ENVIRONMENTAL GEOSCIENCES

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Lecture-33

Aquifer-its Types

Welcome to the SWAYAM NPTEL course on Environmental Geosciences. We are discussing the module 6. We have already discussed the distribution of water on earth, groundwater provinces of India, hydrological cycle. Today we will discuss the lecture 4 that is aquifer and its different types. The important concepts of this lecture will be covered like geological rock formations, forms of subsurface water, aquifer and their types, geological formations as aquifers, aquifer mapping, Indian aquifers and transboundary aquifer system.

We have discussed from the lecture one that groundwater is an important natural resource. The precipitation infiltrates into the ground and travels down until it reaches the impervious stratum where it is stored as a groundwater. So we have seen that if this is the earth's surface. So inside the soil layer remains this is the soil layer and then a rock is remains inside which is just storing the water, so this rock generally we are telling it as an aquifer. So what is happening if the rain drops will fall, if the rain drops will fall, it will first reach to the first layer of the soil. This process is called as infiltration. We have discussed already in the previous lectures.

From first layer of the soil to the bottom layer of the soil, this is called as percolation. So infiltration and percolation both process take place and then ultimately it reaches to an impervious stratum means this won't allow the water to go down. So this is an aquifer, it is storing the water. So this water is stored in the pores in the geological formation. Geological formations are nothing but these are the soil, rocks and etc.

So, an aquifer is a geological formation. In it, groundwater flows very easily, one aquifer to another aquifer. Aquifer should therefore have the two different characteristics, that is, first the permeability and second the porosity. If the two characteristics will remain in certain formations, geological formations, then definitely those formations will behave like an aquifers. So, examples of these geological formations are sandstone, conglomerate, fractured limestone, and unconsolidated sand and gravel formations.

So such type of rock formations, such type of geological formation in which there is a property of porosity and permeability, then those rock formations or soil formations are termed as an aquifer. You can see here also forms of subsurface water. Water in the soil mantle is generally called subsurface water and is considered in two different zones. The first zone is known as the saturated zone, the zone of saturation, or the phreatic zone. Second zone is termed as unsaturated zone, aeration zone or vadose zone.

So what is happening? On to the land surface, the rain drops falls and this drop enters into the soil layer. So here you are seeing the soil water zone is coming first. Then is coming the intermediate zone and this is the capillary fringe zone. So in this zone, the water remains along with air also.

So it is the zone of areation. Here you are seeing a line which is called as water table. But this zone is the saturated zone. So just the above, just the layer of the saturated zone, just the top layer of the saturated zone is termed as water table. This zone is known as saturation zone.

This is the groundwater zone or unconfined zone because the bedrock is remaining here. It is just the confining beds are here. These are the confining beds. This is not allowing the water, this saturated water to go further downward. Now saturated zone.

Is also known as groundwater zone. It is the space in which all the pores and the soils are filled with water. Here in this zone you will see all the pores will remain filled with the water and the water table forms its upper limit this water table is just the upper limit of the saturated zone and marks a free surface that is a surface having direct contact with the atmospheric pressure. Now, unsaturated zone, zone of aeration and vadose zone. Here what is happening, the vadose zone is the earth's terrestrial subsurface that extends from the surface of the earth to the regional groundwater table. In this zone, the soil pores are only partially saturated with water, not fully saturated with water, rather it is partially saturated with water. The vadose zone may be very shallow, less than one meter or very deep, extending hundreds of meter or more, depending upon the depth to the water table.

Hydrologically they represent the portion of the physical system where precipitation partitions the essential elements of the hydrological cycle that is evapotranspirative return to the atmosphere then runoff and deep infiltration that is the aquifer recharge.

Geochemically, the Vadose zone consists the primary zone of the interaction between earth materials and the precipitation. Vadose zone is further divided into three zones that is the soil moisture zone, intermediate Vadose zone and capillary zone. Soil moisture zone, this zone lies just below to the ground surface. Just below to the ground surface is the soil moisture zone.

It is the major root band of the vegetation from which the water is lost to the atmosphere by evapotranspiration processes. So this zone is important for agriculture since the soil water supplies moisture to the plant roots. Soil moisture is expressed as in percentage. Tensiometer is the instrument which is used to measure the soil moisture in percentage. It contains soil water and pellicular water. Soil water is a vadose water.

