Remote Sensing Essentials
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Applications of Remote Sensing in Earthquake Studies – I
Lecture - 53

Hello everyone, and welcome to remote sensing essential course. Today we are going to discuss the application of remote sensing in earthquake studies and this discussion is going to be in 2 parts because it is little lengthier but I am sure it is going to be very interesting. As you know that the remote sensing data is a generic data and that means it can be applied for various applications and including in earthquake studies.

So, we have seen some examples of how remote sensing along with GIS can be applied in water resources studies or related with natural disaster or other things. So, in that a continuation and this is of course, an earthquake is a natural disaster. So, we are going to discuss this part and then some input is also going to be come through the GIS though it is not exactly part of this.

But in order for in order to have a complete discussion, I thought that I will include little bit application of remote sensing in GIS that is an integrated application but most of the application is mainly on the remote sensing data.

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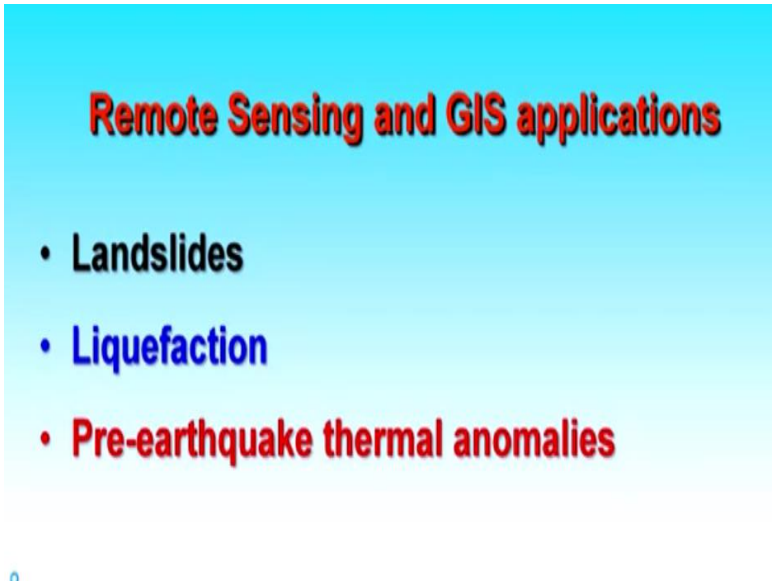

So, this application on earthquake related things is going to be in 3 sections. One is the landslides, how remote sensing data can be used to study the earthquake induced landslide. I am not going to discuss the normal landslide which are awkward either due to rainfall or some other reasons, but I especially I am going to discuss here earthquake induced landslides and also there is a as you might be knowing.

That there is a co-seismic phenomena and that is liquefaction so, when earthquake occurs in a certain conditions when soil is sandy and saturated with water and due to the vibrations are shaking by the earthquake, a phenomena occurs which is called liquefaction and that means that for few seconds maybe 10, 20 or 30 seconds, the soil is starts behaving like a liquid and if any building or structure is standing on that, then that might collapse.

So, we will be seeing some examples, how remote sensing can be used to map the liquefaction only few liquefaction affected areas induced by an earthquake and the finally in this application part of remote sensing, we are also going to discuss how pre earthquake thermal anomalies can be detected. And applying remote sensing data is basically the thermal remote sensing data.

So, these 3 things are there we will be also seeing applications of little bit of SAR interferometry. Though while discussing SAR interferometry be touched upon that, but, these 2 discussions are especially on the applications of remote sensing in earthquake related studies.

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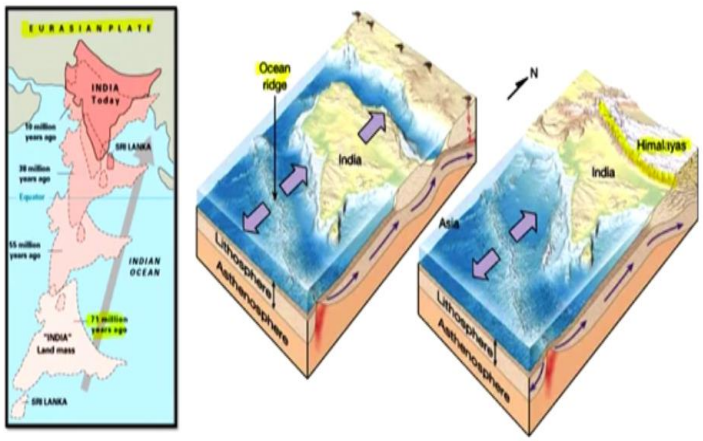

The India-Asia plate tectonic collision (Source: IRIS)

As you know that Indian subcontinent or is especially the Indian plate if I more precisely and would like to call it the Indian plate has been moving and since, you know 71 million years ago it was somewhere else as you can see in this map and then slowly, slowly it has moved to the current position and this moment is still continuing and when it is, you know meeting with the Eurasian plate, which is in the top is shown here in the grey color.

Then this pushing or this migration or movement of this Indian plate is creating stresses in along all along the Himalaya in some other parts of India and time to time we get earthquakes as well. So, as you can see that this movement has also created a huge mountain chain that is Himalaya as well and also same region. Other things as you can see here, that also has been also created in the Indian Ocean.

And offcourse, Himalaya has also been created due to this moment and this is a highly seismic equal seismically active reason, especially part of Himalaya and there are a lot of earthquakes keep coming.

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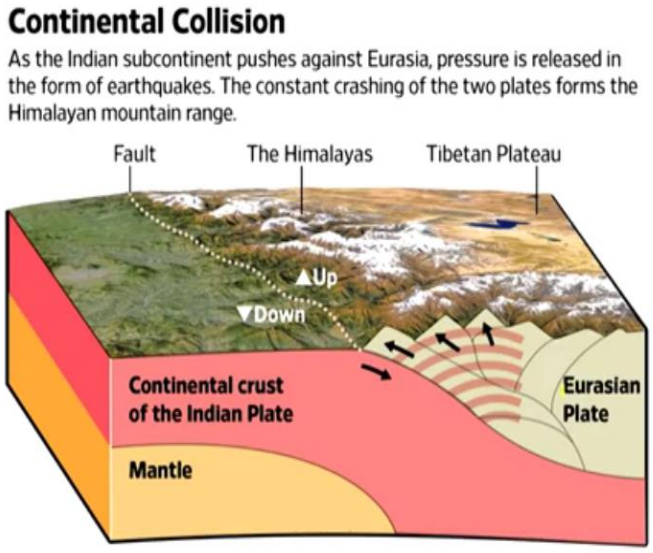

As you know that this is the Eurasian plate and Indian plate is moving, this is continental crust of Indian plate is moving it is going basically you know below the Eurasian plate and which is creating not only the Himalaya along these few well known faults are there, but it is causing a lot of earthquakes.

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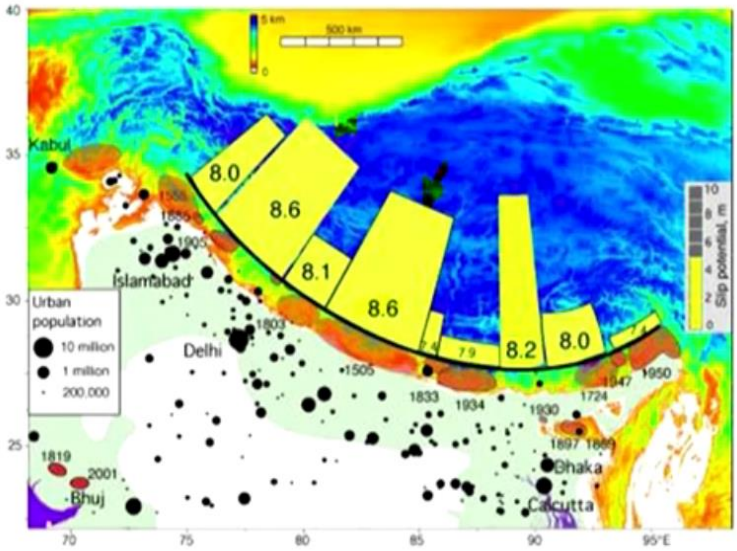

And this is a very famous figure by Roger Willem and based on his research and he has basically estimated that the these different parts of Himalaya are having potential to generate earthquakes of different magnitudes or rather greater earthquakes above and near or above 8 magnitude like here where do you are seeing that this one is 8.6 this area is having that kind of potential.

