REMOTE SENSING FOR NATURAL HAZARD STUDIES

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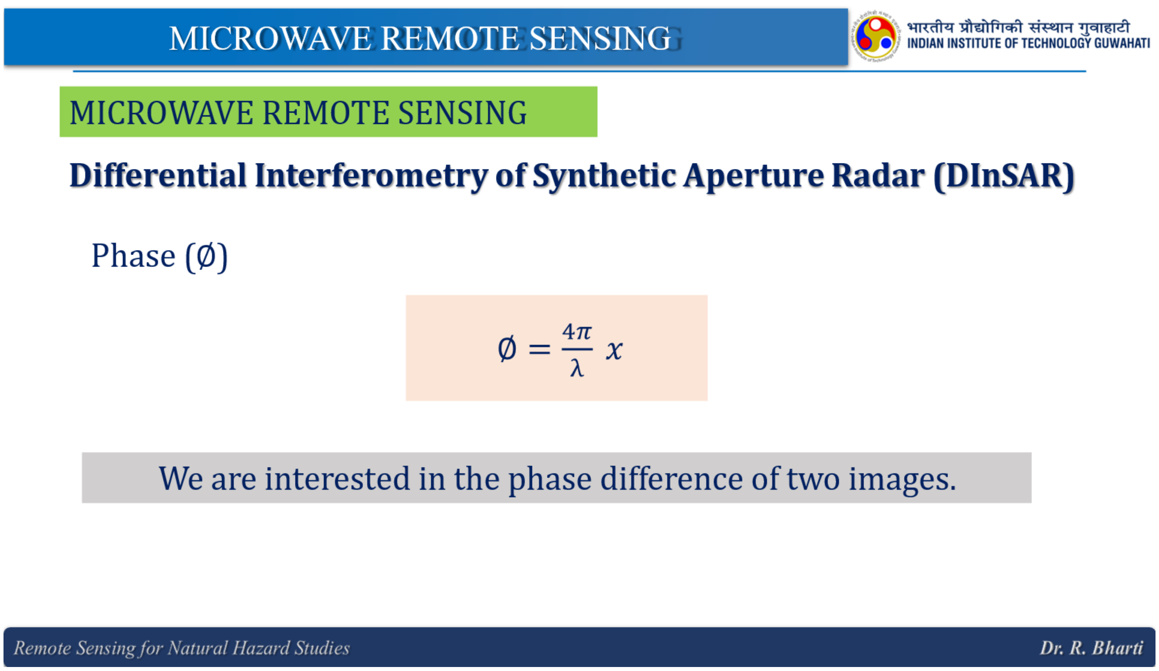
Lec 33b: Remote Sensing for Liquefaction Studies - II Part B

Hello everyone, welcome back to Lecture 33. So, we will continue our discussion on how we can utilize geospatial techniques in liquefaction studies. So, we have seen that in the microwave domain, we are mainly using DInSAR, which is differential interferometry synthetic aperture radar. And the coherence image, which is generated from microwave remote sensing. These two are used in a liquefaction study.



When we talk about the differential interferometry of synthetic aperture radar, the single pixel of a SAR image consists of two parts: the amplitude and the phase, and the amplitude gives us the idea of the intensity of the signal that is reflected from the surface. The backscattered energy and the phase are used to detect changes. Now, here we will be utilizing these two concepts together to identify whether there is any subsidence, structural deformation, or surface deformation. So, here, when we talk about the phase, this is how we calculate it. So, we are interested in the phase difference of two images.

So, which is giving you information about the change in the surface because of the soil? So, the phase difference is basically governed by the shift of the ground surface from one location to another, and it will be in centimeters or millimeters; it is not that high, but we get the phase difference. So, back-calculation gives us ground deformation.

MICROWAVE REMOTE SENSING

Differential Interferometry of Synthetic Aperture Radar (DInSAR)

The Phase Difference is basically governed by the shift of the ground surface from $x(t_1)$ to $x(t_2)$

We get the phase difference. So Back Calculation gives us the ground deformation.

$$\Delta\emptyset = \frac{4\pi}{\lambda}\left(x(t_1) - x(t_2)\right)$$

So, using this, we can calculate the phase difference, and then we will get the difference in the ground deformation. Then we calculate coherence. So, here, InSAR signals decorrelate due to random motion over time, differential geometric, and volumetric scattering that will give you coherence.

