Groundwater Hydrology and Management
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Lecture 29
Artificial Groundwater Recharge

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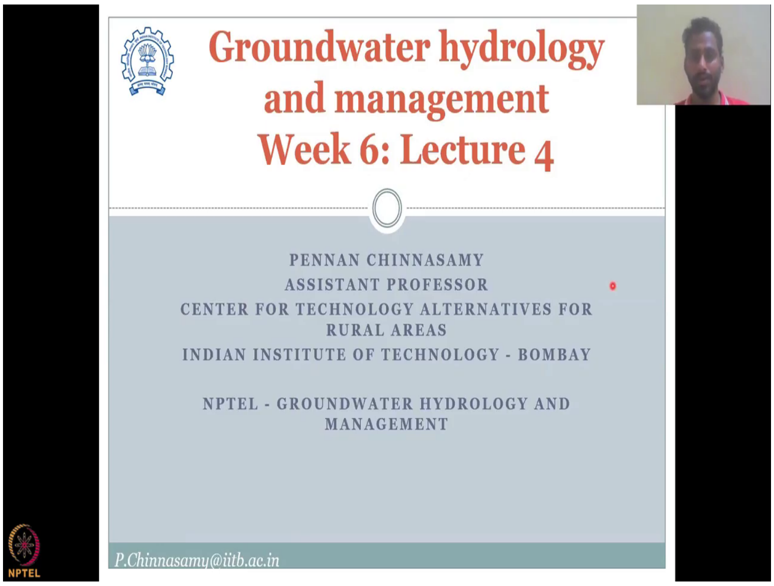

Hello everyone, welcome to NPTEL course on groundwater hydrology and management. This is week six, lecture four. In this course we are looking at more importantly groundwater as a component, how it recharges discharges and then management. How we break in this course is until week six, you will look at most of the important concepts of groundwater then we will jump into managing the groundwater resource.

On that note, we have been looking at the groundwater recharge and discharge properties in this week lecture. In the past couple of day's lecture, we have looked at the last three lectures, we have looked at non water recharge concepts, how is it recharging, what are the different methods to recharge and how to estimate let us move on and look at some more estimation methods.

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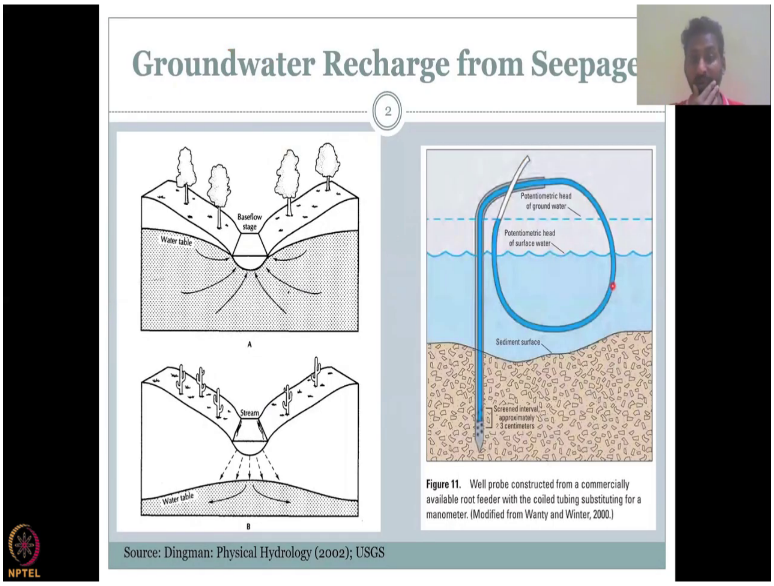
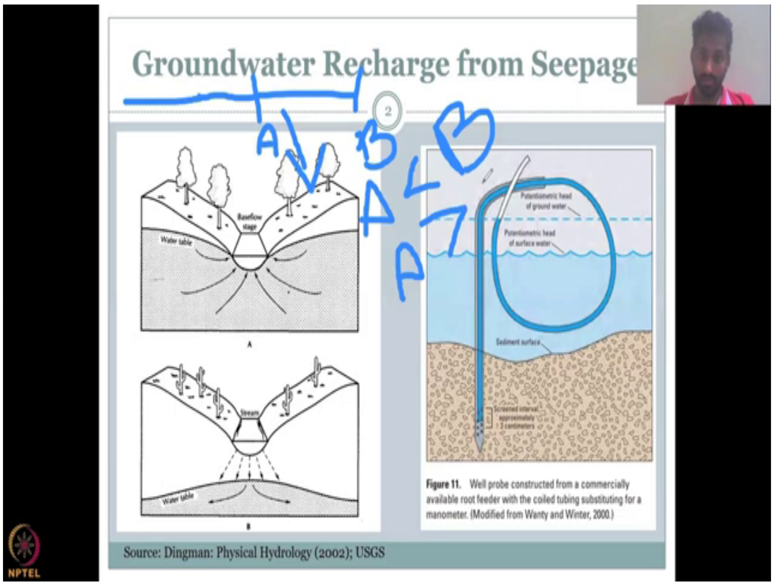
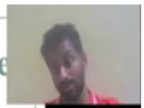
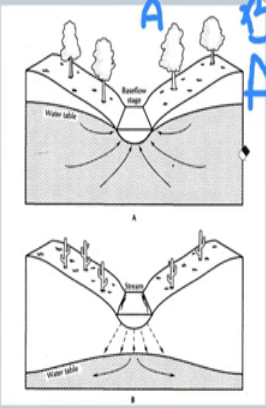




