Remote Sensing and GIS for Rural Development
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Lecture 43
Remote Sensing for irrigation assessments

Hello everyone. Welcome to the NPTEL course on Remote Sensing and GIS for Rural Development. This is week 9, lecture 3. In this week, we have been looking at various applications of remote sensing tools, especially the land use land cover estimations for understanding the land available for rural development. When I mentioned land, it also includes the land and other natural resources attached to the land - water, soil, forest, biodiversity, animals, plants, everything. So, all these are very important for a sustainable rural development.

And we have noticed that there could be some disturbances due to anthropogenic or climate-induced natural systems, for which there is constant monitoring needed, there is constant evaluation needed, and when there is no data, remote sensing plays a vital role. Remote sensing data has to be taken down into the platforms using GIS, and that is where GIS finds applications. So, without further ado, let us move into today's lecture.

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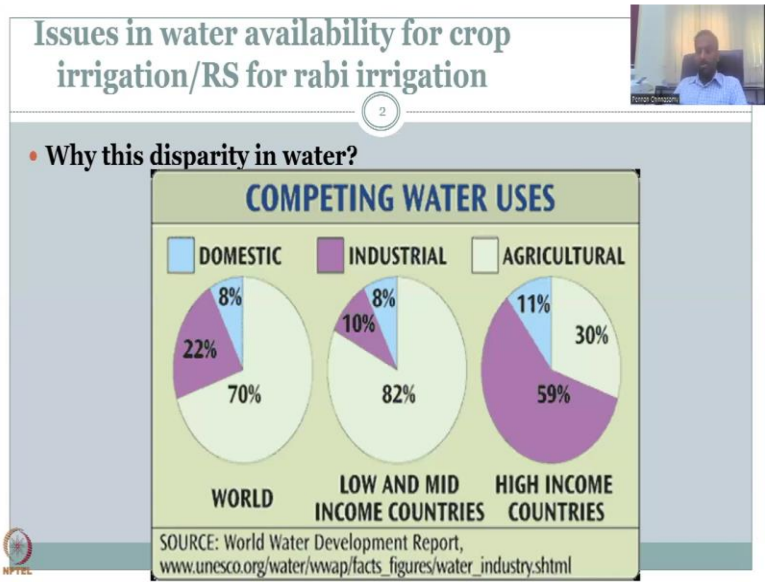

In today's lecture, I would like to discuss about issues in water availability for crop irrigation, especially the Rabi irrigation and Zaid irrigation, where it is non-monsoon irrigation, we will club it together and say non-monsoon irrigation. But before that, I have already touched base on this graph and it is very important to revisit this graph for a minute.

There is always disparity in water across the world; inequity is there, there is no equal distribution of water resources for livelihood options across the world. Let us take an example. In the world, 70 percent of the water is used for agriculture, 22 percent for industries, and 8 percent for domestic use, as per the UNESCO report, World Water Development Report under the UNESCO.

However, in the low and middle income countries, you will see that they have compromised the industrial development and put more water on the agriculture. So, 82 percent is there. And when you go to developed nations, or high income nations, the color flips. So, industry takes the huge chunk of water, 59 percent, very less for agriculture, and very high quality lifestyles they have, swimming pools, car washing facilities, etcetera. So, they have 11 percent. Almost most houses in the developed countries have lawns. So, they have big, big lawns for which water is needed. And that is 11 percent.

So, now if you look at it, the low and middle income countries produce food not only for them, but also for the developed nations. And so, for per liter water, if you look at the profit they get, it is very, very low in compared to the per liter of water used in industries. Let us say bottling industries, processing industries, car industries, steel industries, where they consume a lot of water.

In an industrial high developed countries, high income countries, there is more profit in terms of dollars and rupees per liter of water, whereas in developing nations and low middle income countries such as we have Nepal, Sri Lanka, etcetera, in our own region, and developing nations such as India, we put a lot of water in agriculture. So, there is a disparity. And there is more pressure for the low and middle income countries to feed the world.

When you see the import export data, you can see that a lot of food, initially just the grains was going from Asian countries to developed countries. But now, even perishable items such as fruits, aqua, fish, etcetera, are being exported at a very, very high cost. Poultry meat consumes a lot of water. So, they also are grown here, like chicken and goat, lambs are grown here, and then they are sold across the world.

So, this constitutes to a lot of water virtual trade, and the correct price for water is not reached. So, but let us stick only for agriculture in this lecture series in terms of where water is going, and how do you use remote sensing tools to address this. So, now we know why it is very, very important to have a check on where the water is being put. So, here, as you see, in

India, most of the water is put in agriculture. And we will see how the numbers aggregate towards the irrigation cycles.

