Long-term dynamics of riparian and in-channel vegetation cover on the Beas and Sutlej Rivers, India.

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Abstract

Vegetation is a natural component of river systems and plays important hydrological, ecological and geomorphic roles. However, vegetation cover and dynamics are controlled by numerous factors operating at multiple scales, making it challenging to determine the drivers of changes over time. The Beas and Sutlej Rivers are two of the 'water towers' of the Himalayas that supply water and power for large populations. Previous research has shown that significant geomorphic change has occurred over that last 150 years in both rivers, with differences in the type and magnitude of change in the last few decades. The aim of this study was to quantify the spatial distribution and dynamics of riparian and in-channel vegetation in two Himalayan rivers and evaluate the local and global drivers, such as climate change, alteration of river flows, and river geomorphic adjustment. Annual changes in vegetation cover and channel width were quantified using Normalized Difference Vegetation Index (NDVI), modified Normalized Difference Water Index (mNDWI), and a multispectral supervised classification over a 30-year period, for pre- and post-monsoon seasons, using Landsat data. The results show statistically significant upward trends in NDVI across both catchments, indicating large-scale drivers of change. Relatively greater increases in NDVI in the valley bottom and the active channel zones suggest more localized processes such as recruitment and succession of vegetation and conversion to agriculture following channel narrowing. Spatial variations in vegetation dynamics helps us to better understand vegetation-geomorphology interactions in these large systems and the impacts of human activity and climate change.

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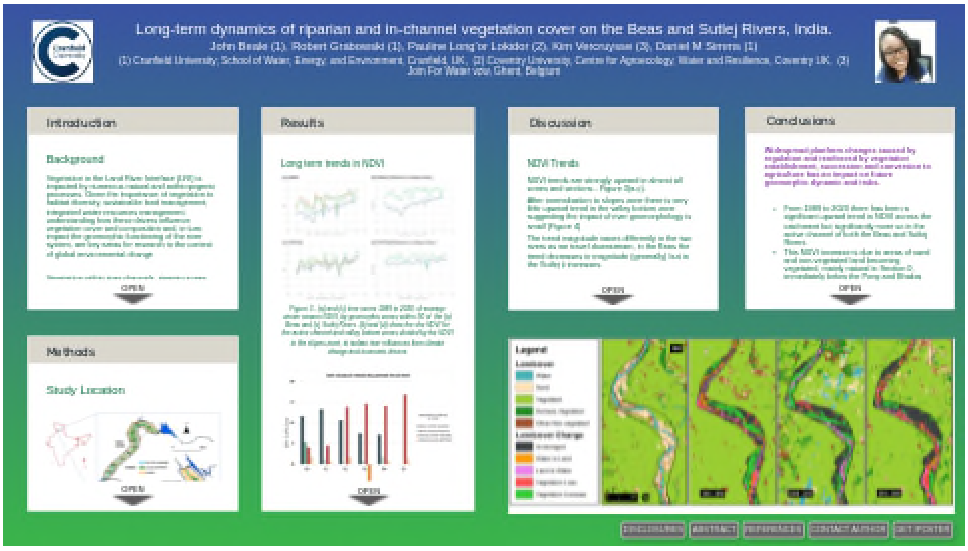

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PRESENTED AT:

INTRODUCTION

Background

Vegetation in the Land River Interface (LRI) is impacted by numerous natural and anthropogenic processes. Given the importance of vegetation to habitat diversity, sustainable land management, integrated water resources management, understanding how these drivers influence vegetation cover and composition and, in turn, impact the geomorphic functioning of the river system, are key areas for research in the context of global environmental change

Vegetation within river channels, riparian zones and flood plains are influenced by geomorphological and hydrological changes in the river channel, flooding, river channel flow dynamics, deposition, erosion, water table depth [6-11]. Conversely, vegetation can help maintain bank stability, constraining lateral erosion and fluvial flooding risk while providing biodiversity functions. Pioneer plants on sand banks makes them more resistant to erosion and transport of sediment downstream, which affects geomorphic form and process rates [11-15]. However, vegetation is also affected by regional changes in rainfall, river flow regulation and anthropogenic change, such as establishment of agriculture; river plan and cross-sectional form are affected by direct and indirect human activity. Therefore, it is difficult to predict how river systems and their vegetation communities may change.

Aim

The aim of this study is to determine how human alteration to river flows and riparian land management cause changes in vegetation communities and how that drives changes in geomorphic form and dynamics.

