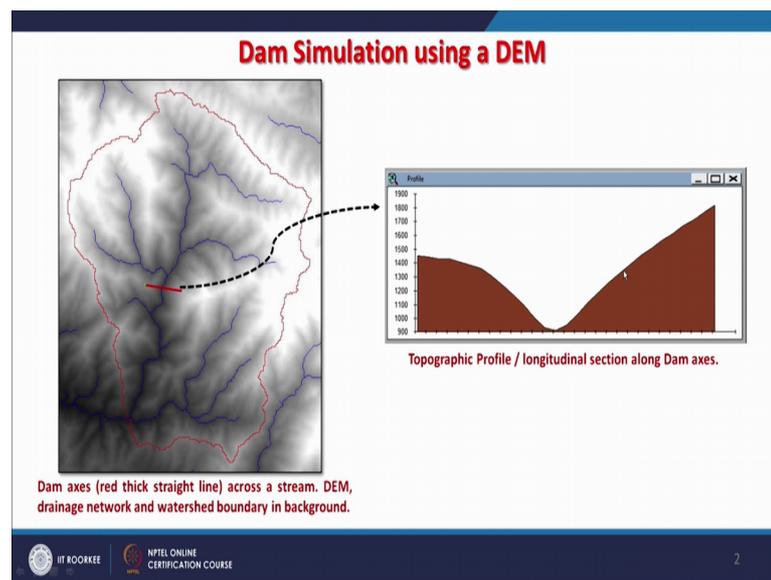


**Digital Elevation Models and Applications**  
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**Indian Institute of Technology, Roorkee**

**Lecture - 17**  
**DEM and Dam Simulation and its Application in Groundwater Hydrology**

Hello everyone, and welcome to digital elevation models and application course. This is the 17th lecture of this course. And in this one we are going to discuss how digital elevation model can be used for dam simulations that is reservoir simulations dam and how this simulation can help us in ground water related studies. So, this a this is another way of using digital elevation model or one can call as a derivative of a digital elevation model.

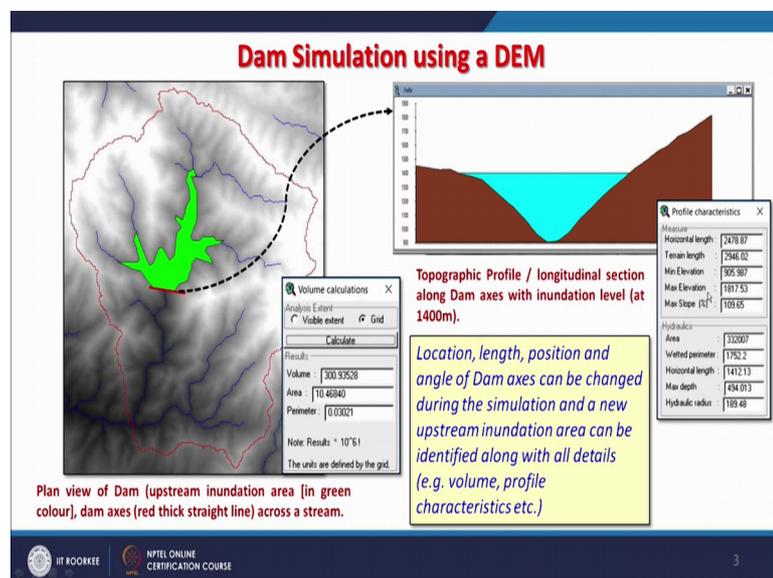
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Again we are going to take the same example of digital elevation model here and what I am showing here is there is a dam axes which has been drawn over the digital elevation model as you can see very clearly that there is a red line. So, this is the dam axes, and the across a stream this has been drawn. Now, in dam simulations the facilities which are available, anytime I can change the length of this line, I can change the direction of this line and roughly at present it is east west, I can change to another directions, but as you will see that it is not it is not really required to change too much because after all what we are going to use this digital elevation model for dam simulation.

So, it has to fill the with it has to fill the water. And therefore, we will keep in this particular example the this dam axes is like this. And this say once you draw a line over a digital elevation model, the next output you can generate is the profile or topographic profile which we have already discussed here. And this is the topography along this straight line as or dam axes. Now, we based on this we can think that if I keep the water level as 1400 a meter here in this particular example, then still water will remain in between these two you know mounts or high areas. And I can fill or simulate the reservoir here. So, based on the topographic profile I can decide the height of the dam here. So, here the height of the dam was kept at 1400 meter.

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As you can see, so the in the profile, this is the section view, and we are seeing that water has filled. And this dam this is being used here and this is the plan view of upstream area which will be inundated if water is filled up to 1400 meter over at this dam axes. And this is how very quickly a dam over a digital elevation model can be simulated very easily, but this is just one simple output. This can be useful for various purposes.

As mentioned that the location, length, position and angle of dam axes can be changed during the simulation. Or after the simulations, if I want one more or two, three, I can have different and a new upstream inundated area as shown here in green colour can be identified along with all details about this reservoir or the inundated water that is the volume, how much volume of water will be stored in this simulated dam. And other

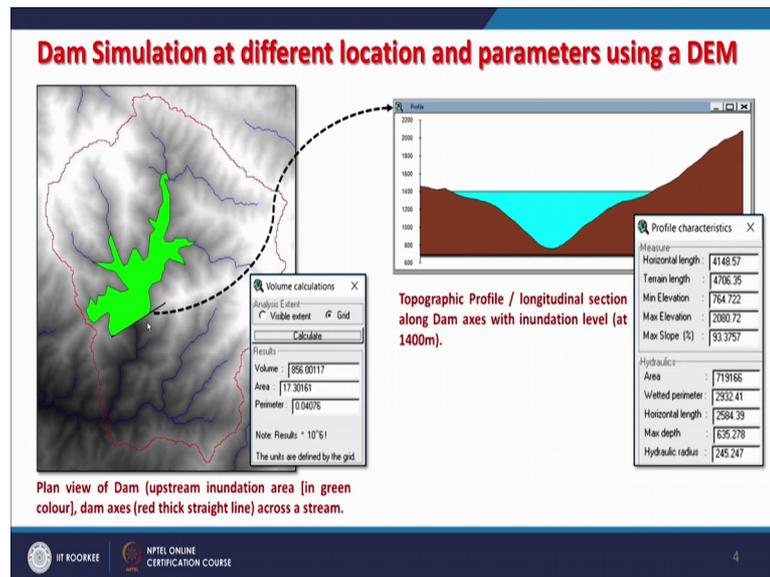
profile characteristics which I will just show you, so that you can you get the calculation about the total volume of water this reservoir will store the how much area will get inundated and what would be the perimeter in mapping scale this is calculated.

So, if you if your x y units are in meters, you will get everything in meters. If they are in degree decimals, then you will get in degree decimal. Another thing which you get about the profile characteristics of this particular topographic profile which you are seeing like what is the horizontal length; that is the length here, the total length of this dam axes. Then terrain length which is going to be more than the horizontal length, this is the terrain length. Then minimum elevation what is the minimum elevation, so this is coming around nine o five here as you can see very easily.

Then maximum elevation available here along this topographic profile is 1817, and then maximum slope also there. And then what other hydraulic characteristics of this topographic profile can also be calculated like area, wetted perimeter, horizontal length, maximum depth and hydraulic radius. The maximum depth will be calculated somewhere here and this is 1400 sorry 494 the maximum depth which we are getting here. ah

So, likewise lot of parameters which are required in the designing of a dam or a reservoir, can we simulate it, can we estimate it before anything is really constructed on a digitally layer on it in a terrain. And this that is the biggest advantage of digital elevation models. And this can be done on a GIS platform. If I if I give you further information about the softwares then the current RGIS software do not have a direct tool available, but nonetheless this and through several steps, this dam simulation exercise can be done or this modelling can be done. Whereas, in the older version that is arc view 3.2, there is a extension which is called profile extractor and using that extension this can be done very quickly in the simulation which I have shown here in this example has been done using profile extractor. So, on arc view GIS software, but on arc GIS the straightforward approach or the special extension or tool is not available, but if one use through cut and fill analysis, almost the same results can be achieved.

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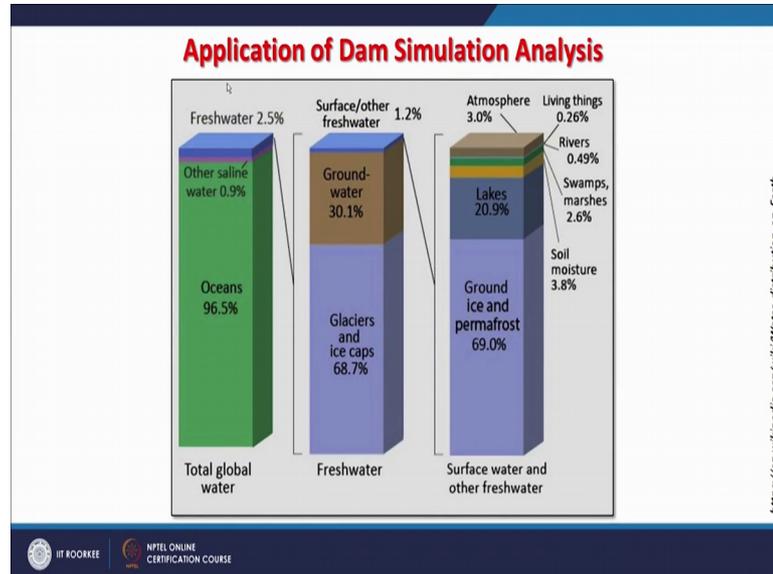
Now, different locations as I have chosen now I have changed the location in the previous example. The dam was somewhere else now I have shifted the dam axes, I have changed the dam length the reser[ve] this dam axes length and the inundated area 2 has changed. So, that is the advantage of simulations or doing these exercises on a gi GIS platform using a digital elevation model that one if one is targeting a particular volume of water in a terrain for storage maybe for hydropower or other things then before anything is done on the ground all these simulations can be done. And a proper decision can be reached. So, that is the advantage of this derivative of a digital elevation model. Of course, one has to imply the GIS here.

