental pollution with suitable geophysical techniques*

Pilot questions 2.1

1. What are geophysical techniques in the context of environmental studies?
2. State two major classes of geophysical methods used in environmental applications.
3. Why are shallow subsurface investigation methods important in environmental geophysics?
4. Explain why electrical methods are widely used in pollution studies.
5. Why is it sometimes necessary to combine more than one geophysical technique in environmental investigations?

2.2 Application of Geophysical Techniques to Environmental Pollution

2.2.1 Use of geophysical methods in soil and groundwater contamination studies

In environmental geophysics, geophysical methods are widely applied to investigate **soil and groundwater contamination**, which often occurs beneath the surface and cannot be detected through visual inspection alone. These methods help identify contaminated zones by detecting changes in subsurface physical properties caused by the presence of pollutants.

Electrical resistivity and electromagnetic surveys are commonly used in contamination studies because contaminants dissolved in groundwater often increase electrical conductivity. For example, leachate from waste dumps, saline water intrusion, and chemical effluents from industrial sites typically reduce subsurface resistivity values. By mapping these variations, geophysical surveys provide a useful indication of contaminated soil and groundwater zones.



Geophysical methods therefore play a vital role in preliminary environmental assessment and support targeted sampling and remediation planning.

Fill in the blank: Soil and groundwater contamination can be detected using geophysical methods because pollutants alter subsurface _____ properties.

[Insert figure here]

Short description: Application of geophysical surveys to contaminated sites

Figure 2.2: Geophysical investigation of soil and groundwater contamination

Suggested AI prompt: *Create an illustration showing geophysical surveys detecting contaminated soil and groundwater zones at an environmental site*

2.2.2 Mapping polluted zones using subsurface physical property contrasts

Environmental pollution often produces clear **physical property contrasts** between polluted and unpolluted subsurface materials. These contrasts form the basis for mapping polluted zones using geophysical techniques. For instance, groundwater contaminated by chemicals or saline water typically exhibits higher conductivity compared with clean groundwater.

By conducting systematic geophysical surveys across an affected area, contaminated zones can be delineated spatially. Electrical resistivity profiles and electromagnetic maps are used to outline the lateral and vertical extent of pollution plumes. This mapping capability is especially valuable for identifying the spread of contamination from point sources such as industrial facilities, landfills, and oil spill locations.

Accurate mapping of polluted zones supports environmental risk assessment and provides essential input for cleanup and monitoring programmes.

Pause and reflect: Polluted subsurface zones can be mapped geophysically because they show measurable _____ contrasts relative to clean areas.

[Insert plate here]

Short description: Delineation of polluted zones using geophysical data

Plate 2.2: Mapping subsurface pollution plumes using electrical or electromagnetic surveys

Suggested AI prompt: *Create a diagram showing how geophysical data outline the extent of a contamination plume underground*

2.2.3 Advantages and limitations of geophysical techniques in pollution assessment

Geophysical techniques offer several important **advantages** in environmental pollution assessment. They are non-invasive, allow rapid coverage of large areas, and reduce the need for extensive drilling or excavation. These methods are cost-effective at the reconnaissance stage and help identify priority areas for more detailed investigation.

However, there are also **limitations**. Geophysical data are indirect and may be influenced by factors unrelated to pollution, such as natural clay layers, variations in moisture content, or changes in soil



type. As a result, similar geophysical responses may arise from different subsurface conditions. This non-uniqueness means that geophysical results must be interpreted carefully and, where possible, supported by direct sampling and hydrogeological data.

Recognising both the strengths and limitations of geophysical techniques is essential for their effective use in environmental pollution studies.

Fill in the blank: A major limitation of geophysical pollution assessment is that interpretations are often _____ and require supporting information.

[Insert table here]

Table 2.2: Advantages and limitations of geophysical techniques in environmental pollution studies

[Insert table placeholder here]

Short description: Summary of strengths and constraints of geophysical methods in pollution assessment

Suggested AI prompt: *Generate a table comparing advantages and limitations of geophysical methods in environmental pollution investigations*

Pilot questions 2.2

1. Why are geophysical methods useful in soil and groundwater contamination studies?
2. Explain how polluted zones are identified using physical property contrasts.
3. State two environmental situations where geophysical pollution mapping is applied.
4. Mention two advantages of using geophysical techniques in pollution assessment.
5. Why must geophysical results be supported by other environmental data?

2.3 Interpretation of Geophysical Data in Environmental Investigations

2.3.1 Linking geophysical anomalies to pollution indicators

In environmental geophysics, a **geophysical anomaly** is a deviation in measured physical properties from the expected background values of the subsurface. Such anomalies often signal changes caused by environmental pollution, saline water intrusion, or degradation of groundwater quality. Interpreting these anomalies involves relating observed geophysical responses to specific environmental conditions.

For example, zones of abnormally low electrical resistivity may indicate contaminated groundwater containing dissolved chemicals or saline water. Similarly, high-conductivity anomalies detected using electromagnetic methods may correspond to leachate plumes from landfills or industrial waste sites. However, geophysical anomalies do not automatically confirm pollution, as natural factors such as clay-rich soils or naturally saline formations can produce similar responses.

Effective interpretation therefore requires understanding the environmental context and correlating geophysical anomalies with known pollution sources, hydrogeological conditions, and surface observations.

Fill in the blank: A geophysical anomaly becomes environmentally meaningful when it is linked to a known _____ indicator.

[Insert figure here]

Short description: Interpretation of geophysical anomalies in pollution studies



Figure 2.3: Linking geophysical anomalies to subsurface pollution indicators

Suggested AI prompt: *Create a diagram showing geophysical anomalies correlated with pollution sources such as landfills or industrial sites*

2.3.2 Distinguishing polluted and unpolluted subsurface zones

A key objective of environmental geophysical interpretation is to distinguish between **polluted** and **unpolluted** subsurface zones. This distinction is achieved by comparing geophysical measurements across the study area and identifying patterns that reflect contamination effects.

Polluted zones often show consistent spatial trends, such as continuous low-resistivity regions extending away from a pollution source, while unpolluted zones tend to exhibit background property values that reflect natural geological conditions. Establishing background conditions is therefore essential for interpretation and often involves surveying areas assumed to be free from contamination.

Temporal monitoring can also aid discrimination, as changes in geophysical responses over time may indicate migration or attenuation of pollution plumes. Combining spatial and temporal analysis strengthens confidence in identifying polluted versus unpolluted subsurface zones.

Pause and reflect: Background geophysical values are needed to distinguish pollution-related anomalies from _____ subsurface conditions.

[Insert plate here]

Short description: Polluted versus unpolluted subsurface zones

Plate 2.3: Comparison of geophysical responses in polluted and clean subsurface environments

Suggested AI prompt: *Create an illustration comparing geophysical profiles across contaminated and uncontaminated areas*

2.3.3 Reliability and challenges of geophysical interpretation in environmental studies

While geophysical techniques are powerful tools, their interpretation in environmental studies presents several **challenges**. One major challenge is non-uniqueness, where different subsurface conditions produce similar geophysical responses. For instance, clay layers and chemical contamination may both result in low resistivity values, making interpretation uncertain if supporting data are lacking.

Data quality, survey design, and environmental noise can also affect reliability. Poor electrode contact, cultural interference, or uneven terrain may introduce errors into measurements. Furthermore, heterogeneity in the subsurface can complicate interpretation, particularly in complex geological environments.

To improve **reliability**, geophysical interpretation should be integrated with geological mapping, hydrogeological data, and, where possible, direct sampling. This multi-disciplinary approach reduces ambiguity and enhances the accuracy of environmental assessments.

Fill in the blank: The main challenge in environmental geophysical interpretation is the _____ nature of geophysical responses.



[Insert table here]

Table 2.3: Challenges and reliability considerations in environmental geophysical interpretation

[Insert table placeholder here]

Short description: Factors affecting the reliability of geophysical interpretation in environmental studies

Suggested AI prompt: *Generate a table listing common interpretation challenges and methods to improve reliability in environmental geophysics*

Pilot questions 2.3

1. What is a geophysical anomaly in environmental investigations?
2. Explain how geophysical anomalies are linked to pollution indicators.
3. Why is it important to establish background geophysical conditions?
4. State one challenge associated with interpreting geophysical data in environmental studies.
5. How can the reliability of geophysical interpretation be improved in pollution assessment?

Series summary

This Series examined the application of **geophysical techniques in environmental pollution studies**, with emphasis on how subsurface physical property measurements are used to detect, map, and assess contamination affecting soil and groundwater systems. The importance of this Series lies in demonstrating that many environmental pollution problems are hidden below the surface and require indirect but reliable investigation methods.

We began by introducing the main classes of geophysical techniques used in environmental studies, highlighting their principles and suitability for shallow subsurface investigations where pollution is most common. Attention was given to why electrical, electromagnetic, and related methods are particularly effective for detecting changes caused by contamination. We then explored the application of geophysical techniques to environmental pollution, focusing on soil and groundwater contamination, mapping of polluted zones, and the advantages and limitations of geophysical approaches in pollution assessment. Finally, we examined the interpretation of geophysical data in environmental investigations, emphasising how geophysical anomalies are linked to pollution indicators, how polluted and unpolluted zones are distinguished, and the challenges and reliability issues associated with environmental geophysical interpretation.

As a result of this Series, you should now be able to explain how geophysical techniques are applied in environmental pollution studies, analyse subsurface physical property variations associated with contamination, interpret geophysical survey results responsibly, and evaluate the strengths and limitations of geophysical methods in environmental pollution assessment, in line with the Series Learning Outcomes.

Glossary of terms

- **Background value:** The normal or natural geophysical measurement of subsurface materials in an area assumed to be free from pollution, used as a reference when identifying contamination anomalies.
- **Chemical contamination:** The presence of harmful chemical substances in soil or groundwater, often originating from industrial activities, waste disposal, or accidental spills.
- **Electrical conductivity:** A physical property that measures the ability of subsurface materials to conduct electric current; often increased by dissolved salts or chemical pollutants in groundwater.
- **Electrical resistivity:** A measure of how strongly subsurface materials oppose the flow of electric current; commonly reduced in polluted or saline groundwater zones.



- **Environmental pollution study:** An investigation aimed at identifying, mapping, and assessing contaminants that degrade soil and groundwater quality using scientific and geophysical methods.
- **Geophysical anomaly:** A measurable deviation in geophysical data from expected background values, which may indicate pollution, saline intrusion, or changes in groundwater quality.
- **Geophysical interpretation:** The process of analysing geophysical survey data to infer subsurface environmental conditions, including the presence or absence of contamination.
- **Non-uniqueness:** A condition in geophysical interpretation where different subsurface materials or processes produce similar geophysical responses, making interpretation uncertain without supporting data.
- **Polluted zone:** An area of the subsurface where geophysical properties have been altered by contaminants such as chemicals, saline water, or hydrocarbons.
- **Pollution mapping:** The use of geophysical techniques to delineate the spatial extent, depth, and shape of contaminated zones in soil and groundwater.
- **Saline water intrusion:** The movement of saline water into freshwater aquifers, leading to reduced groundwater quality and typically identifiable by increased conductivity.
- **Shallow subsurface:** The near-surface portion of the Earth, including soil, weathered rock, and shallow groundwater, which is the primary focus of environmental geophysical investigations.
- **Soil and groundwater contamination:** The degradation of soil and groundwater quality due to the introduction of harmful substances, detectable through changes in subsurface physical properties.
- **Subsurface physical properties:** Measurable characteristics such as resistivity, conductivity, and seismic velocity that vary with pollution, salinity, and groundwater quality.
- **Supporting data:** Additional geological, hydrogeological, or chemical information used alongside geophysical data to improve the reliability of environmental interpretations.

