**Rural Water Resource Management**
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**Week 03 Lecture 03**
**Soil Moisture**

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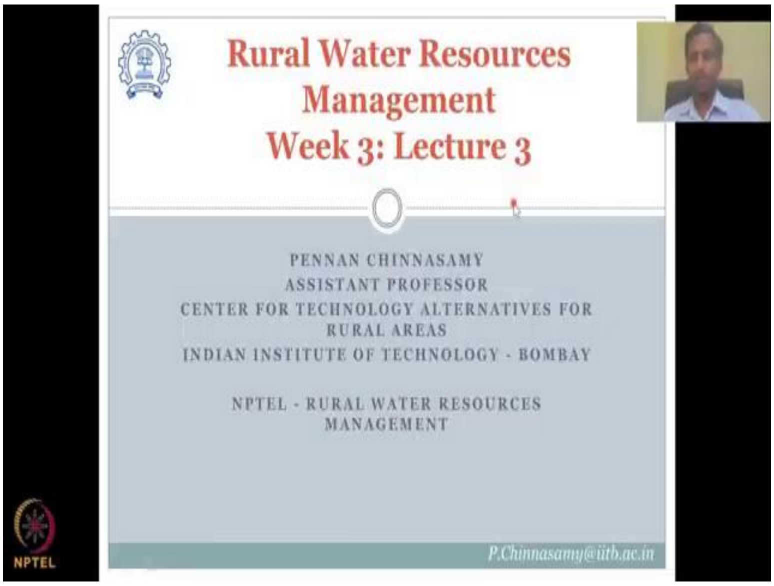


Hello everyone, welcome to NPTEL Rural Water Resource Management course week 3, lecture 3.

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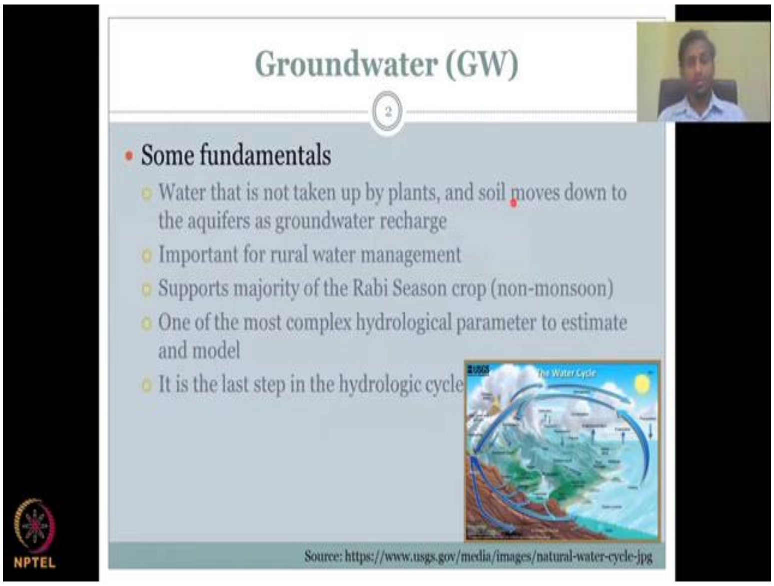


So, we have been seeing the key Hydrological parameters for Rural water resource management and today we will be looking at groundwater, which is, as I said in my introduction lectures, one of the most important resource for monsoon irrigation for rural water. There is a lot of demand for groundwater, it is by itself a course, but the idea behind the lectures now is to introduce you to a concept of groundwater and those who are interested can go on further to understand more advanced topics from the books that are given in the course syllabus.

So, some fundamentals water that is not taken up by plants and animals and soil moves down due to gravity into the soil profile and after some more movement due to gravity and percolation, it goes into the groundwater storage. So, that movement of water into the groundwater storage is called groundwater recharge.

It is very important for Rural Water Management as I was saying, because during your non monsoon irrigation season, where there is no rainfall for watering the crops, then most of the water is taken from groundwater. There are dams, large dams that can cater water, but not all areas have dam connections.

However, groundwater is almost present everywhere, it just depends on where you are in India and how deep the groundwater is. So, as long as you have bore well logger and pump and good electricity supply or diesel pumps you can access the water. Is it sustainable? That is a different question. But access is still available. Its supports a majority of Rabi season crop, the non-monsoon crop as I was mentioning and it is also supplying water for domestic use in urban cities and rural settings etc. One of the most complex hydrological parameters to estimate and model.