Another area which is part of Uttarakhand and Himachal is another having big potential of creating big earthquakes. So, as I mentioned that Himalaya is a large part of Himalaya is highly seismically active reason due to the movement of Indian plate and which is going below the Eurasian plate and it is causing a lot of earthquakes regularly. So, generally, but today we are going to see is the earthquakes which causes are having magnitude 6.

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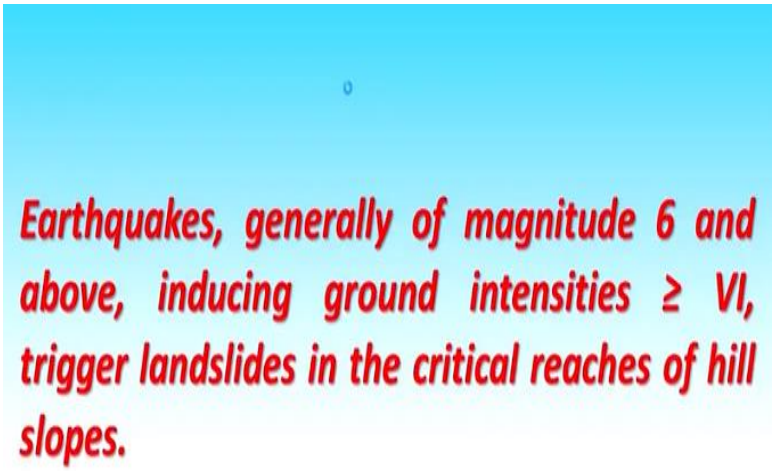

And above including ground intensities of more than 6 which triggers landslides into key critical reaches of his slopes and this we have observed in several past earthquakes.

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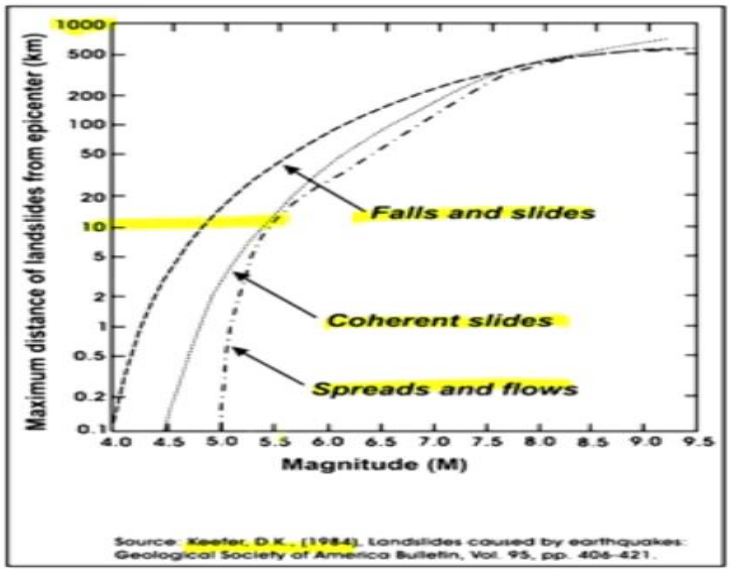

Few examples, I am going to take as you can see in this figure, and given by a Keefer in 1984 and on the x axis we are having the magnitude on the end on the y axis, the distances from the epicenter basically is given. So, as you move towards higher magnitude and what you find that you know lower magnitude, having even lower magnitude having a very less distance to epicenter can also bring landslides.

But as we move on higher and higher then different kinds of land slide like rock falls or slides and slides or a spread and flows all can occur and depending on the distance but when we go much away from the epicenter like 1000 kilometers. Then we do not see any effect of any earthquake even earthquake of above 8 or so. But if we talk as a near say 10 kilometer, then even you know 5.5 magnitude earthquakes and can bring the landslides in this region.

So, this gives a basically perspective view about the how this relationship between magnitude and distance from epicenter and related with landslides as you seen.

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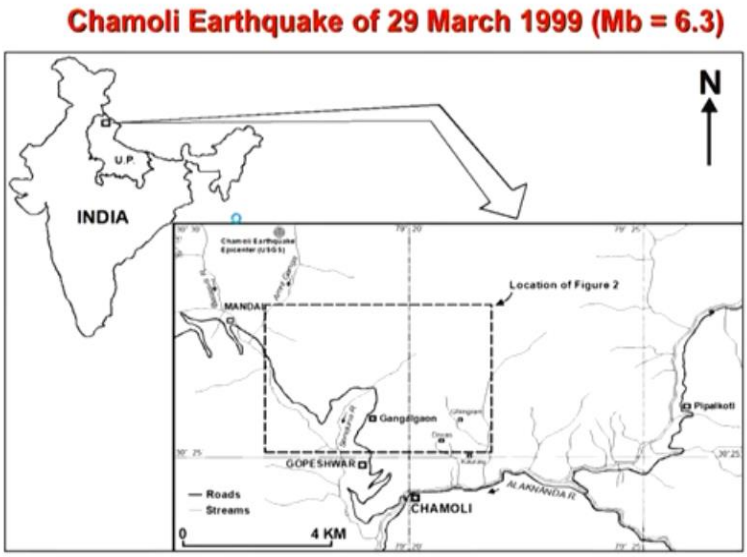

Now I am going to take one example of an earthquake, which is about the co-seismic and landslides, which occurred during this 29th March and 99 earthquake, which is also known as the Chamoli earthquake, it has the magnitude of 6.3 and this of course, occurred in Uttarakhand and what we are going to see here;

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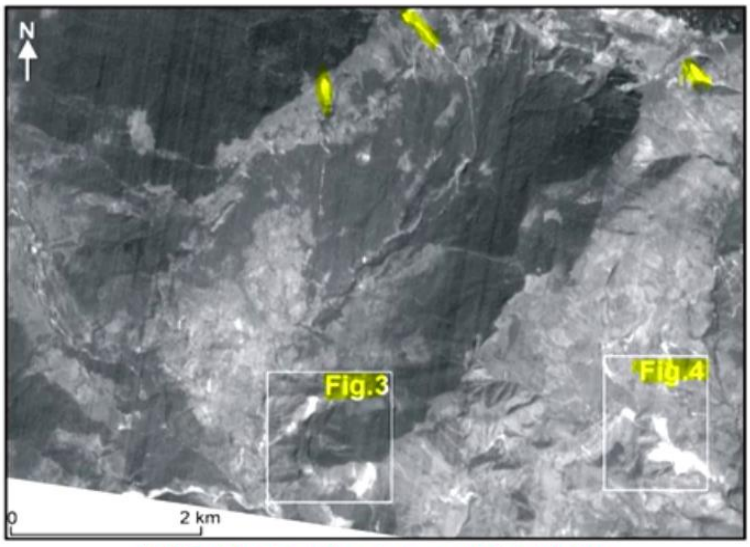

IRS-1C-PAN post-earthquake image of 31 March 1999

Through a satellite image and then interpretation also and that there are a few patches which you are seeing like I will be seeing the law you know blow up or in large part of these 2 boxes which are marked here and a few more landslide which you can see like this one and there is also the slide here. There are also landslides here so, if we compare these, this image with the image before the earthquake.

Then we can make sure and that which are the landslide which is induced by that particular earthquake which occurred on 29th, march 99.

