Geographic Information Systems
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Lecture-46
Common Derivatives of DEMs - Slope and Aspect-03

Hello everyone! and welcome to a new discussion which we are going to have on slope and aspect. So, slope part; we have already covered. This is part 3 and which is one of the again important derivatives of digital elevation model, that is aspect. As you know that when we have been discussing about triangulated irregular network or TIN, that time we have discussed also about that aspect and slope; both are created simultaneously when you create a TIN.

But in case of grid or raster or typical digital elevation model, that has to be derived or created. So how it is done using a grid? We will discuss. Before that we have also discussed about these directions because generally slopes are created for 8 directions. So, Cartesian direction and ordinal directions; both are included.

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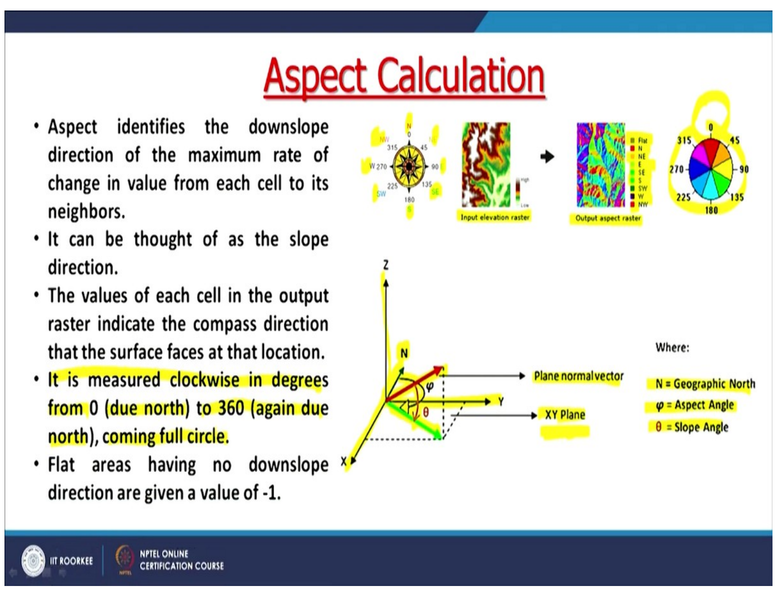

So, you know, you are having north direction, you are having south direction. Then you are having east, west. And then you are having ordinal direction; northeast, southeast, southwest and northwest direction so 8 directions. So basically, aspect identifies the down slope direction of the maximum rate of change in value from each cell to its neighbours. Like in case of slope map, what it is done? It searches the 8 surrounding neighbours of a centre cell.

And whichever is having the lower value or lowest value, that becomes slope basically. Now what should be the direction of slope, that can only be decided based on these 8 directions. And this slope or aspect calculation is done with reference to the north. So always you would see that like in a hilly terrain, some slopes are facing north, some might be facing south and so on. This is basically the direction of the sloping surface, that is what is aspect.

So, here this example you have also seen earlier that this is our input image and this is the output raster. Now here, you would find that there are all 8 directions including one for flat; the top one, because that flat indicating that there is no slope in the surrounding. All 8 pixels or cells are having same value as compared to the central pixel. And therefore, that area is identified as flat. So, in the legend, you will see that there are more than 8.

That is total number of 9 boxes or 9 directions are shown but remember one direction is always about the flat. Initially when the software was under development and this problem was became a sort of big problem because we are not able to identify very easily the flat part. But now there should not be any problem. Now you can either denote using your directions northeast or north or southeast or you can also have in degrees.

So, it starts with north which is always zero. And then moves up to 360 degree and goes back to 0 again. Now when we think about these slopping surfaces for calculation of aspect, you have to think short of in 3D concept so that all three axes are shown here there. This is the X-axis; this is the Y-axis which you are seen here and this is the Z axis. So, this angle between this plane normal vector and this; that is your θ which is slope.

Now with reference to the north which is shown here, the angle with that to this green line; that is sloping surface with reference to north, that becomes our aspect; that Φ angle. And north, you have already seen. So, this is our XY plane on which we project. This is very important because slope is measured in vertical plane whereas aspect is measured on horizontal plane and that is why this XY plane is very much required here.

So, with reference to north, whatever the direction that is projected on the flat plain. And then value is decided. Whichever the direction out of 8 direction or may be flat also. So, it can be thought as a direction of slope. Slope you get in the degrees or in percentage, that is the value but here, the direction for the aspects. So, the values of each cell in a raster indicate the compass direction with reference to North and which is facing the slope location.

And the measured clockwise in the degrees from zero as already indicated here, due north to 360 degree; again, to North and completing a full circle. So, in that way, we can cover the entire 360 degree or full circle. Now this is very important that flat areas having no down slope. In the surrounding directions are given value -1 to identify very clearly because all these values would be varying between 0 to 360 degree.

But here for the flat terrain, particularly in the software, it is assigned -1 value so automatically it can be identified that this is a flat terrain. Here you are seeing only 8 directions in the legend, plus one flat but in the system for each sloping surface, you can have the variations between 0 to 360 degree.

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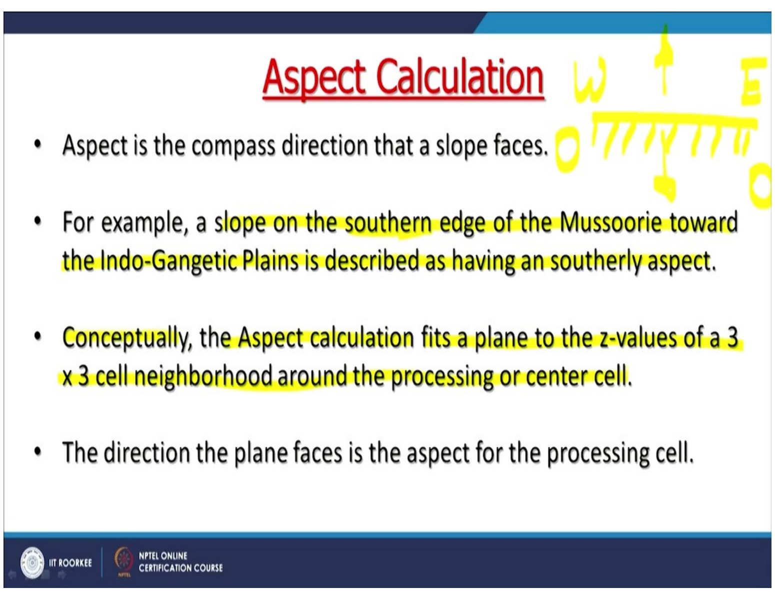

Aspect is basically the compass or magnetic compass direction; that is slope faces and for example a slope on the northern edge of the Mussoorie towards the Indo-Gangetic plains is described as having the southernly aspect. So, slope when it is facing Southward on the ridge, roughly the ridge is like east west and if I am looking towards the south then this sloping surface is southward or also be say, sun facing slope because in the morning, the sun is here.

