ENVIRONMENTAL GEOSCIENCES

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Lecture-39

Pollution of Groundwater Resources

Welcome to the SWAYAM NPTEL course on Environmental Geosciences. We have discussed in module seven law of groundwater movement, Darcy law and its applications, groundwater fluctuations. Today we will discuss the lecture five that is pollution of groundwater resources. The important concepts in this lecture will be covered like introduction to groundwater pollution, factors affecting groundwater pollution, sources of contamination in groundwater, attenuation of pollution, groundwater contamination in India and the harmful effects of groundwater pollution.

We have seen today the accelerated pace of development, rapid industrialization and population density. It has increased with the demand of the water resources. Groundwater which is a gift of nature, is about two twenty billion cubic meters, including recharge through infiltration, seepage, and evapotranspiration. Out of this, nearly one-third is extracted for irrigation, industrial, and domestic use, while most of the water is regenerated into rivers.

Over 98 percent of the freshwater on the earth lies below its surface. The remaining 2 percent is what we see in lakes, rivers, streams and reservoirs. Out of the fresh water below the surface, about ninety percent satisfies the description of the groundwater i.e. water which occurs in saturated materials below the water table. About 2 percent water occurs as soil moisture in the unsaturated zone above the water table which is essential for the plant growth. Groundwater acts as a reservoir by virtue of large pore space in earth materials as a conduit which can transport water over long distances and as a mechanical filter which improves water quality by removing suspended solids and bacterial contamination

It is the source of water for wells and springs that is recommended source of the rural domestic use and groundwater is replenished by precipitation that is through rain, snow, sleet and hail which are the different forms of precipitation. Today, human activities are constantly adding industrial, domestic and agricultural waste to groundwater reservoirs at an alarming rate. Groundwater contamination is generally irreversible that is once if it is contaminated it is difficult to restore the original water quality of the aquifer. Excessive mineralization of groundwater degrades water quality producing an objectionable taste, odor and excessive hardness. Although the soil mantle through which water passes acts as an adsorbent, retaining a large part of colloidal and soluble ions with its cation exchange capacity, but groundwater is not completely free from the menace of chronic pollution.

It is always better to protect groundwater first rather than relying on technology to clean up water from a contaminated source. Ice caps and glaciers account for 76.6 percent of fresh water source on Earth, followed by groundwater twenty-two point seven and surface water a mere 0.5 percent. Despite groundwater being a major source of drinking water, it is often disregarded because of a lack of knowledge about its behavior. Groundwater is a principal source of drinking water particularly in rural areas and also for irrigation but it has earlier been polluted or overused making a importable or resulting in its depletion. In terms of percentage the pollution of groundwater is however quite small.

In cities and villages, pollution activities are high and these are affecting human health as well as the environment. Although only a small fraction of the total groundwater resources are affected by human activities, but the proportion of the local usable resources affected are much higher and becoming critical in some areas close to the major population centers. Developed countries like North America, Europe, Australia are now developing groundwater protection policies which would hopefully lead to the more sustainable development of the water resources. The techniques are also available for cleaning up the polluted or contaminated groundwater sources, but these are very expensive. India has a good industrial infrastructure in core industries like metals, chemicals, fertilizers, drugs and petroleum industries like plastics, pesticides, detergents, fuels, solvents, paints, dyes and food additives, released effluents and emissions polluting soil water plant ecosystem.

The disposal of solid and liquid waste containing heavy metals like lead, nickel, chromium, molybdenum, mercury in land or water bodies leads to the heavy metal contamination of the soil, water, plant, animal and ecosystems. Now we will discuss the factors affecting groundwater pollution. The extent of groundwater pollution depends on the following factors, that is, rainfall pattern, depth of water table, then the distance from the source of contamination and the fourth one is the soil properties such as texture of the soil, structure of the soil and filtration rate through the soil. Now source of contamination. Underground sources of drinking water, especially in outskirts of larger cities and villages, are highly polluted. Groundwater is threatened with the pollution from the following sources, that is from the domestic waste, agricultural waste, industrial waste, runoff from urban areas and some soluble effluents. Because of these, the groundwater becomes polluted in certain localities.

Now pollution in relation to water use. The possible pollutants in groundwater are virtually limitless. The sources and causes of the water pollution are closely associated with human use of water. A complex and interrelated series of modification to natural water quality is created by the diversity of human activities impinging on the hydrological cycle. The principal sources and causes of groundwater pollution can be categorized as municipal, industrial, agricultural and miscellaneous.