This is also used to determine the liquefied surface areas. So, this has been utilized in various studies to identify the liquefiable zones. Here you can see the coherence image results from Sentinel-1C data. So, this is using microwave remote sensing to identify the locations that are susceptible to liquefaction. The green stars in the location here indicate where you can see the epicenters, and the red dashed line shows the approximate areas of the sand blow associated with liquefaction.

So, here is the sand blow area. So, in this paper, they have explained this process nicely. Coherence reduction areas between the pre- and post-earthquake pairs are indicated by white dashed lines. So, here you can see that some of the white dashed lines are there. So, when we talk about optical remote sensing, the pre- and post-earthquake images are identified, downloaded, and pre-processed, which will help you detect the soil moisture by various approaches.

MICROWAVE REMOTE SENSING (CASE STUDY)

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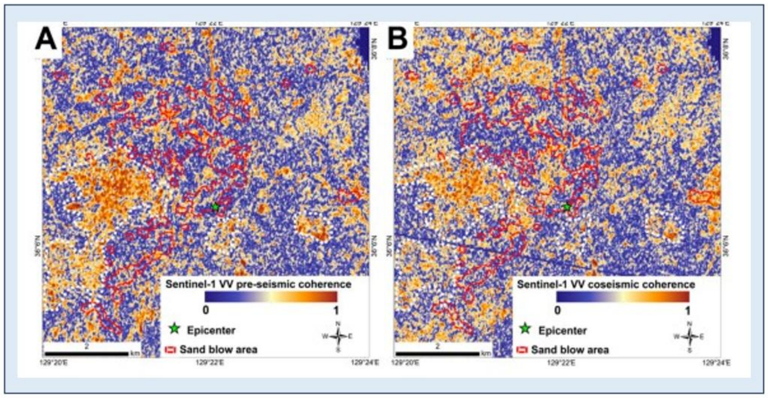

Coherence mapping results of Sentinel-1 C-band SAR images.

The green star is the location of the epicenter and the red dashed line shows the approximate area of the sand blow associated with liquefaction.

Coherence reduction areas between the pre- and post-earthquake pairs are indicated by white dashed lines.

(a) Preseismic coherence (23 October–4 November).

(b) Coseismic coherence (4–16 November)(Baik et al 2019)

And liquefied locations are identified from changes in soil moisture due to earthquakes. So, pre- and post-, you have two images. And then you will go with the soil moisture mapping, and then you will see which hot spots are giving you a drastic change in soil moisture because of an earthquake. So, the normalized difference in water index is one of the very popular methods that is used to identify the moisture content.

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OPTICAL REMOTE SENSING

Different Approaches

Indices

Normalized Differential Water Index (NDWI)

$NDWI_{Gao}$

$$NDWI_{Gao} = \frac{NIR_{860nm} - SWIR_{1600nm}}{NIR_{860nm} + SWIR_{1600nm}}$$

Where,
NIR is Near Infrared Band
SWIR is Short Wave Infrared Band

So, this NDWI was developed by Gao et al. So, here you can see the NIR band of 860 nanometers; this is what we are talking about in optical remote sensing. So, remember that we are 400 to 2500 nanometers here. So, this is 860 nanometers, and then we are using another band, which is 1600 nanometers. Then we have 860 and 1600 nanometers in the denominator again, so we will have the normalized differential water index. NIR is near-infrared, and SWIR is the short-wave infrared bands.

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$NDWI_{green\,,SWIR1}$

$$NDWI_{green,SWIR1} = \frac{Green_{550nm} - SWIR_{1600nm}}{Green_{550nm} + SWIR_{1600nm}}$$

$NDWI_{green\,,SWIR2}$

$$NDWI_{green,SWIR2} = \frac{Green_{550nm} - SWIR_{2200nm}}{Green_{550nm} + SWIR_{2200nm}}$$

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This is another index, which is NDWI green SWIR1; here, we are utilizing 550 nanometers and 1600 nanometers, and then again in the numerator and denominator, we are using the same to provide the normalized difference.

