Engineering Geology
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Lecture - 29
Groundwater over utilization

Hello everyone and welcome back. Today, we are going to talk about the possible detrimental effects of over utilization of groundwater.

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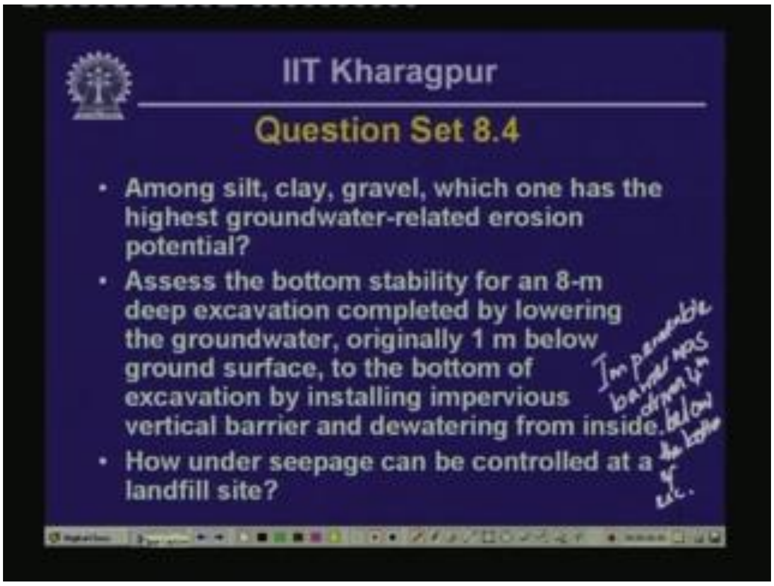

But before we head on with today’s lesson, we are going to look back at the question set that I gave you as a part of the previous lesson. So, these are the questions. The first one the first question that I asked was among silt, clay and gravel, which one has the highest susceptibility to be eroded by groundwater movement. So, as I indicated in the previous lesson, basically the particles that is relatively light as well as once that does not have any tendency of sticking together or cohesive. So, those types of soils are most susceptible to erosion.

So, the soils that are non-cohesive and comprising of fine grains, very fine grains; they exhibit the highest susceptibility of getting eroded by moving groundwater. So, from that point of view, you can see that clay is going to have cohesion. So, it is not going to be susceptible to erosion. Gravel is going to be comprised of heavier particles because of the larger grain size. So, that is also not going to be erodible as much as silt which is fine grained as well as it does not have any cohesion as such to prevent the erosional effect of groundwater movement.

The second question that I asked was for you to assess the bottom stability for an eight meter deep excavation completed by lowering of groundwater originally one meter below the ground surface to the bottom of excavation by installing impervious vertical barrier and dewatering from inside. There is key information missing from this particular statement is that the impermeable barrier was driven; barrier was driven four meters below the bottom of excavation. So, please note this information that the impermeable barrier was installed to a depth of four meter below the bottom of excavation. Now let us see what we can do with this problem.

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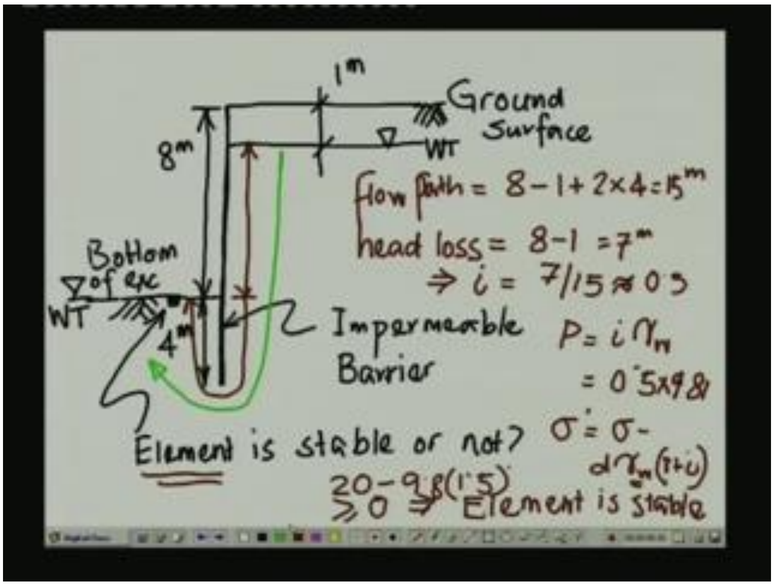

So, the statement is like this. You have got an excavation to take place within an area surrounded by an impermeable barrier. The depth of the excavation here is let us get back there; the depth of the excavation is eight meter, and the groundwater table was originally at one meter below ground surface. So, let us draw it again. This is the section that I am drawing here. This is my impermeable barrier and what I have is a groundwater table originally at one meter below ground surface which is out here. So, this one here is the ground surface, and this is the water table; this is the bottom of excavation.

So, this height here is eight meters, and what I have also given today as supplementary information that this depth is four meter to which the impermeable barrier was inserted into the ground. So that is the geometry. Now we have to find out what is the stability of an element which is right near the bottom of the excavation. So, the question that we are trying to answer here is whether this element is stable or not, okay. So, let us see what we can do with it.

So, here in this particular situation, actually the groundwater table inside the excavation was near the bottom of the excavation as I indicated in the question statement. So, because of the fact that groundwater table on the outside of the excavation is at a greater elevation, then the groundwater table inside the excavation if groundwater is going to move downward around the impermeable boundary impermeable barrier and into the excavation..

So, first of all we have to answer as to what is going to be the hydraulic gradient under which this particular flow is going to take place. So, minimum flow path is going to be in this case 8 meter minus 1 meter; that is the distance from here to here and then the flow path has to find its way around the impermeable boundary. So, what we are going to have is another additional length of two times four; that is the length of the flow path. And the head loss that is going to take place because of this flow is going to be 8 meter minus 1 meter. So, head loss is going to be. So, this is the length of flow path.

So, this one here is the flow path. Head loss for this particular configuration is 8 meter minus 1 meter. So, that is equal to 7 meter, and when you work out the flow path, it is going to be 7 plus 8 that is 15 meters. So, thereby we get hydraulic gradient i to be equal to 7 over 15 that is equal to approximately equal to 0.5, okay. Now you know that because of the flow taking place, you are going to have an upward seepage pressure in this case. And as I have indicated in the previous lesson, seepage pressure is going to be given by P equal to i times gamma w; that is equal to 0.5 times 9.81.

Now the effective stress of the element that we are considering this element, the effective stress for that element is going to be then sigma prime is equal to the total stress minus the whole water pressure. And in this case the whole water pressure is going to be equal to gamma w times one actually 1 plus i. So, gamma w times depth times 1 minus i. So, basically because of the upward movement of the groundwater, the effective stress is going to get reduced.

Now if we had a total a total unit rate of, say, 20 kiloNewton per meter cube, and if we are considering gamma w to be 9.81 kiloNewton per meter cube. So, what we are going to have is our effective unit rate is going to be 20 minus the gamma w value multiplied by 1.5. So, since this value is going to be remaining positive. So, this is going to be greater than zero; we can conclude for this particular configuration that since the effective stress is going to remain positive, the element is going to remain stable; element is stable.

So, that is a very approximate way of looking at the stability of an element near the bottom of an excavation of the type that we considered in this particular problem. Now the third problem that I gave you was essentially a question about how do you control under seepage at a landfill site. Now let us look back basically at the landfill cross section that I provided in the previous lesson.

