REMOTE SENSING FOR NATURAL HAZARD STUDIES

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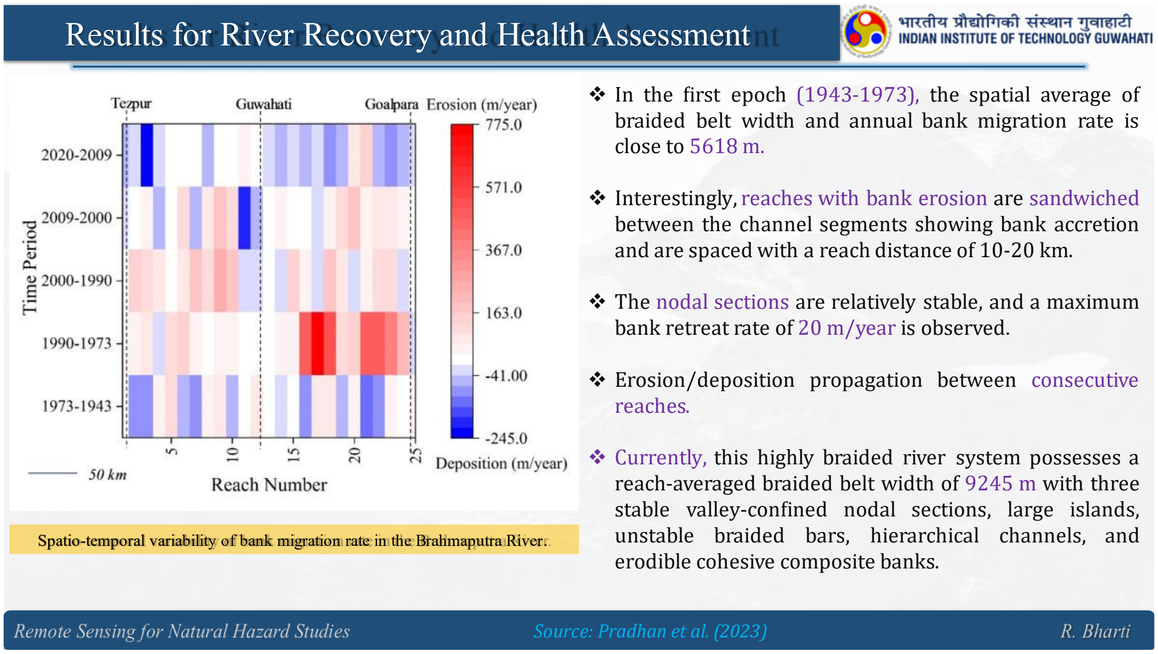
Lec 18b: Remote Sensing for River Health Part B

Hello everyone, welcome back to Part 2 of Lecture 18. So, we will continue our discussion on remote sensing for river health studies. When we formalize the river recovery and health assessment methodology, it is divided into 3 parts. So, in the first part, we use the GEE cloud computing where the JRC surface water and post-monsoon median low flow images were used. Then the identification of out-of-channel geomorphic units was calculated. The braided buffer zone was identified.

Then in the second part, where we talk about the morphological analysis and location probability index, we use this image; morphological analysis is done, and the location probability index is calculated. This basically directly indicates the river recovery and the river health. Then we have this process indicators. And then it moves to the mobility space, braided belt mobility, and then the integration of LPI, the location probability index, and then we have the resilience-based management system.

The GEE was used for the cloud-based mapping, which enables automated extraction of braided buffer zones using JRC water data and geomorphic unit identification. Then we have a morphological assessment; it is Landsat-based morphological analysis that supports the calculation of a location probability index for dynamic fluvial units. The development of indicators, such as process indicators, helps to quantify morphological transitions critical for braided river analysis. Then we have resilience planning the LPI, which was calculated earlier and integrated with mobility matrices, guiding resilience-based management strategies for river corridors. So, here you can see the river recovery concept that was implemented in the Brahmaputra River.



