Geographic Information Systems

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Lecture-34
Concept of Digital Elevation Model [DEM] and How It Is Represented

Hello everyone! and welcome to this discussion which is going to be about digital elevation models. And how it is represented in a form of raster in GIS? And before that I would like to mention that so far, our journey in this course has been about what is basically GIS, different types of data which we handle in GIS; spatial, non-spatial, different types of spatial data and different types of attributes as well.

And then we have also discussed analysis and projection systems and other components or other you know, processing of GIS. Now we are going for, I would say another type of processing which would be mainly focused on raster data and especially digital elevation models. So, how digital elevation models can be exploited? Because we know that digital elevation models are a storehouse of information. And theoretically I would say n number of derivatives can be derived but more than 20 or 25 derivatives which we are going to discuss in future discussion basically will be using digital elevation models.

So, that is why it is very important at this stage to understand fully what is digital elevation model? And then of course, we will start utilizing digital elevation models. Different digital elevation models of different resolutions generated from different techniques of different resources or downloaded from different sources or we can generate our own. So, those things will come little later but first the concept of basically digital elevation model.

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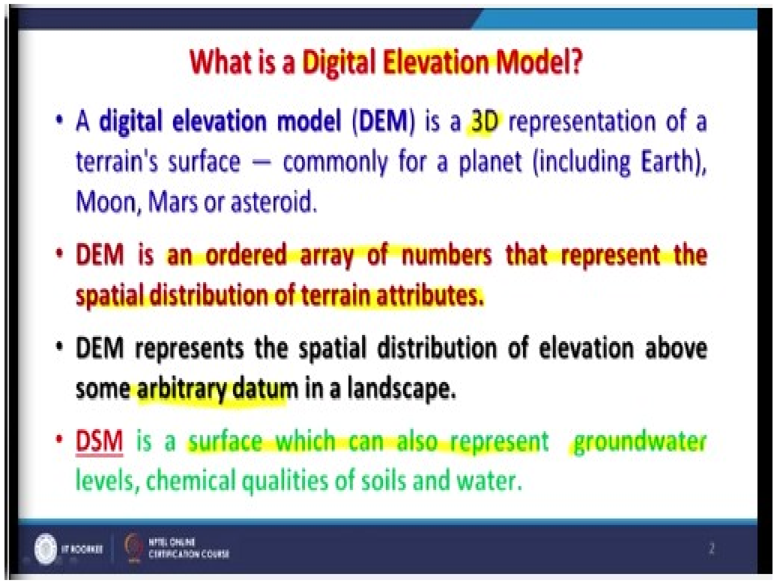

As 3 terms; the digital, elevation and model. So, it is a model. It is not a real world; this one has to remember. And it is in digital form and generally we keep cell value as an elevation value and therefore we call or give a general name that is digital elevation model. But the value of this instead of elevation, we can have some other values also; concentration of certain elements in case of soil or water or pH value or a population value or any other value, we can have in place of elevation.

But like in literature or in software also, everything will be handled as a digital elevation model, though that the middle term is not elevation, this cell value can be any other value. So, it is a basically a 3D representation because though we display 2D but the third dimension is coming from the cell value. So, if it is having the elevation value then we can exploit that elevation value to create a 3D representation of terrain surface otherwise terrain surface would look like flat so with different shades of grays.

Like if you display a contour map, you do not see a 3D perception or 3D representation. What you see just contour lines having different values, may be having different colours. So, in order to represent a terrain in a 3D, we employ digital elevation model that is the first application of this. But there are many-2 derivatives where this concept of digital elevation model can be exploited for many-2 things.

Now as you know that since 1972 onward for the earth, we have been satellites of various countries of various types having various resolutions. And SPOT satellite of France, when it was launched that was the beginning of using satellite images or stereo pairs to create digital elevation models employing this photogrammetric technique. And after that continuously world over, we have been using satellite images mostly nowadays to generate a digital elevation model.

And digital elevation models at different spatial resolutions have been generated so far for the earth. But similarly digital elevation model for moon, mars and asteroids have also been generated. And these digital elevation models of moon and mars, you can see on google earth or some other portals where you can very clearly see. In google earth and especially when instead of not google moon or mars, when we see google earth then in the background from there, we get the elevation value.

Though we do not see directly on a screen except when we use the 3D perspective view or fly through. Then we see terrain representation in 3D, otherwise in the background when we want to see the height of a point or a location on the surface of the earth that information is coming from digital elevation model. So, many-2 places now are playing very-2 important role and lot of applications nowadays are based on digital elevation models.

So, in next say 10-12 lectures discussions, we are going to mainly focus on digital elevation models, how they are generated and what are their different derivatives and how those derivatives can be employed? Including we will also be discussing surface hydrologic modeling using digital elevation model in GIS. As you know that DEM is a raster data so it is a basically an ordered array of numbers or a 2-Dimensional matrix that represent the spatial distribution of terrain attributes.

And here what is terrain attribute, is generally we put elevation but as I have mentioned any other attribute can also be used to create a 3D perspective. Now in short, we say DEM or in plural, we can say DEMs represents basically the spatial distribution of elevation above arbitrary datum in a landscape. Now this arbitrary datum generally is not really arbitrary. Generally, when we use the elevation values as cell values over this 2-Dimensional array then this is not an arbitrary datum. Then it becomes above mean sea level.

But in case of some other concentration or water table in a subsurface condition or maybe concentration of certain elements in soil or water or pH value or similar things then we use this arbitrary datum. Otherwise for typical elevation purposes, it is not an arbitrary, this is above mean sea level. Now there are 2 other terms which are now also coming in our discussion or in literature or in softwares. After this DEM, there is another term which is called DSM. So, DSM is basically a digital surface model.