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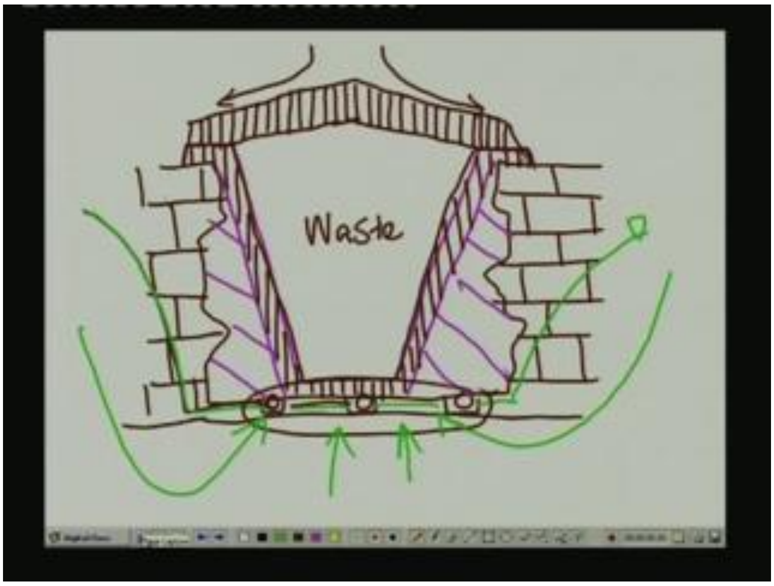

So, what we had there is an excavation within bedrock. This was, in fact, an original limestone quarry which got depleted got passed its economic use and then a landfill was constructed inside this particular quarry site, okay. Now if you recall what we had was a series of pipes at the bottom of the quarry itself. So, what these pipes do is to draw the groundwater table down to a configuration like this. So, let me use a different color pen.

So, let us say the groundwater table in this particular case is going to be drawn down like this. And then inside the excavation was a backfill placed like this and inside the backfill was constructed a clay liner. And on top of the clay liner, there was a geosynthetic membrane, geomembrane actually, impermeable geomembranes. And then waste was placed and on top of the waste material was another cover comprised of very fine grain clay soil which is impervious for all practical purposes.

And the top of the clayey soil was sculpted to provide a surface slope, so that any water due to rain or snowfall or whatever can flow away before it gets a chance of entering the waste placed within the landfill. So, this is the waste that is totally covered on all sides by impermeable barrier. So, basically here you are not allowing any water to enter the waste material; that is one of the way in which the possibility of harmful chemicals flowing along with the moving groundwater from the waste into the aquifer is eliminated.

Another way, the possibility of leaching as the process is called is eliminated is by having a bath tubing effect by lowering the groundwater table using the series of pipes placed near the bottom of the excavation. Because of the fact that the groundwater was lowered in this manner, you can see that the groundwater movement is going to be upward into the waste rather than down away from the waste. So, this upward movement itself is going to stop any water that might leach out harmful chemicals from the waste body into the groundwater. So, these are the measures that we discussed for controlling seepage from a landfill site in the previous lesson. So, that actually settles the questions from the previous lesson.

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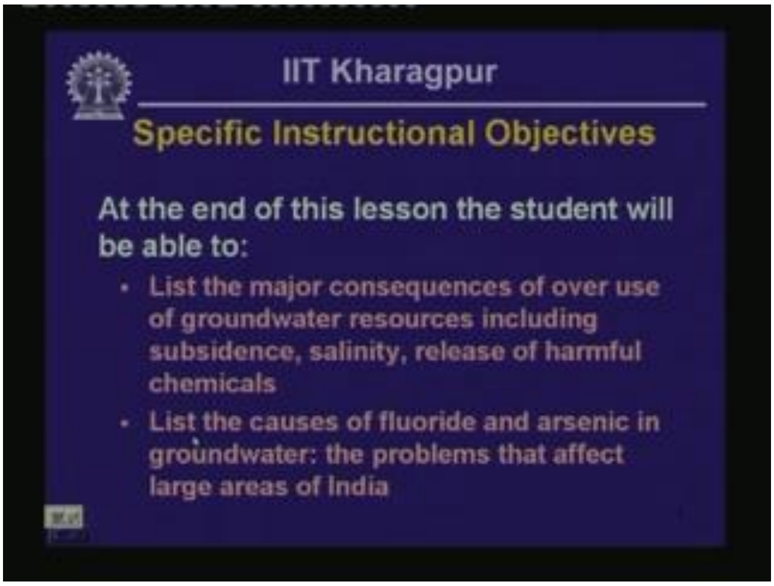

Now we can move on with today's subject matter. What we want to accomplish in this particular lesson are the following. We would like to be able to list the major consequences of over use of groundwater resources such as subsidence, salinity and release of harmful chemicals. And we would like to be able to list the causes of fluoride and arsenic in groundwater. These are some of the major problems that engineers are encountering in recent years for in connection with water supply in various areas of our country, okay. So, those are the objectives.

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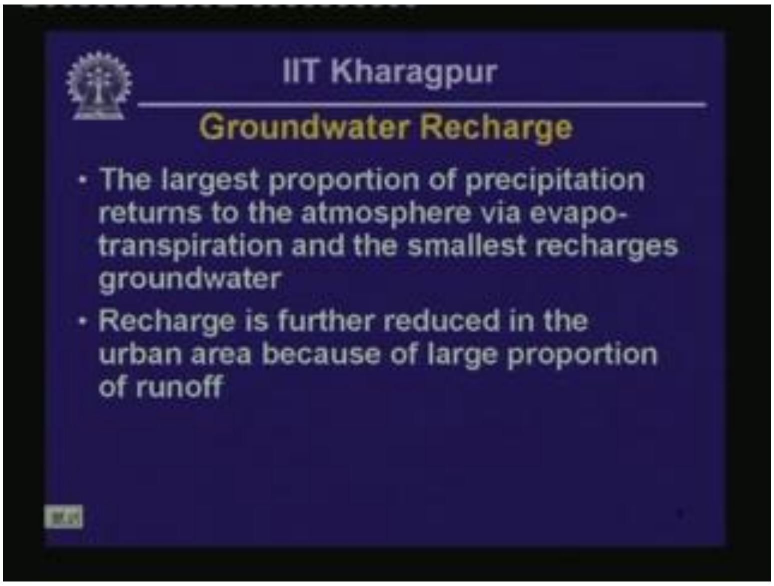

And now we head on with the actual subject. So, what we have to consider first of all we get on with the groundwater depletion; what are the causes of groundwater; why groundwater depletion takes place? Now by far, the largest proportion of precipitation returns to atmosphere via evapo-transpiration, and the smallest proportion of precipitation enter the aquifer as groundwater recharge. So, what that states is groundwater can be over utilized relatively easily, because if you exceed the recharge volume on a year to year basis, then the groundwater resource locally or over a wide area is going to get depleted, okay.