Again in this example we are having a topographic profile and it has been decided by simulation that it has to be filled up to the 1400 meter. And once we go there then we get the these parameters, volume area and perimeter of that reservoir and profile characteristics are also available for at this location if a dam is created there. So, one can shift you know upstream or downstream if we go downstream be more water can be stored , but the height of the dam has to be changed and so on and so forth.

And this is not only for related for irrigation or hydropower, but this dam simulation can also be used in groundwater recharge studies which we will discuss a little later . Before that I want to bring this how important this dam simulation studies are over a digital elevation model on a GIS platform from groundwater point of view. And how we can

exploit this facility or tune of a dam simulation or which is a very important derivative of a digital elevation model .

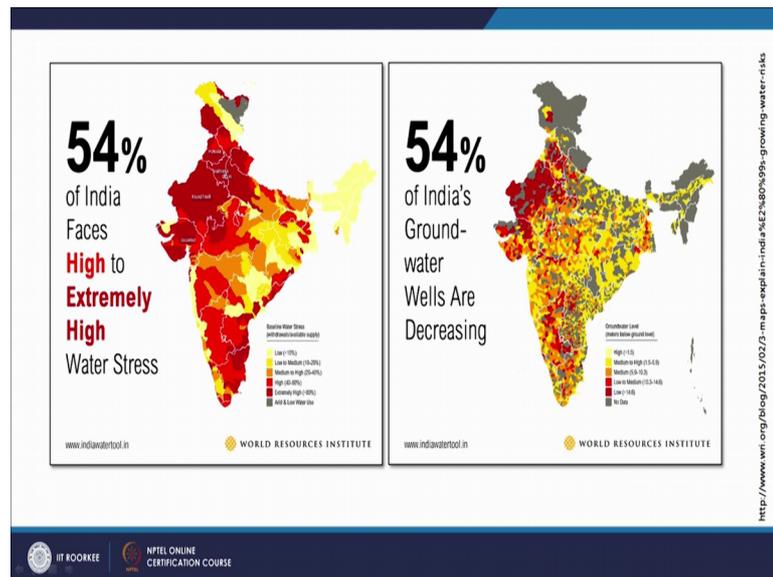
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As we know that the total global water out of which the freshwater is just 2.5 percent and that is the most precious water because 96.5 percent of oceans water is in the oceans we are having the other saline water may be in some lakes; the freshwater is only 2.5 percent. And out of that 2.5 percent the 68 or 67 percent water is available in glaciers or ice caps only the 31 30 or 30.1 percent of water is available in form of groundwater. And if if we go further, then this is how the freshwater is distributed. So, surface water and other fresh waters are distributed.

You can think that out of total hundred percent of water available on earth a very tiny amount that is only 2.5 percent is fresh water. And out of this 2.5 percent only 30 percent is groundwater and most of the time we require this water for drinking maybe for irrigation and other purposes. Therefore, this is very precious and it has to be augmented when rain occurs. So, we would like to recharge the our ground water regime and this dam simulation can really help in this one.

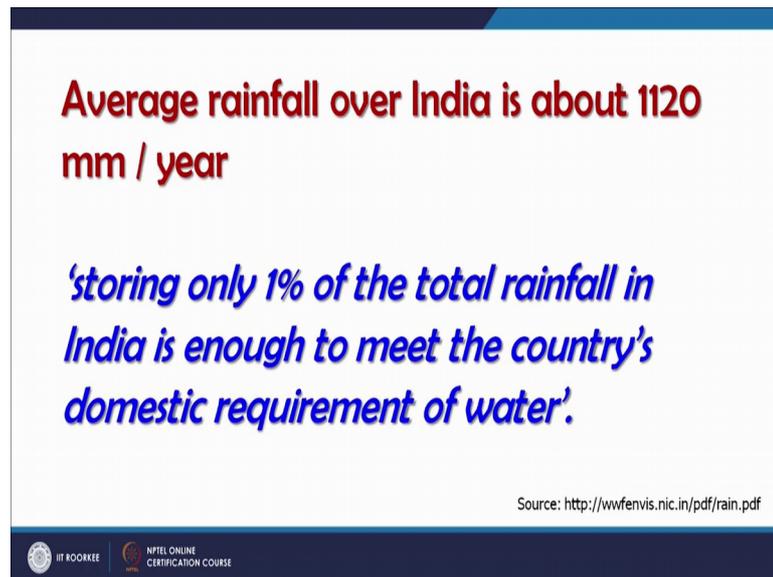
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If we take India in this discussion, then 54 percent of India faces high to extreme high water stresses specially during summer months. As you can see that western part of India is having a big problem. Of course, in the northeast India and eastern part the rain is relatively much more, so and it reaches sometimes earlier. So, they do not have much problem compared to what the western India is having and 50 percent of India's groundwater and wells are decreasing. So, the both percentages are same; that means, that the groundwater is very, very important here.

And again because the scarcity of water in the western part western part of India, the same is here that the and the groundwater would live basically water table in these areas are also going down and down year and after year so that means, the augmentation to a large scale is very much required. But the interesting part here is that average rainfall over India is about 1120 millimetre per year which is not insignificant which is quite good. ah

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**Average rainfall over India is about 1120 mm / year**

*'storing only 1% of the total rainfall in India is enough to meet the country's domestic requirement of water.'*

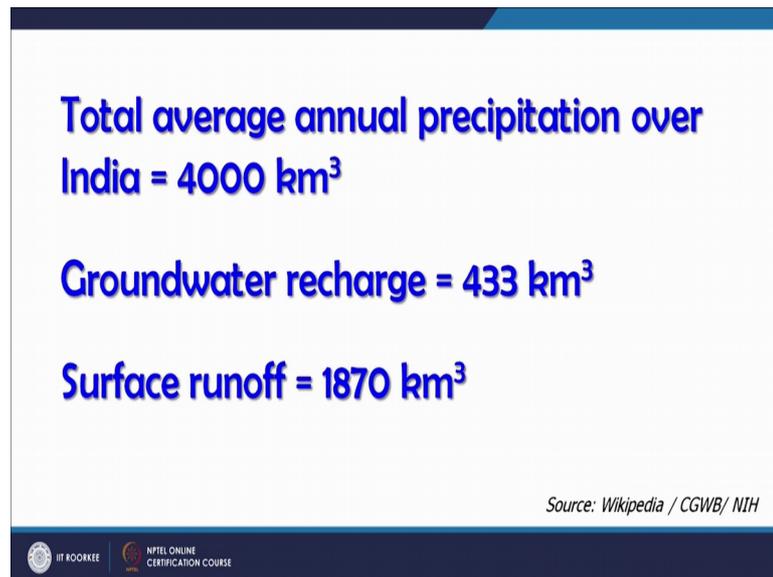
Source: <http://wwfenvs.nic.in/pdf/rain.pdf>

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Just this if we increase just say by 1 percent, the storage of water into the ground water regime why groundwater recharge measures then the domestic requirements of water in the India can be resolved very easily. What I am trying to say is that in average rainfall over India is quite good, it is sufficient. Of course, this distribution is not uniform. And if we increase the storage of groundwater by just 1 percent, we can resolve the groundwater problem.

So, the crisis which we see or the extreme situations which we see in the western part of India in terms of water stress or in terms of lowering water table scenarios can be resolved by just increasing 1 percent of our storage in terms of groundwater. And this can be done very easily by employing these small groundwater recharge structures. And in where groundwater recharge structure can be constructed where what would be the volume which will be stored, how it will influence all these things can be analysed either based on digital elevation model as example I have already shown or incorporating some other information parameters which might be drive from remote sensing data. So, this example we are going to see we will focus on this one.

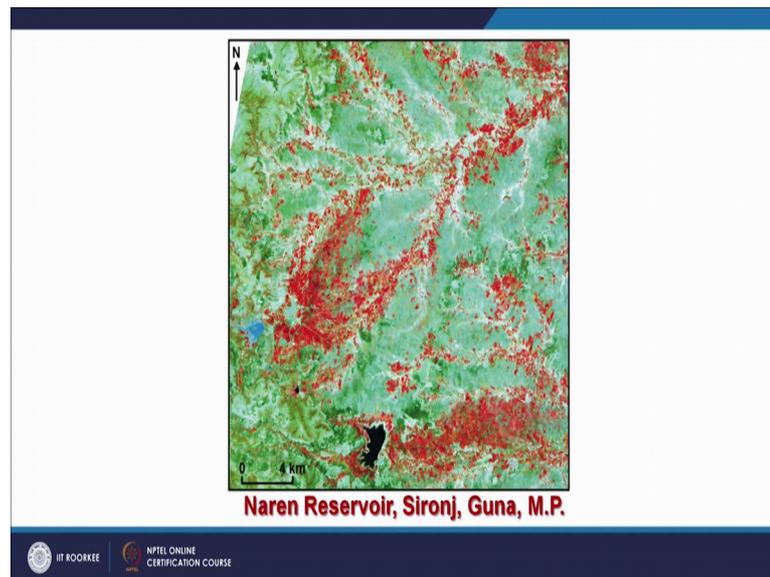
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Another important information here is the total average annual precipitation over India is 4000 cubic kilometre . And groundwater recharge which is a very small amount is going towards the ground water which is 433 cubic kilometre. And the most of the water is flowing as a surface runoff, and ultimately it ends up in the sea. So, we need to store this water before it reaches to the sea. And first it has to be stored initially as a surface water and then let this water should go downward through infiltration percolation processes to the ground water regime or the coffer which are which might be present different parts of the India.