So, here elevation word has been replaced by the surface that means it is only representing whatever is present on surface. So, DSM by definition is a surface which can also represent ground water levels, chemical qualities of soils or water. So, when you do not have the cell value as elevation, instead you are having some other values then you can also call a DSM. But the most popular and common term is of course DEM. So, basically when we say DEM is the most common digital data of the shape of the earth surface.

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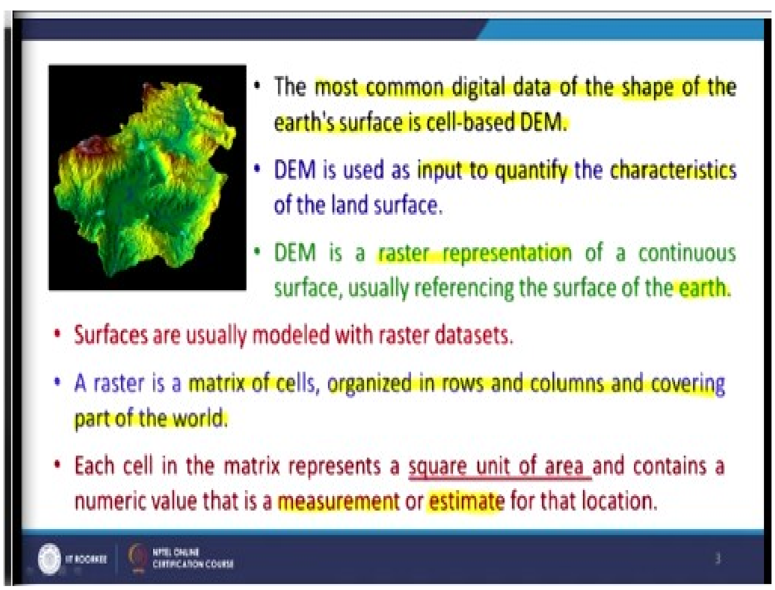

And the shape, this is the important; shape of the earth surface is the cell-based DEM or raster data. Now DEM is used as input to quantify the characteristics of the land surface and what are those characteristics? We start narrating; these are like slope, aspect and gradients and drainage network, watershed boundary and so many other characteristics are there.

So, these are the characteristics of the land surface. And the purpose here is to quantify the characteristics because it is a digital elevation model and therefore the analysis which we do employing digital elevation model is quantitative analysis, not really a qualitative analysis. And as we also know that this has been discussed earlier also that DEM is a raster representation which is a continuous surface.

And usually reference to the surface of the earth when we are doing work for the surface of the earth. But nowadays people have started working on surface of the moon and mars so instead of that this can be replaced by the mars or moon. Now as we know that the surface of the earth is usually modeled with raster datasets because the surface of the earth having a continuous characteristic.

And like for example, one part of land or continent ends then sea comes then when sea ends the land comes. So, therefore all around the globe, it is continuous so that is why raster is the best way to represent that surface of the earth. And as you know that say basically matrix of the cell organized in rows and columns and covering parts of the world. So, when we discuss raster that time also, the similar discussion has come but just for completeness, I am repeating some parts so that when we really go for the digital elevation and it is applications, we must understand everything.

Now also as you know that the unit of raster is always square. And it contains a numeric value that is measured by or estimate for that location. So, if we are employing say satellite images to generate digital elevation model then that value is estimated.

But if we can go on every cell of the grid and can do the measurements then that will be the measurement. So generally, these surfaces which we are using as DEM or DSM, they are representing estimated values for each cell. Like if I am having point data when I submit for interpolations, it creates surface that is a raster surface. And except for those locations where I am having observations or measurement, otherwise all are estimates or predicted value through interpolation. Now this data I have been showing earlier, this is example data. A digital elevation model when it is represented in form of gray.

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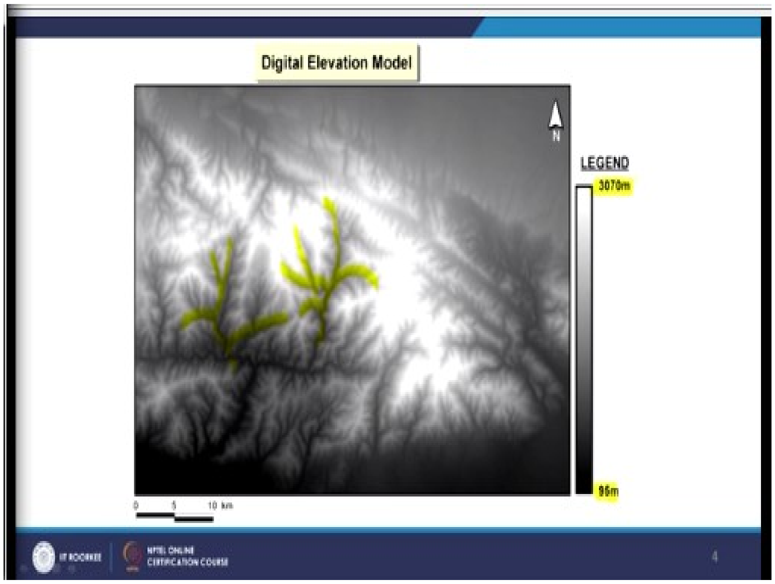

This is how you see that generally the practice is the higher values will have lighter shades or white color or darker values will have a dark gray shade or black color and in between rest of the values are varying. So, if I observe this digital elevation model then very simply, I can say that the minimum elevation within this area of digital elevation model which is being displayed is 95 meter and maximum is 3070.

Also, if I start studying this one then I find that probably these are the drainage systems; natural drainage or stream network which I am seeing quite clearly. So, when you display like this, of course you can also bring colours as well. But generally, in default most of the softwares whenever the first time you display digital elevation model, it would be displayed as a continuous and the minimum and maximum value you can see as well as it will come in gray colour. So, you say most of the time this is the scenario.