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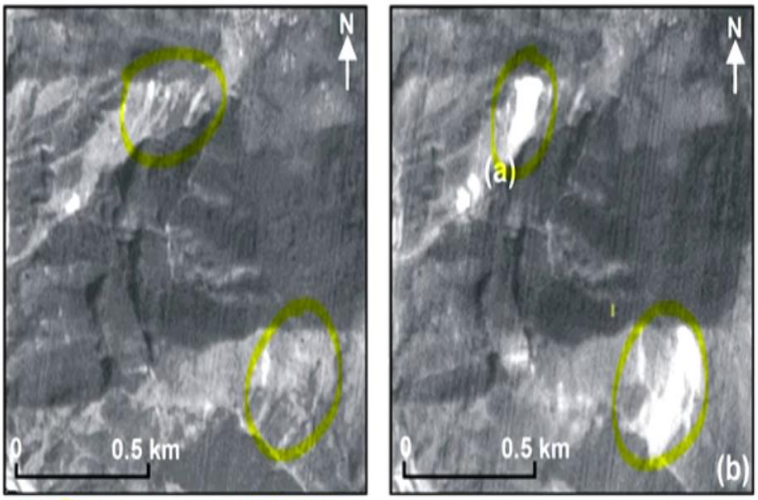

Figure 3

So, here are the, you know the pre earthquake image and post earthquake image and this is from our own Indian remote sensing satellite IRS-I Z and this is panchromatic sensor, and this is of course, pre earthquake image of 26th march just that just 3 days before the Chamoli earthquake off 29th March and right hand image that is the b image is of 31st March 99 and though if you if you recall the discussion on our IRS-I Z.

And repeat cycle, you would find that repeat cycle is not a really the 5 days which is the difference which you are seeing here in the time, so, because that sensor had the capability of a steering that means, from the ground after sending signals, the sensor can be steered or tilted towards a particular direction and this is what exactly done after this 29th March earthquake that day when a neighboring orbit and the same sensor same satellite was orbiting.

It was tilted little bit towards that same area, which is acquired the image on 26 March and then we are having just 5 days time difference images. So, one is pre earthquake image and another one is post earthquake and when we are doing this kind of interpretation, one, one or 2 things which we have to make sure before we attribute that these landslides. Which are going I am going to discuss further are really induced by that earthquake event or they there are some other, you know, reasons.

So what other reasons can be intensely in for other reasons can also be human interventions or road construction other. So when these 2 images we got we make sure that there were no, basically after checking the meteorological data and local inputs beam. We knew that they were no rain between indeed during these days and secondly, there are no road construction, or there were no road construction during that time when these images were acquired.

So, whatever the changes, which we are seeing between these 2 images having 5 days time reference must be induced by that earthquake event, which occurred on 29th of March. So, as you can see that here in this area, there were already some signs of slope failure you, but nobody really noticed and when earthquake occurred, what we are seeing a big landslides, which you can see here. So, definitely we can after going through or checking the meteorological data and other inputs.

We can attribute that this landslide which I have just highlighted is induced by an earthquake event, another area which we can notice is this one and then again and a large landslide has occurred induced by Chamoli earthquake. Now, implying you know we have also discussing the digital image processing techniques.

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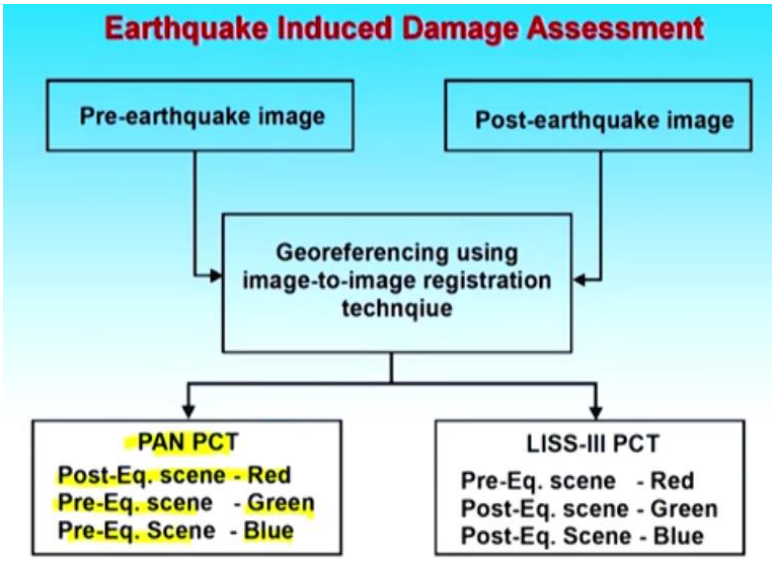

That we can imply some, you know if I was to call a advanced image processing technique, and they can create some pseudo color composites using this PAN data. Because we are in order to create a colored image you require basically 3 colors and you assigned to red green and blue or 3 bands, which you assigned to red, green and blue. But here in our case, we are having just 2 beds, one is pre earthquake, another one is post earthquake.

Band wise or electromagnetic spectrum wise both our panchromatic so, what we did we assigned the red color to the post image and the green and blue color to the pre earthquake image and then this kind of combination it is not neither false color composite nor true color composite. So, we gave in name is a pseudo color composite.

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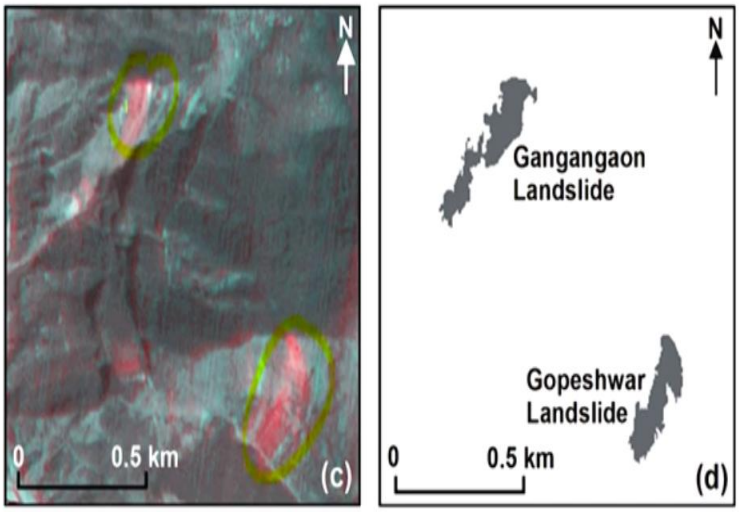

Figure 3

And the advantage of this pseudo color composite is this that pre both pre earthquake and post earthquake images and pixels are on the same image and they whatever the red areas which you are seeing and for this region in this region, and there is some other reasons are the changes in terms of reflection induced by that earthquake event, which has occurred on 29th March and it is time difference between these pre earthquake and post earthquake images are only 5 days.

So, implying this pseudo color techniques using this pre earthquake and post earthquake images, one can very clearly demarcated which are the area which have changed it do in those 5 days another important point which you would notice. That there are areas which are showing just white color which I am highlighting here and here also, that means there were no changes between pre earthquake and post-earthquake.

And this is this is very important from a prevention point of view. That means, there were already some signatures or some signs of slope failure and we will have further discussion on this point. Let me bring one more example of landslides from the same region induced by the same earthquake further, using this pseudo color transform you made your PCT image and by

doing the one more step in the image processing that is masking rest of the things except keeping the red part we can exactly delineate the landslide affected region and this is what exactly it has been done.

On the right side image 2 major landslide which we are known as Gangangaon and Gopeshwar landslides and they were marked very clearly very precisely using this threshold value.