It is the water that is near enough to the surface which remains available to the root of plants. Whereas pellicular water is the water held in the soil by molecular attraction that is adhesion to the walls of the rock or soil particles in the form of film or skin after gravity water has drained. Soil water zone was classified by bricks into three sub zones depending on the concentration of the moisture content. The first is the hygroscopic water, second is the capillary water and third is the gravitational water. So first, hygroscopic water is a thin layer of water adhered to the particles.

Hygroscopic water is unavailable for any use and it is always lost as vapour. Capillary water, it is the water held in small pores and resistant to gravitational drainage. It flows upward via capillary. Third is the gravitational water, it is the water which is stored in large pores. It gets drained readily under its own weight.

Intermediate vadose zone, you can see here, this is the intermediate vadose zone. The intermediate vadose zone extends from the lower edge of the soil water zone to the upper limit of the capillary fringe. So this is the capillary fringe and this is the soil water zone. So in between we are getting the intermediate vadose zone. The pores in the zone are filled with air as well as with water.

This zone contains residual moisture that is the water which is available in the soil and that will not contribute to the liquid flow due to the blockage in flow paths. So this zone, totally this zone is the vadose zone whereas this zone is the saturated zone. Now capillary fringe, the capillary zone extends from the water table up to the limit of capillary rise of water or capillary fringe is one which lies immediately above the zone of saturation. The water available in the zone is termed as capillary water. Water is drawn up from the zone of saturation through capillary action and suspended by capillary force.

Thickness of this zone is dependent upon the texture of the soil formation above the zone of saturation. If the size of pore is fine, the upward movement of water through the soil is comparatively more causing greater thickness. The important features of the capillary zone are its lower part which is immediately adjacent to the water table contained water in all pores. Moisture content is being equal to the porosity of soil formation. Water pressure is less than the atmospheric pressure.

Now the term is water table. The subsoil horizon below the surface of the earth is called as the unsaturated zone of zone of aeration or Vadose zone. Below this zone there is a water saturated media which is called as zone of saturation. The uppermost surface of the zone of saturation is generally termed as water table water table forms the boundary between the zone of aeration and zone of saturation. So this is the zone of aeration and this is the zone of saturation in between we are getting this water table. Saturated formations, all earth materials from soils to rocks have pore spaces. Although these pores are completely saturated with water below the water table, from the groundwater utilization aspects only, such material through which water moves easily and hence can be extracted with ease are significant.

On this basis, the saturated formations are classified into four different categories, that is aquifer, aquitard, aquiclude and aquifuge. Aquifer, the first one, aquifer is a saturated formation of earth material which not only stores water but yields it in sufficient quantity. Thus an aquifer transmits water relatively easy due to its high permeability. Unconsolidated deposits of sand and gravel form good aquifers. It is a formation through which only seepage is possible and thus the yield is insignificant compared to an aquifer.

It is partly permeable. A sandy clay unit is an example of aquitard. Through an aquitard, appreciable quantities of water may lead to the aquifer below it. Third one is the aquiclude. It's a geological formation which is essentially impermeable to the flow of water.

It may be considered as closed to water movement even though it may contains large amount of water due to its high porosity. And clay is a good example of an aquiclude. Next one is the aquifuge. It's a geological formation which is neither porous nor permeable. There are no interconnected openings and hence it cannot transmit water.

Massive compact rock without any fractures is an aquifuge and the good example is granite. Now aquifers, we have known something about aquifer, now we will discuss in detail. An aquifer is a formation of rock mass that contains sufficient saturated permeable materials to yield significant quantities of water to wells and pumps. Examples of aquifers are gravel, limestones, sandstones. These are the good examples of aquifers.

According to the geological terms, an aquifer could be referred as a body of saturated rock or geological formation through which water can easily move, permeability will be good, into wells and streams. An aquifer is a saturated formation of the earth. It not only stores water but also yields it in adequate quantity. It may be overlain and underlain by confining beds. Confining beds, it is a relatively impermeable material of formation stratigraphically adjacent to one or more aquifers.