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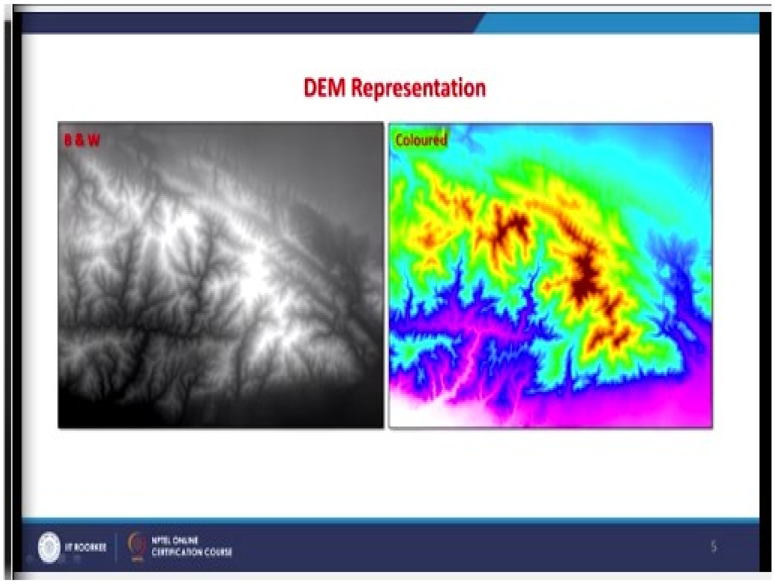

Now as I have said instead of using a gray palette or grey scale, you can use a coloured scale as well, no issue. Remember that colours do not matter. What really matters the cell value or value of the data, whether it is a point, line, polygon or a cell or pixel of a raster. So, this basically the value and now instead of assigning values between black and white and rest are in grey, I can assign values in terms of colours. And if I do it, this is how I get the results. So, sometimes we represent these surfaces in simple gray scales or may be used colours also.

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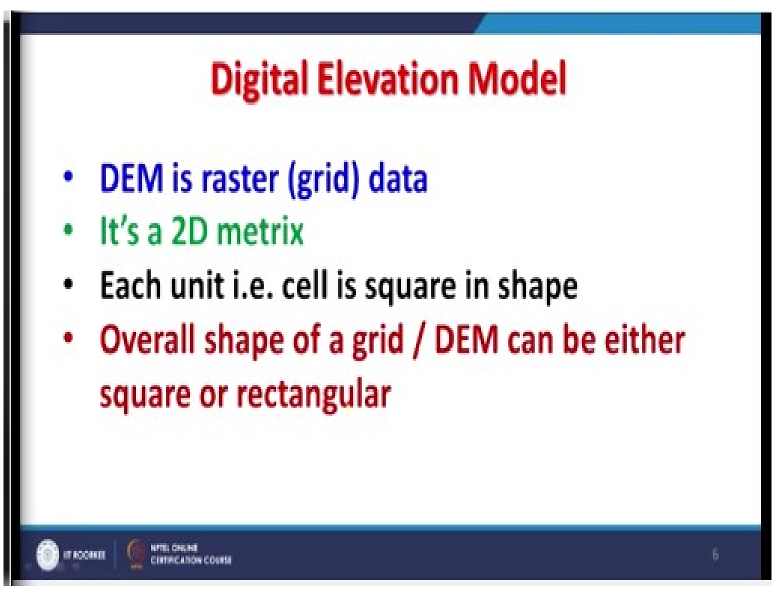

Now as you know that the DEM is raster. It is a 2D matrix and each unit is a cell is a square in shape, overall shape of the grid or DEM can be either square or rectangular. And when we discuss about the no data, at that time also, this came. So, what would happen if I want to represent a DEM for a political boundary or a hydrological boundary then at that time, shape of that boundary is not a square or rectangular. So, then the concept of no data comes there, otherwise in the system or concept wise is a 2-Dimensional matrix. And this 2-Dimensional matrix can have only overall 2 shapes, either square or rectangular.

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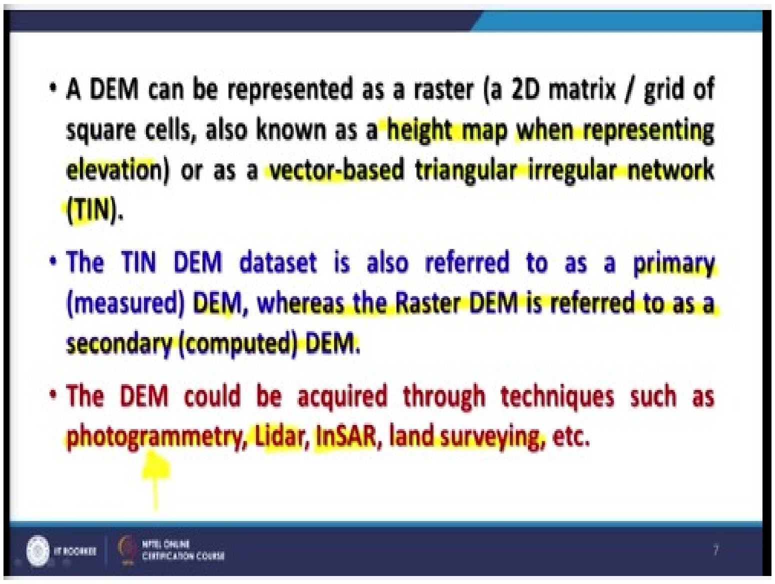

So, sometimes you may find in some literature, they call as a height map; DEM as a height map. Only you can call height map when you are representing cell value as elevation value. Then it is fine when representing elevation. When it is not representing elevation then one should not call as a height map. Now there is another way of representing surface or of a terrain that is through TIN.

