Geographic Information Systems
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Lecture-52
Shaded Relief Models and their Applications

Hello everyone! and welcome to a new discussion which is we are going to have on shaded relief models or hillshades. And how we can apply? How these are very useful for various kinds of studies? This is also one of the derivatives of digital elevation model. But now instead of a derivative 4 or 5, I thought that I will put a completely separate name because I have always found this hillshade or shaded relief model very-2 useful for various representations and various applications which I am going to discuss in this lecture.

I am using both terms like hill shading and shaded relief model. Earlier people were very comfortable with shaded relief model but later on few people started using hill shading. No issue! We can use any of these terms, meaning is the same.

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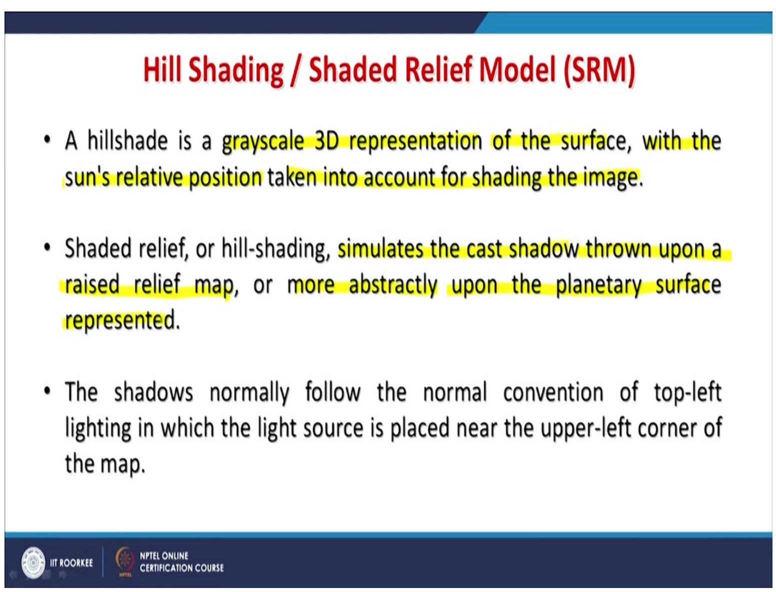

That hill side is a grayscale 3D representation of the surface. Of course, the input is a digital elevation model. And what it exercised here that with Sun's relative position taken into account for shading the image. So, because it is not illuminated. A typical digital elevation model is not illuminated by a light source. What we do in hill shading? We take a light source or you can say position of the Sun and we stimulate that if sun is in this position, how the terrain would look from the top.

And that is what you will get the hill shade. So, this hill shade or shaded relief model basically as I have just mentioned that simulates the cast shadow thrown upon a raised relief map. Because digital elevation model is representing a rugged terrain, might be and more the rugged terrain, more the convincing shaded relief model you can generate. But if terrain is flat then that may not be good for the eyes but still it is very useful.

For example, if I am having a digital elevation model of like Thar desert, I may not be seen many of the dunes and different kinds of aeolian features or landforms. But when I use a shaded relief model; that is the derivative from a digital elevation model, I can start seeing these various types of dunes or some other landforms and can interpret them very easily. So that is why shaded relief models or hill shaded models are very-2 useful.

So, what basically we are doing that more abstractly upon the planetary surface represented. So, that means the digital elevation models can be created for any surfaces. And the position of the illumination source or the Sun's relative position, we can decide by ourselves. What should be the position? So, the shadow normally follows the normal convention and that normal convention is always lighting or illumination source being kept in top left.

In which the light source is placed near the upper left corner of the map. Now there might be some question that why only top left? Why not another? For which we definitely require a complete separate discussion which is my one of the most popular lectures is false topographic perception phenomena in which, I have explained that why it is kept in the top left. But very briefly, I would say that if illumination source and viewer, if both are in the same hemisphere, that means illumination source should always come from opposite direction.

So, this is how our brain assumes. If it is not coming from opposite direction then brain cannot perceive valleys as valleys and ridges as ridges. What they will perceive? Our brain will perceive valleys as ridges and ridges as valleys; that mean a completely inverse topography or I would call as false topographic perception. Since it is a phenomenon so we give a name false topographic perception phenomenon. But for time being, let us assume that by default, all these softwares will bring illumination source always from the top left corner.

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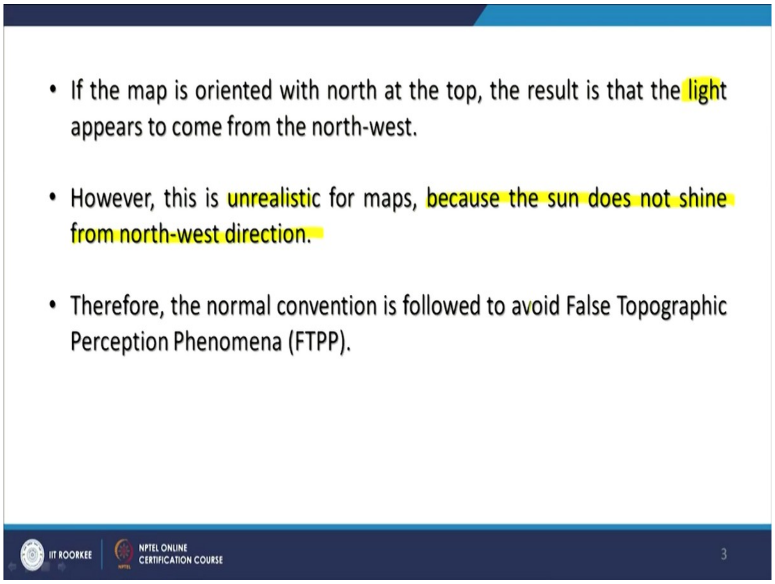

Now if a map is oriented with North at the top, the result that the right appears to come from the Northwest. So, this light will always be coming from that. However, this is unrealistic. Why unrealistic because we know that Sun can never reached in the Northwest. Sun will start from east and will set in the West. So how Sun can reach on the Northwest but because we are working on computer so we can simulate the Sun position in terms of with reference to North as well as the elevation as per our requirement, as per our desire.

Though, that might be unrealistic as here that because the Sun does not shine from the Northwest direction. Therefore, the normal convention is followed to avoid this false topographic perception phenomenon. Now in many-2 literature you may not find a discussion related with like that point like why it is kept in the top left because many times, they just mentioned in the literature especially in the books or in software manuals or helplines but they will not tell why?

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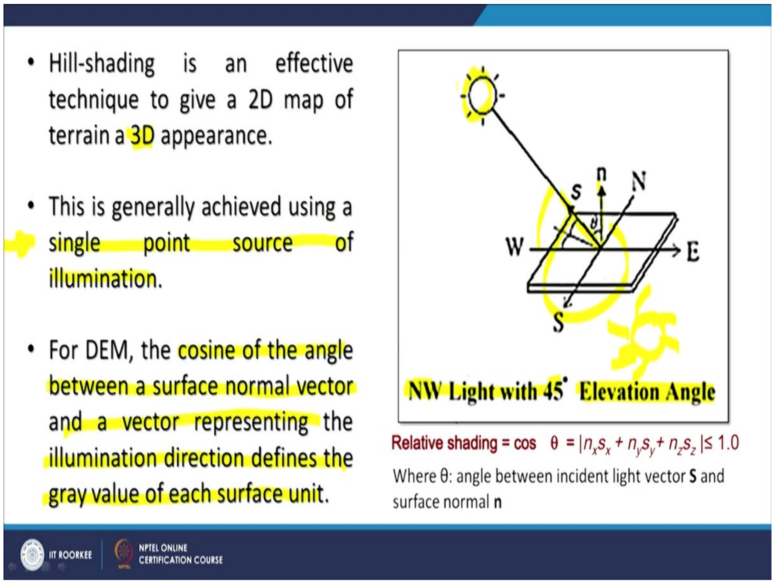

So, that why I have already explain to you because of false topographic perception phenomena. Now, hill shading is an effective technique basically to convert a 2D map or terrain surface into the 3D appearance. Though it is already a digital elevation model; a typical digital elevation model is already bearing the z values but if I am not using then I am representing in a 2D form. But if I use that one; z value and then create a shaded relief model or hill shade then I am using the z value as well.

So generally, it is achieved the shaded relief model by a single point source of illumination. Now here this point is very-2 important is the single because we have been always assuming that there is only one Sun. Though in our modelling or simulation, even when we do the hill shading, we always assume that there is only one source of light. But you might have seen during the night time cricket matches or football and other thing, if there are 4 sources of light used, you see 4 shadows.

So, is it possible that also in our simulations from 2D to 3D, can we go for multiple sources of illumination rather than single point source? That we will discuss little later. So, what generally as I have mentioned that Northwest light from 45 degree and it is measured with reference to north so it would be like this. And the elevation angle you can choose. Generally, it is also kept say at 45 degrees.

If I have to compare my digital elevation model or shaded relief model with satellite image of that particular area then what I can do? I know the Sun position of satellite image when it was acquired. What was the Sun's position in terms of azimuth and elevation angle? I can use those two parameters of the Sun and put here but remember that in case of satellite images, sun will never come in Northwest.