Now, types of aquifers. Most aquifers are of large aerial extent and may be visualized as underground storage reservoir. Water enters the reservoir from natural or artificial recharge. It flows out under the action of gravity or is extracted by wells. Aquifers are classified into two types depending on the presence or absence of a confining beds.

The first type is unconfined aquifer, second is the confined aquifer. Now, unconfined aquifer. An unconfined aquifer is one when a water bearing formation is only underlain by impermeable material. Only underlain, not overlain, only underlain by impermeable material and therefore the water table varies in undulating form depending on the recharge and discharge pumpage from wells and permeability. Recharge of this type of aquifer take place through infiltration of precipitation from the ground surface.

The topmost layer of the water surface of an unconfined aquifer remains in touch with the atmosphere. This layer of water is called as water table aquifer or unconfined aquifer. Good example is the open dug wells. Here you can see this is the case of unconfined aquifer. This is the case of unconfined aquifer.

This is the upper part of an unconfined aquifer which is termed as water table and this layer is the confining beds impermeable material. This is the case of unconfined aquifer. But here what we are seeing in the case of confined aquifer what we are seeing the confining beds are at the top as well as at the bottom also. Means overlain and underlain by confining layers. So this type of aquifer is called as confined aquifers.

The uppermost boundary of the groundwater within the unconfined aquifer is the water table. The groundwater in an unconfined aquifer is more vulnerable to contamination from surface pollution as compared to that in confined aquifers. This been so due to easy groundwater infiltration by land pollutants. Fluctuation in the level of the groundwater varies and depends on the stored up groundwater in the space of the aquifer, which in turn affects the rise or fall of the water level in wells that derive their source from aquifers. Perched Aquifer, It is a special case of an unconfined aquifer.

It involves perched water bodies. This occurs wherever a groundwater body is separated from the main groundwater by a relatively impermeable stratum of small aerial extent and by the zone of aeration above the main body of the groundwater. Here you can see the perched aquifer. It is just separated from the main groundwater by a relatively impermeable stratum. Impermeable stratum, it is just separated by the main groundwater.

Clay lenses in sedimentary deposits often have shallow perched water bodies overlying them. So clay lenses are the good example of perched aquifer. A perched aquifer sits above the main water table. This is the main water table. So it is just lying above the main water table.

Wells tapping these sources, when wells tapping this perched aquifer, then it yields only temporarily or small quantities of water. Not very large quantity of water. Only small quantity of water may be taken out from the such type of formation. That is from the perched aquifer. Now confined aquifer.

It is also known as artesian aquifer or pressure aquifer. This is also known as artesian aquifer or pressure aquifers. This type of aquifer occurs where groundwater is confined under pressure greater than the atmospheric pressure because of overlain and underlain by confining beds. So here you can see this is the case of the confined aquifer. It is overlain and underlain by the confining beds.

Confined aquifers are aquifers that are found to be overlain and underlain by confining rock layers or rock bodies, often made up of clay which might offer some form of protection from surface contamination. The geological barriers which are non-permeable and found exist between the aquifer causes the water within it to be under pressure, which is comparatively more than the atmospheric pressure. The presence of fractures, cracks in bedrocks is also capable of bearing water in large openings within the bedrocks, dissolving some of the rocks and accounts for high yields of well in karst terrain. Geological formations as aquifers. So what we have seen that although groundwater exists everywhere under the ground, some parts of the saturated zone contain more water than others.

Therefore, an aquifer is an underground formation of permeable rock or loose material that can produce useful quantities of water when tapped by a well. Groundwater scientists generally distinguish between two types of aquifers in terms of physical attributes of the aquifer. First is the porous formation and second is the fractured formation. Porous formations have primary porosity from the time of deposition. Porous formation consists of aggregates of individual particles such as sand or gravel.

The groundwater occurs in and moves through the openings between the individual grains. Porous media where the grains are not connected to each other are considered unconsolidated. Unconsolidated formations consist of alluvial sediments of river basins and coastal and deltaic tracts. If the grains are cemented together, such aquifers are called consolidated aquifer. An example of consolidated aquifer is the sandstones.