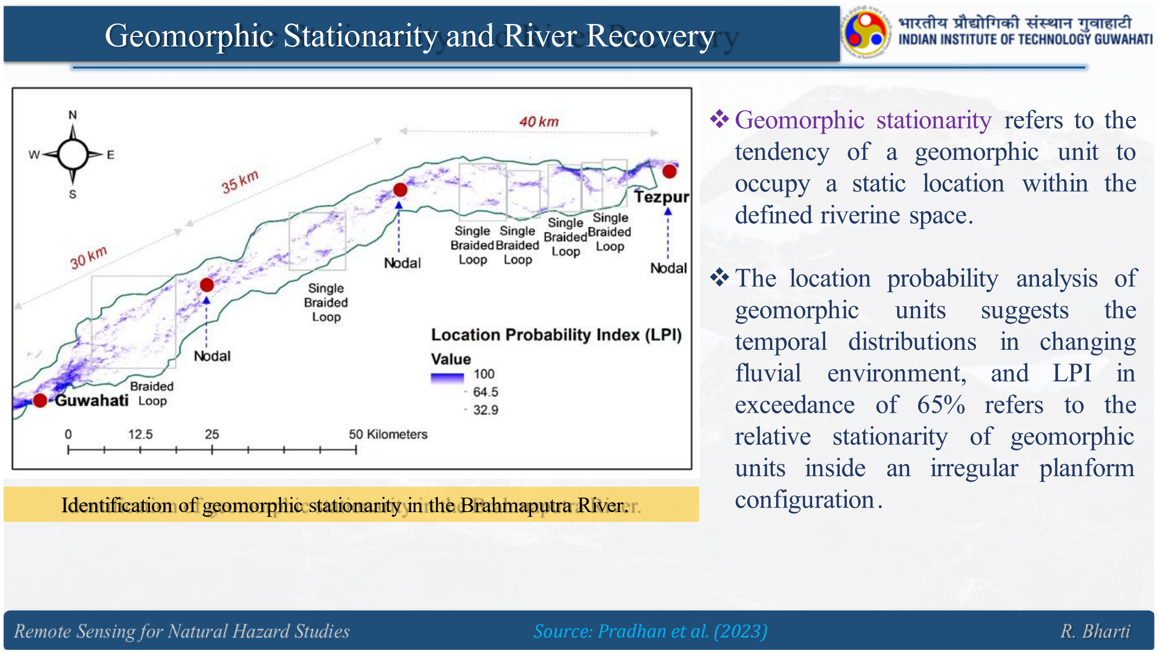
We did this study from 1980 to 2020; the GEE was used for the morphological analysis. Now, here you can see that some of the reaches to the right have very little width. So, here this shows Goalpara, then we have Guwahati, and then we have Tezpur. So, you can see how these are changing over time. So, 1980 to 1990, then 1990 to 2000, then 2000 to 2010, and then we have 2010 to 2020.

So, here is the integration of in-stream and floodplain geomorphic units that is given. Ana branch, alluvial fans, overflow channel, flood channel, chutes, cut-off, meander cut-off, paleo channel, and secondary channels are available here. So, the pixel value is greater than 1; that concept we have used. Frequent morphological changes in terms of bar formation, migration, and sculpting occur at varying flow stages. Then the gradual deposition of the alluvial fan after the 1980s on the right and left banks is prone to more erosion.

So, here you can see which areas are increasing in width. So, that will be due to more erosion. The southward migration of the Brahmaputra is evident from this analysis; you can see how it is moving towards the south. As per the overlay analysis, nodal reaches have a lower erosion rate; basically, we are talking about Goalpara, Guwahati, and Tezpur; these are our nodal reaches that have a low erosion rate. In contrast, the bar-dominant reaches are prone to higher fluvial erosion.