And in the evening, the Sun go somewhere here. So entire day, the south facing slope faces sun whereas north facing slope on the other side or this Northern side, it will have hardly any Sun except in the noon time. So that is why, it is very important to find out aspects in many studies. For example, if somebody is working for snowmelt runoff modelling then one would like to know what is the slope direction, that is the aspect.

So, that it will know that whether that slope is facing the Sun or not. If it is Sun facing slope or southernly slope then it will have maximum Sun; maximum melting occurs. So, it depends the orientation of a Glacier or a slope. Similarly, lot of human activities most of the time in Himalayan Terrain are associated only with the southern facing slopes. Even if you go to Mussoorie, the maximum number of habitation or hotels or everything is in the southern side whereas on Northern side, generally would have forest.

This also becomes important in case of landslide studies or in case of even estimating the surface runoff because like arrangement of in case of Mussoorie, the monsoon generally comes from south and goes towards the north. So, when it hits the southern slope, it rains there. And many times, people have observed that Northern side of Mussoorie, you may not have rain whereas in southern side, you would be having rain.

Lot of landslides which are generally induced by an earthquake event has been observed occurring on the southern facing slopes because these slopes are most vulnerable from landslide point of view also. So, knowing the aspect of a slope of hilly terrain like Himalaya is very-2 important. Now as you know that conceptually the aspect calculation fits a plane to the z value of 3*3 cell, neighbourhoods around processing or the centre cell, almost the same way as in case of slope.

There are also a 3*3 moving roving window which goes through the entire dataset and will try to find out the direction of the sloping surface or sloping cell. So, the direction of the plane faces become the aspect for the processing cell.

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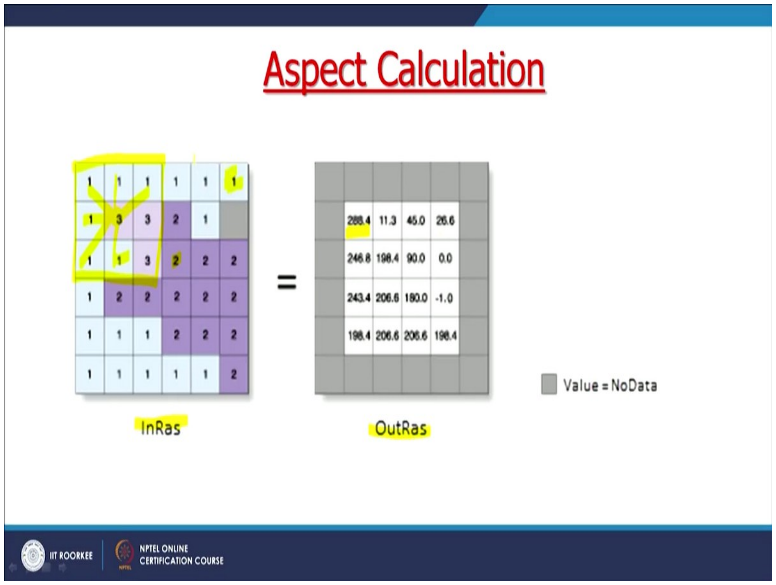

For example, here we are having an input raster. For simplicity, values have been kept either 1, 2 or 3 cell values. Here this is the output raster and now based on whatever the surrounding for each cell. Like if I take this example of this 3, then this will be considered and whichever is having lower value, that may be assigned that direction. So here, see with reference to this, this, this, this and this; all are having lower value than this.

That means that for this cell, this will have a slope or aspect which is having a very high value quite in the Northwest direction, as you can also see that it is in the Northwest direction. One important point you would also note, this I have been also discussing that one thick cell border will always be created whenever you are using this 3*3 Kernel. So, this 3*3 Kernel cannot move on the edges because if this cell is considered then I need further like this which is not possible to get the data.

So therefore, this is not possible. So, that is why on the edges, it cannot perform calculation and hence no data value is assigned. So, this is just a schematic. You are not handling such a small matrix or small raster. You handle a raster which is quite big. So visually, you do not see that on all sides, that is the border of one cell thick is having no data but it should have if the program has been properly made or coded.

Then it should have a border of one cell thick all around. Now like when we have been discussing the slope.

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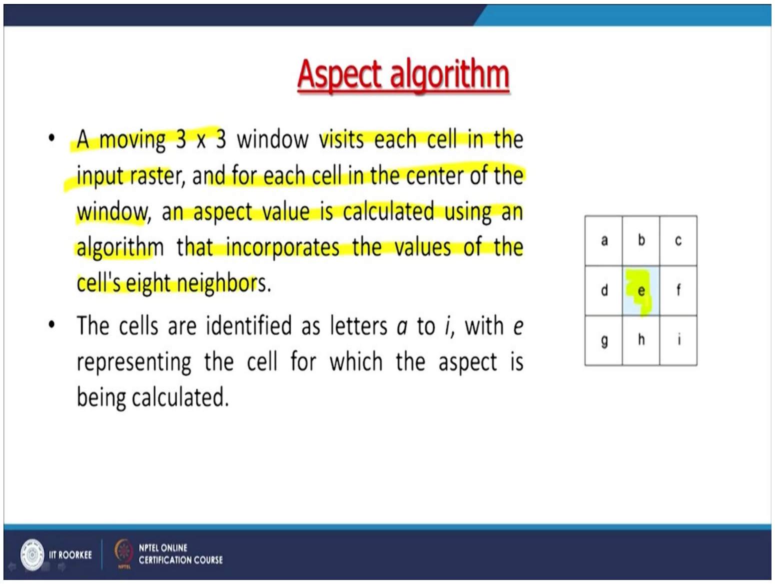

Similarly, here also in case of aspect, there is moving window 3*3 kernel visits each cell in the input raster and for each cell in the centre of the window, aspect value is calculated using algorithm that incorporate the values of the cells 8 neighbours. So, all 8 neighbours are searched and then value is assigned. Now the cells are identified here in forever simplicity as a to i with e representing the centre cell here, for which the aspect to be calculated.

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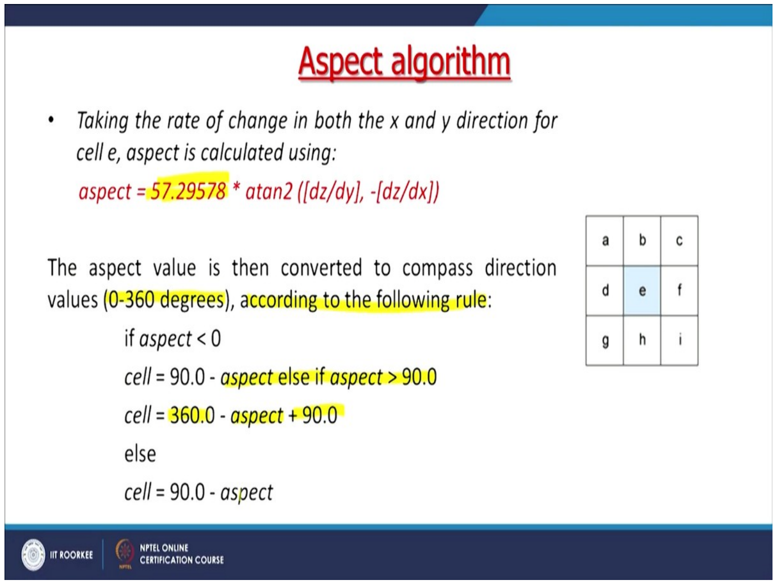

Now taking the rate of change in both X and Y direction for the cell that is coming the slope. For e cell, the aspect is calculated using like this. So here also, you are having a constant and ATAN; that is dz/dy and then minus dz/dx. The aspect value is then converted to compass direction values, between 0 to 360 degrees according to the following rule. And that rule is if aspect is less than 0, then it is of course flat.