Most pollution stems from the disposal of waste on or into the ground. Method of disposal includes placing waste in percolation ponds on the ground surface, spreading or irrigation, in seepage pits or trenches, in dry stream beds, in landfills, into disposal wells and into injection wells. All sources and causes of pollution can be classified as to their geometry. A point source originates from a singular location, a line source has a predominantly linear alignment, and a diffuse source occupies an extensive area that may or may not be clearly defined.

Groundwater contamination scenarios can be segregated into two categories. First category is the point sources and second category is the non-point, that is area or distributed sources. Point sources include storage tanks, both underground and above ground, landfills, pipeline release, chemical manufacturing locations, petroleum refining locations, wood-treating facilities, and many others are considered to be the point sources. Whereas non-point sources, that is area or distributed sources, include agriculture activity. Point source groundwater contamination problems can be further divided into three main categories, that is light non-aqueous phase liquids, dense non-iqueous phase liquids, and inorganics and other dissolved constituents.

In their pure liquid form, LNAPLs are less dense than the water and DNAPLs are denser than water. LNAPL sites are caused by release of petroleum products or crude oil, e.g. service station, refineries and pipeline spills. Whereas DNAPL sites have been caused by dry cleaning, aviation, automobile and electric circuit board operations, which historically have used chlorinated solvents such as trichloroethylene and perchloroethylene. Inorganics and other dissolved constituents include metals and salts. Sources that have added contaminants to groundwater in the dissolved form include but are not limited to mining operations, electroplating operations, leaking wastewater treatment facilities and landfills.

Further, the principal sources and causes of pollution have been described with regard to their occurrence and their effects on groundwater quality in the further slides. First is the municipal sources and causes. Within the municipal sources and causes, first we will discuss the sewer leakage. Sanitary sewers are intended to be watertight. However, in reality, leakage of sewage into the ground is a common occurrence, especially from old sewers.

Leakage may result from poor workmanship, defective sewer pipe, breakage by tree roots, ruptures from heavy loads or soil slippage. fractures from seismic activity, loss of foundation support, shearing due to the differential settlement at manholes, and infiltration causing sewage into abandoned sewer laterals. Because suspended solids in sewage tend to clog sewer cracks, and because the surrounding soil tends to become clogged due to anaerobic conditions, leakage from minor sewer opening is small. Sewer leakage can introduce high concentration of BOD, that is biochemical oxygen demand, COD, that is chemical oxygen demand, nitrate, organic chemicals and possibly bacteria into the groundwater. Where sewers serve industrial areas, heavy metals such as arsenic, cadmium, chromium, cobalt, copper, iron, lead, manganese and mercury may enter the wastewater.

Second type is the liquid waste. Here we will see wastewater in an urban area may originate from domestic uses as shown in the figure. In this figure you can see domestic uses, inside use, then outside use. Inside use we can see pick up of TDS, nitrogen, phosphorus, disinfectants, bacteria, viruses, toxic materials, brines from softening. Whereas in outside use, you can see by lawn watering, fertilizers usage, pesticide usage, soil amendments, car wash, swimming pools.

And these all are giving the wastewater as well as the solid waste. So, most of the highly variable mix of water receives some degree of treatment and is then discharged into the surface water. There is an increasing trend for treated wastewater to be recharged into the ground where it mingles with naturally occurring groundwater and subsequently becomes available for reuse. in this you can see that these are being treated septic tank and leak fields are here then sanitary landfills are also there and then by the different processes such as recharge of groundwater basins reuse of water and surface water streams Again, the domestic usage of water and their effects on water quality can be better seen by this figure.

Land application of municipal effluent is accomplished by one of the three methods that is irrigation, infiltration, percolation or overland flow. The selection of a method at a given site is primarily governed by the drainability of the soil because this property determines the allowable liquid loading rate. In irrigation systems, wastewater is applied by spraying, bridge and furrow, and flooding, and some water is lost by evapotranspiration. For the infiltration percolation method, this method, effluent is applied by spreading in basins or by spraying almost all of the water so applied reaches the groundwater. In the overland flow technique, wastewater is sprayed over the upper reaches of the slope terraces

and allowed to flow across a vegetated surface to runoff collection ditches. Percolation to groundwater is minor in overland flow because surface runoff and evapotranspiration account for most of the applied water. Municipal wastewater can introduce bacteria, viruses, and inorganic and organic chemicals into groundwater, whereas the recharged water is later extracted for potable use Concerns exist regarding the health aspects of their reclaimed water. Of this reclaimed water, particularly involving viruses, trace elements, heavy metals and stable organics.

