Geographic Information Systems
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Lecture-48
DEMs derivatives-1

Hello everyone! and welcome to new discussion. Basically, it is a continuation of our earlier discussions on derivatives of DEM. But those we kept focus mainly on slope and aspect, though they are also part of our terrain analysis but we put them in a very common derivatives or standard derivatives of digital elevation model. When you use the raster data set like digital elevation model or a surface, you have to create slope and aspect as you have seen including in our demonstration.

Whereas when you use TIN model; there you do not have to create a separate slope and aspect maps. The slope and aspect maps are created simultaneously when TIN is created.

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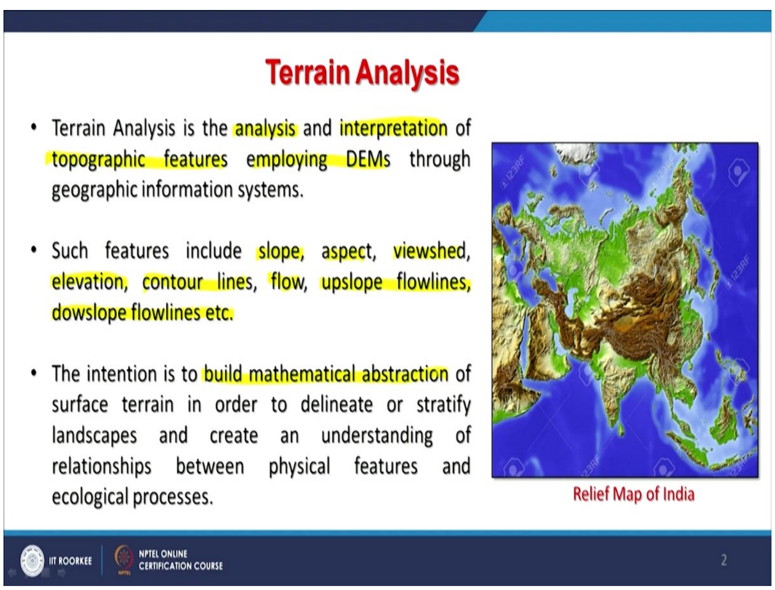

So, for terrain analysis, definitely you need not only slope and aspect information or maps but much other information also. So, this discussion will go on about the different derivatives of DEM and we seen 2 major one; slope and aspect. Now we will continue on this. So, as you know that this terrain analysis includes basically analysis and interpretation of topographic features. Here, I would like to spend some time on interpretation.

Why it is very much required because earlier when we did not have much digital data and people used to have prints of say for example aerial photographs or satellite images or even a topographic map. People used to study these things, that means people used to interpret these things. I remember that we were told to study the toposheets; that means we are interpreting the toposheets, looking the contours, looking the drainage pattern and looking other features which were present on a toposheets.

Similarly, same with the satellite images. So, this analysis and interpretation rather than focusing more on processing because things were not in digital form. So, rather than focusing on processing, our focus was on interpretation and analysis. So, definitely whatever the data you get, one should analysis things like when we are seeing the demonstration of a slope and aspect then software may support various types of methods.

So, which one is suitable for that particular data set which belongs to my area of interest? Then I can try few methods, can create various products and then compare them; do the interpretation and analyse them. Whether things are in order or not. So, this is the analysis and spatially the interpretations, that focus should always be there. Whatever the data, whether satellite data or digital image or your digital elevation models or even a toposheets.

Lot of time we should spend on this Because processing can be done by a technician but the interpretation or that skill which you develop is unprecedented which cannot be replaced by any machine. So basically, for terrain analysis what we do? We do the analysis and interpretation of topographic features that means basically geomorphic landforms which are present on the land or the surface of the earth.

And basically, what we do in this GIS platform? We do this kind of topographic features analysis and interpretation. We employ digital elevation models on a GIS platform. So, this is very simple what we can define what is basically Terrain analysis? And these topographic features which we are talking includes the slope and aspect which we have already discussed. Also viewshed; viewshed analysis again is very-2 useful in many applications.

Then elevation differences and profiles and other things. Then contour lines, flow directions of say water or some pollutants and other things. Upslope flow lines and down slope flow lines etcetera. All these and there are various derivatives of digital elevation model. Most of those are part of terrain analysis and in modern days, we employ digital elevation model on a GIS platform and perform the terrain analysis.

Earlier when we did not have these facilities, that terrain analysis must be performed either using aerial photographs or survey toposheets but now we are having advantage of having digital elevation model and GIS. Basically, the purpose of Terrain analysis is to build mathematical extraction of surface terrain in order to delineate or stratify landscapes. Whatever the landforms which are present, how they are there, can be represent them through mathematical functions and create an understanding of relationship between physical features and ecological processes.

So that to be can include under this Terrain analysis, that means analyzing things related with the topographic surface in a comprehensive manner. So not only you are doing a physical analysis. Our physical features are involved in analysis but ecological processes are also there.

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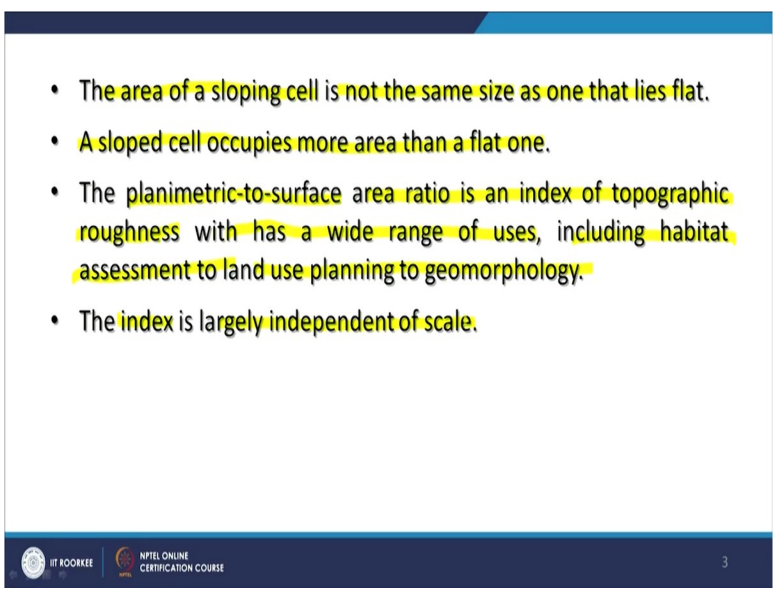

Now as you know that areas of a sloping cell of digital elevation model which has been subjected to create a slope map is not the same size as one that lies flat. So here, what basic point is coming; that you know, when we go for this terrain analysis, the major thing is coming if any area is flat. And see if I am having a digital elevation model of 30m * 30m, that means 30 meters of spatial resolution. For flat area, it would be simply 900 square meters.

But if it is not flat and if it is inclined surface then the area is going to be different than what is flat area because this measurement which I am doing or when we say spatial resolution; we are always talking in terms of horizontal plane but when you know landforms are having slope or facets are having slope or inclinations then the area may change because length will also change. So, this thing is important here that the area of a sloping cell is not same size as one that lies flat.

So, the flat one will always less area. The length will also be less as compared to inclined one. Now the sloped cell occupies more area than a flat one. So, we can give a new term that when we say flat, it means we are talking to planimetric surface. And planimetric surface means we are talking about a flat surface in a horizontal plane. And whereas when we say surface, we are talking about inclined surface. So, planimetric to surface area ratio is an index of topography roughness.

This topographic roughness becomes very-2 useful input for various kind of analysis like for example in erosional studies, in landslide studies or in many ecological assessments also. So, planimetric to surface area ratio is an index of topographic roughness with has a wide range of uses. I just narrate it few, including habitat assessment to land use planning to geomorphology. In recent years, the maximum beneficiary of digital elevation models and GIS platform is geomorphology and a new branch of geomorphology has emerged which is called quantitative geomorphology.

And this is playing very-2important role. Quantitative geomorphology not only interesting in part of field of earth sciences and geography but it is also very important in civil engineering especially related with hydraulics and other engineering. So, quantitative geomorphology is very-2 important for many things including your flood analysis and all. So, whatever related with water and engineering, there geomorphology can play a very important role.