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$NDWI_{green\,,NIR}$

$$NDWI_{green,NIR} = \frac{Green_{560nm} - NIR_{860}}{Green_{560nm} + NIR_{860}}$$

$mNDWI_{Xu}$

$$mNDWI_{Xu} = \frac{Green_{560nm} - SWIR_{1600}}{Green_{560nm} + NIR_{860}}$$

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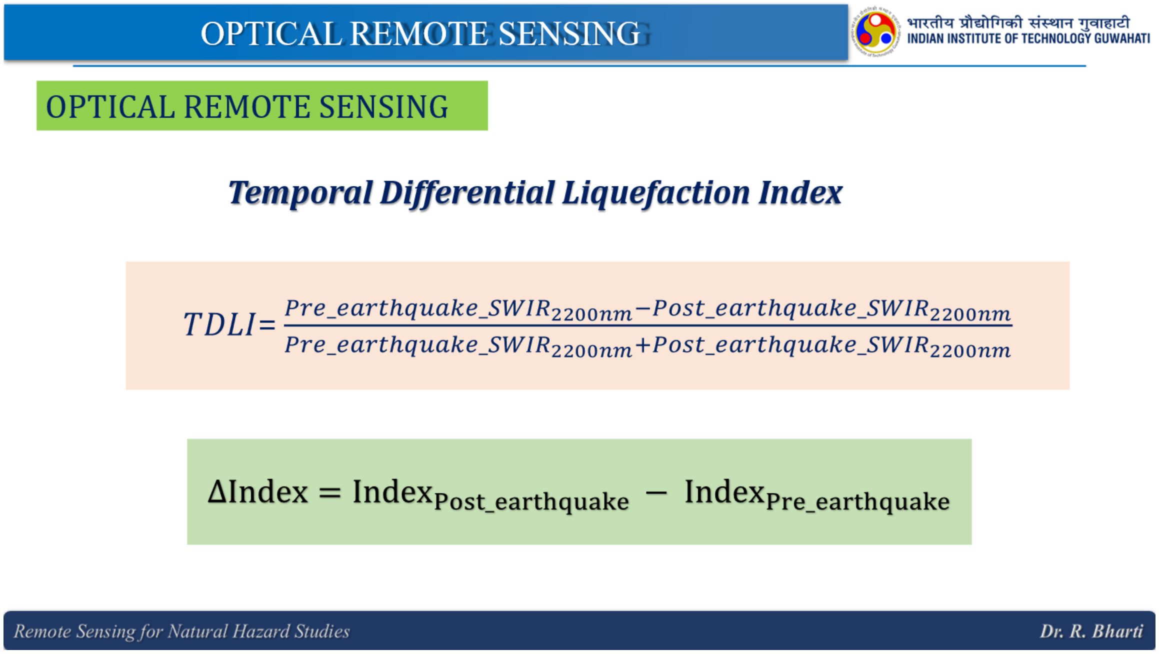
So, in another index, it is green and SWIR 2; here, it is 550 and 2200 nanometers.

So, these are popular in identifying the soil moisture condition. Here, you can see the zoo et al. They have given this modified one. So, 560 nanometers and 1600, and here you have 560 nanometers and 860. So, this will not be the normalized one, but this is MNDWI Xu; then comes the temporal differential liquefaction index.



So, TDLI, this is very, very popular. So, here what we do is use the pre-earthquake SWIR band that has been used and then the post-earthquake SWIR band. So, here you can see both places where we are using a 2200-nanometer wavelength range, and then in the denominator, we have 2200 nanometers pre and then again post.

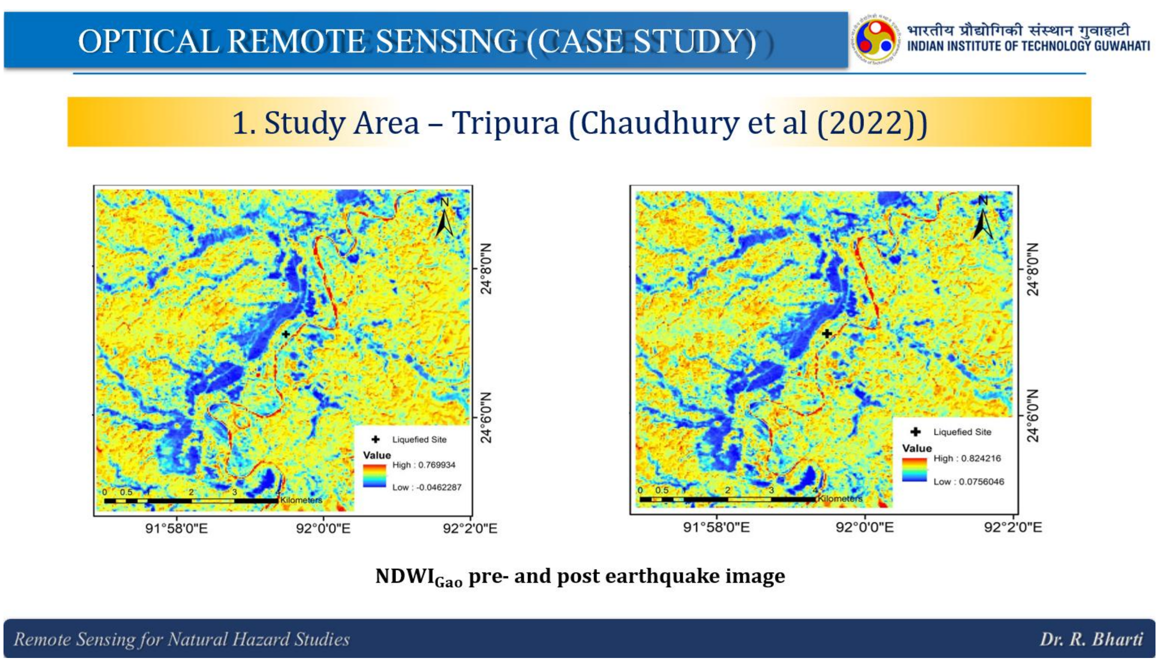
So, it will be a normalized one. So, this will provide you with the temporal differential liquefaction index. This will try to provide you with information about the pre- and post-earthquake events. Then you have the delta index. So, the index post-earthquake and the pre-earthquake, which is calculated from here, and then will provide you with the delta index.