Furthermore, chlorination of wastewater effluent can produce additional potential pollutants. Shallow wells are widely employed to place surface runoff and sometimes treated municipal wastewater underground goes to freshwater aquifers. Such disposal wells have been criticized from a health standpoint because of the potential for pollutants to be released directly into an aquifer. The problem is most critical where disposal wells are near to the pumping wells as shown in the figure and where the beneficial effects of water passing through fine-grained materials may be absent such as in basalt and limestone aquifers. Third is the solid waste.

The land disposal of solid waste creates a potentially important source of groundwater pollution. A landfill may be defined as any land area serving as a depository of urban or municipal solid waste. Many landfills are simply refuse dumps. Only a fraction can be regarded as sanitary landfills, indicating that they were designed and constructed according to engineering specifications. Leachate from a landfill can pollute groundwater if water moves through the fill material.

Possible sources of water include precipitation, surface water, infiltration, percolating water from adjacent land and groundwater in contact with the fill. Ordinary mixed refuse usually has a moisture content less than that of the field capacity. Therefore, leachate from a landfill can be minimized if water from the above sources can be kept away from the fill material. In a properly constructed sanitary landfill, any leachate generated can be controlled and prevented from polluting groundwater. In addition, it is assumed that the landfill is properly located, operated and monitored.

The problem of pollution from landfills is greatest where high rainfall and shallow water tables occur. Important pollutants frequently found in leachate include BOD (Biochemical Oxygen Demand) , Chemical Oxygen Demand (COD), iron, manganese, chloride, nitrate, hardness and trace elements. Hardness, alkalinity and total dissolved solids are often increased while the generation of gases such as methane, carbon dioxide, ammonia, and hydrogen sulfide are further byproducts of the landfills. Now the industrial sources and their causes. The first is the liquid waste.

The major uses of water in industrial plants are for cooling, sanitation, manufacturing, and processing. The quality of wastewater varies with the type of industry and type of use. A generalized flow diagram of industrial water use and its effects on water quality is shown in the figure in next slide. Cooling water that is softened before use to inhibit scale formation produces wastewater with salts and heat as important pollutants. Groundwater pollution can occur when industrial wastewater are discharged into pits, ponds or lagoons, thereby enabling the waste to migrate down to the water table.

Cooling water is sometimes recharged underground through shallow disposal wells because its quality, except for the addition of heat, may be unimpaired. The disposal of hazardous and toxic industrial waste is sometimes accomplished employing deep injection wells that place the fluids into saline water formations far below developed freshwater aquifers. In this diagram, you can see there are the different uses within the industrial use, that is the sanitation use, manufacturing and processing use, and cool use. All these after their processes again coming like industrial waste. Industrial waste we are getting like non-reclaimable wastewater, solid waste, reclaimable wastewater.

And further we can see industrial use of water and its effect on the water quality, the sanitary landfill, sludge lagoons, ocean outfall. Whereas this side we can see reuse, we can recharge of groundwater basins and surface water streams. It will further go to the surface water streams. So in this way we can see the different industrial uses are having the different types of the groundwater pollution. Second, in the industrial usage is the tank pipeline leakage.

Here, underground storage and transmission of a wide variety of fuels and chemicals are common practices for industrial and commercial installations. These tanks and pipelines are subject to structural failures so that the subsequent leakage becomes a source of groundwater pollution. Petroleum and petroleum products are responsible for much of the pollution. Leakage is particularly frequent from gasoline stations and home fuel oil tanks. An immiscible liquid such as oil leaks underground and moves downward through permeable soils until it reaches the water table.

Thereafter, it spreads to form a layer on the top of the water table and migrates laterally with groundwater flow as shown in the figure below. You can see here the liquid radioactive waste are sometimes stored in underground tanks. Leakage from such installations which has occurred can cause serious pollution problems in local groundwater. Pumping wells can be used to create drawdown cones to contain the leakage. As mentioned in the figure also, this is the pumping well and to remove a mixture of gasoline and water.

Third is the mining activities. Mines can produce a variety of groundwater pollution problems. Pollution depends on the material being extracted and the milling processes. Coal, phosphate and uranium mines are major contributors. Metallic ores for the production of iron, copper, zinc and lead are also important.