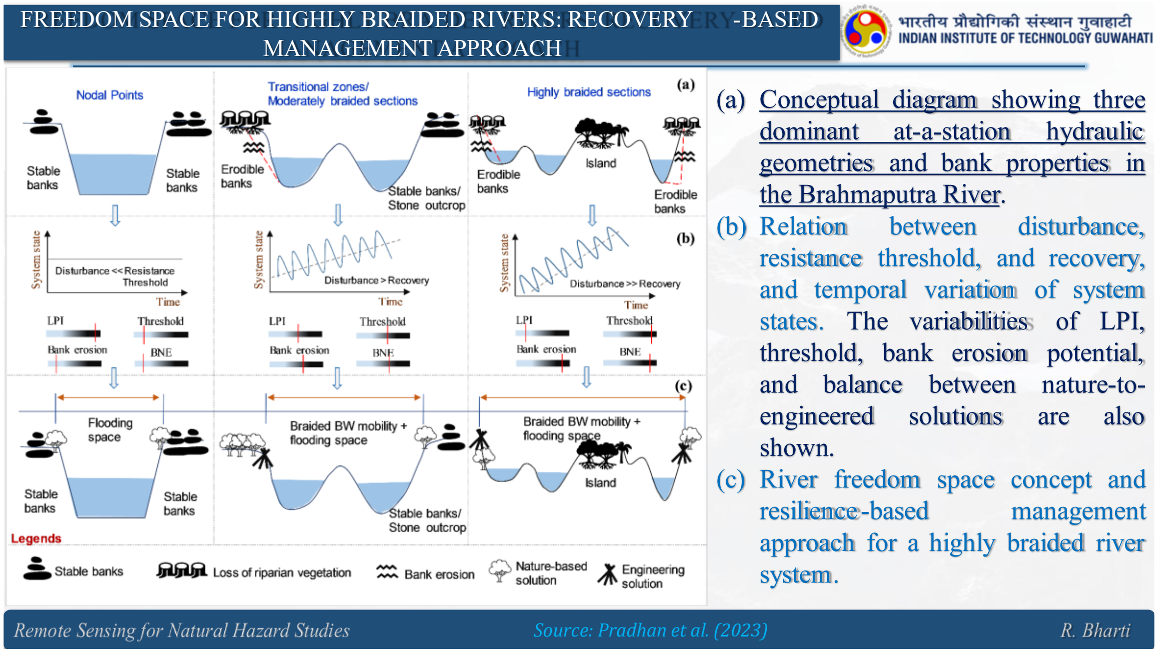
So, that is why if you see these 3 locations, they have the same or a similar width, but as you move in between, they have a width of 30 to 40 kilometer. So, those have a higher erosion rate. And this particular diagram beautifully explains how a particular reach is behaving in different timeframes. So, you can see this scale here. It is erosion here; it is deposition.

So, what happened in Tezpur, then Guwahati, and then Goalpara from 1943 to 1973? So, these three are our nodal stations or nodal reaches. So, you can see that from 1973 to 1990, Goalpara and even Guwahati had the maximum erosion, especially in the Goalpara region where the erosion was the highest. So, in the first epoch, 1943 to 1973, the spatial average of braided belt width and annual bank migration rate is close to 5618 meter. Then, interestingly, reaches with bank erosion are sandwiched between the channel segments showing accelerated bank erosion. and are spaced with a reach distance of 10 to 20 kilometer.



The nodal sections are relatively stable, and a maximum bank retreat rate of 20 meter per year is observed. These are the locations. Erosion or deposition propagation between consecutive reaches is seen here. Currently, this highly braided river system possesses a reach average braided belt width of 9,245 meter with 3 stable valley-confined nodal sections, large islands, unstable braided bars, a hierarchical channel, and erodible cohesive composite banks. Now, here you can see that these are our nodal stations, and these in-between colors that you are seeing here is basically the LPI index, with a value of 32.9 to 100, So, the dark blue color or the purple color indicates 100 percent of the LPI index. So, this image is used to identify the geomorphic stationarity of the Brahmaputra River. So, it refers to the tendency of geomorphic units to occupy a static location within the defined riverine space. The location probability analysis of geomorphic units suggests the temporal distribution in changing fluvial environments. And LPI in exceedance of 65 percent refers to the relative stationarity of geomorphic units within an irregular planform configuration. So, here you can see that we have kept this at 65 percent. Now, this is the freedom space concept for the highly braided river, the Brahmaputra, again. So, a recovery-based management approach is needed. Now, here you can see that this is a conceptual diagram showing three dominant at-a-station hydraulic geometries and bank properties in the