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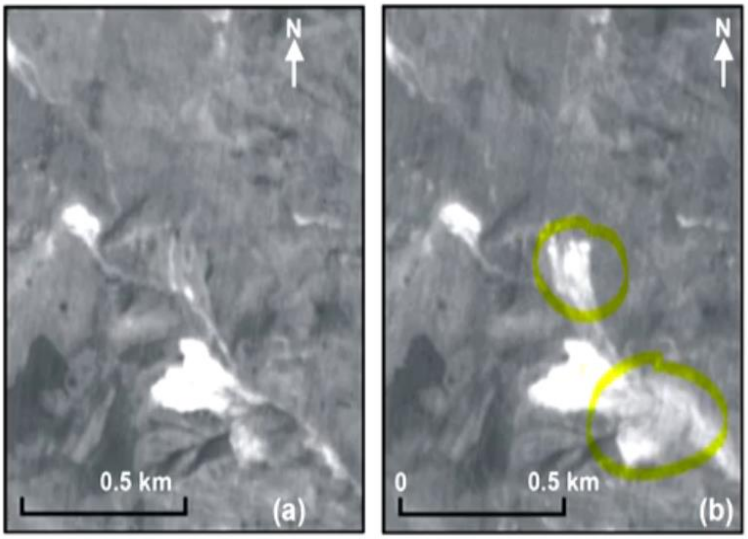

IRS-1C-PAN pre-earthquake image of 26 March 1999 IRS-1C-PAN post-earthquake image of 31 March 1999

Now or masking technique now, another example is again on the left side you are seeing pre earthquake on the right side you are seeing post earthquake time differences again 5 days. So, before the earthquake or 26 March after the earthquake 36, 31st March and then remember, the earthquake occurred on 29th March. Now, here you are seeing on the left image that is pre earthquake amiss already existing some landslides, but this part has got new landslides and the and also the existing landslides announced.

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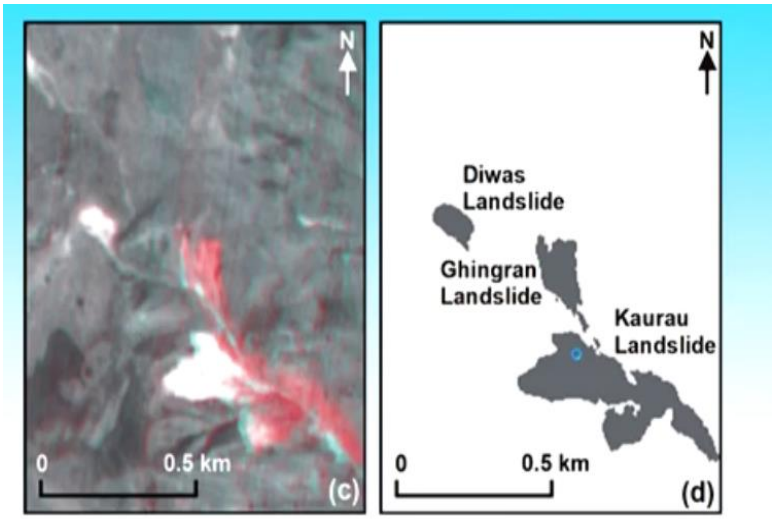

Figure 4

So when we see this BCT image or pseudo color transforming me this things comes very clearly that a red part are also showing the changes which has occurred during those 5 days that is induced by an earthquake event and white parts are showing, basically no changes in those 5 days in the pre earthquake or post earthquake image. So what the lesson we can learn from here is that there were already some signs of slope failure before the earthquake.

There were already some signs of slope failure and basically everyone ignored if care would have been taken then probably whatever the losses which these landslides have caused to the humans and agricultural fields and other things might have been avoided or prevented rather. So, that that is the advantage of remote sensing images, that they keep recording the data after or every orbits and we know where landslides will occur.

And we also know where earthquake induced landslides can occur. We also know where earthquakes can occur. Only thing we do not know what magnitude earthquake will occur and what would be the timing to date or when it will react exactly. But we know that earthquake or seismically active regions like this part of Amalia, so, when we notice a some landslides and then the care should have been taken, and so that the losses can be you know, minimized. So that that should be and that advantage of remote sensing should be taken here.

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One more example of these recent earthquakes let now occurred 2019, but in Nepal from earthquake point to beauty these are recent earthquakes of big magnitudes which is 7.8 magnitude which occurred on 25th April and 7, 7.3 magnitude. So, first one is called Gorkha earthquake another one is called the Dolakha and Nepal earthquake of 12th may 2015 and these 2 successive earthquakes have caused extensive landslides more than 5000 landslides have been a mapped in this area of Nepal.

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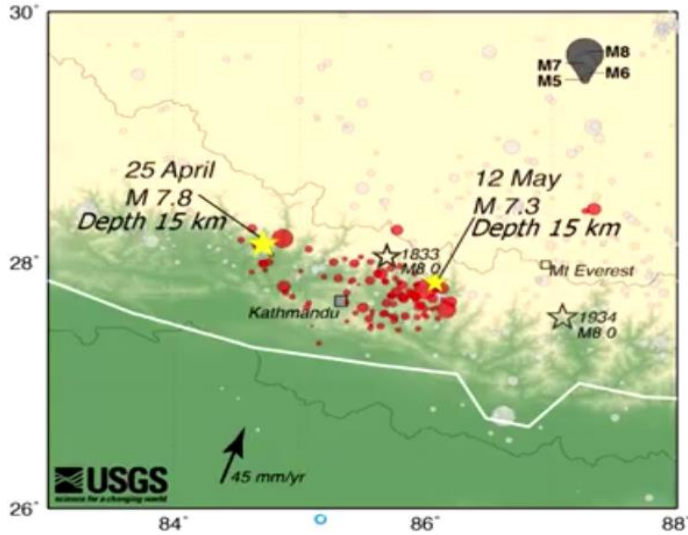

After: http://www.usgs.gov/blogs/features/files/2015/05/Nepal-Aftershock-Map.png

And what basically you here you are seeing that 2 earthquakes are soon as studies called a soaks and the rest of the after soaks are you know the force, which we are all cut and during that time or also shown in red circles. So, in a one area lot of intense seismic activity has occurred in those basically 20 days or less than 20 days and it has caused havoc in terms of landslides and loss of property and houses and everything.

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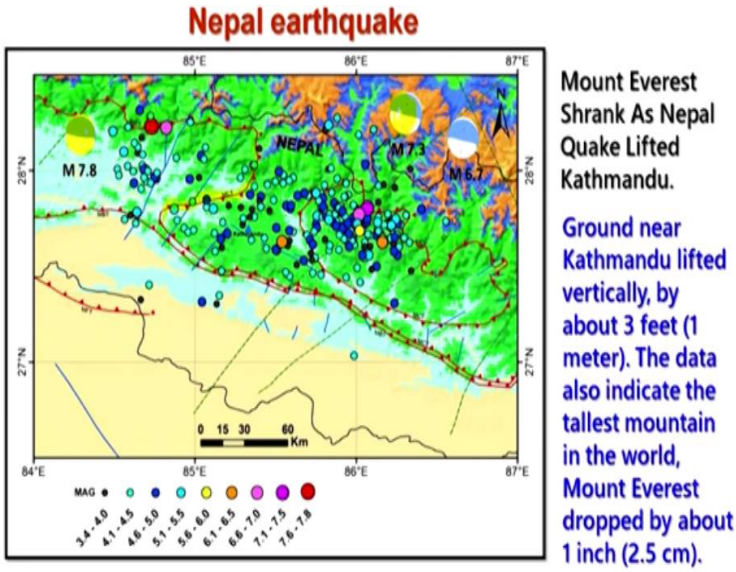

So, this is what the and the fall which was responsible was MCT and as you can see that one earthquake which occurred here, and that 7.8 magnitude earthquake and 7.3 earthquake these 2 has occurred an in between lot of different magnitude earthquakes have also occurred. As we know that through this and this Mount Everest sank as Nepal quake lifted Kathmandu and ground near Katmandu, lifted vertically by about 3 feet.