So, what we can do? Instead of generally Sun will be in the southeast quadrant. So, what we can do? We can add 180 degrees to the position of our satellite image and can shift 200 there. So, this is how you can simulate Sun at in Northwest direction. Currently what we are discussing a single point source illumination. But we may also think now of multiple point source illumination.

So, how it is basically that the cosine of the angle between the surface normal which is as shown here and vector representing the illumination direction like this one here and which defines the grey values of each surface units. So, this will define what should be the grey value because this grey value, when there are different for different sloping surfaces then only you can create a shaded relief model. So, with this Sun position if a slope is facing complete Sun, it will be highly union illuminated but if a slope is just opposite of that Sun direction, that would be in the shadow.

So that is how once you are having shadow and illuminated surfaces or slopes like this then you start feeling the appearance of 3D from a digital elevation model after this processing. So here the relative shading is decided based on the $\cos(\theta)$ and the details are here like this. So, where the θ between the incident light vector S and surface normal N; between this, this is the θ which we are talking.

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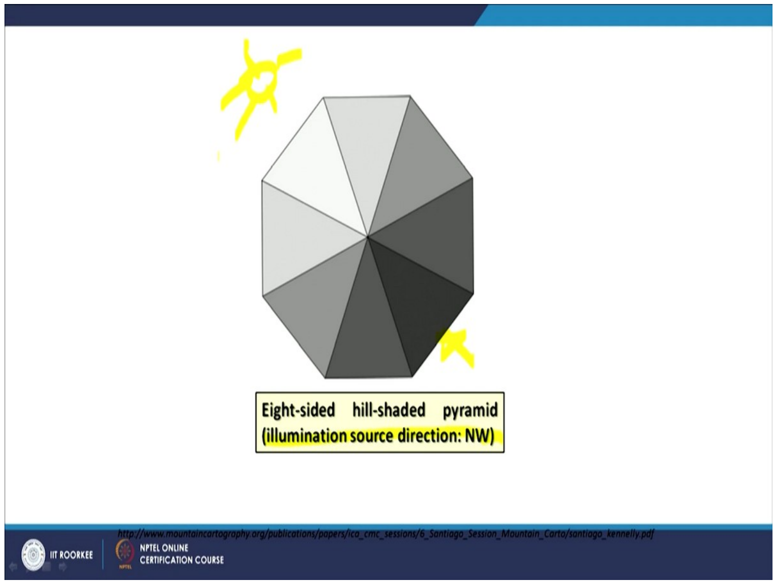

Now here this is the example of 8-sided Hill shaded pyramid. This is what typical currently the softwares are following. This concept that illumination source is though here in the Northwest quadrant so that is why it is highly illuminated. Since it is having some degree so it is not 100% white and this is not also 100% dark but depends what is the height of the Sun and of course the slope also.

So, illumination source direction as I have already said is in the Northwest direction in this scenario. So, 8 because like aspect, the similar things we follow your here also. So, if we start thinking in terms of the values of a digital elevation model and how it is done, again this Kernel of 3*3 will be used because it is basically again in neighbourhood analysis.

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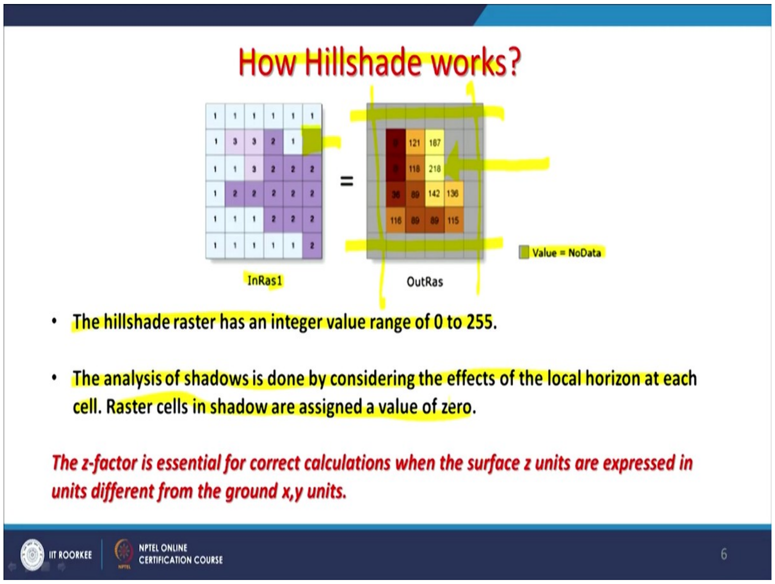

How this will work that I am having input raster. And here I am having the values, for simplicity these cell values have been kept between 1, 2, 3 and of course one cell is also having Nodata which is marked as a grey. So, if input is having Nodata, output will also have Nodata. Further output will also not have any data along the boundary; one cell thick boundary all along your output.

So only for that in the centre area. Excluding that area, you will not have any value. And as you remember that 7 cells out of 8 cells should have a value. If any of that 3*3 kernel for the centre cell calculation because otherwise there are 9 cells. So, for center cell calculation, we are looking the 8 neighbours. So, among these 8 neighbours, at least 7 cells should have values and if any case when you are having more than 2 cells are having Nodata then no calculation will be done.

And that is why I here, what you are seeing here is that Nodata is being replaced for that particular centre cell in the surroundings in the Northern side, there were Nodata. So, the hill shade raster has an integer values ranging from 0 to 255. It is always represented in gray shades. Though some technique you can convert them in colours also which I have also demonstrated earlier through a demonstration of software.

So, the analysis of the shadow is done by considering the effects of local horizon at each cell and the raster cell in the shadow assigned a value of zero. And the z factor again; z factor will keep coming in our discussion that z factor is essential for correct calculation, when the surface z units are represented in units different from the ground units, that is xy units.

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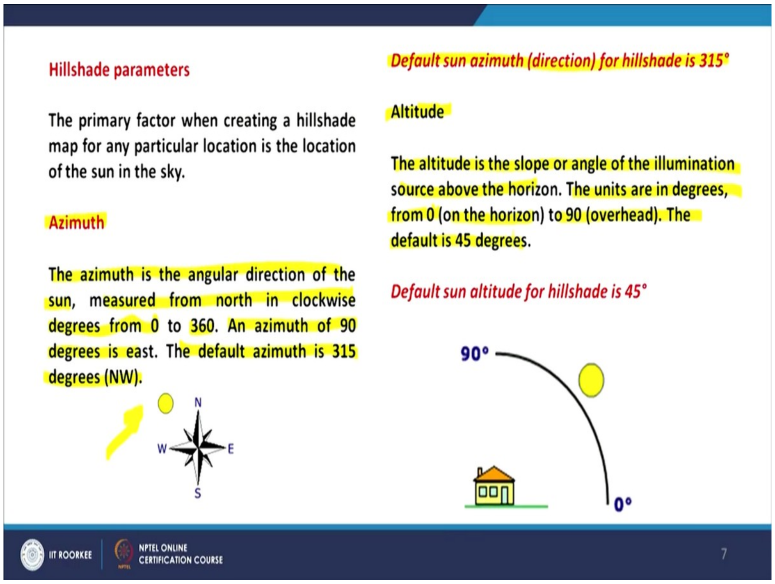

Now hill shade parameters; what you are having here is the primary factors when creating a hill shade for any particular location; that is the location of the Sun in the sky. And two parameters will come; one is azimuth, another one is elevation. So, both are in angles or in degrees. So, azimuth is the basically angular direction of the Sun measured from North clockwise. So north will have 0 or 360 degree and azimuth of 90 that is towards the east. And the default azimuth in most of the software is 315; that is northwest corner or northwest quadrant.

Because it is not kept and suppose it is kept in the southeast corner; illumination source then you would have difficulty of perceiving things completely different. So that is why, that care has to be taken. So, it is always illuminated by default 315. You can check various software; in the default, they will have this value including ArcGIS, they are having the default value is 315 and elevation value as 45 degrees.

So, the default Sun azimuth is 315 in hill shade whereas in case of altitude on elevation, the altitude is a slope or angle of the illumination source above the horizon. The units are in degree from 0; that is parallel to origin to 90 degrees, that is overhead and that happens generally in noon time depending on where you are located and what is the season and default in the software is 45. So, for azimuth, 315 degrees. For an altitude or elevation, 45 degrees. These are the default values. So, like this value is kept here at 45.

