Geographic Information Systems
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Lecture-44
Common Derivatives of DEMs - Slope and Aspect-01

Hello everyone! and welcome to a new discussion which we are going to have on common derivatives of digital elevation models and this is in two parts. So, in first part, we are going to have discussion related with slope and in second part, in aspect. And we will also see some other details here. As you know that basically this is all for the understanding the terrain. And the best representation of terrain or the best data for terrain which we are having, is a digital elevation model.

But simple using digital elevation model will not give you those characteristics or derivatives. So, we have to process that data and the purpose here is to understand the topography. So, now question is what is basically topography?

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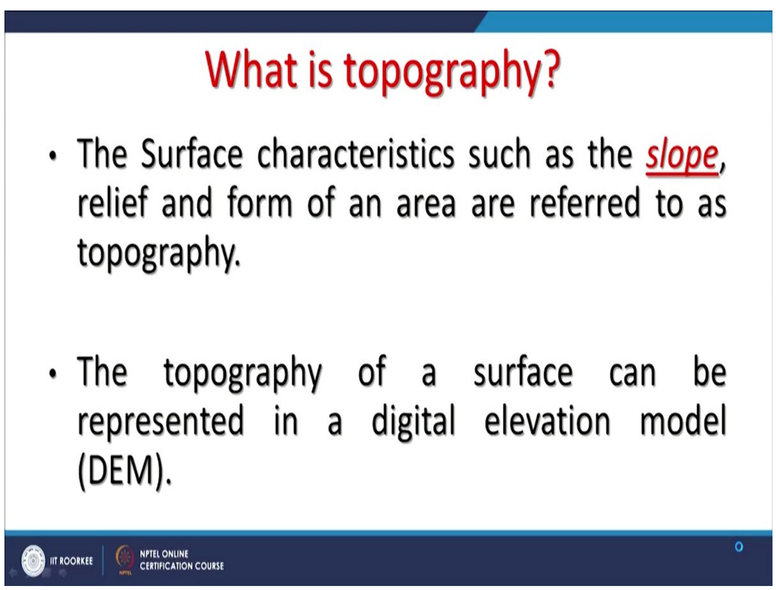

So, basically topography; the surface characteristics such as slope which we are going to discuss aspect, relief and form of an area referred to as topography. So, all these things which are part of topography. And the most common derivatives of a digital elevation models are always slope and aspect. If you recall discussion related with TIN; that is triangulated irregular network. We discussed that when TIN is generated, at the same time, slope and aspect maps are also generated along with that.

So, that is in some way TIN is advantageous. But in case of a raster grid which is a digital elevation model in our discussion then these have to be derived separately. Now as you know that the topography of a surface basically is represented through our digital elevation model and as we are going for higher and higher spatial resolution digital elevation models, we can see or we can study the topography in more detailed form.

And you know we can get information which otherwise was impossible using survey topographic maps or survey toposheets because there the terrain is only represented through contours and you know seeing contour and visualizing topography was very-2 difficult. And all these are slope and aspect were not that easy. As you know that DEM represents a topographic surface in terms of the elevation values measured at a finite number of points.

And that geomorphic features or terrain features characteristics which are important from geomorphological analysis such as valleys, ridges, peaks, pits etc. are very-2 important derivatives of a digital elevation model. Now if we talk about the geomorphological importance then nowadays it is also possible depending on the scale, if we choose appropriate scale for a terrain.

Then employing digital elevation model, we can also classify that terrain from geomorphological point of view as well, that means whether it's a peak, ridge, valleys, pits etc. So, this kind of analysis is also possible. In later discussions, we will bring that analysis also as one of the derivatives that ultimately what we get the geomorphological importance. For like a geomorphology is very-2 important for civil engineers too and there can be a completely separate course for importance of geomorphology for civil engineers, especially.

Because if somebody you know about to construct or finding a suitable site for a bridge construction on a river then they must understand the fluvial geomorphology. How that river is behaving in that part of the land? And therefore if same requirement is for a hilly terrain like

Himalayan then these valleys, ridges and where the bends are there in the river; not meanders, meanders will be seen only in plane area.

So, these bands of river, these are also important from sighting a very suitable location for a bridge. So, many times say if this exercise has not been done, that means that geomorphology of the area has not been studied properly then these projects might fail. So, whether it is a construction of a hydropower site or a reservoir or a bridge, any such thing, whether it in hilly terrain or flat areas or plane areas, geomorphology should be studied first.

And what is the best tool available today for us to understand the geomorphology is doing extensive analysis using digital elevation model. This I have been also telling that DEM and satellite images are storehouse of information. As much information as you can drive, these can provide you. Only requirement is that we have to understand first these two different datasets, though both are raster.

But also, we should know what are my requirements in a project or in study or research and accordingly, I can exploit and these two big data sets on a GIS platform, maybe in an integrated manner to bring lot of insight of the terrain which is otherwise is impossible, not even sometimes through field investigations. So, this is a very important as also you know that DEMs are commonly organized you know in a grid format.

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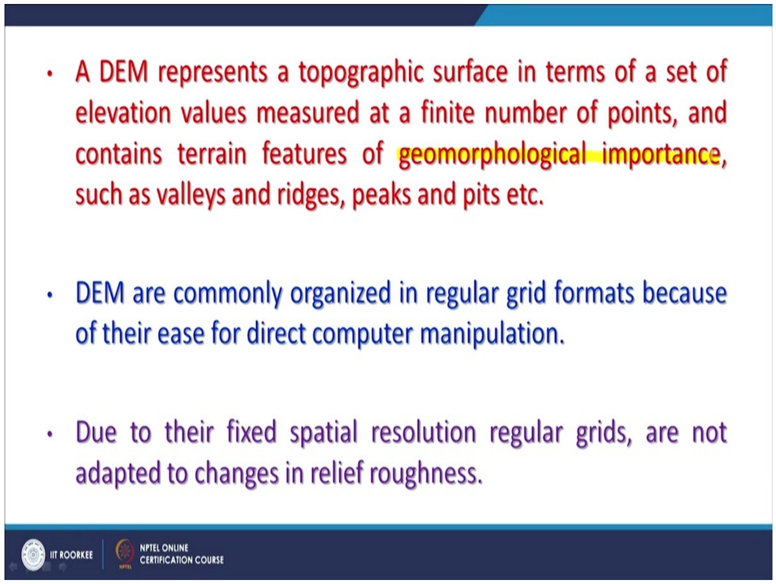

And because of they are represented or terrain is represented through a two-dimensional matrix and therefore the computer manipulations or processing on computer becomes much easier. So, that is why these have become very2- popular datasets. And that is another reason because lot of people are looking for digital elevation models so the organizations and countries are producing digital elevation models on regular basis for higher and higher spatial resolutions.