So, unlike the other parameters, which is either happening on the surface where you can visually see it, then you can recalibrate your models, you can adjust your assumptions. Groundwater is a component that is deeper under the ground and it is not visible, only one or two wells you can see but between wells you can see a difference in water levels. So, if you go to a rural village, you always have complaints from farmers saying I put a bore well here, I access groundwater, but my neighbour who just put it right next to my well, there is no water.

And same depths same depths, everything is same soil is same, the aquifer geology is same, but one farmer is getting water while the other is not. So, that is the complexity of groundwater by the way it is set up. So, it is one of the most complex hydrological parameters, I would say it is the most because the others happen on the ground for example, evapo transpiration, you can look at the plant and the plant dies, you can assume there is no water loss.

And if the plant is fully grown, you can know how much at full growth stage the plant grows, but you cannot visualize the movement of groundwater and recharge and discharge. So, it is the last step in the hydrological cycle before the water gets into the oceans and lakes. So, let us look at it here. The last step which I mean is the deepest step.

So, you have precipitation converting into snowmelt runoff in the rivers and then storage. So, these are earlier in the stages, then some part of the water gets into the system as soil moisture and that water is taken up by plants. So, water level is not remaining, from this exercise, like plants have taken the water animals have taken the water, the remaining water goes down because of gravity.

And that groundwater is either stored as deep aquifer water, or it moves back into the system into the ocean so, it eventually meets the oceans and gives it as a discharge into the ocean. So, it is the one of the last steps in completing the hydrological cycle. You start from the oceans, you go to the atmosphere, come down as precipitation, runoff, going to the groundwater and then come back to the oceans.

And under that there is nothing which means under the groundwater there is no movement of water because it is hard rock or impermeable surface. So, beyond that water does not move very negligible water which is which you can easily say it is negligible.

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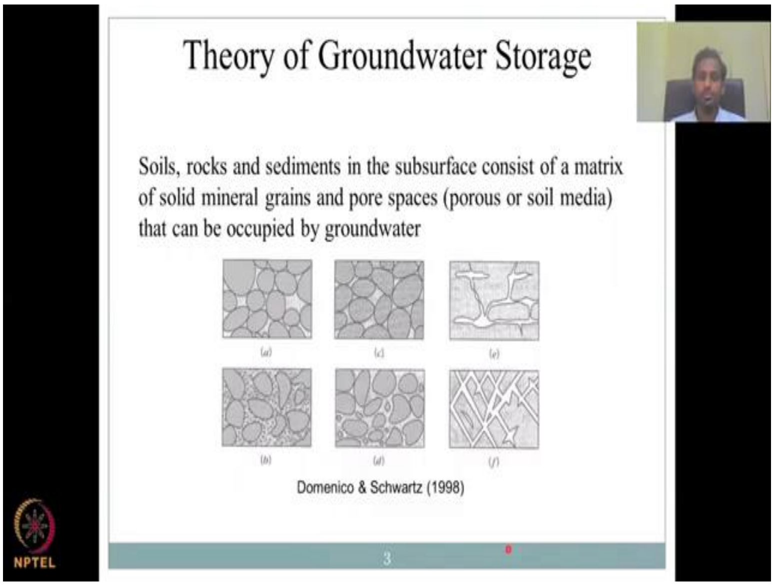


Let us get into the theory of Groundwater Storage, once you understand the storage you can also understand the movement. So, soil rocks and sediments in a subsurface consist of a matrix of solid minerals and grains. So, this is the solid part of your soil as you have soil formation, there are some courses on soil formation, in NPTEL, what you find is the soil is a weathering process and on the top of the soil you have purely soil and more aggregate materials.

But when you move down, down, down where groundwater occurs on the top it is soil moisture, down it is groundwater. When you come to the groundwater stage, you will see bigger size of soil or rock particles and in between them same like soil you have void space, here air is very less. So, most of the time it is water.

So, in the groundwater aquifer, you would find almost all the pore spaces are with water. So, the minerals and grains have pore spaces and that is fully occupied by water which constitutes your groundwater table. So, you can see how different materials are a, b, c, d all have some particle in it and then lot of spaces. And depending on the spaces water occupies it.