How this all information is coming it is all coming through the analysis of remote sensing data. So lot of interferometry or SAR interferometric techniques we are implying using different census data like a loss pulsar data or a your name and we said data Sentinel data and people have analyzed extensively and could come up to these conclusions that the ground. Katmandu area has vertically lifted by 3 which is a large, very large movement, if you think in terms of earthquakes, and as you can think that what it will cause it has really caused havoc, as you can see the ground photographs taken just after the earthquake.

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So this is a you know, one of the main roads of Kathmandu and as you can see that the entire road has exploded in 2 parts and another area which is shown here the complete road has got damaged.

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See the damage a these stuffs you know the vertical raising of the Scott Mondo Valley which has caused a huge damage to buildings as you can see here.

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Again some buildings again these areas as you can see here and the monuments and temples. There were a lot of temples which we have also and damaged.

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Like here this is a Kaltura tower and see this is now luminance of this tower and before the earthquake this was and this mean or was like this. So, before this the temple was like this now it is like this and before this and this whole temple area was like this and after that so every almost every such moments were damaged in Katmandu in area and because of earthquake, but our purpose here is to discuss earthquake induced landslides.

So I am coming and how a time series data can be implied. Because remote sensing data is available regularly may not be from same sensor, but maybe from different sensors also. So, we can imply this data.

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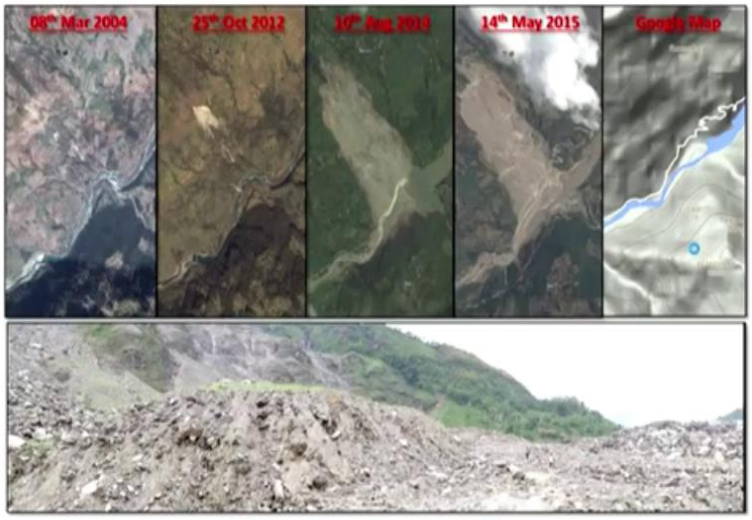

Bahrabise landslide

I have put all these images except the bottom images which we have taken from the ground itself just after the earthquake, but other images are the first 4 images from left are from Google Earth. As you can see that this is 14th May 2015 image and this after these earthquakes, and as you can see this landslides and this is called a Bahrabise landslides and it has become really huge.

But between October 2012 and August 2014 you can see that they will hardly any landslide and because of rain, this landslide became of this much size. Now, another co-landslide you know induced problem is another which occurred in Nepal during these earthquakes is that these many landslide have caused or dam delivers and this is what you can see here also that a new dam was created a you know, you can call as a landslide induced dam.

And these are very dangerous because in the upstream it will fill the water and anytime these dam can break an endowment stream they can bring havoc in because of dam break. So, that is another concern. So, what I am trying to say here through these time series images, that there were already some signs of slope failure in 2004 in 2012 and then this those slopes have now taking shape as the landslides the preventive measures should have been taken.

Then in 2012 or just little later, so that this would not have become a large now in 2014 do it became large, but a after the earthquake it has become further so, this land slide has enlarge. So, this land slide is started with a small you know, movement of slope and they induced by

rain it became a quite large and after the earthquake, it has enlarged further and further it has demi or a dam the river and created a problem here.

Just to give you an idea how big this landslide was, and this is the human is standing here. So it is a huge landslide and road which was going to Bahrabise village is completely destroyed. And then accessibility became a big problem.

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Now another example from Nepal earthquake, there is a pre earthquake and post earthquake images as you can see here, that there were already some signs of slow failure, everyone ignored and earthquake has lost this landslide, we also visited on the ground. And by the time things were cleared on the road, but it became a large landslide as you can see.

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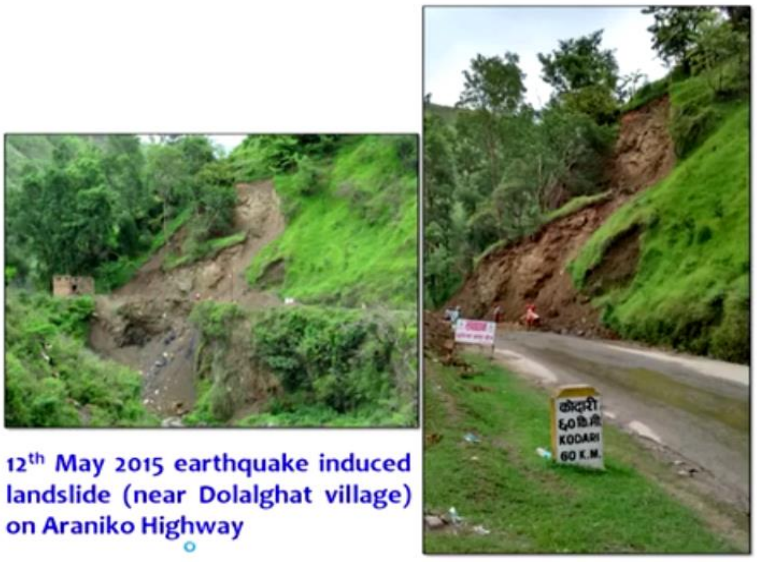

Another is a Dolalghat landslide, which you can see here and Kodarivastha epicenter of the first earthquake. This was also the road was blocked because of landslide but later on, it was cleared.

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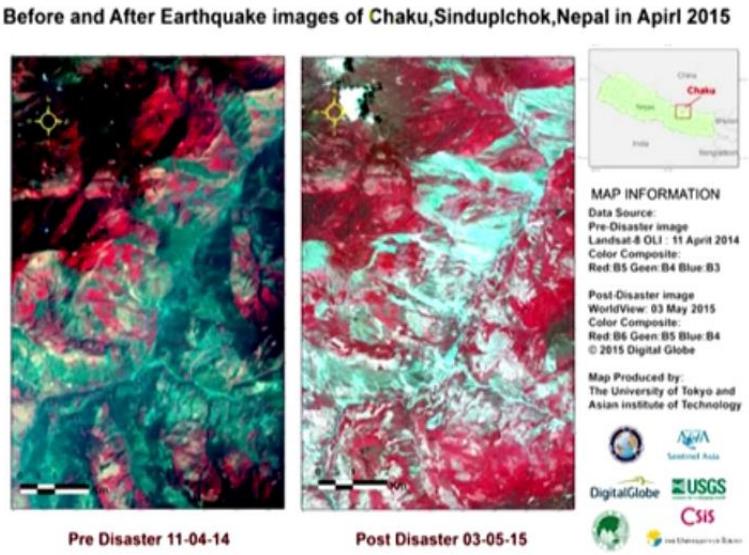

So 100s of such landslides have occurred in entire region so this is Chaku, Sindupl area Chaku, Sinduplchok and, this is a April 2015.