Concept check questions 2

Objective questions

1. Environmental pollution studies using geophysical techniques mainly aim to:
 - a) Determine atmospheric pollution levels
 - b) Locate deep mineral deposits
 - c) Detect and map subsurface contamination
 - d) Analyse surface vegetation patterns
 (Linked to SLO 2.1)
2. Electrical and electromagnetic geophysical methods are widely used in pollution studies because they are sensitive to changes in:
 - a) Rock colour and texture
 - b) Temperature alone
 - c) Electrical properties affected by contaminants
 - d) Seismic velocity only
 (Linked to SLO 2.2)
3. A low-resistivity geophysical anomaly in environmental studies may indicate:
 - a) Dry, compact bedrock
 - b) Clean, uncontaminated groundwater
 - c) Clay layers or chemically contaminated groundwater
 - d) Volcanic intrusions
 (Linked to SLO 2.3)
4. The main challenge in interpreting geophysical data for pollution assessment is:
 - a) Lack of field equipment
 - b) Excessive drilling depth
 - c) Non-uniqueness of geophysical responses



d) Absence of pollution sources
(Linked to SLO 2.5)

Short-answer questions

1. Explain why geophysical techniques are preferred for investigating subsurface environmental pollution.
(Linked to SLO 2.1)
 2. State two ways in which contamination can change subsurface physical properties.
(Linked to SLO 2.3)
 3. Why is it important to establish background geophysical values in pollution studies?
(Linked to SLO 2.4)
 4. Explain one limitation of geophysical techniques when used alone for environmental pollution assessment.
(Linked to SLO 2.5)
-

Long-answer questions

1. Describe how geophysical techniques are applied to soil and groundwater contamination studies, and explain how polluted zones are mapped using subsurface physical property contrasts.
(Linked to SLO 2.2 and SLO 2.3)
2. Analyse the challenges associated with interpreting geophysical data in environmental pollution studies and discuss how the reliability of interpretation can be improved.
(Linked to SLO 2.4 and SLO 2.5)

Pilot questions 2.1

1. Geophysical techniques in environmental studies are methods used to investigate subsurface conditions by measuring physical properties that respond to pollution and groundwater quality changes.
 2. Electrical methods and electromagnetic methods, or seismic methods.
 3. Shallow subsurface investigation methods are important because most environmental pollution occurs within soil, weathered rock, and shallow groundwater zones.
 4. Electrical methods are widely used because contaminants often increase conductivity and reduce resistivity, creating measurable contrasts in polluted zones.
 5. It is sometimes necessary to combine more than one geophysical technique because no single method can uniquely identify all types of pollution or subsurface conditions.
-

Pilot questions 2.2

1. Geophysical methods are useful in soil and groundwater contamination studies because they can detect subsurface pollution indirectly through changes in physical properties.
2. Polluted zones are identified by observing contrasts in physical properties, such as lower resistivity or higher conductivity, compared with background conditions.



3. Examples include mapping landfill leachate contamination and delineating saline water intrusion, or investigating chemical pollution at industrial sites.
 4. Advantages include non-invasive investigation, rapid coverage of large areas, and cost effectiveness at the reconnaissance stage.
 5. Geophysical results must be supported by other environmental data because similar geophysical responses may be caused by natural materials such as clay, leading to non-unique interpretations.
-

Pilot questions 2.3

1. A geophysical anomaly is a deviation in measured subsurface physical properties from normal background values that may indicate environmental pollution.
2. Geophysical anomalies are linked to pollution indicators by correlating them with known sources of contamination, hydrogeological conditions, and surface observations.
3. Establishing background geophysical conditions is important in order to distinguish pollution-related anomalies from natural geological variations.
4. One major challenge is non-uniqueness, where different subsurface conditions produce similar geophysical responses.
5. Reliability can be improved by integrating geophysical data with geological, hydrogeological, and, where possible, chemical sampling information.

References and attributions 2

Department-approved course outline and instructional materials for **GPH 414: Environmental Geophysics**, used as the primary institutional reference for geophysical techniques applied to environmental pollution studies, soil and groundwater contamination, and subsurface pollution mapping.

Kearey, P., Brooks, M., & Hill, I. (2002). *An introduction to geophysical exploration* (3rd ed.). Oxford: Blackwell Science.

Reynolds, J. M. (2011). *An introduction to applied and environmental geophysics* (2nd ed.). Chichester: Wiley-Blackwell.

Burger, H. R., Sheehan, A. F., & Jones, C. H. (2006). *Introduction to applied geophysics: Exploring the shallow subsurface*. New York: W. W. Norton & Company.

Illustrations, figures, plates, and tables

- **Figure 2.1:** Classification of geophysical techniques applied in environmental investigations. AI-generated using the instructional prompt provided in Part 2.1.
- **Plate 2.1:** Application of shallow geophysical surveys in environmental site investigation. Intended to be sourced from open educational repositories or generated using the suggested AI prompt.
- **Figure 2.2:** Geophysical investigation of soil and groundwater contamination. AI-generated illustration based on the prompt embedded in Part 2.2.



- **Plate 2.2:** Mapping subsurface pollution plumes using electrical or electromagnetic surveys. Intended to be sourced from open educational resources or generated using an AI prompt.
- **Figure 2.3:** Linking geophysical anomalies to subsurface pollution indicators. AI-generated using the instructional prompt provided in Part 2.3.
- **Plate 2.3:** Comparison of geophysical responses in polluted and unpolluted subsurface environments. Intended to be sourced from open educational repositories or generated using the suggested AI prompt.
- **Table 2.1:** Geophysical techniques and their suitability for environmental pollution studies.
- **Table 2.2:** Advantages and limitations of geophysical techniques in environmental pollution assessment.
- **Table 2.3:** Challenges and reliability considerations in environmental geophysical interpretation.

COURSE CODE:GPH 414

COURSE TITLE: Environmental Geophysics

COURSE UNIT LOAD (2 Units C: LH 30)

- Foundations of Environmental Geophysics and Earth Science Concepts.
- Geophysical Techniques in Environmental Pollution Studies.
- Saline Water Intrusion and Groundwater Quality Mapping.
- Geophysical Investigation of Chemical Pollution and Industrial Contamination.
- Oil Spillage, Pollution Delineation, and Environmental Mapping.

Part 3.1 Nature and causes of saline water intrusion.

- Definition and characteristics of saline water intrusion
- Natural and anthropogenic causes of salinisation
- Environmental and groundwater quality implications

Part 3.2 Geophysical investigation of saline water intrusion.

- Subsurface physical property changes associated with saline intrusion
- Application of geophysical techniques in saline water mapping
- Identification and delineation of saline–freshwater interfaces

Part 3.3 Groundwater quality assessment and mapping.

- Indicators of groundwater quality degradation
- Use of geophysical data for groundwater quality evaluation
- Interpretation and mapping of groundwater quality zones

Introduction



Saline water intrusion is a major environmental and groundwater quality problem, particularly in coastal and low-lying regions where freshwater aquifers are vulnerable to encroachment by saline water. This process degrades groundwater quality, reduces the availability of potable water, and poses significant challenges to water resource management. Understanding the causes, behaviour, and extent of saline water intrusion is therefore essential for effective environmental assessment and sustainable groundwater use.

The aim of this Series is to explain the nature and causes of saline water intrusion and to demonstrate how geophysical techniques are applied to assess groundwater quality and map zones affected by salinisation.

We shall commence this Series by examining the concept of saline water intrusion, focusing on its defining characteristics, natural and human-induced causes, and its implications for groundwater quality and the environment. We will then explore how geophysical methods are used to investigate saline water intrusion, emphasising the physical property changes associated with salinity and the application of geophysical techniques in mapping saline and freshwater zones. Finally, the Series will address groundwater quality assessment and mapping, showing how geophysical data are interpreted to evaluate groundwater quality and to distinguish between saline-affected and freshwater aquifers for informed environmental and water resource management decisions.

Series learning outcomes

Upon completing this Series, you should be able to:

- **SLO 3.1** define saline water intrusion and explain its characteristics and impact on groundwater quality.
- **SLO 3.2** analyse the natural and anthropogenic factors responsible for saline water intrusion in groundwater systems.
- **SLO 3.3** explain how changes in subsurface physical properties are associated with salinisation of groundwater.
- **SLO 3.4** apply geophysical techniques to investigate, delineate, and map saline water intrusion zones.
- **SLO 3.5** evaluate groundwater quality using geophysical data and interpret groundwater quality maps for environmental and water resource management.

3.1 Nature and Causes of Saline Water Intrusion

3.1.1 Definition and characteristics of saline water intrusion

Saline water intrusion is the process by which saline water encroaches into freshwater aquifers, leading to deterioration of groundwater quality. It occurs when the natural balance between freshwater and saline water in an aquifer system is disturbed, allowing saline water to migrate into zones that were previously occupied by freshwater.

Saline intrusion is commonly associated with coastal aquifers, where freshwater normally overlies denser saline water. Under natural conditions, freshwater pressure keeps saline water at depth. When this balance is altered, saline water may move inland or upward into freshwater zones. Saline water intrusion is characterised by increased groundwater salinity, higher electrical conductivity, and reduced suitability of groundwater for drinking, irrigation, and industrial use.

Understanding the defining features of saline water intrusion is essential for identifying affected aquifers and planning appropriate investigation and management strategies.



Fill in the blank: Saline water intrusion occurs when saline water encroaches into _____ aquifers.

[Insert figure here]

Short description: Saline water intrusion into a freshwater aquifer

Figure 3.1: Conceptual model showing saline water intrusion in a coastal aquifer

Suggested AI prompt: *Create a diagram illustrating freshwater-saline water interface and saline water intrusion in a coastal aquifer*

3.1.2 Natural and anthropogenic causes of salinisation

Saline water intrusion may result from **natural causes**, **anthropogenic causes**, or a combination of both. Natural causes include sea-level changes, tidal fluctuations, natural groundwater flow patterns, and prolonged dry periods that reduce groundwater recharge. In coastal regions, low hydraulic gradients and reduced recharge can allow saline water to migrate inland naturally over time.

Anthropogenic causes are increasingly significant and often accelerate salinisation processes. Excessive groundwater abstraction for domestic, agricultural, or industrial use lowers the freshwater hydraulic head, reducing the pressure that restrains saline water. Land reclamation, canal construction, and improper well design can further disturb natural groundwater systems and promote saline intrusion.

Distinguishing between natural and human-induced causes is important for effective groundwater management and for designing appropriate mitigation measures.