And water is very flexible, it can go through any space, it can manage manoeuvre any shape. So, it is very lucid, and it can actually be flexibly into any shape. So, you can see how it can go into a fracture which is connected and all it needs is a connection from one pore to the other pore. So, all these pores are connected very slightly, the water fills here, after it fills down it goes moved down to the other pore. So, it depends on the pore space, if you do not have a pore space, for example, here, there is no water, only in the pore space where you have space water gets in and then it stores there.

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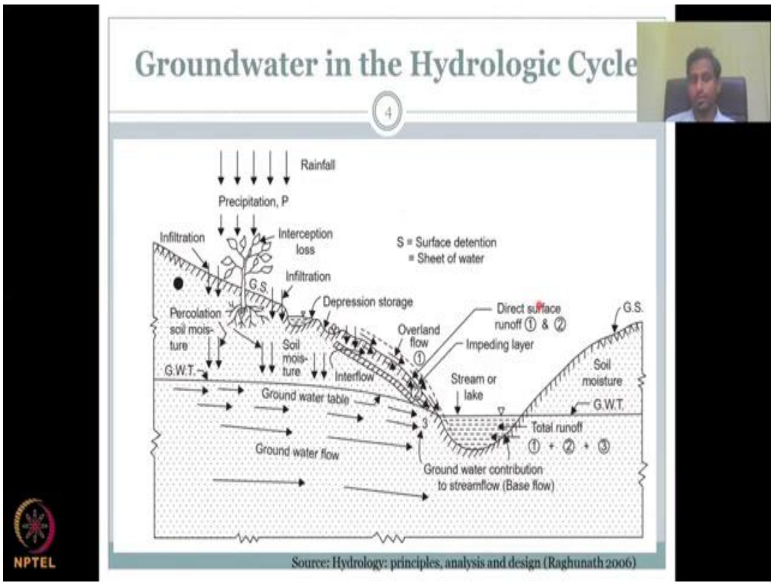

Let us bring the Hydrological cycle again to understand where we are, we have precipitation and whatever water is not taken up by plants, after infiltration moves down, further downward in the soil profile as percolation and that percolated water hits a level where it is called the groundwater table level. And underneath that fully the aquifer is formed wherein all the pore spaces have full of water.

So, here you have all the water is being reallocated into all the pore spaces that it can find. And it is the last stage because we know that there is no movement of water. So, water moves, goes into the groundwater table, there is no further downward movement, but the water has to come back to a surface discharge, it could be the ocean, it could be the lake, pond, stream, river, etc.

There are some instances where water is kept in a pocket, which means water gets in but does not get out of the system. So, those are pockets are aquifers, we will look at some examples. And that water is very, very hard to take out. Because we do not know where it is. It is just a hit and a miss. It is it happens because how the earth has been formed.

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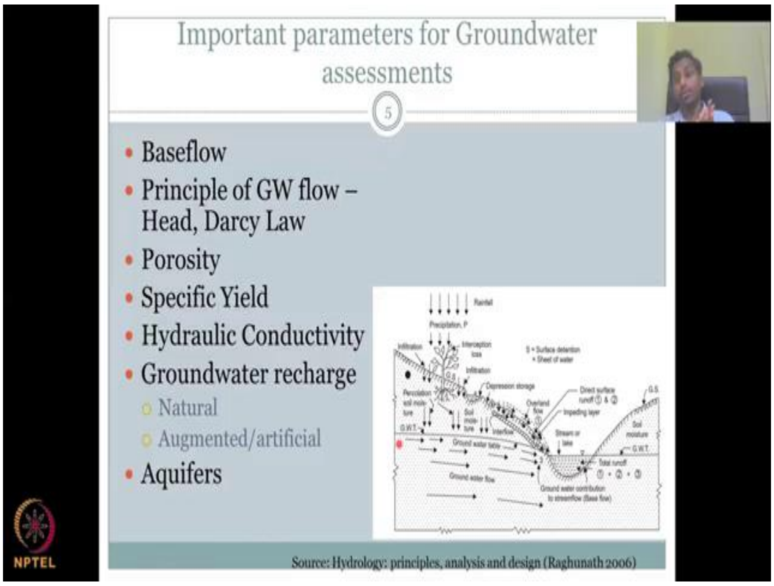


So, important parameters for assessing groundwater. We know how water gets in. Now let us look at what are the driving parameters and how can you assess groundwater. First one is Baseflow, which is the discharge curve that we looked in the surface runoff discharge class, you could understand what component of water in the stream or the river is given by Baseflow. And as we know base flow is given by groundwater discharge.