METHODS

Study Location

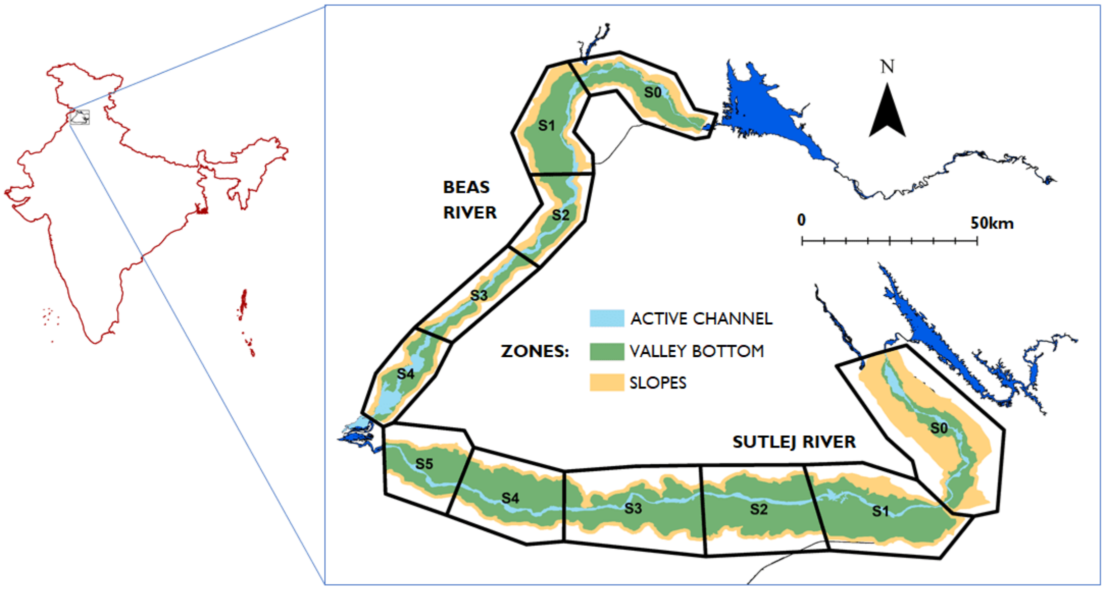

Figure 1 - The study site location in the lower reaches of the Beas and Sutlej catchments in Himachal Pradesh and Punjab, India. The section boundaries and geomorphic zones are shown .

The Beas and Sutlej Rivers - tributaries of the Indus - drain the Western Himalayas have experienced significant geomorphic changes over the last 150 years due to dam construction for water abstraction and hydropower. Whilst sharing similar characteristics, the rivers differ in the type and magnitude of geomorphic change in recent decades. The Sutlej River, at the Bhakra Dam, receives 56% of its water from glacier and snow melt whereas the Beas receives only 18% from these sources at the Pong Dam [5].

Three case study sites were chosen where significant geomorphic change was previously identified: Goindwal-Sahib (Beas), Zindanpur and Mau (Sutlej).

Geomorphic Zones

1. Active channel is the maximum wetted area between 1989-2018 my mNDWI thresholding (water if mNDWI > 0.15) [16].
2. Valley bottom and slopes boundaries drawn at transitions between geomorphon [17,18] classifications of ALOS 30m DSM data [2].

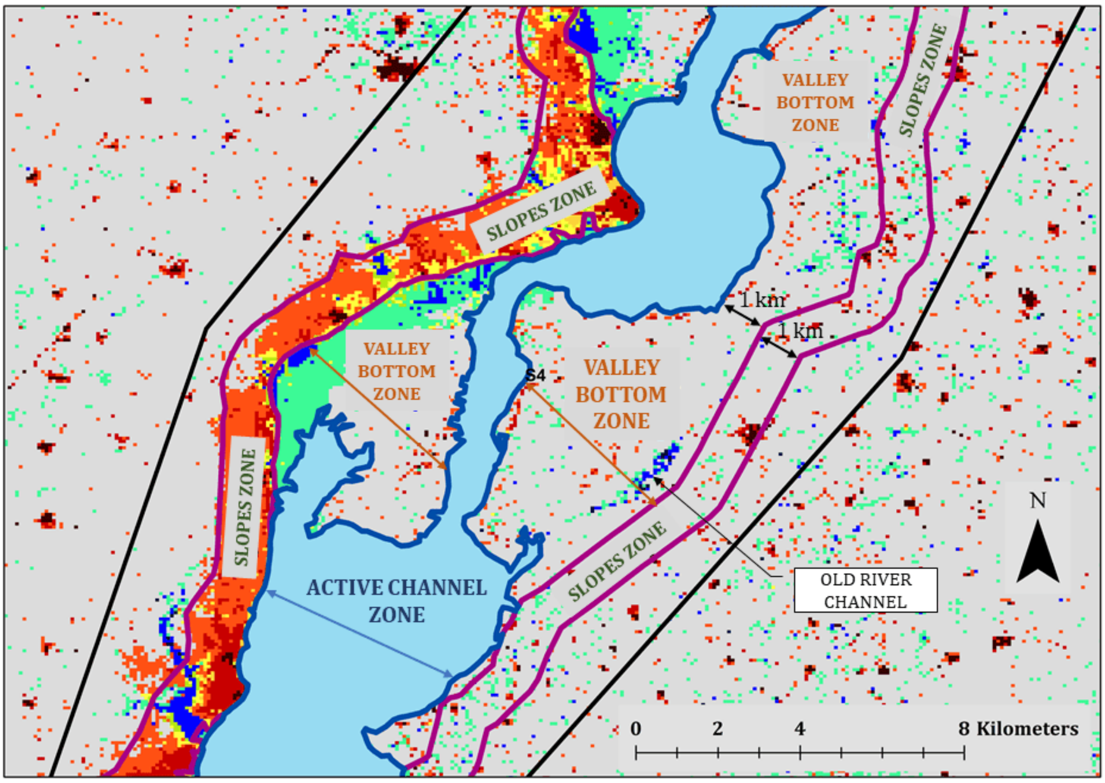

Figure 2 - Example of geomorphon processing and geomorphic zone definition in Beas valley.