So, this is very-2 important. This one more point which is kind of repeat which we have already discussed that in a grid or in a raster, the cell size or pixel size is fixed and you cannot change, that means within a file, every cell will represent the same ground area whereas in case of a TIN, it is adaptable to relief roughness. So, DEMs or grid or satellite images do not allow that adaptation of relief roughness. But only TIN model allows us to do that thing.

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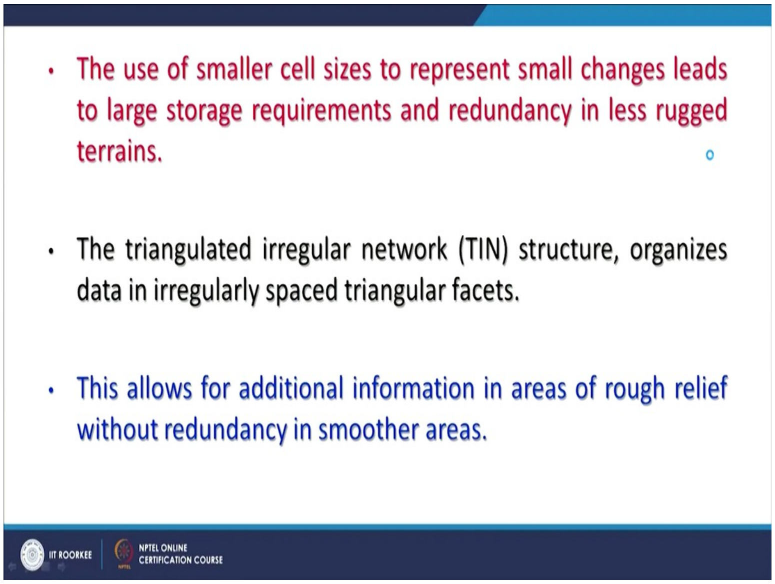

Though, by employing higher spatial resolution data or a small cell size data that means representing a small ground area or field area, we can definitely go in much more detail. But if we go for higher and higher spatial resolution, though our requirements may not be for that kind of resolution or scale then it will be unnecessary, redundant and it will require large storages space on your storage devices and unnecessary, it may create some problem in future.

Because remember we have also discussed while discussing evaluating different digital elevation models and which one is the best. At that time, we discussed that it is not always true that higher spatial resolution means more accurate representation of the terrain may not be always true. So, one has to be also aware before we choose a much higher spatial resolution digital elevation model. Only one should go if it is required in our projects or in our studies.

TIN, we have already discussed. So, as you know that it is all triangulated irregular network. In a one file or one TIN, all triangles may be of different sizes and shapes. But they represent triangular facets of the terrain and that is the advantage because it is adaptable to relief roughness. This information about the relief roughness is only possible through this TIN and as you know that the sizes of triangles will depend on what is the density of my observations.

If density of observations is very high and each those observation points or data or spot heights are representing different elevation values like in case of hilly terrain then these will adopt or these will create a smaller-2 triangle and reverse in case of plane areas. So, what we do in order to drive these slope and aspects; the most common derivatives and there are different variations are also there or variants are also there.

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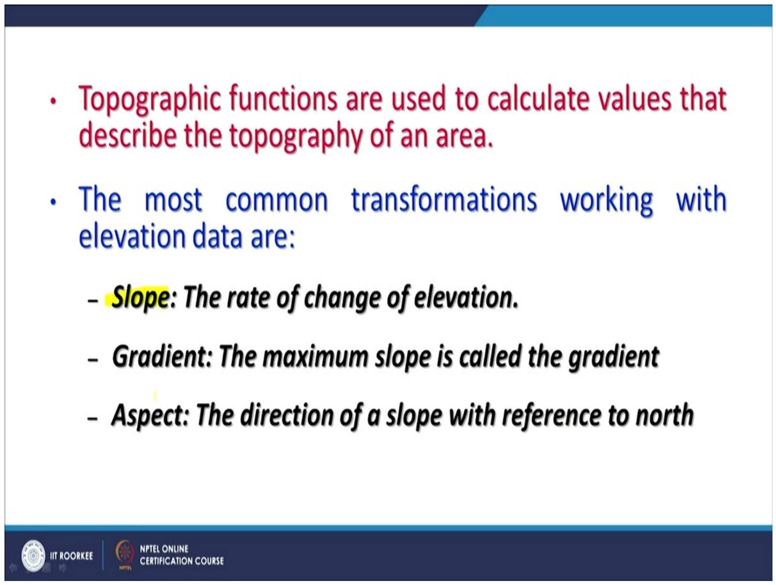

So, we do it through a function which is called topographic function and which calculate for topography. Suppose if I am going to calculate for slope then what it will do? It is a neighborhood function basically. So, it would look in the surrounding and wherever against the center cell value, if value anywhere in the surrounding is less then it will note that one and that becomes the direction of the slope as well.

And also depending on the variation; how much variation with the central cell in terms of values, that will also decide the slope angle, that means the value of the slope. So, the most common topographic functions or transformations which we work with digital elevation models as I have said; one is the slope which simply we can define is the rate of change of elevation. So, if two cells, they are having a large elevation difference then that means there, the slope is very high.

How much it is there? That can also be decided easily through these transformation functions. There is another term which is used called gradient. Now this is basically the maximum slope is called gradient. So, you may have a sloping surface. But all parts may not have the maximum.