Brahmaputra River. The relationship between disturbance, resistance threshold, recovery, and temporal variation of system states is important.



The variability of the LPI threshold, bank erosion potential, and the balance between nature and engineered solutions is also shown here. So, here you can see that this is a nodal point. Then this is a stable bank you can see here: we have this LPI, which is high; the threshold is low, and bank erosion is less. And here you can see the flooded area. So, this is the stable bank; in the second one, we have transitional zones, a moderately braided section; here, you have both erodible banks and stable banks.

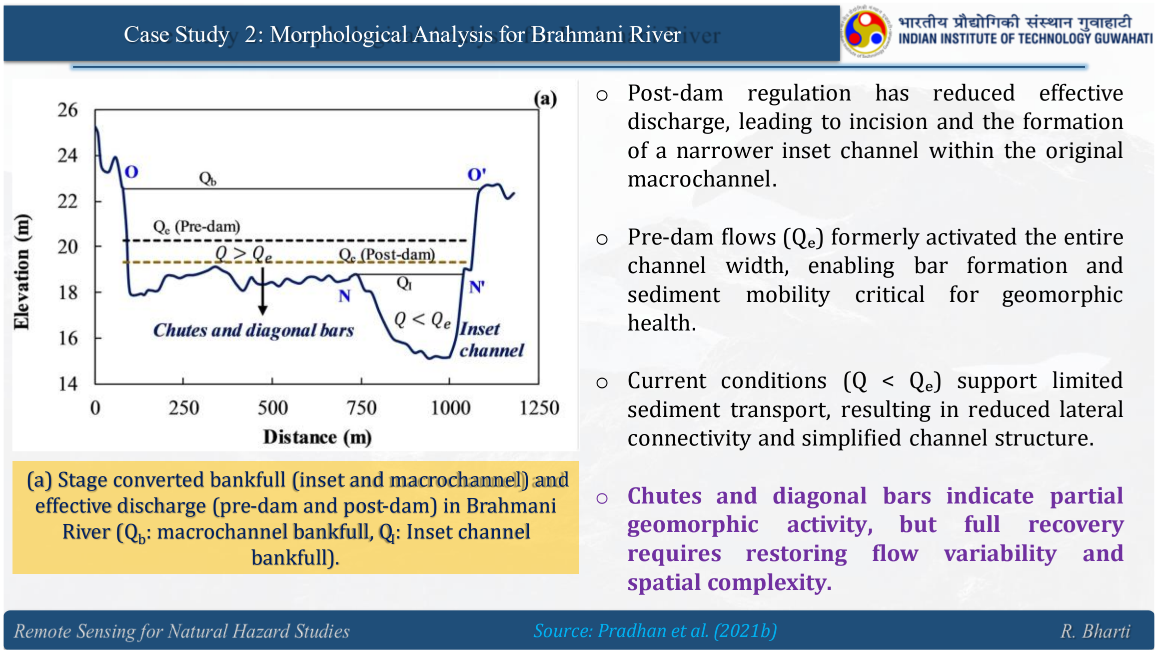
So, if you see this diagram the system rate versus the time so disturbance is greater than recovery. But in the previous one, the disturbance was less than the resistance threshold. So, because of that, you have braided mobility and flooding space. In the third one, we have the highly braided sections. So, here you have an erodible bank; you also have islands, and then the banks again.