I am going to take an example of a hard rock terrain just how these dam simulations can be used in groundwater related studies. So, for that I have chosen an area which is in hard rock terrain and the basement you are having Bundelkhand granite which is a very hard rock. And the area is almost every year especially in summer months, you are having water stresses problems. However, rainfall is about 900 millimetre per annum in this part of the country. So, 900 is still not bad, but only thing we need to store the water. Example how we can learn from a simple remote sensing or satellite image, and how this learning or knowledge we can imply on the ground while using this dam simulation technique this is how I am going to explain quite quickly here.

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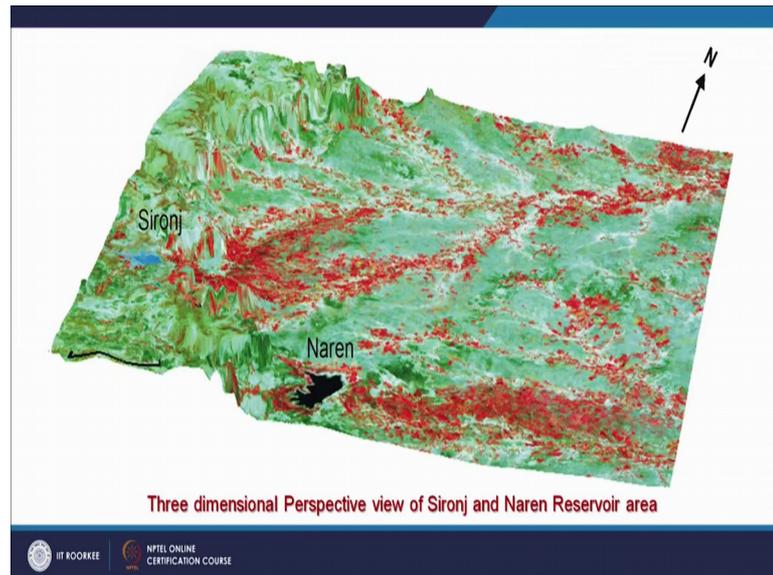


Ah There are two dams or rather three dams which you can observe here. This is a false colour composite image in which the vegetation is appearing as in red. One reservoir you are seeing has a light blue colour; another reservoir you are seeing in a dark or black colour and a very tiny one is also seen here. What you would also observe that downstream of these reservoirs there is a growth of vegetation. Now, this growth of vegetation this vegetation includes the agricultural lands and maybe some natural vegetation which is growing, because in the downstream of these reservoirs there is a availability of groundwater. And that the groundwater and moisture is allowing the growth of vegetation in these areas. Ah

Whereas, where wherever you do not have such reservoirs like here though terrain wise is same topographically is almost same scenario, geologically these are same different rocks, soil types are also same as here. But since we do not have any reservoirs at the these margins as here, and therefore, we do not have much recharge in the downstream areas and you do not have much growth of vegetations. So, what we learn from interpreting this studying, this particular satellite image is that if we want to make this area green or enrich or rich from groundwater point of view then reservoir something like this have to be constructed here, and these will serve as a groundwater recharge structures.

So, what we need a digital elevation model which are available, and need a dam simulation which we can simulate where exactly things will come. And also we can estimate how much time it will take to gro[und] to recharge groundwater regime and that can be that can be estimated through the growth of vegetation in there in the same area, where the same geological and topographical conditions are prevailing.

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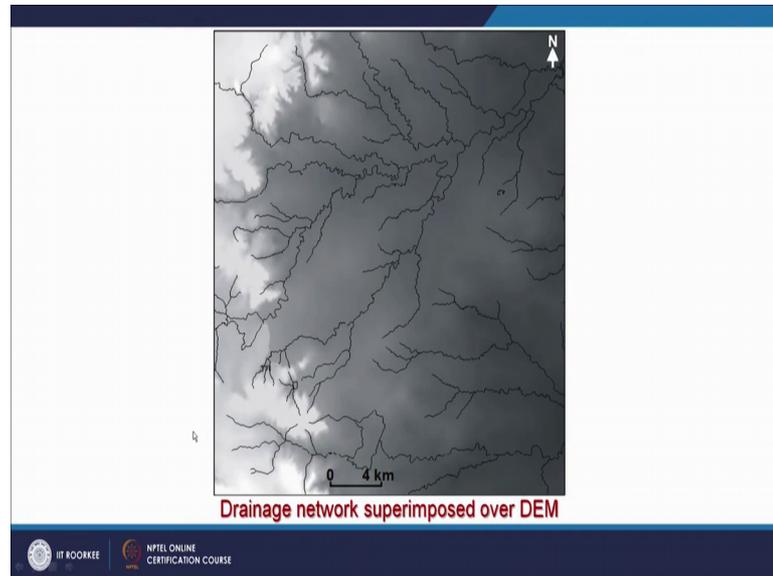


So, let us say let us see that some more differences between these three reservoirs what we are seeing that the reservoir which is named as na Naren reservoir is a having a the benefit area a is a quite large, but not as big as Sironj reservoir. But the size of this reservoir is in less as compared to Naren reservoir; however, it is located on the higher grounds. So, the hydraulic gradient which is being provided by this Sironj reservoir is relatively more as compared to Naren. So, if a if we want that other parts of this area should also become green or the ground waters should made available then the reservoir should be constructed at little higher levels as in case of Sironj. But not at the almost same level as in case of Naren, because this here the hydraulic gradient is not as big as in case of Sironj.

And this, this, so just employing a digital elevation model creating a three d perspective view this has given further knowledge to us that a though though the reservoir may be smaller, but if it is located on higher grounds, then it will provide much better groundwater recharge then a reservoir located on lower ground. So, few things which we

have just learned through the interpreting the satellite image through the interpretation of satellite image, and employing a digital elevation model here, and this thing about the location of the reservoir.

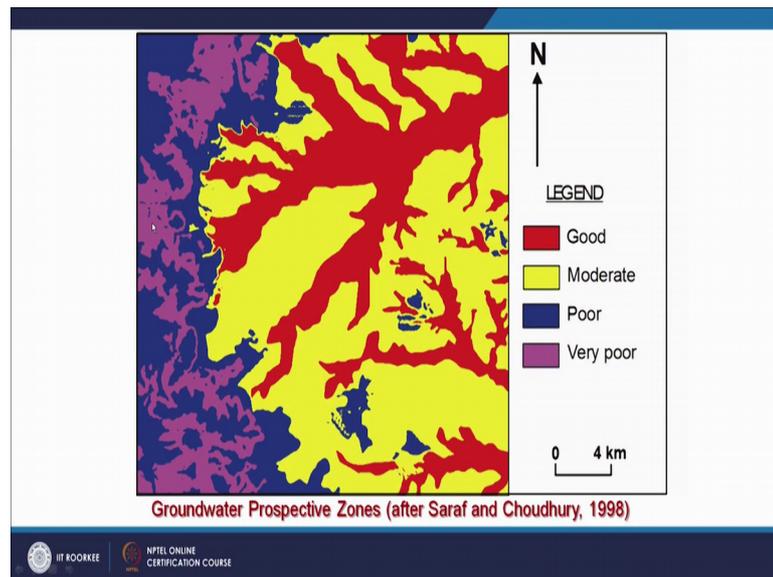
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Now, what this is a the digital elevation model of the same area, where these three reservoirs are there this is Naren, this is smaller one and this is Sironj reservoir what we are seeing here. And a as you can see also in this digital elevation model that the Sironj reservoir is located on relatively higher ground as Naren one. And of course, it is having the drainage network which has been derived from this topographic sheets.

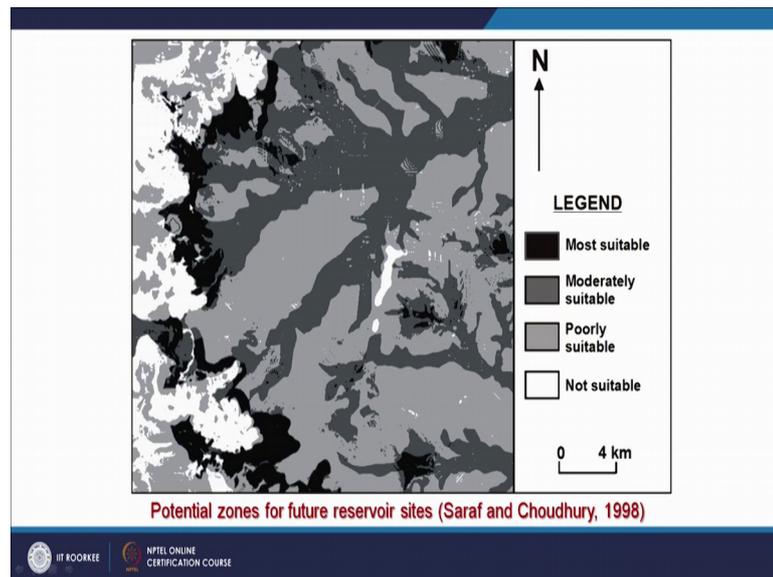
So, implying these things and the knowledge which we gathered integrating on a GIS platform including info including information about soil lithology, and lineaments and other things, we can reach to a output map which is a groundwater prospective zone. So, what here it is telling that if somebody is looking groundwater then these are the area which are suitable for groundwater the red one, and they then yellow one.