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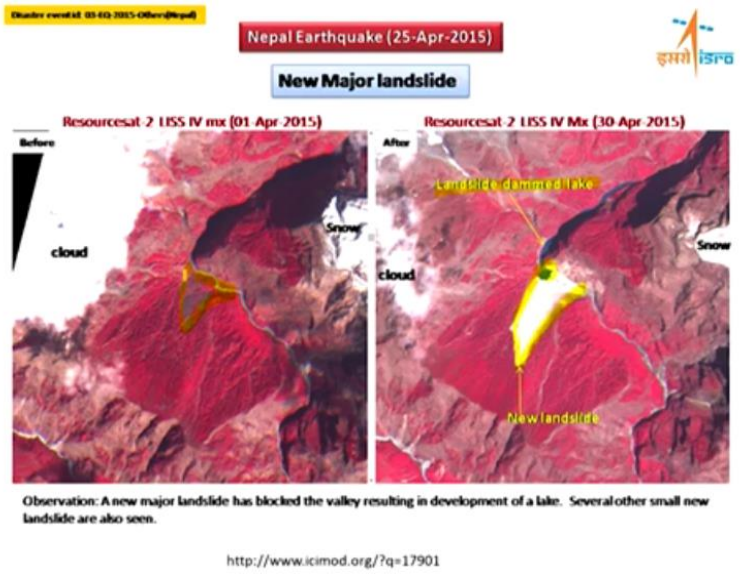

Similarly, as you can see a large of landslides have occurred it has also dammed the river and this you can see that how it can create problems. So, this dam the lake or a bad thing or you know damn can create havoc in the downstream important point to note here that they were already some science of you know slow failure or treatment due to the drying of the vegetation.

And dead was also a sign that slope in this area is about to fail. It was just waiting for some triggering effect. That might be because of road construction, that might be monsoon rainfall, or that might be an earthquake, and what earthquake once the earthquake has occurred, it has really created a problem and it this landslide has become very large and this is absolutely induced by an earthquake.

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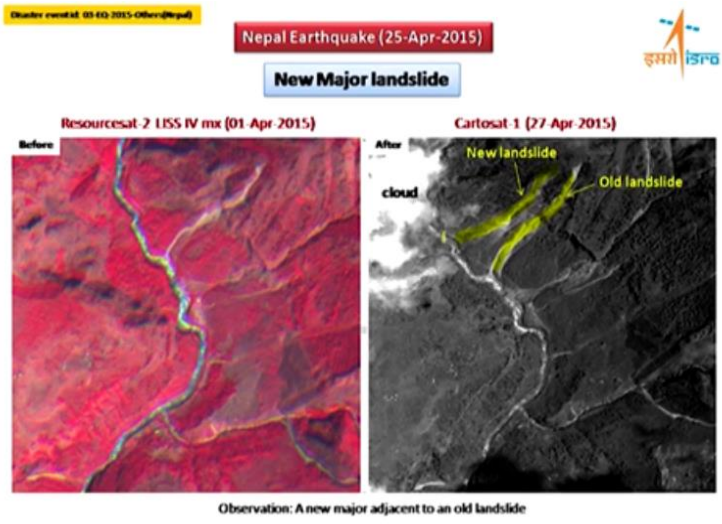

Similarly, there are many landslides, some are old, some are new, which has got or some rig got reactivated.

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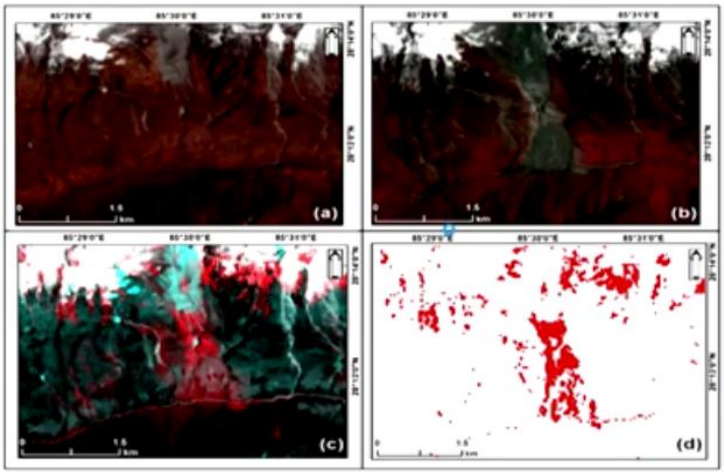

Figure: (a) Pre-earthquake Landsat-8 image of 11 April 2014. There are a few small white areas depicting existing landslides. (b) Post-earthquake Landsat-8 image of 1 June 2015 illustrating major new landslides triggered by the Nepal earthquake of 25 April 2015 and 12 May 2015. (c) PCT image of the Langtang valley (near Langtang Khola) as shown in (a) and (b). Red areas depict earthquake induced landslides and other ground changes. (d) Masked image of (c) showing major landslides.

Be implied the same pseudo color transformed technique and a large area in this could be map which we are induced by that those particular earthquakes and similar another example from the Nepal area.

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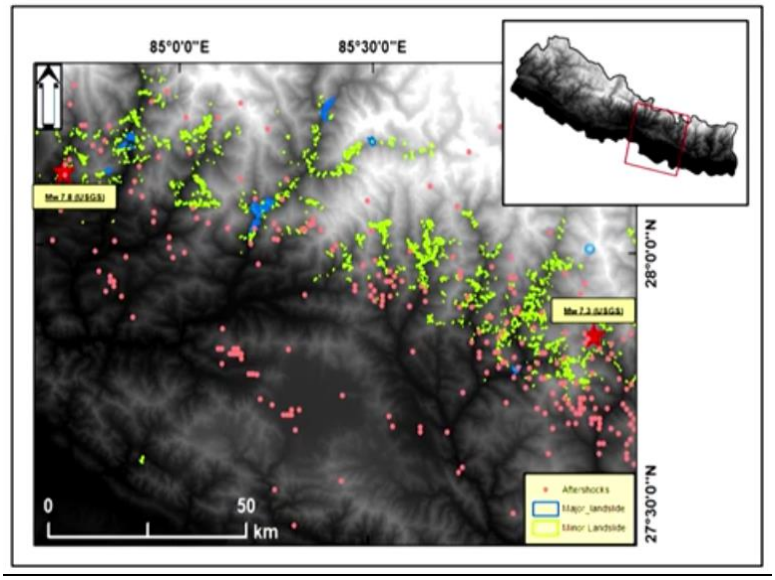

So, what do you in this summary you figure what we see here, these 2 earthquakes are marked here on the left and right and there are some landslides which have been marked as the minor landslides there are you know, major landslides which have been marked as blue color. But the important point to note here is that almost every these landslides are, and north on the hanging wall of MCT and they we could by looking such plots.

We can see that that earthquake probably was responsible. Later on it was confirmed with some other studies that that fault was responsible for these 2 earthquakes or we can see the movement has occurred maximum momentum occurred along this main central thrust or in sort of the same city.

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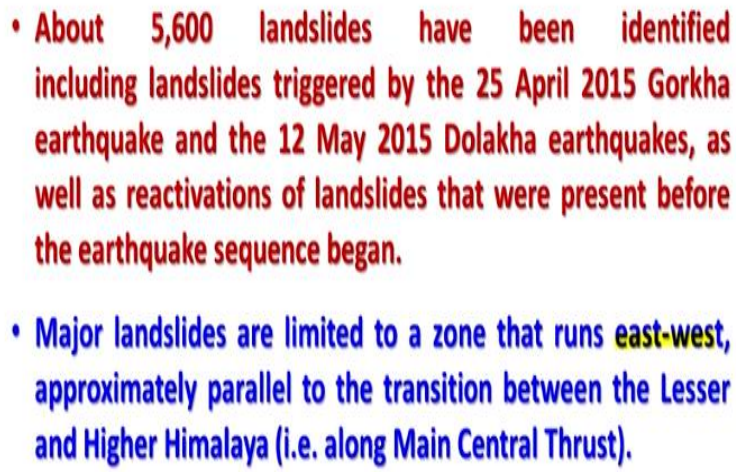

So, about more about 5600 landslides have been identified. In this area using pre earthquake and post earthquake images and also implying this pseudo color. Transformation techniques, major landslides, of course, are limited to the zone which runs East West that is approximately parallel to the transition between lesser or higher Himalaya a specially all along the MCT. So, that is more important point. So, what we can do middle stage what we can say about that earthquake into landslides.