And obviously quantitative geomorphology can provide a direct input to various models which are used for estimation of flood inundated areas or snow melt runoff and for many-2 other things. Now this topographic planimetric to surface ratio which we can also called as index is largely independent of scale. So, whether you are using a 30-meter spatial resolution data or 90-meter spatial resolution digital elevation models, still this ratio would be there. That means there will be difference between planimetric area and surface area.

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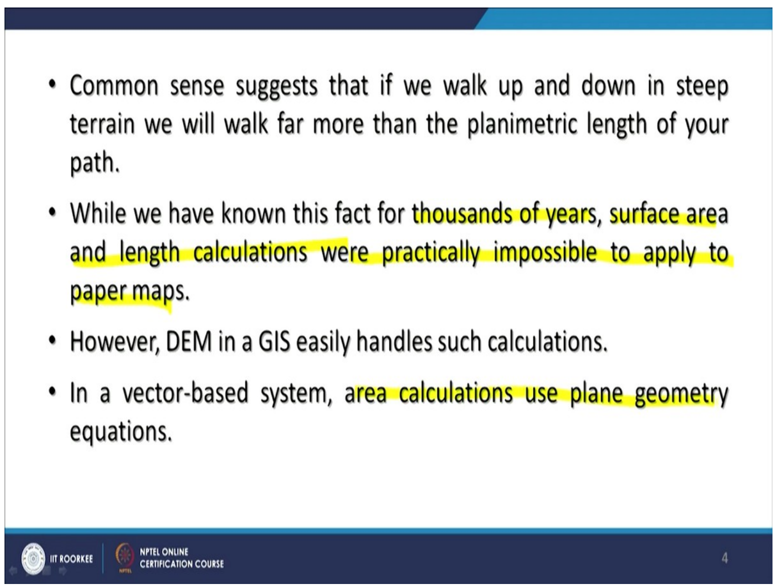

As we know that in our day-to-day life that if we walk up and down in a steep terrain, we will walk far more than the planimetric length of your path. So, in flat, your planimetric length is always less than what you get surface length in a hilly terrain. While we have known these facts for thousands of years, the surface area and the length calculations were particularly impossible to apply to paper maps such as topography map.

So, using topographic maps, it was not possible to find out what is surface area or what is planimetric area or surface length or planimetric value. But with employing digital elevation model on the GIS platform, it has become definitely possibly. GIS allows us to handle a digital elevation model and also allows us to perform such calculations. In a vector-based GIS, area calculation are plane geometry equations.

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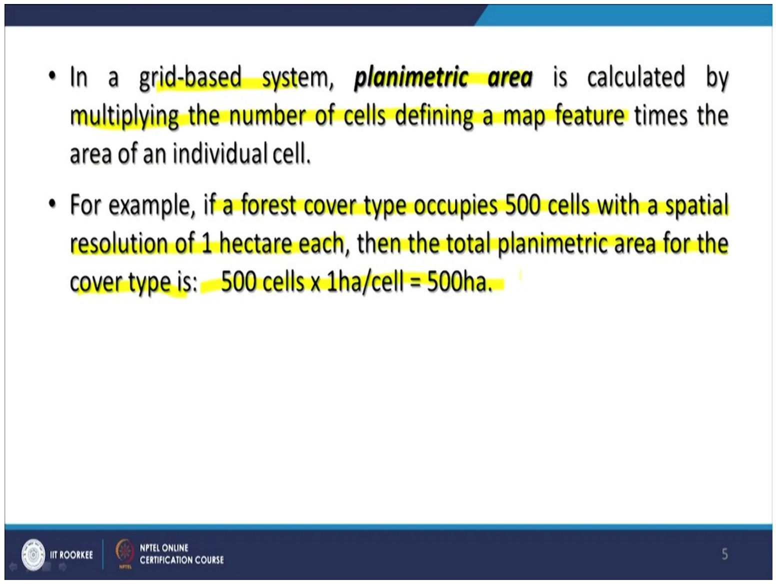

Whereas in raster or in a grid-based system, planimetric area is calculated by multiplying the number of cells defining map feature times the area of individual cell. So planimetric area calculation is very simple because we know that the area of one cell and that ground area which is representing say 30m * 30m; that is 900 square meter and if we are having 10000 such cells in our data and we will multiply by 10000 to get the correct result. For example, here if forests cover types occupies 500 cells with a spatial resolution of one hectare each then the total planimetric area for covered type is 500 cells * 1 hectare / cell = 500; simple calculations.

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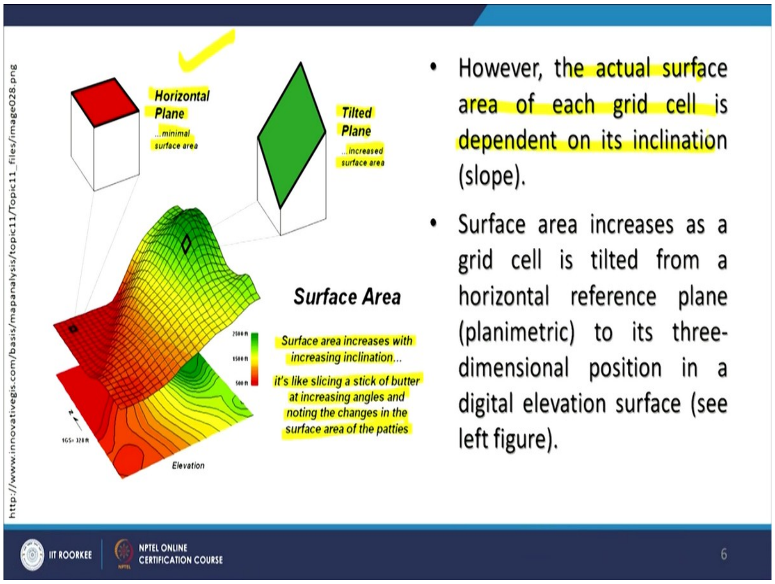

But when we go for surface area calculations or surface length calculation then things will be different. Here both examples are given; this is horizontal plane or planimetric surface and this is the tilted or inclined surface. As you can see here, of course for our understanding this has been exaggerated in this schematic. So, this is going to be the minimal surface area if it is flat or when it is measured on a horizontal plane, whereas this tilted one or where the sloping surfaces are there, this will be increased surface area as compared to your planimetric area.

Which is depicted here that the cell though in our raster format or any digital elevation model, this will be representing a square area but that square area is not truly on the ground as a square but it is a surface area. So, in sloping conditions, the area is going to be more. But if by mistake somebody does the calculation only using horizontal plane then basically, he is underestimating and I tell you I know various projects picture failed because people have underestimated the earth work for example.

Using just planimetric concept and assuming everything flat like employing survey toposheets, calculated the length, area and grocery underestimated the work. And later on, such projects go in real trouble. So, nowadays it should not be done in that way. If it is you know an inclined area or sloppy land then the surface area should be calculated rather than planimetric area. So, surface area increases with the increasing inclination.

So, in a highly rugged terrain, this situation will increase; that means the surface area will increase much more than in a flat part. It is like slicing a stick of butter at increased angles of noting the changes in the surface area of our sliced or patties. So, that is why it is very-2 important to understand this difference that planimetry area or planimeter length will always be less compared to your surface area or inclined area.

So, this actual surface area of each grid cell is dependent on its inclination so it's basically inclination dependent. And surface area; this we have already discussed increases as a grid cell is tilted from a horizontal reference plane, that is planimetric to its 3-dimensional position in a digital elevation surface and like here which is just we have discussed.