Pause and reflect: Excessive groundwater pumping is a major _____ cause of saline water intrusion.

[Insert plate here]

Short description: Human and natural factors contributing to saline water intrusion

Plate 3.1: Natural and anthropogenic drivers of saline water intrusion

Suggested AI prompt: *Create an illustration showing groundwater pumping and natural coastal processes leading to saline intrusion*

3.1.3 Environmental and groundwater quality implications

The environmental and groundwater quality implications of saline water intrusion are significant. Elevated salinity renders groundwater unsuitable for drinking without treatment and adversely affects agricultural productivity by reducing soil quality and crop yields. Saline water may also corrode infrastructure such as pipes and pumping equipment, increasing maintenance costs.

From an environmental perspective, salinisation can alter ecosystems dependent on freshwater, particularly wetlands and near-coastal habitats. Once saline water intrusion has progressed, remediation becomes difficult and costly, making early detection and monitoring essential.

These implications highlight the need for reliable investigation tools, including geophysical methods, to identify, map, and monitor saline water intrusion and support sustainable groundwater management.



Fill in the blank: Saline water intrusion reduces groundwater suitability for domestic, agricultural, and _____ use.

[Insert table here]

Table 3.1: Impacts of saline water intrusion on groundwater quality and environment

[Insert table placeholder here]

Short description: Summary of effects associated with groundwater salinisation

Suggested AI prompt: *Generate a table summarising environmental and water quality impacts of saline water intrusion*

Pilot questions 3.1

1. What is meant by saline water intrusion?
2. Where is saline water intrusion most commonly observed?
3. Distinguish between natural and anthropogenic causes of saline water intrusion.
4. Explain how groundwater abstraction contributes to salinisation.
5. State two implications of saline water intrusion on groundwater quality.

3.2 Geophysical Investigation of Saline Water Intrusion

3.2.1 Subsurface physical property changes associated with saline intrusion

Saline water intrusion produces distinct changes in **subsurface physical properties**, which form the basis for its detection using geophysical techniques. One of the most important effects of salinisation is an increase in groundwater **electrical conductivity**, resulting from the high concentration of dissolved salts in saline water. As conductivity increases, the corresponding electrical resistivity of the subsurface decreases.

In freshwater aquifers, resistivity values are generally higher because freshwater contains relatively low concentrations of dissolved ions. When saline water intrudes into these aquifers, the replacement or mixing of freshwater with saline water leads to measurable reductions in resistivity. These changes are often gradual and form transition zones rather than sharp boundaries, reflecting mixing processes within the aquifer.

Recognising how saline water alters subsurface physical properties is essential for selecting appropriate geophysical methods and interpreting survey results accurately.

Fill in the blank: Saline water intrusion typically causes a decrease in subsurface electrical _____.

[Insert figure here]

Short description: Effect of salinity on subsurface electrical properties

Figure 3.2: Variation of electrical resistivity between freshwater and saline groundwater zones

Suggested AI prompt: *Create a diagram showing resistivity differences between freshwater and saline groundwater in an aquifer*

3.2.2 Application of geophysical techniques in saline water mapping



Several **geophysical techniques** are applied to map saline water intrusion by exploiting contrasts in subsurface physical properties. Electrical resistivity methods are the most widely used because of their strong sensitivity to groundwater salinity. Resistivity profiling and sounding can be used to assess lateral and vertical changes in salinity within aquifer systems.

Electromagnetic methods are also effective, particularly for rapid reconnaissance surveys over large areas. These methods detect variations in conductivity associated with saline intrusion and are useful for identifying zones of advanced salinisation. In some cases, seismic methods may support interpretation by providing information on subsurface layering that controls the movement and distribution of saline water.

The choice of technique depends on site conditions, depth of investigation, and the scale of salinisation. Often, combining multiple geophysical methods improves the reliability of saline water mapping.

Pause and reflect: Electrical resistivity methods are commonly used in saline intrusion studies because they respond strongly to groundwater _____.

[Insert plate here]

Short description: Geophysical survey for saline water intrusion

Plate 3.2: Application of electrical or electromagnetic surveys to detect saline water intrusion

Suggested AI prompt: *Create an illustration showing geophysical surveys mapping saline intrusion in a coastal aquifer*

3.2.3 Identification and delineation of saline–freshwater interfaces

A key objective of geophysical investigation in saline intrusion studies is the identification and delineation of the **saline–freshwater interface**, which separates saline water from freshwater within an aquifer. This interface is often not a sharp boundary but a transition zone where mixing occurs.

Geophysical data are interpreted to identify zones of low resistivity or high conductivity associated with saline water and higher resistivity zones associated with freshwater. By correlating resistivity or conductivity values with depth and spatial position, the approximate location and geometry of the interface can be inferred.

Repeated geophysical surveys over time allow monitoring of interface movement, providing insight into whether saline intrusion is advancing, stabilising, or retreating. This information is essential for groundwater management and for evaluating the effectiveness of mitigation measures.

Fill in the blank: The saline–freshwater interface is often a _____ zone rather than a sharp boundary.

[Insert table here]

Table 3.2: Geophysical indicators used to delineate saline–freshwater interfaces

[Insert table placeholder here]

Short description: Typical geophysical responses associated with saline and fresh groundwater

Suggested AI prompt: *Generate a table linking resistivity values to saline and freshwater conditions in aquifers*

Pilot questions 3.2



1. How does saline water intrusion affect subsurface electrical properties?
2. Why are resistivity values lower in saline-affected aquifers than in freshwater aquifers?
3. State two geophysical techniques commonly used to map saline water intrusion.
4. What is meant by the saline-freshwater interface?
5. Why is repeated geophysical surveying useful in saline intrusion studies?

3.3 Groundwater Quality Assessment and Mapping

3.3.1 Indicators of groundwater quality degradation

Groundwater quality refers to the chemical, physical, and biological characteristics of groundwater that determine its suitability for various uses. Degradation of groundwater quality occurs when these characteristics change unfavourably due to processes such as saline water intrusion, chemical contamination, or pollution from industrial and domestic sources.

Important indicators of groundwater quality degradation include increased salinity, elevated electrical conductivity, abnormal chemical composition, and changes in subsurface physical properties. Saline intrusion, in particular, leads to high concentrations of dissolved salts, making groundwater unsuitable for drinking and irrigation. Chemical pollution may introduce hazardous substances that further alter groundwater quality.

In environmental geophysics, these indicators are identified indirectly through changes in subsurface physical properties rather than direct water sampling. Recognising such indicators is essential for early detection of groundwater quality problems.

Fill in the blank: Elevated salinity is a key indicator of groundwater quality _____.

[Insert figure here]

Short description: Groundwater quality degradation indicators

Figure 3.3: Conceptual relationship between groundwater quality degradation and physical property changes

Suggested AI prompt: *Create a diagram showing indicators of groundwater quality degradation linked to changes in subsurface physical properties*

3.3.2 Use of geophysical data for groundwater quality evaluation

Geophysical data are widely used for **groundwater quality evaluation** because they provide spatially continuous information about subsurface conditions. Electrical resistivity and electromagnetic data are particularly valuable, as groundwater quality strongly influences electrical properties.

Fresh groundwater typically shows moderate to high resistivity values, while saline or polluted groundwater exhibits lower resistivity and higher conductivity. By analysing these patterns, zones of degraded groundwater quality can be identified and compared with background conditions. Geophysical surveys therefore help distinguish areas of acceptable groundwater quality from zones affected by salinisation or chemical pollution.

Although geophysical data do not provide direct chemical concentrations, they serve as effective screening tools that guide sampling, monitoring, and remediation efforts.



Pause and reflect: Geophysical data help assess groundwater quality by detecting changes in subsurface _____ properties.

[Insert plate here]

Short description: Groundwater quality assessment using geophysical surveys

Plate 3.3: Use of geophysical data to evaluate groundwater quality variations

Suggested AI prompt: *Create an illustration showing resistivity variations related to fresh and saline groundwater quality*

3.3.3 Interpretation and mapping of groundwater quality zones

The final stage of groundwater quality assessment involves the **interpretation and mapping** of groundwater quality zones using geophysical data. Mapping integrates geophysical measurements with spatial location, allowing visual representation of fresh, transitional, and saline or polluted groundwater zones.

Geophysical interpretation produces maps and sections that show lateral and vertical variations in physical properties associated with groundwater quality. Low-resistivity or high-conductivity zones are interpreted as areas of degraded quality, while higher resistivity zones represent fresher groundwater. These maps support environmental decision-making by identifying vulnerable areas, guiding well placement, and prioritising areas for protection or remediation.

Monitoring changes in groundwater quality maps over time also provides insight into the progression or retreat of saline intrusion and pollution plumes, supporting long-term groundwater management.

Fill in the blank: Groundwater quality mapping helps visualise the spatial distribution of _____ and degraded water zones.

[Insert table here]

Table 3.3: Typical groundwater quality zones and their geophysical characteristics

[Insert table placeholder here]

Short description: Relationship between groundwater quality status and geophysical responses

Suggested AI prompt: *Generate a table linking groundwater quality categories with typical resistivity and conductivity ranges*

Pilot questions 3.3

1. What is meant by groundwater quality degradation?
2. State two indicators of groundwater quality deterioration.
3. Explain how geophysical data are used to evaluate groundwater quality.
4. Why are resistivity and conductivity useful parameters in groundwater quality assessment?
5. How does groundwater quality mapping support environmental and water resource management?

Series summary

This Series examined **saline water intrusion and groundwater quality mapping** as critical components of environmental geophysics and groundwater management. Its importance lies in addressing one of



the most significant causes of groundwater quality degradation, particularly in coastal and vulnerable aquifer systems where saline encroachment threatens freshwater resources.

We began by explaining the nature and causes of saline water intrusion, highlighting how the natural balance between freshwater and saline water can be disturbed by both natural processes, such as sea-level variation and reduced recharge, and anthropogenic activities, particularly excessive groundwater abstraction. The environmental and socio-economic implications of salinisation, including reduced water usability, agricultural impacts, and infrastructure corrosion, were also emphasised. We then explored the geophysical investigation of saline water intrusion, focusing on how salinisation alters subsurface physical properties, especially electrical resistivity and conductivity. The application of electrical and electromagnetic geophysical techniques in detecting and delineating saline-affected zones and identifying saline-freshwater interfaces was discussed in detail. Finally, we examined groundwater quality assessment and mapping, showing how geophysical data are interpreted to evaluate groundwater quality, distinguish between fresh and degraded water zones, and produce groundwater quality maps that support monitoring and management decisions.

As a result of this Series, you should now be able to define saline water intrusion, analyse its causes and impacts, explain how geophysical techniques detect and map salinisation, and use geophysical data to assess and map groundwater quality. These skills are essential for effective environmental assessment and sustainable groundwater resource management, in line with the Series Learning Outcomes.