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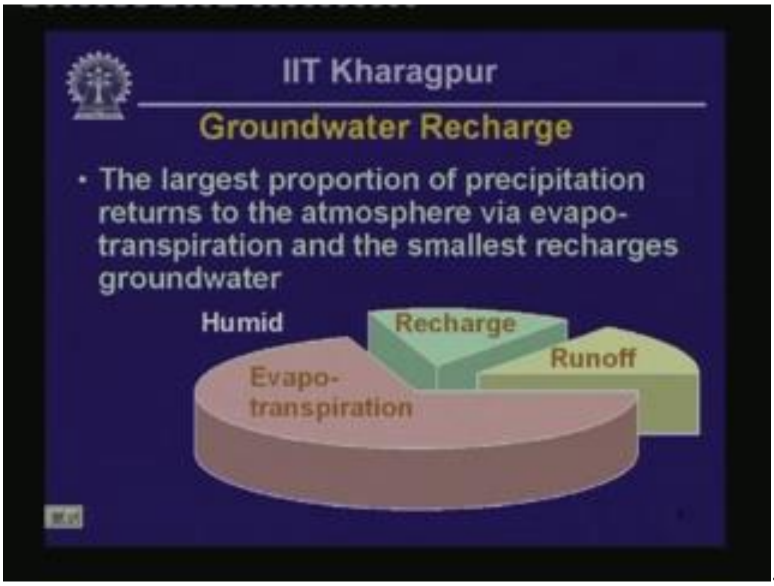

So, this pie chart here gives you the proportion that you could expect in a humid environment for recharge, and you can see here is that evapo-transpiration is approximately 70 percent of the total precipitation received in the area; approximately, 50 percent run, it is lost as runoff. Only fifteen percent is available to groundwater recharge.

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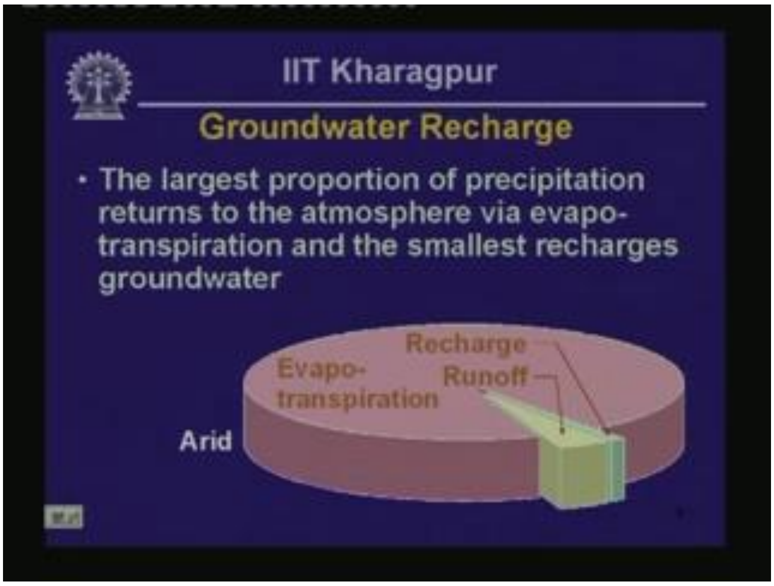

If you consider an arid environment, then the situation is even worse where only a few percent approximately five percent of the total precipitation or even less actually of the total precipitation received enters groundwater as recharge, okay. So, what happens because of the fact that recharge is a relatively small proportion of total precipitation received, groundwater resource is susceptible; it is very sensitive to inappropriate use or over use. And you should also note that recharge in the urban areas is further reduced because of the existence of built-up areas from which the rain or precipitation that is received runs off to the nearest stream and exits the area in the form of surface runoff.

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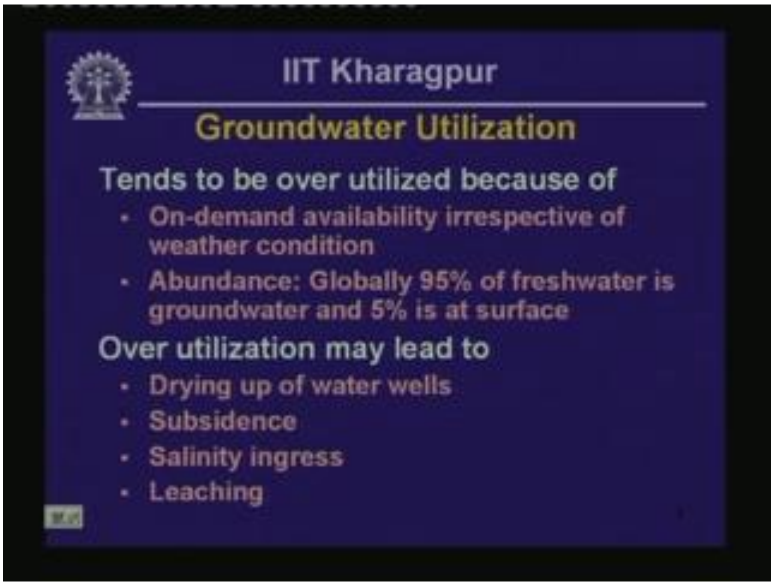

So, you have to be very judicious when you are planning to utilize a groundwater resource in a certain area. Groundwater also tends to be over utilized because groundwater is essentially an on demand supply. So, apparently, you can tap a groundwater resource at any time when you require the resource, you do not have to worry about the weather condition or whether there is any flow available in a surface irrigation ditch because of drought.

Secondly, groundwater resource is quite abundant, in fact, if you look at the resource globally, then approximately 95 percent of the fresh water is available as groundwater resource whereas only five percent is at surface. So, this tells you that groundwater is an easily available resource, and any easily available resource tends to be over utilized. And if you over utilize groundwater resource, then what would cause is drying up of water wells, subsidence, salinity of soil and leaching of harmful chemicals in some instances from the soil into the surrounding groundwater. We are going to look at all these issues which are of particular relevance in the context of Indian scenario, okay.

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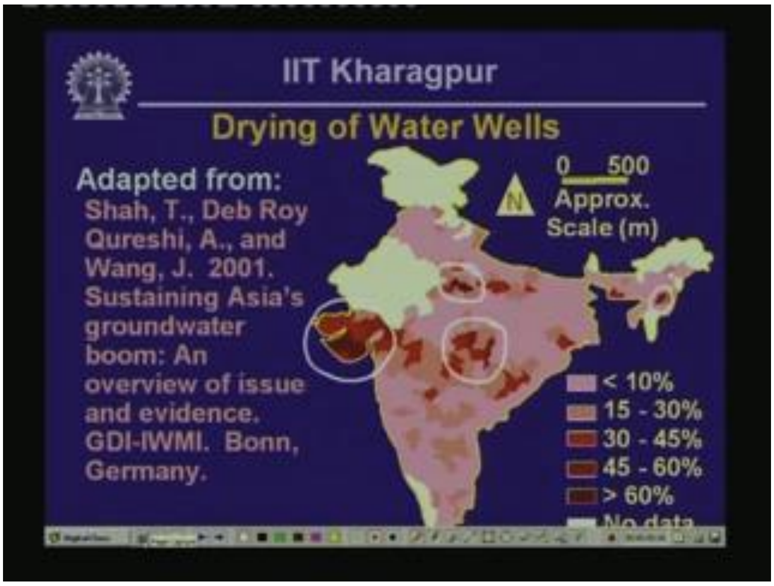

So, the first aspect that we are going to consider here is drying up of water wells. Now this particular slide shows you a map of our country, and it is basically color coded several areas within the country is color coded. And the deeper the color basically that shows the color coding is done in such a manner that deeper colors denote areas, where larger proportion of water wells have gone dry. And lighter colors are areas where only smaller proportion of wells has gone dry over recent years.