Groundwater Recharge from Seepage





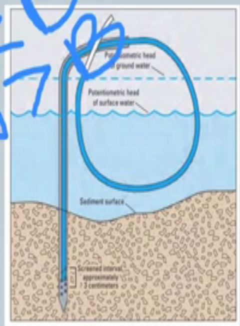
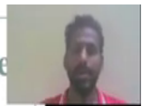
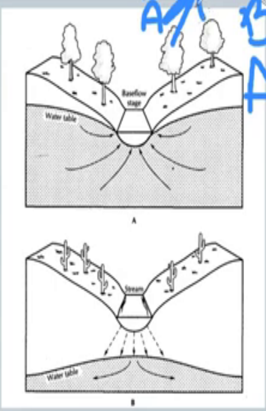


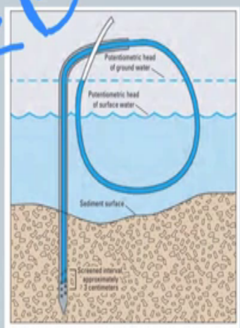
Figure 11. Well probe constructed from a commercially available root feeder with the coiled tubing substituting for a manometer. (Modified from Wanty and Winter, 2000.)

Source: Dingman: Physical Hydrology (2002); USGS

Groundwater Recharge from Seepage







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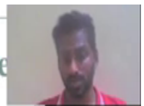
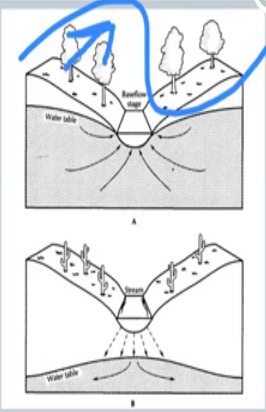
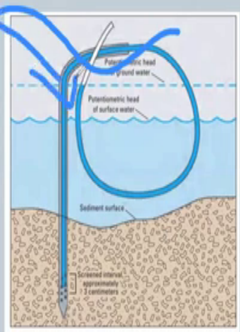
Groundwater Recharge from Seepage







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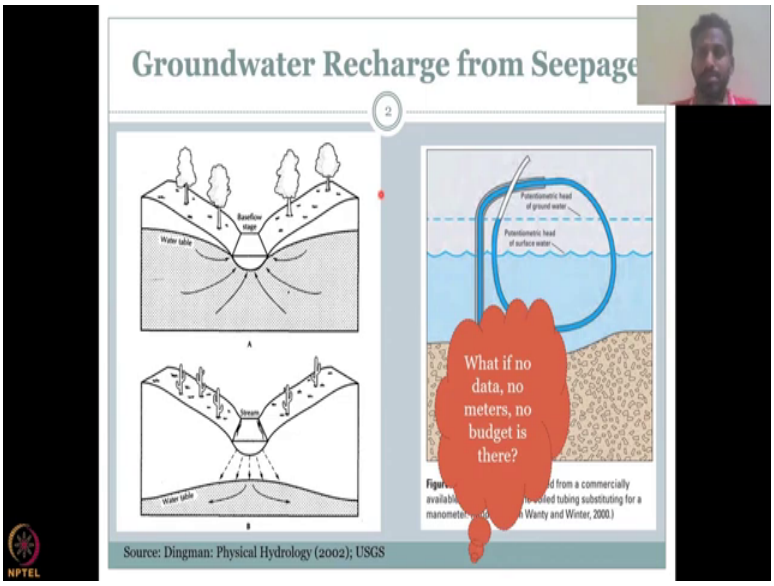

Look out recharge from seepage, why is this very important this forms a very important task especially in environments where there is a water body because a water body can influence the groundwater movement both recharge and discharge. So, in this term, we are going to look at recharge and as I said in the previous lecture, just before the end of the lecture, I mentioned that recharge and discharge are happening through similar monitoring process which is the water level, at what timeline it happens may be different.