So, for identifying that which part is having the maximum slope, that we call as gradient which is also possible and which we put also as one of the common derivatives of digital elevation model.

And third common derivative is the aspect which basically is the direction of a slope with reference to north. So, if I am having for example a sloping surface so this will decide with the horizontal plane. This will decide what is the slope angle with this. But what is the orientation of this sloping surface with reference to the north will be decided in this analysis which is aspect.

So, this is the direction of a sloping surface with reference to the north is. Those who are a geologist having geological or our sciences background, they can understand much easier slope is something like dip amount and aspect is the you know strike direction basically. So, slope is measured in the vertical plane whereas aspect is measured in horizontal plane because it is where you are bringing the direction that means it has to be related with the north. Generally, we take north as reference and do it as per our compass.

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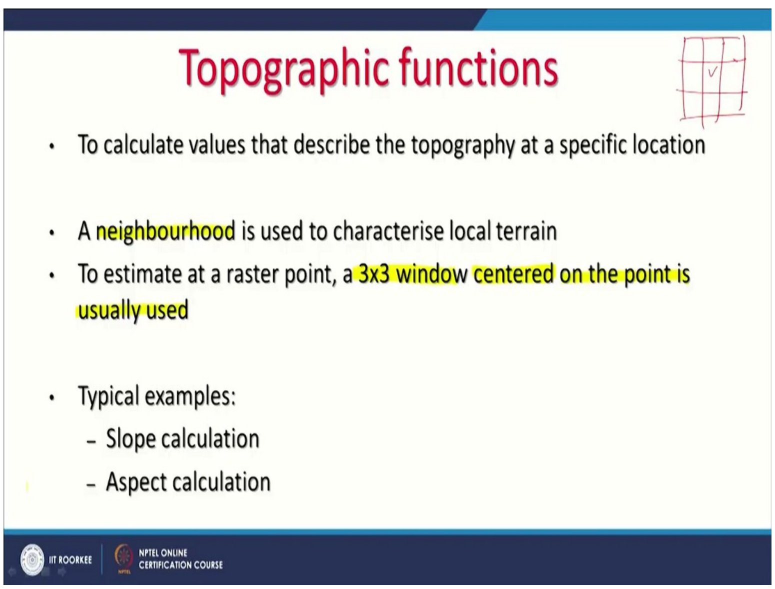

Now in order to calculate this slope or any these common derivatives which describe the topography at a specific location, what we resort as earlier also mentioned is the neighbourhood. So, what is in the neighbourhood? Relatively that will be decided. So, if neighborhood suppose in a 3*3 matrix of cells, all cells are having the same value, that means the area is flat. But say in the southeast direction in the corner, one cell is having lower value compared to the center cell.

Then we can say the slope is towards southeast direction. So, with reference to north or that becomes our aspect. Now what is the value of the slope in terms of either degree or percentage, that can be decided based on the difference between the central cell value and say in this example southeast cell value.

So, in order to estimate these topographic functions or derivatives, generally a 3*3 window; a roving or moving window is used and as on the center cell, what we are deciding the value for the center cell on the point is usually used. So, if I am having a 3*3 window then that window will move throughout all digital elevation file or two-dimensional matrix and whatever the value here for the center cell, is decided by looking the neighbourhood cells.

So, this is how. Now these cells of this 3*3 moving or roving window can also have their own weightages and that can help us to find certain things in much easier way. It is very close to special filtering in terms of digital image processing. So, there are two kinds of filtering; one which is a spatial filtering, another one based on the frequency and that is Fast Fourier Transformation, other thing.

So, here we are going for spatial filtering which can be applied on any two-dimensional matrix. Now as we have been discussing that the most common derivatives of these topographic functions are slope and aspect calculation.

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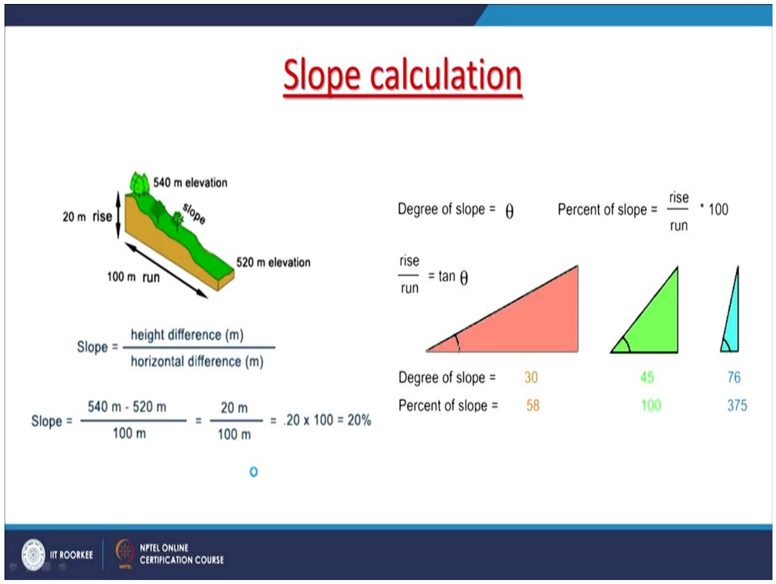

Now let us take a first slope calculation. As you can see it is based on simple trigonometry that rise/run=0 tanθ and this is what tanθ is here. So, if this rise is much more compared to what you know run then you would have a larger tanθ value or if it is a smaller then you may have smaller. So, relatively like here, this one is having very less value and degree of slope is being determined is 30.

Here it is a run and length are the same. So, tanθ or tan45 here is like 45 degree; this tanθ here. And in this case, when run is less and rise is very high then we may have a much higher degree of slope. Now the same slopes can also be represented in form of percentage when we scale instead of 0 to 90, if we rescale from 0 to 100 then we can also represent in terms of percentages.

By default, in most of the GIS software's, you would find that they will derive your slope in terms of degree because our brain is much better trained to understand the degree rather than percentage. But the option is definitely available in most of the GIS. It is simple calculation that instead of having 0 to 90, you can have percentage from 0 to 100 in that case.