In consolidated rocks, the grains are held firmly together by cementation, compaction and recrystallization. The porosity and permeability of consolidated rocks are due to the fracturing and weathering. Fractured Formation. Fractured formations have secondary porosity developed due to the various geological and tectonic processes. Fractured aquifers are rocks in which the groundwater moves through cracks, joints or fractures in otherwise solid rock.

Examples of fractured aquifers include granite and basalt, category of igneous rock. Chalk, made up of remains of countless tiny cells, is also permeable mainly because there are cracks in the rock. The nature and lateral and vertical extent of aquifers are controlled by lithology, stratigraphy and structure of the rock formations. Aquifer mapping may be adopted for delineation of primary and principal aquifers that are extensive, limited in extent and oblique or local aquifers of regional extent. The primary and principal aquifers can be grouped under following categories:

First is the porous rock aquifers. Second is the fissured and fractured aquifers. Third is the carbonate rock aquifers. Fourth is the volcanic rock aquifers. And fifth is the semi-consolidated rock aquifers.

The aquifers can be characterized on the basis of well yield, thickness of aquifer and other relevant parameters. The well yield index is determined by dividing the average discharge by the average interval between each time the pump was shut off. The well yield index is the most used parameter. It is based on the following categories:

First category is category one. 0 - 5 gallon per minute. Second category is 5 to 25 gallon per minute. Third category is 25 to 100 gallon per minute. Fourth category is 100 to 500 gallon per minute and fifth category is greater than 500 gallon per minute. The aquifer may be further grouped under the following three broad categories based on the thickness.

First category, thickness less than 30 meter. Second category, aquifer thickness between 30 to 100 meter. And third category, aquifer thickness greater than 100 meter. Now, after knowing about the saturated and unsaturated formations, confining beds, aquifer and the types of aquifer, water table, now we will discuss the aquifer mapping. The National Project on Aquifer Management is an initiative of the Ministry of Jalsakti Government of India for mapping and managing the entire aquifer system in the country.

Its vision is to identify and map aquifers at the micro level to quantify the available groundwater resources and to propose plans appropriate to the scale of demand and other aquifer characteristics, and institutional arrangements for participatory management. Therefore, aquifer mapping is needed to develop an understanding of the groundwater flow systems and to support better management of the groundwater resources. The aquifer mapping can be defined as an interdisciplinary scientific processes wherein a combination of geologic, geophysical, hydrologic and chemical field and laboratory analysis are applied to characterize the quantity, quality and distribution of groundwater in aquifers. This type of mapping, that is aquifer mapping, enhances the knowledge about groundwater occurrence and distribution in space and time and helps in resource assessment, planning and management of groundwater at local as well as in regional scale. Systematic aquifer mapping helps in improving understanding of the geological framework of aquifers, their hydrologic characteristics, water levels in the aquifers and how they change over time, and the occurrence of natural anthropogenic contaminants that affect the portability of the groundwater.

Aquifer mapping also involves in detailed analysis of the underlying geological formations and delineating the areas from which the groundwater flows into the wells. The location and yield of aquifers are dependent on some of the factors and these are the six factors. First is the geological conditions such as rock type. Second is the thickness of formation. Third is the sorting of grains in unconsolidated formation.

Fourth is the grain size of the sediments. Fifth is the faulting and sixth one is the degree of fractures present. The thickness of an aquifer may be few meters or hundreds of meters. An aquifer may be just below the land surface or a hundred of meters below. Aquifer mapping depicts all the information.

A typical aquifer map generally includes the information regarding aquifer geometry, then the contour maps for water table and hydrostatic heads of the different aquifers, then the groundwater flow maps, maps on aquifer depths, saturated water, or total thickness and estimated yield, maps on spatial variation of hydraulic parameters, maps on quality of groundwater in different aquifers, hydrogeological cross-sections and 3D aquifer disposition diagrams, depth of drilling, discharge, well spacing and the limits, level of exploitation of aquifers, annual recharge, vulnerable aquifers, their protection and sites for their monitoring, dynamic and static resource and aquifer-wise water budget, and areas of artificial recharge. Once the aquifer mapping becomes available for whole of the country, it will provide detailed information on groundwater potential, groundwater flow systems, groundwater quality and quantity aspects, aquifer detailing, recharge status and vulnerability of aquifers and many more things. Such information will help in resource assessment, planning and management of groundwater resources at local as well as in regional scale.