Glossary of terms

- **Aquifer salinisation:** The process by which freshwater aquifers become contaminated by saline water, resulting in reduced groundwater quality.
- **Electrical conductivity:** A measure of the ability of groundwater or subsurface materials to conduct electric current, commonly increased by high salinity or dissolved contaminants.
- **Electrical resistivity:** The resistance of subsurface materials to the flow of electric current, typically lower in saline or polluted groundwater zones.
- **Freshwater aquifer:** A groundwater-bearing formation containing low-salinity water suitable for domestic, agricultural, or industrial use.
- **Groundwater quality:** The chemical and physical condition of groundwater that determines its suitability for use, influenced by salinity and contamination levels.
- **Groundwater quality degradation:** The deterioration of groundwater suitability due to processes such as saline water intrusion or chemical pollution.
- **Saline-freshwater interface:** The transition zone within an aquifer where saline water and freshwater mix, often identified using geophysical methods.
- **Saline water intrusion:** The movement of saline water into freshwater aquifers, commonly occurring in coastal areas or where groundwater abstraction is excessive.
- **Salinisation:** The increase in salt concentration in soil or groundwater, leading to reduced environmental and water resource quality.
- **Subsurface physical property:** A measurable characteristic of subsurface materials, such as resistivity or conductivity, that changes in response to salinity or groundwater quality.
- **Transition zone:** A subsurface region where gradual mixing occurs between saline water and freshwater rather than a sharp boundary.
- **Water quality mapping:** The spatial representation of groundwater quality variations using interpreted geophysical data.

Concept check questions 3

Objective questions



1. Saline water intrusion is best described as:
 - a) The movement of freshwater into saline aquifers
 - b) The encroachment of saline water into freshwater aquifers
 - c) The discharge of pollutants into surface water only
 - d) The evaporation of groundwater in arid regions*(Linked to SLO 3.1)*
 2. Which human activity most commonly accelerates saline water intrusion in coastal aquifers?
 - a) Increased rainfall
 - b) Construction of monitoring wells
 - c) Excessive groundwater abstraction
 - d) Natural weathering processes*(Linked to SLO 3.2)*
 3. In geophysical surveys, saline water intrusion is commonly indicated by:
 - a) High resistivity and low conductivity
 - b) Low resistivity and high conductivity
 - c) No change in physical properties
 - d) Increased seismic velocity only*(Linked to SLO 3.3)*
 4. The saline–freshwater interface in an aquifer is usually:
 - a) A sharp, permanent boundary
 - b) A transition zone where mixing occurs
 - c) Located only at the coastline surface
 - d) Independent of groundwater flow conditions*(Linked to SLO 3.4)*
-

Short-answer questions

1. Explain why saline water intrusion is considered a major groundwater quality problem.
(Linked to SLO 3.1)
 2. State two natural causes of saline water intrusion.
(Linked to SLO 3.2)
 3. Why are electrical resistivity methods suitable for investigating saline water intrusion?
(Linked to SLO 3.3)
 4. Explain how groundwater quality maps assist in environmental management decisions.
(Linked to SLO 3.5)
-

Long-answer questions

1. Describe the causes and environmental implications of saline water intrusion, and explain how geophysical techniques are used to investigate this problem.
(Linked to SLO 3.1, SLO 3.2, and SLO 3.4)
 2. Analyse how changes in subsurface physical properties associated with salinisation support groundwater quality assessment and mapping using geophysical data.
(Linked to SLO 3.3 and SLO 3.5)
-

Pilot questions 3.1



1. **Saline water intrusion** is the process by which saline water moves into freshwater aquifers, leading to deterioration of groundwater quality.
 2. Saline water intrusion is most commonly observed in **coastal aquifers**, although it may also occur inland under certain geological and hydrological conditions.
 3. Natural causes include sea-level variation, reduced groundwater recharge, and natural groundwater flow patterns, while anthropogenic causes include excessive groundwater abstraction, land reclamation, and poor well construction.
 4. Groundwater abstraction lowers the freshwater hydraulic head, reducing the pressure that prevents saline water from advancing into freshwater zones.
 5. Two implications are reduced suitability of groundwater for drinking and irrigation, and damage to infrastructure due to corrosion caused by saline water.
-

Pilot questions 3.2

1. Saline water intrusion increases subsurface electrical conductivity and decreases electrical resistivity due to the high concentration of dissolved salts.
 2. Resistivity values are lower in saline-affected aquifers because saline water conducts electricity more effectively than freshwater.
 3. Electrical resistivity methods and electromagnetic methods are commonly used to map saline water intrusion.
 4. The saline-freshwater interface is the transition zone within an aquifer where saline water and freshwater mix.
 5. Repeated geophysical surveys allow monitoring of changes in the position and extent of saline intrusion, indicating whether salinisation is advancing or retreating.
-

Pilot questions 3.3

1. Groundwater quality degradation refers to the deterioration of groundwater suitability due to increased salinity or contamination by pollutants.
 2. Elevated salinity and increased electrical conductivity are two key indicators of groundwater quality deterioration.
 3. Geophysical data are used to evaluate groundwater quality by identifying zones of low resistivity or high conductivity associated with degraded water.
 4. Resistivity and conductivity are useful because they change predictably in response to salinity and dissolved contaminants in groundwater.
 5. Groundwater quality mapping supports environmental and water resource management by identifying affected zones, guiding well placement, and supporting protection and remediation planning.
-

References and attributions 3

Department-approved course outline and instructional materials for **GPH 414: Environmental Geophysics**, used as the primary institutional reference for saline water intrusion, groundwater quality determination, geophysical mapping of salinisation, and environmental groundwater assessment.

Kearey, P., Brooks, M., & Hill, I. (2002). *An introduction to geophysical exploration* (3rd ed.). Oxford: Blackwell Science.



Reynolds, J. M. (2011). *An introduction to applied and environmental geophysics* (2nd ed.). Chichester: Wiley-Blackwell.

Freeze, R. A., & Cherry, J. A. (1979). *Groundwater*. Englewood Cliffs: Prentice-Hall.

Bear, J. (1979). *Hydraulics of groundwater*. New York: McGraw-Hill.

Illustrations, figures, plates, and tables

- **Figure 3.1:** Conceptual model showing saline water intrusion in a coastal aquifer. AI-generated using the instructional prompt provided in Part 3.1.
- **Plate 3.1:** Natural and anthropogenic drivers of saline water intrusion. Intended to be sourced from open educational repositories or generated using the suggested AI prompt.
- **Figure 3.2:** Variation of electrical resistivity between freshwater and saline groundwater zones. AI-generated illustration based on the prompt embedded in Part 3.2.
- **Plate 3.2:** Application of electrical or electromagnetic surveys to detect saline water intrusion. Intended to be sourced from open educational resources or generated using an AI prompt.
- **Figure 3.3:** Conceptual relationship between groundwater quality degradation and physical property changes. AI-generated using the instructional prompt provided in Part 3.3.
- **Plate 3.3:** Use of geophysical data to evaluate groundwater quality variations. Intended to be sourced from open educational repositories or generated using the suggested AI prompt.
- **Table 3.1:** Impacts of saline water intrusion on groundwater quality and environment.
- **Table 3.2:** Geophysical indicators used to delineate saline-freshwater interfaces.
- **Table 3.3:** Typical groundwater quality zones and their geophysical characteristics.

COURSE CODE:GPH 414

COURSE TITLE: Environmental Geophysics

COURSE UNIT LOAD (2 Units C: LH 30)

- Foundations of Environmental Geophysics and Earth Science Concepts.
- Geophysical Techniques in Environmental Pollution Studies.
- Saline Water Intrusion and Groundwater Quality Mapping.
- Geophysical Investigation of Chemical Pollution and Industrial Contamination.
- Oil Spillage, Pollution Delineation, and Environmental Mapping.

Part 4.1 Nature and sources of chemical pollution in the environment.

- Characteristics of chemical pollution in soil and groundwater
- Sources of chemical contamination at industrial and waste disposal sites
- Environmental and health implications of chemical pollutants



Part 4.2 Geophysical techniques for investigating chemical pollution.

- Subsurface physical property changes caused by chemical contamination
- Application of geophysical methods at industrial pollution sites
- Delineation of chemical contamination zones and plumes

Part 4.3 Delineation and assessment of chemical pollution plumes.

- Concept of chemical plumes and contaminant migration
- Interpretation of geophysical data for plume mapping
- Role of geophysical mapping in remediation planning

Introduction

Chemical pollution and industrial contamination represent some of the most serious environmental challenges affecting soil and groundwater systems. Industrial activities such as manufacturing, chemical processing, waste storage, and accidental spills can introduce hazardous substances into the subsurface, where they may persist for long periods and pose risks to human health and the environment. Because these contaminants often migrate below ground and are not visible at the surface, effective investigation requires methods capable of detecting and delineating subsurface contamination without extensive excavation.

The aim of this Series is to introduce you to the geophysical investigation of chemical pollution and industrial contamination, with emphasis on understanding pollution sources, recognising contaminant migration patterns, and using geophysical techniques to delineate polluted zones and chemical plumes.

We shall commence this Series by examining the nature and sources of chemical pollution in the environment, focusing on how industrial activities lead to soil and groundwater contamination and the associated environmental and health implications. We will then explore the geophysical techniques used to investigate chemical pollution, explaining how contaminants alter subsurface physical properties and how geophysical surveys are applied at industrial and contaminated sites. Finally, the Series will address the delineation and assessment of chemical pollution plumes, demonstrating how geophysical data are interpreted to map contaminant spread and support remediation planning and environmental management.

Series learning outcomes

Upon completing this Series, you should be able to:

- **SLO 4.1** describe the nature, sources, and characteristics of chemical pollution affecting soil and groundwater environments.
- **SLO 4.2** analyse the environmental and potential health implications of chemical contamination at industrial and waste-related sites.
- **SLO 4.3** explain how chemical pollutants alter subsurface physical properties detectable by geophysical techniques.
- **SLO 4.4** apply appropriate geophysical methods to investigate chemical pollution at industrial sites and contaminated environments.
- **SLO 4.5** interpret geophysical data to delineate chemical contamination zones and plumes for environmental assessment and remediation planning.

4.1 Nature and Sources of Chemical Pollution in the Environment



4.1.1 Characteristics of chemical pollution in soil and groundwater

Chemical pollution refers to the presence of hazardous chemical substances in the environment in quantities that cause harm to soil, groundwater, ecosystems, or human health. In the subsurface, chemical pollution is often persistent because contaminants may become trapped within soil pores or dissolve into groundwater, allowing them to migrate over time.

In soil, chemical pollutants may adsorb onto mineral surfaces, accumulate in fine-grained materials such as clay, or percolate downward with infiltrating water. In groundwater, dissolved chemicals can spread laterally, forming zones of contamination that may extend far beyond the original pollution source. Such contamination is difficult to observe directly and may remain undetected without detailed investigation.

Chemical pollution is therefore characterised by persistence, subsurface migration, and potential long-term impact on groundwater quality and environmental health.

Fill in the blank: Chemical pollution in the subsurface is often persistent because contaminants can remain trapped in soil or dissolved in _____.