So, by knowing Baseflow you can know what is groundwater gradient, groundwater flow. Principles of groundwater flow are given by Darcy's law and in that the very important parameter is groundwater head or the elevation of the groundwater level. So, that is the groundwater table like here. So, this from the ground zero, the top is your groundwater level, and that drives your groundwater movement based on Darcy's or Richardson's law.

Basically what is this is any water would flow from high potential to low potential, from a higher level to lower level. Imagine you have water in the tank, to get water through the tank you use a pump, because water cannot go from lower potential to higher potential, so you spend energy to put it up, but when you leave water to stay there, what it would do, it would even still want to come down.

So, water naturally flows from high potential to low potential. So, this is the engineer setting. Let us look at a normal setting. So, water is happening in rainfall in a mountain region, which is high potential, water is stored there as ice, once it melts, it does not want to stay there it wants to come to the lower potential which is your rivers, lakes. So, which is the lowest potential it will come to the ocean.

So, that is where if you are groundwater table is here and this one the groundwater table is here, so it will flow from your left to right in this diagram, that is why, you have the arrows here because the groundwater table is here is at a higher potential compared to the groundwater table here which is at a lower potential, you could see that elevation height which is given by Head and Darcy's law.

The other thing is Porosity, how much pore space is available in your material and that determines the Groundwater Storage. So, once you have groundwater storage, then the water starts to move. So, the process is groundwater is going through a system by first precipitation, precipitation occurs it goes into your soil, then it gets stored in your pore spaces the porosity, once it gets stored fully then it starts to move.

Then it establishes the groundwater table and then Aquifer concept thereby you have movement. Please understand that this is not fully water, you still have solid particles, soil or rock particles here. Only thing is it is all connected, so you can visualize it as a flowing river under the ground. So, here it is like flowing, but flowing means it is connected through the pore spaces of one pore to the next pore it just flows through.

Specific Yield is another concept which is very important, it is the drainable porosity, how much water can be extracted from your aquifer is a function of a specific yield. The Hydraulic Conductivity is the ease by which water get moved from one point to the other point, and  this I will explain in the Darcy's law, but for now you just understand that there is a property which allows the water to move through the system.

What would will it be a function of? If we look at the concept of groundwater, it is stored water in the pores where which means there is still solid material and it is interconnected. So, all this is a property of the soil. So, the hydraulic conductivity or the ease by which water can move, conduct between a pore and another next pore is given by Hydraulic Conductivity, it is a property of the soil.

Groundwater recharge is a very important aspect to understand groundwater assessment. Groundwater recharge can happen naturally by infiltration, percolation etc. But sometimes it is not enough, it is very, very slow and the farmer wants the wells to recharge for the next irrigation. So, what will they do, we have augmented an artificial recharge. So, the well which was initially dug for domestic use to bring water for cattle, slowly began to be used for irrigation and then the number of wells multiply.

So, all this is having a tremendous impact on the groundwater sustainability because groundwater is a very slow process, it has to go through the soil, the rocks, the pore etc., but then you can easily extract it using a pump. So, to increase the groundwater level people would do augmented which means additional structures or artificial structures to recharge.

Then the concept of aquifers so here this is your aquifer. Aquifer is the level at which water has been connected and water flows through the aquifer. So, this part would be aquifer, a non permeable layer which means a big rock or something which is separated from top and the bottom, then you can have an aquifer on the top also.

Because there is no flow on the bottom and water can flow and inside underneath here there is another flow which happens so we have two aquifers like a layer cake, you have a cake and then some cream and then a cake. Look at the cream as a non-penetrable layer which water cannot go through, so the water will flow through the cake, then no flow and then another so they have two aquifers.