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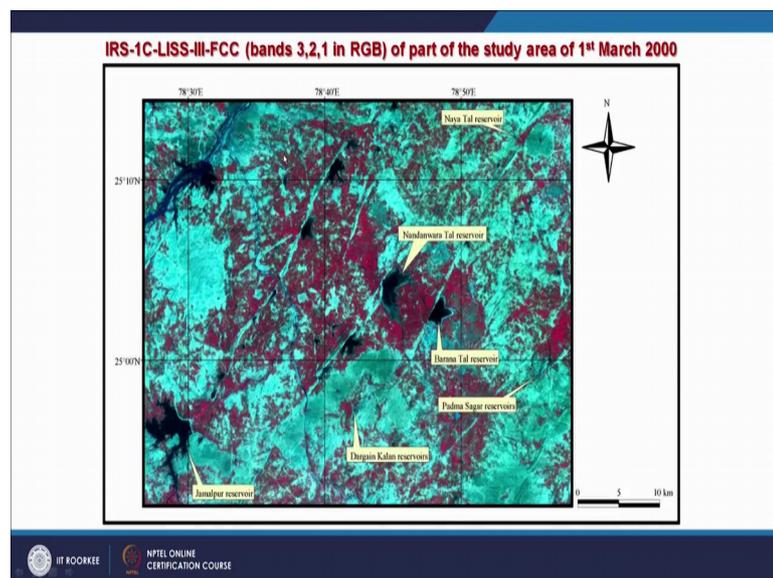
And the higher grounds which are hav[ing] which are having hard rocks and the water set size are very small and you are having either first or second order streams and therefore, there are very poor chances of availability of water. So, using a simple digital elevation model some knowledge which has been derived or interpreted through a a satellite images we can create such products which will tell us the availability of water potential potential availability of water. Second thing is that which are the areas which are which is going which are going to be most suitable for groundwater recharge structures, because if we have to simulate dam everywhere one will not simulate dam. So, we will you would like to know exactly which are the most suitable areas within a study area.

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So, in this study again using the previous knowledge we can we can generate a output that these black areas are showing the most suitable areas for groundwater recharge. These are at the higher grounds learning from Sironj reservoir because of better hydraulic gradient that they should not be located on the almost same level. If we can provide a sufficient hydraulic gradient and also at the same time sufficient upstream catchment. If these two things can be satisfied then these areas becomes more suitable for groundwater recharge.

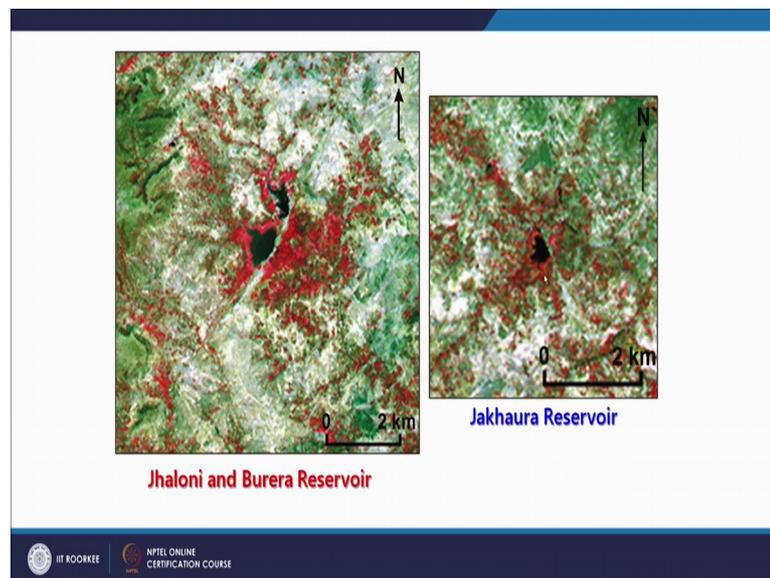
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Now, further understanding one can develop again implying satellite images of the same area of Bundelkhand region is there are the quartz reefs which are you can call them as a natural dam axes running for hundreds of kilometres. And across these quartz reef at places you are having streams which are crossing these. So, in past people knew about the advantages of these quartz reefs, and they plugged these quartz reef at places and created reservoirs.

As you can see in this false colour composite that wherever there are reservoirs you see the growth of vegetation in this false colour composite vegetation will appear as red colour. And wherever you do not have reservoirs like in this area or this area, you do not have any growth of vegetation, so that terrain is dry these quartz reefs are running for hundreds of kilometres, there are still various streams which are not plugged yet. So, we can plug them imply our digital elevation model, use these dam axes, simulate the reservoir size and we can know exactly that how much volume of water it will store, how effective it is going to be, how much time it will take to take effect for the ground water regime. So, all these things can be study by driving a index which I will just discuss. If I take few examples of individual reservoirs, this is the quartz reef.

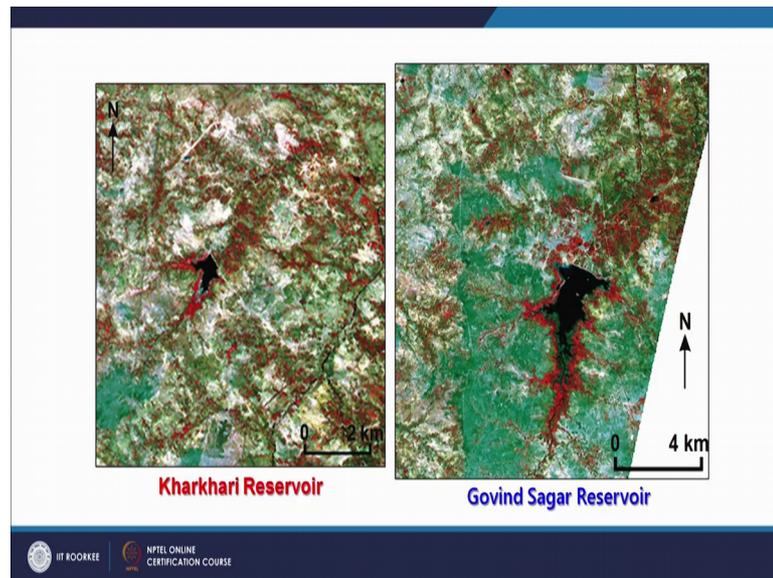
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This is the downstream area. This is towards the southeast direction. And the streams have been plugged reservoirs have been created. So, in the downstream area you are having growth of vegetation as well as in the perime upstream little bit upstream area

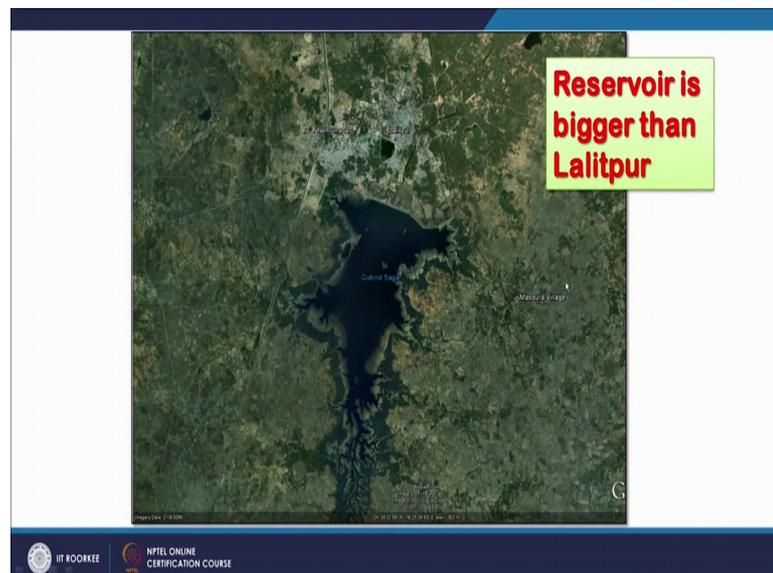
you are having growth of vegetation. Wherever you do not have the water body, you do not have any growth of vegetation. Another example here is the downstream area is in the northeast direction and you are here you are having maximum growth of vegetation around along this reservoir.

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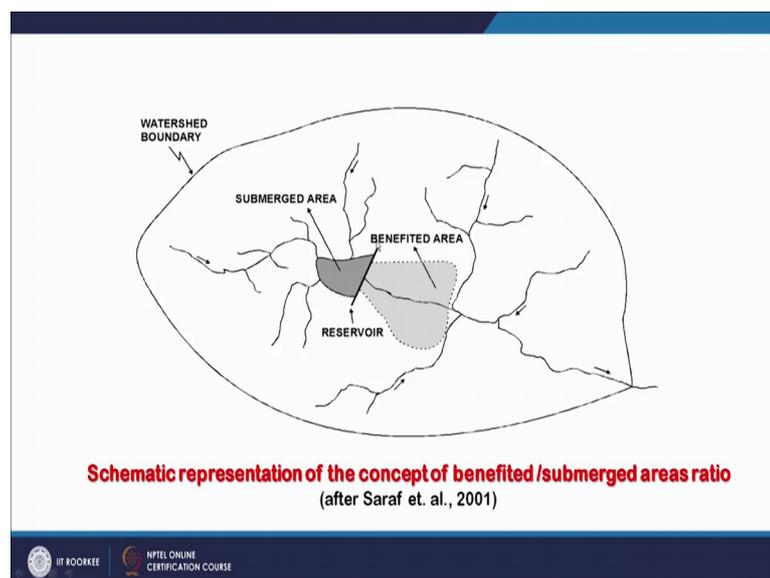
Again this quartz reef is going and in downstream area you are having growth of vegetation that is the what I am calling as a benefit area. Again one more reservoir here is Govind Sagar reservoir.