So, that will provide you with more information about the location. Then comes the tasseled cap wetness; it is a statistical method, and statistical analysis is used to come up with an orthogonal transformation that would capture the wetness difference. So, for the pre- and post-earthquake. This transformation was produced by Huang et al. (2002) based on hundreds of field measurements of soil, impervious surfaces, dense vegetation, and moisture content.

So, this was an extensive study where they utilized many field observation data to come up with the tasseled cap wetness. So, now we will see some case studies. So, first we will talk about the Tripura region, then we will have Egypt, and then we will discuss

Madhubani, and these are published literature; we will see some of the details. So that you will have an idea of how geospatial techniques are used. So, when we talk about this optical remote sensing, reported liquefied locations are georeferenced within the study area. Different geospatial techniques are used to obtain moisture changes due to earthquakes in the study area, and then the results from the geospatial techniques are compared with the results from the literature to find the best technique. This was a comparative study, and here we try to evaluate different approaches to remote sensing. And which one is giving you the best results? So, this is for the first case study, which is for the Tripura region. Here, we had a magnitude of 5.2, and then in 2017, we had a magnitude of 5.7. The depth of the epicenter was given, and this is the time and date of the earthquake. So, there has been a significant earthquake in Tripura since 2010; this is from the USGS earthquake catalog. So, the liquefaction feature in this study area appears in the field.

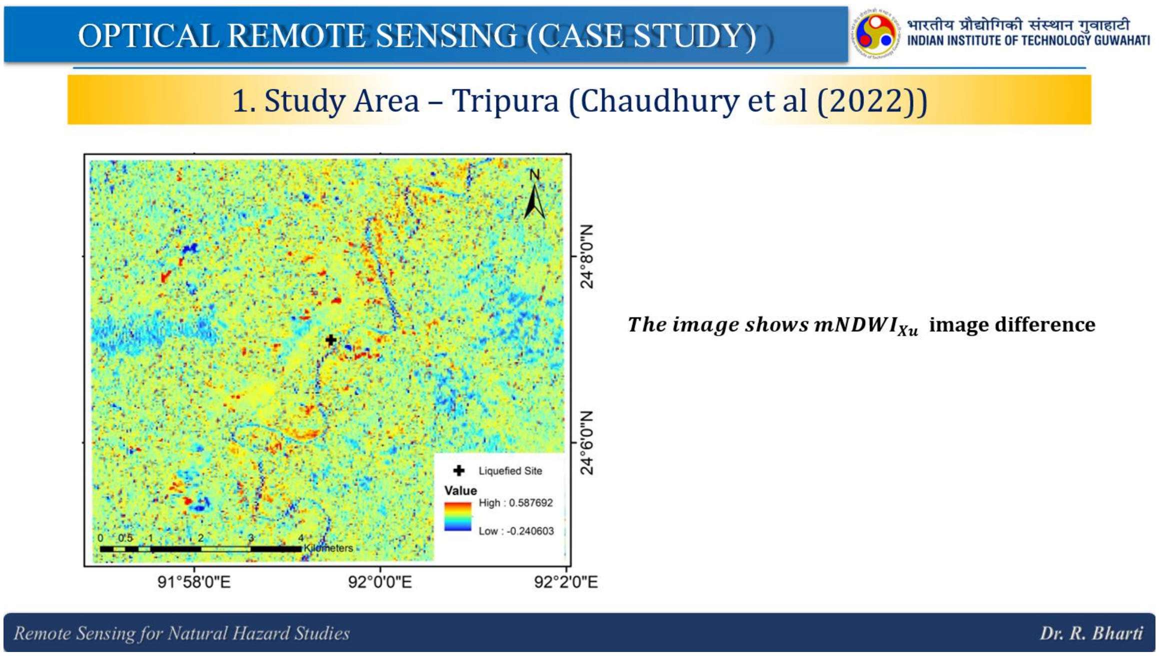
So, this is from this paper; you can see these surface cracks. After the earthquake, you can also see some changes in the soil. Reports from this paper show that the river Manus's current course has shifted from its original course. This is the old river alignment, and you can see that this is the new one. The distance from the current course to the liquefaction feature is approximately 124.5 meters. So, this is the Google Earth image of the liquefied site from this paper.