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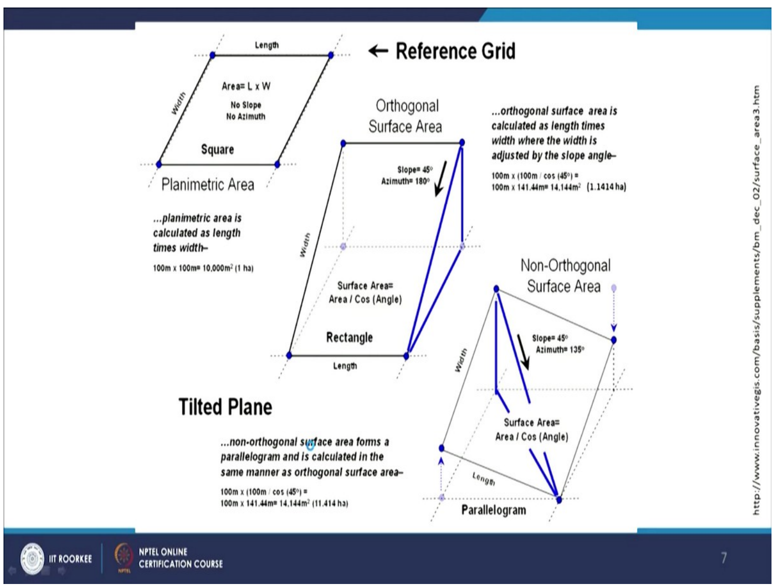

Now little more complication I would like to add here that in planimetric area, here you just multiply length and width and you get the area. But if the surface area is orthogonal; that means you are having inclined surface which is in orthogonal fashion then again, you can calculate the one with Length and width, where the slope is 45 degree and azimuth; that means with reference to the north is 180 degree.

But if it is non orthogonal like in this scenario, the surface area will increase further and here the slope though remain 45 degree as in the previous example in case of orthogonal. However, the azimuth has changed and azimuth is 135 degree because in nature, it is not necessary that all the time, the surface area would be orthogonal. Generally, these would be non-orthogonal and there you would have like this so this is a parallelogram scenario.

So, in orthogonal, surface area is calculated as length times width whereas the width is adjusted by slope angle. The example is given here that like in this one:

$$100m * 100m* \cos 45 \text{ (degree)} = 11.414 \text{ hectare}$$

If I do it for in a planimetric fashion using a toposheets, that area is coming just 1 hectare. But if it is none orthogonal then it is coming 11.414 hectare.

See the difference! huge difference in the surface area. Instead of 1 hectare, it is coming now 11.414 hectare. And that is why I said when discussing with previous slides that if lot of work is estimated based just planimetric surface assuming everything in 2D using survey toposheet, you are going to grossly underestimate the work and that will cause lot of problem. So non-orthogonal surface area forms a parallelogram and is calculated in the same manner as orthogonal surface area.

So again, you have cos 45 degree, 100 and then you end up with 11.414 hectare. So here this is a 10,000 square meters, 141.44 square meters, 14.144 square meters so one has to take care about this. In this particular example, orthogonal and non-orthogonal are giving the same area. But in some other situations, there might be some differences there but planimetric and surface area is going to be the difference. So, the plain area; that means be considered in 2D is always less then when we consider in 3D.

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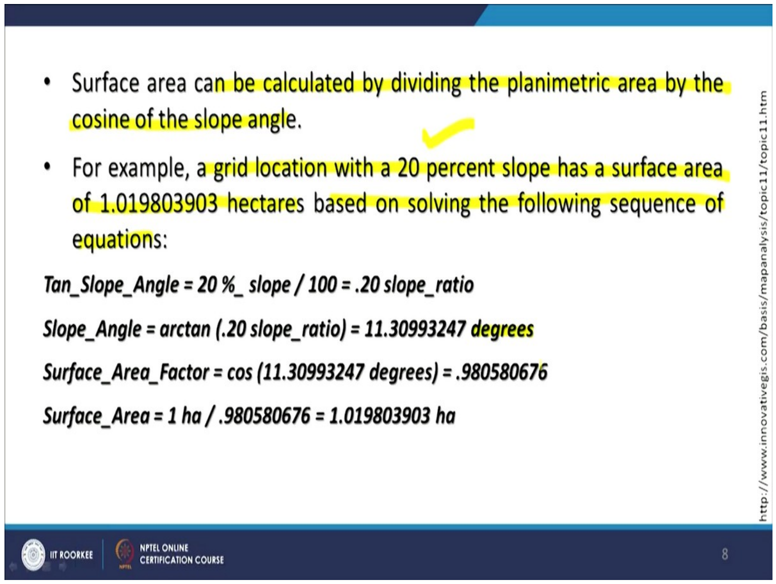

So, surface area can be calculated by dividing the planimetric area by cosine of the slope angle and this grid location of 20% slope as a surface area of this much hectares based on solving the following equations which we have already seen.

So, Tan_Slope_Angle = 20%_slope/ 100 = .20 slope_ratio because 20% is our slope, and we get this ratio. So, Slope_Angle = arctan (.20 slope_ratio) = 11.30993247 and this much of 11.3099 degree.

And

Surface_Area_Factor = cos (11.30993247 degree) = 0.980580676 then it becomes 0.980. And ultimately then surface area equal to about 1 hectare and so we get this kind of result.

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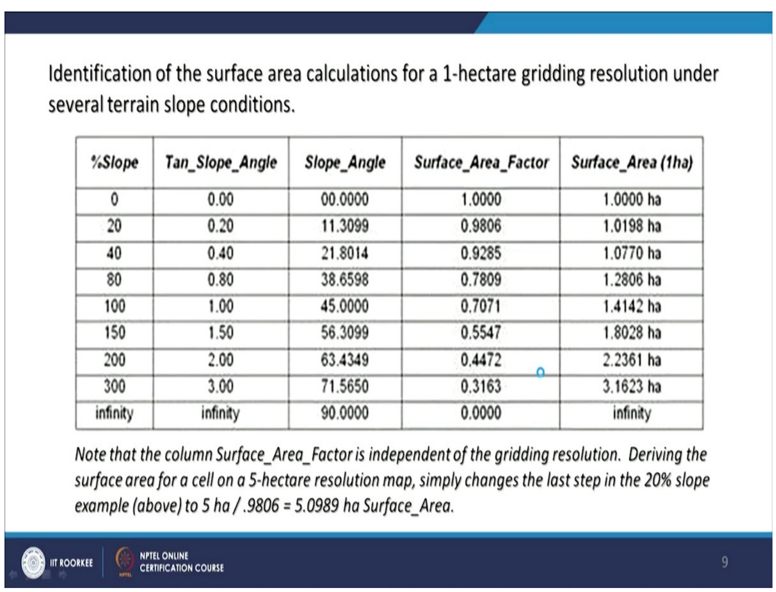
Identification of the surface area calculations for a 1-hectare gridding resolution under several terrain slope conditions.

%Slope	Tan_Slope_Angle	Slope_Angle	Surface_Area_Factor	Surface_Area (1ha)
0	0.00	00.0000	1.0000	1.0000 ha
20	0.20	11.3099	0.9806	1.0198 ha
40	0.40	21.8014	0.9285	1.0770 ha
80	0.80	38.6598	0.7809	1.2806 ha
100	1.00	45.0000	0.7071	1.4142 ha
150	1.50	56.3099	0.5547	1.8028 ha
200	2.00	63.4349	0.4472	2.2361 ha
300	3.00	71.5650	0.3163	3.1623 ha
infinity	infinity	90.0000	0.0000	infinity

Note that the column Surface_Area_Factor is independent of the gridding resolution. Deriving the surface area for a cell on a 5-hectare resolution map, simply changes the last step in the 20% slope example (above) to 5 ha / .9806 = 5.0989 ha Surface_Area.

So, if we will do the calculations for different angles, what happens? So, this is identification of surface area calculation for 1-hectare gridding resolution under several terrain slope condition. So, when you are having slope say 20%, instead of degree here are the examples in percent then the tan(θ) is here. The angle is taken 0.20, slope angle is 11.3099 and surface area factor is 0.98 and surface area is about 1 hectare.

If we go for say 100% slope then 1, 45 degree and then here 0.7071 and here you are getting 1.41. So, as you can see here between these two that there is a difference in the surface area. So, higher the angle, more the surface area is going to be. So, the surface area factor is independent of gridding resolution; that it is independent of scale. Driving the surface area of a cell on a 5-hectare resolution map, simply change is the last step of 20% above to 5-hectare and you get the area.