What is driving the recharge or discharge may be different, but monitoring is almost same because you want to use a similar methods here the physics that drives it is just opposite, for example, in a recharge water goes in and discharge water comes out, can you push water in that is recharge you pump water out that is discharge.

Similarly, in a natural environment where there is a water body and a high elevation land with groundwater table, water table would flow into the stream river network, whatever you call it, lakes, ponds etcetera. And that is groundwater recharge into the stream, but it is a discharge for the groundwater. In this lecture, we are looking at groundwater recharge. So, let us take this example where you have a land which is also a high elevation, however, the water table is at a lower elevation compared to the stream.

So, when water comes in the stream, it tends to flow down and recharge your aquifer. So, to prevent this, think of this as a canal. To prevent this in regions like Gujarat, they put lining which is cement to prevent the water to recharge into the ground. They do not want it they want to take it to the farm, which is also why dig the canal.

So now coming back, depending on the use, you can make a canal recharge or just take the water. Now let us look at the recharge concept. So, water is seeping into the groundwater table. You can see here water seeping into it. It is not infiltration, it is not percolation, it is seepage, because infiltration, percolation happens in the medium, where there is pore spaces, and then the water has to push through those medium and come.

Whereas in seepage, it is water that is pushing water at a good table. Look at it, there is a good water level. And then it pushes itself it seeps leaks into the groundwater. That is groundwater recharge through seepage. So, let us see how we can measure it. This is a method as given by Wanty and Winter and promoted in the USGS book.

So, USGS has a manual for all these different different things for recharge estimation, discharge estimation, for rainfall etcetera. And most are used in Indian terms with slight modifications. So, let us look at how recharge is estimated through seepage. So, this is your sediment surface or your stream bed. Right here on the stream bed you will put the meter in and here the meter is like a pipe with a screen interval of three centimeters and that is where water can move in or out.

So, in this example your potential metric surface or groundwater head is at a higher elevation compared to the surface. So, it is this example. And what happens is because of the potential difference because water wants to flow from high to low potential water would seep in from groundwater and then come out and join your surface water and this can be monitored through the pipe here and the pipe has some meters which actually monitors how fast water is seeping through.

And the manometer is a meter which is also looking at how fast the suction happens the suction or how fast the water moves through this tube and reading is given for the velocity of water discharge of water etcetera. So, these seepage meters are kind of expensive and does not give you the right picture all the time, why, because it depends on where you put it in the land.

So, you can put it here you can get a different seepage you can put it on this point you can get different seepage, because rocks and bedrocks are not the same everywhere. So, that is why in most terms, it is just simple enough to estimate it rather than putting a meter and estimating the data more or less it gives a different flavor. The easiest way to look at it is you have a river flowing.

And you take discharge measurement, how much water comes in the river at point A and take reading at point B you have to discharge now QA, QB, if QA is equal to QB there is no recharge there is no discharge, which means the water is not losing water is not gaining. However, if A is less than B that means water is losing into the ground which is discharge of the stream water into the ground which is a recharge first.

So, that is the case where you have A is less than B. And the subtraction of B minus A. B minus A would give you the actual water which is gained in this stream because of groundwater coming into the river. There is a discharge if you want to recharge A is greater than B, if A is greater than B what is happening? Water is losing into the groundwater which means groundwater is getting recharge.

So, A minus B is the total volume lost by the river but gained by the groundwater and that gaming is groundwater recharge, for ground discharge how do you do. Let us take a system where no water is coming in groundwater is giving water into the river. So, A is less than B, or B is greater than A, B minus A is the net volume of water recharge because of this length on non-rainy days.

So, all these equations should apply on a no rainy day because rain is happening and what was just picking up because of rain. So, you need to take it in a non-rainy day. So, here we are. We can estimate the actual groundwater recharge, just looking at two sections in a river and making see the connection of how the water is recharging or discharging the groundwater aquifer. Again, a lot of people does not actually do these they just estimated because it is a lot of data.

It is not one-point data you have to take multiple data, what they do, they go on the riverbed, they look at the rivers, material, the riverbed material, and then they estimate the value and the other easiest way, which is really, in some ways is they say for example, this is the river, they say water groundwater is giving into in this location. And groundwater is giving out into this location, which means QA, or here, let us say G for groundwater.

So, GA, which comes into the river is equal to GB, which leaves the river. So, GA is equal to GB, no changes, the river is neither gaining or losing in the long run, which is a good estimate, one would say. So, you can see how estimations and assumptions can also make your life easy in terms of groundwater recharge, and you are not that particular about groundwater recharge happening along the river, because your lands are away from the river, or your house or the water level is away. So, it is more on how you want to use a recharge.

So, now here comes the tricky part. What is no data? Is there no meters no money for meters no time? No budget, which is money put on the meters? If nothing is there, what happens? This is a concerning part, which is crippling lot of places because India is the most highest groundwater user in the world.