So, in this, what we did is use the USGS Earth Explorer to get pre- and post-earthquake images. Then it was converted to reflectance, we performed the normalization, and these two different approaches, one is a tasseled cap, and the other consists of different indices that are available, were used to identify the moisture content or changes in the area. So, the processed pre-earthquake image is from December 2016, and this is January 2017.

Then, here again for the same date, we are getting the image difference from both, and that will try to give you what the hot spots of that particular region are. Here, you can see this is from the $(NDWI)_{Gao}$ before and after the earthquake.

So, I hope you can see the changes here; you can see the minimum and maximum. This is the image difference. I told you that the image difference would give you more information about the study area. So, this is the liquefied site from the field or from the published literature, and here you can see the minimum and maximum values that it can provide. You with more information about such areas that are getting liquefied.



So, this is the $mNDWI_{xu}$ pre- and post-earthquake image.

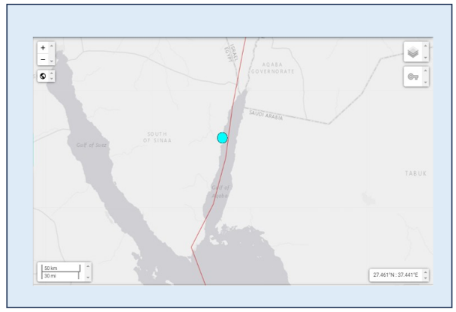
Here, you can see the minimum and maximum values and how they are changing, and then you have the image difference of the mNDWIxu. So, here you can see the changes, and this is the location. This is the tessellated cap wetness and pre- and post-earthquake image. So, here you can see this is the pre, this is the range, and this is the range, how it has changed. This is the liquefied location; this is the difference, the delta Tasseled cap. So, here you can see the minimum and maximum, and this is the liquefied zone.

So, this is one example of how different remote sensing approaches can be used to develop a method to identify the liquefaction potential zones. So, this is another study from Egypt. So, the 1995 Gulf of Aqaba earthquake left its mark in the vicinity through ground and structural failure.

2. Case Study in Nuweiba, Egypt (Chaudhury et al (2022))

Nuweiba Earthquake

- Moment Magnitude – 5.5
- Date – 27th June, 2015
- Focal Depth – 22 km
- Epicenter - 29.040° N, 34.667°E



2015 Nuweiba Earthquake (USGS Earthquake Catalogue)

This is from Halim et al. (2004). Possible liquefaction caused by ground deformation was observed along the coastline near this city, especially in the hotel areas. Ground fissures were even as wide as 10 centimeters were reported. So, this was huge. These failures caused major economic drawbacks and a decrease in tourism. So, here for the earthquake, we had a moment magnitude of 5.5, the date was 27th June 2015, and the focal depth was 22 kilometers. and here you can see this is the location.

So, here again, the pre- and post-earthquake images were accessed through USGS Earth Explorer, and then the DN to reflectance was converted. After that, we had the normalization, and like the previous study, different geospatial techniques were used, and then we identified the image difference. So, different geospatial techniques were used to identify the surface changes.

So, here you can see. The city and the earthquake; this is the earthquake. So, here you can see the extracted save file from Google Earth; this is the save, and for this study area, you have the tasseled cap-witnessed image, and here you can see the minimum and maximum values. This is for $(NDWI)_{Gao}$ again, the minimum and maximum you can see. This is $NDWI_{Green, SWIR2}$. So that I discussed in the previous slides.