Stone, sand and gravel quarries, although numerous, are chemically much less important. Both surface and underground mines invariably extend below the water table so that the dewatering to expand mining is common. Water so pumped may be highly mineralized and is frequently referred to as acid mine drainage. Typical characteristics include the low pH and high iron and aluminium and sulphate concentration. Coal deposits are often associated with pyrite that is FeS.

This is a stable for conditions. below the water table, but if the water table is lowered, oxidation occurs. Oxidation of pyrite followed by contact with water produces ferrous sulphate ($FeSO_4$) and sulphuric acid (H_2SO_4) in solution. Groundwater intermingling with this water will have a reduced pH and an increase in iron and sulphate contents. Pollution of groundwater can also result from the leaching of old mine tailings and settling ponds. Therefore, pollution problems can be associated with both active and abundant mines.

Next from oil-filled brines, you can see that production of oil and gas is usually accompanied by substantial discharges of wastewater in the form of brine. Constituents of brine include sodium, calcium, ammonia, boron, chloride, sulphate, trace metals, and high total dissolved solids. In the past, oil-filled brine disposal was handled by the discharge to streams or evaporation ponds. In both instances, brine-polluted aquifers became common place in oil production areas as the infiltrating water reached the underlying groundwater. Today, such disposal methods are prohibited by most regulatory agencies.

However, regulation is often ineffective so that many brine-affected areas remain and will persist for years into the future. The figure provides a graphic example of aquifer pollution from an oil-filled brine disposal pit. This one is the pit and just you can see the distribution of saline water in confined aquifer resulting from an oil-filled brine disposal. Now next is the agriculture sources and causes. So within it, the first is the irrigation return flows.

Approximately one-half to two-thirds of the water applied for irrigation of crops is consumed by evapotranspiration. The remainder termed irrigation return flow drains to surface channels or joins the underlying groundwater. Irrigation increases the salinity of irrigation return flow from three to ten times that of the applied water. The degradation results from the addition of salts by dissolution during the irrigation processes, from salts added as fertilizers or soil amendments, and from the concentration of salts by evapotranspiration. Principal cations include calcium, magnesium, and sodium.

Major anions include bicarbonate, sulfate, chloride, and nitrate. Because irrigation is the primary use for water in arid and semi-arid regions, irrigation return flow can be the major cause of groundwater pollution in such regions. Second is the animal waste. Where animals are confined within a limited area, as for beef or milk production, large amounts of waste are deposited on the ground. For the one twenty to one fifty days that a beef animal remains in a feedlot, it will produce over a half ton of manure on a dry weight basis.

With thousands of animals in a single feedlot, the natural assimilative capacity of the soil can become overtaxed. Storm runoff in contact with the manure carries highly concentrated pollutants to surface and subsurface waters. Animal waste may transport salts, organic loads, and bacteria into the soil. Nitrate nitrogen is the most important persistent pollutant that may reach the water table. Fertilizers and soil amendments.

When fertilizers are applied to the agricultural land, a portion usually leaches to the soil and to the water table. The primary fertilizers are compounds of nitrogen, phosphorus and potassium. Phosphate and potassium fertilizers are readily absorbed on soil particles and seldom constitute a pollution problem. But nitrogen in solution is only partially used by plants or absorbed by the soils and it is the primary fertilizer pollutant. Fertilizers are extensively used and will undoubtedly increase in the future.

Soil amendments are applied to irrigated lands to alter the physical or chemical properties of the soil. Lime, gypsum and sulfur are widely used for this purpose. Substantial amount of these soil amendments may eventually leads to the groundwater thereby increasing its salinity. Next is the pesticides, insecticides and herbicides generally used in the agriculture areas. Pesticides can be significant in agriculture areas as a diffuse source of groundwater pollution.

The term pesticide, insecticide and herbicides are broadly interpreted here to embrace any chemical applied to control, destroy or mitigate pests. The presence of these materials in groundwater, even in a minute concentration, can have serious consequences in relation to the potability of the water. The impact of these chemicals on groundwater quality depends on the properties of these chemicals, residue, rainfall or irrigation rates and soil characteristics. Most pesticides are relatively insoluble in water while others are readily absorbed by soil particles or are subject to microbial degradation. Now, the miscellaneous sources and causes.