If cell is having 90, the aspect else is greater than 90 then cell is 360 degree then aspect + 90 and else, then cell = 90.0 - aspect. So, this way for each input cell, the calculation is done for aspect determination except for one thick cell all around for the border area.

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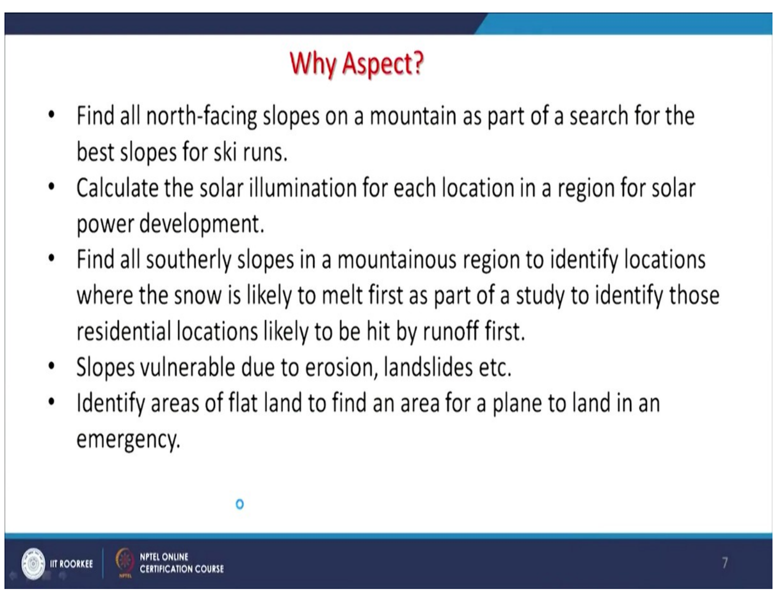

Now this point I have already touched little bit but I will go for completeness. I will go through one by one. Why basically aspect; why we want to calculate aspect? As you know that in mountainous terrain, this north facing slopes are good for certain things. But south facing slopes are good for certain thing. So, if somebody is looking for a ski run or sports which are related with snow or ice then north facing slopes are very good because they will not receive much Sunshine except in noon time.

Contrary to this, southern facing slopes will receive more Sun shine. So, if somebody is looking for solar illumination, for each location in a region for solar power development then aspect calculation would be required. May be for find all Southern slopes in the mountainous region to identify locations where snow is likely to be melt first because it will get the maximum Sun shine. As part of a study to identify those residential locations likely to be hit by the runoff first.

So far lot of modelling, lot of analysis and natural disasters, aspect becomes very-2 important. Slopes vulnerable due to erosion, landslides. And most of the time, you would observe that southern facing slopes will face these problems of erosion, landslides or flooding because they receive the Sun; they are most vulnerable slopes. Identify areas of flat land to find an area of plane in an emergency.

So even in a hilly Terrain, if you run a slope calculation, you can find out which are the flat areas available which can be used for landing of a plane or development of an airport or runway or whatever. So, it has got a lot of applications. Now when we go towards the calculations based on a software like example, we are taking here is ArcGIS. It is not necessary that you should also use. You can also use QGIS P-map or you know, Intergraph software for Geo media or many-2 GIS software's.

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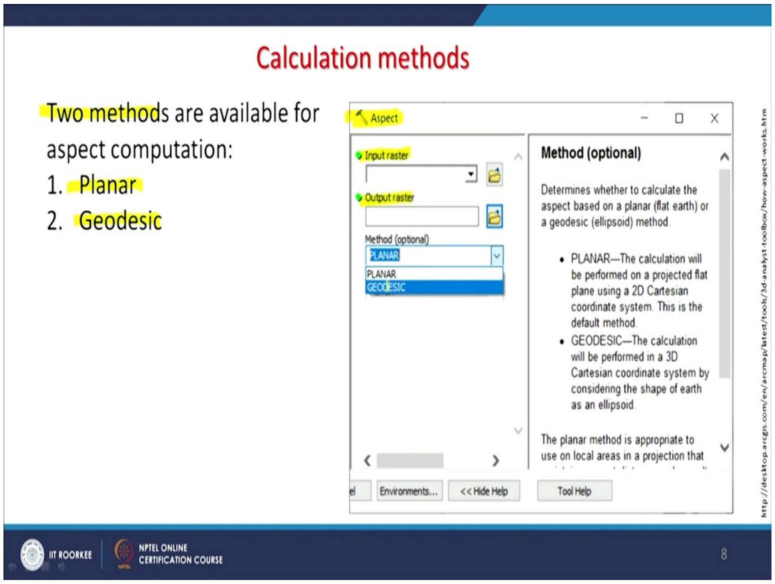

There, almost similar option should be available. So, again 2 methods like in case of slope. Here also two methods: one is the planner method; another one is the geodesic method. As soon as you go for this tool aspect calculation, these options are available to us. Only you have to provide input raster, you have to provide where the output raster would be located and then you provide either one in these methods. By default, the Planner is there. Help is always available, should be available in all good software.

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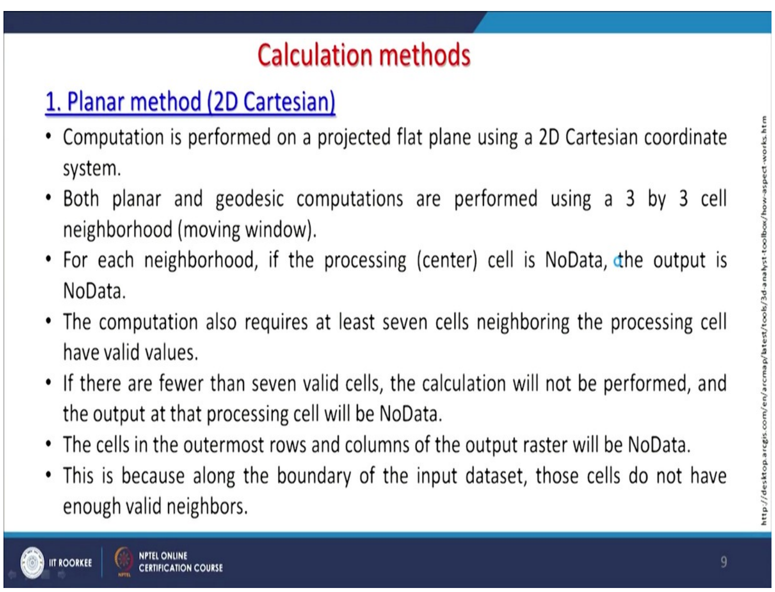

So, what these will do? As you know also that planner method is for 2D Cartesian and that another method, that is a geodesic method is for 3D Cartesian. So let us go for discussion of planer method; that this computation is performed on a projected flat plane using a 3D Cartesian co-ordinate system. I have already told you that aspect is calculated or measured on a plane or on a horizontal plane, not on a vertical plane.