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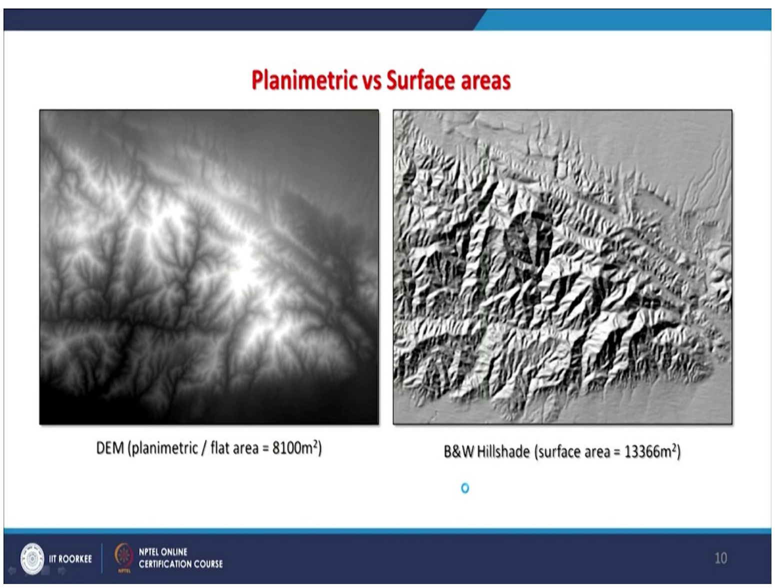

If I show the real example, this is what on the left side which you are seeing a simple digital elevation model. And when we use for calculations of surface area, this comes around this much; 8100 square meters. But when the same area is subjected to calculations through this surface area rather than planimetric area, then this is much higher as compared to that one because you know that terrain is highly undulated and surface area is going to be much more.

So, based on simple a digital elevation model which is in planimetric representation or survey toposheets if I make estimation about sediment supply from a basin or flow conditions or erosion or snowmelt then I am grossly underestimating these values. So always it is necessary to take care if you are handling an area which you know that it is having undulation, it is rugged and it is hilly terrain then you must take care about this part.

Otherwise, you know the purpose GIS is not to introduce errors. The purpose of GIS is to bring new insight about the data which otherwise impossible. And purpose of GIS is also to keep errors at the minimum. Even if there are inherent errors, keep them at the minimum. Not to introduce new errors because error propagates in GIS. If errors are not controlled in the beginning, then your results are going to be highly unreliable and nobody would believe on solution which are provided through GIS.

GIS is a very powerful and very wonderful tool but it should be handles with very much care, with full understanding about these intricacies. Now when we go for instead of a plane; whether it is inclined or surface, when we start looking at much large scale means to a zoomed part for a small area then the surface curvature also plays a very important role.

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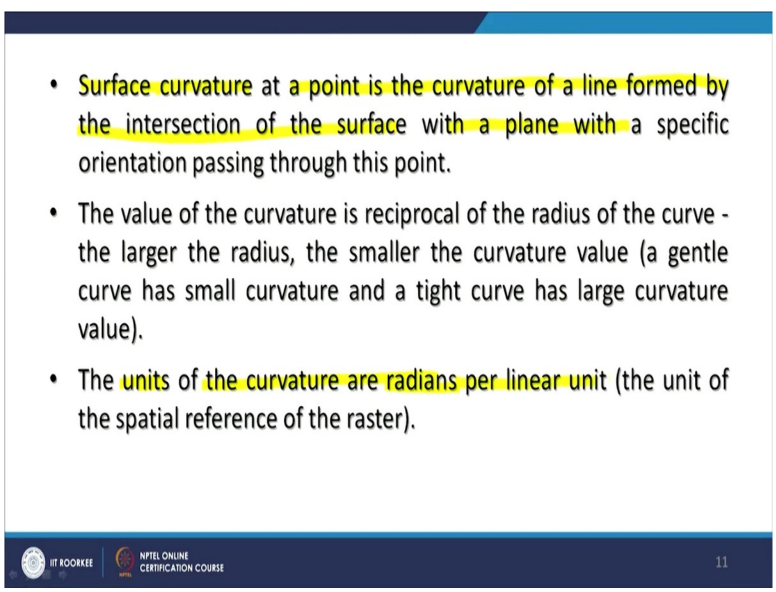

So, the surface curvature; let it define here at a given point is the curvature of a line formed by the intersection of surface area with a plane with a specific orientation passing through this point.

We will see more details about this through diagram and figures also. So, the value of curvature is reciprocal of the radius of curve- the larger the radius, the smaller the curvature value is. A gentle curve has small curvature and a tight curve always have large curvature. The units here of curvature which are in radians per linear unit and the unit of the spatial references of the raster.

So, our units if they are in our DD then per Linear units; that per linear DD. Now curvatures can be of various types. So first we will discuss the plan curvature or when we consider curvature or a curve surface in a flat.

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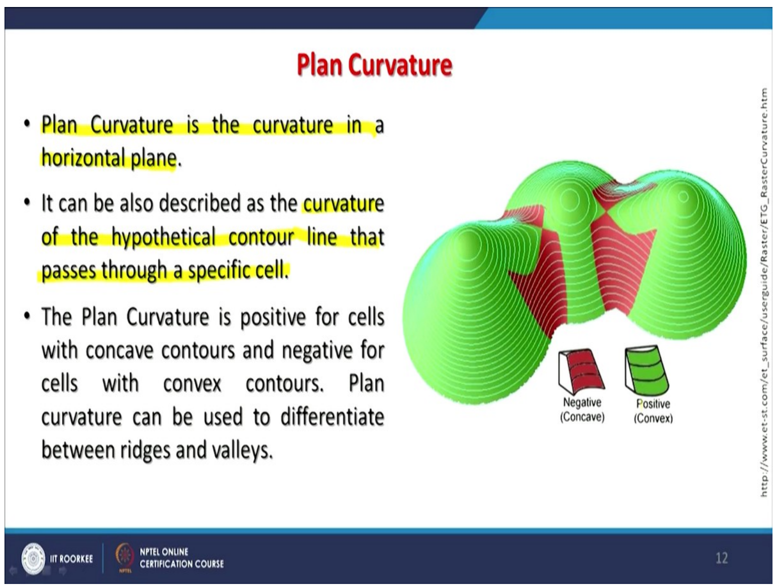

Like here, the plan curvature is the curvature in a horizontal plane like planimetric area. So, when we measure in a horizontal plane or we try to understand in a horizontal plane then it becomes our plan curvature. So, it can also describe as the curvature of hypothetical contour line that passes through a specific cell. Like here shown, various contour lines passing through various cells here. So, plan curvature is positive for cells with concave contours.

The example here; the green one in this figure, they are all concave contours and the plan curvature is positive for the cells with concave contours and negative for the cell with convex contours. The plan curvature can be used to differentiate between the ridges and valleys.

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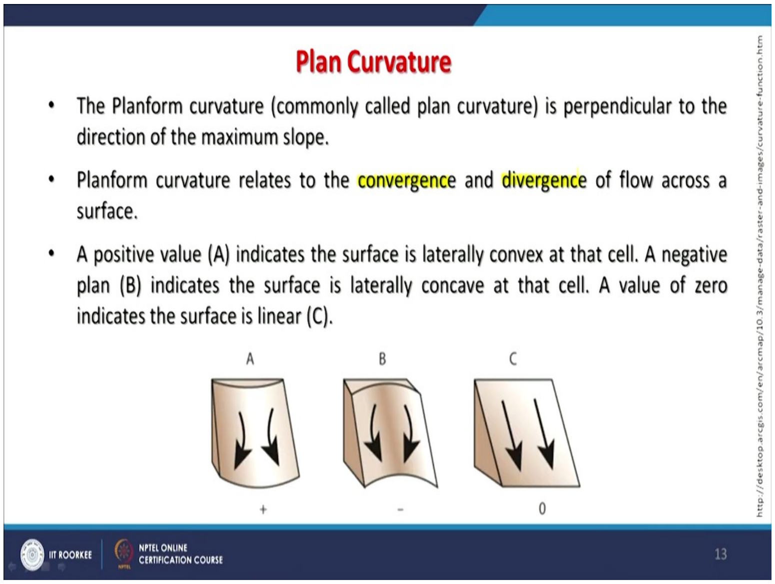

Now this plan curvature, also called planform curvature in some software or literature is perpendicular to the direction of maximum slope. And this plan curvature is related to the convergence and divergence of flow across a slope. And convergence and divergence of flow for example water, place very-2 important role in terms of erosion or in land sliding.

So here when we are having these values like here; positive values A when you are having a convex surface. The arrows indicating that the movement is laterally convex at the cell whereas in negative that is like example B which is concave, they are converging towards each other. Any value with zero that means the surface, though it is incline but it's flat then you are having a straight line. So, these lines basically will decide whether they are convergence or divergence.