First is the urbanization. Shallow groundwater quality can be affected by residential and commercial development. Residential development have taken up the large tracts of land and as a consequence have widespread influence on the quality of water that recharges aquifers and discharge into streams, lakes and wetlands. The study indicates that the young and shallow waters have significantly higher median concentration of nitrate, chloride, dissolved solids, sodium, calcium and potassium than old and deep waters. Spills and surface discharges.

Liquids discharged onto the ground surface in an uncontrolled manner can migrate downward to degrade groundwater quality. At industrial sites, casual activities may include boilovers, losses during transfer of liquids, leaks from pipes and valves, and inadequate control of waste and storm runoff. Washing aircraft with solvents and spills of fuel at airports can form a layer of hydrocarbons floating on the water table. Pollution can also occur from the intermittent dumping of fluids on the ground, especially near gasoline stations, small commercial establishments and construction sites. It has been estimated that millions of gallons of automobile waste oil are discharged on the ground surface annually.

Finally, accidents involving above-ground pipelines, storage tanks, railroad cars and trucks, can release large quantity of pollutant at a particular site. Hazardous and flammable liquids are often flushed by water from highways. This action may actually aid in transporting the pollutant to the water table. Stockpiles, solid materials, are frequently stockpiled near industrial plants, construction sites, and large agricultural operations. These may be the raw materials awaiting use, or they may be solid waste placed for temporary or permanent storage.

Precipitation falling on unsheltered stockpiles causes leaching into the soil to occur. This may transport heavy metals, salt, and other inorganic and organic constituents as pollutants to the groundwater. Next is the septic tanks and cesspools. Another potential source of groundwater pollution is septic tanks and cesspools. Commercial establishments, hospitals, industrial plants and resorts employ septic tanks in areas where community sewer systems are not available.

A septic tank is a watertight basin intended to separate floating and settleable solids from the liquid fraction of a domestic sewage and to discharge this liquid with its dissolved and suspended solids into the biologically active zone of the soil mantle through a subsurface percolation system such as a tile fill, a seepage bed or a sand-covered sand filter as shown in this figure. Here you can see this is a basic zone of polluted groundwater. And these are the just the steps you can see soil absorption, biological treatment and what we've seen to the water table. So cesspool is a large buried chamber with porous walls designed to receive and percolate raw sewage. Domestic sewage adds mineral to groundwater.

Bacteria and viruses are normally regrouped by the soil system. Phosphorus is generally retained by the soil, but significant quantity of nitrogen can be added to the groundwater. Next is the surface water. Polluted surface water bodies that contribute to groundwater recharge become sources of groundwater pollution. The recharge may occur naturally from a losing stream or it may be introduced by a nearby pumping well, as indicated in the given figure.

Here you can see the polluted surface water. It is just And this is the pumping water level. So this diagram shows how polluted water can be induced to flow from a surface stream to a pumping well. Now attenuation of pollution. Pollutants in groundwater tend to be removed or reduced in concentration with time and with distance travel.

Mechanisms involved include filtration, sorption, chemical processes, microbiological decomposition, and dilution. The rate of pollution attenuation depends on the type of pollutant and on the local hydrogeological situation. Attenuation mechanisms tend to localize groundwater pollution near its source. They also are responsible for the interest in groundwater recharge as a water reclamation. Filtration removes suspended materials.

Hence, this action is most important at ground surface where polluted surface water is infiltrating into the ground. During groundwater flow, filtration can remove particulate forms of iron and manganese as well as precipitates formed by the chemical reactions. Second is sorption. Sorption serves as a major mechanism for attenuating groundwater pollution. Clays, metallic oxides and hydroxides and organic matter function as sorptive materials.

Most pollutants can be sorbed under favorable conditions with the general exception of chloride and to a lesser extent nitrate and sulfate. The sorption process depends on the type of pollutant and the physical and chemical properties of both the solutions and the subsurface materials are substantially contained in the strata above the water table is a key factor. Sorptive capacity of geological material is finite for most inorganic substances. However, for biodegradable substances such as bacteria and ammonia, the sorptive capacity may be renewed indefinitely. Then the chemical processes, precipitation in groundwater can occur where appropriate ions are in solution in sufficient quantities.