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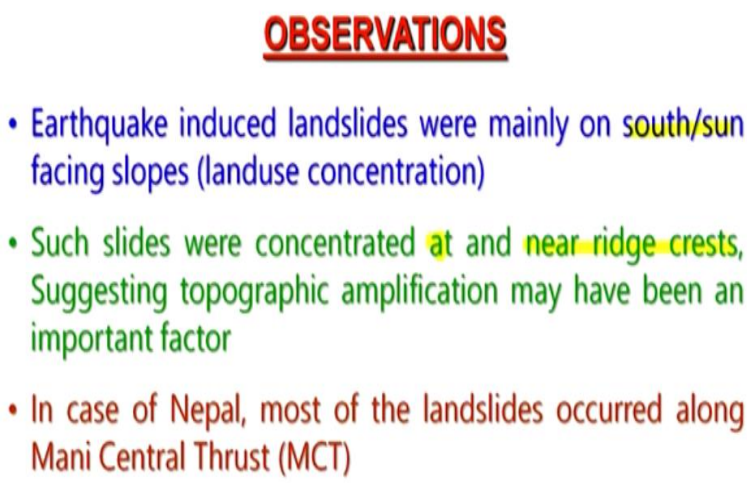

Generally occur and this is a long term observation which we have seen in many earthquakes in Himalaya. Which are on the sun or south facing slopes, because most of the land use concentration is on that part human interventions are also and heating and cooling also there on the south facing slopes and these landslides have been the earthquake induced landslides or have originated near and or at the ridge crest that is top of the hill or mountain.

And which suggests that they might be there might be topographic implications, and which we might have played very important role. So, in most of these earthquake indeed, landslide, this is one common observation which we have seen also that landslide occurred in Nepal. Most of these things as you know that we have discussed this part.

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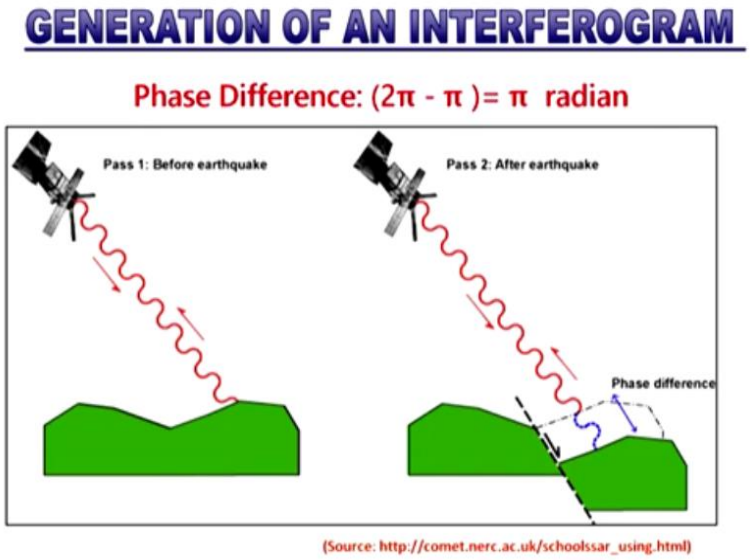

So I am not going to that and this is about the SAR interferometry. So, SAR interferometric technique was also implied in case of Nepal earthquake,

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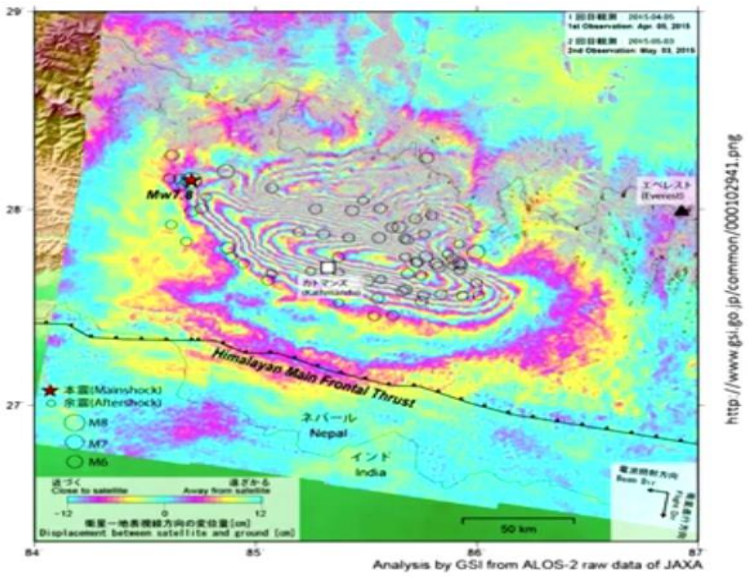

You can see the interferogram and you can see that a large a large number of fringes. That means they are showing a huge movement, as we said it is 3 feet movement has occurred in this valley and that one can really estimate very accurately using SAR interferometric

techniques. So, this is one of that example and this includes only the first earthquake this does not include the second earthquake.

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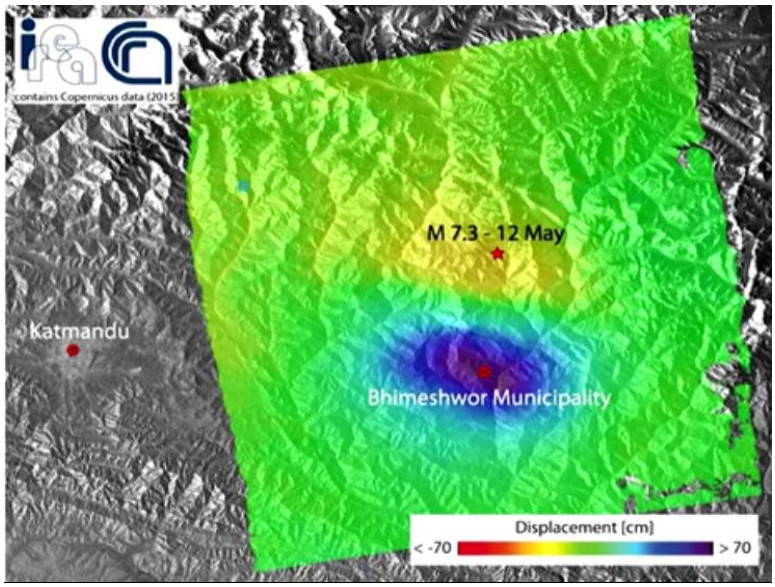

So it is be can deformation map of that area, but we find of this literal earthquakes of 12 to me of magnitude 7.3. That the central part of the area has gone by you know, 70 centimeters towards the line of sight and the remaining area is there of course, no subsidence has occurred maximum upliftment in this area has occurred after this induced by this second earthquake.

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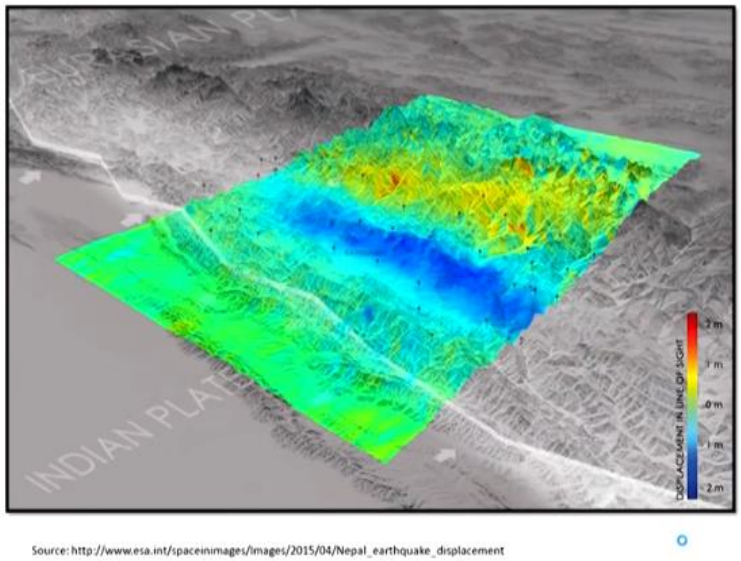

Source: http://www.esa.int/spaceinimages/Images/2015/04/Nepal_earthquake_displacement

So, this is how the entire picture comes through SAR interferometry analysis that a large part in the Katmandu area and gone you know some part has gone up like peaks in the Himalayan range and some part has gone down by 2 feet or 2 meter or one 3 feet or so. So, this is this

kind of estimations can be done using SAR interferometry technique. Now, second part is about liquefaction as I have discussed that liquefaction.