Like here example A is for convergence and example B for the divergence and this is value 0. Now there can be another curvature, instead of plan curvature now, we talk about the profile curvature.

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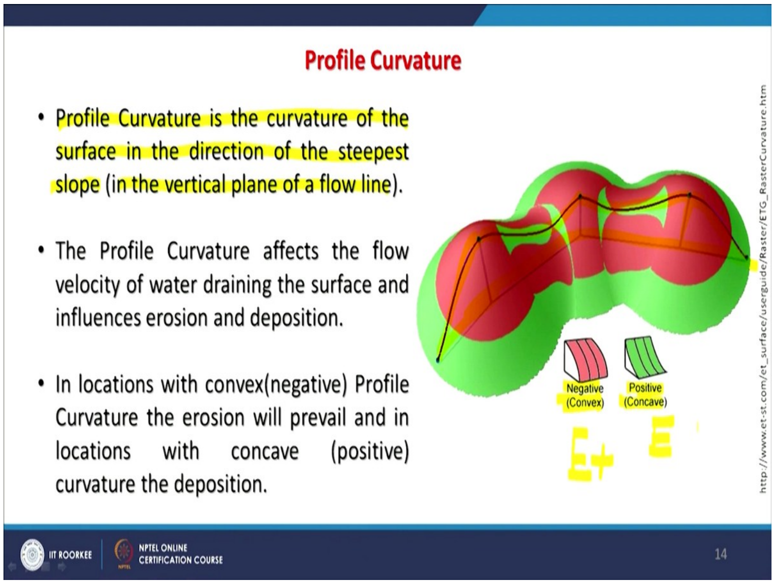

Profile curvature is basically the curvature of the surface in the direction of steepest slope in the vertical plane of flow lines. So, as you can see here that this blue line and these others, they are creating a vertical plane which is going through this hillock which is having three peaks. So, this entire part if I colour it, this is the vertical plane in which we are having this kind of profile curvature. So, profile curvature is the curvature of the steepest surface in the direction of steeper slope in the vertical plane of flow line.

So here now we will consider these slopes which will decide our profile curvature. So, when these are convex, we call as negative because erosion will occur more on these convex profile curvatures compare to the concave which are shown here in the green colour are where the deposition might take place or less erosion will take place. So, profile curvature affects the flow velocity of water draining the surface and influences erosion and deposition.

So, negative or convex profile curvature will have more erosion, say E+ and this will have simple E or may not be E, at all. So, it influences the erosion and deposition processes. In locations with convex that is a negative profile curvature, the erosion will prevail and in locations with concave position curvature, the deposition might be there.

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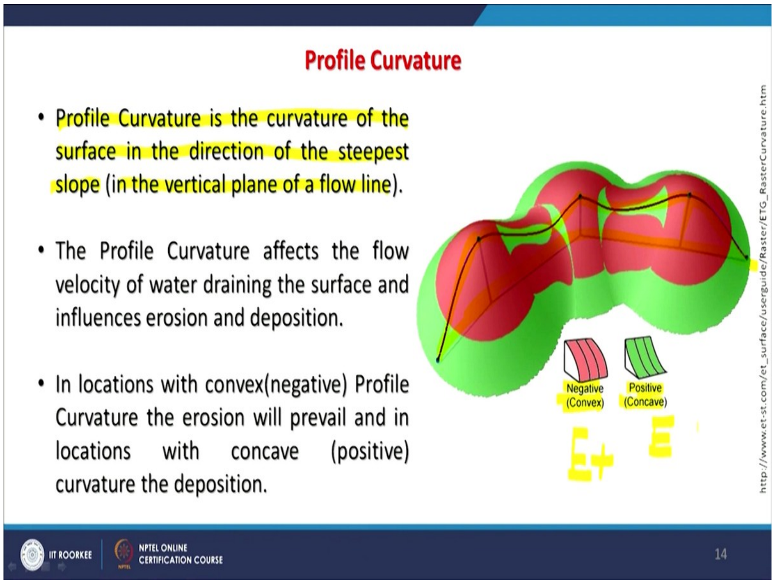

Now we continue with this discussion on profile curvature that profile curvature is parallel to the slope and indicates the direction of maximum slope. And it affects the acceleration and the acceleration of flow across the surface, that is why we can think in the direction of erosion and deposition. Acceleration means it is a conv ex. It is negative in that sense and it will have erosion. And de-acceleration means it is concave. It will have deposition or may have less erosion or on erosion.

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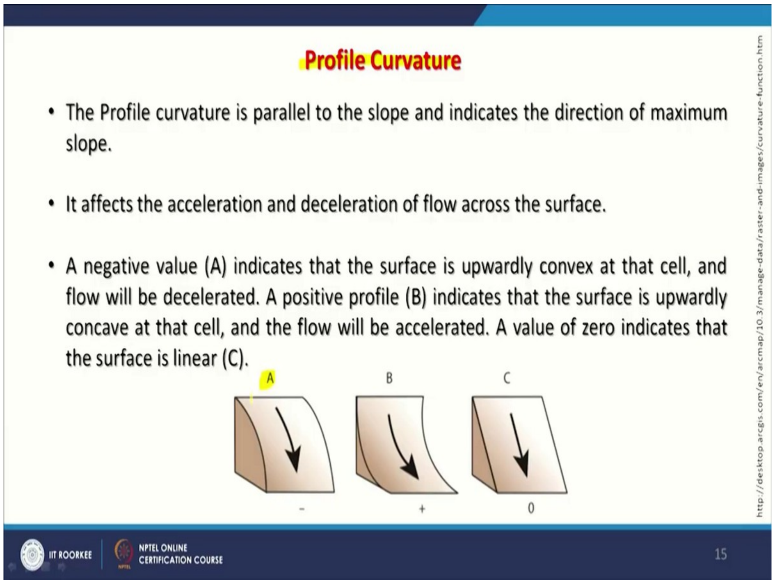

Now negative value A here indicate the surface upward convex. So now it is a different scenario here. So, this is an upward convex at that cell and flow will be de-accelerated because it is like that, you know that it is upward convex. Whereas here the positive indicates the surface is upward concave here and that concave will have the acceleration. And of course, for value 0 the surface is linear and this example is seeing where this is a straight line as shown here.

So, this is negative. This is positive and this is 0. Negative means it will upward and it will de-accelerate here the flow conditions. Whereas it will accelerate the flow condition, this is plus.

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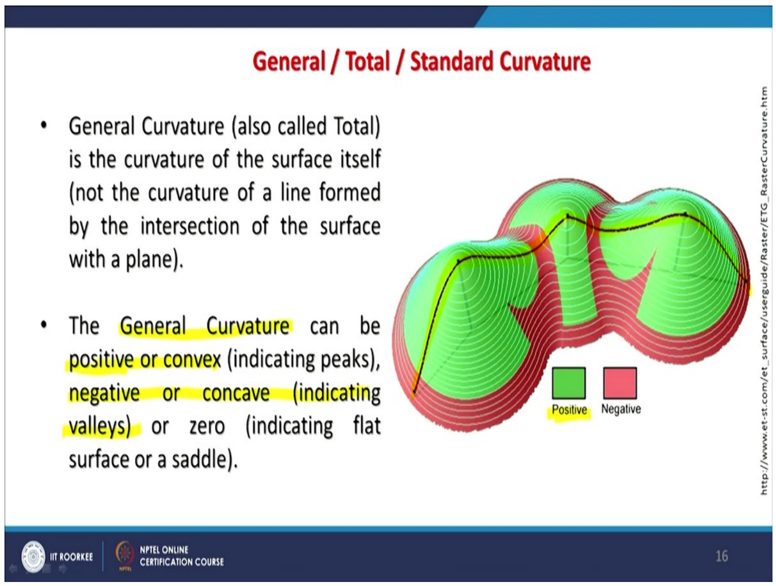

Now we can also have a general total or standard curvature. These terms are also used in literature or by various software's by deciding these curvatures. So, instead of plan or profile, we can have a total of standard curvature. So, general curvature is also total; three terms are used. So, it is the curvature of the surface itself, not the curvature of a line, formed by intersection of the surface with a plane. Like here again with that vertical plane you are having and then when it cuts the surface then this is the line which we are talking here.