Inter-Annual Vegetation Trends

1. Water pixels excluded (where mNDWI > 0.15) [16].

2. In Google Earth Engine (GEE) [19] average winter season normalised difference vegetation index (NDVI) calculated from Landsat [1] 5, 7 and 8 remote sensing data, for each river section and zone.

3. Data normalised to valley slope zone to isolate river effects

4. Trends analysed with Mann-Kendall test [20,21,24] and Sen's Slope [22].

Inter-annual Landcover Trends

1. Supervised classification of landcover from Landsat images (blue, green, red, NIR, SWIR1 and SWIR2 bands).
2. Performed in GEE using the Gradient Tree Boost classifier [23] with 10 decision trees.
3. Same invariant training set for each year
4. Landcover fractions of water, sand, vegetation, dense vegetation and non-vegetated calculated for each river, section, zone and season
5. Inter-annual time series for winter season analysed with the Mann-Kendall test and Sen’s Slope
6. Correlation explored between fractional landcover of all vegetation with NDVI

Landcover Transition

1. Transition matrix method
2. Landcover change between two years reclassified pixels into transition classes:
   - unchanged, erosion, deposition, vegetation destruction, greening

3. Maps created in GEE and compared to flood frequency analysis [25] on the daily release rates from the Pong and Bhakra Dams.

RESULTS

Long term trends in NDVI

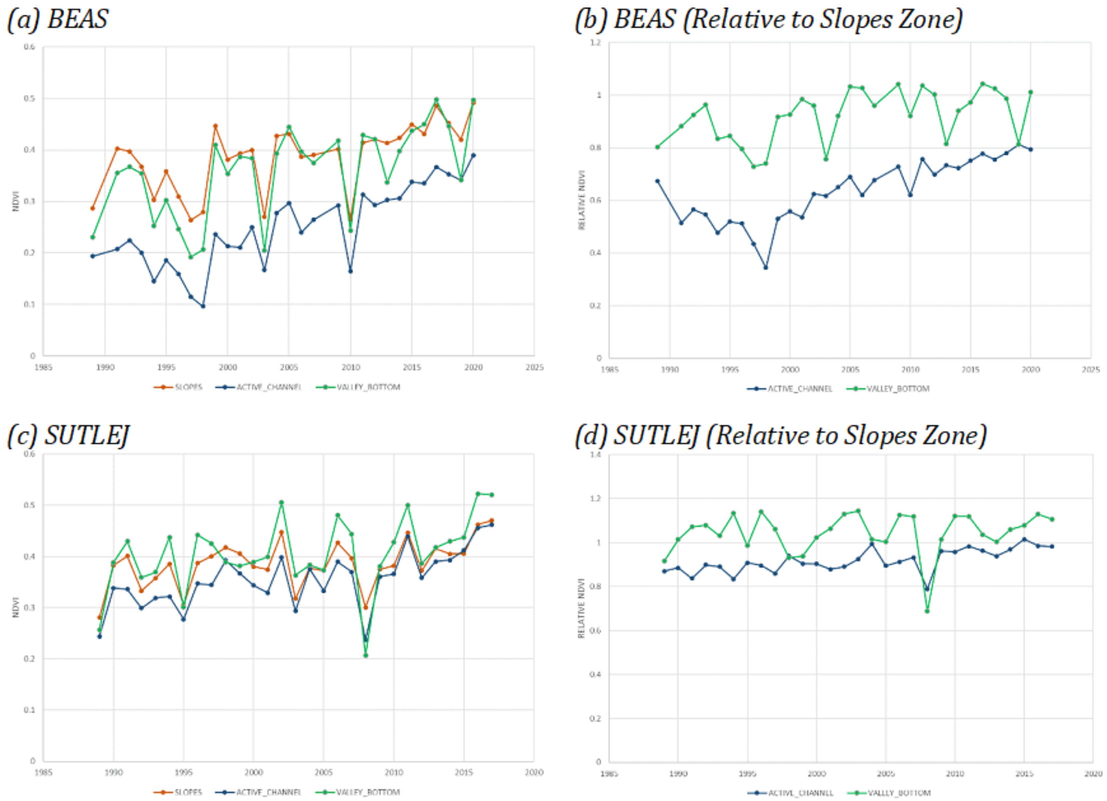

Figure 3 - (a) and (c) time series 1989 to 2020, of average winter season NDVI, by geomorphic zones within S0 of the (a) Beas and (c) Sutlej Rivers .(b) and (d) show the she NDVI for the active channel and valley bottom zones divided by the NDVI in the slopes zone, to isolate river influences from climate change and economic drivers.