Now you can see that by far, majority of the area of our country has got drying of water well to the extent of less than five percent. But areas such as here in the western part of the state of Gujarat and some of the areas in the central part of India and in western UP as well as in north eastern states; in these areas, groundwater has been used to such an extent that over 60 percent of water wells up to over 60 percent of water wells have gone dry in recent years. The source of these data is on the left of this particular slide; you can take a note of that, okay.

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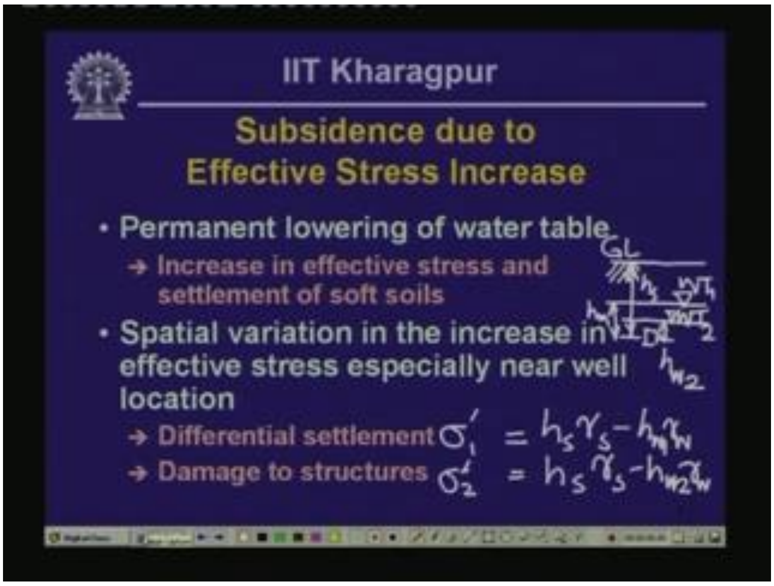

So, that tells you that drying of water well is a very significant problem all over India. Now the second problem that is of engineering relevance because of groundwater over utilization is subsidence. Now why subsidence is going to be triggered? Subsidence is going to be triggered because of lowering of water table and the effective stress increase that occurs because of the lowering of water table. Now if you recall, I have already talked about in detail earlier on.

Let us say you have got a flat, you have got a site of relatively low relief underlain by a flat groundwater table. So, this is our water table, and the ground level is like that. So, if the water table, say, if we are considering an element at that depth, then the effective stress in this within this element is going to be given by height of soil multiplied by the total unit rate of soil minus the height of water table above the elevation of the element times the effective stress of all the unit rate of water.

So, this is going to be the effective stress that the element shown there on the sketch is going to encounter going to be under when the water table is at the position shown in the sketch there. Now if we lower the water table to a greater depth below the ground surface. So, wt 2 is at a lower elevation than wt 1. In that case, the effective stress for water table position 2 is going to be given by h s multiplied by gamma s minus hw 2 times gamma w.

Since hw 2 is actually is less than hw 1, hw 2 is going to be this quantity here. Then sigma 2 prime is going to be larger than sigma 1 prime. So, what that does? That actually is going to trigger a vertical settlement in the area. Now you should also recall since lowering of water table more often than not takes place under the influence of dewatering from water wells. So, the lowering of water table is not going to be uniform specially, and it is going to be more remarkable near the location of the water well than at a greater distance from the water well.

So, what is going to happen because of that is the increase of effective stress is going to be non-uniform depending on the distance that you are considering from the location of the water well. And this is going to trigger differential settlement within any facility that is constructed within the zone of influence of the water well, and differential settlement is highly detrimental to the performance of structure. And it could actually damage structure; cracks could develop and it could even lead to a major serviceability problem of a building that might be located within such areas, okay. So, there are the harmful effects of subsidence.

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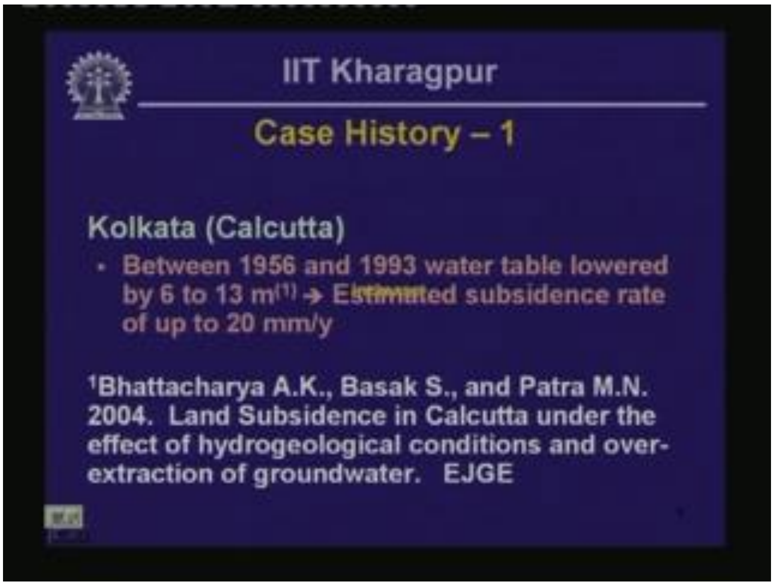

Now lets us consider some case histories. One of the case histories that I am going to discuss here is from Calcutta. In the city it is estimated that between 1956 and 1993, the water table has been lowered by about 6 to 13 meters, and this translates to a subsidence's rate of up to about 20 millimeter per year in the northern parts of the city, generally the rate of subsidence; however, is much smaller. And it is generally lower than 13 millimeter per year and since that rate is quite slow. So, structures that are constructed generally can cope up with that slow rate of subsidence, and the serviceability of these structures, buildings or other facilities that are constructed at these areas; they are not compromised to a significant extent.

However, many apartment buildings in the city of Calcutta, they draw groundwater by installing deep water wells within the property limit of the apartment. So, in many areas high rise apartments, they suffer from differential settlement leading to cracking of masonry infill walls within the reinforcement concrete frames. This is a real problem in the city of Calcutta.

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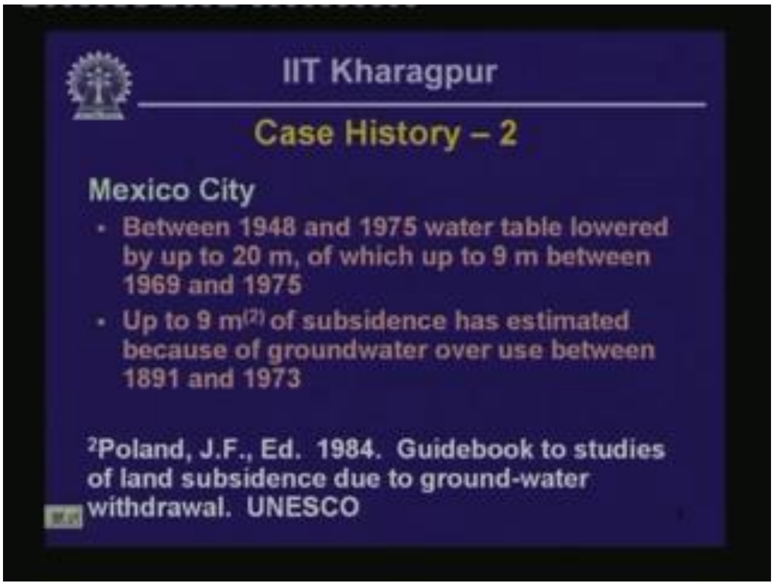

But the problem is more remarkable in another case history involving the capital city of Mexico. In Mexico city between 1948 and 1975, water table has been lowered by up to 20 meters. And out of these out of these 20 meters, 9 meter has taken place between 1969 and 1975. And unlike Calcutta, the soil condition in Mexico is comprised largely of fine grain material, but the fine grain soils are much softer remarkably softer in comparison with those encountered within the city of Calcutta.