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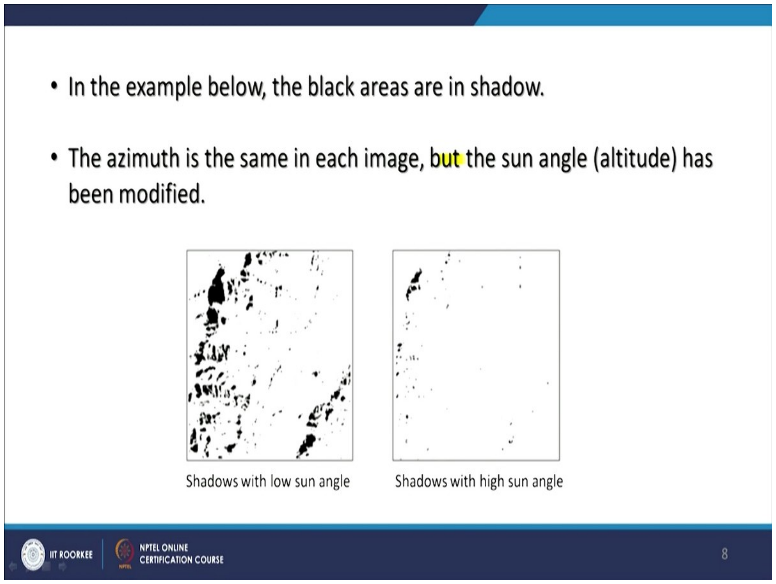

Now the example which we are going to cover because as I have already said that if Sun is in the opposite quadrant, then the other areas will have completely in Shadow. So, azimuth is the same in these two images but what has been done that the change in the altitude or elevation has been done. If as you know that when Sun is near horizon, you would have large shadow and when sun is overhead, you would have minimum shadow or virtually no shadow; should not have even a shadow.

Again, as I said depending on where you are located on the globe and in which season but it is assumed if you are on the equator in the noon time, the Sun would overhead and no shadows will be there. So, you can simulate with low angle Sun or high angles sun as per your requirements.

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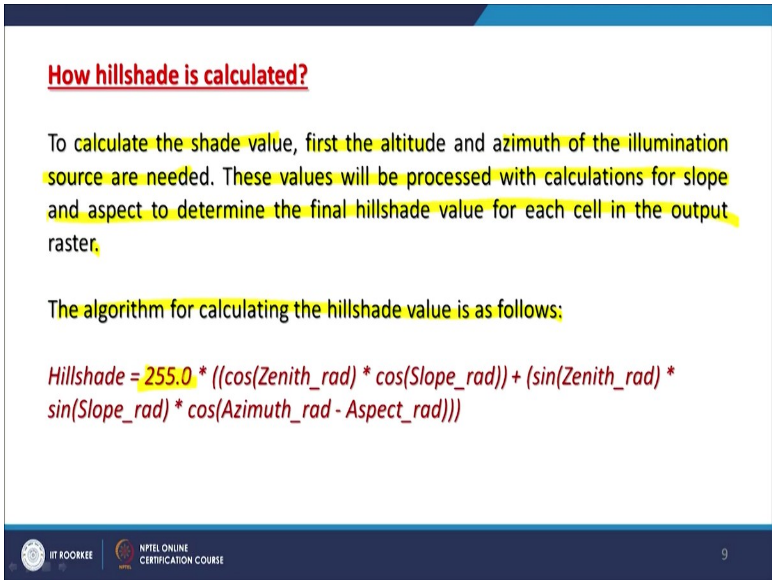

Now how hill shade is calculated? Some indications are already discussed as indicated that to calculate the shade value, first the altitude and azimuth of illumination source are needed. So, these are the 2 inputs along with your input digital elevation model and these values will be process with calculations for slope and aspect to determine the final hill shade value for each cell in the output raster.

So, if you are using a TIN and creating hill shade because TIN, by itself carrying slope and aspect map and therefore this hillshade product will be created very quickly whereas in case of typical raster you know in the background, it will calculate slope and aspect and based on that then hillshade values will be created. And the algorithm for calculating the hill shade value which we have also touched little bit like a 255 here because we are keeping the range between 0 to 255

Hillshade = 255.0* ((cos (Zenith_rad) * (cos (Slope_rad) + (sin (Zenith_rad) * (sin (Slope_rad) * cos (Azimuth_rad-Aspect_rad))))

So, once that is done for both directions. Now if the calculation of hillshade value is less than zero, the output cell will be zero. So, because in that case, that is why we multiply by 255.

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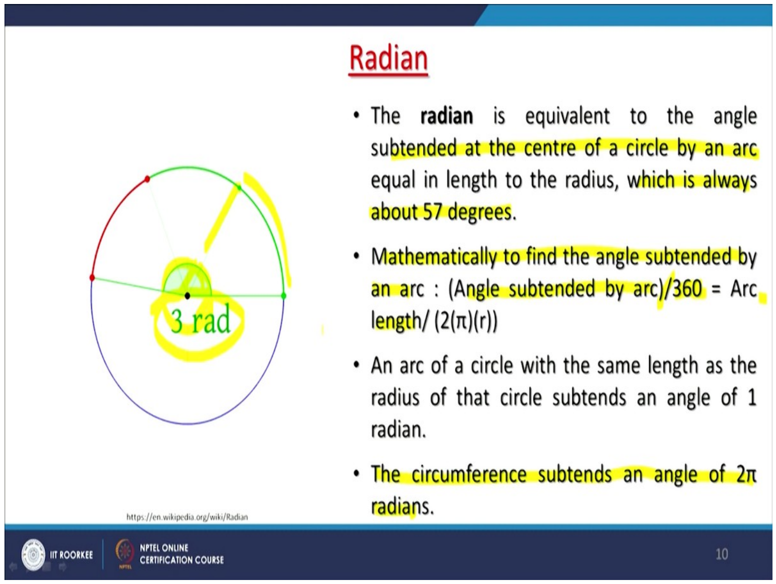

Now the radian; as you are seeing on the left side, what is this zip file or this simulation is showing, what is basically radian is. That the radian is equivalent to the angle subtended at the centre of the circle by an arc. So, this arc which we are talking and this is the Radian and arclength equal to radius which always 57 degrees because this is equivalent to radius. When we convert this radius into arc so then this angle becomes always 57 degrees.

Now this half-become π and whole one becomes 2π. So mathematically to find the angle subtended an arc, the angle subtended by the arc divided by 360; that is arc length/2π. And then arc of a circle with the same length as the radius of the circle subtends an angle 1 Radian as you are seeing currently here. And the circumference subtends an angle of 2π radians.

So, if you are covering the entire circumference then the radian value would be equivalent to 2π. So, that is why in that calculation there, what we are finding that the values are always in radians.

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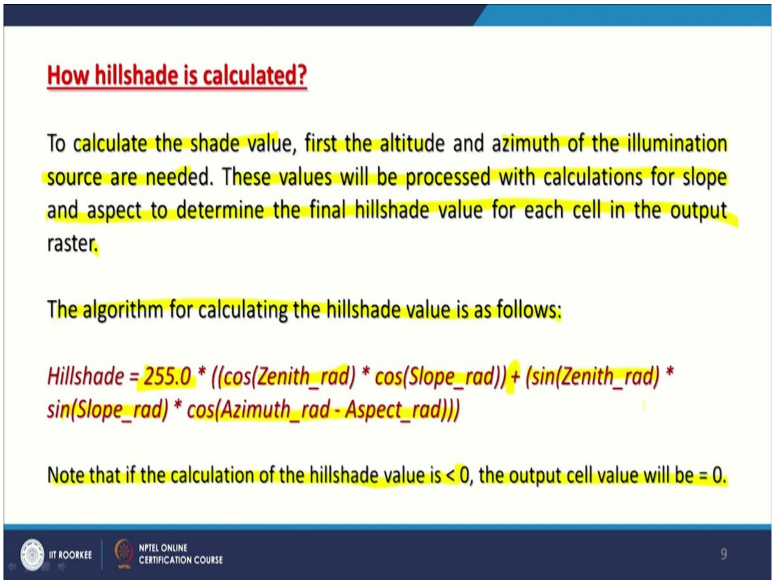

Anyway, now option available say in standard GIS software about the Hillshade. Most of the time I am using examples from ArcGIS or ArcView. The reason is because I am using these softwares but no way I am promoting these softwares. It is your choice but for examples, I have to show through some software. Since I am comfortable with these softwares so I am showing but from commercial angle point of view, there is no promotion of these softwares. Please I would definitely suggest you start using these public domain softwares or open-source softwares like QGIS, there is no problem. But since I was or I am hooked to this ArcGIS so I always take example from that.

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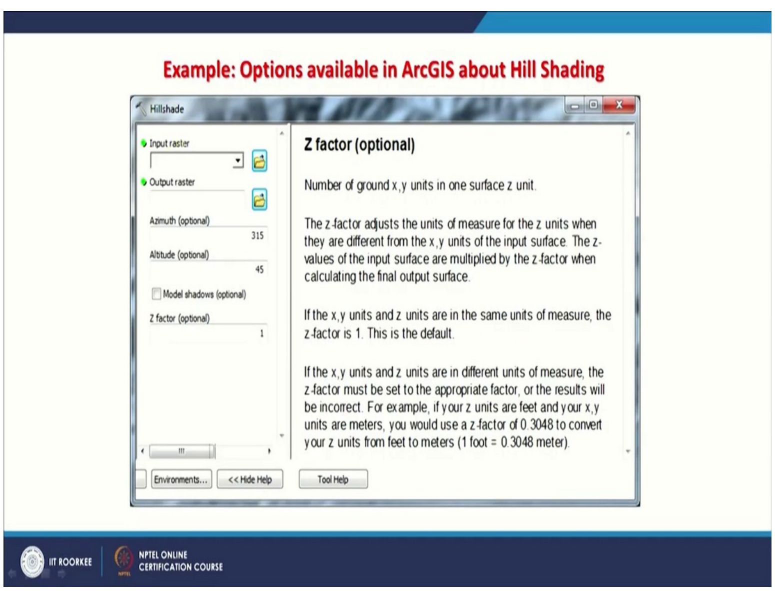

Now here what you have to provide for hill shade; input, output and these are the two default values which I was mentioning. Automatically these values will be prompted. However, you can definitely change these values. But by software, it is always put as these values and z factor also in the default is 1. So, you have to take care about z factor as well. And once you do it, you can do.