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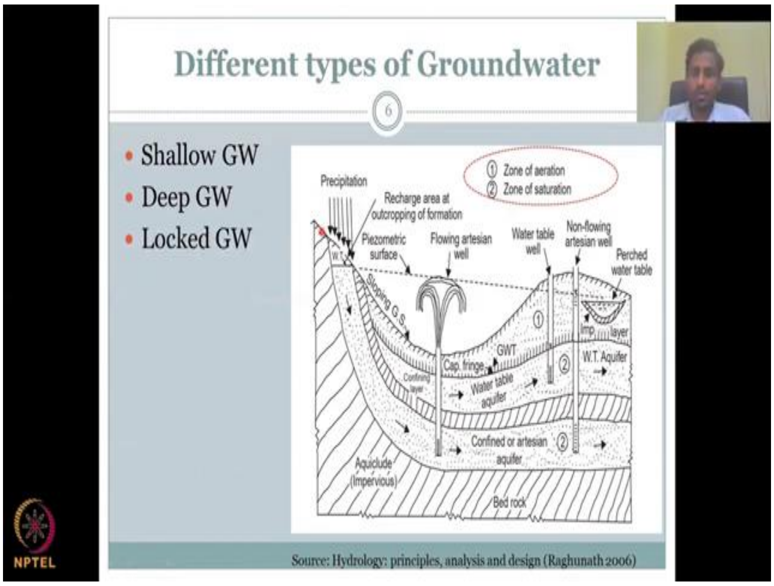


Let us start with the different types of groundwater. So, there are multiple different types of groundwater aquifers and all aquifers can be explained in this cross section. So, what we have here is precipitation which is the recharge for all of the groundwater resources and first precipitation occurs into a land and then it starts to move down. While it moves down it faces impermeable surfaces at different levels.

So, here we have the bedrock which is impervious, which means water cannot move through. So, water would move in a lateral way. So, from vertical it goes horizontal. Similarly, the top surface which is your land surface where infiltration happens, water moves down and then slowly it sees another impervious layer which is not as highly impenetrable like your bedrock because bedrock is the deepest you have while this one is not as strong in penetration.

So, you have water coming in and hits your impervious layer, impervious layer, then what happens, water starts to pond up. While water starts to pond up, your soil gets, soil or the solid particles the pore space gets water. So, number 2 what you see here is called the zone of saturation, which means the water is full, remember the soil moisture we discussed same here your zone of saturation is the fully watered with full of water aquifer.

So, this becomes your water table aquifer. What about the water which is moving in the soil and coming down? That becomes your zone of aeration. So, you have a water aquifer which is formed and right on top of it you have a zone of aeration which can still take water and become saturated. So, those are the two types you have zone of aeration and zone of saturation in one aquifer, one aquifer unit.

Then you have your confined aquifer. So, this is an unconfined aquifer which means on the top you do not have an impervious layer, you can still infiltrate water and you can still convert the zone of aeration into zone of saturation. Whereas, this layer between two impervious layers as impervious layer one and the bedrock, the layer of soil or weathered rock which has water is a confined unit, it is confined between two impermeable layers, you get the point.

So, water can flow get in but it cannot go up or down because it is confined within that unit. And these are much deeper aquifer. In other terms this is called a deep aquifer, whereas, the top one which has still potential to recharge is called a shallow aquifer. In hydraulic terms we call it zone of aeration and zone of saturation. And then different wells can be put to access the water.

So, un a zone of aeration and a zone of saturation you can have shallow wells, where you can drill down and take the water, whereas, you can take a water from your confined unit with deep bore wells and the deep bore wells can have a screen here to just take this water or two screens on the top and the bottom to take the shallow aquifer and the deep aquifer. If you are a farmer, you would like to have all the water coming into the well, not just small water.

But if this was polluted, then you would screen the well and only open the screen here so that your deep aquifer is giving you water. So, the shallow groundwater is the water which we have used in a well. So when you see a pulley system in a well, those are shallow aquifers shallow groundwater, where water gets recharged annually and it can be used for domestic and irrigation purposes.

Whereas the deep groundwater has taken a long time to recharge, because it is not as ready as infiltration, percolation then groundwater, it is recharging somewhere else and then coming here. See here, this water can be vertically recharged, but for this water it has to come from a very far distance, so it takes time. So, the deep groundwater is the water much, much older than that shallow groundwater.

And then on top of this you have a locked groundwater, which perched groundwater table, which means in your soil sometimes you have a confining unit like a bowl or small shape where water can get in, but it cannot get out. So which means downward movement cannot happen, but water can get on the top. So, that water is called a perched groundwater and that is a locked groundwater where it cannot move laterally, but once it gets fill, it just gets saturated.