[Insert figure here]

Short description: Chemical pollution in soil and groundwater systems

Figure 4.1: Pathways of chemical pollutants in soil and groundwater

Suggested AI prompt: *Create a diagram illustrating chemical pollutants moving through soil layers into groundwater*

4.1.2 Sources of chemical contamination at industrial and waste disposal sites

Chemical contamination commonly originates from **industrial sites** and **waste disposal facilities**, where hazardous substances are manufactured, processed, stored, or discarded. Typical industrial sources include chemical plants, refineries, metal-processing facilities, and manufacturing industries that generate liquid and solid chemical wastes.

Waste disposal sites such as landfills, waste dumps, and tailings ponds can also act as major sources of chemical pollution. Leachate generated from these sites may contain harmful chemicals that infiltrate surrounding soil and groundwater. Accidental spills, leaking storage tanks, damaged pipelines, and improper waste handling further increase the risk of contamination.

Identifying the source of chemical contamination is essential for environmental assessment, as it influences the type of pollutants present, their likely behaviour, and the selection of appropriate geophysical investigation methods.

Pause and reflect: Industrial facilities and waste disposal sites are major _____ of subsurface chemical pollution.

[Insert plate here]

Short description: Industrial and waste-related sources of chemical pollution

Plate 4.1: Common industrial and waste disposal sources of soil and groundwater contamination

Suggested AI prompt: *Create an illustration showing industrial plants and landfills releasing chemical contaminants into the subsurface*



4.1.3 Environmental and health implications of chemical pollutants

Chemical pollutants in soil and groundwater pose serious **environmental and health risks**. Contaminated groundwater may become unsuitable for drinking, irrigation, or industrial use, while polluted soil may affect vegetation and agricultural productivity. In some cases, chemical contaminants may enter the food chain through crops or livestock.

From a health perspective, exposure to contaminated water or soil can lead to acute or chronic health problems depending on the nature and concentration of the pollutants. Communities relying on groundwater supplies near industrial or waste sites are particularly vulnerable. Environmental impacts may also include degradation of ecosystems, loss of biodiversity, and long-term damage to natural resources.

These implications underline the importance of early detection, accurate delineation, and effective management of chemical pollution using reliable investigation techniques such as environmental geophysics.

Fill in the blank: Chemical pollution poses risks to human health, ecosystems, and long-term _____ sustainability.

[Insert table here]

Table 4.1: Environmental and health impacts of chemical pollution

[Insert table placeholder here]

Short description: Summary of common effects of chemical pollutants in soil and groundwater

Suggested AI prompt: *Generate a table summarising environmental and human health impacts of chemical pollution*

Pilot questions 4.1

1. What is meant by chemical pollution in the environment?
2. Explain how chemical pollutants behave in soil and groundwater systems.
3. State two common industrial sources of chemical contamination.
4. How do waste disposal sites contribute to chemical pollution?
5. Why is chemical pollution considered a serious environmental and health concern?

4.2 Geophysical Techniques for Investigating Chemical Pollution

4.2.1 Subsurface physical property changes caused by chemical contamination

Chemical contamination alters the **subsurface physical properties** of soil and groundwater, which makes geophysical investigation possible. Many chemical pollutants dissolve in groundwater and increase the concentration of ions, leading to higher electrical conductivity and, consequently, lower electrical resistivity. These changes are commonly observed around industrial sites, waste disposal areas, and locations affected by chemical spills.

Some chemical contaminants may also interact with soil minerals, affecting porosity and moisture distribution. In clay-rich environments, contaminants may accumulate and further enhance conductivity contrasts. In contrast, hydrocarbons from industrial leakage or storage tanks may displace



groundwater in pore spaces, producing different geophysical responses than saline or chemically dissolved pollutants.

Recognising how chemical contamination modifies subsurface physical properties is fundamental for selecting suitable geophysical techniques and for reliable interpretation.

Fill in the blank: Chemical contamination often reduces subsurface resistivity by increasing groundwater _____.

[Insert figure here]

Short description: Effect of chemical contamination on subsurface physical properties

Figure 4.2: Contrast between uncontaminated and chemically contaminated subsurface zones

Suggested AI prompt: *Create a diagram showing soil and groundwater with normal resistivity compared to chemically contaminated zones with lower resistivity*

4.2.2 Application of geophysical methods at industrial pollution sites

At **industrial pollution sites**, geophysical techniques are widely applied to investigate the presence and extent of chemical contamination without disturbing the ground. Electrical resistivity and electromagnetic methods are particularly effective because they can rapidly identify conductive anomalies associated with contaminated groundwater or soil.

Resistivity profiling is often used to trace contamination pathways, while resistivity sounding helps estimate the depth and thickness of polluted layers. Electromagnetic surveys are valuable for reconnaissance mapping over large industrial areas, allowing rapid identification of potential contamination hotspots. In some cases, seismic methods may be employed to understand subsurface structure, especially where fractures or layering influence contaminant migration.

These applications make geophysical techniques essential tools for preliminary site assessment, guiding targeted sampling and reducing the cost and risk associated with extensive drilling.

Pause and reflect: Geophysical surveys at industrial sites help identify contamination _____ before intrusive investigations are carried out.

[Insert plate here]

Short description: Geophysical investigation at an industrial contamination site

Plate 4.2: Use of geophysical surveys to assess chemical contamination at an industrial site

Suggested AI prompt: *Create an illustration showing resistivity or electromagnetic surveys being conducted across an industrial facility*

4.2.3 Delineation of chemical contamination zones and plumes

One of the key objectives of environmental geophysics at chemically contaminated sites is the delineation of **chemical contamination zones** and **plumes**. A chemical plume is formed when dissolved contaminants migrate through soil and groundwater, often moving in the direction of groundwater flow.



Geophysical data are interpreted spatially to map the lateral spread and vertical extent of these plumes. Low-resistivity or high-conductivity zones that extend away from known contamination sources are commonly interpreted as chemical plumes. The shape and orientation of the plume provide insight into contaminant transport pathways and hydrogeological controls.

Delineating contamination zones and plumes supports risk assessment, remediation planning, and monitoring of contamination movement over time. When integrated with geological and groundwater flow information, geophysical plume mapping becomes a powerful decision-support tool in environmental management.

Fill in the blank: Chemical plumes often extend in the direction of groundwater _____.

[Insert table here]

Table 4.2: Geophysical indicators used to delineate chemical contamination zones and plumes

[Insert table placeholder here]

Short description: Typical geophysical characteristics of chemically contaminated subsurface zones

Suggested AI prompt: *Generate a table linking geophysical responses to chemical contamination zones and plume characteristics*

Pilot questions 4.2

1. How does chemical contamination affect subsurface physical properties?
2. Why are electrical and electromagnetic methods suitable for investigating chemical pollution?
3. Explain the use of geophysical surveys at industrial contamination sites.
4. What is a chemical contamination plume?
5. How do geophysical techniques help delineate chemical pollution zones?

4.3 Delineation and Assessment of Chemical Pollution Plumes

4.3.1 Concept of chemical plumes and contaminant migration

A **chemical pollution plume** is a zone of subsurface contamination formed when dissolved chemical pollutants migrate away from their source through soil and groundwater systems. Plumes typically develop when contaminants enter the groundwater and are transported by natural groundwater flow processes, spreading both laterally and vertically over time.

The direction and shape of a chemical plume depend on factors such as groundwater flow velocity, hydraulic gradient, permeability of subsurface materials, and the chemical properties of the pollutant. In many cases, plumes extend down-gradient from industrial facilities, waste disposal sites, or spill locations, following the dominant direction of groundwater movement. The plume may widen with distance as dispersion and diffusion occur.

Understanding the concept of chemical plumes and contaminant migration is essential for effective environmental assessment because it helps predict the extent of contamination and potential receptors at risk.

Fill in the blank: Chemical pollution plumes generally migrate in response to groundwater _____ and subsurface permeability.

[Insert figure here]

Short description: Migration of a chemical plume in groundwater



Figure 4.3: Conceptual illustration of chemical plume formation and migration in a groundwater system
Suggested AI prompt: *Create a diagram showing a chemical contaminant source and the resulting plume moving with groundwater flow*

4.3.2 Interpretation of geophysical data for plume mapping

Geophysical data play a crucial role in the **interpretation and mapping of chemical pollution plumes**. Because chemical contaminants alter subsurface physical properties, geophysical surveys can identify anomalous zones associated with plume presence. Electrical resistivity and electromagnetic data are particularly useful, as chemical plumes often produce regions of low resistivity or high conductivity relative to background conditions.

By analysing spatial variations in geophysical measurements, the lateral extent and approximate depth of chemical plumes can be delineated. Profiles and maps generated from survey data help visualise plume geometry and identify areas of greatest contamination. Interpretation often involves comparing observed anomalies with known pollution sources, hydrogeological data, and surface features to ensure correct attribution.

Careful interpretation is essential, as similar geophysical responses may arise from non-pollution factors such as clay layers or natural salinity. Integration with supporting data improves the reliability of plume mapping.

Pause and reflect: Geophysical plume mapping relies on identifying subsurface zones with anomalously _____ physical property values.

[Insert plate here]

Short description: Geophysical interpretation of a contamination plume

Plate 4.3: Geophysical delineation of a chemical pollution plume in the subsurface

Suggested AI prompt: *Create an illustration showing resistivity or conductivity anomalies interpreted as a chemical plume*

4.3.3 Role of geophysical mapping in remediation planning

Geophysical mapping of chemical pollution plumes provides valuable input for **remediation planning and environmental management**. By defining the extent and geometry of contamination, geophysical surveys help prioritise areas requiring cleanup and guide the placement of monitoring or remediation wells.

Plume maps support decisions about the most appropriate remediation strategies, such as containment, removal, or natural attenuation. They also allow baseline conditions to be established before remediation begins, enabling subsequent monitoring of remediation effectiveness through repeated geophysical surveys. This non-invasive monitoring capability reduces reliance on extensive drilling and sampling, lowering costs and environmental disturbance.

The integration of geophysical plume delineation with engineering and environmental assessment ensures that remediation efforts are targeted, efficient, and based on reliable subsurface information.



Fill in the blank: Geophysical plume mapping supports remediation by guiding monitoring and _____ well placement.

[Insert table here]

Table 4.3: Contribution of geophysical plume mapping to remediation planning

[Insert table placeholder here]

Short description: Use of geophysical data in chemical pollution management and remediation

Suggested AI prompt: *Generate a table summarising how geophysical plume mapping supports remediation and monitoring activities*

Pilot questions 4.3

1. What is a chemical contamination plume?
2. Explain how contaminants migrate to form plumes in groundwater systems.
3. Why are electrical resistivity and electromagnetic data useful for plume mapping?
4. State one challenge in interpreting geophysical data for chemical plumes.
5. How does geophysical plume mapping support remediation planning?

Series summary

This Series focused on the **geophysical investigation of chemical pollution and industrial contamination**, emphasising how geophysical methods are applied to identify, delineate, and assess chemical pollutants in soil and groundwater systems. Its importance lies in addressing pollution problems that are largely hidden beneath the ground surface and therefore require indirect, non-invasive investigative approaches.