So, in that way, it can be decided. Now these values will be accordingly change. How these have been implemented in the software, one has to really check. The best one which I prefer always is keep in degree which people understand very easily without any problem. Like here on the left image as you can see that run is 100 meters, the rise is 20 meters. So, when we substitute these values; 20 and 100 in this equation, you get a 20% slope in that sense.

Now this is one example of how the calculation is done and using these rowing windows or moving windows of 3*3 size. So, over the matrix, a small window will move throughout and will try to see what is in the data and accordingly, it will calculate.

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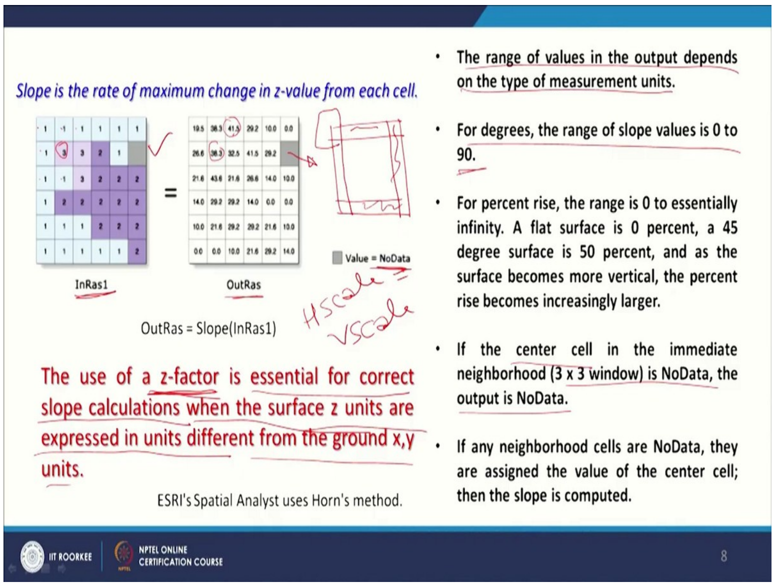

For example, here this is the input raster which you are seeing and in order to understand, that values have been kept in very simple range that is between only 1, 2, 3. And this is the output raster basically and what is the value calculation here? The only problem it comes when I have to calculate for you know the boundary area. So, if my data is like here that I am having a something like this raster then on left side one row, right side one column, top and bottom, for which the calculations cannot be done.

Here the calculations cannot be done because when I will keep this moving roving 3*3 window then because these areas, I will not have any data available and therefore you know, one cell thick boundary would be there, though in this example that is not shown.

But when you would do the real analysis, you can zoom it on the margins of your data set and you can definitely observe that point. Now here if I take for the central pixel like this 3, how the calculation has been done. So, if you see here compared to the value 3, these are the things which in the surrounding are having lower value. So, this is having what 36. But the other cells are having less value.

But one may argue that why this value is higher because this is part of an output. So, in the surrounding of this one, that means mainly on the northern side, the values might be much lower and therefore this cell is getting higher slope value. So, for each cell, that roving or moving window moves throughout your data set; throughout your matrix and keep calculating slope value for the center cell and this is how it is determined.

So, the use of another very important part which I was about very keen to discuss here and it is very-2 important is called Z factor. Now as you know that a digital elevation model when I was discussing introduced digital elevation model and at that time, I said that there are two resolutions associated with any digital elevation model; one is for horizontal and one is for vertical. Because generally the data set might be represented for oriental, it might be represented through degree decimals.

But the height or the cell which are representing the height of a mean sea level, will be having value in meters. So, that means the XY scale or horizontal scale is completely different than vertical scale. So, when we go for this slope, aspect or many other such analyses, we find that there will be always a question about Z factor. What should be the Z factor? Z factor basically will allow you to rescale one of the scales.

And either you rescale the horizontal scale or vertical scale. So, the use of Z factor is essential for correct slope calculations. Not only slope, but many other calculations. When the surface Z units are expressed in unit from the ground of XY unit, that means the horizontal scale is not equal to vertical scale in case of a digital elevation model. Only it possible when I am having a UTM projection easting, northing and everything is represented in meters for horizontal also.

So, my vertical scale that is Z values and XY values, all are in meters. Then I can choose z factor as one in my software otherwise I have to provide a value. So, you know basically this is we have to control and take care about this. Now when we bring this data set or our digital elevation model which is required for calculation of a slope then the range of values in the output will depend on the type of measurement units. That means that the roving metrics, whether it is also having some weightage or not or every cell is having value 1.

So, the biasedness or weightage can also be assigned to that. So, for degree, the range of the slope values will depend of course 0 to 90 degree or 0 to 100 in case of percentage. And sometimes we may get value 0, like here in this example. This cell is bearing value zero and then zero has been or it is saying no data basically or if it is flat terrain then value would be zero and of course, it is really flat. So, no slope at all, zero-degree slope.

So, this center cell for this 3*3 matrix will go through the entire data set. If it finds no data, it will result in no data. But if it finds flat terrain that means all cells below that 3*3 matrix are having same value then the center cell will be assigned zero value, not no data. So, no data will always read no data. Like in this example, this is no data; result will have no data whereas you know 3*3 cells, all 9 cells if they are having same value then 0 will be assigned, that means it is declaring it's a flat terrain in compared to the neighbourhood.

Now there will be a question why only 3*3 roving, moving window; this moving matrix. Why not 5*5, why not 7*7? Yes, it can be done. But it will bring you know more computation time and may not bring very good results either because it will smoothen the things, which you do not want. So, this is the best option available and most of these software's have implemented only for 3*3.