However, if you look at monitoring per centimeter area of your map, or let us say per kilometer area, it is not much it is very less compared to the other countries that are actually monitoring groundwater pretty well. So, here is where we are in this situation, what if no data exists? And again, think about only four months we are monitoring? What if no data exists? No meters are there in some locations and budget is less to augment or add meters?

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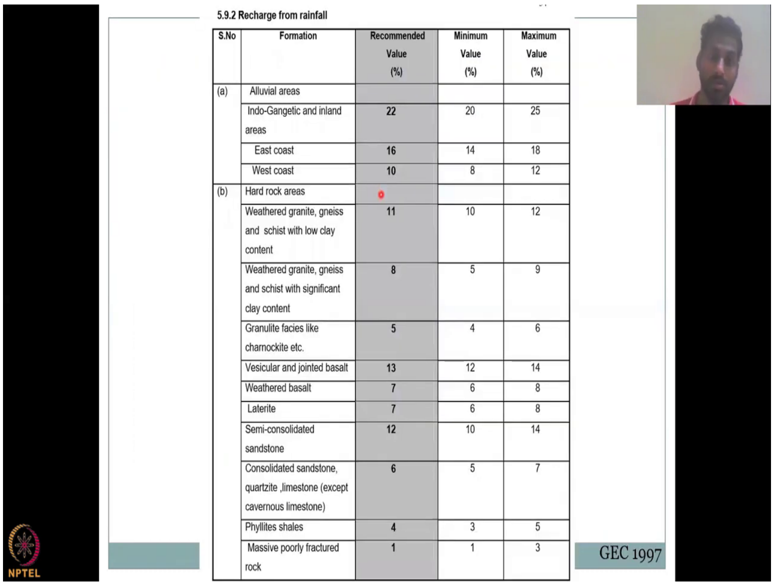

5.9.2 Recharge from rainfall

S.No	Formation	Recommended Value (%)	Minimum Value (%)	Maximum Value (%)
(a)	Alluvial areas			
	Indo-Gangetic and inland areas	22	20	25
	East coast	16	14	18
	West coast	10	8	12
(b)	Hard rock areas			
	Weathered granite, gneiss and schist with low clay content	11	10	12
	Weathered granite, gneiss and schist with significant clay content	8	5	9
	Granulite facies like charnockite etc.	5	4	6
	Vesicular and jointed basalt	13	12	14
	Weathered basalt	7	6	8
	Laterite	7	6	8
	Semi-consolidated sandstone	12	10	14
	Consolidated sandstone, quartzite ,limestone (except cavernous limestone)	6	5	7
	Phyllites shales	4	3	5
	Massive poorly fractured rock	1	1	3

What do you do, if you simply GEC has given you that option also, that you can simply estimate the recharge from rainfall because rainfall for sure you will have and these satellite products have given you a lot of rainfall data for a lot of years, at least 1857 till date. So, around 250 years of data you have for rainfall, and you know, the soil material, the rock material, because those does not change, you can use the GSI Geological Survey of India maps, all these are in my slides, please go and look at these maps.

And when I am teaching the groundwater data, I will show you how to take rate for data. So, what you will do is you can see that your recharge happens as a function of your rainfall. So, this is a simple logical hypothesis given by Jay Z. Jay says your rainfall is what was recharging of groundwater, let us put a percentage a percentage of rainfall and based on the physical setting of the aquifer, the land surface, the land cover etcetera.

And the rainfall you could estimate how much is your recharge. Again, let us do this exercise, they have divided India into two major hard rock formations or rock formations one is hard rock and the other is Alluvial. Alluvial takes around 20 to 30 percent of the land whereas the remaining is mostly hard rock aquifers.

So, the alluvial are mostly in the river, Delta regions belts etcetera gauges, Kaveri, Narmada, Tapti, etcetera. So, those regions have alluvial sediments and formations. And after that indo gangetic has the major formations because it is big, and the river flows every day every year.

So, it brings a lot of sediments and still it is a young river because it kind of was it cuts through and also brings a lot of sediments which form the alluvial aquifers.

So, they say that if there is rainfall say for example 100mm rainfall 22 percent of that is your recharge. In the previous example, we looked at infiltration, if you do not know the rock material, it is going to be very hard. So you have to know the rock material which is formed by the map if you know all you have to know is the location. For example, if I say Mumbai or Chennai, I go to the map I look at the alluvial or hard rock area type, what is the rock type?

And then I look at the rainfall and then I can estimate in the last lecture, we looked at what is the infiltration rate? infiltration Rate is different, recharge is different because infiltration is the water going into the ground and then plants take it soil take it and then still further water has moved on. So, you see that infiltration percentage from rainfall is much bigger than your recharge from rainfall because recharge groundwater still has to move further and after plant uptake, soil uptake etcetera.