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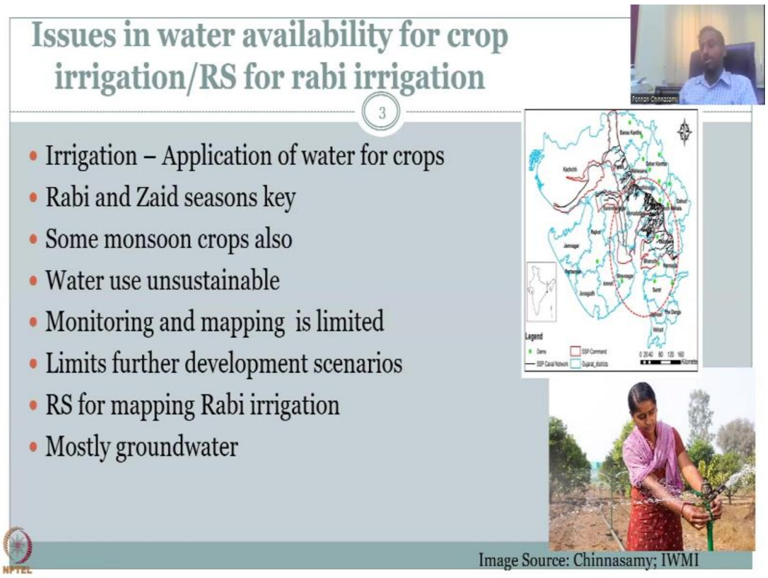

So, issues in water availability is very important for rural development because most of the crops are also grown during non-monsoon season. So, non-monsoon season attracts water application through crop irrigation cycles. Irrigation is the application of water for crops, so you can just say irrigation water, you do not have to say agriculture, because irrigation means that it is used for agriculture. So, application of water for crops is irrigation. Underline the word application, because you are applying.

It could be sprinkler, canal, groundwater, anything that you apply is called application. The opposite to that is nature based natural resources, which is the rainfall, only rainfall is there. Or dew, whatever moisture is there in the water, vapor or in the atmosphere, the moisture is being absorbed by some plants and trees, and they grow. So, here it is mostly the application of water for crops, especially cash crops that grow more than the monsoon season. Sugarcane is very important across the world, not only in India, and very important in Maharashtra, where it is a lot of sugarcane industries are there.

And you could see that sugarcane consumes a lot of water. It is not a monsoon crop, it grows either one year, which is 12 months or 16 to 18 months, couple of varieties are there; even the shortest will go around 12 months. So, we have two seasons, which is Rabi and Zaid seasons are the key for irrigation cycles. Rabi and Zaid are supported by irrigation, not the monsoon. Some monsoon crops also take irrigation water, for example, especially during the climate change scenarios, when there is not enough water available in the rain season, or the dams are not filled up during the rain season, then there is more water needed to be supplied either through groundwater or canal irrigation from other resources.

So, some monsoon crops at the end cycle, normally, they will wait for the IMD's prediction of the onset of monsoon. They say June 6 is the monsoon, then farmers prepare the land. And around June first week, they start sowing the seeds. But if the rainfall does not come, then the seeds will not germinate. So, at that time, the farmer has to spend money to put water in. Then also, they assume that three months the water will be there, so the crops will grow. But suddenly, the monsoon is truncated at two and a half months. So, for the rest of the half a month, the farmer has to put water in terms of irrigation. So, these are irrigations in the monsoon cycle.

In the Rabi and Zaid, normally, they will use more and more irrigation supply. So, water use is unsustainable in India. India has become a food exporter from the past, to now, it has become a food and crop exporting nation across the world. So, initially, it was only exporting, as I said, only for neighboring countries or very, very small volumes. But now it exports across the world. You could have seen the India wheat is in demand, India rice is in demand.

Initially, before the Green Revolution, it was a food importer, we would import wheat, we would import sugar and other food cereals. But now we are exporting, which is good for the country. But is it sustainable is the question, because a lot of water is used at unsustainable rates. Monitoring and mapping of the water resources is limited, the land under agriculture is limited. And without knowing this, it is very hard to manage the water, we know that it is unsustainable, because suddenly, it has grown from a food importer to a food exporter.

So, there is considerable amount of change in the food part. And that cannot come naturally, it has to come through water application. So, water is tight and let us see how things move. So, it limits further development scenarios. If you spend more water, which means more budgets and funds for irrigation, then there is less water available for other resources, like livelihood options, sanitation, and also there is less water available for drinking. This you can see in agricultural towns.