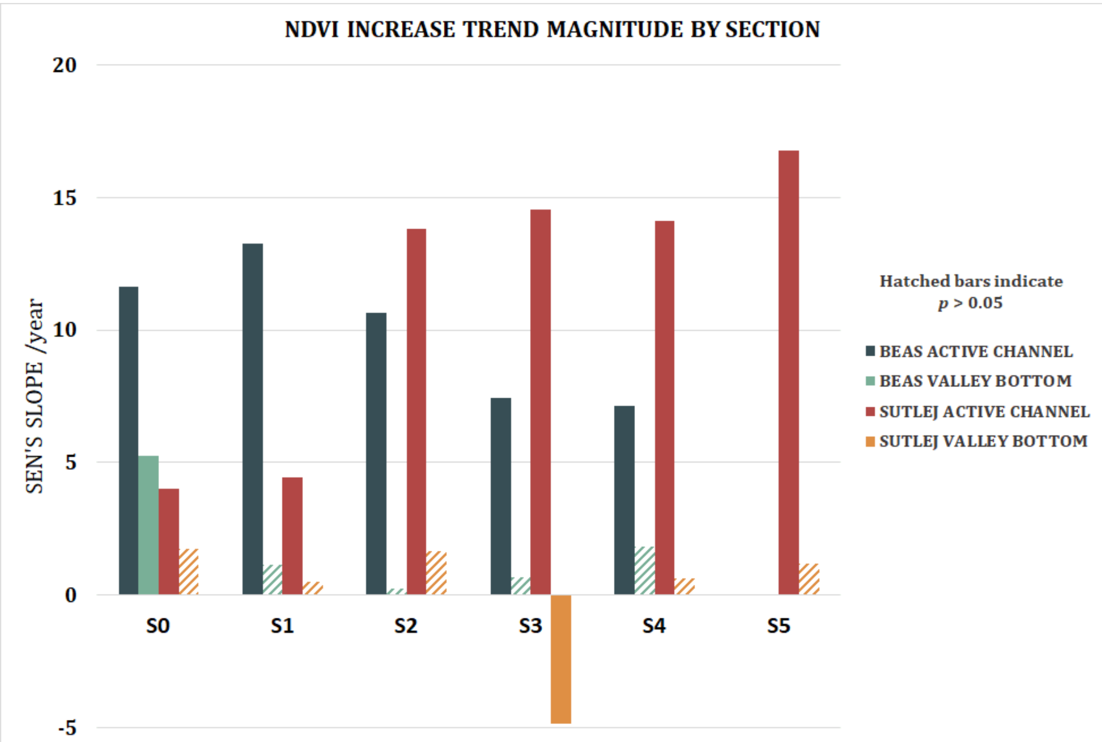

Figure 4 - Sen's slope measure of relative NDVI trends in winter season active channel from 1989-2010. Solid bars for p ≤ 0.05.