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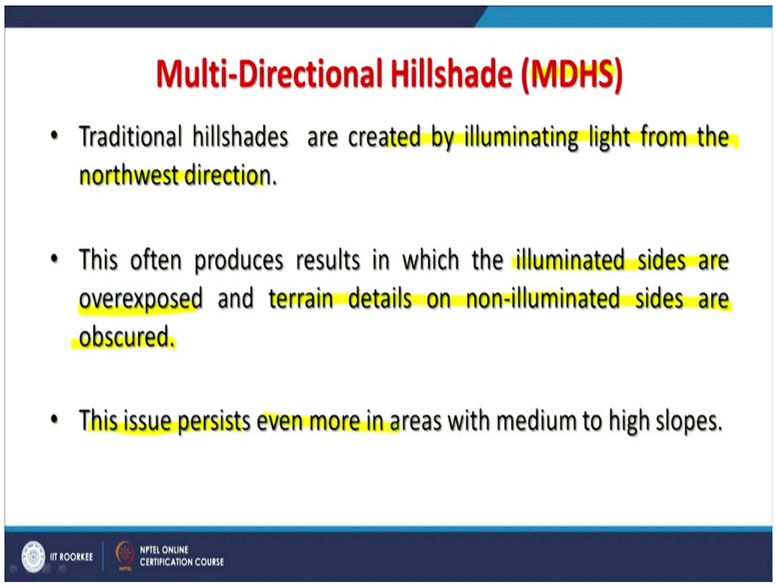

Now comes about this discussion about the multi-illumination source, instead of one. Is it possible? Now, it is becoming possible. I will show you some examples and the utility of also multi-directional hill shading or in short, we say MDHS. Because the traditional shades are creating illumination light from only northwest direction, though I can create from any direction by changing the angle in my software but always it would be a single direction.

What if I want to create a shaded relief model having multiple direction; that is MDHS then how to do it and how this concept works? So, single direction will always produce illuminated sides which are overexposed and the terrain details of non illuminates side are obscured or goes in darkness. So that is the disadvantage if I am having one single illumination source. I give the example of cricket pitch or football ground. In the nighttime, when these matches are held, generally you see 4 shadows.

Because 4 illumination sources and none of the shadows would be as strong as in case of single shadow. So, your terrain may completely different if I am having multi directional illumination source or multidirectional hill shading. The issue persists even more in areas with medium to high slopes. There only we require many times this hill shading and the problem is more becomes obvious in case of hilly terrain.

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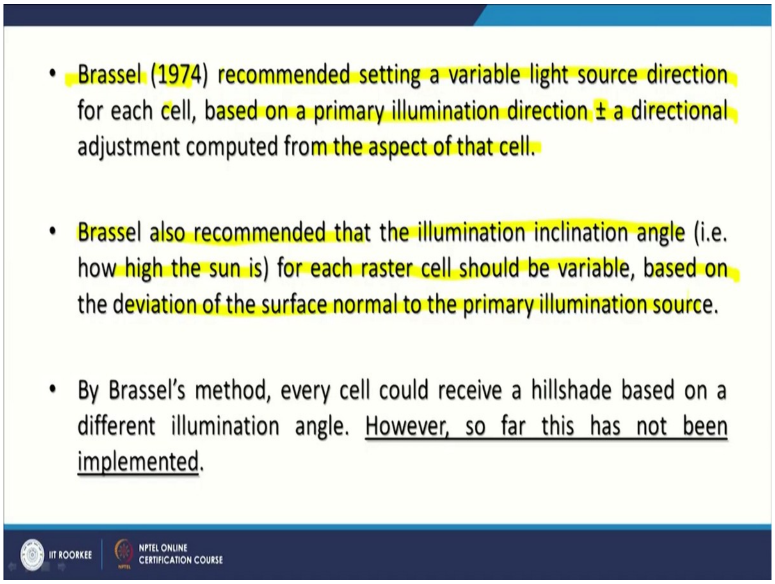

So, Brassel (1974) started working on this, recommended setting a variable light source or multiple light sources for each cell based on a primary illumination direction that is plus minus a directional adjustment computed from the aspect of the cell. Even in the first part when we are having the single source illumination, there are also slope and aspects are used. So, aspects and slopes play very-2 important role even if you have to calculate hill shading whether it is single illumination source or multiple directions.

Now this scientist Brassel also recommended that illumination inclination angle; that is how high the Sun is for each raster cells should be variable. So, not only the direction but the elevation of the Sun between 0 to 90 degrees, that should also vary based on the derivation of the surface normal to primary illumination source. So, if a sloping surface is like this then this would be the normal.

So based on that normal or this illumination angle so every time what this illumination source for each cell is doing, it is calculated surface normal for each sloping surface. And accordingly, it is keeping the illumination elevation or the source elevation accordingly so keeping this thing as surface normal. And then this same method developed by Brussels, every cell would receive a hillshade based on a different illumination angle.

In case of single source illumination or in a conventional hill shading what we do? We keep both things constant; that means illumination direction as well as elevation. But here things are changing; not only one single direction, multiple direction one and another thing this height of illumination source that is in terms of elevation angle. We are also change changing for each cell as per their inclination or creating a surface normal. So however so far this has not been implemented in various softwares but there are some examples.

Indirectly definitely you can do it. But direct menu you may not find in any standard software. Of course, indirectly one can do it without much problem.

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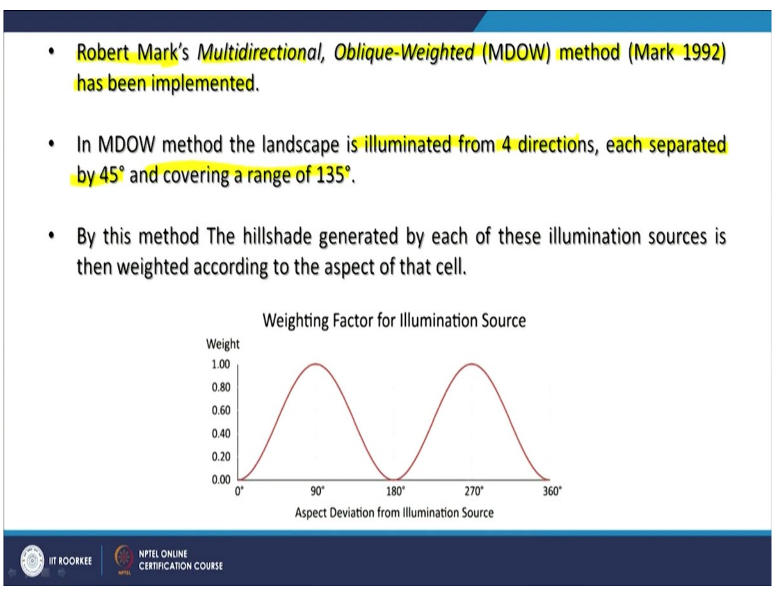

Whereas others like Robert Mark's multidirectional Oblique-Weighted; MDOW method that is through Mark 1992 has been implemented. So, Brussel's method has not been implemented. But this one has been implemented. The only difference is both are multi-directional, fine! Similarity is fine but this is oblique-weighted, there it is based on the surface normal. Now MDOW method is the landscape is illuminated from four directions, each separated by 45-degree and covering a range of 135 degrees.

Like here what you are seeing so this is 180-degrees then again, another 180-degrees; total is 360. So, aspect deviation from the illumination source and weights are given. So, if they are in the 90 degree then maximum weight. If it is a 180-degree, this is minimum weight keeping that illumination is coming from say one particular direction. So, if there are four directions, it will illuminate from all directions so this would be direction, this would be, this would be and that would be also.

0 and 360 degrees in a whole circle is the same. So, by this method, the hill shade generated by each these illumination sources is then weighted according to aspect of that cell.