So, here you can see that the disturbance is much higher than the recovery. So, in such cases, you will have braided mobility, plus flooding space and the formation of islands. So, here, if you see the nature-based solution. So, this nature-based solution can be used here; an engineering solution can also be used here, and here, you can only have the nature-based solution. So, the river freedom space concept and resilience-based management approach for a highly braided system are presented here.

This is from case study 2 on river health effective discharge estimation from the Brahmaputra; the diagram is a conceptual diagram that illustrates the process form and relaxation period variability leading to dam closure in a peninsular river. The possible alteration in the channel forms an effective discharge downstream from the dam. Here, you can see how these curves are behaving. So, if you see before the dam, what is the situation? And after the dam, what is the situation? The channel characteristics of peninsular rivers are predominantly alluvial and often exhibit a compound channel form with a primary channel and inset floodplains. Geomorphic response and alteration of the natural flow regime can lead to variable relaxation periods and induce diverse geomorphic adjustments.

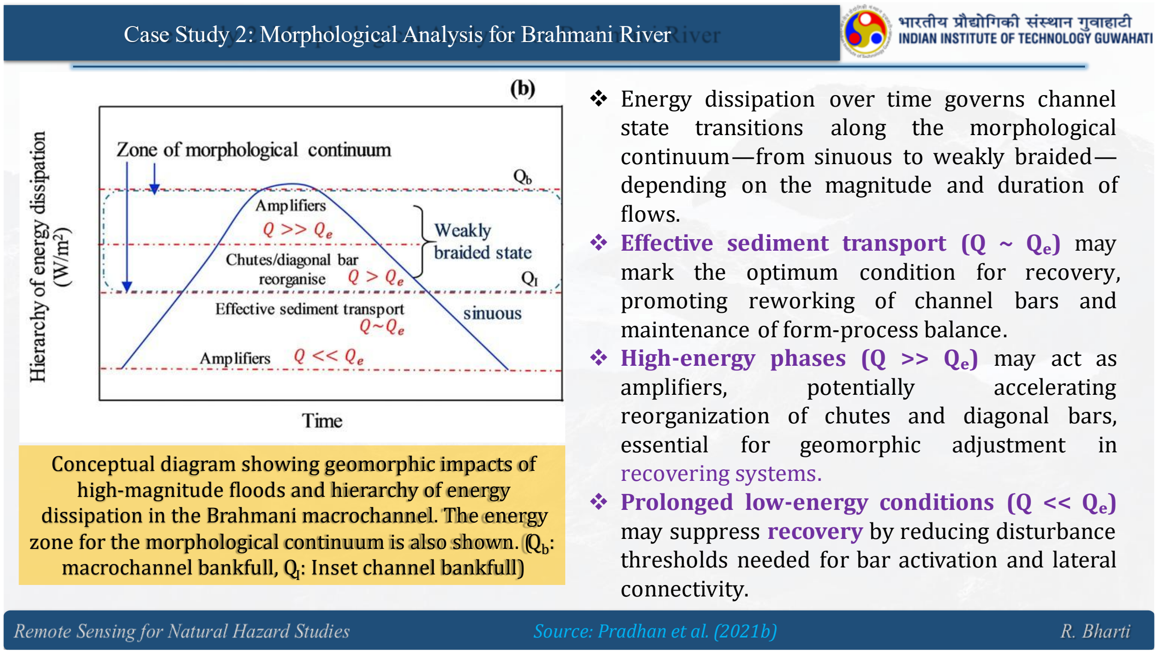
Then we have recovery sensitivity: the extent and nature of morphological change depend on physiographic conditions, disturbance intensity, and historic human intervention. So, for the Peninsular River, we have the Brahmani River as our study area. So, it is one of the major peninsular rivers with a catchment area of 39,000 square kilometer and a channel length of 799 kilometer. This river drains through sandy, loamy, and coastal alluvial soils and has an average annual rainfall of about 1,305 millimeter during the southwest monsoon. The major river interventions, the Rengali dam and the Samal barrage, are present near the city of Talcher. So, this is Talcher, and near it, you have a barrage and the dam. The Rengali Dam has been operating since 1985. So, you can see that here you have these two, and then you have Talcher, and then at the end, you have again the measuring station at Jenapur. So, these are the field photographs of the Brahmani River, and this is the post-dam scenario.