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ah This is interesting is here that see the size of this place is Lalitpur which is incidentally my hometown, and is the size of the reservoir. This was constructed about 50 years back or maybe more. At that time, the water supply to this small town at that time it was a small town was 24 hours. But as town grown the requirements of water has increased, but our size of reservoir has not increased and therefore, water supply reduced to roughly 2 hours per day. So, that what it is telling basically that in this part of the country when the terrain conditions are like that hard rock terrain, then in order to supply water, you need a bigger reservoir or maybe series of reservoir, maybe cascading reservoirs to provide water maybe 24 hours as it was in the past. Because town is growing your water storage has not grown in that proportion, and therefore, the water scarcity is there. But at the same time, the rainfall is available.

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So, if we want to derive some index or indices then as I have been mentioning that a upstream of this reservoir dam we can call as a submerged area and downstream of this reservoir where which we can delineate based on the growth of vegetation, we can call as a benefit area. And we can create a ratio between benefit area and submerged area and can estimate can predict that what would happen if a reservoir is constructed in that particular area.

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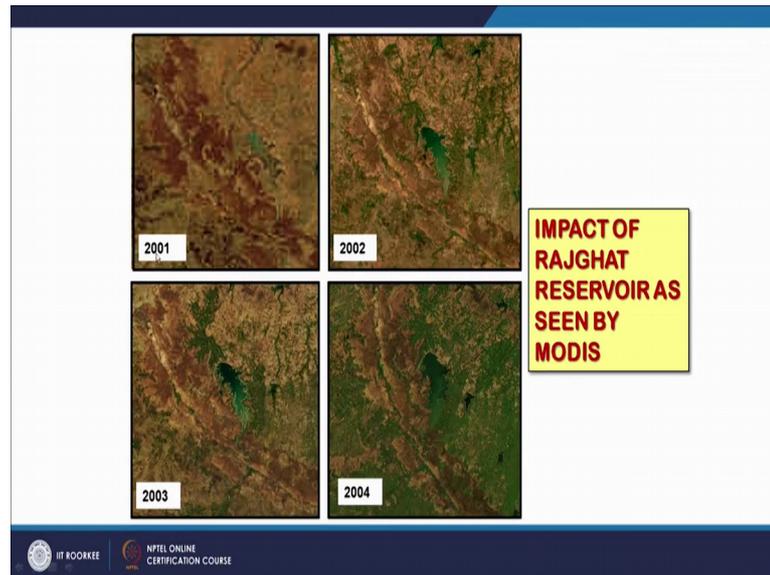
Name of the Reservoir	Benefited area (km <sup>2</sup> )	Submerged area (km <sup>2</sup> )	Benefited / Submerged area ratio
Chanderi Reservoir	15.78	0.56	28.18
Jakhaura Reservoir	8.4	0.3	28.00
Padma Sagar Reservoir	19.89	0.76	26.17
Kharkhari Reservoir	19.5	0.8	24.3
Naya Tal Reservoir	2.67	0.15	17.80
Gwal Sagar Reservoir	2.87	0.17	16.88
Phutwar Talab Reservoir	13.78	1.07	12.88
Ghisauli Tal Reservoir	2.53	0.21	12.05
Dargain Kulan Reservoir	2.62	0.23	11.39
Sironj Reservoir	31.7	2.8	11.32
Bikampur Reservoir	3.68	0.35	10.51
Nanawa Tal Reservoir	3.04	0.29	10.48
Silbi Sagar Reservoir	4.41	0.46	9.59
Nazari Reservoir	41.2	5.3	7.77
Pawa Tal Reservoir	4.32	0.65	6.63
Govind Sagar Reservoir	147.28	22.63	6.51
Nagda Tal Reservoir	15.27	2.41	6.34
Palwara Reservoir	6.49	1.04	6.24
Rannagar Reservoir	3.8	0.71	5.35
Nandanwara Tal Reservoir	53.04	10.08	5.26
Nagda Sagar Reservoir	27.95	6.44	4.34
Barana Tal Reservoir	25.48	6.38	3.99
Kharkhari Reservoir	6.53	2.03	3.22
Barera / Jhaloni Tal Reservoir	4.60	1.59	2.89
Janapal Reservoir	13.92	20.96	0.66

**Benefited area, submerged area and the ratio between benefited and submerged area of the reservoirs**

And by doing this thing and studying various these reservoirs which were present in this hard rock terrain, we can see that like in case of this a Chanderi reservoir it though is size wise not very big, but it is providing benefits versus submerged ratio is 28 times. What it means basically that a if I submerged or invest one square kilometre of land towards the construction of reservoir in this particular area, then I am going to have 28 times benefit area. So, my returns are going to be 28 times it is a very good investment.

However, there is one example where a reverse scenario is also possible that benefit area this submerged area is more benefit area is less and therefore, my ratio is less than 1. So, these areas may not be used immediately for the groundwater recharge or to augment the groundwater recharge. But the areas surrounding these areas where my returns are in the range of 28 times, 26 times, 24 times can be used immediately locate where dam ax dam can be constructed and before that dam can be simulated over a dm on a GIS platform. How quickly the effect takes place and that can be reflected or measured or seen through satellite images one of the example here though reservoir is larger.

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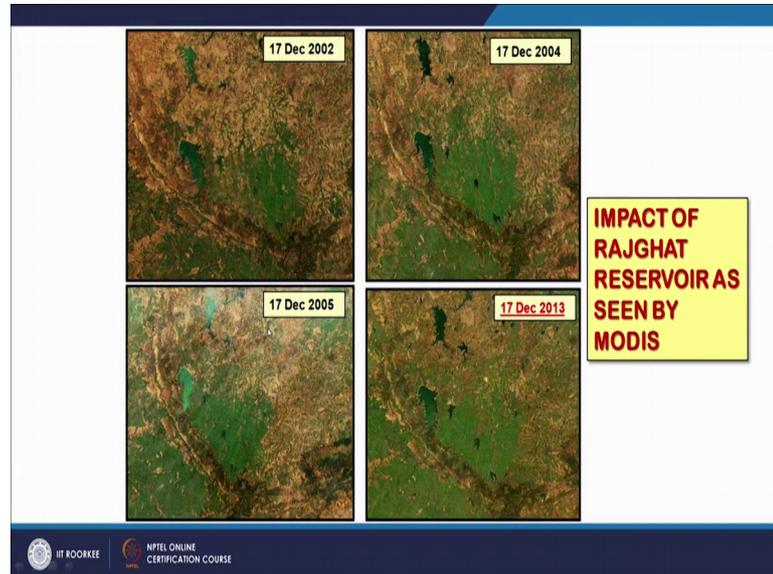
What we are seeing here is a 2001 image, 2002 image, 3 and 4. Reservoir was under construction it was a quite big reservoir, multipurpose reservoir means hydropower irrigation, lift irrigation and of course, indirectly it is providing groundwater recharge as well as you can see here. So, as reservoir was started reservoir started filling in 2001 this is the scenario in 2002 again in 2003 and 4, what you start seeing the growth of vegetation. Just compare 2001 and 2003 and compare 2001 and 2004.

So, this entire area became almost green just in 3 years time, because the aquifers are unconfined here. So, you impound the water on surface it because it remains mainly in the unconfined aquifers, because these are the hard rock terrain especially the granite Bundelkhand granite or nice a complex. And the only top part is having some fractures or some weathered zones where water groundwater is stored and that is why you that water does not remain very long and few months of summer are difficult time.

So, if we construct reservoirs a small, small or large reservoirs in that area and then in few years time just two, three years time, the effects will come through the growth of vegetation because ultimately when you are impounding water it is going also towards downstream in in the towards the ground water regime. The charging ground water regime that water is becoming available in downstream area and other parts; and ultimately it is bringing growth of vegetation either through agriculture practices or a natural growth of vegetation. Somebody might have argued with this previous slide that

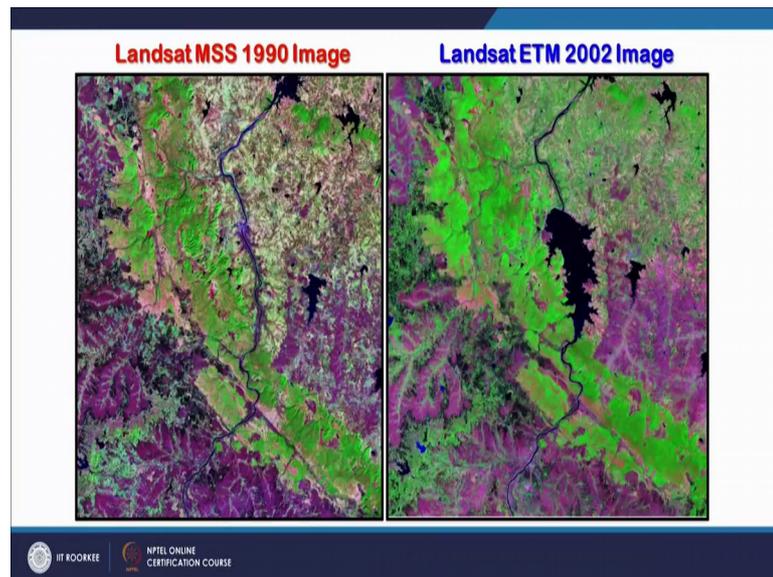
there might be you know some play that the date or months are not constant. So, one 2001 which is shown may be a pre monsoon, 2004 might be post monsoon.