So, TIN is also can be used here, though it is written here is the vector waste because there we are using basically triangles or facets. But truly as you know that it is neither a vector representation of the surface or nor a raster representation, though it is continuous. So, it fits in that sense in the category of raster but it is not discrete so that is why it is not very easy to put either with vector or raster.

So, let us consider TIN as a completely separate data model to represent the surface. And basically as you know that when we have also discussed in detail about TIN. So, this primarily measured as DEM whereas the raster DEM is referred as a secondary or computed DEM.

Because we imply either the satellite images then photogrammetric technique and then estimate the values for each pixel or cell.

Now here also we imply sometimes using point data, the interpolation so that is why it is mentioned that TIN is a primary measured surface. And whereas raster DEM is the secondary computed DEM or surface. And these DEMs, I already mentioned that nowadays they are being prepared or developed using various techniques. And various techniques, among them is of course the based on stereo pair techniques which is imply the photogrammetry technique.

Then InSAR technique is another one and very famous product from InSAR technique that the InSAR stands for SAR interferometry and SAR stands for synthetic aperture radar. This is a radar remote sensing-based technique so in short, we say InSAR. And shuttle radar topographic mission or SRTM global DEM has been generated using this InSAR technique. Whereas like Cartosat, our Indian satellite or SPOT or many other satellites ASTER and others, they have used stereo pairs and photogrammetry technique.

And land surveying is another way, collects the point data and do the interpolation. Again, you can create a surface and DEM. Or you can use another technique which is laser waves and which is LIDAR. Generally, it is used on ground to create a 3D perspective of buildings or other features but nowadays airborne LIDAR is also possible.

So, at a very high-resolution digital elevation models can be generated employing Lidar. Various techniques, one more thermal remote sensing techniques has also been developed by us to create a digital elevation model of quite good accuracy to some extent. So maybe in future, we may see few more techniques to develop digital elevation models.

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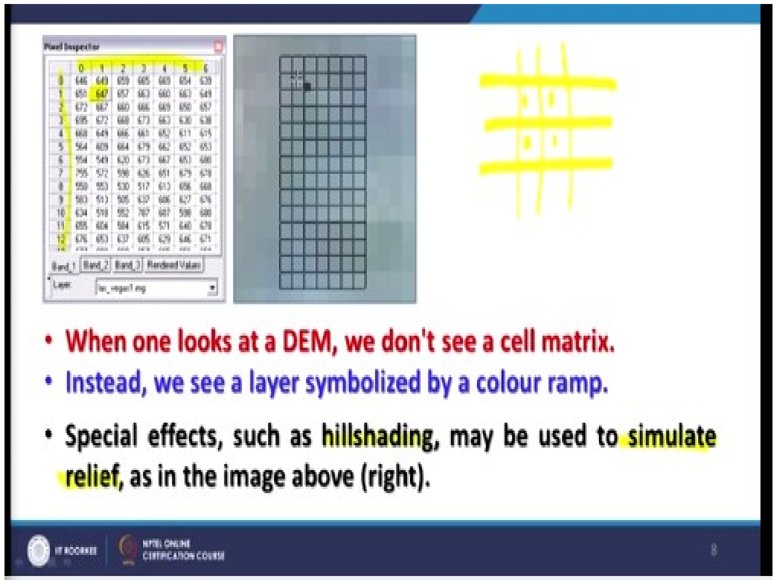

When you go inside of a digital elevation model, on the right side the matrix which you are seeing, basically it is for our understanding a wire mesh is there. But these boundaries or lines are not there at all in the data. How the data is represented something like this. So, when I put my cursor on the right-side sort of matrix, I get the value something like this. Of course, here this cursor is bringing a 3*3 or 4*4 display also.

So, these are the columns and these are the rows and for every cell, you are having data. Again, the lines which you are seeing here are just for our understanding. In fact, there are no lines. Only the numbers are written in 2-Dimensional matrix. So, when one looks at DEM, we do not see the cell matrix. We see only the values or we can use the symbols as a colour or grayscale to display on our screen as I have shown earlier in my example.

So, before the display, that values are assigned certain colour or grayscale and then on screen, this is what you see. But in the system, it is nothing but a 2-Dimensional matrix. And there are of course columns and rows but there are no lines or wire mesh. Only the numbers are there in form of 2-Dimensional matrix, this you have to remember.

But always whenever we want to explain, we always use these lines, columns and rows and then we will talk about the values which are there. Now like spatial effects or derivatives of digital elevation model which is very popular derivative is called hill shading or shaded relief model, SRM may also use to simulate relief that means we can use that the elevation value as z value and can create a 3D perspective kind of thing. And that means that will bring a terrain to real life. Rather than just simple grayscale, we will have a shaded relief model which will give you a good feeling or real feeling about the terrain.