On the second hand, you also see that budgets are less in these environments where more budgets are spent for water, less budgets for skill development, housing development in rural areas, and also during the disease scenarios, health facilities and skill development facilities are limited. Remote sensing can help in mapping irrigation patterns. Basically, the area is key. Once we know the area using the evaporation and transpiration water demands, we can assess how much water is needed for the particular crop, particular area.

The striking truth is, mostly groundwater is used for irrigation scenarios, which needs to be addressed in a very alarming situation. The country is the highest extractor of groundwater, and it cannot sustain at this current rate, there has to be intervention, there has to be stopping of this process of overpumping aquifers in India. And that can only happen if we know scientifically that there is a lot of water consumed without need. Some regions have canal irrigation as like the Gujarat.

And even there, we would need to show the public and the government that this is the water available in the dams and these are how many acres that have been irrigated using the water. And for that, since every plot they cannot go and monitor individually, the satellites and remote sensing based data can aid for mapping the area, which is acreage, we say crop acreage. And you can see that along the canal areas, we have some results, which we will see in the twelfth lecture week, we will see that along these canal areas, there is a lot of soil moisture because the water is applied on the ground and it infiltrates.

So, while it infiltrates, you have increased soil moisture in these regions. And there is also adoption of groundwater in along with some technologies such as sprinkler, pivot systems, etcetera. So, these actually reduce the water demand for the crops. However, they are still irrigating, you can see very high-tech devices used for accessing the groundwater, putting it through devices to apply water across the field and along with that, fertigation is also done. So, mostly groundwater is used for Rabi and Zaid irrigation or for non-monsoon irrigation. And it is at very unsustainable rates.

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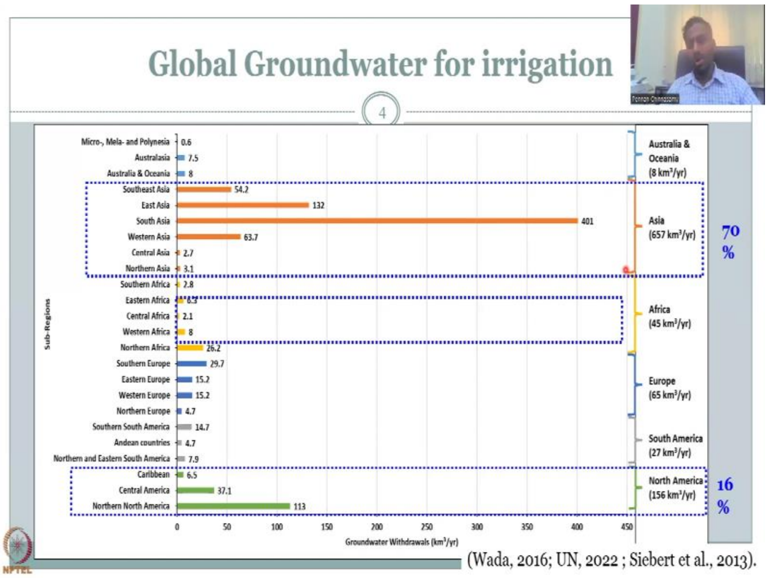

Let us see how India ranks along the global water demands for groundwater, groundwater irrigation. And you can see that this is the global groundwater withdrawals at kilometer cube per year. And you could see around Southeast Asia, South Asia, Western Asia consumes more than 70 percent of the water. So, if you compare this to the numbers, which I had in the disparity of water, you could see that the developed nations are not having that much water demand.

For example, you have Europe, Europe has only 15.2, 15.2, around 65 kilometer cube per year in Europe, whereas Asia is only 657 kilometer per cube per year. And you have South America along the lines of Europe, or maybe even lesser than Europe. And North America is a little bit higher because they do have some agriculture going on, mostly the almonds and orchards that they have in California. So, you see that the other part of the world which is poor in terms of water consuming is African regions, they have economic crunch, they do not have the funds to access the groundwater.

And as a result, they are pushing more into poverty and or malnutrition because they cannot grow their own crops. So, groundwater is available, but they cannot access it readily. And there is also very low rainfall, so which is not conducive for agricultural development. So, irrigation water demand is still happening, but very, very low. And comparatively, the developed nations have some demand, but it is still one sixth of what we use in Asia. So, Asia has become the football for the entire globe and in particular, India, which consumes a lot of water, not only for its own population, which is ranked number 2 in the world, but also across regions in the world.

So, that is why we are at number one as the highest groundwater extractor in the world. So, out of 657 kilometer cube per year, we extract around 245 kilometer cube per year, which is a big amount compared that the Asian region is big, also Asian region is big in agriculture.