So, let us look at some examples. So, you have the indo gangetic and inland areas suppose 100mm rainfall. So, in for example, in the indo gangetic you have 1500 mm rainfall 22 percent of that recommend valley is recharging into the groundwater. So, if you have your rainfall as millimeters, you can have fewer reaches also millimeters. So, 100 mm rainfall gives you 22 millimeters of recharge what happens to the rest, it goes ET and surface runoff.

Then, you know the east coast and west coast as I said along the east and west, you have a lot of rivers actually flowing out and those are alluvial aquifers, like Kaveri, the Penna on the east coast on the west coast, you have Narmada, Tapti and other rivers. The hard rock other central part of India and you could see that there is a lot of these multiple types weathered granite, muscular weathered basalt flat rate etcetera.

And depending on the rock type there is a fracture percentage all this has been done by GSI and other studies across the world and they have estimated how much infiltration happens in how much of that goes further in to groundwater recharge and this is the value, so 11 percent of the rainfall 8 percent of the rainfall etcetera.

So now I am giving you the volume, but what is the time that is hard to tell? So, I can say I give you 100mm rainfall in an alluvial aquifer, you get 22 mm as recharge but is it going to happen the next day the rainfall happens no, because it is a process which takes slow slow time to go in. So, it is better to say annual.

Annually Kolkata in the Ganges Belt son gets 100mm for example, takes much more and it gets around 22 percent of the annual rainfall which is 22 millimeters of rain of recharge from rainfall in a year. So, that is a good way to tell you cannot say that tomorrow, there is rain the day after tomorrow it will be recharged no. So, if I take 100 mm rainfall today, today I am getting 100 mm rainfall, which is like a flood.

Does that mean tomorrow I will get 88 percent as runoff and 22 percent which is 22 mm in my groundwater recharge, not, it will take some more time. So, please think this out and when you discuss this with others, make sure there is a time aspect and the time no one can tell only you would be able to estimate but again at the end of the day they want annual recharge if you look at the year, last lecture I gave the groundwater board has given you a recharge annually. So, take annually that is fine. But for understanding the physical process, you need to understand that it is not a daily process, it takes time.

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Software and Models, Methods for Estimating Groundwater Recharge In Humid Regions

Sorted by Method

Method	Category	Program	Author	Date	Title
Base Flow	Streamflow	WHAT	K.J. Lim, B.A. Engel, Z. Tang, J. Choi, K. Kim, S. Muthukrishnan, and D. Tripathy	2005	Web GIS-based Hydrograph Analysis Tool, WHAT
Base Flow	Streamflow	PART	Rutledge, A.T.	1993	Computer programs for describing the recession of ground-water discharge and for estimating mean ground-water recharge and discharge from streamflow records
Base Flow	Streamflow	BFI	Wahl, K.L. and Wahl, T.L.	1988	A computer program for determining an index to base flow
Base Flow	Streamflow	HYSEP	Sloto, R.A., and Crouse, M.Y.	1996	HYSEP: a computer program for streamflow hydrograph separation and analysis
GW Models	Groundwater	MODFLOW	Harbaugh, A.W.	2005	A modular three-dimensional finite-difference ground-water flow model
GW Models	Groundwater	MODFE	Torak, L.J.	1993	A MODular Finite-Element model (MODFE) for areal and axisymmetric ground-water-flow problems
GW Models	Groundwater	SUTRA	Voss, C. I., and Provost, A.M.,	2002	SUTRA, A model for saturated-unsaturated variable-density ground-water flow with solute or energy transport
HELP3	Water Budget	HELP	Schroeder, P.R., Aziz, N.M., Lloyd, C.M., and Zappi, P.A.	1994	The hydrologic evaluation of landfill performance (HELP) model, user's guide for version 3
New Jersey	Water Budget	DGS99-2	Charles, E.G.	1993	A method for evaluating ground-water recharge areas in New Jersey
Recession-Curve Displacement	Streamflow	RORA	Rutledge, A.T.	1998	Computer programs for describing the recession of ground-water discharge and for estimating mean ground-water recharge and discharge from streamflow data – update
Recession-Curve Displacement	Streamflow	PULSE	Rutledge, A.T.	2002	User guide for the PULSE program:
Regression	Regionalization	GLSNet	Tasker, G.D., and Stedinger, J.R., 1989, An operational GLS model for hydrologic regression: Journal of Hydrology, v. 111, p. 361-375.	1989	Tasker, G.D., and Stedinger, J.R., 1989, An operational GLS model for hydrologic regression: Journal of Hydrology, v. 111, p. 361-375.
UZ Models	Unsaturated Zone	VS2D	Hsieh, P.A., Wingle, William, and Healy, R.W.	2000	VS2DI--A graphical software package for simulating fluid flow and solute or energy transport in variably saturated porous media
Watershed Models	Streamflow	SWAT	Neitsch, S.L., Arnold, J.G., Kiniry, J.R., Williams, J.R.	2005	Soil and water assessment tool -- theoretical development
Watershed Models	Streamflow	HSPF	Bicknell, B.R., Imhoff, J.C., Kittle, J.L., Jr., Donigian, A.S., Jr., and Johanson, R.C.	1997	Hydrological Simulation Program--Fortran, User's manual for version 11
Watershed Models	Streamflow	PRMS	Leavesley, G.H., Lichty, R.W., Troutman, B.M., and Saindon, L.G., 1983, Precipitation-Runoff Modeling System: User's Manual: U.S. Geological Survey Water-Resources Investigations 83-4238, 207 p.	2000	Leavesley, G.H., Lichty, R.W., Troutman, B.M., and Saindon, L.G., 1983, Precipitation-Runoff Modeling System: User's Manual: U.S. Geological Survey Water-Resources Investigations 83-4238, 207 p.