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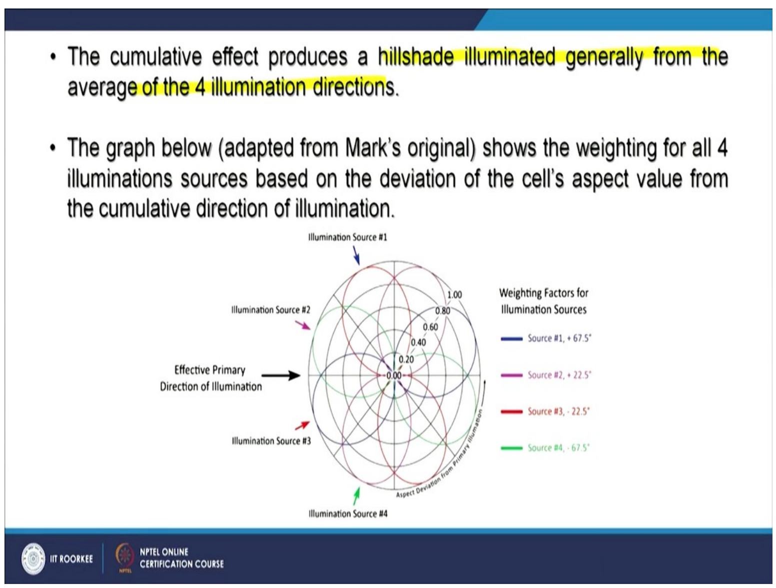

So, in Brussel's method and Mark's methods, this is the major difference they are having. Illumination source are multiple, no doubt but here both are using aspect but little differently. Now this cumulative effect produces a Hillshade illuminated generally from average of four illuminations directions and the graph which I am going to show here may look little complicated. But let me explain that this is the illumination source one.

And what we have said that illumination source is coming from four directions and each separated by 45-degree covering and range of 135-degrees. So, in this figure which we are seeing. each covering a 45-degree so this is 45-degree. And this is what it is covering by illumination source one. This is illumination source 2. This is illumination source 3 and then it is illumination source 4. So, of course this is total 180 degrees.

But if we take the value from here and here, this would be 135 degrees only. So, this much it will cover. So, this is based on Mark's original idea which shows that the weighting of all four illumination sources and there are only in the western hemisphere on the deviation of the cell's aspect value from cumulative direction illumination. So, this is how these are done and weighting factors for illumination source are also given here.

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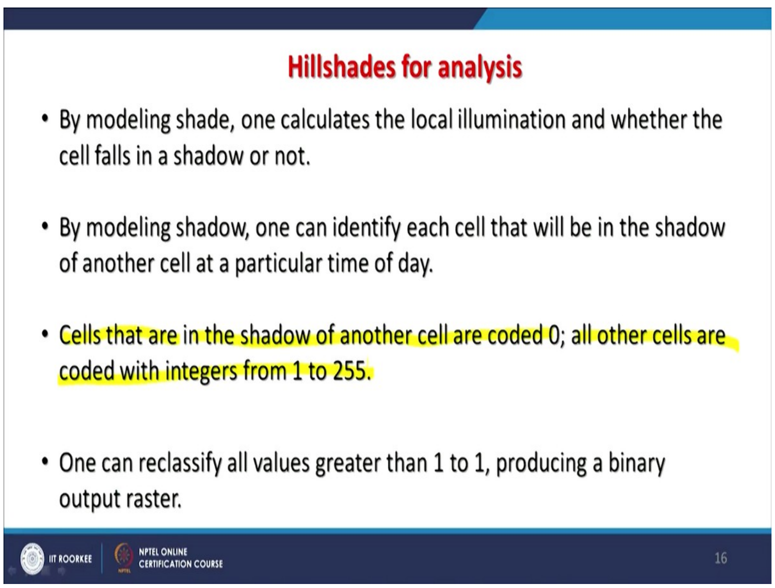

Now when we go for analysis by modelling the hill shade, one calculates the local illumination and whether the cell falls in the shadow or not also. And by modelling shadow, one identifies each cell that will be in either shadow or will be illuminated at a particular time. So, if we want for different timings of the same terrain and Hillshade say starting from morning to evening, you can keep changing the Sun position and then can create a simulation about how the shadows varies or changes with throughout the day.

So, for this analysis of this hill shade, the cells that are in the shadow of another cells are coded 0. All other cells coded with integers between values 1 to 255 because this will always create a grayscale product. Though by some techniques, you can create a coloured one also. So, one can reclassify all values greater than 1 to 1, producing a binary output raster also.

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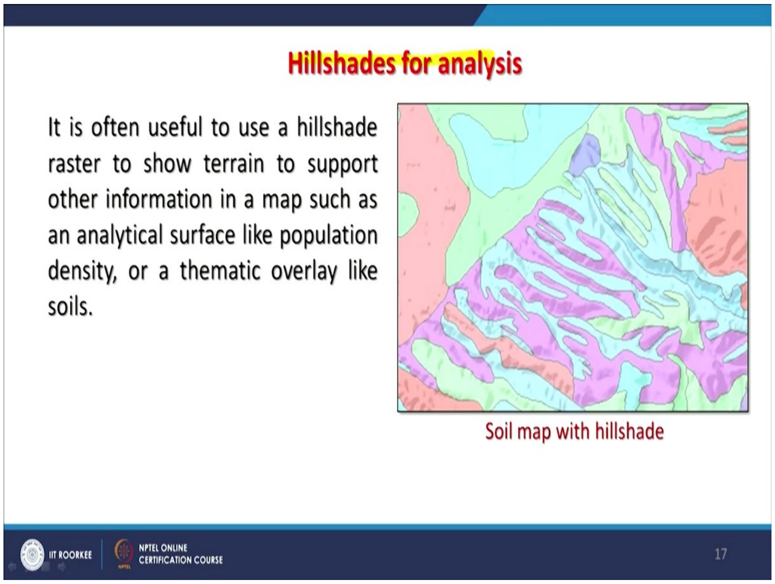

Like here Hillshade analysis and this is soil map with Hillshade. Simple Hillshade, one directional and soil map. If you overlay like this, what is the advantage? Immediately you would realize that there is a relationship between soil and landforms. So, it is a very-2 useful that a Hillshade raster to shows the terrain support other information. So, correlation between an elevations or landforms and a soil map can be found very easily. Similarly with the geology, similarly with many chemical qualities; many-2 things can be seen.

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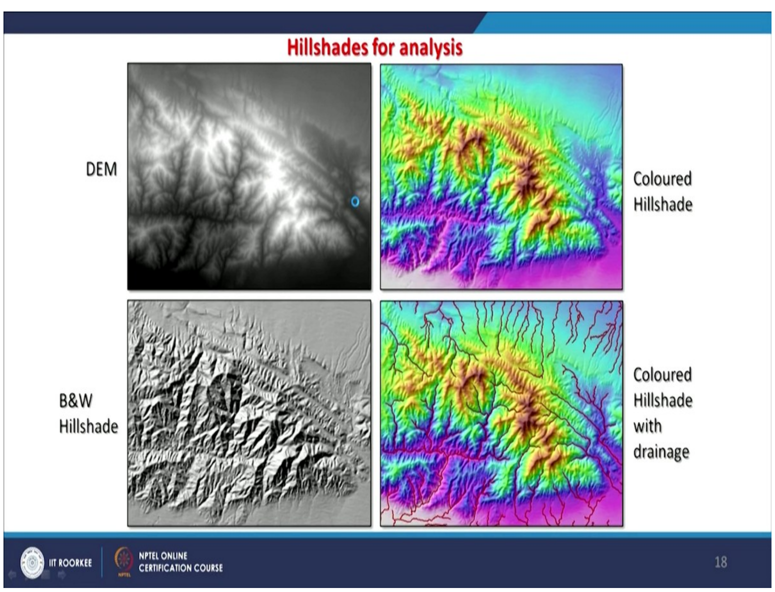

Now as I have been mentioning that by employing some tricks or techniques, you can always create a hillshade of even in coloured. Though original output would be in the black and white. So here again the same digital elevation model which we have been taken in every example, I have created a black and white hillshade then coloured hillshade is also here because the top one DEM has been assigned a colour ramp and hillshade has been kept in the background.

And this DEM has been kept at 50% transparency so both are being displayed here. So, ultimately what you are seeing is a hillshade in colour. It is more useful in that one. Also, I just for convincing that everything was done correctly. If you overlay a drainage network, these should go in the valleys; that is the one way of checking that all angles and everything was fine while creating the shaded relief model.

And as I have been saying that these Hillshades; whether multidirectional or single directional are very-2 useful for various purpose.

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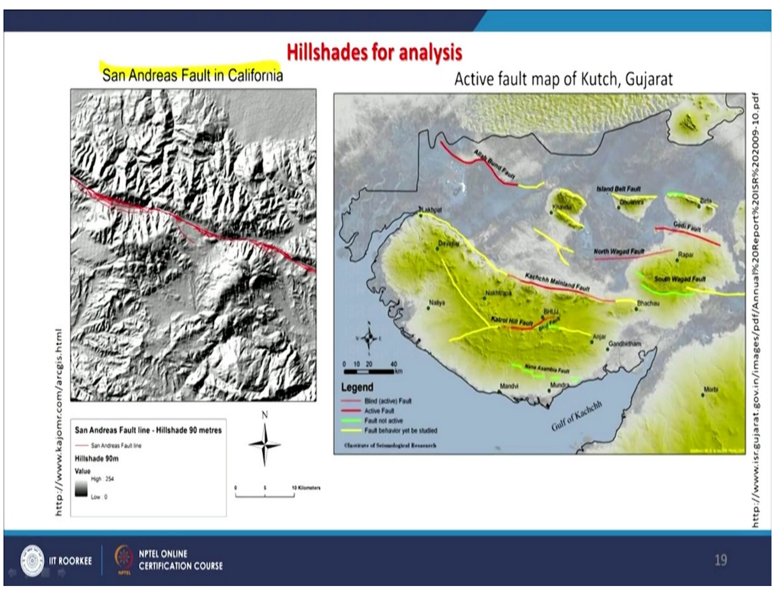

Here what you are seeing? This is example of San Andreas faults; very seismically active regions of the world and here we are having our India falls in seismic zone 5; the Kutch region. Again, you are seeing Hillshades in the background and then you are having other information’s top of that. If I would have represented this San Andreas faults in a plane digital elevation model without hillshade, that may not be very convincing.