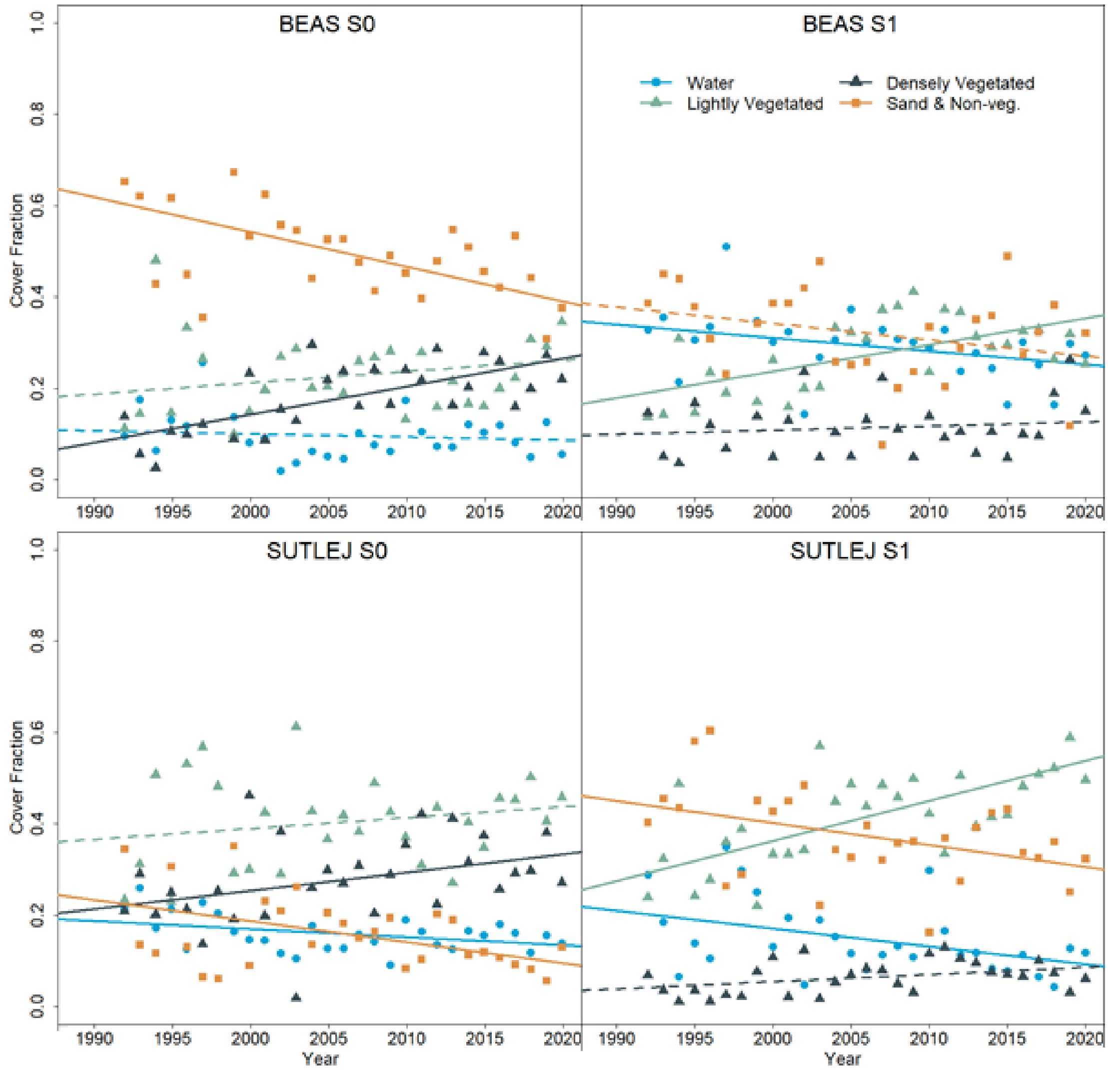

Figure 5 - Example winter season trends in active channel landcover for S0 and S1. The trend lines are the best fit line with Sen's Slope. Solid lines indicate p ≤ 0.05 and dashed p > 0.05

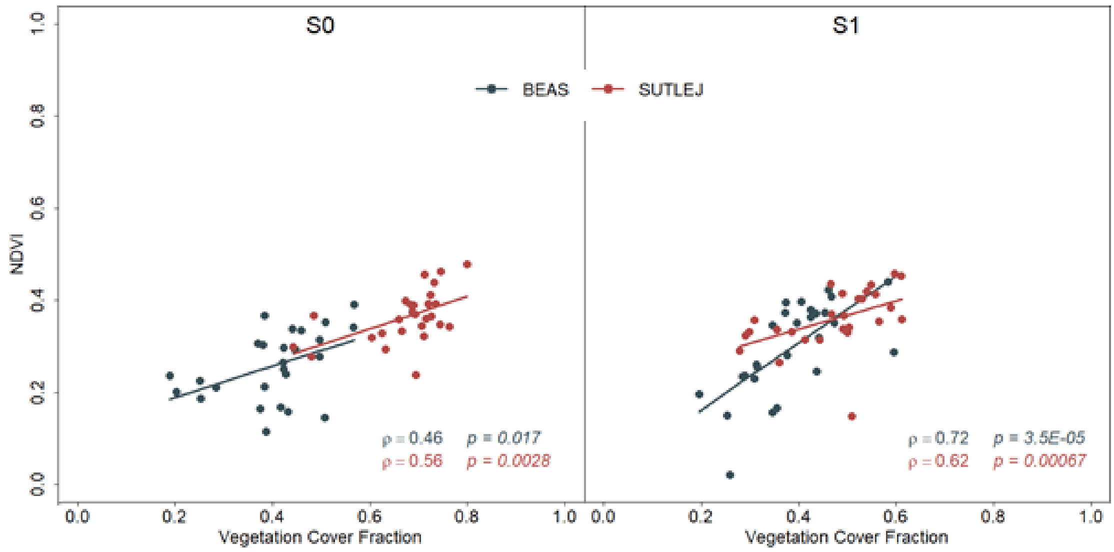

Figure 6 - Example (S0 & S1) correlations between NDVI and vegetated landcover fraction, winter seasons 1992 - 2020. . Showing Spearman's rank correlation coefficient (ρ) & p-value.

DISCUSSION

NDVI Trends

NDVI trends are strongly upward in almost all zones and sections - Figure 3(a,c).

After normalisation to slopes zone there is very little upward trend in the valley bottom zone suggesting the impact of river geomorphology is small (Figure 4)

The trend magnitude varies differently in the two rivers as we travel downstream, in the Beas the trend decreases in magnitude (generally) but in the Sutlej it increases.