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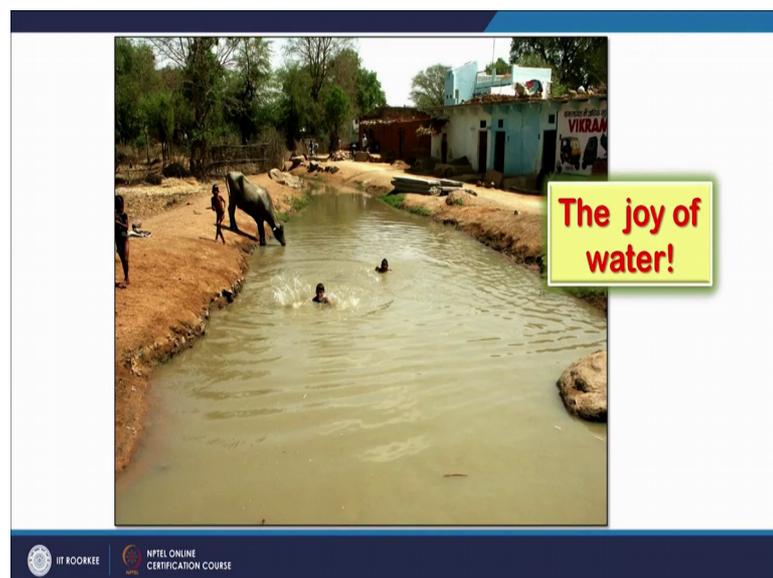
So, in order to clear that doubt I have specially selected four images of the same date of different years which were cloud free. And as you can see that in 2002, this reservoir got completely filled, and this is the effect that. In 2013, this is the scenario; just compare 2002. So, in this time series remote sensing data can allow us to know that how much time would take to get this benefit in a particular area. So, you know that one way is you know that if I investment of the land in that is the ratio benefit versus submerged. And here is the time also can also be estimated how much time I would get the returns. So, how much return I can estimate, how much time it will require to get those kind of returns can also be estimated here.

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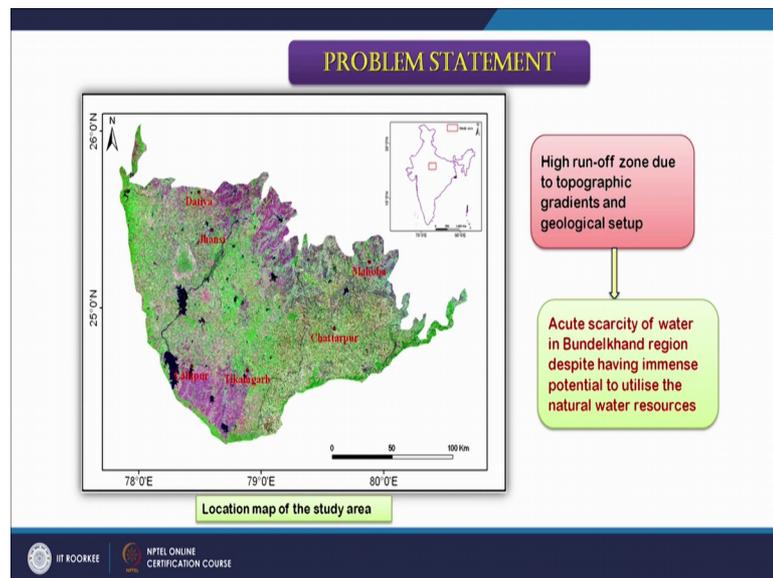
Same example here that in the year 1990 this was the scenario and in the year 2002 this is the. So, in 1990 there were no signs of this reservoir the Raj Ghat dam or Rani Laxmibhai reservoir. But in 2002 it is there just see that this is a true colour image and see the green. And especially in the downstream area in this in a big region, because it is a multipurpose reservoir. So, you are having irrigation through canals, you are having irrigation through lift irrigation and of course, groundwater recharge as you can see here. And this is the benefit of water.

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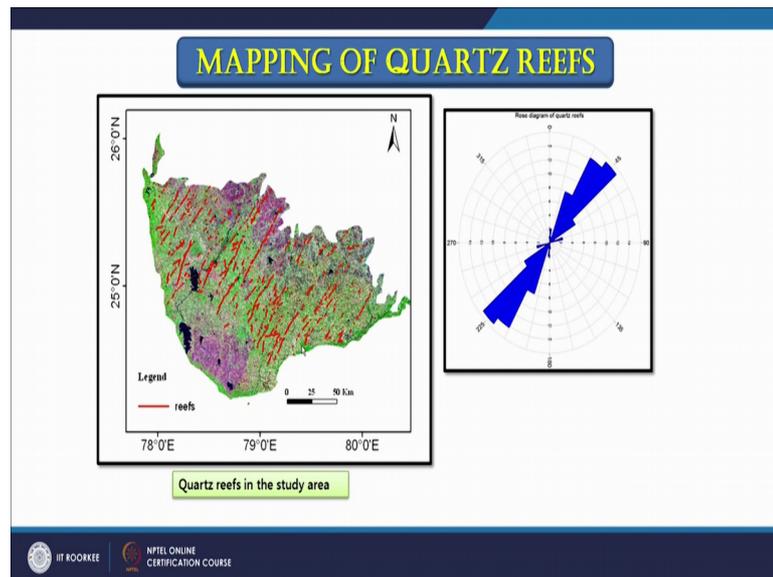
This is the joy of water in the area where water is was scare, but because of construction of these reservoirs especially these canals which are completely unlined canal, they are recharging the ground water regime as you can see in the surroundings you are having growth of vegetation. In just few years time you will have vegetation growing all over the area. Now, I take again we go back to that dam simulation, how exactly we can now exploit that tool or that benefit of a digital elevation model derivative and taken the example in the same area as we have been discussing.

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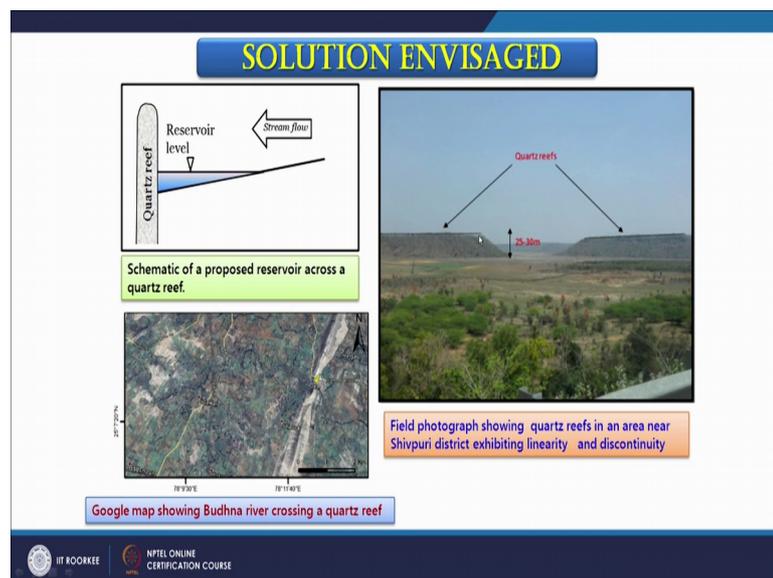
These are these two reservoirs especially the Raj Ghat we have already discussed. So, the what we can do here is a because this Bundelkhand granite is having tens of or hundreds of these quartz reefs.

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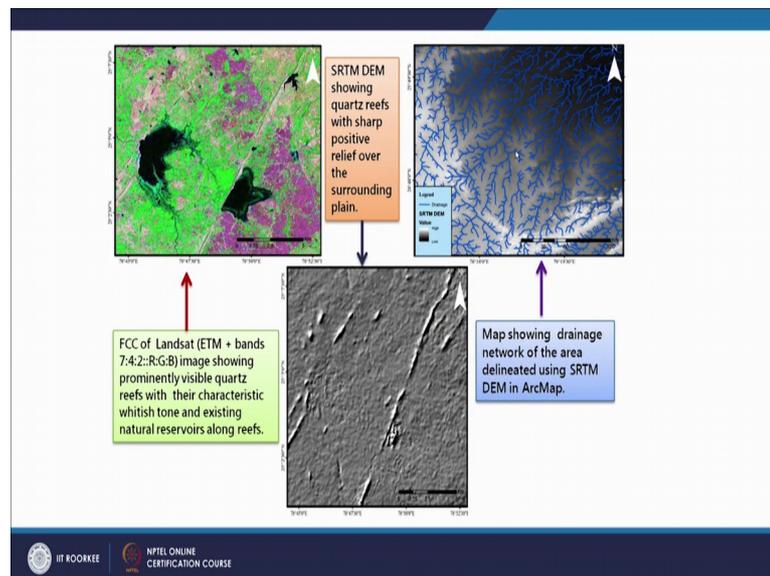
Which are serving as a as a dam axes, can serve as a dam axes. Already serving for few dams which are there in past people have constructed. And these quartz reefs are running roughly east-west, sorry northeast, southwest direction which have been delineated using satellite images as you can see these red lines. And these can serve as a these are the general directions of these quartz reefs. And the major drainage is going from southeast direction towards the northwest direction. So, this is that means, they are perpendicular to each other and that can be exploited very easily.