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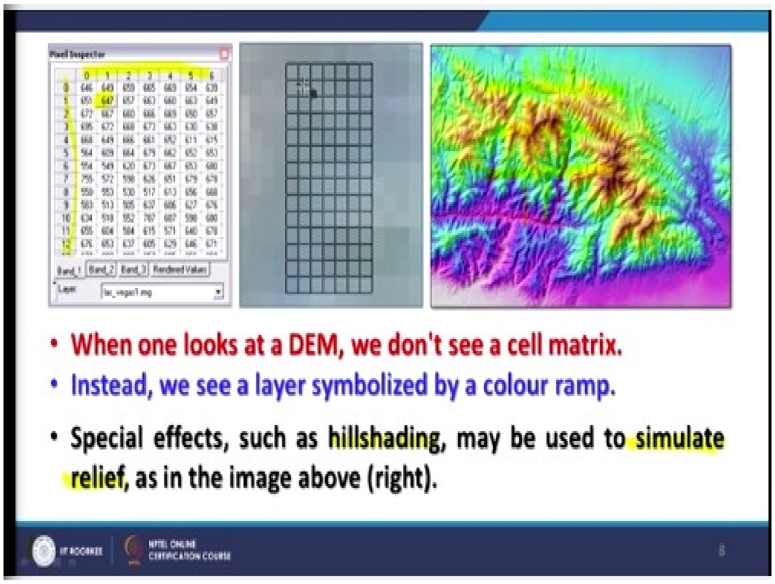

So here is the example, what it has been done that using that digital elevation model which I showed earlier which was in grayscale. And on the right side I kept the coloured one also but here what happened that using that digital elevation model, a hill shade or shaded relief model has been generated and colours have also been provided. And therefore, you can say is one of the very common product of digital elevation model is creating hill shade.

And this hill shade is now bringing very clearly, your valleys and ridges etcetera. Like here earlier also, I mentioned that one can utilize these lines to understand that these are representing drainage network like here and so on. So, the interpretation becomes much easier. Everyone can understand after seeing this hill shade that which is the higher ground, which is the lower ground, what are the ridges, what are the valleys?

So, the terrain appears very close to the reality whereas when we are having just representing in gray form without hill shading then it becomes little difficult to understand the entire terrain.

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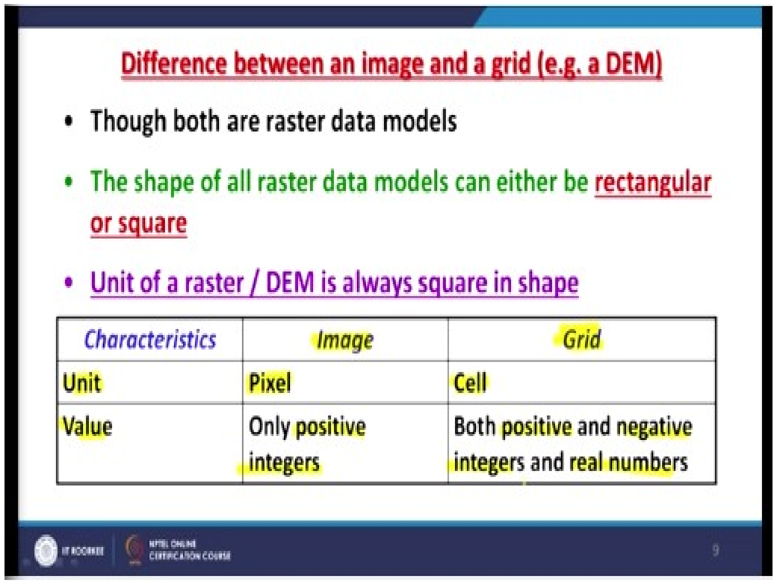

Now though both are raster models as you know that image and grid because we also combined image with our DEM to create a 3D perspective like in case of google earth. So, whenever you use the terrain and when you start creating a tilt and other things that is what you are doing that in the background, a digital elevation model has been used first to create a 3D perspective or hill shade and top of that then satellite image is trapped.

But remember both are raster but there are very small differences. These differences we have also discussed earlier but just for completeness, I am reviewing that one that overall like in case of grid, overall shape of image is a rectangular or square. And each cell, each unit here is called pixel whereas the shape of that one is always square in shape.

And whereas overall shape of raster whether it is an image or grid can be square or rectangular. So, these are two major differences otherwise everything is same. The major difference is that in image, the unit is called pixel rather than cell. So, it becomes much easier whenever I say pixel, I mean I am talking about image. And whenever I say cell then I am talking about the grid.

So, unit here in case of image is always called pixel whereas a unit of grid is called cell, both are raster. Second is the values that is another very big difference between these 2 raster's that image can carry only positive integer values whereas grid can have both positive and negative integers and real numbers. All types of values but it has to be numeric only, a cell value can be but pixel value is always positive integer. So, these are the 2 major differences between image and grid.

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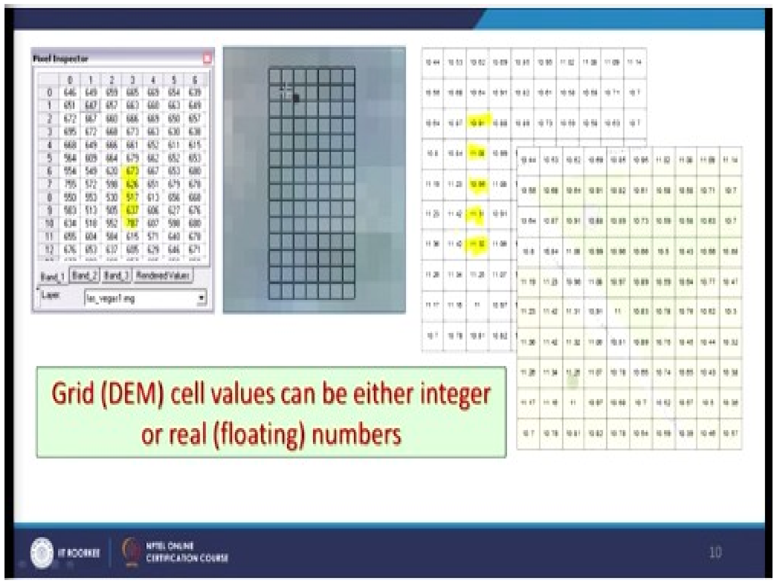

Now here if you see any these images, the example is given here that this is the image so the pixel values are in integer form, no decimals. But this is about the grid or a digital elevation model and therefore the values are also in real numbers and that is a precision up to 2 places after decimal. So, likewise both are though raster but the there is a difference between the cell values.