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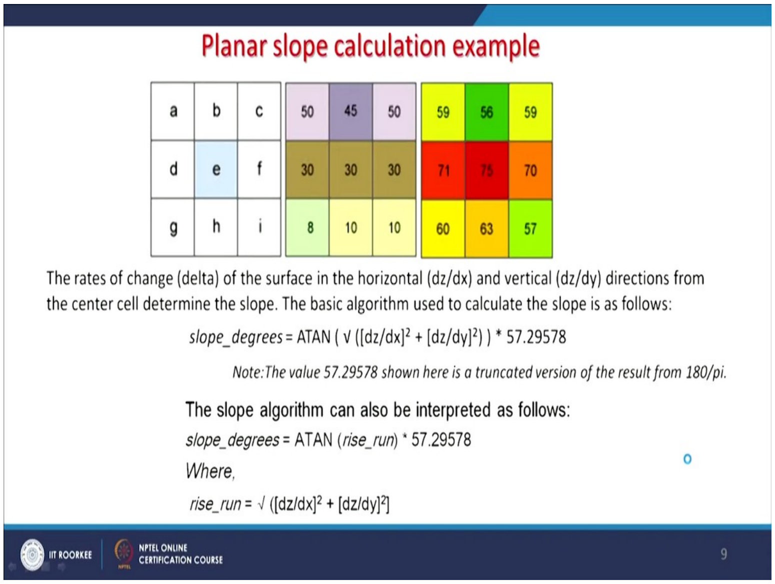

But I am sure that some software might allow you to design your own matrix and changing the dimension, instead of 3*3, you can go any odd number. So, neighbourhood cells will decide what should be the value. Let us take another example. But now I am introducing you know two different types of slopes; one is the planar slope. And in case of planar slope, this rate of change or delta of the surface is in horizontal that is dz/dx and the vertical; dz/dy, directions from the center cell determine the slope.

And the basic function or algorithm used to calculate the slope is something like this, that the slope(degrees) = ATAN($\sqrt{\{[dz/dx]^2 + [dz/dy]^2\}}$) * 57.29578. Then this square over all under root multiplied by this you know 57.29578 truncated version which is 180/π. So, this value has to be multiplied with that and then you get slope in degree. Now this slope algorithm or this concept can also be interpreted as follows that the slope(degree) = ATAN (rise/run) *57.29578

And where you know that rise, run is this function. So, by this, say you get the planar slope calculation.

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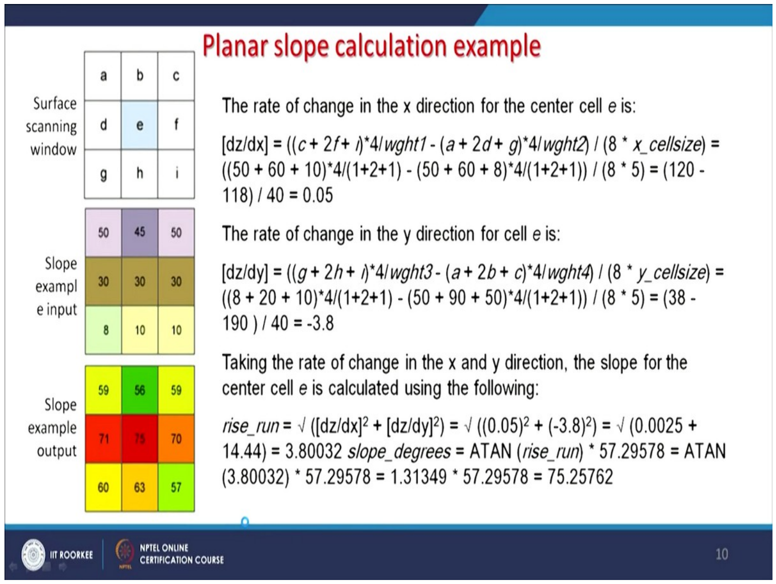

Further if we see that the rate of change in x direction for the center cell that is the e is calculated like this and then rate of change in the y direction is calculated like this. So, for each direction because it's a horizontal and there are two directions; x and y, therefore such calculations will be required and then finally you get a slope. So, in this example like here, this is my roving or moving window which is on run on this one. This is my input raster.

And this is what the result I get, that these are slope output which I am getting in terms of degree. So, likewise I can do this calculation.

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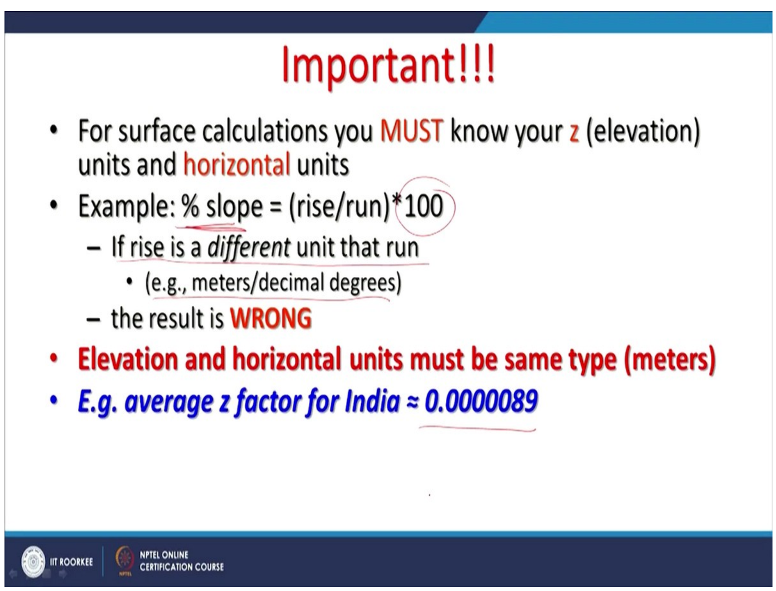

What are the important things to remember is of course z factor because if z units are not same or rather vertical units are not same as horizontal units, one must take care about z factor. When we go for percentage slows basically, we are multiplying with a 100. And if rise is different unit then run, then we should take care about z factor otherwise it will bring completely wrong results.

So, while doing this demonstration on computer of slope calculation, I will show you that what the difference it will bring if you do not take care about the z factor. So, that means the elevation and horizontal units must be same type in meters and if they are not, then z factors say so cannot be one. You know generally by default, most of the software's would keep z factor as one; assuming that horizontal and vertical scale are same.