So, the general curvature or the total curvature or standard curvature can be either positive in case of convex as you can see here; positive and indicating peaks as you have seen here or negative or concave indicating valleys like here; middle part. And of course, indicating whenever you are having value 0, that is indicating saddle or flat surface. So, it's flat surface without or a saddle; might be a situation with slight changes or flat also.

So, when you are having this general curvature is convex, that is positive indicating peaks and that means employing this or doing this analysis, employing digital elevation models, we can also identify which are the peaks and which are the valleys. That is what is part of our Terrain analysis?

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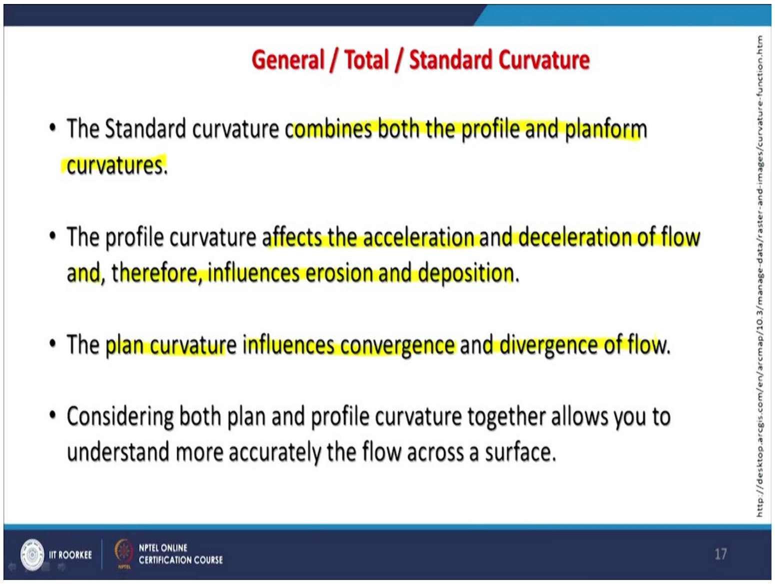

Now standard curvature combines both the profile and planform or plan curvature. And profile curvatures affect the acceleration and de-acceleration flow therefore influences erosion and deposition and plan curvature whereas influences the convergence and divergence of flow. So, if we combined both and create a standard curvature, this will allow us to understand more accurately the flow across a surface.

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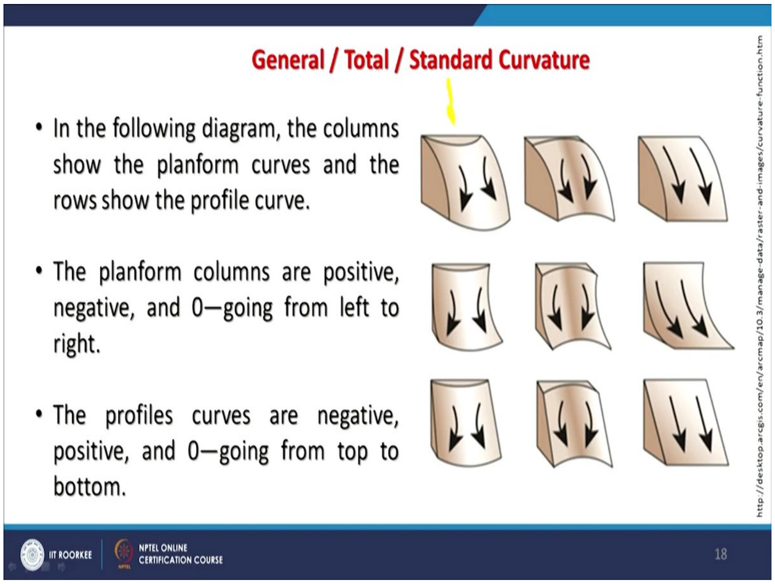

That will allow us to even predict what is going to happen in certain conditions? So, diagram, which we are going to have here vertically in the columns, the planforms are there and in rows, we are having the profile. So, in planform column, we are having positive, negative and zero. So, the first one is the positive, this is negative and this is 0. So, profile curvatures curves are also negative, positive and zero going from top to bottom.

Positive, negative and zero in all three cases. So, here things are convex but still in certain conditions when it is upward convex then you are having positive but if it is divergent kind of situation, you are having negative. Similarly, here this is convergent and concave upward, you are having a convergent and still convergent and still convergent. Here no changes because it is flat in that sense. So, no curve part is there for that flat and that is the least possible scenario in natural conditions.

Now, we can employ these curvatures; either the total, plan or profile curvatures for land form classification which is based on a combination of horizontal curvature and vertical curvature.

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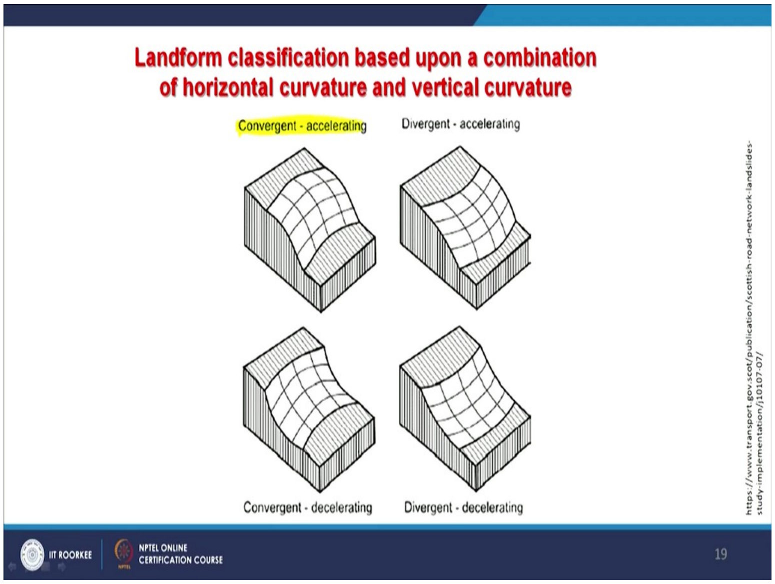

So, convergent will accelerate, divergent also accelerate example here; this one. And in this one, this is convergent, de-accelerating because now it is concave. And here divergent, de-accelerating though it is diverting but still it is de-accelerating. So, top 2 in the First row, both are accelerating examples and, in the bottom, 2 are de-accelerating examples. And also in the rows, you are having convergent in 1st row and in 2nd row, it's divergent.

That means in natural conditions, you can have various types of combination and accordingly things will vary.

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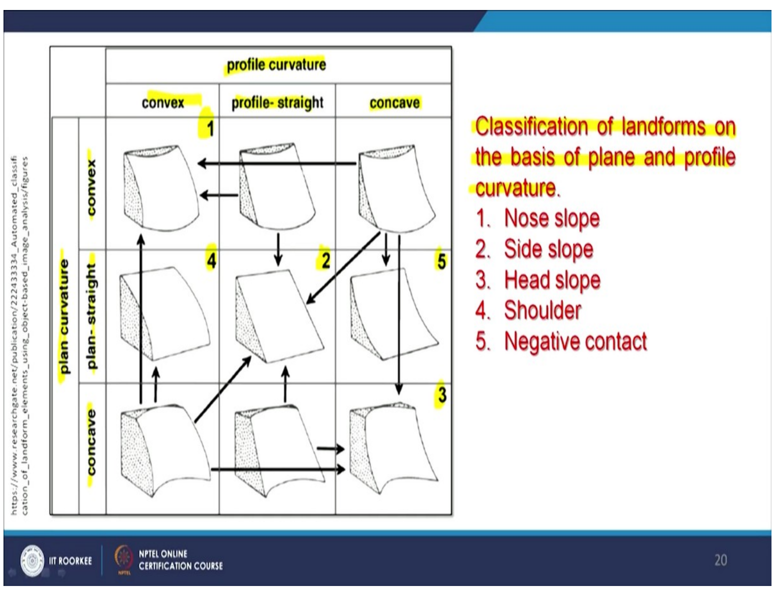

So, a similar kind of thing that the classification of landforms on the basis of plan and profile curvature. So here in this Matrix, you are having plan curvatures. Here you are having profile curvature. You are having convex, convex profile-straight and concave, concave. So, these will influence each other depending on the conditions. So, the first one, we call as nose type just like a human nose.