So, grid DEM values can be or cell values can be either integer or real floating numbers. Also grid values can be negative also whereas in case of image, this has to be only positive integer values. So here in case of grid, we can have negative values, we can have positive values, we can have integer values, we can have real numbers.

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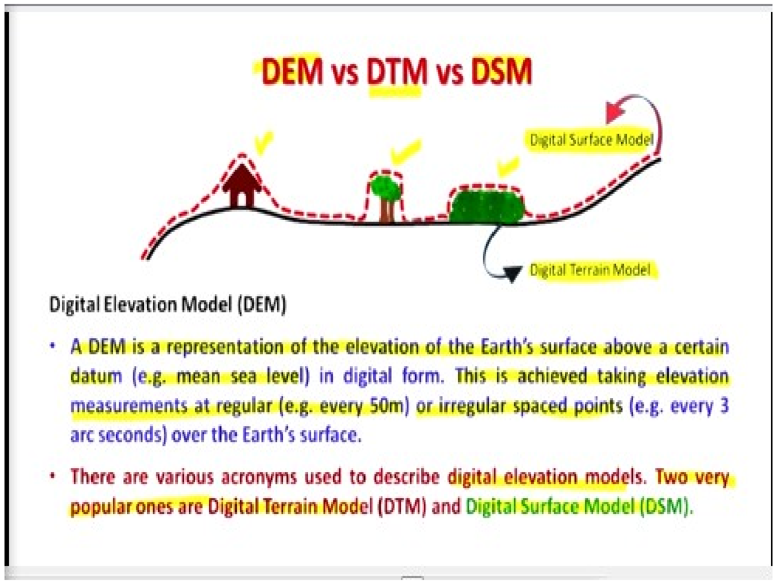

Now three terms, earlier we touch little bit about DSM and DEM. Now there is another term which is called DTM; digital terrain model. Though DEM is also representing terrain when we are using. This E is for elevation. But there are some slight differences which are now being considered because of the new techniques which we are employing to generate digital elevation model.

So, what you are seeing here the red dashed line that is what the DSM; digital surface model. So, any object which is present on the earth when it is represented top of that surface which is going above of all these objects then truly it is called a digital surface model; DSM. And when we employ this Lidar technique, this is what the Lidar does. It creates a digital surface model rather than DEM.

Though there are techniques by which we can remove these like here a house or tree or bush, we can remove them. And then if we can remove then it becomes a digital elevation model or digital terrain model here. Now there will be again difference between elevation and terrain model. So let us go on that part also that a DEM is a representation of the elevation of the earth's surface above a certain datum.

And generally, our datum is mean sea level in digital form and this is achieved taking elevation measurements a regular or every 50 meter or irregular space point for every 3 arc seconds above the earth surface. That means we are having some way of filling each cell of that grid with some elevation value. And there are various acronyms used to describe digital elevation models but there are two very popular ones are digital terrain model and digital surface model. Digital surface model is generally generated by the Lidar technique.

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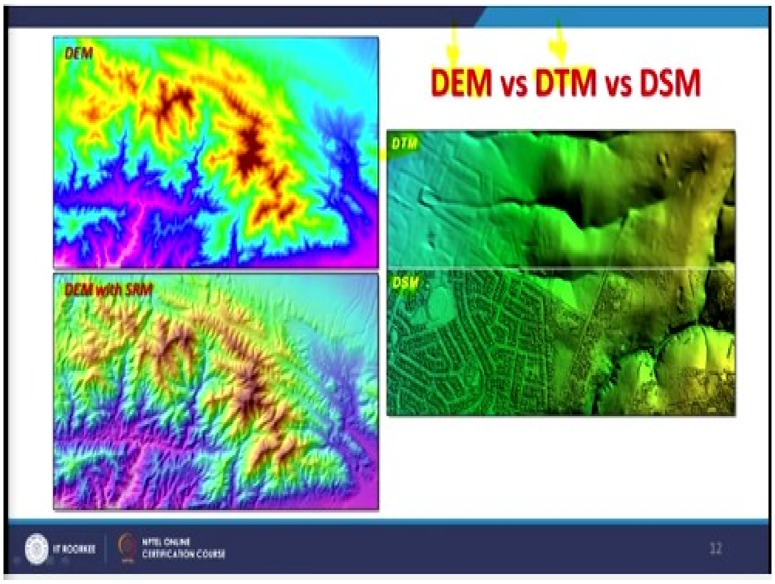

Now when we see a simple DEM or when we say digital elevation model, this is how it is represented as a top figure. Here you are not having any feeling of terrain; if it is in gray colour just by using gray colours or that understanding you can say which is higher ground or lower ground. But if I change that palette just opposite which is possible in software then it would be a complete reverse scenario.

So, in that way, that is considered as a simple DEM. But here as you can say the DEM with SRM or hill shade where both are there, the same input but one is SRM and another one DEM and DEM that is the colour one is over the surface. So, we call as a DEM with SRM. Now here this is DTM; digital terrain model and this is DSM so this DSM, the bottom one is having each object recorded from the top.

So, whether it is a tree, house or building or anything, everything is recorded. But when we remove this one then it becomes a sort of DTM. So, what I am trying to say that there is less difference between DEM and DTM but there is a definite difference between DEM and DSM, same DTM and DSM. DSM is completely different than DEM or DTM. So, sometimes people use terrain when it is related with the real elevation then we can call as either DEM or DTM.

But as you know that DEM has become a generic word, so this E value can be any other value. So, therefore a new term has been introduced that whenever we say DTM, it means the cell value is elevation value. And whenever we say DEM that means that either it is elevation value of the cell value or the cell value can be any other value. So, DEM is a very generalized term compared to DTM which is only related with the elevation. And DSM includes all surface features which are present during the survey.