So, the first one shows the microchannel banks. So, here you can see, and here in (b), you have diagonal bars and chute formations. Then in (c) you have a lateral bar, close to the flow boundary, and (d) is the vegetation on the mid-channel bar. So, these are evident in the field investigation. So, the microchannel position and the width adjustment are insignificant over the time frame of analysis. So, we consider that from 1980 to 2013, no notable lateral migration occurred in this particular study reach, However, a significant alteration to the in-stream geomorphic unit assemblage is observed, reflecting continuous erosional and depositional activities at different flow stages. So, here you can see the post-damp scenario. The post-damp regulation has reduced effective discharge, leading to incision and deformation of the narrower insert channel within the original microchannel.



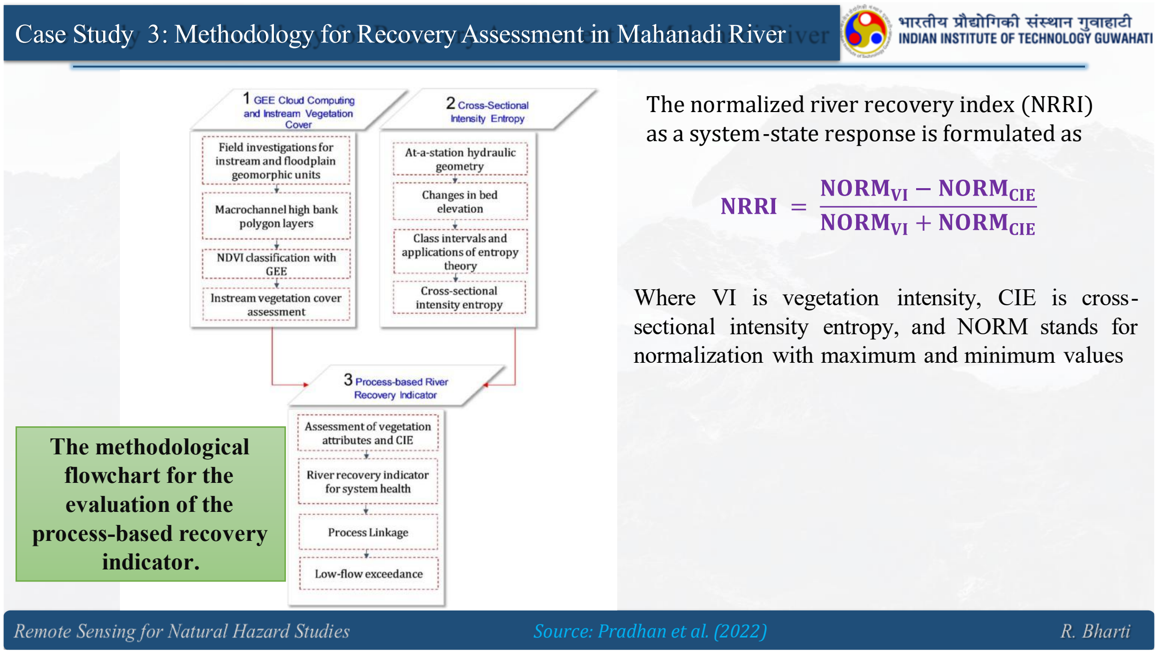
So, here you can see that chutes and diagonal bars; this is the insert channel, and here the Q is less than the effective discharge, and in this particular condition, Q is greater than the effective discharge. So, pre-damped flows that are the effective discharge formally activate the entire channel width, enabling bar formation and sediment mobility critical for geomorphic health. The current location where we have this Q is less than effective, discharging support, limited sediment transport, and resulting in reduced lateral connectivity and a simplified channel structure.