Because of the fact that these soils are so soft, the lowering groundwater by as much as 20 meter has led to up to 9 meter of subsidence between 1891 and 1973. And, in fact, there are historic buildings within the city limits of Mexico which has sunk into the ground to the extent of one full storey height. And in some of these buildings have not undergone differential settlement; the entire building has sunk into the ground in a single block. As a result, they have not suffered from any structural damage; they are still in use. But only thing is that the lower floor has become a basement instead of being at the ground level.

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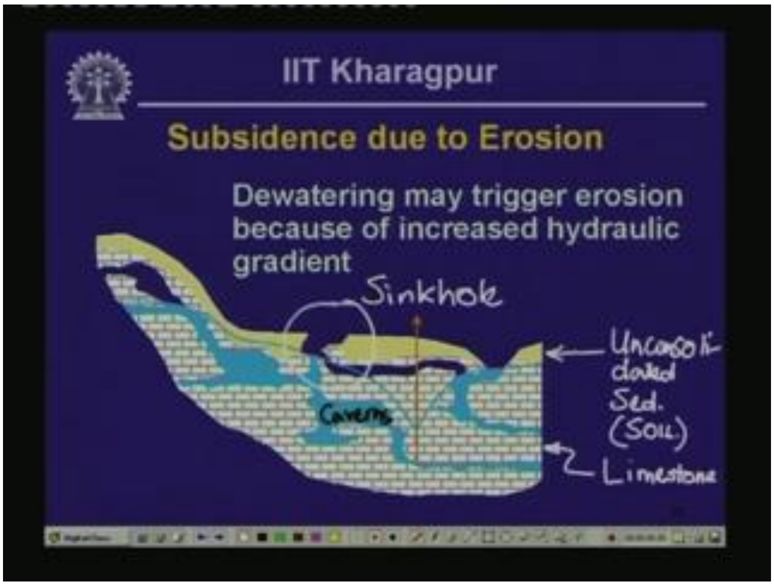

So, those are some of the case histories related to subsidence due to lowering of subsidence caused by compressibility of soft soils because of lowering of groundwater table. Subsidence could also be caused because of erosion caused by groundwater movement. Dewatering actually could trigger erosion, because generally what happens because of dewatering, hydraulic gradient increases or the slope of the groundwater table increases. And that increases the flow velocity or the velocity of moving groundwater and that triggers erosion.

So, what we consider here is a cast topography involving limestone. And you can see that the limestone is crisscrossed by solution channels; a part of it is empty near the top left corner of this particular sketch, and a part of it is full as indicated by shading using light blue color. And the location of the groundwater table is indicated by a thick light blue line that more or less follows the topography, then you can see that towards the right of the section, there is a sub-aerial water course. Then what happened actually at this site, a water well was installed at this location.

And operation of this particular water well, groundwater table went down, and you can see that the slope of the groundwater table in the vicinity of the water well has increased quite significantly. And this triggered erosion of the surface sediments indicated by light yellow color, and the underlying limestone here is indicated using a blocky brick like shading. So, this particular area was eroded out, and what happened? A large sinkhole developed at this location here. So, this is the location where the sinkhole developed.

This is an actual case history reported by the United States geologic survey from a location near one of the southern states of the United States. So, here let me label this stratigraphy for your information. So, this one here is unconsolidated sediments. So, this is essentially soil, and at the bottom, what we got is limestone. And these are the caverns within the limestone, and this one here is the sinkhole which we just saw how it developed.

Now sinkholes typically develop in a much more rapid sequence than the settlement that soft soils undergo because of lowering of groundwater table. So, if you have got a structure within the area affected by development of sinkhole, the structure can collapse, and it could cause a lot of damage to property and life. So, this is another way lowering of groundwater table can cause problems to constructed facilities.

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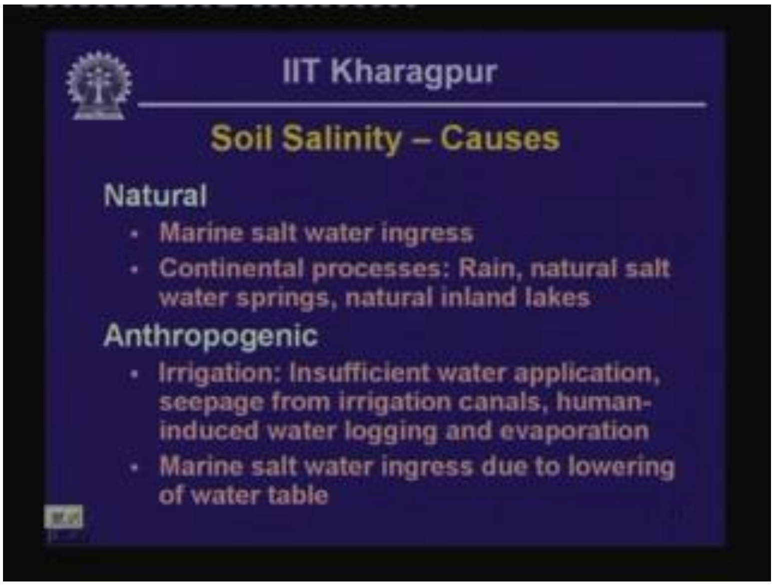

Okay, the second problem that we are going to treat with is soil salinity because of several different reasons. Now soil salinity can take place, because of natural cause. For instance, marine salt water could get into the area underlain by fresh water and displace the water table underneath. And this could happen during storm events, or there could be continental processes such as rainfall comprising salt containing soluble salts, then natural salt water springs and natural inland flakes. So, these are the natural causes of soil salinity.

We are particularly interested about the anthropogenic cause in this particular lesson. Irrigation is one of the contributors to soil salinity particularly in areas where subsistence farming take takes place involving use of insufficient quantity of water because of insufficient quantity of water application or seepage from irrigation canals. The salt particles that are contained within the water that is applied that gets accumulated within the soil voids, and this increases soil salinity so much more, a large proportion of surface irrigated area in many countries have gone unproductive from the agricultural point of view because of increased salinity.

That is not so much of a problem in India, although, a significant proportion of the irrigated area of our country is also affected by irrigation related salinity. So, what we are interested here primarily is marine salt water ingress caused by lowering of groundwater table.