But here it is very much convincing that faults are creating a depression because of such movements are there and high erosional activity. Lot of outputs or presentations people do in which they keep always a shaded relief model in the background like done here also.

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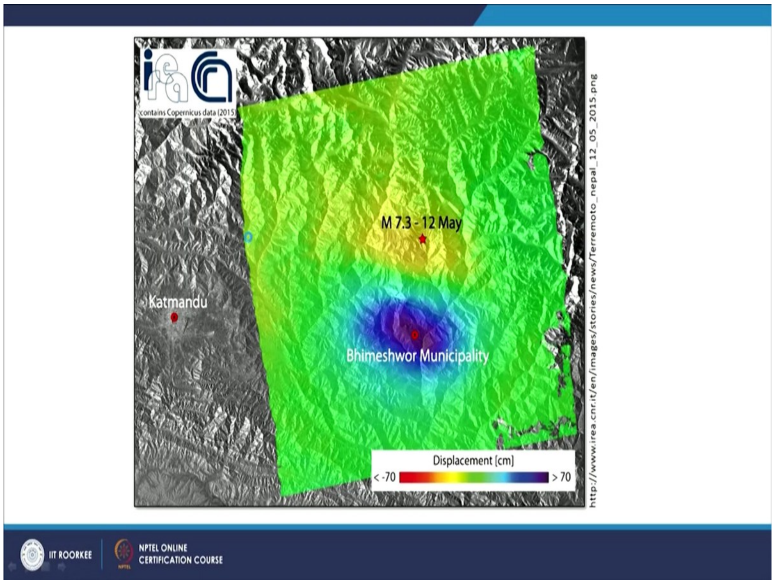

So, in case of SAR interferometry-based studies of ground deformations which were because of an earthquake which occurred on 12th May in Nepal of magnitude 7.3. So, instead of you know presenting your work with simple thing, if you can bring a shaded relief model in the background and put that layer on top, it is more interesting and convincing also.

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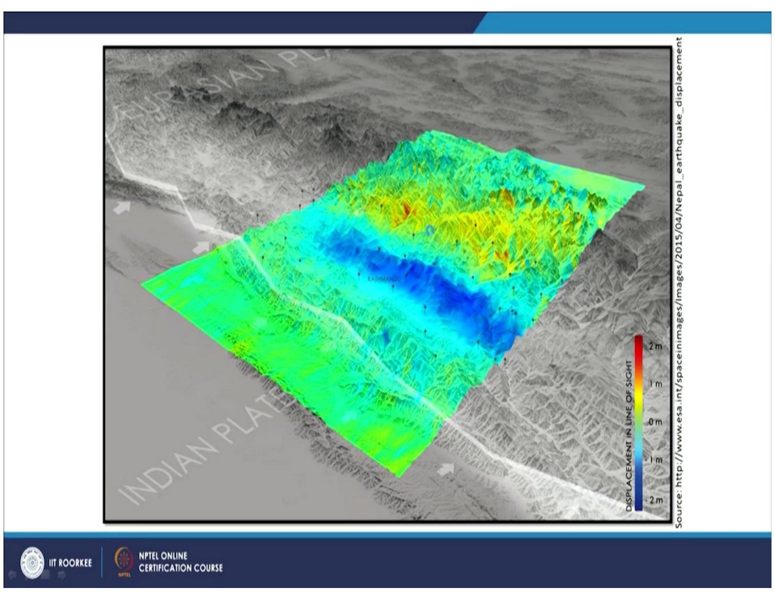

One more example of another earthquake which occurred. That was on the 12th May, Kathmandu one was on 25th April and again in the background, you are having shaded relief model.

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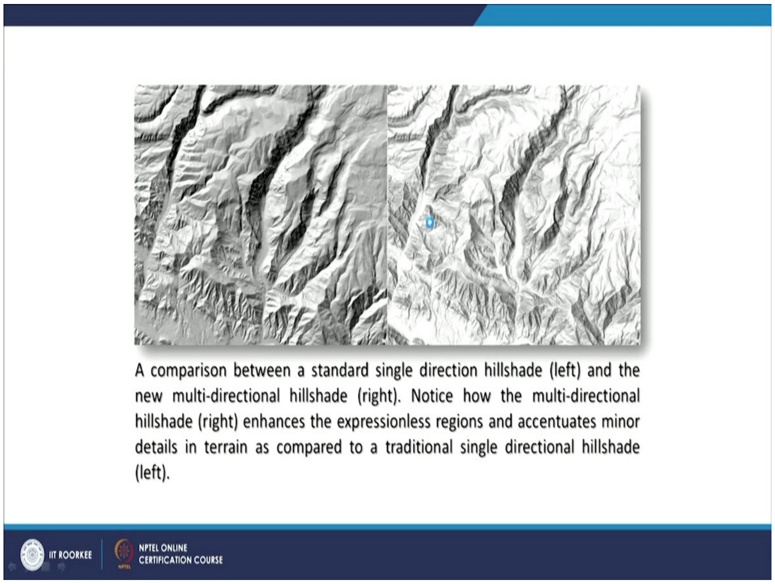

Now this is the comparison between single directional hillshade versus multi-directional hillshade. So here, you can see very clearly that a lot of features; landforms, ground features which we are have been completely missing in single direction hillshade are becoming obvious in multidirectional hillshade. So, definitely those people who have been using single directional, if this becomes very easily reproducible using standard software then people would definitely go for multi direction.

Because if I have to do the simulation; that means simulation I am putting the Sun in Northwest direction then question will come why only in the northwest direction? Why not in other direction? Why not multiple illumination source? So, if we do that kind of work, we can produce much better hillshade than a single direction one. So, this one is a completely expressionless region and accentuates minor details in the terrain as compared to the traditional one. This is bringing really minute details about the terrain.

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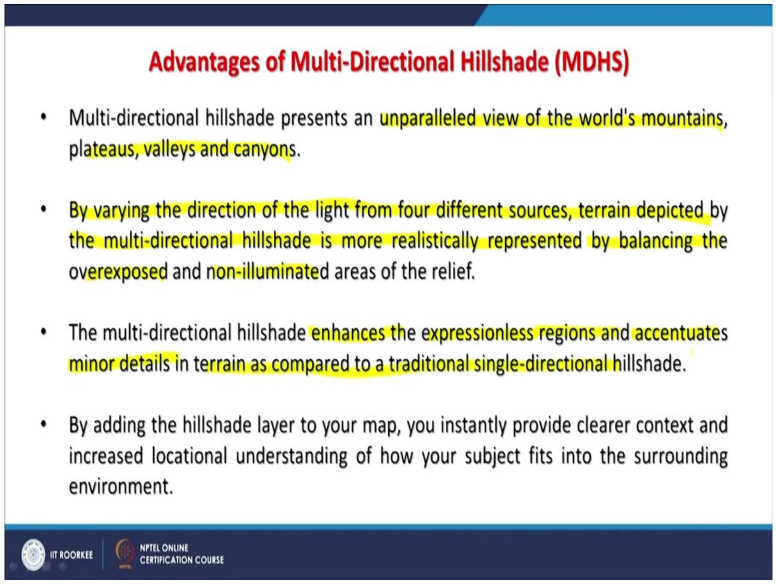

Now there are further advantages of multi directional (MDHS) that Hillshade presents unparallel view of the world's mountains, plateaus, valleys and canyons. And by varying the direction of the light from four different sources, terrain depicted by multi-directional Hillshade is more realistic representation because here the balancing is being done between overexposed and none illuminated or under exposed surfaces.

This MDHS also enhances the expressionless region. We have seen in the example and exaggerates the minor details in terrain as compared to the single directional one. And by adding this Hillshade layer to your map, basically as I have been discussing your presentation becomes very convincing very clear. I give the example of San Andreas fault or Bhuj or Kutch region and instantly people will feel very convincing and they may show very much interest and it provides a clear context and increase the local understanding of how your subject fits in the surrounding.

So, if it is part of the highly rugged terrain immediately that feeling will come but in a simple digital elevation model, that ruggedness of the terrain, that feeling will never come. That perception user will never develop.