For the slope, it is measured on a vertical plane. So anyway, we need a flat surface or plane. Now both planner and geodesic computations are performed using 3*3 neighbourhood moving window. This is another standard which is followed by most of the software, rather than going for 5*5 or 7*7 Kernel, generally 3*3 has been implemented. Now for each neighbourhood out of those 8, if the processing cell or centre cell is no data, the same condition as in case of slope calculation; the output will also have Nodata.

If input is Nodata, output would also have Nodata. Further in computation also requires at least 7 cells bearing the processing cell have valid values. So, at least 7 cells must be there. If you are having less than 7 cells, means more than 1 Nodata then calculation is not possible. If there are fewer than 7 valid cells, the calculation will not be performed. The output of that processing cell will be Nodata. And then cell in the outermost rows and columns which I have repeatedly mentioned, will have Nodata because beyond that, you do not have the input.

So, this condition of the requirement of 7 cells cannot be fulfilled for border cells. And therefore, border cells one thick cell both in rows and columns will have Nodata and this is also along the boundary as input dataset, those cells do not have enough valid neighbours. So, because this is neighbourhood operation, a 3*3 kernel moves all around but, in the corners or in the border area, it cannot be done because you do not get the required number of neighbours and therefore calculation cannot be done. This condition is true; both in case of slope calculations as well as in aspect calculations.

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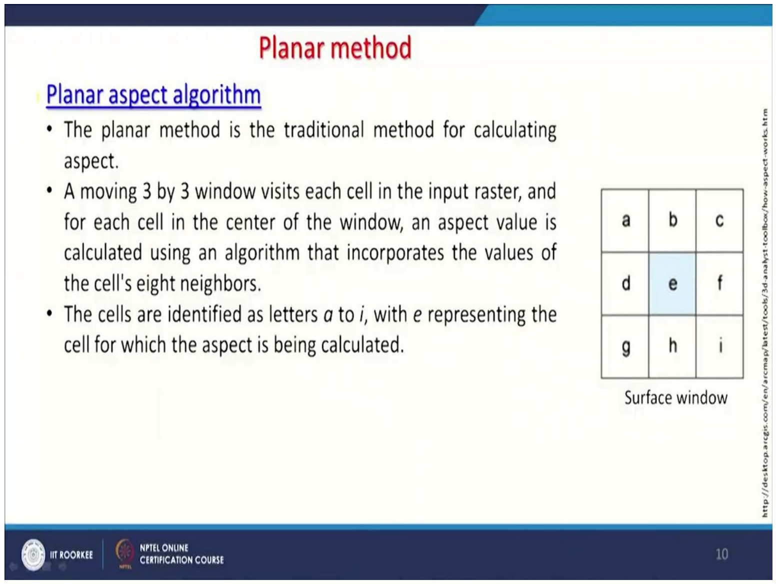

Now when we go for this planner aspect algorithm then this planar method is traditional method for calculating aspect. But there are some other developments have also done. Then the moving 3*3 window visits each cell in the input raster and then each cell of the centre window and aspect value is calculated using an algorithm that incorporates the values of each 8 neighbours or cells neighbours.

Like here again, you are having cells in our moving or roving window; that is a to i so the cells are identified latter a to i with e representing the cell for the aspect is being calculated.

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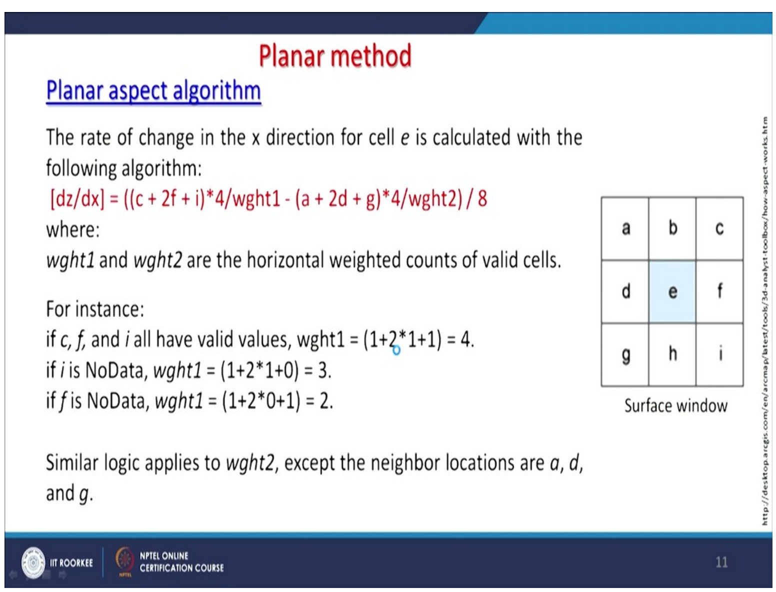

Here the weight concept may not be possible because here for all 8 directions, we have to calculate the value. Now further when we go towards the More algorithm, this is how the rate of change in X direction of a cell e calculated with the following algorithm and whereas weight 1 and weight 2 are the horizontal weighted counts for valid cells. And for instance, like this you can have different things but this is not really you know implemented in that sense that for each direction, you have to have the calculations for directions.

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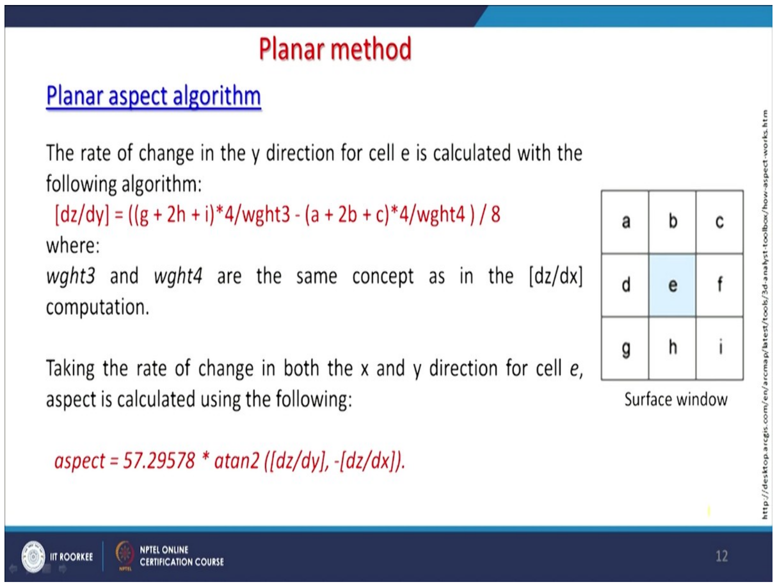