The NDVI in the active channel zone is significantly correlated with the landcover fraction of vegetation (Figure 6) suggesting that the increase in NDVI is linked strongly to vegetation establishment on former areas of water or sand and gravel. Other factors may also contribute such as irrigation, use of fertilisers and climate changes.

Vegetation Establishment and Geomorphic Change

In Sections S0 of both rivers there is a trend from sand and gravel to densely vegetated land cover suggesting establishment of natural vegetation such as shrubs and trees - Figure 5.

From Sections S1 onwards the trends are towards lighter vegetation that may indicate that the land is being used for agriculture, as shown in Figure 11 as an example.

In Beas Sections S1 to S3 and Sutlej Sections S0 to S4 there is evidence of reduced water area due to channel narrowing and simplification, or a reduction in branching (number of channels). Figure 8 (Goindwal-Sahib) demonstrates channel simplification and straightening with former channel areas becoming vegetated over time. Figures 9, 10 and 11 show areas of channel narrowing.

Drivers of Geomorphic Change

High levels of river flow resulting from high dam discharges during the monsoon season appear to be the cause of the majority of geomorphic change in the active channel zone. Flood frequency analysis (Figure 7) shows a relatively high number of low return time events in the 1990s which can be seen in the rate of change of landcover. Longer term, the build of the Pong and Bhakra dams may have slowed the rate of geomorphic change and allowed vegetation to establish. The existence of flood defences that are often some distance from the main channels (as seen in Figure 11) seems to confirm this.

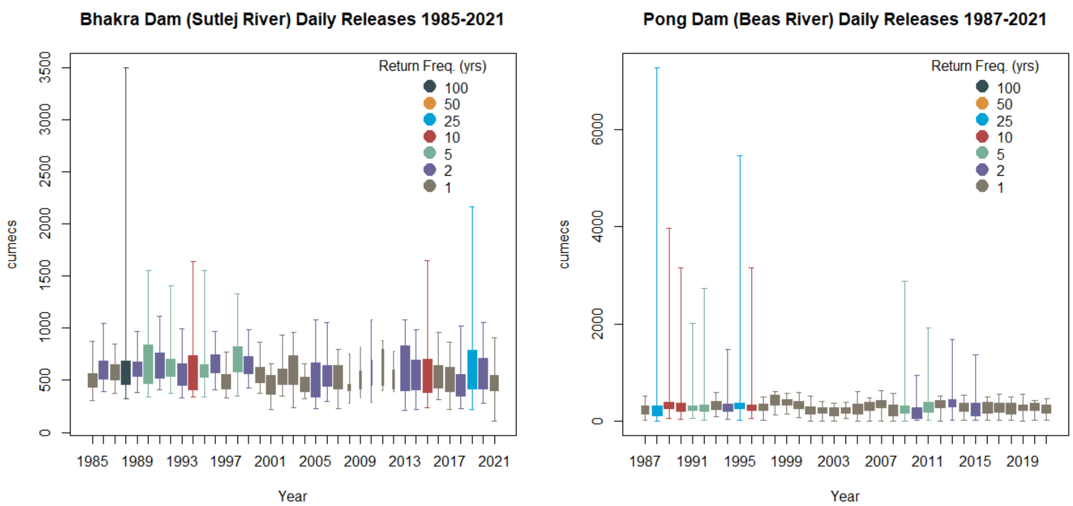

Figure 7 - Flood Frequency Analysis of the daily dam release rates from the Pong and Chakra Dams

Anthropogenic changes are also evident in this region. Flood defences continue to be deployed in areas of rapid erosion, as seen in Figure 9, along with those to protect new bridges, for example. Sand and aggregate mining is also commonly practiced in these rivers, leading to temporary, local changes in the rive morphology. These activities rob the river of sediment and may affect the type of change further downstream.

CONCLUSIONS

Widespread planform changes caused by regulation and reinforced by vegetation establishment, succession and conversion to agriculture has an impact on future geomorphic dynamic and risks.

- From 1989 to 2020 there has been a significant upward trend in NDVI across the catchment but significantly more so in the active channel of both the Beas and Sutlej Rivers
- This NDVI increase is due to areas of sand and non-vegetated land becoming vegetated, mainly natural in Section 0, immediately below the Pong and Bhakra Dams and agriculture further downriver.
- Vegetation changes correspond with narrowing of channels, loss of anabranches and more constraint in the regions or erosion and deposition.
- The impacts of flow regulation differ in their location between the rivers. The Pong Dam (Beas) is continuing to have an impact on planform immediately downstream , but in the Sutlej River, the Bhakra Dam is causing impact much further downstream.
- Due to planform change, vegetation establishment and conversion of land to agriculture, future high discharge events will manifest into different fluvial hazards, such as bank erosion in a more single thread river system.
- The shifts in vegetation cover provide insights into the social and geomorphic response of Himalayan rivers to regulation and development. The increased area of productive land poses a risk to economic damage due to future extreme flooding events.