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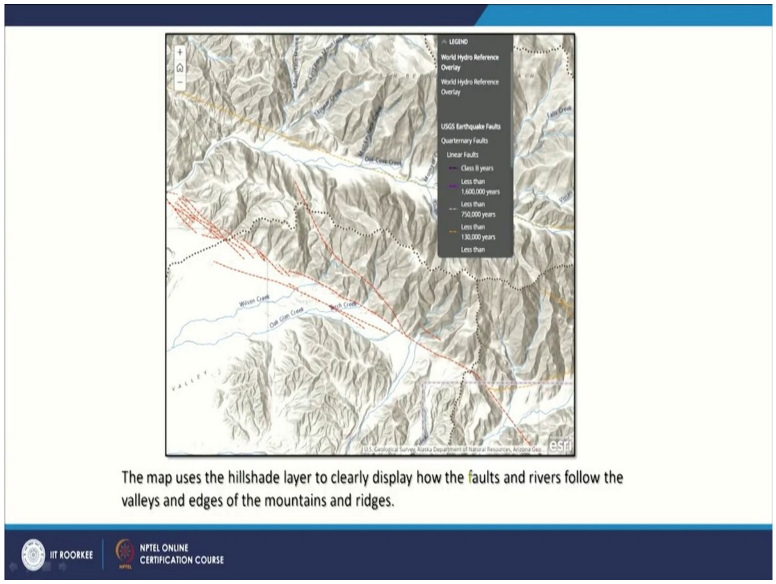

This is another example of Hillshade where the faults and rivers have been follows valleys and ridges and mountains. In the background, a hillshade is there and this is what you see. So, lot of Atlas is nowadays which are digital or analogue; they are also doing this thing. Not only in subject of civil engineering or in earth sciences but in geography also, extensively now Hillshades are being used. And if it is possible to generate multidirectional, that would be much better.

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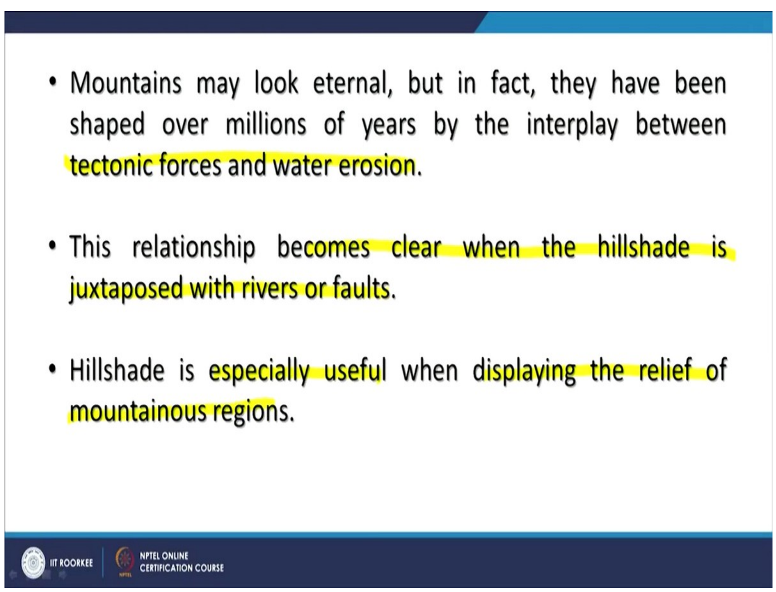

Because you know that if I can produce a hillshade then mountains may look eternal but in fact, they have been shaped over millions of years by the interplay between tectonic forces and water erosion. So, these things keep happening especially like young mountain chains of Himalaya so these two forces are very much active there. And this relationship becomes clearer when Hillshade juxtaposed with the rivers or fault. That is why I was saying that for presentations always if possible, bring a Hillshade in the background.

And then plot your data. It would be more interesting, more convincing and audience can immediately feel that what is the ruggedness of the terrain. Hillshade is also useful when displaying the relief of mountainous region, for plain areas also.

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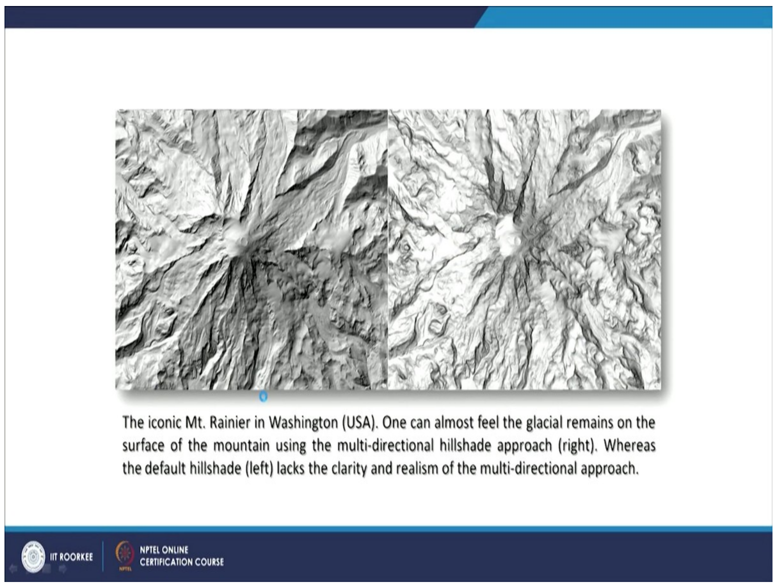

Like for example Hillshade in a single direction illumination source, Hillshade multi-directional illumination source and this is Mount Rainier; Very famous landform or landscape of Washington DC region. There you can see that what are the advantages of multi directional. You know all minute details are there.

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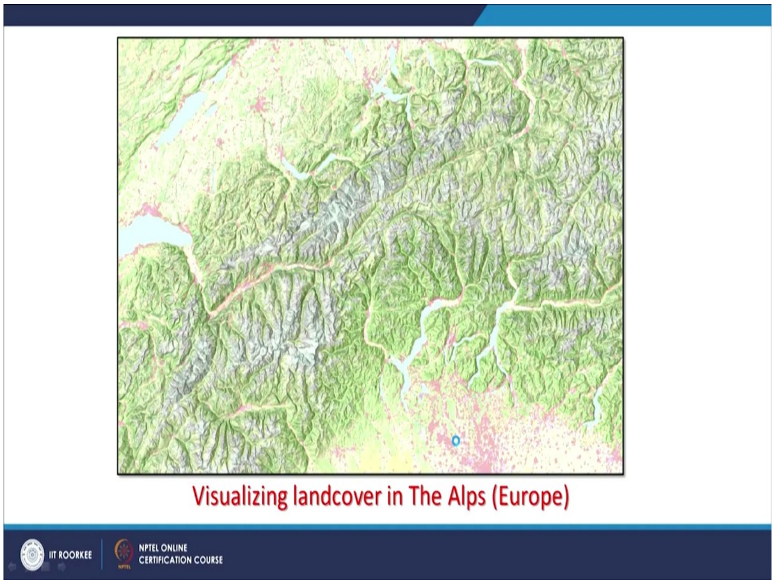

This is Alp's example; very close to Himalaya, not physically but terrain wise, though ruggedness is not as high as in Himalaya. But if I remove this caption, somebody may feel it's a part of Himalaya. That is why I said very close to Himalaya. And it will give you a very clear picture immediately without much. You do not need much training if things have been represented through Hillshade multi-directional illumination source.

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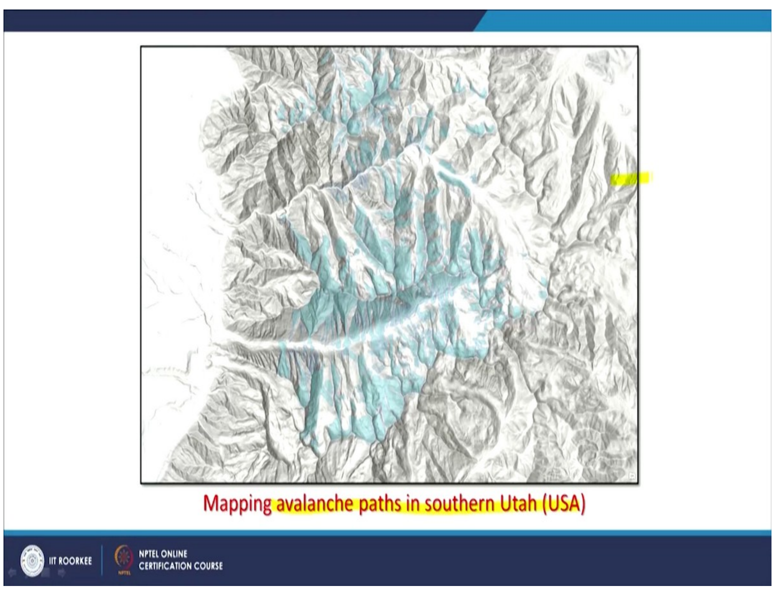

If somebody is working on glaciers, avalanches, again if they are put in the background. You are having the multidirectional Hillshade, put over a glaciers or avalanche side or snow-covered area, immediately things because very-2 clear.