Chutes and diagonal bars indicate partial geomorphic activities, but full recovery requires restoring flow variability and spatial complexity. Here you can see that energy dissipation over time governs channel state transition along the morphological continuum from sinuous to weakly braided, depending on the magnitude and duration of the flow. So, here when we have Q, it is much less than Qe, which is the effective discharge. So, then you have the amplifiers, effective sediment transport, the sinuous; then you have chutes and diagonal bars; recognize the amplifiers. So, this is a weakly braided state, this is sinuous, and this is the zone of your morphological continuum.



Effective sediment transport may mark the optimal condition for recovery, promoting the reworking of channel bars and the maintenance of form-process balance. High-energy phase where Q is much larger than Qe may act as an amplifier, potentially accelerating the reorganization of chutes and diagonal bars essential for geomorphic adjustment in the recovery system. Prolonged low-energy conditions may support recovery by reducing the disturbance threshold needed for bar activation and channel connectivity. So, this is from the Mahanadi; this is case study three. And here we have considered the Ong and Tel sub-basins of the Mahanadi for our study.

So, the microchannel structure here exhibits a microchannel form with inset low-flow channels promoting hydromorphic diversity and recovery space. Vegetated landform development is something we have seen in some of the photographs in the previous slide. Submerged and exposed channel cells have transformed into bars and benches colonized by stabilizing vegetation, enhancing morphological resilience. Geomorphic adjustment, the evolution of stable vegetated features, indicates an active recovery process influenced by sediment deposition and seasonal hydrology. So, these are the field photographs; here you can see the submerged shelf, flow channels, lateral bars, and linear benches.



So, these are from the field. So, based on that, we have formalized the river recovery assessment for the Mahanadi River. So here again we have the GEE cloud computing and in-stream vegetation cover. The field investigation for instream and floodplain geomorphic units was conducted. This is the flowchart for the evaluation of process-based recovery indicators. So, with this, we have the normalized river recovery index (NRRI) as a system state response, which can be formulated as follows.

So, where VI is the vegetation intensity, CIE is the cross-sectional intensity entropy, and the norm stands for normalization with maximum and minimum values. So, here you can see that we have started our work with the Survey of India's topographic sheet. So, this is from 1955. And then we had these satellite images from the GEE and direct access from the different space agencies; we downloaded the freely available data sets and then processed them, which are used here. Now you can see that some of the figures are marked with LC and BC, So, you see it carefully.

So, this is the low flow channel; LC is the load flow channel, BC is the bench, VL is the vegetated landform, and CT is the chute. So, which is available in different sections at different timeframes. So, the vegetation expansion between 2015 and 2020 shows a significant increase in cumulative area, indicating an enhanced stabilization and recovery process in high-energy zones. And the fluvial disturbances decrease with elevation because the slope is less while plant biomass increases, highlighting the formation of stable vegetated landforms at higher elevation zones. So, here you can see that the plant biomass is increasing, and moisture availability aligns with vegetated regions, suggesting their role as key drivers in post-disturbance ecological recovery.

Case Study 3: Results of Recovery Assessment in Mahanadi River

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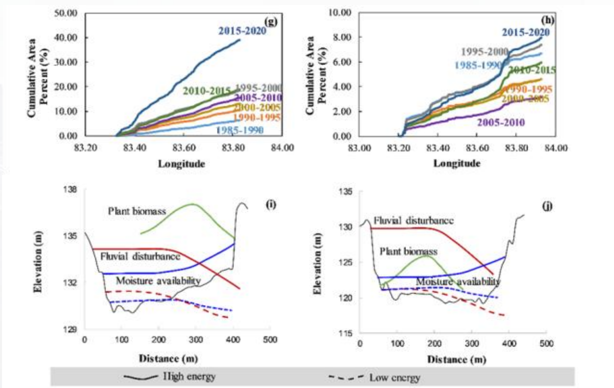

The conceptual plots showing cross-sectional variability of plant biomass, fluvial disturbance, and moisture availability in (i) Ong and (j) Tel Rivers.