Here you can see the aquifer mapping of our country in which the different aquifers are in different colors. You are seeing here alluvium, laterite, basalt, sandstone, shale, limestone, granite, schist, quartzite, charnockite, khondalite, gneiss, BGC, intrusives, unclassified. So all have been mapped here. The different formation have been mapped here. So this is the principal aquifers of India as per our information received from the Central Groundwater Board of the year 2012.

Now Indian aquifers. India has fourteen principal aquifers and forty two major aquifers. The most productive aquifers are composed of unconsolidated sand and gravel, fractured limestone and sandstone. Alluvium is the major aquifer system that covers around 31 percent of the entire country and available in Uttar Pradesh, Bihar, West Bengal and Assam, Odisha and Rajasthan. In India, around 8 percent of the area in Chhattisgarh, Andhra Pradesh, Madhya Pradesh, Gujarat, Karnataka and Rajasthan contains sandstone aquifer.

While limestone aquifer cover around 2 percent mainly in Chhattisgarh, Andhra Pradesh, Karnataka, Gujarat and the Himalayan states. The rest around 60 percent of the area of the country is covered with other formation i.e. basalt aquifer 17 percent, shale aquifer 7 percent, gneiss aquifer 20 percent, schists, granite and quartzite, charnochite, khondalite, laterites, intrusives and so on aquifers - 15 percent of the area of the country. Alluvial Deposits. Probably 9 percent of the developed aquifers consist of unconsolidated rocks, chiefly gravel and sand. These are the most significant groundwater reservoirs for large-scale development in the high rainfall and recharge areas.

They are not prolific in desert conditions with less rainfall recharge. These aquifers may be divided into four categories based on manner of occurrence, water courses, abundant or buried valleys, alluvial plains, and intermountane valleys. Water course consists of the alluvium that forms and underlies stream channels as well as forming the adjacent floodplains. Abandoned or buried valleys are the valleys no longer occupied by the stream that formed them. Although such valleys may resemble watercourses in permeability and quantity of groundwater storage, their recharge and perennial yield are usually less.

Extensive alluvial plains underlain by unconsolidated sediments may exist at many places. In some places gravel and sand beds form important aquifers under these plains. In other places they are relatively thin and have limited productivity. Intermountane valleys or valley fields may be underlain by tremendous volumes of unconsolidated rock materials derived by erosion of bordering mountains. The Indo-Gangetic plains have alluvial deposits over thousand meter. The alluvial aquifers have transmissivity values from two fifty to four thousand meter square per day and hydraulic conductivity from ten to eight hundred meter per day. The well yields range up to 100 liter per second and more but yields of 40 to 100 liter per second are common.

Many high capacity tube wells were installed in the Banas Valley fill to supply water to big cities in semi-arid region of the Rajasthan. Limestone varies widely in density, porosity and permeability depending on degree of consolidation and development of permeable zones after deposition. Opening in limestone may range from microscopic original pores to large solution caverns forming subterranean channels sufficiently large to carry the entire flow of stream. The dissolution of calcium carbonate by water causes prevailingly hard groundwater to be found in limestone aquifers. Also, by dissolving the rock, water tends to increase the pore space and permeability with time.

Solution development of limestone forms a cast terrain characterized by solution channels, closed depressions, subterranean drainage through sinkholes and caves. Such regions normally contain large quantities of groundwater. Aquifers developed by erosive weathering action instead of solution processes cannot be considered as karst. Holokarst, complete karst, develops in soluble carbonate rocks characterized by vast, bare and rocky land without arable land. Merokarst, incomplete karst, occur in lower depths wherein carbonate sediments are covered with arable soil and with vegetation.

Karst aquifers are filled and emptied by water very fast due to large size and interconnectivity of cracks, caverns and channels. The difference between maximum water level after rainy season and minimum water level after dry season can be very high. Water wells in karst aquifers should be carefully located and drilled on fracture intersections. Potential limestone aquifers are found to occur in Rajasthan and peninsular India in which hills range from five to twenty five litre per second. Large spring exists in the Himalayan region is also remain in the limestone formations.