But they do not know that my data is in you know the digital elevation model, horizontal is in degree decimal whereas my units for vertical are in meters. So, this change is required. Average z factor for India which we have calculated is 0.0000089. So, how this figure has come. Basically, you are converting you know through this z factor your meters into DD. So, then the correct calculations of slope would be there or correct estimation.

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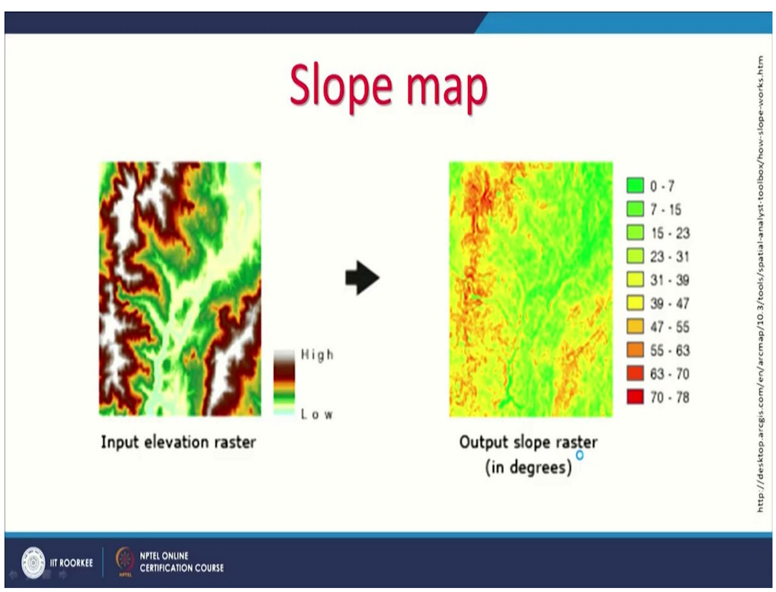

So, z factor is only applicable in case of planar method. This is one typical example; this is the input yor digital elevation model. When it is subjected to you know for the slope calculation, this is what output you get in degree. Now how you classify this one, it’s a different thing. I may classify only in 5 categories and have range. So, the classification methods of continuous data, we have already discussed so that you can apply.

Instead, because by default, it is always equal distance classification will be done, that each class will represent almost the equal variations in the slope. But if I want to change to equal area or quantile or standard deviation, I can choose accordingly.

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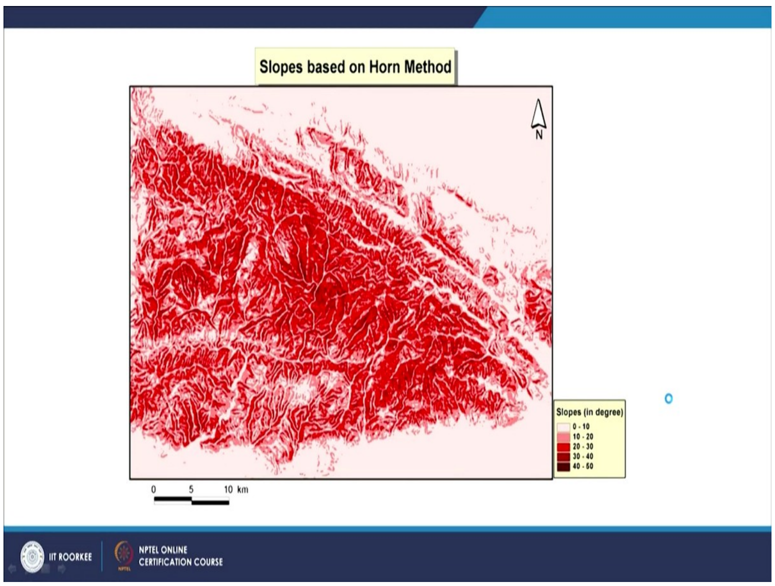

There are now different variations which can be done or calculations can be done on a GIS platform using some other methods rather than what the standard method. So, there is a one Horn method and that slopes can also be calculated in percentage. Like here, it is in though in degree.

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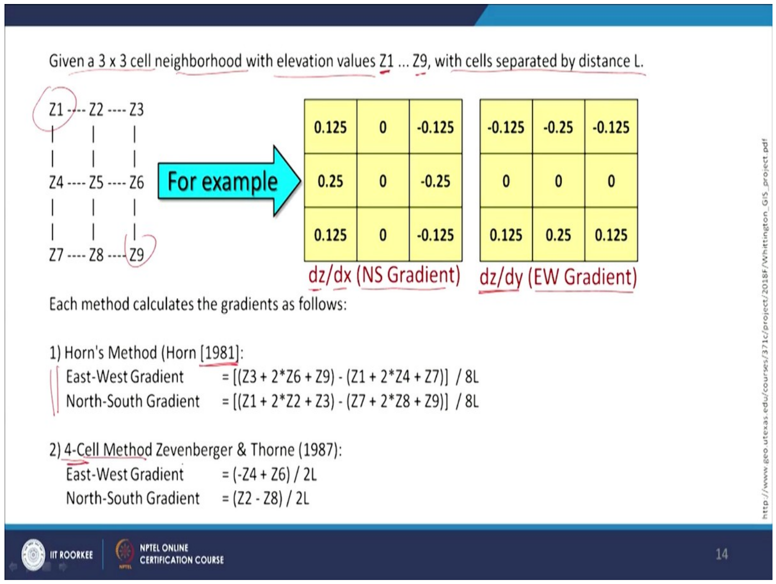

Now what in horn method is that you know these 3*3 cells and they have been given here in this example z1, z2, z3 like this. So, given 3*3 cell neighbourhood with elevation z1 to z9 with the cells separated by distance L. Now here because in both directions, it has to be calculated. So, dz/dx; that is a north south gradient will be calculated.