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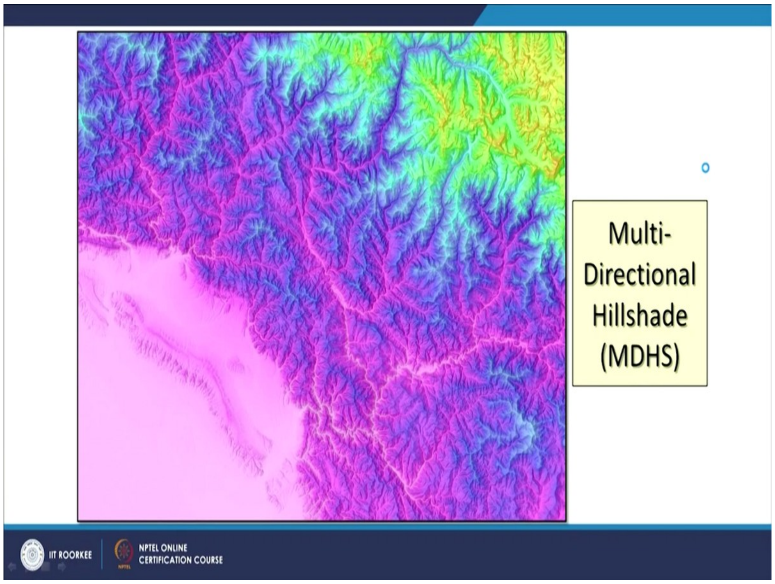

This is the multidirectional hillshade which I have created using this MDHS or this earlier method. Though because it is covering a large area and therefore you are not seeing much details but if you zoom any part and compared with the conventional one, you would really appreciate that what is the advantage of having multidirectional hillshade. Now very few more minutes I would take about this discussion of how to exploit further these hillshade which they have done to remove false topographic perception phenomena.

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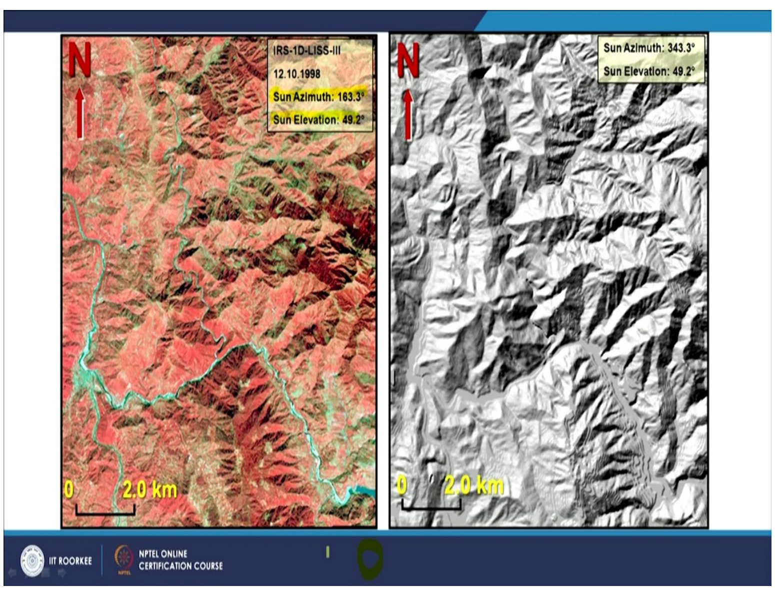

And like here on the left image, a satellite image is there. I have also retained the Sun azimuth and elevation angle and what happens here that because the Sun is in the southeast quadrant when this satellite image was taken and therefore it is giving wrong perception about topography or existence of false topographic perception phenomena (FTPP). And because of that, you might be feeling that this Bhagirathi River which is part of or tributary of the Ganges is flowing on the ridge.

That means it is wrong perception. A river cannot flow on the ridge. Topographically or geo-morphologically, it is not possible so that is something wrong in our perception. How can we get rid of this wrong or FTPP from our satellite image? So, what we did? We exploited the shaded relief model and created a shaded relief model corresponding shaded relief model using opposite sun azimuth and illumination. So, sun illumination was added; 163.3 degree, it was added 180 degrees so it becomes 343.3 degree.

And elevation angle was kept as the same. And then when the same terrain, a digital elevation model of this corresponding satellite image was used and illuminated from northwest direction then you see that the river is flowing in the valley but this is not the true representation as satellite image is doing. So, with employing digital image processing techniques, we can do colour transformations and can bring other characteristics of satellite images over this shaded relief model, having opposite illumination direction as compared to your satellite image like here.

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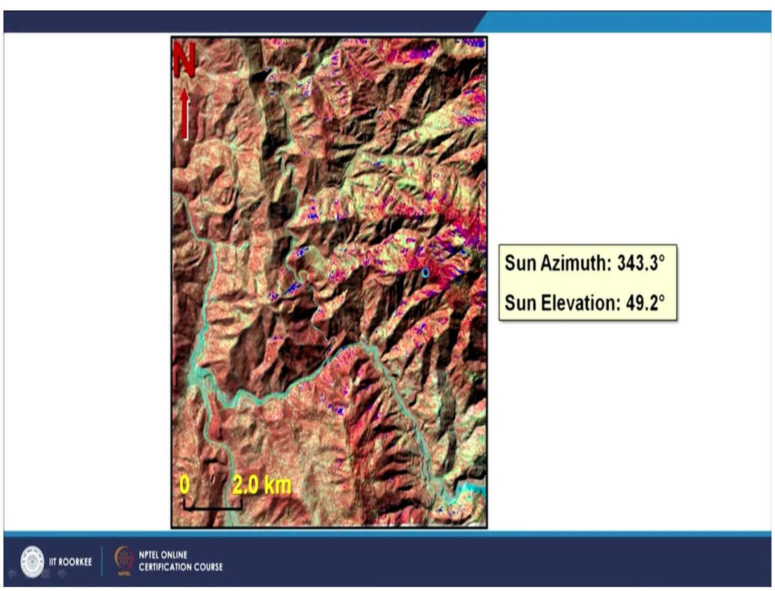

So here this is not suffering from FTPP and it is bearing all the content of your satellite image and your river is flowing in the valley. At least it is being perceived that it is flowing in the valley. Note in the previous example that here, it is being perceived that it is flowing on the ridge which is incorrect perception. Here your perception will improve. So, removing a false topographic perception phenomena, we can definitely employ a digital elevation model.

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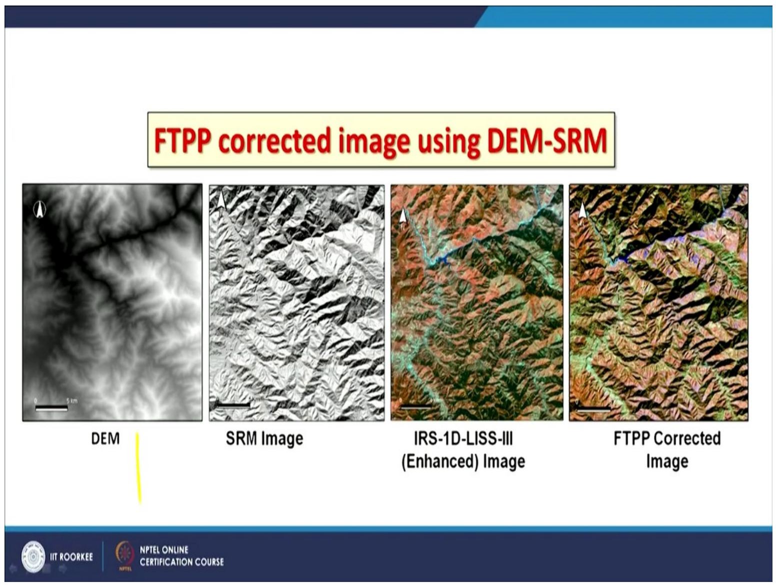

There are other examples that this is digital elevation model. This is shaded relief model of the same area. Then this is the image and this one has been created using against Sun illumination which was here. We have forcefully sent here in the northwest direction and when colour transformation were done, you get a FTPP corrected satellite image. Now 2 animations; these are the last and then I will close.

(Video Start Time: 44:19)

There I am depicting these two Sun parameters like elevation and azimuth. First, I would be depicting the azimuth and then how the changes which elevation can bring in our perception. So, first changing the azimuth. What you are seeing here that the white one is the Sun. So, when sun is in the Northern hemisphere. So, I say this is Northern hemisphere, this is Southern hemisphere. So, when the Sun is in the Northern hemisphere, I am not seeing false topographic perception phenomena. I am not observing that.

But once the sun comes in the southern hemisphere, I start see this FTPP. So, for that purpose only if because each satellite image which is being acquired by sun synchronous polar orbiting satellites of any part of the globe of Earth, Moon or Mars, all of them are suffering from FTPP. So FTPP is universal phenomenon.

And therefore, before satellite images are put for Interpretation or further analysis, it is always that one should exploit this technique of hill shading and remove this FTPP from the images. So here, there are 8 images. 4 images without FTPP and 4 images when the sun is in the southern hemisphere are suffering from FTPP. Now another simulated animation is starting the sun elevation, of course Sun is kept here. But elevation is being changed from 5-degree to 90-degree.

So, when Sun is near Horizon; that is 5-degree, you see a very dark image. And when Sun comes overhead, you see the brightest but important point is also, your depth perception changes. When the shadows are large, your depth perception is more. When shadows are less or no shadow, your depth perception is different.

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So that means the illumination source, azimuth and elevation place very-2 important role about the depth perception of satellite images or of a hillshade. So, while creating or using or interpreting, one should take care about these things and should develop a very good understanding about this as I have explained. With this, I end. Thank you very much.