The second type of landform, we say side slope which is this one 2. The third one is the head slow which is this one and fourth one is like shoulder. So, you are having a kind of shoulder and fifth one is negative contact; this is one, negative contact. In terms of profile curvature, it's concave and in plan curvature, it is plan or straight, that is negative. So, this basically here arrows are indicating possible combinations of classification. Some have already indicated that how these can be classified.

The classification of total curvature or standard curvature will allow you to understand the terrain from geomorphic or landforms point of view much easier. Now let us take examples at the value level, that is the cell value level.

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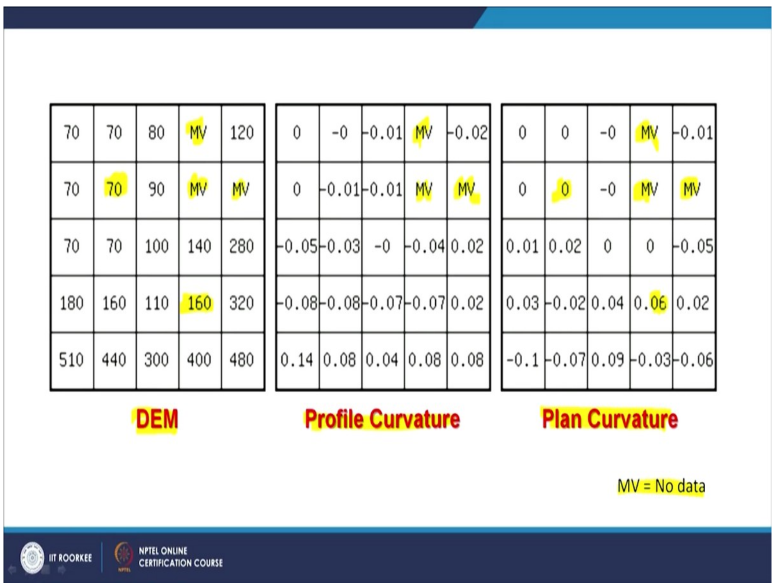

70	70	80	MV	120
70	70	90	MV	MV
70	70	100	140	280
180	160	110	160	320
510	440	300	400	480

DEM

0	-0	-0.01	MV	-0.02
0	-0.01	-0.01	MV	MV
-0.05	-0.03	-0	-0.04	0.02
-0.08	-0.08	-0.07	-0.07	0.02
0.14	0.08	0.04	0.08	0.08

Profile Curvature

0	0	-0	MV	-0.01
0	0	-0	MV	MV
0.01	0.02	0	0	-0.05
0.03	-0.02	0.04	0.06	0.02
-0.1	-0.07	0.09	-0.03	-0.06

Plan Curvature

So, this is our digital elevation model. This is the profile curvature; output using that same digital elevation model. This is the plan curvature and you can see that things are varying and MV basically stands for no data here or value MV is no data. So wherever in input if you are having no data, in output also whether it is a plan curvature profile curvature, you will have no data. Otherwise, you would have data. Of course, this is also a neighbourhood analysis.

So based on that, if I ever considered say this cell which is 70, here in the profile curvature, the value is -0.01 and whereas it is zero. If I considered 160, this is -0.07 and whereas this is positive value 0.06. So obviously, the profile and plan curvature for the same area is going to be different, though the DEM may be the same input.

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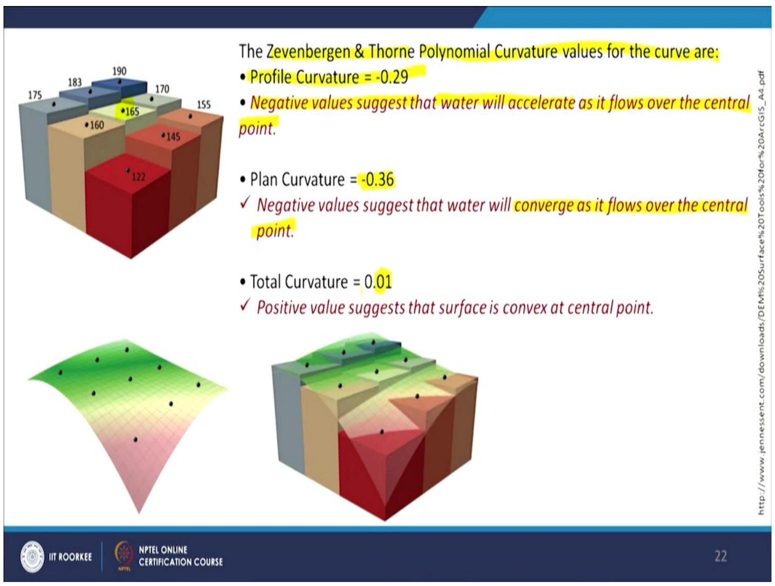

Now, different methods again like Zevenbergen and Thorne method for polynomial curvature value for a curve, profile curvature which is giving value 0.29 and that negative value means suggested that water will accelerate as it flows over the central point. So, this is for the central point; this one. And in plan curvature, the value is -0.36. And that means it is also negative value and suggests that water will converge as it flows over the central point.

And the total curvature when you calculate, it is 0.01 and that basically indicates that this is positive value, suggest that the surface is convex at the centre point which you can also feel here because there are 160 value and less than 165 values are there. So, this is a convex scenario.

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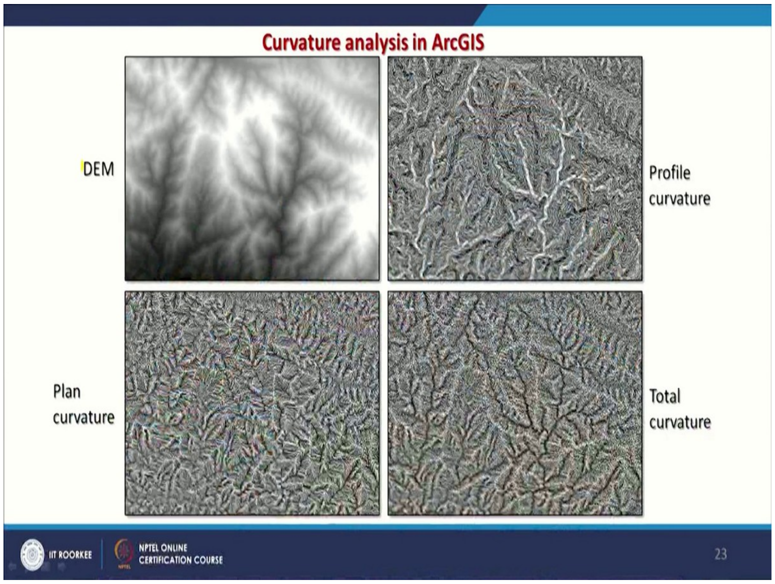

Now using different methods and these plan curvature, profile curvature and total curvature along with digital elevation model. So, first one; the top left is the input digital elevation model. This is the plan curvature which you can see. The profile curvature on the top right and the bottom right is the total curvature. Of course, all three will depict altogether different things. But if you see carefully, you would find that the total curvature is encompassing both plant curvature and profile curvature.

For example, in plan curvature, you do not see the drainage network very clearly; in this one. Whereas in profile curvature, you see this drainage network appearing in the white line but in total curvature instead of white lines, these are appearing as Black lines. And the details which we are present in the plant curvature are also incorporated in total curvature. So, total curvature can be more useful that means compared to using individual curvature profiles.

However, it depends on the application. If somebody is really interested from deposition point of view, erosion point of view, landslide point of view, flooding point of view accordingly then appropriate curvature calculation should be done.