Further, for rate of change in Y direction. Earlier it was in X direction. Similar things you would do and then taking the rate of change in both directions X and Y for each cell, the aspect is calculated using the following formula which is

$$aspect = 57.29578*atan2\,([dz/dy] - [dz/dx])$$

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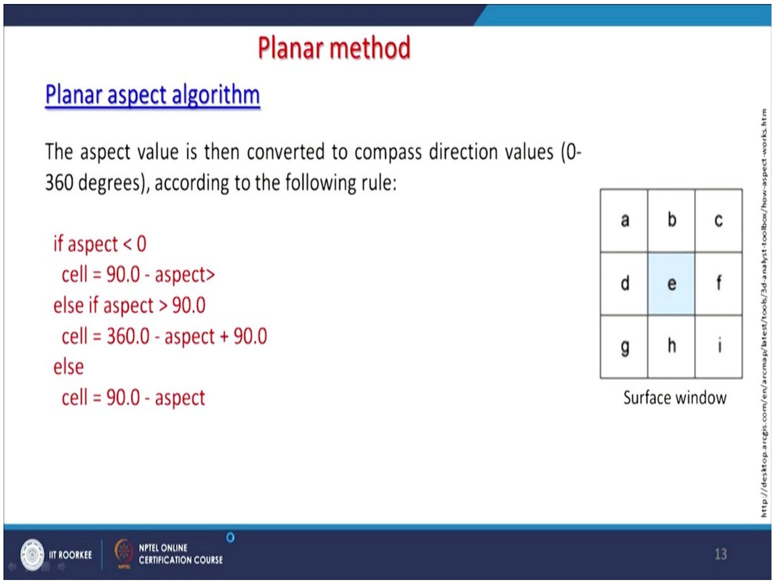

Now the aspect value is then converted to compass direction which between 0 to 360 degree according to the following rule which we have already discussed. The condition is here that if aspect is less than 0, the cell 90 (degree) - aspect will be done. If aspect is more than 90 (degree) then cell 360 (degree) - aspect + 90. And else, cell 90 – aspect, by which you can do the calculation.

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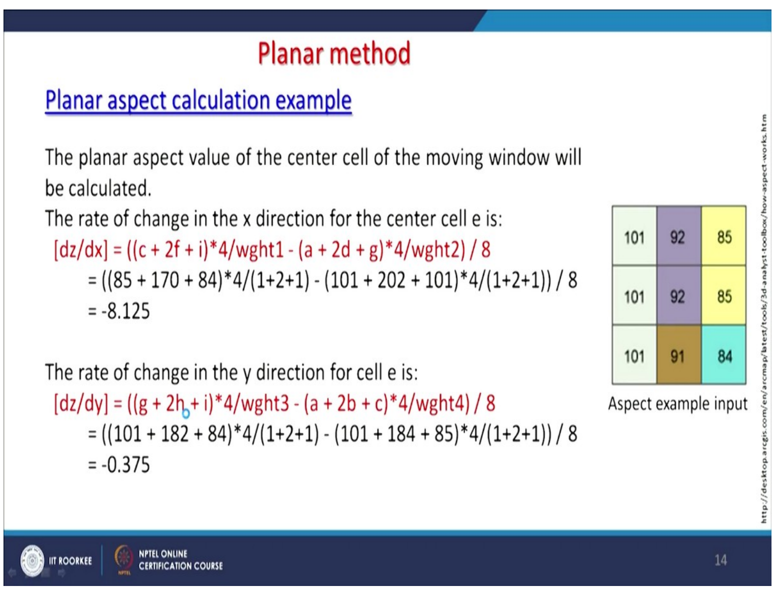

Example is given here. This is my aspect calculation. So, this is my input raster. Only 3*3 example is given here. Values are substituted for x direction equation and values are substituted for the y direction equation and then you get these values.

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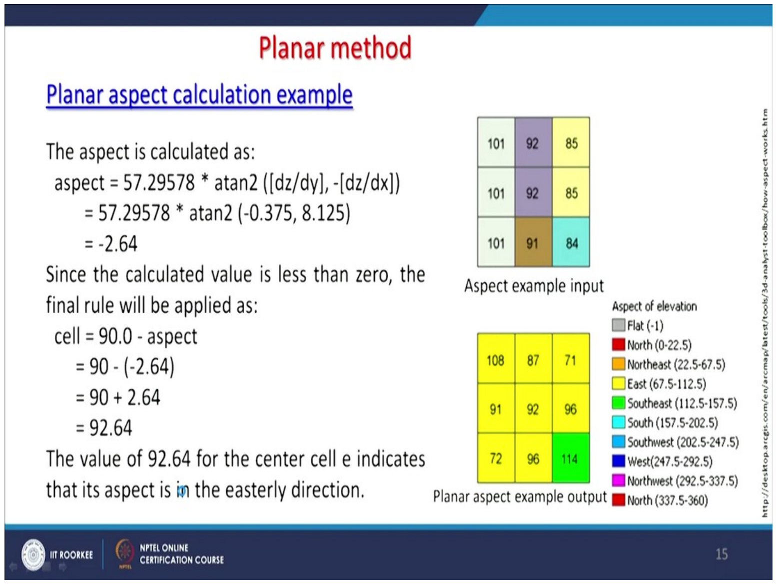

After this, you have to combined one and once that you combine, the value becomes 92.64 for the centre cell e indicates that the aspect in the easterly direction. So, likewise the calculation is done. So, this was my input and this is my output. You can also see that here like 84 is the minimum and therefore it is having you know the value as per the slope direction. This is 140 value which is falling in this one, that is the southeast one. So likewise, the calculation is done.