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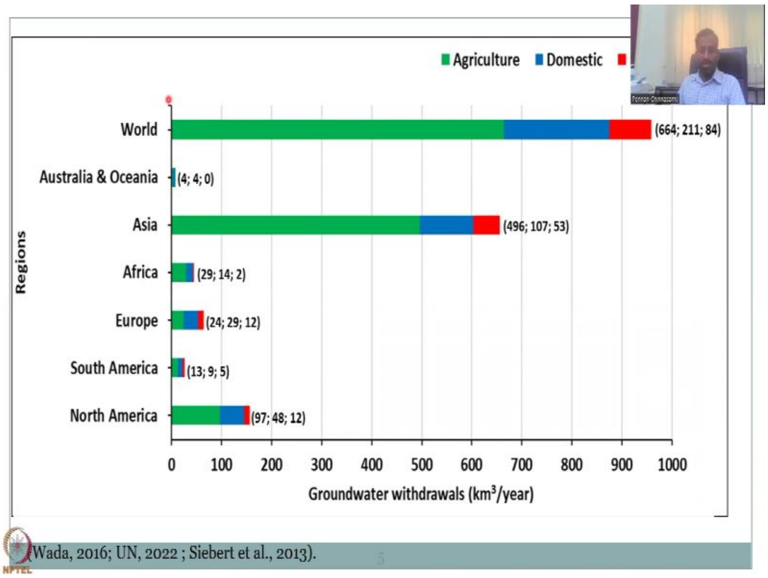

So, we can also see that the groundwater withdrawals in another paper for the world is mostly you can see how it is being spread, the water budgets, however they are spread, agriculture takes the biggest percentage along the groundwater applications and then domestic use is there, industry use is there. And then Asia follows very closely to the world average because it leads the world average. But then when you come to Europe, you can see that industry tops the agricultural water demand, and North America has some or more or less industrial water demand compared to the agricultural water demand.

So, almost 50 percent, I would say. So, what happens here is we will be looking at the demand of groundwater in India and how it is used for agriculture, one. And is it sustainable for rural development? And what data do we have?

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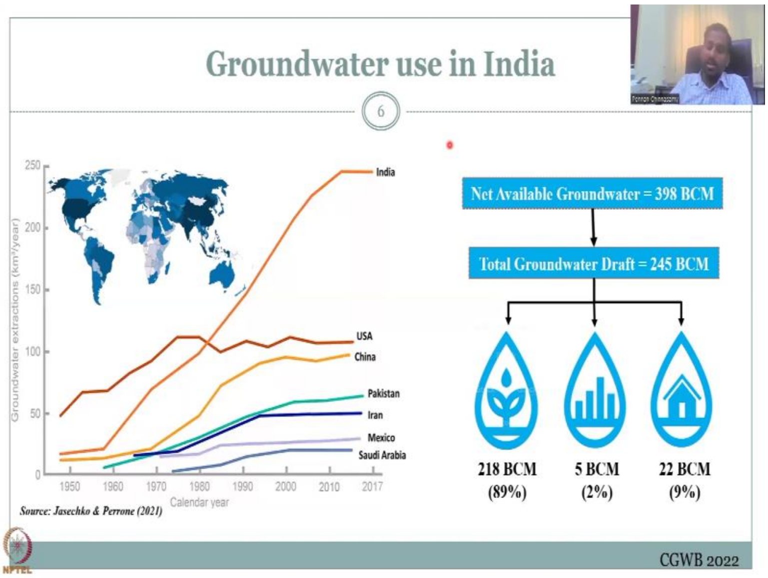

So, you could see here again, another study by Jasechko and Perron, 2021, that groundwater use or abuse in India is really, really high. We are number one, brand number one in the world, with around 245 kilometer cube. Whereas the other nations have the second and third are US and China. Even if you combine them, let us say, US is around 110 and China is around 100, even if you combine them, it is 220 kilometer cube per year, whereas India is 245 kilometer cube per year.

So, that is how unsustainable the groundwater extraction is going on. And mostly it is only for agriculture, around 89 percent is for agriculture, which needs to be stopped, almost 90 percent. So, the net available groundwater per year is 398 billion cubic meters. And of that billion cubic meters, the total groundwater draft is 245 billion cubic meters, which is put in as 90 percent or 89 percent into agriculture to 18 billion cubic meters, and then 2 percent into domestic water supply for drinking, washing, cleaning vessels, bathing.

So, that is around 2 percent at 5 billion cubic meters, and around 9 percent or 22 billion cubic meters for industrial development. So, agriculture is around 10 times of industry in India. Is it sustainable? It is not, because industry, you can still maneuver the technologies and use less water intensive industrial applications. But in agriculture, the food demand is high in India, both in the local market and the industrial market. And so, there is a big push for further expansion of agricultural lands at the cost of water resources.