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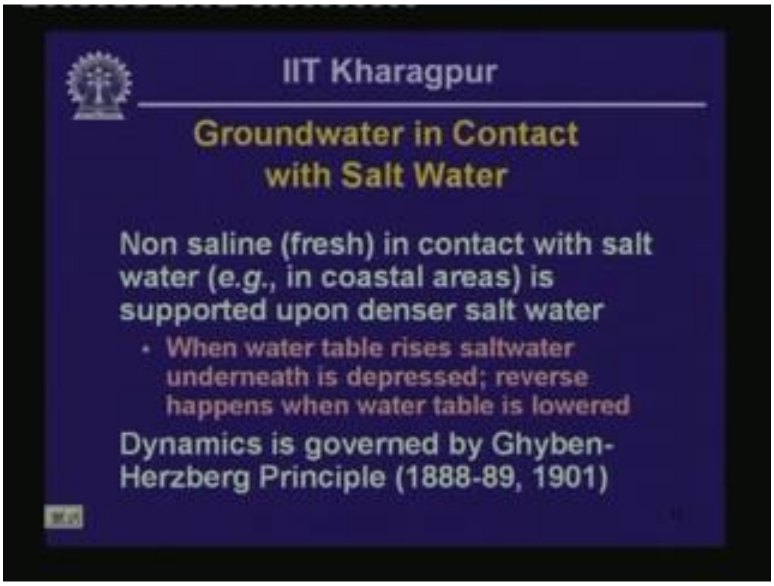

So, what are the causes; how do you determine how do you estimate whether lowering of groundwater table in a coastal area is going to trigger ingress of salt water and eventually displacing the fresh water from the area. Now what happens in coastal area is non-saline water or fresh water is contact with salt water. And because of the fact that salt water is denser than fresh water, actually the fresh water forms a lens supported on top of salt water. Now we want to actually look at the dynamics or the stability of the lens of the salt water in the following slide.

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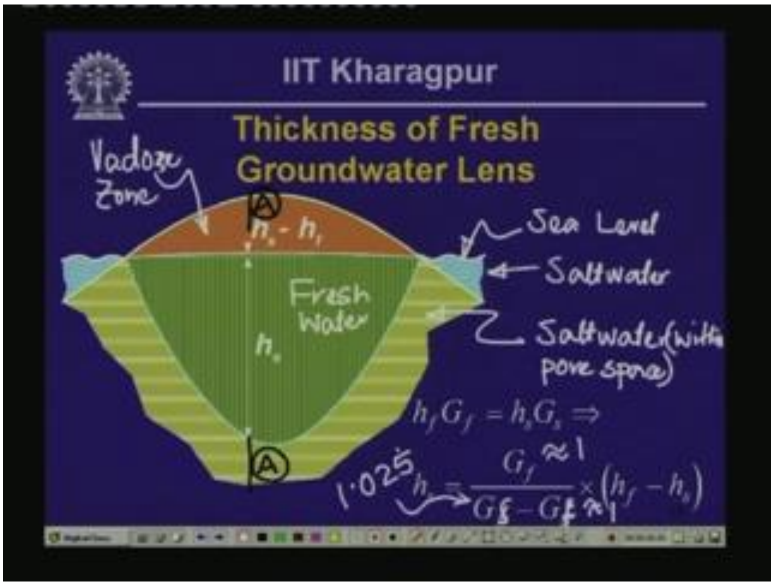

And this particular dynamics is governed by a principle called Ghyben-Herzberg principle, and this principle was originally taught about by the gentleman with whose name appear in the name of the principle Ghyben and Herzberg in late 1800s and early 1900s. Now let us consider an area which is surrounded by salt water. So, here what we have is this one is the salt water, and this is the sea level. Similarly, you have got the sea on the other side of this particular sketch as well.

Now this one here at the bottom is also salt water within pore space. So, this one is within soil pore space, okay. Now this one here shaded with a stripped green is fresh water, and vadoze zone is indicated by orange shading, okay. Now how do you analyze the stability of the fresh water lens in this particular case? Now height of the fresh water lens height of fresh water above a certain point at a certain vertical slice such as this one such as section A; height of the fresh water is we are going to call it with symbol h f, h subscript f, and height of the salt water we are going to call it with symbol h subscript s.

And since salt water has got let us say the salt water has got specific gravity of G subscript s, and fresh water has got a specific gravity of G subscript f. So, what that gives is h subscript f multiplied by G subscript f is going to be equal to h subscript s multiplied by G subscript s. So, if you rearrange this thing, then you are going to get h subscript s equal to G subscript f over G subscript f minus G subscript s multiplied by h subscript f minus h subscript s.

Actually here, there is a mistake which you should take note of G subscript s should be here and G subscript f should be here. So, what that gives since let us put some numbers here, G subscript f is approximately equal to one. So, this term here is approximately equal to one, and the specific gravity of salt water is approximately equal to 1.025. So, if you substitute these numbers, then what you are going to have is h subscript s is equal to 1 over 0.25 times h f minus h s.

So, h subscript s then is going to be equal to approximately forty times the difference between the height of fresh water minus the height of salt water at a given vertical section. That is very important, because then we can try to see what happens if we lower the groundwater only by a tiny bit; we are going to consider the same configuration as in the previous slide.

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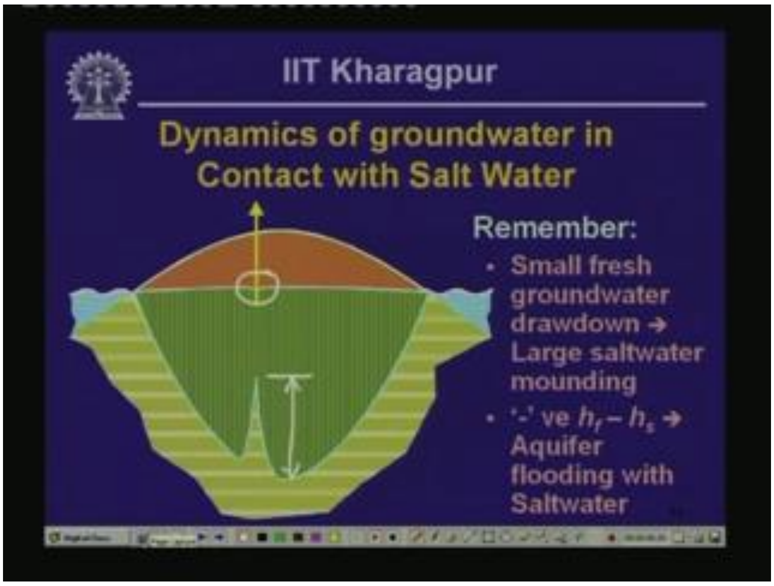

So, let us say we install water well at some location within the land mass within the land area and we start dewatering. And if we dewater leading to a slight lowering of water table, a remarkable salt water mount is going to form near the bottom of the fresh water wedge. And this you can see that this particular wedge is much larger actually, the height of this particular mounting is much larger in comparison with the tiny dewatering that we considered in this particular case.

So, our dewatering is only this much; our dewatering here is only a very small amount only this much, whereas the height of rise of the salt water is quite remarkable. And you should also consider the equation that I gave in the previous slide and you should see that you cannot sustain a negative value of h f minus h s; in other words, the elevation of the fresh water level should be above the surrounding sea water level and if the water table lowering is so much that the fresh water elevation goes down below the surrounding sea water level, then the aquifer gets flooded with salt water.

Now one question you could ask is how this fresh water wedge forms in the first place? Fresh water wedge forms because of recite of precipitation within the landed area and accumulate and downward seepage of the precipitation that is received into the vadoze zone and eventually that forms the lens. So, this how the lens is formed and in fact, as you can see from the information that I have presented in this slide and the previous one that the fresh water lens is quite fragile in the sense that if the fresh water is over used, then there could be a permanent damage to the aquifer containing fresh water which comprises that fresh water lens, okay.