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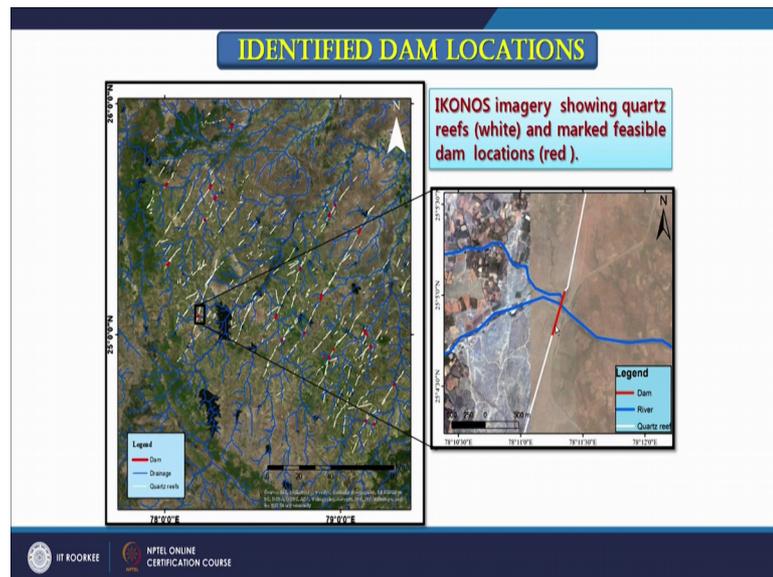
So, this is the scenario here in a through a schematic. Suppose, this quartz reef quartz reef can serve as a dam axes, if I fill with water this is what the scenario I can have. And as a one quartz reef here in this example has been identified based on the Google satellite images study based on that study we have identified there can be many such locations and we can simulate a dam. So, this is the ground scenario, this is how this quartz reefs which are about 25 to 30 metre height relative to that ground and a stream is going across this. So, if we plug this one then in upstream, we can have a reservoir.

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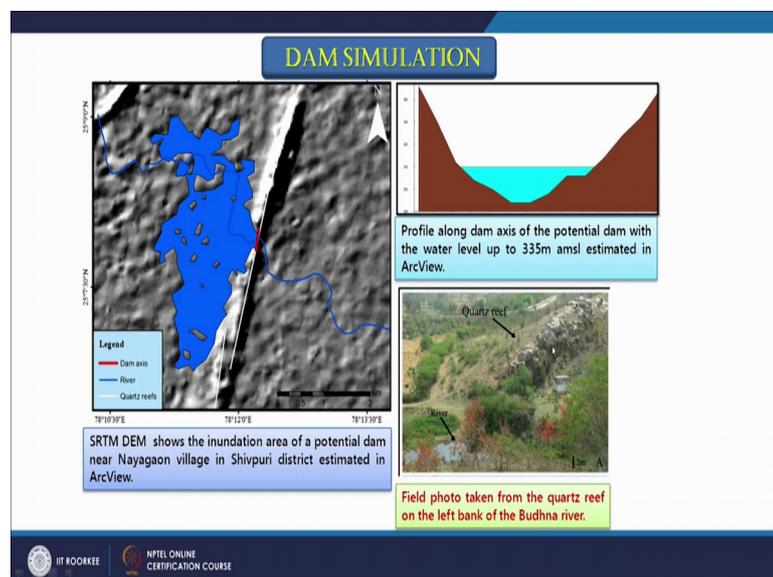
Like these have been done in past. So, we can this is a shaded relief model of that part; drainage lines can be identified again can be derived from surface hydrologic modelling.

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And we take example here and this is the scenario that quartz reef is running like this and this is the dam axes proposed dam axes for simulations. And we can simulate that how where how much area it will if we fix some height.

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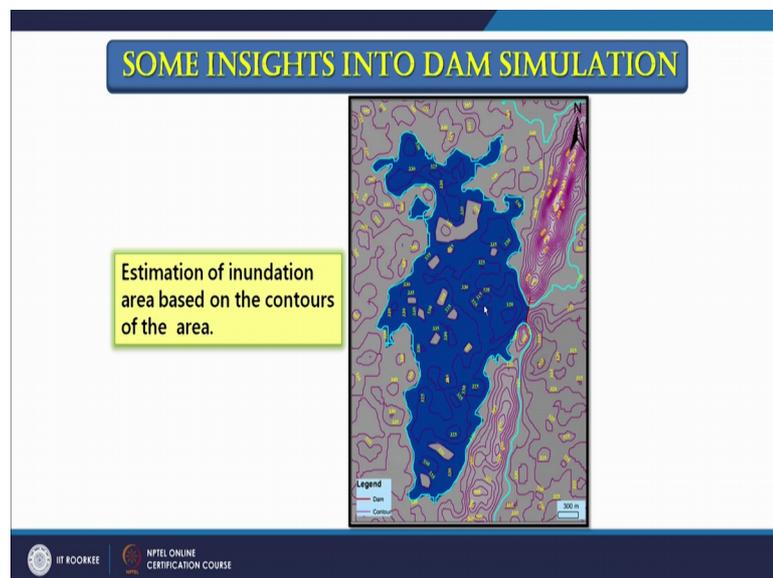


And then this is the scenario . So, this dam simulation which we have just discussed using a digital elevation model on a GIS platform can give us four locations of small reservoirs which can be used directly for groundwater recharge. And the dam axes is a nature has already created in form of quartz reefs which are 20 or 30 meter height. So, if

we put this dam axes plug that stream along this dam axes or quartz reef, a reservoir can be constructed very quickly.

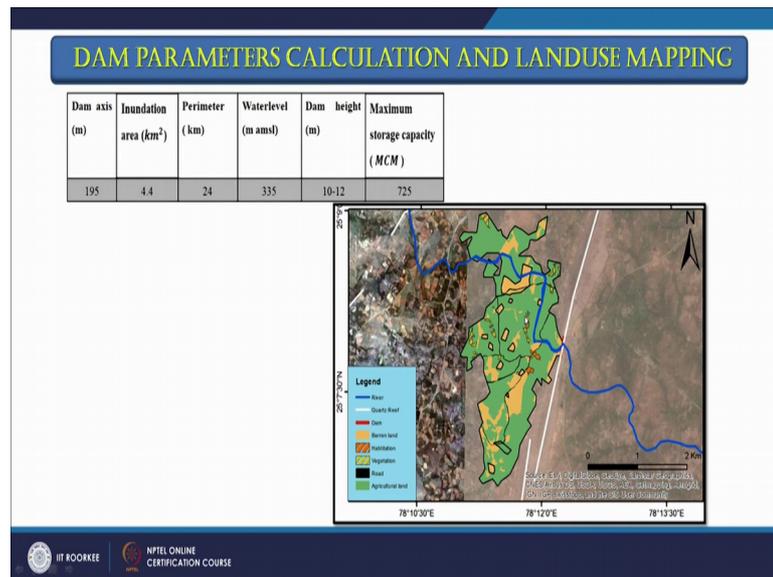
Also one can see thus the cross section or profile along this dam axes still if we one want one can increase the height that means, the inundated area will increase the volume will increase, but whether that is required whether that would be beneficial all these things can be assessed before anything is really constructed on the ground. As a field photographs shows that this is the situation of the quartz reef, and this is the water or river which is flowing or going across this stream; only thing it is required it has to be flagged only one bank is shown here, the other side is not in this photograph.

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And also you can get about this estimation how inundations will occur at different water level in the reservoir.

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Also employing the satellite images one can estimate what is which are different land uses which will submerge if a reservoir is constructed here. And if it can be shifted, if it is required then those things can also be done quite easily as here shown in this particular example. Remember this thing nothing has been constructed on the reservoir. And this is the best example of modelling or simulation what inputs we are having a simple digital elevation model. In this case, we may require relatively higher spatial resolution digital elevation model may be 30 meter or 10 metre digital elevation model and and the satellite images to estimate to predict many things which might happen in that particular area especially focusing towards the groundwater recharge studies.

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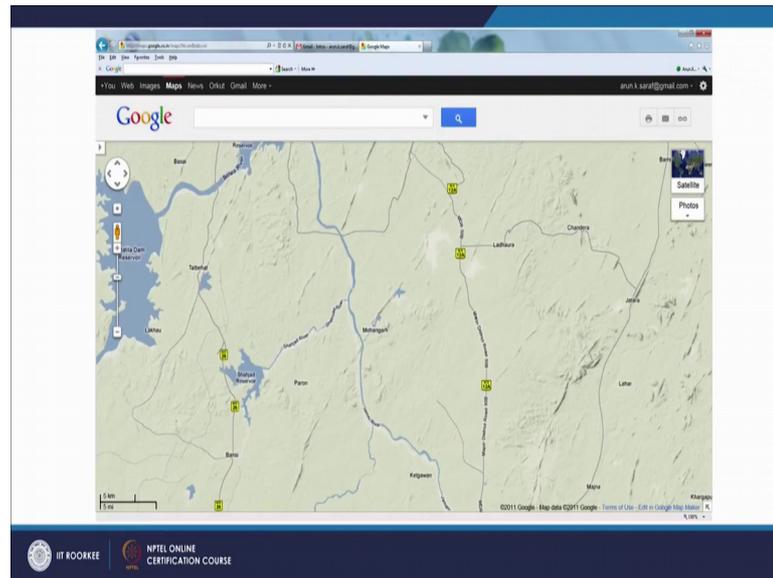
**Possibilities**

- ✓ **Identification of suitable sites for water harvesting made easy using Geoinformatics**
- ✓ **Preliminary assessment of impacts of reservoir before construction of such projects**
- ✓ **Simple solutions with local people and local materials**

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So, what are these are the possibilities that we can identify suitable sites for water harvesting and using this digital elevation model and remote sensing inputs on a GIS platform and preliminary assessment of impact of reservoir before construction of such projects. So, by looking the surroundings interpreting site satellite images, we can predict that how much time it would take to take effects of these groundwater restructures towards groundwater regimes through growth of vegetation. And simple solutions are possible as a shown in or discussed in this lecture with the local people and local materials which are available. Nature has created few things like dam axes in that particular part of the country only thing is this required the identification of suitable sites a simulation, and then the construction on the ground.