Then you have the $NDWI_{Green, SWIR1}$ values that you can check. TDLI of the region of interest; here, low and high values represent the city. Then you have the $NDWI_{Green, NIR}$ of the study region. Then study the area along with the liquefied sites. This was an example of how we can evaluate the potential of geospatial techniques in liquefaction studies.

So, it is not only that we go with field-based or lab-based analysis; we can also look for an alternative by which we can identify the liquefiable zones. So, this is another case study from Madhubani. So, here you can see the study area along with the liquefied sites. So, this is India. And here you can see this is Darbhanga, and here you can see zone 1, zone 4, zone 2, and zone 3 for the liquefied sites.

So, what we did here is apply geospatial techniques; we utilized different methods to estimate the image differences. And then we classified the image differences into three classes, and then extracted the higher value pixels, which indicated the liquefied zones. So, here is the image difference from 5 geospatial techniques: the first one (A) is Tasseled Cap wetness, (B) is $(NDWI)_{Gao}$, then (C) is $NDWI_{Green,\ NIR}$, then (D) is $NDWI_{Green,\ SWIR}$, and the (E) image is $NDWI_{Green,\ SWIR}$. So, you can see how different they appear and the range of how it is changing when you have different approaches. So, the comparison is between the pixel with the highest moisture change and the liquefied location from the literature corresponding to the $(NDWI)_{Gao}$ image difference.

So, here you can see the difference in the image. So, this star is giving you the liquefied location, and this blue color is the pixel in class three. Then again, the comparison between pixels with the highest moisture change and the liquefied location from the literature corresponds to the $NDWI_{Green,NIR}$ image difference. Then this is from $NDWI_{Green,\ SWIR1}$. This is from $NDWI_{Green,SWIR}$, the same approach, and then a comparison between pixels with the highest moisture change and liquefied locations from the literature corresponding to the tasseled cap wetness image difference.

So, here you can see for each of the locations how the tasseled cap values are coming. So, the conclusion is that the tasseled cap wetness index is a suitable technique to find liquefaction-related moisture changes in soil, at least for the Darbhanga region; it was very clear, and the limitation is cloud cover in the data because we are talking about optical remote sensing. Then the vegetation cover in the area is observed using optical remote sensing; when we talk about 400 to 2500 nanometers, it gives you the surface characteristics. If your area has vegetation, the vegetation will act as a surface, and the surface will reflect the energy that you will be calculating. So, you will be getting the reflected energy from this vegetation and the rainfall in the period between pre- and post-earthquake image acquisition, which will change the wetness condition and restrict the capture of this optical remote sensing data.

So, when we talk about the application of geospatial techniques, liquefied areas are mapped. So, you have historical datasets; you can also collect them, and then you can put them into a star and overlay them over the satellite images. So, liquefied and non-liquefied datasets are prepared using different band ratios, tasseled caps, and then the proxy parameters can be investigated. So, the proxy parameter is not the direct parameter that plays a critical role in liquefaction. But, since we have limitations with remote sensing, we can also look for proxy parameters that can have an impact on the liquefaction study.

So, a model can be developed based on these proxy parameters, and that will try to help you identify the liquefiable zones. So, the existing models are from Zhu et al. (2015). So, the proxy parameters for three main factors, such as soil density, soil saturation, and earthquake loading, were chosen. Soil property has not been included in this particular work. So, they did not consider this, but then they used logistic regression to develop the Zhu et al. model. Then, the probability of liquefaction is calculated using their model, and they have also validated it. So, a global model and a regional model for the coastal region were chosen.

The parameters in global models are PGA, CTI, and VS30. The parameters in regional coastline models are PGA, CTI, and ND. So, you can see here this legend: PGA is your peak ground acceleration, CTI is the compound topographic index, VS30 is the shear wave velocity of the top 30 meters of the soil, and ND is the normalized distance. So,

These were utilized to develop regional and global models, and they have again come up with this 2017 model. So, 23 additional earthquakes from the USA, Japan, Taiwan, China, and India were added to make the model more accurate. Both liquefied and non-liquefied incidents were considered to omit sample bias. So, this is what they have done: they have improved the database, and then they improved the prediction. Incidents were classified into two categories: coastal events and non-coastal events, because we are talking about the interaction of water, even if it is surface water, with the soil. So, that is reducing the shear strength. So, these are the references you can see here that I have been referring to in this slide. So, if you are interested, you can go through them, which will help you understand the application of geospatial techniques in a better way.

Thank you very much.