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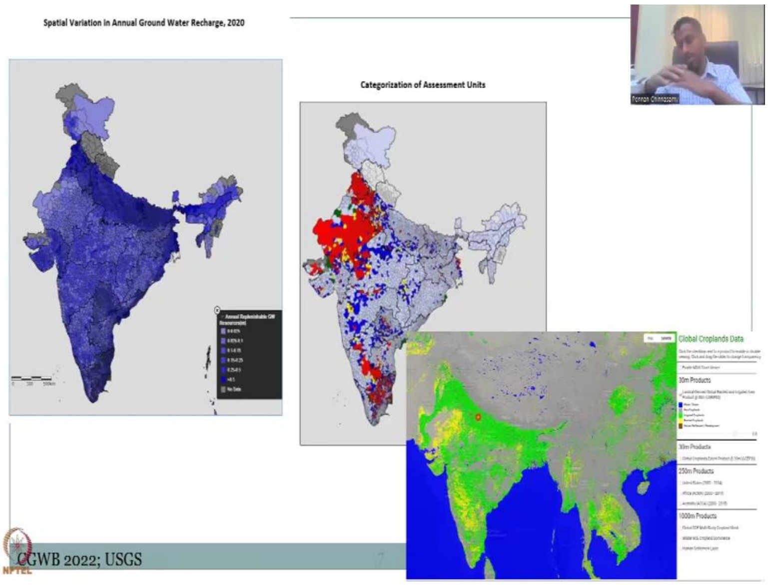

So, if you look at the spatial variation of groundwater recharge, how much water is recharging across India, you could see that along the Ganges basin where alluvial aquifers are there, there is a lot of water recharge and along the Western Ghats and Central India. Whereas if you look at the CGWB's estimates of groundwater blocks, basically red means over exploited, they are exploiting more than the water which is recharging. And you can see that mostly Rajasthan, Gujarat, Haryana, Punjab, all have too much groundwater abuse or groundwater extraction. And this cannot go along in the current scenario, because it is very unsustainable.

There are some reasons without data, but we will focus on reasons where the blocks are considered as critical and over exploited. So, both are very dangerous, because critical means you are almost extracting water, which is actually recharging. And over exploiting means if you put 100 liters, you are extracting more than 100 liters, let us say 110 liters. So, that is over exploitation, so which is not good for the current scenario.

Now, as a remote sensing and a groundwater specialist, if you ask me, I will quickly make some maps and then compare it. So, if you just visually compare, you can see that where the recharge is happening, there is good agriculture happening. So, you can say, there is recharge and the green color resembles your rain fed irrigation.

Whereas, your irrigated cropland is in your green and light green. So, you have the greens mixed here. So, you have forest also there. But let us not look into the forest per se. This green color reflects your monsoon irrigated crops, which is the rain fed crops. And then your irrigated crops also mixed in between. So, there is two layers because sometimes you have monsoon and then after there is a harvest.

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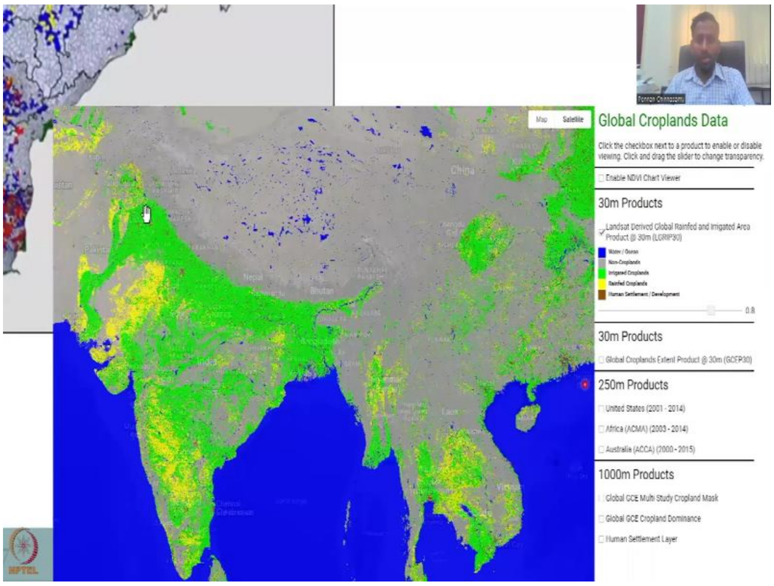

And there is also, let us zoom in to the legend so that you can see. So, you can see that irrigated croplands are green in color, whereas the rain fed are yellow. And as I said, when there is rain fed, there can also be irrigation because when the rain water is not enough, then farmers put more effort into pumping out the water. So, if you compare these diagrams, all these images, you could see that along where there is a lot of recharge along this part, the Ganges part, there is no blue color turning into red, which is okay.