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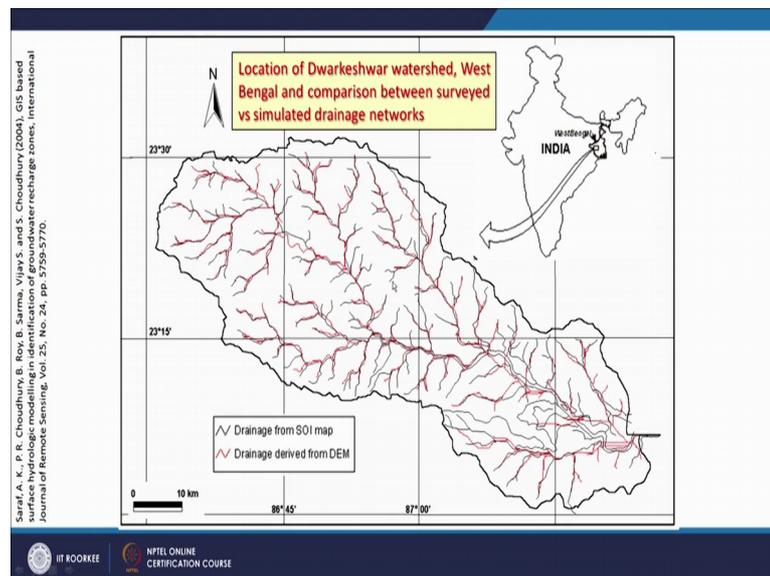
One can use simply the Google map in which this terrain information in form of shaded relief model is there also the locations of streams are there. And you know exactly where dam can be like, for example, here quartz reef is running from northeast to southwest direction, this part is going this river is going unplugged. So, if we can plug that one a reservoir can be constructed very easily. So, the data is available, techniques are available only thing is that it is required the things to be implemented on the ground. And then we can augment the ground water regime through these measures though the rainfall remember this we have a discussion about the rainfall is quite sufficient, it is not bad too bad. So, rainfall is there terrain is very suitable for such ground water measures; only thing it is required to cons for the constructions.

And there are some other ways of employing and very quickly I would like to go again this is based on digital elevation model as we have seen that we can simulate or we can derive the drainage network. So, what a what we have done is a remember that we have discussed that in surface hydrologic modelling, one major assumption is that each drop of water has to flow on the surface. And, so this is that means, there is there are no losses either to ground water or to atmosphere and that means, there is no losses in form of evapotranspiration or neither infiltration or percolation .

But this is the simulated drainage that means, the drainage network which we are deriving based on surface hydrologic modelling using a digital elevation model in a GIS

platform. But natural drainage which we can extract through topographic maps will have some differences, because natural drainage is the real location of drainage present on the surface. Whereas, the simulated drainage will have some mismatches and this mismatch we have exploited. So, this surface hydrologic modelling based on DM and the drainage network coming from drainage from topographic maps have been exploited again targeting the ground water towards groundwater studies to locate which are the areas in a particular watershed are suitable for groundwater recharge.

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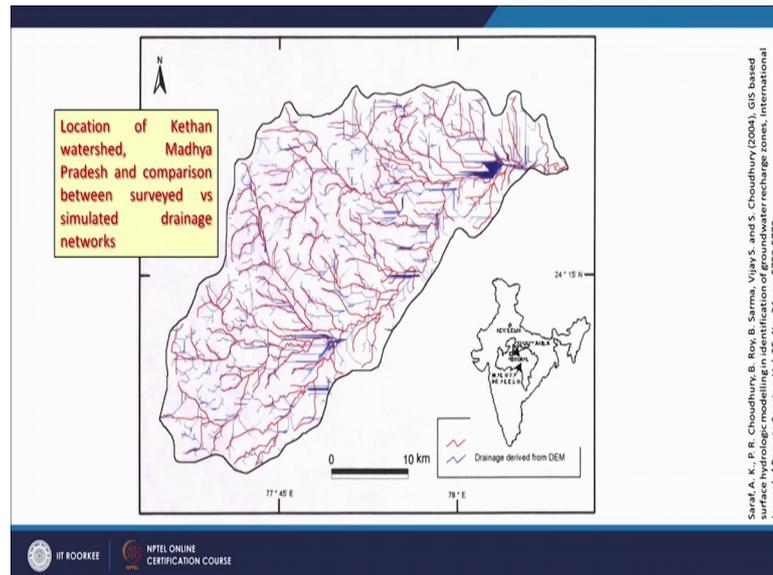


One example from West Bengal of Bankura district. What we see here in the background is the black colour drainage network which you are seeing is the drainage which has been digitized using survey of India Topo sheets of 50,000 scale. And over which the red colour one which you are seeing is the simulated drainage based on surface hydrologic modelling because the assumption there is the water has to flow on the surface, but in natural drainage that assumption is not there. And therefore, there is likelihood that there might be if we assume that loss to atmosphere remain in a small watershed remain uniform, then whatever the losses which are occurring are due to towards for because of groundwater recharge.

And therefore, this would be some mismatches. And this is what we have observed in this particular example that in the upstream part this is all hard rock terrain. The natural drainage is following what the model drainages or simulated drainage that means, there

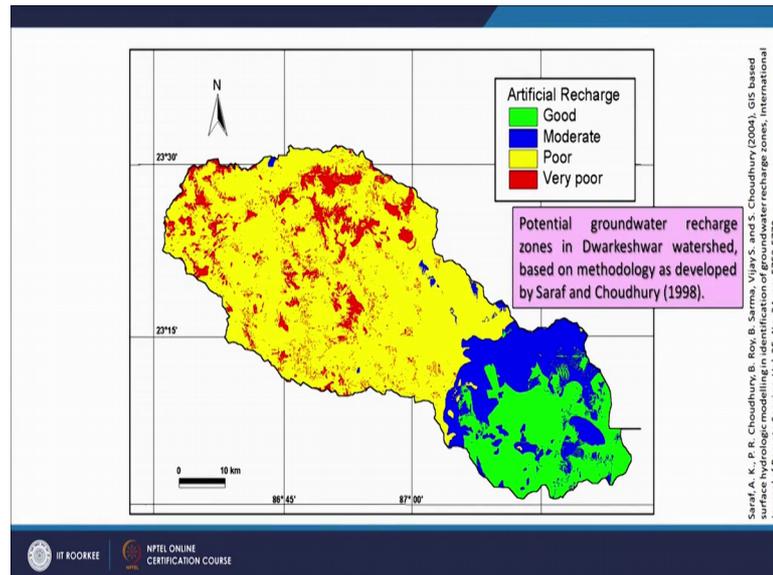
is no loss of water towards the groundwater regime. Whereas in the downstream area there are a large mismatches and that means, the water is not following the natural drainage is not following the model one and that means, there is a loss to the groundwater. And in fact, this loss we can picked up for the sites suitable for groundwater recharge locations. So, these are the sites which may be.

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Another example here when we overlay these two this simulated drainage and natural drainage the mismatches can be identified very easily. And wherever the mismatches; that means, blessing in disguise where are the mismatches, we can exploit those mismatches and find and the these are the probably the suitable sites for groundwater recharge.

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And this independently this was created without involving the drainage and this is what was seen that in this part these are not suitable for any groundwater recharge structures. Whereas, this blue or green parts are most suitable where we have observed that the drainage simulated drainage and your natural drainage had the maximum mismatch. So, likewise employing a surface hydrologic modelling and a DM we can get such analysis very quickly. So, there is an overall there is a need to develop a benefits submerge ratio that index for different parts of different regions of the country.

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### Remarks

- There is a need to develop benefit / submerged area ratio for different regions of the country
- Water harvesting know-how is available only implementation at ground level is required
- Identification of suitable sites for water harvesting
- Preliminary assessment of impacts of reservoir before construction of such projects
- Simple solutions with local people and local materials

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So, we know exactly how much land I have to invest for such structures, how what benefit I will get in the downstream or the vicinity of a reservoir future reservoir. And a water harvesting and know-how is available that we know only thing it has to be implemented on the ground. We can identify suitable sites for water harvesting or groundwater recharge. And a preliminary assessment of reservoirs can be done through on GIS platform using the surface hydrologic modelling and your digital elevation models and satellite images.

And they this is the repeat the simple solutions with local people and local materials; that means, we started with if we increase 1 percent of groundwater storage, we can solve the problem of groundwater in this country especially in those area where water is a big problem. And by im by implementing such a understanding or such studies as possible as shown through this discussion then it is very easy in just few years time we can bring addition of 1 percent of ground water into our ground water regime. So, this brings to the end of this discussion.

Thank you very much.