https://water.usgs.gov/ogw/gwrp/methods/software/

And the last part I would like to say after we did the estimations through water budgets, through your meters seepage meters etcetera and water flow fluctuations. The last part is models, multiple models that can easily estimate your groundwater recharge based on the driving factors, which is your land use land cover your rainfall, the type of aquifer, type of rocks or etcetera. And those can be taken from these open source models.

So, the link I am giving here in the bottom, if you just go there, all these models are all in there. And you can click on the title and it goes into the model where you can learn it for free. So, it is very important that these models have their own positives and negatives you can look at the rate and there are multiple models for a single parameter which is groundwater recharge. Please understand that it is because of the changes in the modelling world because the computers have become faster.

The data has become more accessible you will see more models coming up every couple of years once. So, year around 1988 there is a model and then there is some new models in 2002 etcetera. So, you have to read more these models the suitability for your research area and then you pick and choose your research model.

Now, someone can ask me, which is the best model we as a faculty, what do you teach, I would say the best model for groundwater as an open source and widely used as smart flow It runs on Darcy's law, which we have already explained and it is a very simple model less data intensive. However, it has been very successful in getting remote resumes across the world not only in US, India, wherever the water extraction is happening.

But most of the studies have used smart flow whereas, some have actually gone out or outdated etcetera some of the models. So, what is a recharge estimation model not a groundwater model, but it is very good surface water model surface water you have rainfall converting to runoff and an infiltration after infiltration it goes into recharge where more flow comes in MODFLOW this one.

There is also good model but MODFLOW is widely known as a very good model it is a 3D model also we will see some of these models, how to set it up etcetera in the class.

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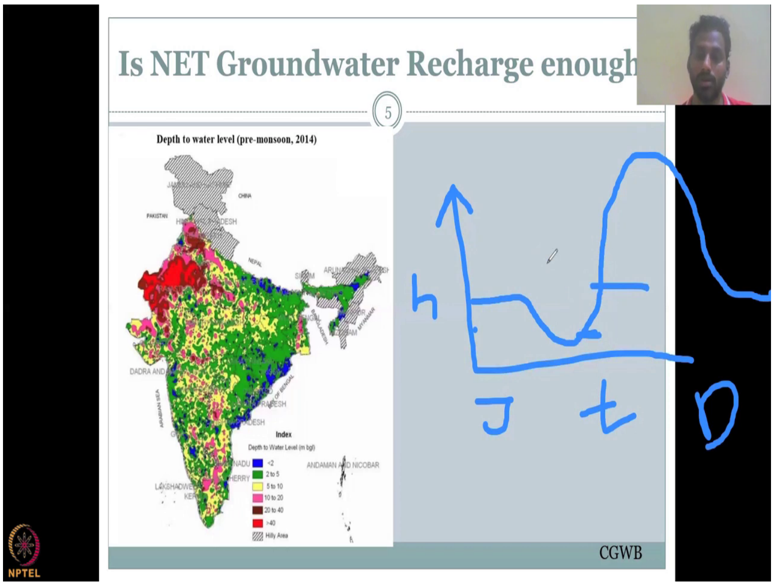