So, this is where I was saying a farmer can put a well here, and in just 30 meters he can get water. Another farmer which his house is here, which is very close to the other he would drill that 30 meters, he would not get water, he will still have to go down. So, this understanding is not available for farmers, they cannot understand it, how come you put a well there and get water, but just 10 feet away, I am not getting water, this is because of the complexity inside the ground.

We do not know where this impervious layer will form. There is no idea how it forms. I am saying you cannot model where it forms. So, you will have to be careful in understanding these externalities in groundwater. So, these are the three different types of groundwater as after water moves in, you have your shallow groundwater, then you have your deep groundwater and lo groundwater.

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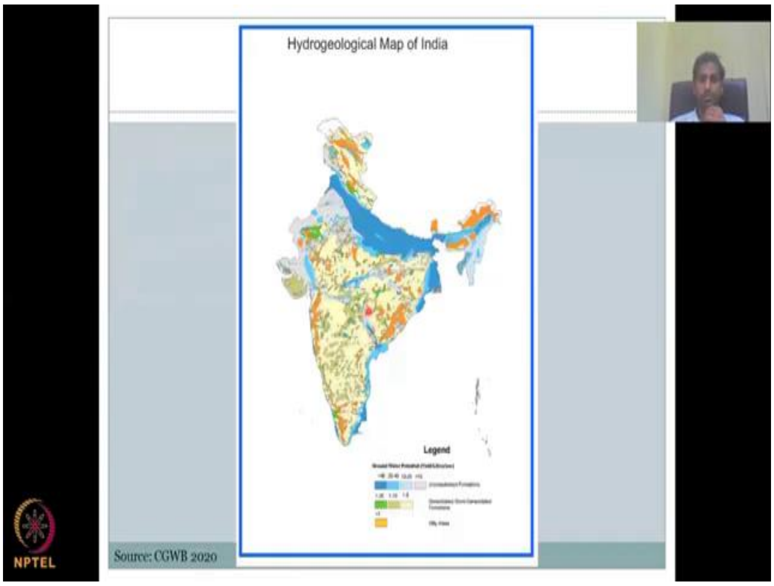


So, all these are based on your hydrogeology the rock material that is present in India and this has been given by the Central Groundwater Board, the map and there is not much change between years, because the rock is a rock, right, you do not change the parent material that easily. It can whether as soil, so, groundwater moves through the soil and then moves through the hydrogeology, but the geology still stays.

So, what you see here is the different types of aquifers based on the geology of India. And you could see that this part where you have unconsolidated formations or more unconfined aquifers, alluvial aquifers, you can find a lot of water. So, the yield is pretty high, you see high yield in litres per second and in the blue colour. So, all the basins or all the areas with big river network, you could see a good groundwater availability in terms of navy blue.

And here on the coastal regions also because all these central flowing rivers would come and deposit here. So, all the sediments would give you a good aquifer, alluvial or sediment aquifers. Then we have the consolidated or semi consolidated areas which is most of central India, where you have deep aquifers, most of it is deep aquifers, because the formations do not happen every day. Here every day you have sedimentation, so, you have an aquifer which is being built up, whereas here it is not that frequent.

So, these are the unconsolidated aquifers on the rivers, then you have in central India more consolidated or semi-consolidated, some rivers are flowing. So, you have consolidated and semi-consolidated aquifers, wherein the yield is much lesser compared to your unconsolidated formations. Then you have hilly areas almost very negligible water, because water does not penetrate in, your hill is just a rock, mountains are rock.

So, well is the pore space for the water to storage, it is very less compared to a soil where the soil air and pore space, your rock does not have that much. So when you pour water on a rock, it just falls down. So, that is where you have less yield in groundwater. So, now you understand that for groundwater you need to understand your precipitation, you need to understand the soil and the type of soil which gives you the details of porosity, hydraulic conductivity, etc.

Then the geology to understand the deep aquifers and if it is a hilly region and rock, there is not much water that will be stored. So, if you look at mountains and stuff, you might get good rainfall. But you need to capture the rainfall for agricultural domestic use, because groundwater potential is very, very low. And even drilling into a mountain area is very hard. Because it is so rock, so it is very hard to even get your drill down.