They say that, you are recharging and you are using. And that also resembles this part where you could see that the green color resembles in this diagram, irrigated croplands. So, groundwater is being used.

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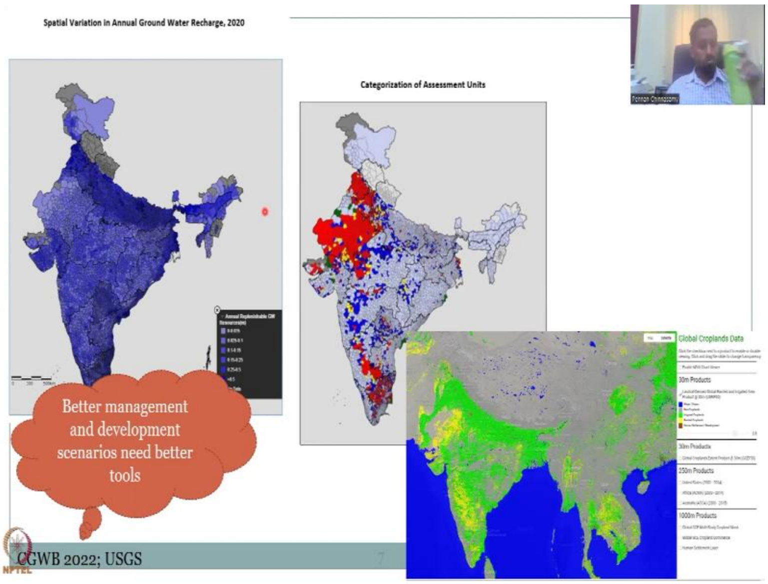

But here in this part where recharge is happening, however, you are exploiting more water than your recharge. And that is also captured in the green color here because green reflects the irrigated crops. Whereas the rain fed areas are not turning much into red because you have these rain fed areas along here. There is some water demand, rain fed along here. So, you have water demand, but it only grows rain fed. There is no pumping, over extraction of pumping.

Along the regions where the red color is and the green color is, that is where there is a problem, because there is a lot of irrigation happening, a lot of application of water through groundwater resources, which is extracted more than the recharge. And that is where it is very concerning. So, to cover it up, we need better management and development scenarios, especially to conserve groundwater so that the croplands can be sustainably developed and you can have a sustainable agriculture for a long period. Otherwise, you will have 2 or 3 years of crops and then suddenly everything stops for 5, 10 years. That cannot be a sustainable solution for farmers.

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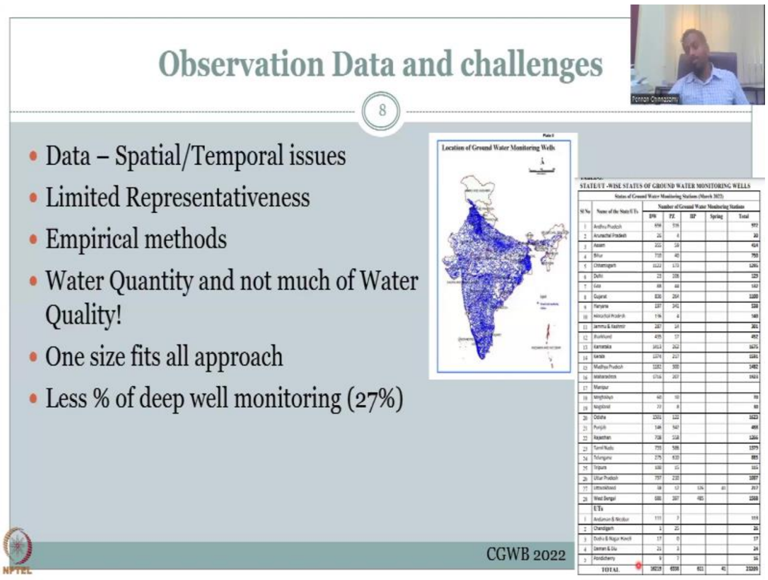

So, let us see why the groundwater is not being monitored to support this irrigation schedules and stuff. There is a lot of observation data challenges. Data spatial and temporal issues are there. For example, the wells are not placed; all across India, you see some white spots, you see some high dense groundwater monitoring stations. So, not evenly spaced or not perfectly spaced and not all spatial regulations are there.