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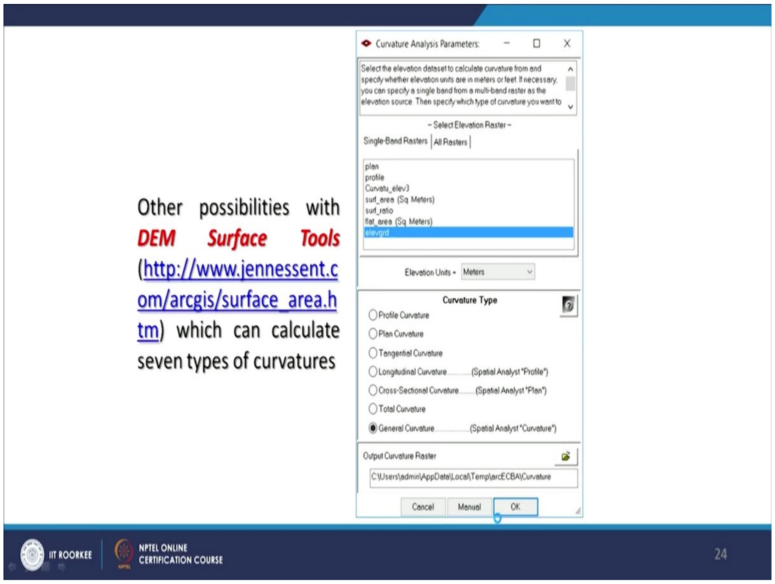

In a standard GIS software like in ArcGIS, you may not get these facilities to calculate profile curvature, plan curvature using various method. But there is an extension which is jennessent available on net at free of cost where you can calculate seven types of curvature. As you can see curvature types; profile curvature, plan curvature, tangential curvature, longitudinal, cross-sectional, total curvature and general curvature.

And it is telling what are the requirements and other things. So again, the tools may not be there but on this site, they have developed a tool which is allowing all kinds of calculations very easily. Whatever the output any such option creates, we must understand what is that because after all we are going to use for solving some real-life problem. O, the output must be must be understood fully and careful.

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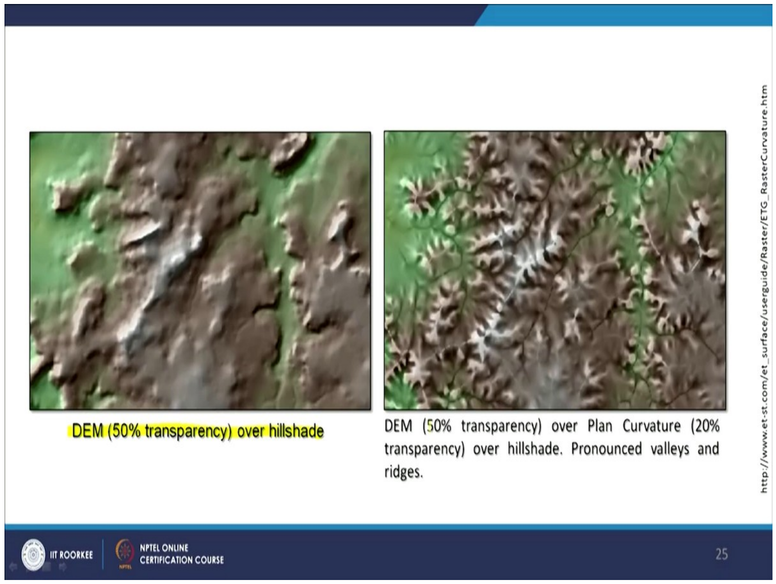

Another example here that DEM 50% transparency over the hill side. This I also so you through demonstration that you can bring a shaded relief model and digital elevation model together. And digital elevation model, you can choose a colour palette and keep 50% transparent. In the background, you are hill shade and top of that, you are having a digital elevation model which is having colours. So again 50% transparency example, over plan curvature 20% transparency and over hill side that is also there. Pronounce valleys and the ridges that means now for the same area if I use for the plan curvature, I can find out which are the ridges and which are the valleys very clearly.

Just using a simple digital elevation model and a hill side, I may not be able to identify valleys and ridges as easily, as accurately as in this plan curvature map. For display purposes, we are using the same method that the in the background, you are having this plan curvature and top of that you are having DEM with 50% transparency and using colour palette. So finally, we come to the applications part where many applications we have already touch but very quickly, I will go through.

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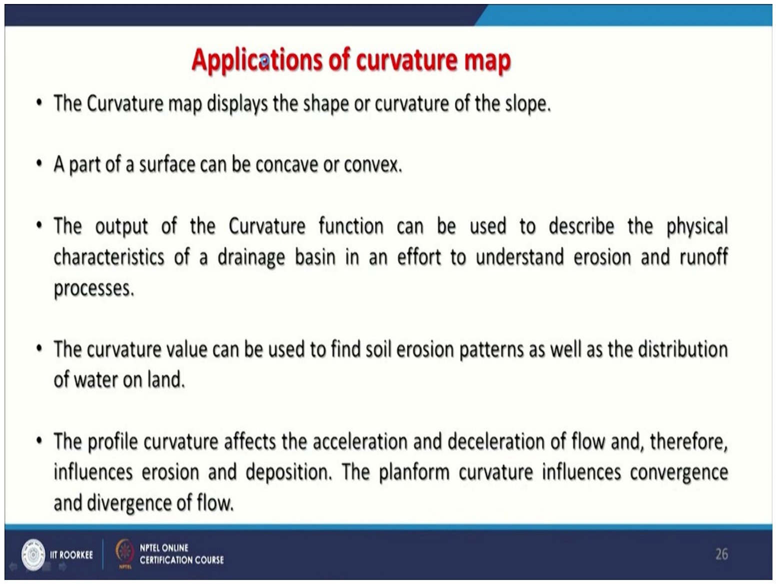

That the curvature map displays the shape or the curvature of the slope which is very-2 important and at a local scale because that is what it will control your divergent, convergent flows and ultimately erosion and deposition. So, part of surface can be concave or convex. The output of the curvature functions can be used to describe the physical characteristics of a drainage basin in an effort to understand erosion and runoff processes.

And these curvature values can be used to find soil erosion patterns as well as distribution of water on land or even in case of landslide studies. Whereas profile curvature affects the acceleration and de-acceleration of flow; that is mainly water flow and therefore the influences erosion and deposition. So, planform curvature influences convergence and divergence flows.

Further useful to understand the physical characteristics. When we drive these curvatures; total curvature, standard curvature will allow us to understand physical characteristics of drainage basin. Also, erosion and runoff processes. And it also will help us to determine the local factors of dynamics of overland and intra soil water.

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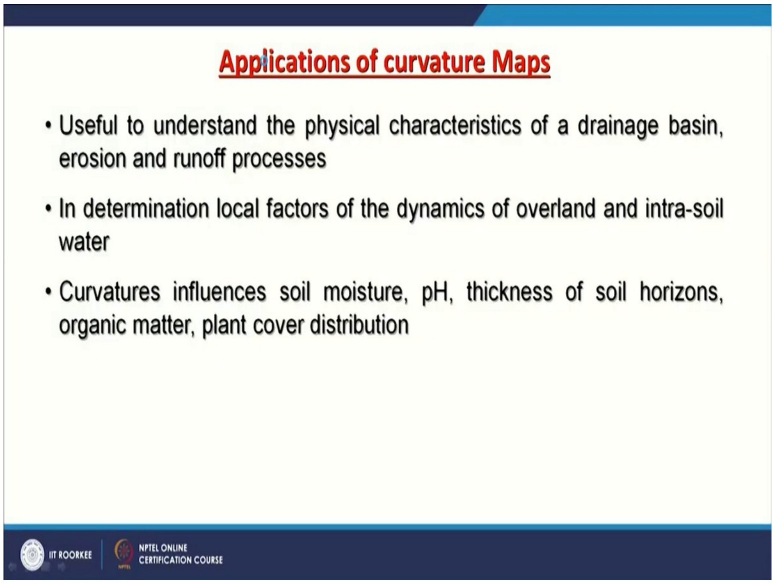

Curvatures as you know influences soil moisture because erosion and deposition, divergent and convergent flow will control the soil moisture conditions. May influences even pH values of soil, thickness of the soil erosions because if erosions are taking place, there will be less thick soil horizon and if deposition is taking place there might be more soil horizon depending on the conditions organic matter, plant cover distribution etcetera.

And curvatures are indicators of geologic lineament, ring structure and can be used to determine fault morphology as well. And curvature can be used to map accumulation, transit and dissipation zones of land surface. Not only from that point of view, from snow or Glacier point of view as well. So, with this end this discussion about one of the very important derivatives after slope and aspect is about the surface area, plain area and different types of curvature. Thank you very much.