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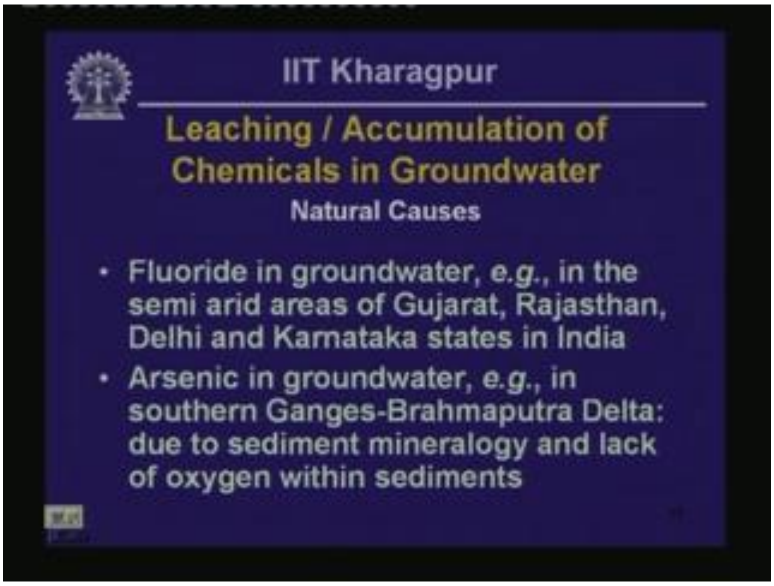

So, such damage has occurred in many coastal areas in India leading to ingress of salt water within the land area. The third major issue that we are going to consider related to over use of groundwater is leaching and accumulation of chemicals in groundwater. It could be because of natural causes such as fluoride in groundwater and fluoride is it occurs in an abundant quantity in the semi arid areas in Gujarat, Rajasthan, Delhi and Karnataka in India are arsenic in groundwater such as those that occur in profuse amounts in Ganges-Brahmaputra delta covering the southern parts of the state of West Bengal and adjoining Bangladesh.

Both of these, the major causes for both of these chemical species that are found in groundwater are natural causes. We are going to look at the details of these things in the next little bit.

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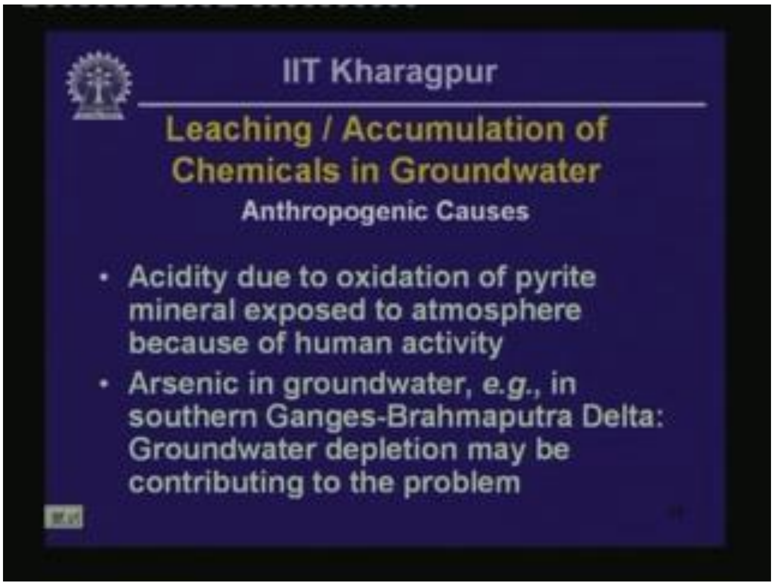

Or leaching or accumulation of chemicals could take place in groundwater because of anthropogenic causes because of human activities such as acidity due to oxidation of pyrite minerals. And that could happen in mine waste dumps, where the waste rock is comprised of pyrite minerals and oxidation of the pyrite mineral and leaching out and subsequent leaching releases acid in the groundwater.

And that actually decreases the agricultural potential of the areas around these facilities to a significant extent, or arsenic in groundwater also could be released because of groundwater depletion. And it is not the researchers are not very sure about the extent to which lowering of groundwater in the Ganges-Brahmaputra delta is causing the arsenic problem in West Bengal and Bangladesh.

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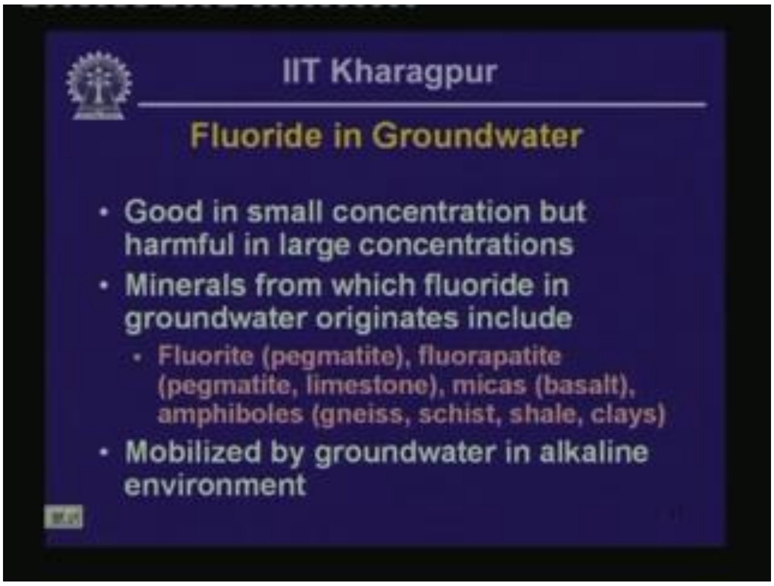

First we consider fluoride in groundwater. As you know fluoride is good in small concentration, but it can cause bone disease when ingested in large quantities; what is the reason? One of the reasons what leads to ingestion of fluoride is the presence of fluoride mineral in groundwater, and that actually occurs because of the mineralogical characteristics of the sediments presence of fluoride such as in pegmatite rock, fluorapatite in pegmatite and limestone, metamorphose limestone or micas such as those in basalt rock, amphiboles such as those found in gneiss, schist, shale and in some clays.

Now the fluoride is mobilized in groundwater in alkaline movement. So, if the local geochemistry is alkaline or the Ph level is above neutral more than seven, then the fluoride in the rock or soil, it gets mobilized and carried with groundwater. And if there is water well installed within such an aquifer, the water that is going to be drawn if ingested is going to cause the health problems that are related to elevated fluoride level such as fluorosis.