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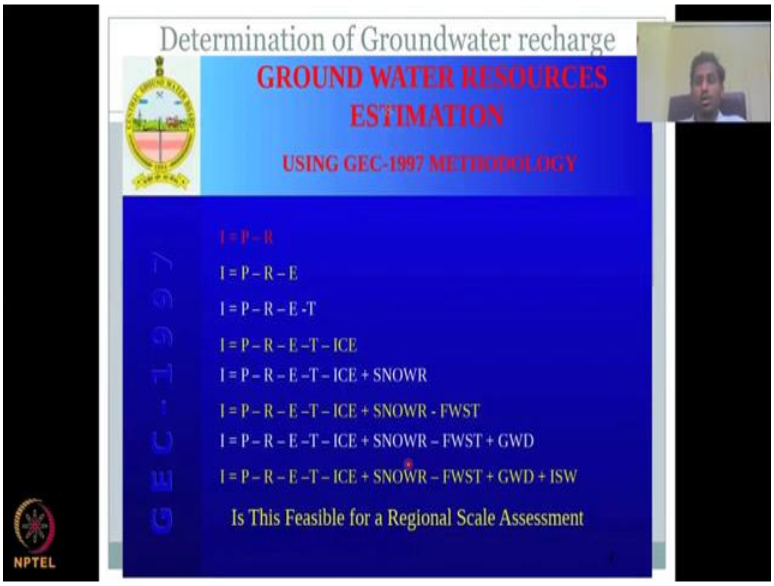


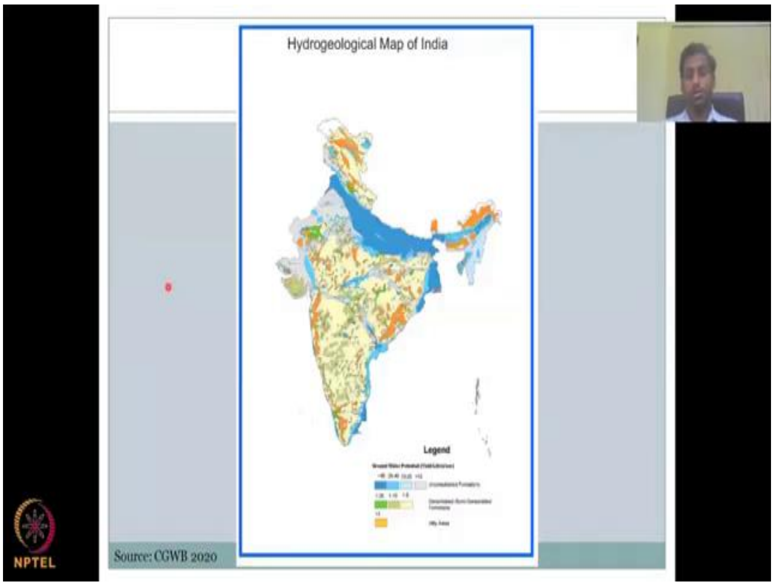


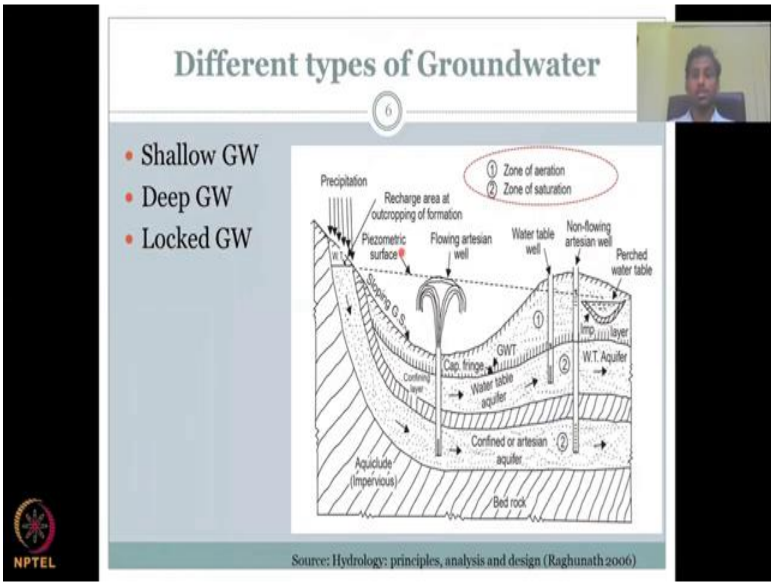

How do you determine groundwater recharge? It is because of its complexity. Mostly it is made by your groundwater budgets. So, if you know the groundwater resources are determined by precipitation and runoff, you can calculate your infiltration. So, let us look at some of the groundwater estimation committees 1997 report which is still used now, because it is just a formula.