When I do dz/dy then east west gradient is calculated. So, in Horn method, this is what it is followed. He gave this idea in 1981 and this is how the calculation will be done. Once these values are substituted, you get the example also. Now 4 cells instead of 3 cell method. 4 cell method was also given and that is basically Javen Berger and Thorne method in 1987. So, you may find lot of variations because once somebody has developed initially a 3*3 matrix to calculate the slope, people are will definitely think why 3*3? Why not 4*4, why not 5*5.

So, that may bring new developments in this. But the basic concept will remain same. These variants will bring little different results, not major differences. And that is always true that after each and every calculation, one must go and check for errors. So, you have to have some idea about the terrain before you calculate for slopes. If you are already having idea of the terrain and a value is coming accordingly, you may get a satisfaction or you may say it is now calculating correctly. So, one has to be really careful about the z factor and other things.

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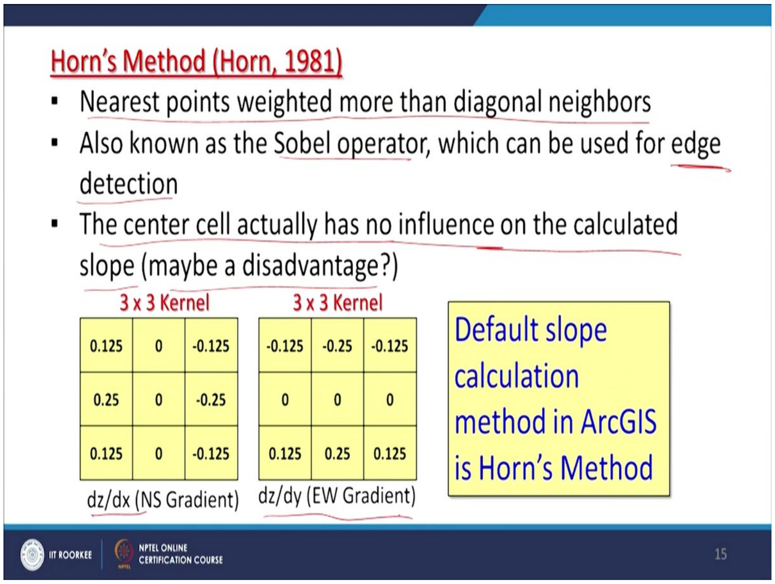

Now you know the nearest point weighted more than the diagonal neighbours if I choose this Horn method this. Also known as the Sobel operator in terms of you know special filtering in digital image processing. There we call as a Sobel filter, here it is Sobel operator which can be used for edge detection. So, there in digital image processing of remote sensing data, we use this spatial filter which is a Sobel filter for edge detection.

So, wherever we are having the sharp changes in the cell values, those are highlighted through this filtering technique. Because in this horn, the center cell actually has no influence on the calculated slope, maybe a disadvantage. So, basically depending what you are going to calculate here. So, this is how in one direction, it is in the east-west gradient direction. Now default slope calculation method in ArcGIS is horns method. This has been implemented, not the other one; Javen Berger and Thorne method but Horn method that has been implemented in default.

But if you want to calculate by implying other methods, those options you can also explore.

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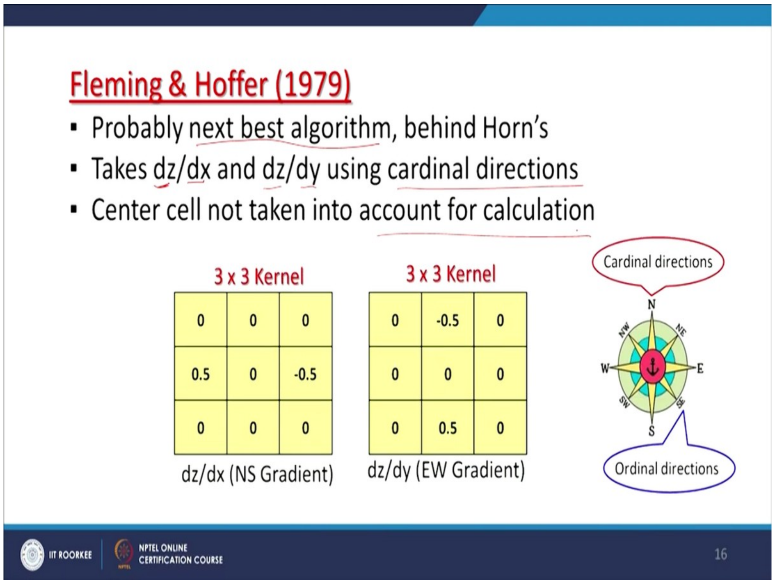

For example, there is another one which was given by Fleming and Hoffer in 1979 which is the next best method or algorithm after this Horn method, is that it takes dz and dx and dz and dy using cardinal direction. Now these cardinal directions I will just discuss in a minute. The center cell not taken into account for the calculation, completely ignored.

Now about the cardinal direction so these directions with reference to north like north, south and northeast, southwest. And when these are there, basically the north, south, east, west; we say cardinal direction. When northeast, northwest, southwest and southeast are there then we say ordinal direction. In case of aspect, all cardinal and ordinal directions are used. But in case of our slope calculations, only cardinal directions are you know in this particular method are used.

So, takes that using cardinal directions, only east-west or north-south; this is what you have been seeing. No diagonal calculations are possible at that stage but later on, that is also considered.