We began by examining the nature and sources of chemical pollution in the environment, highlighting how industrial activities and waste disposal practices introduce hazardous substances into soil and groundwater. The behaviour of chemical pollutants in the subsurface and their environmental and health implications were discussed to establish the need for reliable investigation tools. We then explored the geophysical techniques used to investigate chemical pollution, focusing on how contamination alters subsurface physical properties, particularly electrical resistivity and conductivity, and how geophysical surveys are applied at industrial pollution sites. Finally, we examined the concept of chemical pollution plumes, explaining contaminant migration processes, interpretation of geophysical data for plume delineation, and the role of geophysical mapping in remediation planning and environmental management.

As a result of this Series, you should now be able to describe the nature and sources of chemical pollution, explain how chemical contaminants modify subsurface physical properties, apply geophysical techniques to investigate contaminated sites, and interpret geophysical data to delineate pollution plumes and support remediation strategies. These competencies are essential for effective environmental assessment and management in settings impacted by industrial and chemical pollution, in line with the Series Learning Outcomes.

Glossary of terms

- **Chemical contamination:** The presence of harmful chemical substances in soil or groundwater at concentrations that pose risks to human health, ecosystems, or environmental quality.
- **Chemical pollution plume:** A subsurface zone formed by the migration of dissolved chemical contaminants away from their source, typically following groundwater flow paths.



- **Contaminant migration:** The movement of chemical pollutants through soil and groundwater systems under the influence of physical, chemical, and hydrological processes.
- **Electrical conductivity:** A physical property measuring the ability of subsurface materials or groundwater to conduct electrical current, often increased by dissolved salts or chemical contaminants.
- **Electrical resistivity:** The resistance of subsurface materials to electrical current flow, commonly reduced in areas affected by chemical pollution or saline groundwater.
- **Environmental remediation:** Actions taken to remove, contain, or reduce environmental contamination in soil or groundwater to protect human health and ecosystems.
- **Geophysical plume mapping:** The use of geophysical survey data to delineate the shape, extent, and movement of subsurface contamination plumes.
- **Groundwater flow:** The movement of groundwater through subsurface materials, which strongly influences the direction and extent of chemical plume migration.
- **Industrial contamination site:** A location where industrial activities have introduced chemical pollutants into soil or groundwater, often requiring detailed investigation and remediation.
- **Non-invasive investigation:** An investigation approach that examines subsurface conditions without excavation or drilling, a key characteristic of geophysical methods.
- **Physical property contrast:** A measurable difference in subsurface properties, such as resistivity or conductivity, between clean and contaminated zones that allows geophysical detection.
- **Pollution source:** The origin point from which chemical contaminants are released into the environment, such as factories, storage tanks, pipelines, or waste dumps.
- **Remediation planning:** The process of designing strategies to manage and clean up contaminated sites, often informed by geophysical mapping of pollution extent.
- **Subsurface contamination:** The presence of chemical pollutants beneath the ground surface within soil and groundwater systems.
- **Waste disposal site:** A facility such as a landfill or waste dump where chemical substances may generate leachate that contaminates surrounding soil and groundwater.

Concept check questions 4

Objective questions

1. Chemical pollution in the subsurface is best described as:
 - a) Natural variation in soil mineral composition
 - b) Presence of harmless salts in groundwater
 - c) Accumulation of hazardous chemical substances in soil or groundwater
 - d) Temporary surface contamination only
 (Linked to SLO 4.1)
2. A major source of chemical contamination at industrial sites is:
 - a) Natural rainfall infiltration
 - b) Weathering of bedrock
 - c) Leakage, spills, or improper disposal of industrial chemicals
 - d) Seismic activity
 (Linked to SLO 4.2)
3. In geophysical surveys, chemical contamination is often indicated by:
 - a) Increased resistivity values
 - b) No change in subsurface properties
 - c) Reduced resistivity and increased conductivity



- d) Uniform seismic velocities
(Linked to SLO 4.3)
 - 4. A chemical pollution plume is formed mainly due to:
 - a) Evaporation of surface water
 - b) Vertical movement of air in soil
 - c) Migration of dissolved contaminants with groundwater flow
 - d) Erosion by surface runoff(Linked to SLO 4.5)
-

Short-answer questions

1. Explain why chemical pollution in soil and groundwater is difficult to detect without geophysical methods.
(Linked to SLO 4.1)
 2. State two common industrial or waste-related sources of chemical contamination.
(Linked to SLO 4.2)
 3. Why are electrical resistivity and electromagnetic methods commonly used at chemically contaminated sites?
(Linked to SLO 4.3)
 4. Explain one way geophysical plume mapping supports remediation planning.
(Linked to SLO 4.5)
-

Long-answer questions

1. Describe the nature and sources of chemical pollution in the environment and analyse how geophysical techniques are applied to investigate contamination at industrial sites.
(Linked to SLO 4.1, SLO 4.2, and SLO 4.4)
2. Analyse the concept of chemical pollution plumes, explaining contaminant migration processes and discussing how geophysical data are interpreted to delineate plumes and support environmental remediation.
(Linked to SLO 4.3 and SLO 4.5)

Pilot questions 4.1

1. Chemical pollution is the presence of hazardous chemical substances in soil or groundwater at concentrations that can harm the environment or human health.
 2. Chemical pollutants in soil and groundwater may adsorb onto soil particles, dissolve into groundwater, and migrate over time through infiltration and lateral groundwater flow.
 3. Common industrial sources include chemical manufacturing plants and refineries, as well as metal-processing and manufacturing industries.
 4. Waste disposal sites contribute to chemical pollution through leachate generation, leaking storage systems, and improper waste handling that allows contaminants to infiltrate soil and groundwater.
 5. Chemical pollution is a serious concern because it degrades groundwater quality, threatens ecosystems, and poses direct and long-term risks to human health.
-



Pilot questions 4.2

1. Chemical contamination affects subsurface physical properties by increasing groundwater conductivity and reducing electrical resistivity due to dissolved ions and chemical reactions.
 2. Electrical and electromagnetic methods are suitable because they respond sensitively to changes in conductivity and resistivity caused by chemical pollutants in soil and groundwater.
 3. Geophysical surveys at industrial sites are used to detect contamination zones, map subsurface anomalies, and guide targeted sampling without ground disturbance.
 4. A chemical contamination plume is a zone of subsurface pollution formed as dissolved chemicals migrate away from their source through soil and groundwater.
 5. Geophysical techniques delineate pollution zones and plumes by mapping spatial patterns of anomalous physical properties associated with contaminated areas.
-

Pilot questions 4.3

1. A chemical contamination plume is a migrating region of polluted soil or groundwater formed when dissolved contaminants move with groundwater flow.
2. Contaminants migrate to form plumes through infiltration, advection with groundwater flow, dispersion, and diffusion in permeable subsurface materials.
3. Electrical resistivity and electromagnetic data are useful because chemical plumes typically produce low-resistivity or high-conductivity anomalies relative to background conditions.
4. One challenge is non-uniqueness, where similar geophysical responses may be produced by natural materials, such as clay, rather than chemical pollution.
5. Geophysical plume mapping supports remediation planning by defining contamination extent, guiding monitoring well placement, and enabling non-invasive monitoring of remediation progress.

References and attributions 4

Department-approved course outline and instructional materials for **GPH 414: Environmental Geophysics**, used as the primary institutional reference for chemical pollution, industrial contamination, plume delineation, and the application of geophysical techniques in environmental investigations.

Kearey, P., Brooks, M., & Hill, I. (2002). *An introduction to geophysical exploration* (3rd ed.). Oxford: Blackwell Science.

Reynolds, J. M. (2011). *An introduction to applied and environmental geophysics* (2nd ed.). Chichester: Wiley-Blackwell.

Burger, H. R., Sheehan, A. F., & Jones, C. H. (2006). *Introduction to applied geophysics: Exploring the shallow subsurface*. New York: W. W. Norton & Company.

Freeze, R. A., & Cherry, J. A. (1979). *Groundwater*. Englewood Cliffs: Prentice-Hall.

Illustrations, figures, plates, and tables



- **Figure 4.1:** Pathways of chemical pollutants in soil and groundwater. AI-generated using the instructional prompt provided in Part 4.1.
- **Plate 4.1:** Common industrial and waste disposal sources of soil and groundwater contamination. Intended to be sourced from open educational repositories or generated using the suggested AI prompt.
- **Figure 4.2:** Contrast between uncontaminated and chemically contaminated subsurface zones. AI-generated illustration based on the prompt embedded in Part 4.2.
- **Plate 4.2:** Use of geophysical surveys to assess chemical contamination at an industrial site. Intended to be sourced from open educational resources or generated using an AI prompt.
- **Figure 4.3:** Conceptual illustration of chemical plume formation and migration in a groundwater system. AI-generated using the instructional prompt provided in Part 4.3.
- **Plate 4.3:** Geophysical delineation of a chemical pollution plume in the subsurface. Intended to be sourced from open educational repositories or generated using the suggested AI prompt.
- **Table 4.1:** Environmental and health impacts of chemical pollution.
- **Table 4.2:** Geophysical indicators used to delineate chemical contamination zones and plumes.
- **Table 4.3:** Contribution of geophysical plume mapping to remediation planning.

COURSE CODE:GPH 414

COURSE TITLE: Environmental Geophysics

COURSE UNIT LOAD (2 Units C: LH 30)

- Foundations of Environmental Geophysics and Earth Science Concepts.
- Geophysical Techniques in Environmental Pollution Studies.
- Saline Water Intrusion and Groundwater Quality Mapping.
- Geophysical Investigation of Chemical Pollution and Industrial Contamination.
- Oil Spillage, Pollution Delineation, and Environmental Mapping.

Part 5.1 Nature and sources of oil spillage and petroleum pollution.

- Causes and types of oil spillage
- Behaviour of petroleum pollutants in soil and groundwater
- Environmental impacts of oil pollution

Part 5.2 Geophysical methods for oil spillage investigation.

- Subsurface physical property changes caused by oil contamination
- Application of geophysical techniques in oil-polluted environments
- Detection and delineation of hydrocarbon-affected zones

Part 5.3 Environmental mapping of pollution and impacted zones.



- Concept and importance of environmental mapping
- Geophysical mapping of oil pollution extent
- Use of pollution maps in environmental assessment and management

Introduction

Oil spillage and petroleum pollution represent significant environmental challenges because hydrocarbons can persist in soil and groundwater systems and cause long-term environmental degradation. Accidental oil spills, leaking pipelines, storage tank failures, and improper handling of petroleum products introduce hydrocarbons into the subsurface, where they may migrate, alter soil properties, contaminate groundwater, and threaten ecosystems and human health. Because oil contamination often occurs beneath the ground surface, reliable investigation and mapping techniques are essential for effective environmental assessment and management.

The aim of this Series is to examine the nature of oil spillage and petroleum pollution and to demonstrate how geophysical techniques are applied to delineate contaminated zones and support environmental mapping.