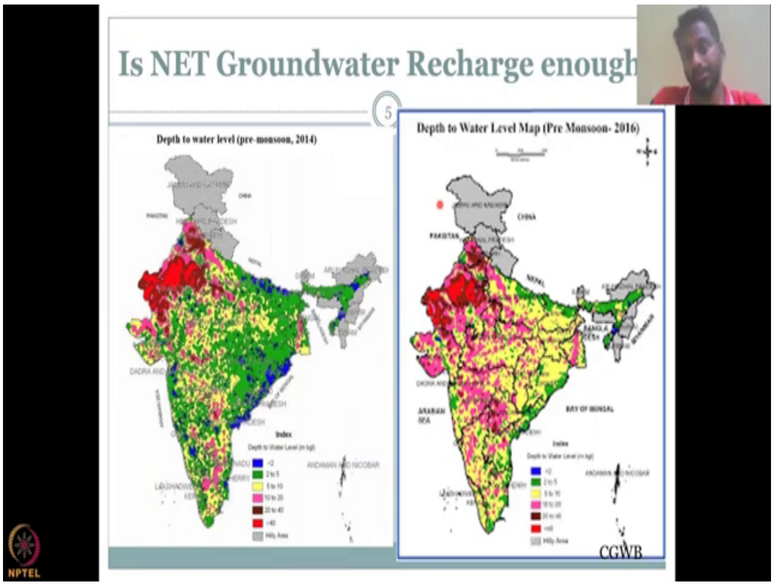

So, now we have looked at recharge estimates and how to do recharge etcetera. What are the different methods and then we came to models but the important question is net groundwater recharge enough? What is your net groundwater recharge? So, this is your time on your x axis and then your Y axis you have your H just hydraulic head. Let us do Jan to December normally you do water year which means she at least here monsoon starts in June.

So, I will do June to job but let us do calendar because most of you would like to have calendar year. So, the water would start around here and then come down during your summer and then rise up during your monsoon and then come back to the same value. So, this is happening the downfall of the water level is because of discharge and pumping etcetera and then your recharge happens because of monsoon. What is net?

Net is not only the groundwater recharge happening through your rainfall, but also the seepage, the dams, etcetera. And you have to also calculate your water used because that is also being taken for from your net groundwater recharge, correct, it has been taken for your agriculture but it is taken from a recharged well, so that is what net recharges.

So, you have to take it from here. So, from here the recharge is happening. You cannot say that oh no, no, I will start here, because I does not take into consider the water I used for agriculture etcetera. So, you have to take from this and also include the water that you have taken out for recharge and groundwater, irrigation etcetera.

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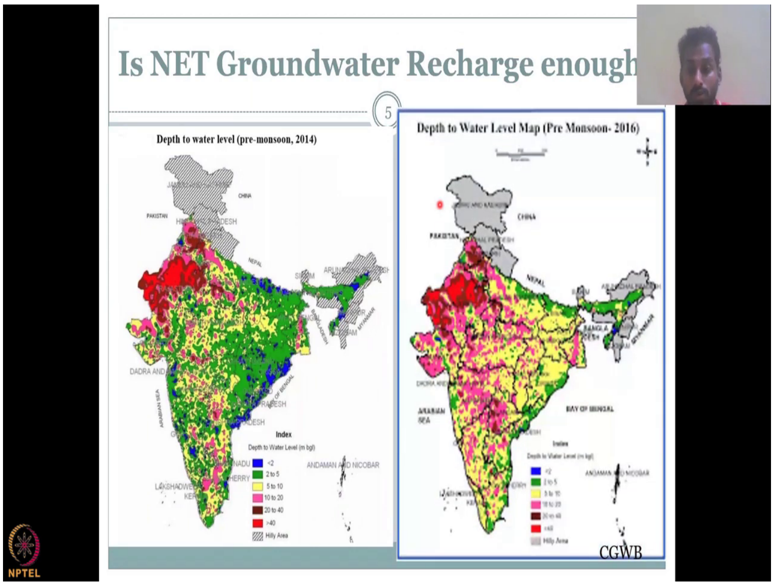

So, it is very important to understand that net groundwater recharge, is it enough is it able is a question and as you know, as we spoke, the groundwater use has always been increasing in India. So, definitely the groundwater recharge is not enough it is going down. The rainfall patterns have changed the climate patterns have changed. And then the monsoon level which is before your monsoon before your monsoon which is from your peak monsoon to your next monsoon the water that you have used.

In summertime, if you look at it, it is a drastic condition most of regions are red in comparisons from 2014 to 2016. The index is the same, the colours are the same. So, what it means is those areas which were green, having healthy groundwater levels of two to five, so within two to five meters will have groundwater, all those are changing into yellow and pink and red, which is not sustainable in the long run.

So, it is very important to do more groundwater recharge. So, here is the question is it possible to do more groundwater recharge because rainfall patterns are changing naturally it is not going to be enough. And that is why there are a lot of schemes just look at the central part of India here, this red part where Rajasthan and Punjab, Haryana those regions, you have a lot of groundwater use, a lot of agricultural activities, but look at central India.