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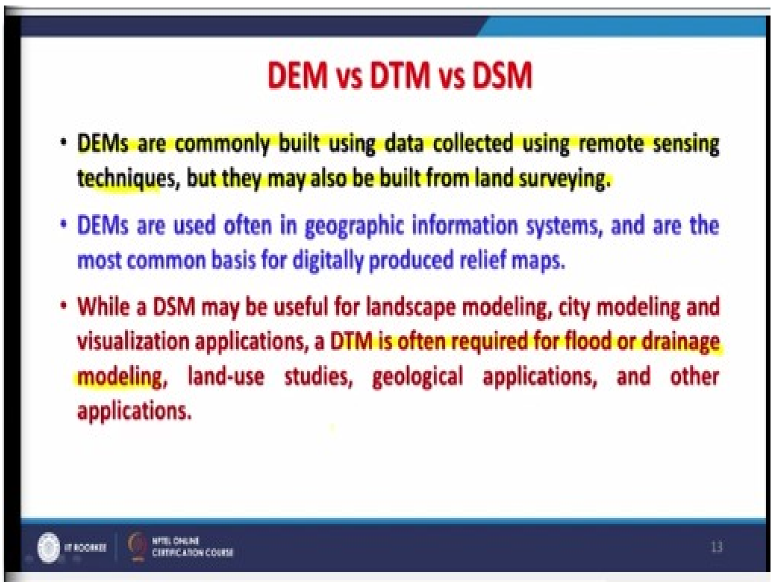

So, DEMs are commonly built using data collected, using remote sensing techniques but they have also been built from land surveying. Like if I am having contour lines then implying interpolation techniques, I can create DEM. If I am having point elevation data, using interpolation I can create a DEM, no problem. So, elevation or DEMs are used in our GIS and our most common basis for digital produce relief maps or shaded relief model.

That is very-2 popular product of a digital elevation model while this digital surface model or DSM may be useful for landscape modeling, city modeling, visualization application because in many applications, they want not only the height but they want recording of all surface features. And whereas DTM or DEM is without surface features so for that purpose DSM are quite useful.

So, DTM is often required for flood or drainage modeling whereas DSM is for different purposes and other studies are there. So, depending on your requirement, one can choose these but DSM are generated when we employ this Lidar technique.

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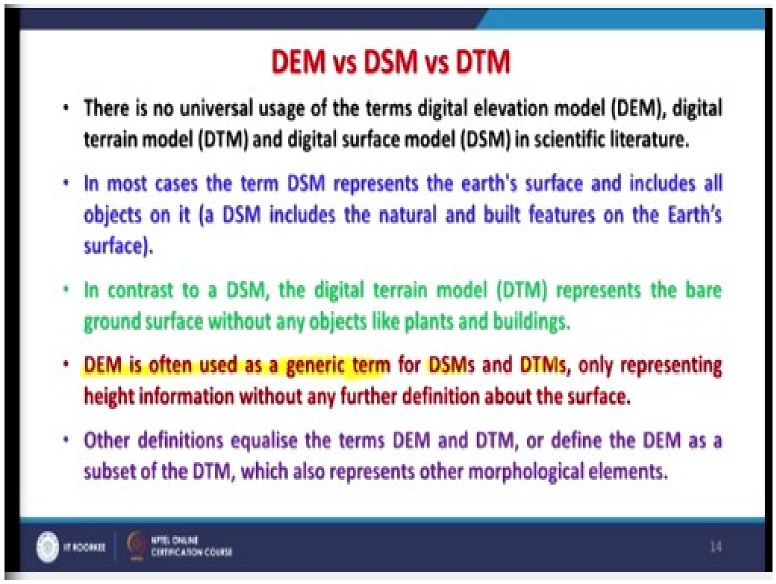

Now of course, there is no universal usage of term digital elevation model or DTM or DSM in scientific literature. Sometimes people are using synonymously but as I have explained all three terms are different and one should not get confused after this discussion. So, we have already discussed that what is DSM, DTM and another thing. And then as you also know that DEM as I have already said is a generic term, a common term for DSM and DTM but DTM and DSM are also different surfaces.

Other definitions also equalize the terms DEM or define this subset of DTM which also represent other morphological elements. So, it is always better if we are using in general terms say DEM. If you are using for only elevations, you may call DEM or DTM. But if you are having surface feature recorded also like in case of Lidar then you can call DSM.

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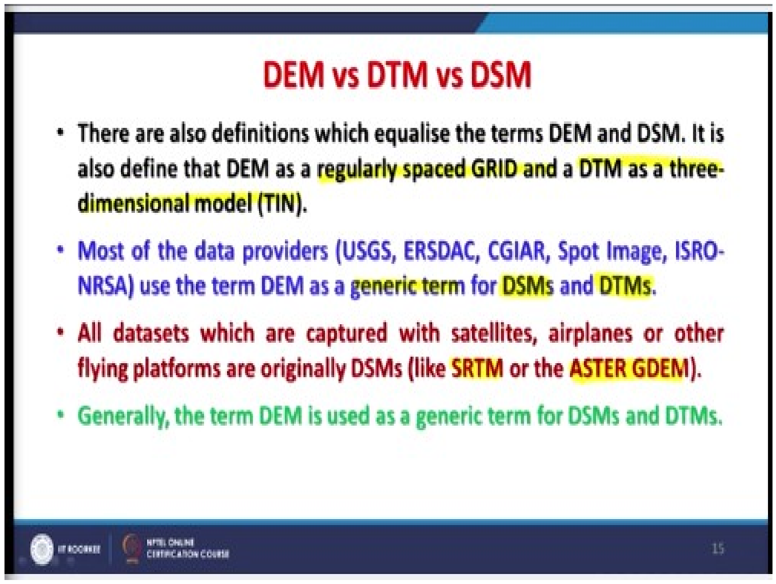

So, there are also definitions which equalize the term DEM and DSM which is defined as DEM which is of course regularly space grid and DTM is a 3-Dimensional model. So, for TIN also, we can call as a DTM. So, most of the data providers which provide lot of DEMs, they all use this term DTM, most of them generic term which is DTM. Or sometimes you may get usage of term DSM if it is based on the Lidar technique.