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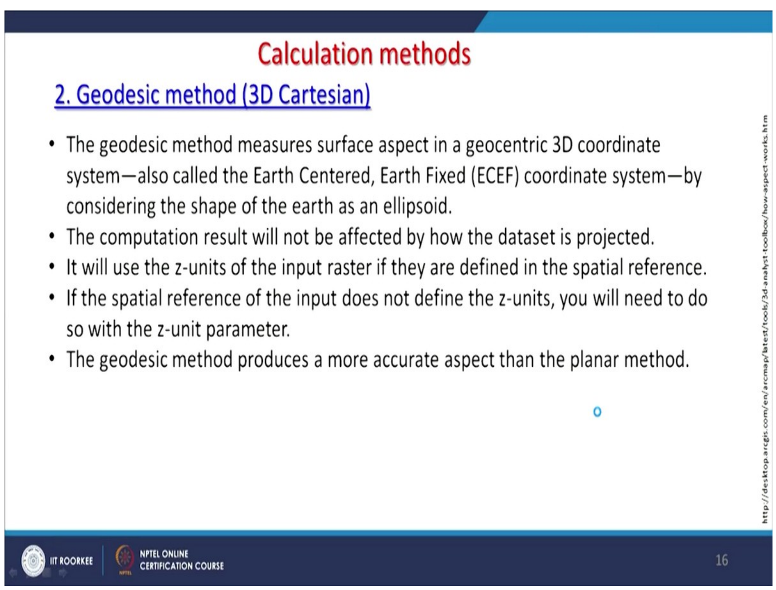

Now when we go for geodesic method; that is 3D Cartesian. The geodesic method measure surface aspect in geo centric co-ordinate system; again, that Earth centre, Earth fixed co-ordinate system. And the computation result will not be affected how the dataset is projected because this projection part, we have already discussed in theory. So, we have to be little careful while doing. However, in these particular calculations, no effect take place.

It will use z units for the input raster if they are defined in the spatial reference. And the spatial reference of input does not define the z unit and one have to do with z unit parameters. Geodesic method produces more accurate aspect than the planer method but it will involve lot of calculations.

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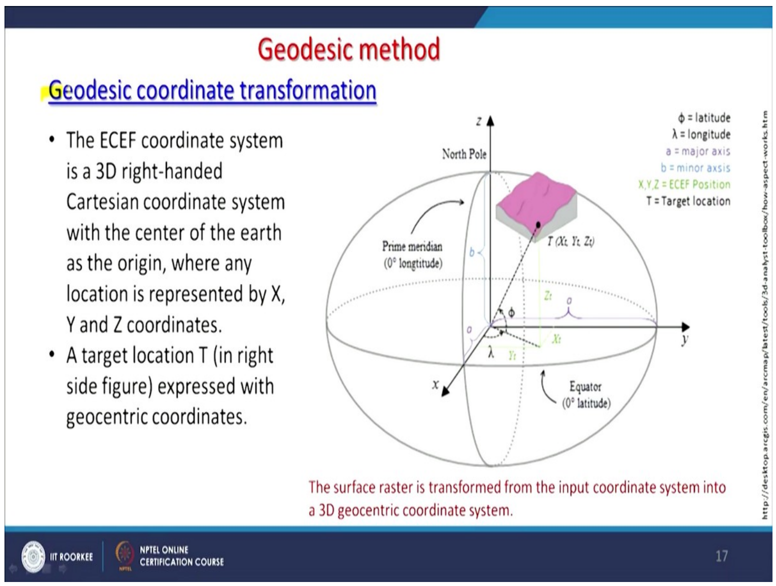

So, this geodesic co-ordinate system; that is Earth centre, Earth fixed co-ordinate system. The same concept is also used in case of global Navigation satellite systems where the centre of the Earth is taken like this. This is little exaggerated in sense that on the Polar Regions, it is a suppressed just to enhanced that part in our diagram.

So, these ECEF co-ordinate system is basically 3D right-handed Cartesian co-ordinate system, with the centre of the earth as the origin and where any location is represented by X, Y and Z like here, it is being done. So, a target location T in this figure express with the geo-centric coordinates that target location T.

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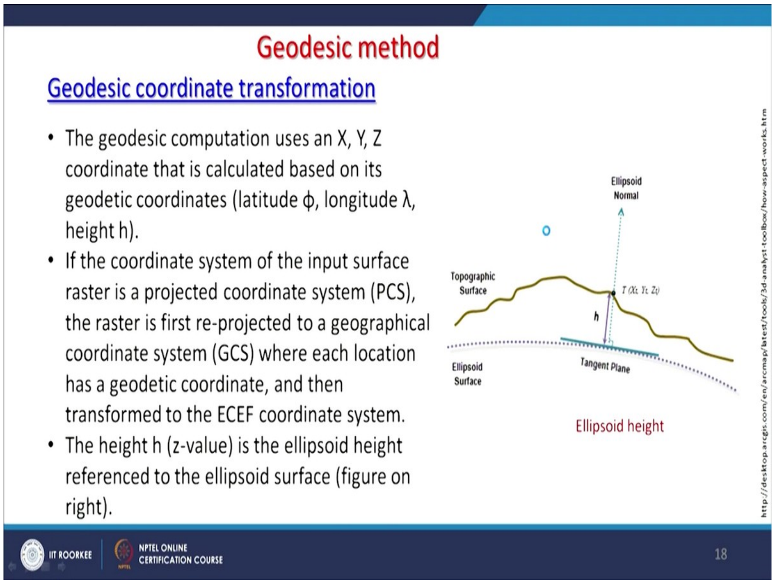

Now using this, you can again calculate aspect more accurately. Same discussion also about geo-centric or geodesic coordinate transformation, we have discussed in slope discussion. So, I will move forward on this one.

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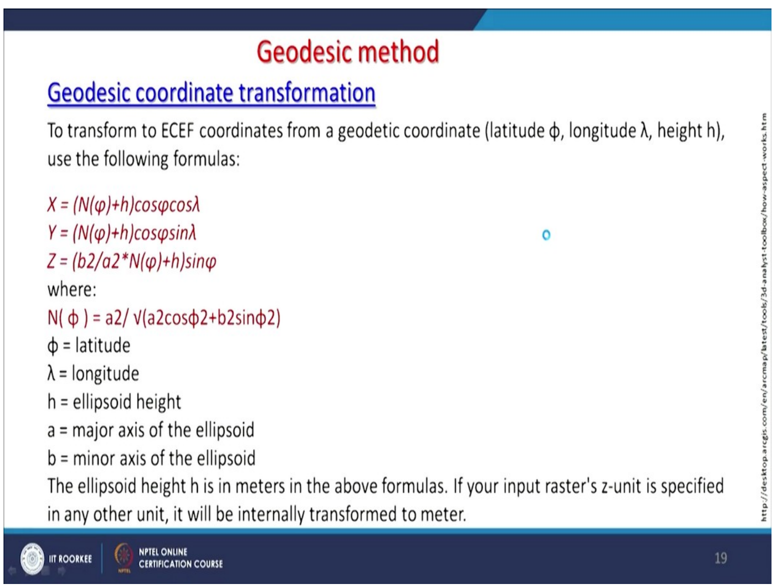

Now in these transformations because it has to be done for all three direction because this is 3D Cartesian system so it has to be done for X, Y and Z also. And then there you will have these formulae and this is for latitude, longitude and other details are also there for ellipsoidal height because Z is involved so that will also play a very important role.