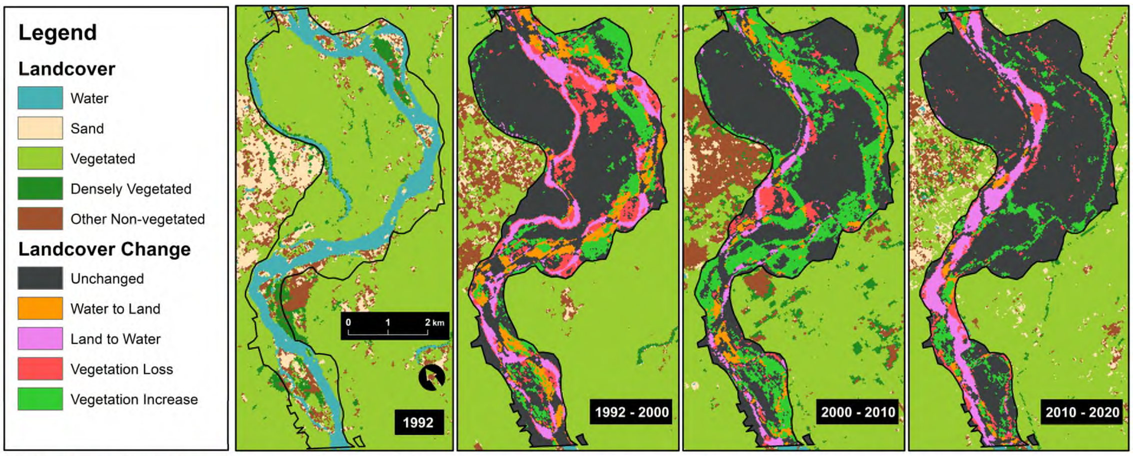

Figure 8 - Landcover transition map for Goindwal-Sahib site showing, left, the landcover map in 1992 followed by the landcover transition maps over (approximately) three decades up to 2020. The transition map is shown only inside the active channel zone (outlined in black) overlaid on the landcover map for 2000, 2010 or 2020.

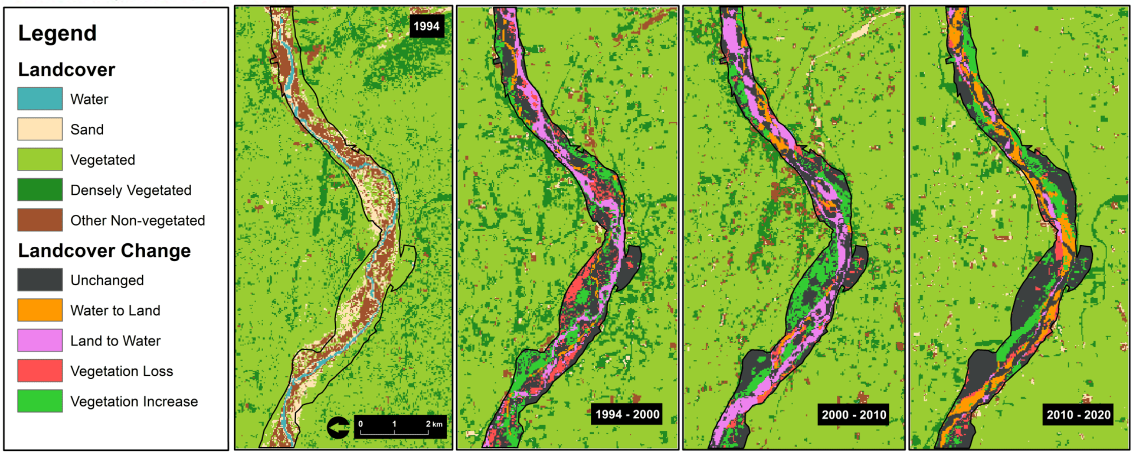

Figure 9 - Landcover transition map for Zindanpur site showing, left, the landcover map in 1994 followed by the landcover transition maps over (approximately) three decades up to 2020. The transition map is shown only inside the active channel zone (outlined in black) overlaid on the landcover map for 2000, 2010 or 2020.