We shall commence this Series by examining the causes, sources, and behaviour of oil spillage and petroleum pollutants in soil and groundwater, with emphasis on their environmental impacts. We will then explore the geophysical methods used to investigate oil-polluted environments, focusing on how hydrocarbon contamination alters subsurface physical properties and how these changes are detected using geophysical surveys. Finally, the Series will address environmental mapping of pollution, showing how geophysical data are used to delineate the spatial extent of oil contamination and produce maps that support environmental assessment, remediation planning, and sustainable environmental management.

Series learning outcomes

Upon completing this Series, you should be able to:

- **SLO 5.1** explain the causes, sources, and characteristics of oil spillage and petroleum pollution in soil and groundwater environments.
- **SLO 5.2** analyse the behaviour and movement of hydrocarbon pollutants in subsurface systems and their environmental impacts.
- **SLO 5.3** explain how oil contamination alters subsurface physical properties detectable by geophysical methods.
- **SLO 5.4** apply appropriate geophysical techniques to detect and delineate oil-polluted zones in the subsurface.
- **SLO 5.5** interpret geophysical data to produce environmental pollution maps that support assessment, remediation planning, and environmental management.

5.1 Nature and Sources of Oil Spillage and Petroleum Pollution

5.1.1 Causes and types of oil spillage

Oil spillage refers to the accidental or uncontrolled release of petroleum products into the environment, particularly onto land or into water bodies where they may infiltrate soil and groundwater systems. Oil spills may occur suddenly as a result of accidents or develop gradually through prolonged leakage.



Common causes of oil spillage include rupture of pipelines, failure of storage tanks, transportation accidents involving tankers, mechanical faults in oil production facilities, and poor maintenance of petroleum infrastructure. Human error, equipment ageing, vandalism, and inadequate regulation can also contribute significantly to spill incidents.

Oil spillage may be classified into different types based on the source and mode of release. **Acute spills** occur as sudden events, such as tanker accidents or pipeline ruptures, while **chronic spills** involve slow, continuous leakage over extended periods. Both types pose serious environmental risks, although chronic spills are often more difficult to detect and monitor.

Fill in the blank: Oil spillage may occur suddenly as acute events or gradually through _____ leakage.

[Insert figure here]

Short description: Common causes of oil spillage

Figure 5.1: Typical sources and causes of oil spillage in terrestrial environments

Suggested AI prompt: *Create a diagram showing pipelines, storage tanks, and transport routes as sources of oil spillage*

5.1.2 Behaviour of petroleum pollutants in soil and groundwater

Once released into the environment, **petroleum pollutants** exhibit complex behaviour in soil and groundwater systems. Hydrocarbons may spread laterally across the ground surface or infiltrate downward through soil pores under the influence of gravity. Their movement depends on factors such as soil permeability, groundwater depth, chemical composition of the oil, and environmental conditions.

In the subsurface, lighter petroleum products may float on the water table, forming distinct hydrocarbon layers, while heavier components may sink or adhere strongly to soil particles. Dissolved hydrocarbon fractions can migrate with groundwater flow, creating contamination zones that extend beyond the original spill site.

Petroleum contamination often alters soil structure and reduces groundwater quality, making contamination persistent and difficult to remediate. Understanding these behaviours is essential for selecting appropriate geophysical investigation techniques.

Pause and reflect: Dissolved petroleum contaminants may migrate in the subsurface along _____ flow paths.

[Insert plate here]

Short description: Migration of petroleum pollutants in soil and groundwater

Plate 5.1: Behaviour of hydrocarbon pollutants after oil spillage in the subsurface

Suggested AI prompt: *Create an illustration showing oil infiltration through soil and migration within groundwater*

5.1.3 Environmental impacts of oil pollution



Oil pollution has severe **environmental impacts** on soil, groundwater, surface water, and ecosystems. Hydrocarbon contamination can destroy soil fertility, affect plant growth, and render land unsuitable for agriculture. In groundwater systems, oil pollution degrades water quality, making it unfit for drinking and other domestic uses without extensive treatment.

Ecologically, oil pollution threatens wetlands, terrestrial habitats, and aquatic ecosystems by disrupting biological processes and harming living organisms. Petroleum hydrocarbons can also persist in the subsurface for long periods, prolonging environmental damage. Socio-economic consequences often include loss of livelihoods, increased remediation costs, and health risks for affected communities.

These impacts highlight the importance of early detection, accurate delineation, and effective mapping of oil-polluted zones using environmental geophysics.

Fill in the blank: Oil pollution can render soil barren and groundwater unfit for _____ use.

[Insert table here]

Table 5.1: Environmental and socio-economic impacts of oil spillage

[Insert table placeholder here]

Short description: Effects of petroleum pollution on soil, water, and ecosystems

Suggested AI prompt: *Generate a table summarising environmental impacts of oil spillage on soil and groundwater*

Pilot questions 5.1

1. What is meant by oil spillage in environmental studies?
2. State two common causes of oil spillage.
3. Distinguish between acute and chronic oil spills.
4. Explain how petroleum pollutants behave in soil and groundwater systems.
5. Why is oil pollution considered a serious environmental problem?

5.2 Geophysical Methods for Oil Spillage Investigation

5.2.1 Subsurface physical property changes caused by oil contamination

Oil contamination in the subsurface leads to measurable changes in **subsurface physical properties**, which form the basis for geophysical investigation. Petroleum hydrocarbons interact with soil and groundwater in ways that affect porosity, fluid content, and electrical characteristics. Unlike saline or chemically dissolved pollutants, hydrocarbons may reduce electrical conductivity by displacing conductive groundwater from pore spaces.

In many cases, oil-polluted zones display higher electrical resistivity compared with surrounding clean groundwater zones, particularly where non-aqueous phase liquids accumulate. However, biodegradation of hydrocarbons over time may generate conductive by-products, leading to reduced resistivity in older plumes. This variability means that oil contamination can produce complex geophysical responses depending on the age of the spill and environmental conditions.

Understanding how oil contamination modifies subsurface physical properties is essential for selecting appropriate geophysical methods and avoiding misinterpretation.

Fill in the blank: Fresh hydrocarbon contamination may increase subsurface resistivity by displacing _____ groundwater from pore spaces.



[Insert figure here]

Short description: Physical property changes associated with oil contamination

Figure 5.2: Comparison of subsurface physical properties in clean and oil-contaminated zones

Suggested AI prompt: *Create a diagram showing resistivity contrasts between clean groundwater and hydrocarbon-polluted subsurface zones*

5.2.2 Application of geophysical techniques in oil-polluted environments

Several **geophysical techniques** are applied to investigate oil-polluted environments, depending on site conditions and contamination characteristics. Electrical resistivity methods are commonly used to map zones where hydrocarbons have altered fluid content and electrical properties of the subsurface. Resistivity profiling allows identification of lateral contamination spread, while resistivity sounding helps estimate depth and thickness of oil-affected layers.

Electromagnetic methods provide rapid surveys over large areas and are particularly useful where contamination is extensive or access is limited. These methods can identify conductivity anomalies associated with biodegradation zones around oil spills. In some cases, seismic methods may support investigation by identifying changes in soil structure or stratigraphy that influence oil migration pathways.

The selection of geophysical techniques must consider the type of petroleum product, subsurface geology, and stage of contamination to ensure reliable results.

Pause and reflect: Electrical resistivity surveys are useful in oil spillage studies because hydrocarbons alter subsurface _____ characteristics.

[Insert plate here]

Short description: Geophysical survey of an oil-polluted site

Plate 5.2: Application of geophysical methods in investigating oil-contaminated environments

Suggested AI prompt: *Create an illustration showing resistivity and electromagnetic surveys conducted at an oil spill site*

5.2.3 Detection and delineation of hydrocarbon-affected zones

A major objective of geophysical investigation in oil spillage studies is the **detection and delineation of hydrocarbon-affected zones**. These zones may include free-phase hydrocarbons, residual contamination within soil pores, and dissolved hydrocarbon fractions migrating with groundwater.

Geophysical data are analysed to identify anomalies that contrast with background conditions. High-resistivity zones may indicate fresh hydrocarbon accumulation, while zones of altered conductivity may reflect degradation products around older spills. Mapping these anomalies allows estimation of contamination extent, depth, and geometry.

Delineation of hydrocarbon-affected zones supports environmental assessment, risk evaluation, and remediation planning by identifying areas requiring further investigation or cleanup. Integration with geological and groundwater flow information improves interpretation reliability.



Fill in the blank: Hydrocarbon-affected zones are delineated geophysically by identifying subsurface _____ relative to background conditions.

[Insert table here]

Table 5.2: Geophysical indicators of hydrocarbon-affected subsurface zones

[Insert table placeholder here]

Short description: Typical geophysical responses associated with oil contamination

Suggested AI prompt: *Generate a table linking geophysical responses to different stages of hydrocarbon contamination*

Pilot questions 5.2

1. How does oil contamination affect subsurface physical properties?
2. Why may oil-polluted zones show higher resistivity than surrounding areas?
3. State two geophysical techniques commonly used in oil spillage investigations.
4. Explain why geophysical responses to oil contamination may vary with time.
5. How does geophysical delineation of hydrocarbon-affected zones support environmental assessment?

5.3 Environmental Mapping of Pollution and Impacted Zones

5.3.1 Concept and importance of environmental mapping

Environmental mapping is the process of representing environmental conditions spatially in order to visualise the distribution, extent, and intensity of pollution within an area. In the context of oil spillage and environmental geophysics, environmental mapping focuses on displaying contaminated and impacted zones in a clear and interpretable form.

Environmental maps integrate geophysical survey results with geographical location to show where pollution occurs, how far it extends, and which areas are most affected. Such maps are essential tools for communicating complex subsurface information to engineers, environmental managers, decision-makers, and local communities. They provide a basis for understanding pollution patterns and for prioritising areas that require further investigation, protection, or remediation.

Environmental mapping therefore transforms geophysical data into practical information that supports environmental assessment and sustainable land and water management.

Fill in the blank: Environmental mapping represents pollution _____ patterns and impacted zones in a visual form.

[Insert figure here]

Short description: Environmental mapping of pollution zones

Figure 5.3: Conceptual example of an environmental pollution map derived from geophysical data

Suggested AI prompt: *Create a map showing polluted and unpolluted zones based on interpreted geophysical survey results*

5.3.2 Geophysical mapping of oil pollution extent



Geophysical mapping of oil pollution involves using interpreted geophysical survey data to delineate the lateral and vertical extent of hydrocarbon contamination. Electrical resistivity and electromagnetic survey results are commonly converted into maps and cross-sections that highlight zones where subsurface physical properties differ from background conditions due to oil contamination.

In oil-polluted environments, geophysical maps may show high-resistivity zones associated with fresh hydrocarbon accumulation or altered conductivity zones linked to biodegradation products. These maps help identify contamination hotspots, plume boundaries, and areas where oil pollution has migrated along preferential pathways such as fractures or permeable layers.

Geophysical mapping provides continuous spatial coverage, offering advantages over point-based sampling methods. When combined with site information and hydrogeological knowledge, it enables more accurate characterisation of oil pollution extent.

Pause and reflect: Geophysical mapping helps determine the lateral and Vertical _____ of oil-polluted zones.