For example, the Himalayan regions are not having groundwater monitoring wells. However, that is what water they use for subsistence farming and drinking. If you go to these areas, the groundwater goes in and comes out as springs. So, if groundwater is reducing, the spring water does not come out and the drinking water resources jeopardized. So, this is the latest data as per the 2022 CGWB book. You could see that around 23,200 wells are there and all of that around 6,300 wells, around 25 percent are on the deep aquifers, whereas the dug wells are around 75 percent, 16 20 2019.

Is this sustainable? Is this correct? Is a good question to ask because most of the people in these regions are pumping from deep aquifers. Let us say Punjab, for example, Punjab, they have 146 wells, which are the dug wells, 342 in the deeper aquifers at 488. So, this is good because you have more wells in the deeper aquifer regions. If you go to Tamil Nadu regions, you can see that the Tamil Nadu has 793 out of 1,379 wells, you have around 793 wells, which is around 60 percent in the shallow wells, and then 40 percent in the deep wells.

So, here is another point; coming from Tamil Nadu and have been worked there for a long time, I know that farmers do pump very, very deep, not at 50 feet shallow wells. And so, these data could be really wrong in terms of monitoring and evaluating alone, just if you use these data alone, it has to be merged with some other data to look at, long term. So, limited representativeness, the monitoring well is at a distance, whereas the farmers well is at a distance of 1-2 kilometers apart.

So, they are not actually capturing the correct values. The recharge estimates are done using empirical methods, not only physical based methods, and water quantity is measured, not the quality. So, this leads to one size fits all approach of management, where they say that, oh, you just put in some groundwater recharge structures, it will work. It will not work everywhere, there needs to be some scientific understanding.

So, less percentage of deep well monitoring, around 27 percent actual values of wells are in the deep aquifers, whereas the percentage of people using deep aquifers for domestic use and for agriculture is much, much bigger than that. So, we should be aware of this and use also other data that can help.

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So, when we talk about other data, there is a lot of automation happening. And one tool is your remote sensing - remote sensing, near sensing and crowd sourcing can aid. You can see here, the FAO is also promoting the use of drone imagery, and the image is converted to a data set using remote sensing GIS tools. So, crowd sourcing can be a part of remote sensing also, because when you take an image without touching the object, it is kind of remote sensing.

But drones are definitely there along with satellites. It gives you a better holistic understanding, all the data comes in together rather than just using the well data. And the farmers take more ownership because they supply the data to the farm management scenarios. And so, there is better management. We will look at case studies in the week 12. But now I will jump into the satellite that can do groundwater, which is called remote sensing of groundwater using GRACE.

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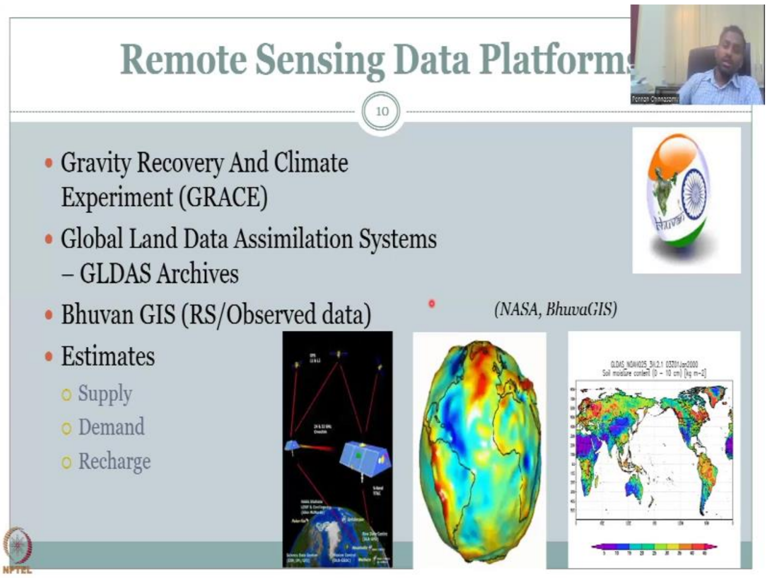

So, as I said, there is a lot of remote sensing platforms that can actually be used for crop water demands. But when it comes to groundwater, there is only one satellite in the world that can estimate groundwater demand till date. And that is GRACE. We will touch upon the GRACE working principle soon, and also show some examples, especially from my research group, and how they use it. So, the GRACE stands for Gravity Recovery and Climate Experiment. It is a joint project with NASA, JPL, JFZ, Germany, etcetera.