Aeolian Sediments. The deposition of Aeolian sediments follows a definite pattern that is largely dependent on direction and velocity of wind, geology of source rock, topography of the host rocks, drainage and climate. Aeolian sediments such as dune sand and loess are uniform in grain size distribution, mineral composition and textural characteristics. These deposits have high infiltration rate. Many times well cemented calcareous sediments, Pans are found in the Aeolian deposits which may result in confining bed or perched water table conditions. Lowest Aeolian deposits pose problems in well construction and drilling but the presence of calcareous material make possible digging of even open wells.

The transmissivity, hydraulic conductivity and yields of tube wells may range from fifty to eight hundred meter square per day, three to twenty meter square per day and twenty five to hundred cubic meter per hour respectively in the Aeolian aquifers in Rajasthan. Sandstone is the most productive among the semi-consolidated sedimentary rocks. Sandstone and conglomerate are cemented forms of sand and gravel. As such, their porosity and yield have been reduced by the cement. The best sandstone aquifers yield water through their joints.

Conglomerates have limited distribution and are unimportant as aquifers. Potential semi-consolidated sandstone aquifers, particularly those belonging to Gondwanas and Tertiaries, have transmissivity values of hundred to twenty three hundred meter square per day and hydraulic conductivity value from zero point five to seventy meter per day. Generally, the well yields in productive area range from ten to fifty litre per second. Lathi sandstone and Nagaur sandstone in Rajasthan and Tipam sandstone in Tripura state also form productive aquifers. Volcanic rock such as basalt can form highly permeable aquifer.

The type of openings contributing to the permeability of basalt aquifers include interstitial spaces in clinkery, lava at the tops of the flows, cavities between adjacent lava beds, shrinkage cracks, lava tubes, gas vesicles, fissures resulting from faulting and cracking after rocks have cooled, and holes left by the burning of trees overwhelmed by lava. In India, predominant types of volcanic rocks are the basaltic lava flows of Deccan Trap plateau. The Deccan Traps have usually poor to moderate permeability depending on the presence of primary and secondary fractures. Igneous and metamorphic rocks. In solid forms, igneous and metamorphic rocks are relatively impermeable and hence serve as poor aquifers.

Whereas if such rocks occur near the surface under weathered conditions, they have been developed into small wells for domestic water supply. The yield potential of the crystalline and metasedimentary rocks shows wide variations. Bore wells tapping the fracture system generally yield less than one to ten LPS. The transmissivity value of fractured rock aquifers vary from ten to five hundred meter square per day and the hydraulic conductivity varies from zero point one to ten meter square per day. Clay and Shale.

The clay and coarser material mixed with clay are generally porous, but their pores are so small that they may be regarded as relatively impermeable. Clayey soils can provide small domestic water supplies from shallow, large-diameter wells. Shale is formed by consolidation and induration of clayey sediments. Fractured shale furnishes small water supplies. Dense shales devoid of fractures are practically impervious and form confining layers.

Now just summarizing the lecture, Aquifer and its type, we have discussed the geological rock formations in which generally the groundwater occurs. Examples of the geological formations are sandstone, conglomerate, fractured limestone and unconsolidated sand and gravel formations. Then we have discussed about the zone of subsurface water. The zone of subsurface water consists of saturated zone, zone of saturation, phreatic zone and unsaturated zone, aeration zone or vadose zone. Then we have discussed about the saturated formations.

We have seen the different terms aquifer, aquitard, aquiclude and aquifuge. Aquifer can store, transmit and yield significant quantities of water. Example is sandstone gravel beds. Aquitard shows water movement but can still transmit limited amounts of water. example is sandy clay shale, aquiclude not transmit water effectively but may store some water, example is clay, unfractured limestone, aquifuge neither stores nor transmits water, example is granite and quartzite.

Then we have discussed about the aquifer, it is a formation that is rock mass which contains sufficient saturated permeable materials to yield significant quantities of water to wells and pumps. And lastly, we have discussed about the different types of aquifer. We have seen there are two different types, unconfined aquifer and confined aquifer. Unconfined aquifer, when it is underlain by some confining beds and the top will remain in contact with the atmosphere. Whereas confined aquifer, it is a rock formation which is just overlain and underlain by some confining beds.

Then it is confined aquifer. Thank you very much to all.