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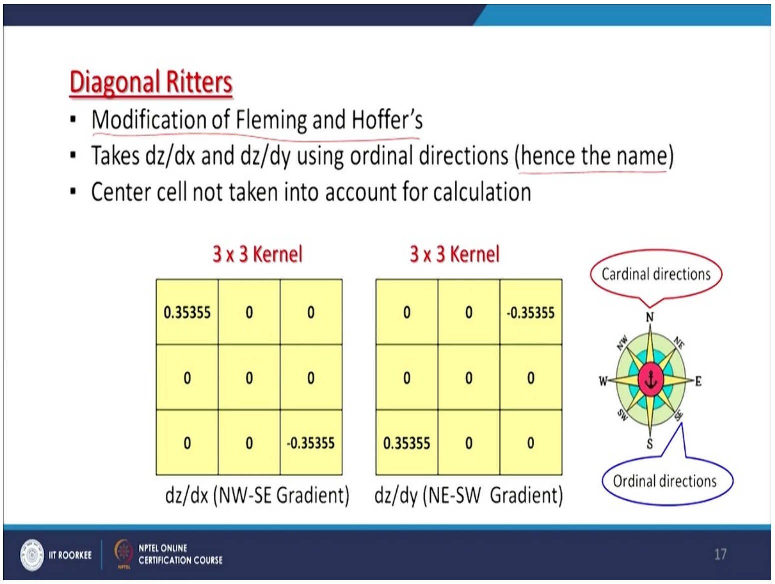

Now diagonal Ritters or diagonal methods are also there which is the basically modifications of flaming and Hoffer methods which takes dz/dx and dz/dy using ordinal direction and therefore that is why the name is diagonal. And the center cell not taken again into account for calculation like here and this is how the result will come about when you employ this diagonal ritter.

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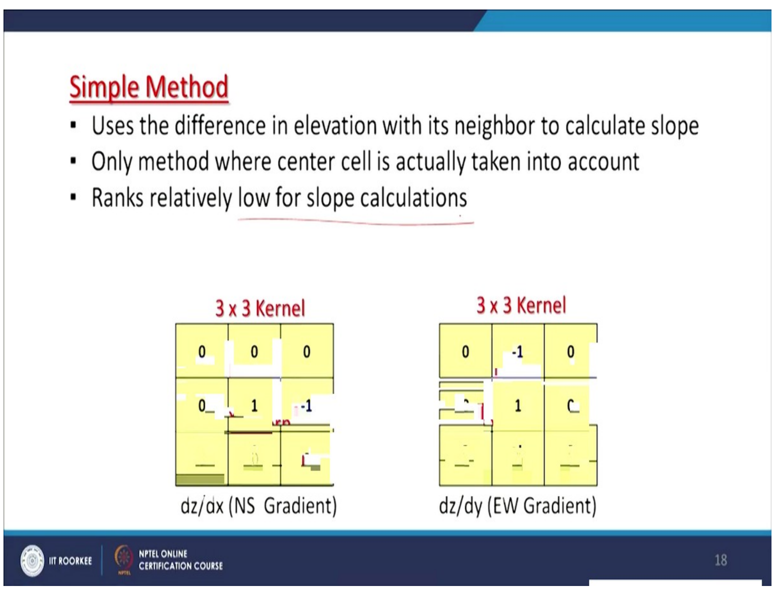

Various variants are available. The simple method is basically by the concept as which uses the difference in elevation with its neighbour to calculate the slope. So, whichever the cell against the center cell is having low value, that becomes basically the slope. The difference will decide the amount or in terms of degree, we can calculate and it will also decide the direction, both in cardinal and ordinary direction.

So, 8 directions would be possible, only that is basically decided for aspect. So, only method where center cell is actually taken into account is through this simple method. Ranks which relatively low for slope calculations because it depends on how people prefer. But this is what is the most popular one, though it may rank among calculations from very accuracy point of view may be low.

And this is how again this kernel; also, these roving or moving windows are also called kernel. So, you can do the calculation like this. Now I have already shown the same digital elevation model was subjected to Horn method. Now this is the Javen Berger and Thorne method.

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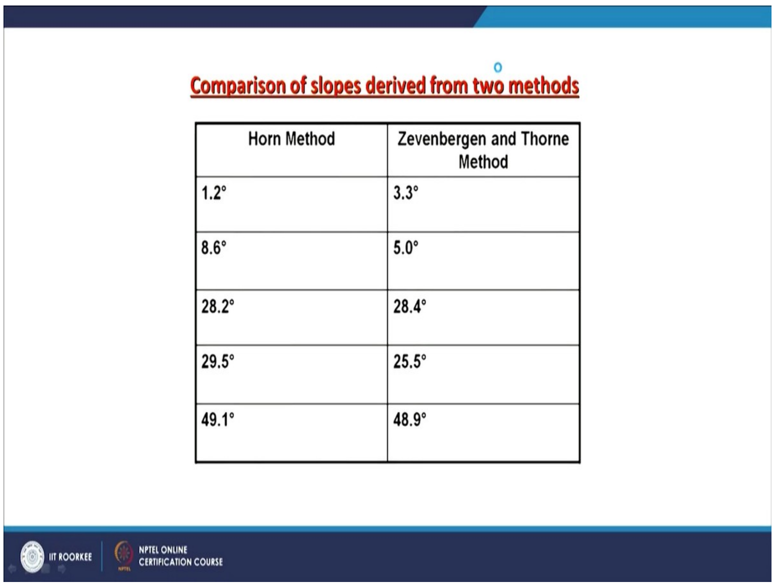

Horn Method	Zevenbergen and Thorne Method
1.2°	3.3°
8.6°	5.0°
28.2°	28.4°
29.5°	25.5°
49.1°	48.9°

I will also show you the comparison when the same digital elevation model was subjected to two completely different methods, this is how you get the results also. So, for one particular cell against cells so 1, 2, 3, 4, 5; against 5 individual cells when the comparison was made, here we are getting 1.2 degree, here we are getting 3.3 degree. So, it is more than double. Again here 8.6 degree, it is giving 5 degree.

So, as you go and towards higher degree, you may get a different thing. Now here it is almost same 29 degree; it is giving the lower value, 49 degree; it is quite close to that one. So, that means especially it is varying when we compare two slopes based on two different methods

Horn and Javen Berger and Thorne method. Now which one is correct, again it has to be decided the same way as we decide which interpolation method is correct.

You select certain points. If it is possibly, go in the field, check it and then choose the appropriate one. So, by this way, you can get otherwise the simple method or Horn method which has been implemented is a quite good. Except in certain cases, you may get lot of variations between two methods. But visually of course, you may not realize that they are having different values. But when you go and probe these derivatives or these products; slope products which have been generated using different methods on individuals cell basis, this is what the result you get that the slope values may vary very largely, especially at the lower end of the slope

So, with this, I end this discussion. Thank you very much.