- **Vegetation expansion** (2015–2020) shows a significant increase in cumulative area, indicating enhanced stabilization and recovery processes in high-energy zones.
- **Fluvial disturbance** decreases with elevation, while plant biomass increases—highlighting the formation of stable, vegetated landforms at higher elevation zones.
- **Moisture availability** aligns with vegetated regions, suggesting its role as a key driver in post-disturbance ecological recovery.
- **Low-energy zones** show reduced disturbance and gradual biomass buildup, indicating passive recovery and morphological stability over time.

Low-energy zones show reduced disturbance and gradual biomass buildup, indicating passive recovery and morphological stability over time. Now here you can see the vegetated CIE interplay and the flood-induced response, and here you can see this particular graph; this dotted blue line shows the NRRI. So, for this particular section, you see it is increasing, and for this, it is decreasing. So, what this means is that this is towards recovery; this is not towards recovery.

So, it is getting disturbed. So, here you can see in these two figures that the temporal variation of yearly vegetation percentage, cross-sectional intensity entropy, and normalized river recovery index is plotted. So, this is Ong; this is Tel. So, in Ong, the NRRI is in the upper right and is going down. So that means this Ong is towards the recovery, but Tel does not so that one. So, the relationship between normalized low flow exceeding and the normalized river recovery index along the Ong and Tel Rivers is given here.

Case Study 3: Results of Recovery Assessment in Mahanadi River

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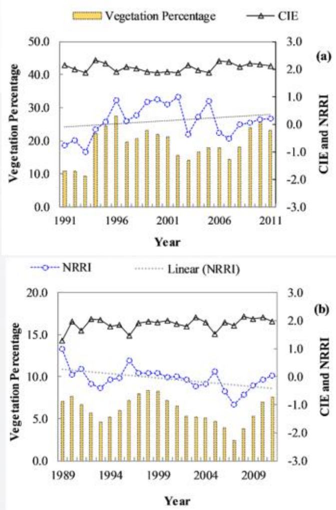

- **Vegetation-CIE Interplay:** Alterations in instream vegetation and Channel Instability Extent (CIE) have produced variable recovery responses across the river reach.
- **Flood-Induced Response:** The 1994 catastrophic flood triggered a sustained decline in CIE for over a decade, indicating delayed geomorphic recovery under regulated flow.
- **Vegetation-led Recovery:** In the Ong River, instream vegetation cover nearly doubled between 1992 and 2001, contributing to a positive shift in the NRRI (Normalized River Recovery Index) from -0.56 to 0.70.
- **Tel River Stability:** Unlike Ong, the Tel River maintained relative stability and recovered internally by adjusting within its behavioral regime, without major morphological transformation.

The temporal variation of yearly vegetation percentage, cross-sectional intensity entropy (CIE) and normalised river recovery index (NRRI) in (a) Ong (b) Tel Rivers. The linear trends of NRRI are also shown.

This is the conceptual diagram for the hierarchy of energy dissipation in the microchannel system, and the dominant variables for the hotspot zones of ecosystem engineering are also presented. So, here (b) is the Ong, and (d) is the Tel, So the results can be presented this way. The present study has developed an entropy-based system state and river recovery indicator for anthropogenically disturbed microchannel river systems. So, the major conclusion from this study is that the disorder in bed elevation at sub-bank full stage is effectively captured by a system state indicator CIE. Vegetation density, the CIA Integrated Recovery Indicator, and the NRRI symbolize river health for channels in fluvial systems.

Finally, the dominance between the self-organization of vegetation landforms and fluvial disturbances developed an additional degree of freedom and further determines the recovery state of microchannel and planform fluctuations between the endpoint of the morphological continuum that is sinuous and weakly braided. So, with this, I will end this lecture, and these are some of the references that I have been using in this lecture. If you are interested in knowing more details about this river recovery index, then you can refer to this literature.

Thank you. Thank you very much.