[Insert plate here]

Short description: Geophysical mapping of oil-affected areas

Plate 5.3: Example of geophysical mapping showing the extent of oil contamination

Suggested AI prompt: *Create an illustration of a site map where geophysical data are used to outline oil-polluted zones*

5.3.3 Use of pollution maps in environmental assessment and management

Pollution maps derived from geophysical investigations play a vital role in **environmental assessment and management**. They help authorities and environmental professionals identify areas at risk, assess the severity of contamination, and evaluate potential impacts on groundwater, soil, and nearby ecosystems.

In remediation planning, pollution maps guide the placement of monitoring wells, excavation zones, or treatment systems. They also allow progress to be tracked by comparing repeated geophysical maps over time, providing insight into whether oil contamination is spreading, stabilising, or being successfully remediated. For environmental monitoring, these maps support early warning systems and long-term management strategies.

By providing a clear spatial framework, pollution maps improve decision-making, optimise use of resources, and contribute to effective environmental protection and sustainable development.

Fill in the blank: Pollution maps support environmental management by guiding remediation and _____ monitoring activities.

[Insert table here]

Table 5.3: Applications of environmental pollution maps in assessment and management

[Insert table placeholder here]

Short description: Use of geophysical pollution maps in environmental decision-making

Suggested AI prompt: *Generate a table summarising how environmental maps are used in pollution assessment, remediation, and monitoring*



Pilot questions 5.3

1. What is meant by environmental mapping in pollution studies?
2. Why is environmental mapping important in oil spillage investigations?
3. Explain how geophysical data are used to map oil pollution extent.
4. State two advantages of geophysical pollution maps over point sampling methods.
5. How do pollution maps support environmental management and remediation planning?

Series summary

This Series examined **oil spillage, pollution delineation, and environmental mapping** as key areas of application within environmental geophysics. Its importance lies in addressing petroleum-related contamination problems that affect soil and groundwater systems and require reliable subsurface investigation methods for effective management and remediation.

We began by examining the nature and sources of oil spillage and petroleum pollution, highlighting the causes of oil spills, the different forms in which petroleum contaminants occur, and their behaviour in soil and groundwater systems. Attention was given to how hydrocarbons migrate, persist, and degrade in the subsurface, as well as the environmental and socio-economic impacts of oil pollution on land, water resources, ecosystems, and human livelihoods. We then explored the geophysical methods used to investigate oil-polluted environments, focusing on how hydrocarbon contamination alters subsurface physical properties and how electrical resistivity and electromagnetic techniques are applied to detect and delineate hydrocarbon-affected zones. Finally, we considered environmental mapping of pollution, explaining how geophysical data are transformed into maps that show the spatial extent of oil contamination and how such maps support environmental assessment, remediation planning, monitoring, and sustainable environmental management.

As a result of this Series, you should now be able to explain the causes and impacts of oil spillage, analyse the behaviour of petroleum pollutants in the subsurface, apply geophysical techniques to detect and delineate oil-contaminated zones, and interpret geophysical data to produce environmental pollution maps. These capabilities are essential for effective environmental assessment, remediation planning, and long-term management of oil-polluted environments, in line with the Series Learning Outcomes.

Glossary of terms

- **Biodegradation:** The process by which microorganisms break down petroleum hydrocarbons in the subsurface, sometimes altering geophysical responses over time.
- **Environmental mapping:** The spatial representation of environmental conditions, such as pollution extent and impacted zones, using interpreted geophysical and spatial data.
- **Free-phase hydrocarbons:** Petroleum products present as a separate liquid phase in the subsurface, often floating on the water table or accumulating in soil pores.
- **Geophysical mapping:** The process of converting geophysical survey results into maps and cross-sections that show subsurface conditions related to pollution.
- **Hydrocarbon contamination:** Pollution of soil or groundwater by petroleum products resulting from oil spillage or leakage.
- **Hydrocarbon plume:** A subsurface zone formed by the migration of dissolved petroleum components in groundwater away from an oil spill source.
- **Oil spillage:** The accidental or uncontrolled release of petroleum products into the environment, leading to soil and groundwater pollution.
- **Petroleum pollution:** Environmental contamination caused by crude oil or refined petroleum products affecting soil, groundwater, or surface water.



- **Pollution delineation:** The identification and outlining of the spatial extent of contaminated zones using geophysical and environmental data.
- **Pollution hotspot:** An area where contamination levels are significantly higher compared with surrounding regions, often identified through geophysical mapping.
- **Remediation monitoring:** The use of repeated surveys and measurements, including geophysical mapping, to track the effectiveness of cleanup efforts over time.
- **Residual contamination:** Petroleum hydrocarbons retained within soil pores after initial spillage and partial migration, contributing to long-term pollution.
- **Subsurface contamination zone:** A region beneath the ground surface where physical properties have been altered due to pollution.
- **Environmental assessment:** The evaluation of environmental conditions and risks based on investigation, mapping, and interpretation of pollution data.

Concept check questions 5

Objective questions

1. Oil spillage refers to:
 - a) Natural seepage of groundwater to the surface
 - b) Controlled discharge of petroleum products
 - c) Accidental or uncontrolled release of petroleum into the environment
 - d) Evaporation of hydrocarbons from soil
 (Linked to SLO 5.1)
2. In oil-polluted subsurface environments, fresh hydrocarbon contamination commonly results in:
 - a) Increased electrical conductivity
 - b) Reduced resistivity due to dissolved salts
 - c) Increased resistivity caused by displacement of groundwater
 - d) No change in physical properties
 (Linked to SLO 5.3)
3. Geophysical mapping of oil pollution is important because it:
 - a) Replaces the need for environmental management
 - b) Shows only surface spills
 - c) Delineates the spatial extent of subsurface contamination
 - d) Determines chemical composition directly
 (Linked to SLO 5.5)
4. Environmental maps derived from geophysical data are mainly used to:
 - a) Predict climatic conditions
 - b) Display pollution extent and guide remediation
 - c) Identify mineral resources
 - d) Measure surface topography only
 (Linked to SLO 5.5)

Short-answer questions

1. Explain why oil contamination in the subsurface is difficult to detect without geophysical methods.
(Linked to SLO 5.1)
2. State two common causes of oil spillage in terrestrial environments.
(Linked to SLO 5.1)



3. Why may geophysical responses to oil pollution vary with time?
(Linked to SLO 5.3)
 4. Explain one advantage of using geophysical maps for environmental pollution assessment.
(Linked to SLO 5.5)
-

Long-answer questions

1. Describe the behaviour of petroleum pollutants in soil and groundwater systems and explain how geophysical techniques are applied to detect and delineate hydrocarbon-affected zones.
(Linked to SLO 5.2, SLO 5.3, and SLO 5.4)
2. Analyse the role of environmental mapping in oil spillage investigations and discuss how geophysical pollution maps support environmental management and remediation planning.
(Linked to SLO 5.4 and SLO 5.5)

Pilot questions 5.1

1. **Oil spillage** refers to the accidental or uncontrolled release of crude oil or refined petroleum products into the environment, leading to contamination of soil, groundwater, or surface water systems.
 2. Common causes of oil spillage include rupture or leakage of pipelines and storage tanks, transportation accidents, equipment failure, and poor maintenance of petroleum infrastructure.
 3. Acute oil spills occur suddenly as single events such as pipeline rupture or tanker accidents, while chronic spills involve slow, continuous leakage of petroleum products over an extended period.
 4. Petroleum pollutants may infiltrate soil, spread laterally on the land surface, float on the water table, dissolve partially into groundwater, or migrate along groundwater flow paths depending on subsurface conditions and hydrocarbon properties.
 5. Oil pollution is considered a serious environmental problem because it degrades soil fertility, contaminates groundwater, threatens ecosystems, and poses health and socio-economic risks to affected communities.
-

Pilot questions 5.2

1. Oil contamination affects subsurface physical properties by displacing groundwater in pore spaces, altering conductivity, resistivity, porosity, and moisture distribution.
 2. Oil-polluted zones may show higher resistivity because non-aqueous hydrocarbons reduce the electrical conductivity of the subsurface by replacing conductive groundwater.
 3. Electrical resistivity methods and electromagnetic methods are commonly used in oil spillage investigations.
 4. Geophysical responses to oil contamination may vary with time due to processes such as biodegradation, dispersion, and changes in groundwater conditions that modify subsurface physical properties.
 5. Geophysical delineation supports environmental assessment by identifying the extent and geometry of hydrocarbon-affected zones, guiding targeted sampling and remediation planning.
-



Pilot questions 5.3

1. **Environmental mapping** in pollution studies is the spatial representation of contamination patterns and impacted zones derived from interpreted geophysical data.
2. Environmental mapping is important in oil spillage investigations because it shows the spatial extent of subsurface contamination and helps prioritise areas for remediation and monitoring.
3. Geophysical data are used to map oil pollution by converting resistivity or conductivity anomalies into maps and sections that outline contaminated zones.
4. Two advantages of geophysical pollution maps over point sampling are their continuous spatial coverage and their non-invasive nature.
5. Pollution maps support environmental management by guiding remediation activities, monitoring contamination behaviour over time, and supporting informed decision-making.

References and attributions 5

Department-approved course outline and instructional materials for **GPH 414: Environmental Geophysics**, used as the primary institutional reference for oil spillage, petroleum pollution, pollution delineation, and environmental mapping using geophysical techniques.

Kearey, P., Brooks, M., & Hill, I. (2002). *An introduction to geophysical exploration* (3rd ed.). Oxford: Blackwell Science.

Reynolds, J. M. (2011). *An introduction to applied and environmental geophysics* (2nd ed.). Chichester: Wiley-Blackwell.

Burger, H. R., Sheehan, A. F., & Jones, C. H. (2006). *Introduction to applied geophysics: Exploring the shallow subsurface*. New York: W. W. Norton & Company.

Freeze, R. A., & Cherry, J. A. (1979). *Groundwater*. Englewood Cliffs: Prentice-Hall.

Illustrations, figures, plates, and tables

- **Figure 5.1:** Typical sources and causes of oil spillage in terrestrial environments. AI-generated using the instructional prompt provided in Part 5.1.
- **Plate 5.1:** Behaviour of hydrocarbon pollutants after oil spillage in the subsurface. Intended to be sourced from open educational repositories or generated using the suggested AI prompt.
- **Figure 5.2:** Comparison of subsurface physical properties in clean and oil-contaminated zones. AI-generated illustration based on the prompt embedded in Part 5.2.
- **Plate 5.2:** Application of geophysical methods in investigating oil-contaminated environments. Intended to be sourced from open educational resources or generated using an AI prompt.
- **Figure 5.3:** Conceptual example of an environmental pollution map derived from geophysical data. AI-generated using the instructional prompt provided in Part 5.3.
- **Plate 5.3:** Example of geophysical mapping showing the extent of oil contamination. Intended to be sourced from open educational repositories or generated using the suggested AI prompt.
- **Table 5.1:** Environmental and socio-economic impacts of oil spillage.
- **Table 5.2:** Geophysical indicators of hydrocarbon-affected subsurface zones.
- **Table 5.3:** Applications of environmental pollution maps in assessment and management.



lanetonline.com