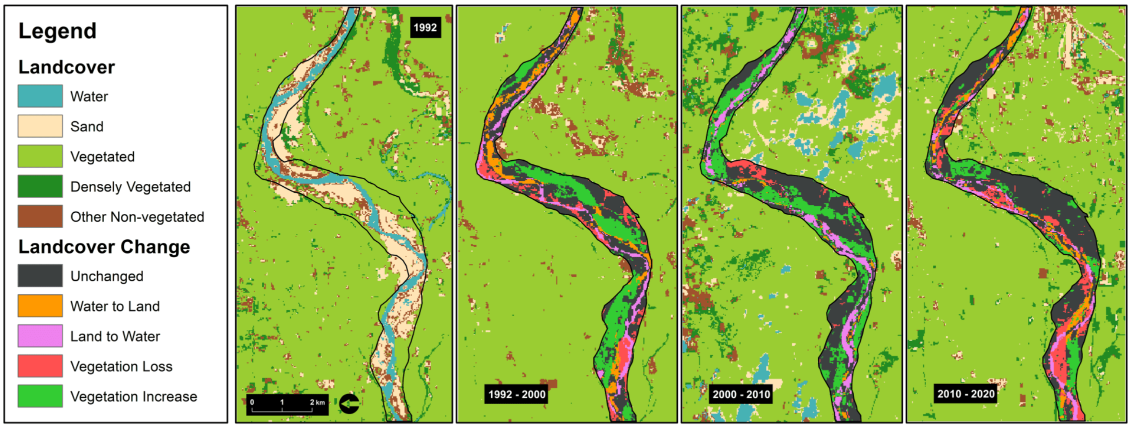

Figure 10- Landcover transition map for Mau site showing, left, the landcover map in 1994 followed by the landcover transition maps over (approximately) three decades up to 2020. The transition map is shown only inside the active channel zone (outlined in black) overlaid on the landcover map for 2000, 2010 or 2020.

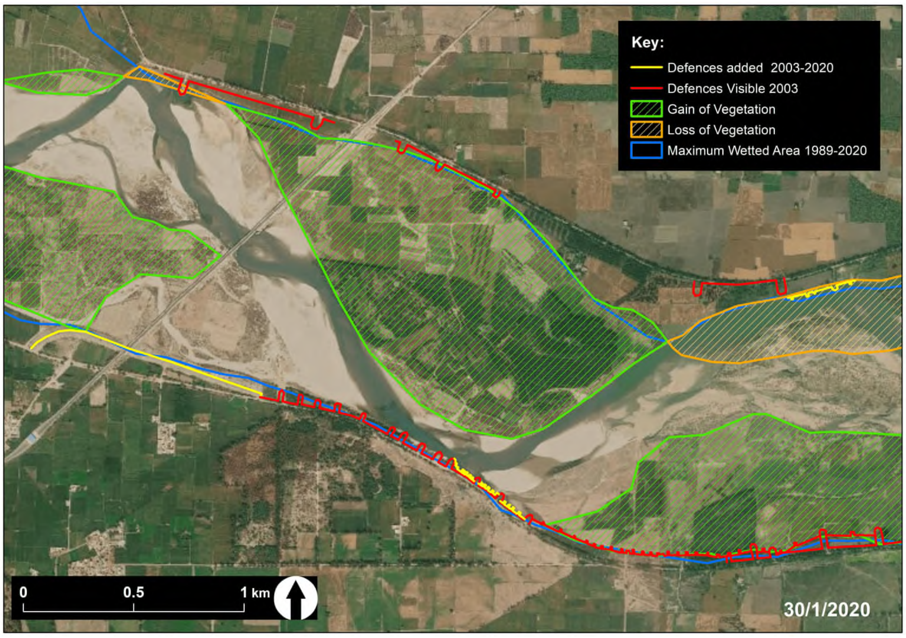

Figure 11- Example of channel narrowing at Togar site (Sutlej River) showing the satellite image from 2020 (copyright Maxar Corporation) overlaid with changes in the areas of vegetation within the active channel zone between 2003 and 2020. Also shown are the flood defences that were visbible in 2003 satellite imagery and those that appear to have been added between 2003 and 2020.

DISCLOSURES

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- Landsat images courtesy U.S. Geological Survey [1]
- Digital Elevation Map provided by ALOS (Japan Aerospace Exploration Agency) [2]
- Pong and Bhakra dam release data from Bhakra Beas Management Board [4]
- 1 degree gridded rainfall data [3]

ABSTRACT

Vegetation is a natural component of river systems and plays important hydrological, ecological and geomorphic roles. However, vegetation cover and dynamics are controlled by numerous factors operating at multiple scales, making it challenging to determine the drivers of changes over time. The Beas and Sutlej Rivers are two of the 'water towers' of the Himalayas that supply water and power for large populations. Previous research has shown that significant geomorphic change has occurred over that last 150 years in both rivers, with differences in the type and magnitude of change in the last few decades. The aim of this study was to quantify the spatial distribution and dynamics of riparian and in-channel vegetation in two Himalayan rivers and evaluate the local and global drivers, such as climate change, alteration of river flows, and river geomorphic adjustment. Annual changes in vegetation cover and channel width were quantified using Normalized Difference Vegetation Index (NDVI), modified Normalized Difference Water Index (mNDWI), and a multispectral supervised classification over a 30-year period, for pre- and post-monsoon seasons, using Landsat data. The results show statistically significant upward trends in NDVI across both catchments, indicating large-scale drivers of change. Relatively greater increases in NDVI in the valley bottom and the active channel zones suggest more localized processes such as recruitment and succession of vegetation and conversion to agriculture following channel narrowing. Spatial variations in vegetation dynamics helps us to better understand vegetation-geomorphology interactions in these large systems and the impacts of human activity and climate change.

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