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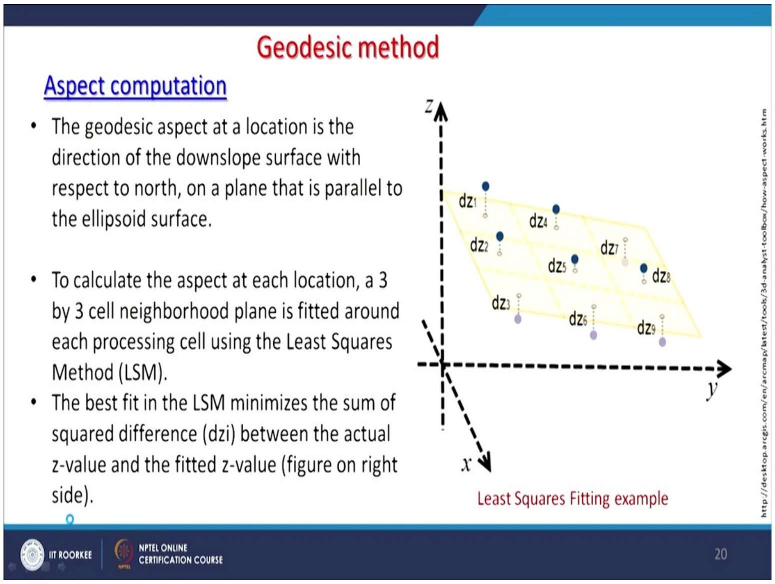

Now in this geodesic calculation of aspect is the direction of basically down slope surface and measured with reference to the north, of course on a plane that is parallel to the ellipsoidal surface because it has to be only measured in a horizontal plane basically. To calculate the aspect at each location, a 3*3 again neighbourhood window or kernel is fitted around each processing cell using the least square method.

And then the best fit for this LMS minimizes the sum of squared difference; the dzi and between the actual z value and fitted z value.

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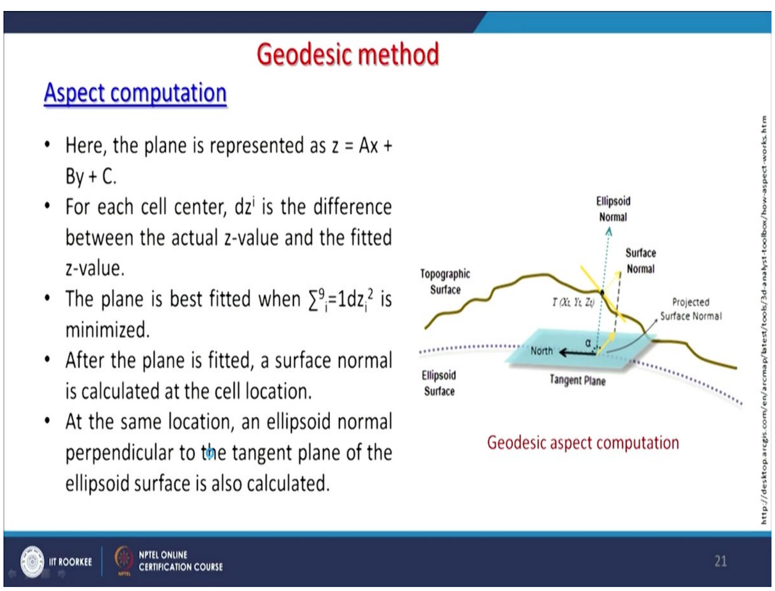

So, in this calculation, the plane is represented as z = Ax + By + C and for each cell, dzi; the difference between the actual z value and the fitted z value because here, we are taking one ellipsoid. So, there will be a difference in the z value. So that has to be also counted while doing this aspect calculation employing geodesic 3D Cartesian system. Then plane is fitted with this formula which minimizes the variance.

And after the plane is fitted, a surface normal is calculated like this that the surface normal is calculated and at the same location, an ellipsoid normal is also there which is perpendicular to the tangent of the ellipsoid surface is also calculated. And likewise, this tangent of the ellipsoid surface is considered reference plane. So, this plane becomes our reference plane.

Again, we are you know coming to that point where the aspect is always measured in horizontal plane. So, this surface is perpendicular projected onto a plane and finally, the geodesic aspect is calculated; measured the angle α, clockwise direction between north and the perpendicular projected normal which is here. So, if it is towards west then this angle will be calculated.

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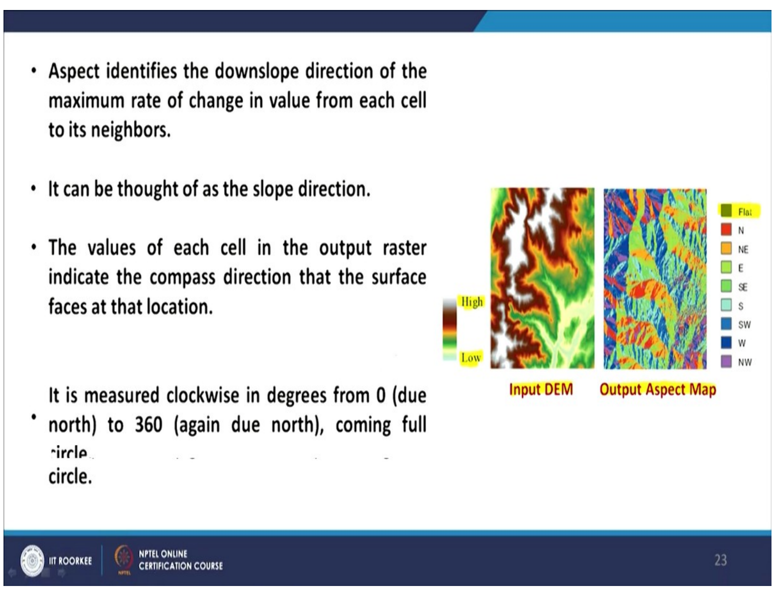

Now, see some examples here. This is my digital elevation model and these are representing low elevation value, high elevation value. When this is subjected to aspect calculation, this is what I see. The aspect is here. Of course, the flat part is always depending whether that area is having flat part or not. But generally, few cells will be counted or will be identified as flat part. So, aspect basically identifies down slope direction of the Maximum rate of change in the value from each cell to its neighbours which are 8 neighbours.

And it can be thought as a direction of a sloping surface and values for each cell in output raster indicate the compass direction. And measured clockwise in degree 0 to 360 degree. Flat areas having no down slopes directions are given -1 value.

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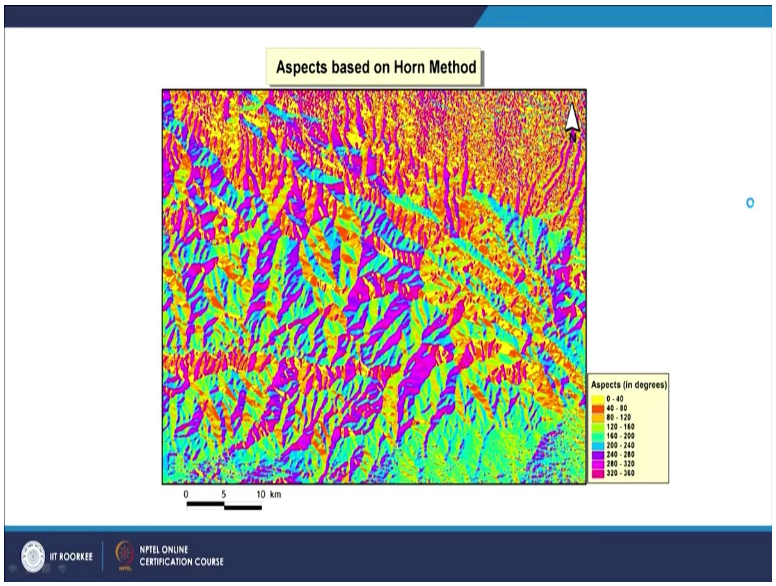

Now like in case of slope, there are also little variants are available. Either you imply for Horn method which will bring some changes or Javen Bergen and Thorne method which we also discussed these same methods for slope calculations.