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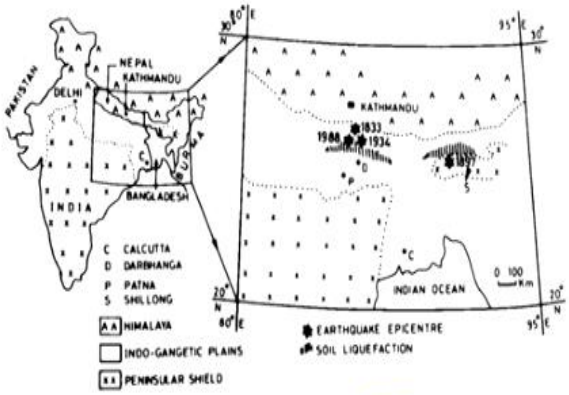

Soil liquefaction induced by Bihar-Nepal 1934 Earthquake in the Indo-Gengetic plains

(Source: R. P. Gupta, A. K. Saraf and R. Chander, (1998). Discrimination of areas susceptible to earthquake-induced liquefaction from Landsat data. International Journal of Remote Sensing, 1998, Vol.19, No.4, pp.569-572.)

So, this is the a an earthquake which really occurred way back in 1934 this has a this has caused the extensive liquefaction in indogangatic plane and it was possible for us to imply while implying remote sensing data, we could map even in the images of 1972 onward that liquefaction affected area induced by that 1934 behind Nepal earthquake, and there are a lot of large water bodies, which we are own here.

So, though at time the old him who was one of the very well known geologist of that time he recorded and put memo about this earthquake and using that information and the satellite images which made available after 1972 onward, and we could map the liquefaction affected area induced by 1934 earthquake as you can see.

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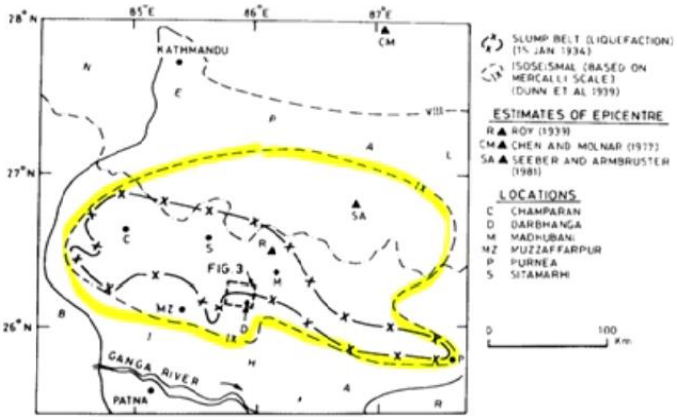

Isoseismals of the Bihar-Nepal earthquake of 1934. The liquefaction region (slump belt) covering vast tracts in northern Bihar.

(Source: R. P. Gupta, A. K. Saraf and R. Chander, (1998), Discrimination of areas susceptible to earthquake-induced liquefaction from Landsat data, International Journal of Remote Sensing, 1998, Vol 19, No 4, pp 569-572.)

This is the area which we have made if you try to see the area isosesismals can come up with exactly where things have occurred.

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If liquefaction occurs like in case of Nepal earthquake, this is what you see that their bumps center you know comes out or water comes out from there and these ascend volcanoes kind of situation, though the scale is not that big and there may be some water bodies might appear. Because of liquefaction so, these observations made in April 25 in 2015 Nepal earthquake.

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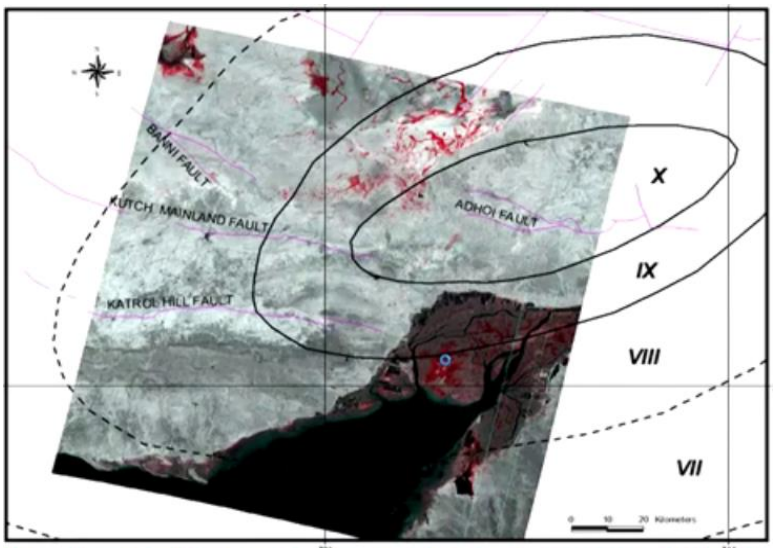

PCT Image prepared using IRS-1D-LISS-III pre-earthquake image of 4 Jan 2001 & post-earthquake image of 29 Jan 2001

Another important application of remote sensing now I am going to discuss very briefly in case of an earthquake or 2001 or 26 January, here again, be implied, pre earthquake and post earthquake images instead of visible images be implied here as infrared images because we wanted to detect the water bodies. Because whenever liquefaction occurs the water comes on the surface and that may there might be some channels and this is what.

So, this is again it pseudo color transforming ways as discussed earlier and when this was created, and what we find a lot of you know, water bodies or channels appeared and they say these images are just having and 25 time difference, but the post earthquake image is just 3 days after the earthquake. So, in that way is a highly reliable image and we could exactly map this is this has happened first time in the world.

That implying remote sensing data the liquefaction affected area induced by an earthquake was mapped very accurately, as you can see here and this as per the intensity map of you know, the zone intensity zone 9 had the maximum liquefied area and this earthquake. So, these things now, what lessons we can learn one part is analyzing the data another part is interpretations and now real applications.

Now, we know in this part of the country that earthquake can bring liquefaction. Luckily, in 2001 they were not many and civil, structures or buildings towers or bridges be are there in this part of the area we are we are seeing the maximum liquefaction after this earthquake lot of development has taken place and people have ignored this information that this area is susceptible to liquefaction.

So, if you create any structures civil structure bridge or tower building, multi-story, then cares should be taken and those buildings would be designed, which will incorporate the this factor if like if earthquake occurs if liquefaction occurs is still they will sustain otherwise what will happen something like this.

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This is in a these are the images are the photograph ground photograph of 1964 Niigata earthquake of Japan and this is what happens in case of earthquake if you are having multi storey buildings for a few seconds, the building will be on in a liquid basically because the soil is starts behaving like a liquid because of this and water which comes out and therefore, the soil where the foundation of these buildings and the soil looses incomplete is strengthen and anything which is standing is not in balancing position may topple like this as you are seeing here.

So, this brings the part one discussion and in this one we have seen earthquake induced landslides and what lessons we can learn second is about earthquake induce liquefaction. In the next discussion, we are going to see as indicated that we will see how remote sensing can be implied using thermal image data to detect pre earthquake thermal anomalies. So, we will be seeing a few examples of that in the next discussion for time being thank you very much