You have infiltration, which is the water that gets into the soil and that is the water which goes to percolation and your groundwater recharge. So, infiltration is kind of the first step in your groundwater recharge. So, you could see it as it can be very simple as precipitation minus runoff. So, precipitation is the water coming in and runoff is the water that goes off the system.

So, the difference gives you the volume which actually infiltrates, then you have your evaporation, then you can add on your evapotranspiration which means you can make your equation more complex by throwing more and more variables and by on you can actually add your groundwater, you can add your snowmelt, runoff or your ice etc., etc.

Infiltration, storage of water, so, all this can be done at different scales regional or sub-regional scales. And you could also look at different methods suited to your land. So, for example, in your land if there is no agriculture or if there is no transpiration happening or no water bodies, then most of it is going to be precipitation and runoff. So, after runoff, if you can capture the water and understand how much runoff is there and you can capture the rainfall, understand how much rainfall is there, the subtraction will give you your infiltration more or less.

So, these are the different methods and based on this, there are a lot of models that estimate groundwater. There are satellites right now, but we will not get into that because it is not at a rural scale, the satellites for groundwater. So, I am not including that in this picture someone might ask me tomorrow sir, will you do have groundwater recharge based estimations from GRACE satellite, which is NASA, US satellite, but I do that for a state level or country level not for a village level, because at village it is such a small and the resolution is not good.

So, how do you estimate groundwater recharge is by looking at your wells, understanding the hydraulic conductivity, understanding the properties of the soil you could estimate that calculate your recharge by these kind of methods. It is very expensive to do everywhere monitoring by groundwater.

So, Groundwater Board, the Central Groundwater Board, which you see here is the authority in India to have these monitoring wells and regularly gives you data once in every three months at least. So, quarterly you get data and across India they have around 15,000 wells, to monitor and give you the data.

So, I think every year they do add more wells and it is a very, very time consuming and costly affair to get the groundwater data. So, you do not see too many estimations. So, somewhere you need to model it, somewhere you need to estimate it based on your precipitation and runoff and somewhere you would estimate it based on your characteristics of the geology like we saw here.

The geology, if I know the geology, I could estimate how much porous space is there on the porous space and the rainfall, I could estimate, for example if the Ganges was not flowing, there is no water there, there you have porous space, but you do not have water correct. So, based on your runoff, based on your precipitation and your soil and geology characteristics, you can estimate groundwater recharge and run water storage.

Driving home messages, please understand there are multiple groundwater wells or groundwater storage. And what a farmer uses might be shallow aquifer initially, but as the water level goes down, so, for example, if the water consumption is high, the water level will keep falling and after this water is totally used, then this well becomes abandoned.

He or she would drill another well, much, much deeper and get what could be a deep groundwater aquifer. So driving message here is it sustainable if you just keep on drilling deep and deep, so all of you notice that even in urban centres, you start with a well depth, and then suddenly after some years there is no water you drill deep, then you drill deep.

And because you know that as you go deeper and deeper, there will be some water based on this diagram. But once you hit bedrock, there is no water. So, it is not sustainable to keep drilling. Sustainable way is to increase your recharge, increase the groundwater flow so that you can store more water and reduce your consumption.

If you know that you cannot grow your crop, why are you going to use a groundwater? So you might use it in three fourths of the time. For example, if your crop needs 10 Irrigation schedules, your groundwater can give water for 3. But what about the remaining seven and if you do not have water for the seven, your crop is lost. So, the idea is to understand how much groundwater you have before using it and depending on that you use a crop or an area of crop for watering.

So, please understand these three different types. The locked groundwater can be misleading, because you will find water will be happy, but it is such a small component and your shallow groundwater would eventually lead to a deep groundwater access. So, this is the problem in India currently. We will get into the rural issues when we go into the groundwater lectures in the future. I would like to stop here. Thank you.