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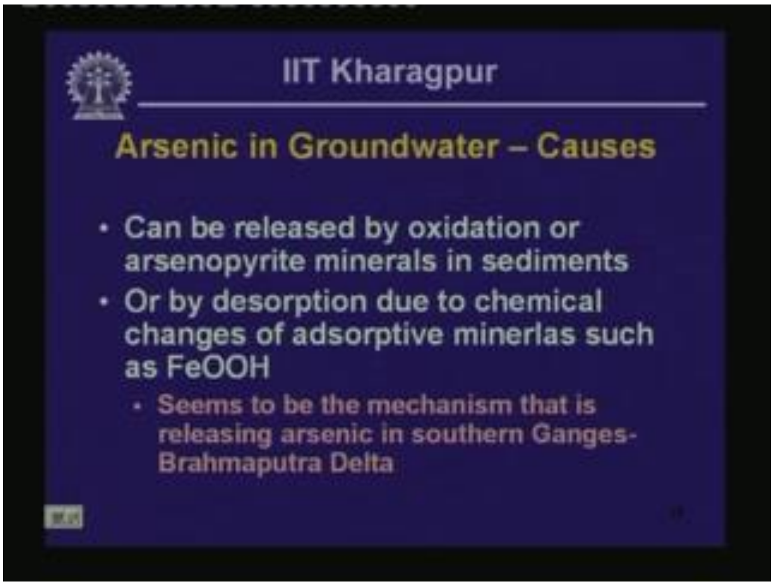

Now arsenic in groundwater, it could be released by oxygen of arsenopyrite mineral or by desorption due to chemical changes of adsorptive minerals naturally occurring adsorptive minerals within the sediment such as FeOOH. And the second cause or the anaerobic cause, the first one is an aerobic trigger while the second one is the anaerobic trigger. Second one, in fact, is apparently the mechanism that is releasing arsenic in the Ganges-Brahmaputra delta.

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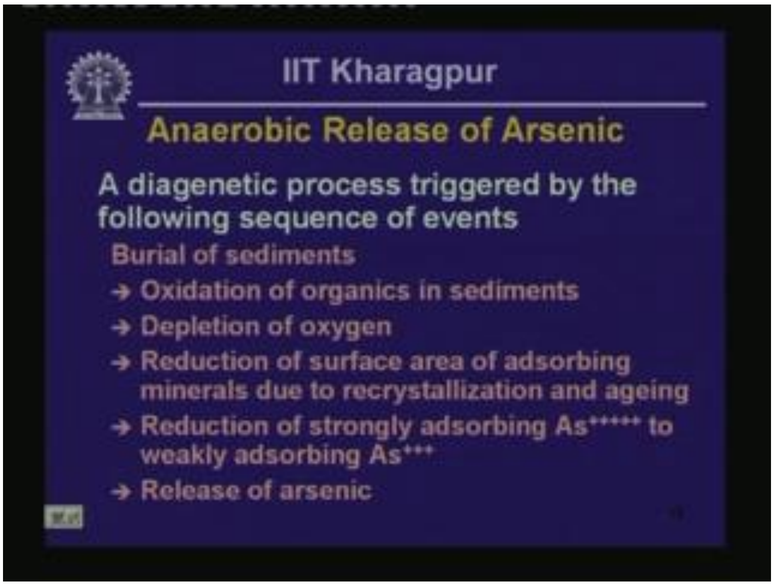

How that sequence takes place this sequence takes place it is listed here. It is essentially a digenetic process involving burial of sediments, oxidation of organics within the sediments that causes depletion of oxygen. And in that reducing environment leads to recrystallization and ageing of iron content within the sediments, and those iron under reduced condition is less adsorptive than in the oxidized state.

Reduction also changes pentavalent arsenic that naturally occurs within the sediment to trivalent arsenic. And trivalent arsenic is weakly adsorbing in comparison with pentavalent arsenic, and that leads to release of arsenic in groundwater. And because of the fact that lower reaches of the Ganges-Brahmaputra delta is also affected by very low hydraulic gradient or very slow ground water movement, as a result the arsenic that is released remains or accumulates within the groundwater. So, the problem does not go away very fast, and it remains a problem over a relatively long duration.

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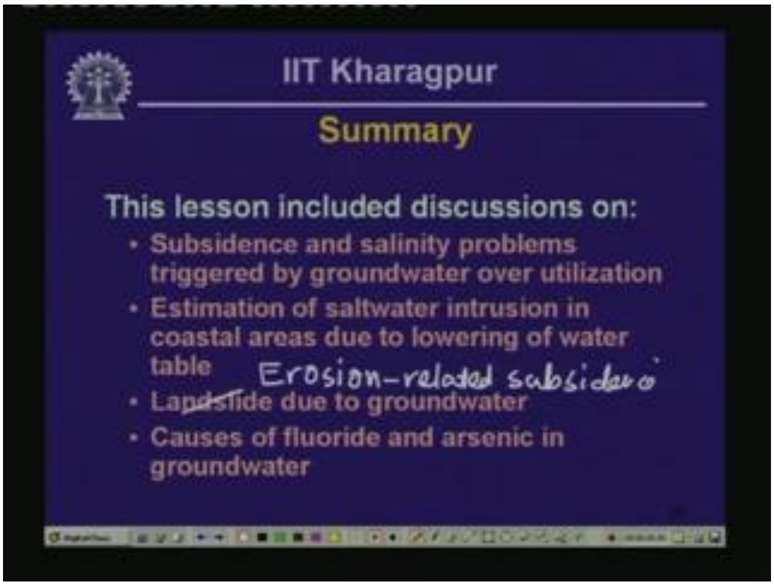

Now we have come to the end of this particular lesson; we want to summarize what we learnt. We have looked at the issues related to groundwater overuse such as subsidence, salinity problem. We looked at a simple procedure for estimation of salt water intrusion in coastal areas due to lowering of water table; how much water table you could lower before salt water ingress could be a problem? Landslide triggered or erosion actually it should be erosion triggered because of erosion related subsidence caused by groundwater movement. And then finally, we looked at the causes of presence of fluoride and arsenic in groundwater. So, these are topics that we covered.

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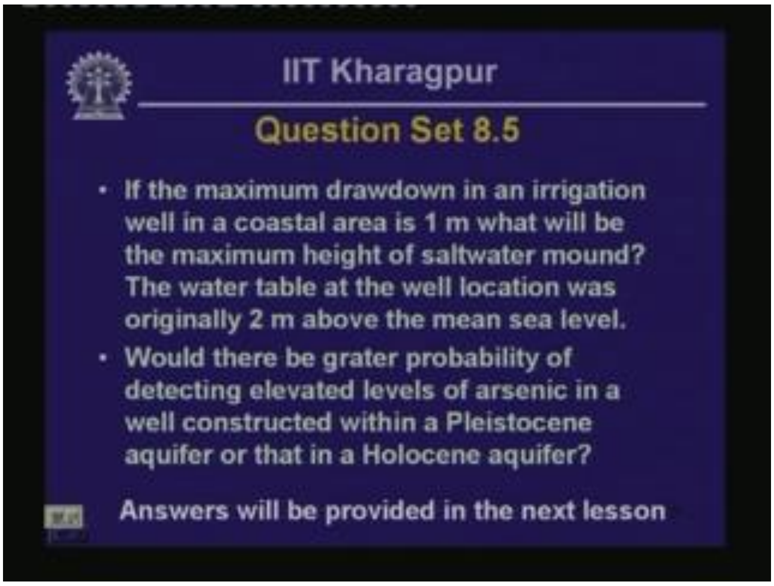

And finally, we wrap this particular lesson with a question set. The first one is that if the maximum drawdown in irrigation well in a coastal area is one meter, what will be the maximum height of saltwater mount? The water table at the well location was originally 2 meter above the mean sea level. And the second question that I asked is would there be a greater probability of detecting elevated levels of arsenic in a well constructed within a Pleistocene aquifer or that in a Holocene aquifer, okay. Try to answer these questions at your leisure; I am going to provide you with my answers when we meet the next time around, so until then bye for now.