So, where the hard rock aquifers are so much water used and that is why it shows a big drop in the pre-monsoon levels. So, the net recharge is not enough change or you are using more water even though the rainfall is same, you may be using too much of water so the net recharge is not enough. And as I said with climate change within even couple of years, you are seeing the groundwater available for irrigation is being unsustainably used annual rainfall is giving less into the recharge because faster rain forests coming flash floods are coming. So, all this has to be accounted for in the ground water management.

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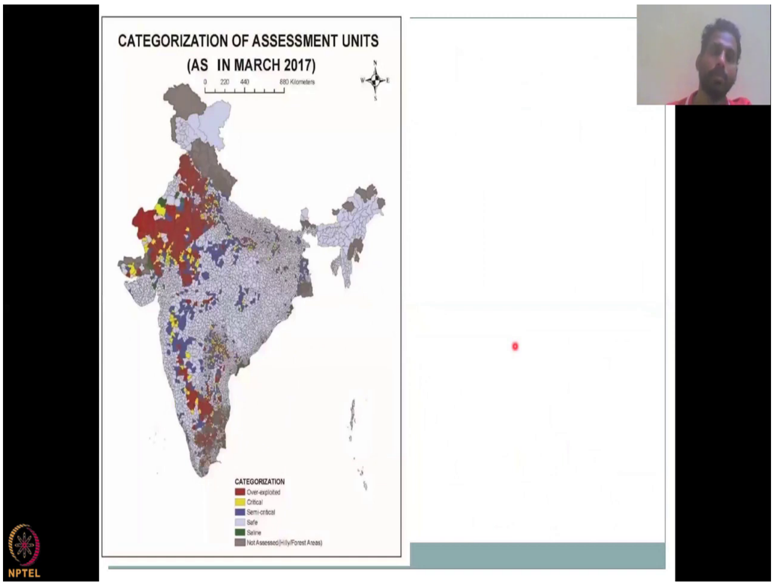

Let us look at the situation of the number of blocks that have been done as critical or semi critical. Overexploited means you are exploiting more than 100 percent of the groundwater that is recharge and critical is somewhere around your 100 percent, 72 to 100 percent and 70 percent Semi critical below that is safe. So, what do you recommend now?

So, in India, is it safe? Yes, because of the water level if you look at India level is what it was it was 62 percent, or for 33 billion cubic meters, you are using 245 billion cubic meters as per CGWB, it is outdated, but says, it is a 62 percent use of groundwater in the country, which is fine, they said it is safe. However, if you look at certain blocks, it is really bad. And it is in the over exploited condition.

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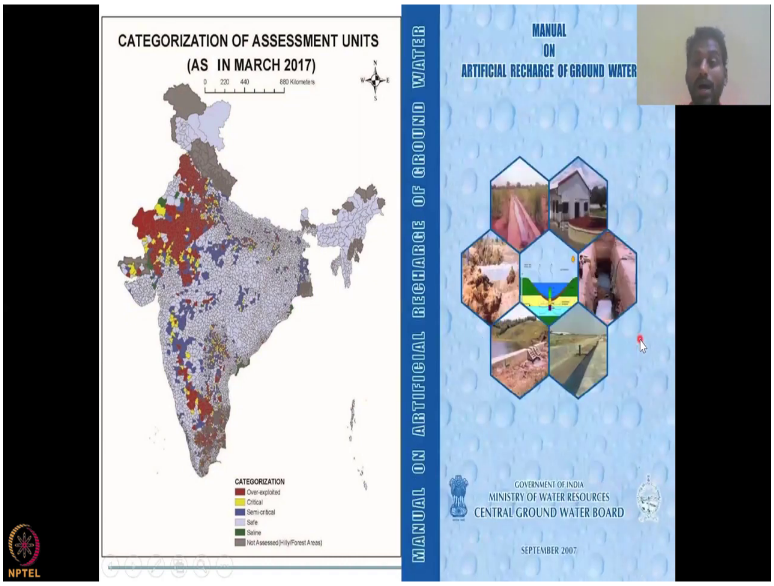

And that is why it is important to artificially recharge groundwater. I will continue with these methods in the next class, but let me give you an introduction to what is artificial recharge. As the name suggests, artificial means this is not natural. Meaning it will take more time for the groundwater to go in within a natural setting. And that cannot be sustained for the life forms agriculture in the current India. You need to push methods that can augment groundwater and increase groundwater recharge.

And luckily the GEC the groundwater estimation committee and the groundwater board, the central groundwater water board have made these kinds of very useful documents with live examples you could see here pictures of examples from study areas on how you could increase the groundwater recharge using artificial means.

Anything you construct on land is artificial because it is not natural recharge. In the next class, I will start with the introduction of natural recharge versus artificial recharge. And then we will look at some examples and wrap up with six. With this, I conclude today’s lecture.