But otherwise, if you go on these sites like earth explorer of USGS or ERSDAC or any others these sites or like ISRO that is BHUVAN and go for downloading of the digital elevation model or these elevation models, you would find they are using term DEM. So, all datasets which are captured with satellites, aero planes, through aerial photography or other flying platforms are originally though they are DSMs but they are called DEMs.

Like for example SRTM which is a shuttle radar topographic mission in which SAR interferometry was used or ASTER GDEM which is ASTER is the name of satellite GDEM is global DEM, so again DEM word has been used. And though they may be having some recordings of surface features and generally the term DEM is used as in generic term for DSM and DEM.

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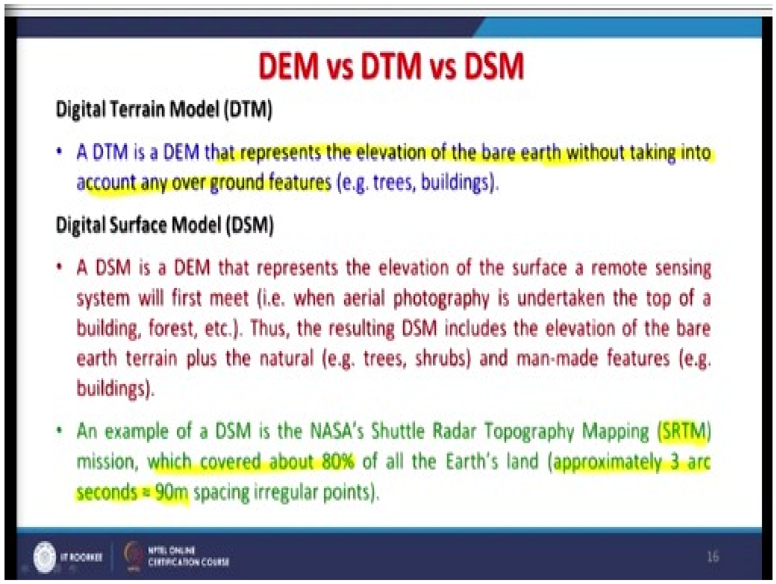

Now DTM is a DEM basically which we have already discussed but it is also that DEM that represent elevation of the bare earth, without taking into account of any over ground features. So, what I am would like to say at this stage that even DEM is also not very pure. Pure means it is not truly representing.

It is supposed to be representing the bare earth model of the earth but when it is based on satellite data then at that time it may also be recording some features which are either trees or artificial manmade features. So, this is the problem. Now when we talk about this SRTM that which has covered about 80% of the globe or earth and this about 90 meter or 3 arc seconds digital elevation model has been generated.

But now 3 arc seconds is roughly equal to 90-meter, 1 arc second is equal to roughly 30-meter. So, for now 30-meter spatial resolution SRTM based digital elevation model of entire globe except for polar regions is also available. Earlier it became available first for American countries and later on, now for the entire world.

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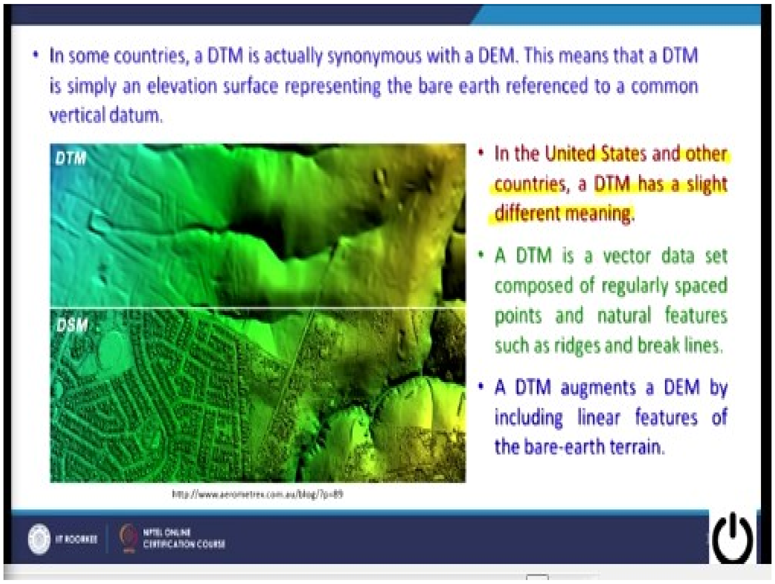

Now here some countries are having some extra or high-resolution surfaces like in U.S and many other countries, DTM has a slightly different meaning. So, again country to country, it will vary so one has to be little careful. I would suggest the best way to address any these surfaces is use word DEM because DEM is a generic word. There will not be any argument or confusion about these things.

So, with this I end this discussion. Please whenever you get time on these softwares, explore and just add one DEM which you can download if you just type in google like SRTM DEM download. You would be taken to some portal and simple login credentials would be required. And once you are through, you can search for your area of interest. Initially download just one tile, add into the software in your view

And start exploring that means zooming it, seeing the values and also then try to extract part of that DEM using some arbitrary boundary. And then you can practice or see and understand what is the concept of no data. So, with this, thank you very much.