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Comparison of aspects derived from two methods

Horn Method	Zevenbergen and Thorne Method
9.0°	10.1°
52.0°	49.6°
97.1°	102.7°
134.4°	135.7°
171.8°	168.1°
215.2°	211.7°
256.7°	259.0°
333.8°	331.3°

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When we do the comparison, we find that there are variations. And let us see that for Horn method and Javen Burger method for certain identified cells. So, 2 such aspect maps were generated using the same digital elevation model. And randomly few cells were identified which have been explored further to see what are the values they are carrying about the aspects. So here in Horn method, it is coming say for one cell, 9 degree.

For the same cell in this map; Javen Burger and Throne method, it is coming 10.1. So, some variations, you can observe. Like here in larger or in the West or northwest direction here, 215 it is coming, it is 211, 256, 259, 333 and 331. In slope map, the variations were much more as compared to aspect maps created using two methods. So, definitely each method will have own advantages and disadvantages.

Now which one to choose? Like when we discussed slope part, we said that like in ArcGIS software or many software, this Horn method has been implemented so in case of aspect calculation also, horn method has been implemented. But if somebody would like to create this one, then the tools are also available. May not be within that software, you have to search the net. Very other important thing is that once you have created a slope map. You have also created an aspect map.

You can combine these two maps and can create a new output which would be more useful than individual maps.

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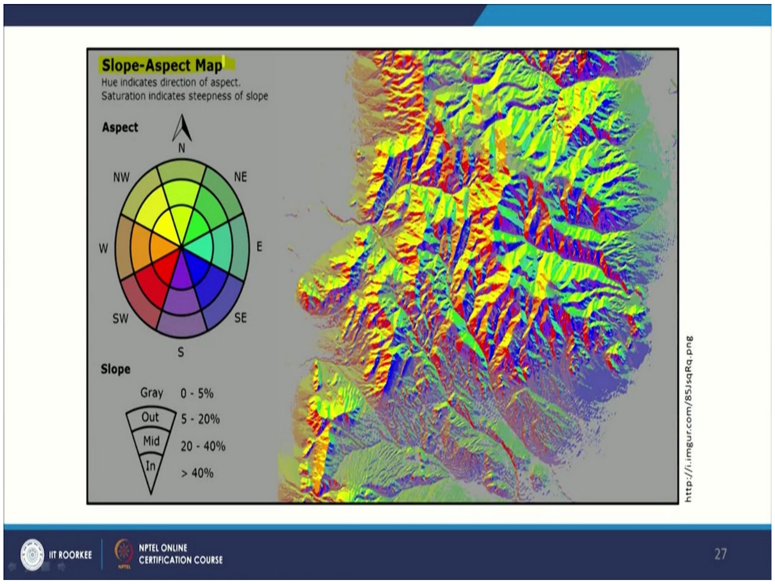

This is what it has been done that slope and aspect map, this is very interesting; one can try whatever the software you are using. And little different way, you have to interpret this one. So, what it's saying that hue indicates direction of the aspect. So, which direction? Like if I am getting like these light green colour, then that is the north facing slopes. If I am getting the blue colours, then I am talking of southeast colour.

If I am getting red colour, that means I am talking southwest colour. So, this hue indicates the direction of aspect of sloping surface and saturation indicates the steepness of slow; that is the Value of the slope. So, more the colour you are having, more the slope you are having. Though it is shown in terms of percentage, does not matter. So, as you are going inside of the circle; the above one, you are finding that this saturation of colours is increasing.

So similarly, here if take any sloping surface here, I am getting very bright colour in this part so for green. So that means they are having high slope values and direction is towards the north, for the light green fully saturated colour. If I am getting fully blue colours like here, like which I am getting here, then what I am saying that means the slopes are facing towards southeast and there you know in terms of percentage, the slope is more than 40%.

So, a combined or joint or composite can be created employing both these maps otherwise people generally interpret these maps separately or utilize these maps separately but by this scheme for aspect and slope. So, aspect is being represented with colours and this slope values are being represented with the saturation of colour, one can create some beautiful output. So, this you can also try on your software.

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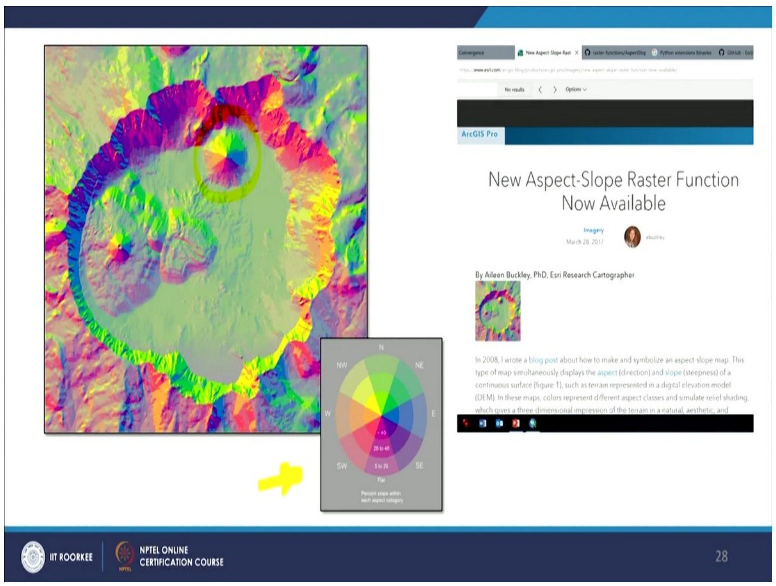

Another example using the same technique as it has been tried on a crater and there you see that similar scheme is there. Like a very saturated yellow colour, that means the slopes are facing northwest direction. If I take this central part of my crater, here many colours are there which are very nicely depicting the sloping surfaces and their values. So here near the top, you are having very high slope values.

And therefore, the colours are saturated. As soon as you go towards the bottom of the hillock within that creator, you see a completely different or changes in colour or changes in saturation of colours, like as indicated in this legend or index circle. This in ArcGIS Pro in new aspect raster tool function available. Otherwise in other software’s if it is not directly available, no problem. You are having set of tools in your software. You can definitely try and can create similar products very easily. So, with this, I end this discussion. Thank you very much.