And it is a very unique system, very unique system, which works on the principle of acceleration and gravity. So, that is why the name gravity is there. It consists of two satellites. Normally a mission is one satellite, Landsat means one, MODIS means one, LISS means one, but however, this satellite was sent in pairs. So, two satellites went up and has been monitoring the groundwater resources effectively. So, it measures something else, but that if you subtract and then do some calculations, you get to groundwater.

So, there is a lot of GLDAS archives, global land data assimilation systems, which are clubbed together with the GRACE data to estimate groundwater. And some of the data could be from Bhuvan GIS and remote sensing and observed data. So, you have supply estimates. Supply is how much groundwater is supplied to the crops. The demand estimates how much water is needed and the recharge. So, in the supply, demand and recharge, supply and recharge can be estimated by GRACE.

Whereas the demand, the demand is how much is needed by the crop is modeled using the Bhuvan GIS archives and GLDS datasets. So, basically if you do a land use land cover, and let us say you have a 1 hectare farm and 1 hectare farm has sugarcane, so you multiply per sugarcane water demand to the number of sugarcane plants in 1 hectare, let us say 100 plants are there. So, 100 times 1 liter per day is equal to 100 liters per day you have to supply. So, these kinds of estimates we can readily work out using, if you use the acreage, how much land cover is there on your farm using sugarcane.

So, these are used for demand estimates, whereas the actual water applied because it is growing or how much water is applied can be taken from GRACE. GRACE does have some limitations and challenges, but we will look at the positives more when we look at the case studies because the GRACE data has been widely accepted across the world.

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So, this book, which I also co-authored the Asian Development Bank released in December, 2020, where it discusses about where can the water security initiatives be achieved by fundings across the Asia and the Pacific. So, basically looking at regions where there is a need of infrastructures and how the bank, the Asian Development Bank can support for development. And you could see that there are multiple indicators that were needed for this exercise.

And one indicator is the groundwater resource availability. And there was no other data that they could use because of the data issues and challenges that I described. So, they had to use GRACE data. So, that is where I did most of the GRACE data analysis and then provided it as a report on how much water has been used and how much water has been remaining in the storage structures. So, using GRACE, we can estimate the recharge. So, how much groundwater comes into the aquifer and then how much water is being taken out and put into the plants.

And then finally, we can also look at how much water is remaining in the aquifer. So, these are all important because if you know how much water is applied, you know how much fertilizers, how much storage needs to be done for the crops. And then, if you know how much remains, you know how much water is remaining for the next cropping season because groundwater does not recharge fast. So, this storage unit is very, very important.

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This was also reflected in our 2019 working paper on climate change science knowledge and impacts on water resources in South Asia funded by the World Bank. And we had used the GRACE data again to showcase that climate change happening or not, still people go into groundwater to access the aquifer water for agriculture. And that has not been that successful because you can get away with water for one year. But if it is 2-3 years, then there is no water. And so, it is very important to create infrastructures to recharge the groundwater before you go and exploit all the groundwater reserves.

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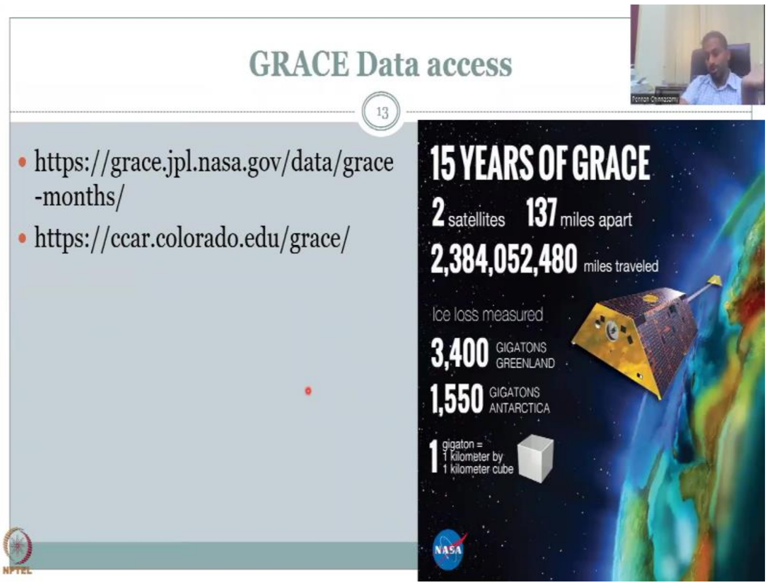

So, with this, I will briefly introduce the GRACE mission links. So, this is the link to download GRACE data. I would recommend you to go through the links before we meet in the next class. I will also go through the principle of GRACE data so that we can look at how GRACE data is collected and how can we use it in the research. I would conclude here. Thank you.