The most important precipitation reactions for the major constituents involve calcium, magnesium, bicarbonate and sulphate. Trace elements having important precipitation potential include arsenic, barium, cadmium, copper, cyanide, fluoride, iron, lead and mercury, molybdenum, radium and zinc. In arid regions where moisture in the near surface zone may be minimal, chemical precipitation becomes a major attenuation mechanism. In the zone above the water table, oxidation of organic matter acts as an important attenuation mechanism. Complex organic compounds are oxidized stepwise to more simple organic compounds until CO and H are formed along with the numerous inorganic ions and compounds.

Both oxidation and reduction reactions can occur underground in conjunction with other mechanisms, leading to precipitates, deposits of installable trace metals and gases. Volatilization and loss as a gas apply particularly to reactions involving nitrates and sulfate. Radioactive decay based on the half-life of a radioisotope acts as an attenuation mechanism for radioactive pollutants. Microbiological decomposition Most pathogenic microorganisms in the soil do not flourish in the soil and hence are subject to ultimate destruction.

The timing of this depends on different species and environmental conditions. Bacteria and viruses, as particulate matter suspended in water, tend to move slower through a porous media than water. Field studies indicate that these pathogens are largely removed by passage through as one meter of soil provided reasonable amounts of silt and clay are present. Dilution is the next one. Pollutants in groundwater flowing through porous media tend to become diluted in concentration due to hydrodynamic dispersion occurring on both microscopic and macroscopic scales.

These mixing mechanisms produce a longitudinal and lateral spreading of pollutants within the groundwater so that the volume affected increases and the concentration decreases with distance traveled. Dilution is the most important attenuation mechanism for pollutants after they reach the water table. Now, we will see the groundwater contamination in India. In India, Central Groundwater Board regularly monitors the quality of groundwater of shallow aquifers on a regional scale. Groundwater quality data generated indicate that the groundwater in major part of the country is potable.

However, groundwater in some parts of the different states in India are contaminated by salinity, arsenic, fluoride, iron, nitrate, and heavy metals beyond the permissible limits prescribed by the BIS. The possible sources of contamination of groundwater are either geogenic or anthropogenic in nature. Anthropogenic contamination of groundwater is due to the industrial discharges, landfills, diffuse sources of pollution such as fertilizers and pesticides from agricultural fields. A vast majority of groundwater quality problems present today are caused by contamination and by overexploitation or by a combination of both. The problem is more severe in and around large cities as also in the vicinity of various industrial clusters.

In many of these areas, groundwater is the only source of drinking water. Thus, a large population is exposed to risk of consuming contaminated water. Now we will see the harmful effects of groundwater pollution. Groundwater, first we will see the harmful effects on man. Polluted groundwater is the major cause for the spread of epidemics and chronic diseases in man.

It causes typhoid, jaundice, dysentery, diarrhoea, tuberculosis and hepatitis. Water contaminated by fibers that is asbestos causes fatal diseases like asbestosis and lung cancer. Groundwater in excessive rainfall areas contains iron in toxic amount. In deep tube well iron exists as ferrous iron which on taking out rapidly changes to light yellow-orange color due to oxidation and precipitation as ferric oxide. In Punjab, Ludhiana, Haryana, Ambala and Sonepat, the woolen industries contribute large amounts of toxic metals such as mercury, nickel, copper, chromium, iron and cyanides to groundwater causing skin and stomach diseases in the man.

Harmful effects on soil, the usage of polluted groundwater for irrigating agricultural fields severely damages crops and decreases grain production. Polluted water acutely affects soil fertility by killing bacteria and soil microorganisms. Contaminated groundwater increases alkalinity in the soils. Groundwater pollution affects plant metabolism severely and disturbs the whole ecosystem. Now concluding the module seven, Darcy's law provides the fundamental principle governing groundwater movement, establishing the relationship between the hydraulic gradient, permeability and flow rate.

It is widely used in hydrogeology for predicting and managing the groundwater resources. Darcy Law is instrumental in designing water wells, predicting contaminant transport, and managing aquifer recharge and remediation efforts, making it a key tool in hydrogeological and environmental engineering applications. Groundwater levels fluctuate due to natural factors like precipitation, evapotranspiration, and geological conditions, as well as anthropogenic activities such as excessive extraction and land use changes. Monitoring beach fluctuations is crucial for sustainable groundwater management. Groundwater contamination arises from industrial waste, agricultural runoff, and improper disposal of domestic sewage, leading to severe environmental and public health concerns.

Understanding pollutant transport mechanisms help in designing the effective mitigation strategies. These are the references for the module seven. Thank you very much to all.