Assessment of geomorphic evolutionary pathways and hydrological connectivity of Kaabar Tal (wetland) using multi-source remotely sensed datasets

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1. Introduction:

The alluvial wetlands are one of the most important ecosystems of the world and are in abundance in the vast Indo-Gangetic plains. The wetlands of this region are of variable sizes and characteristics but currently face similar problems of drying-out and fragmentation. It is empirical to understand the evolutionary pathways and hydrological connectivity of these wetlands for planning and execution of management and restoration for them. These pathways have been studied for a wetland namely, the Kaabar Tal (KT), situated in the Kosi-Gandak interfan region of the eastern Gangetic plains. With a total catchment of 250 km^2 and wetland area of 51 km^2, it is the largest wetland of the region and a potential Ramsar site (WISE, 2013). Kaabar Tal is principally a rain-fed wetland located in flat terrain (average slope of ~2°) under intensive agriculture and receives water as overland flows. Once a single waterbody, it is now highly fragmented and currently appears like a mosaic of small wetlands with variable hydroperiods.

2. Materials and method:

2.1. Study area:

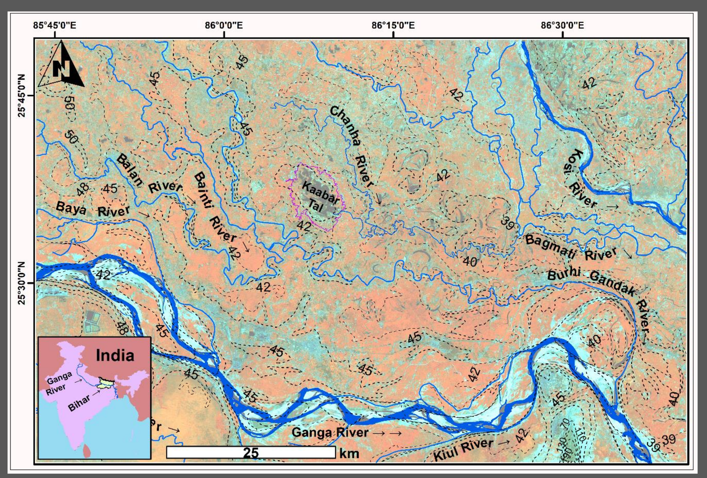


Fig. 1: Geographic location of the study area. The study area is a part of middle Ganga plains in North Bihar and lies between Kosi-Ganga interfluve.

2.2. Datasets

Table 1: Data used. DEM – Digital elevation Model, UAS – Unmanned Aerial System.

Dataset	Data type	Spatial resolution
Landsat 5 (TM)	Satellite Imagery (Multispectral)	30 m
Landsat 8 (OLI)	Satellite Imagery (Multispectral)	30 m
Trimble UX5 UAS Aerial ortho-imagery	Aerial Photo and DEM	1 m
CartoDEM	DEM	30 m
Survey of India Maps (Auxiliary data)	Toposheets	1:50,000

2.3. Method

2.3.1. Hydroperiod

Landsat → PCA → ISO-cluster

PCA: Principal component analysis; ISO: iterative self-organizing

2.3.2. Geomorphic mapping

On-screen digitization using UAS-aerial photo and auxiliary datasets.

2.3.3. Hydrological connectivity

Connectivity Response Unit (CRU) concept: The CRUs have been conceptualised as the landscape units that show similar connectivity response when a process acts on them. The CRUs can be defined as the 'clusters' of response *elements* and are the results of the physical properties of those *elements* (Singh et al., 2017).

Index of connectivity (IC):

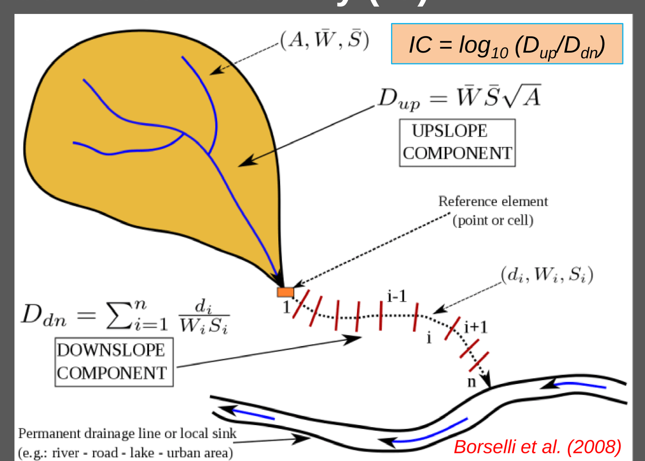


Fig. 2: Concept of connectivity index.

3. Results

3.1. Hydroperiod

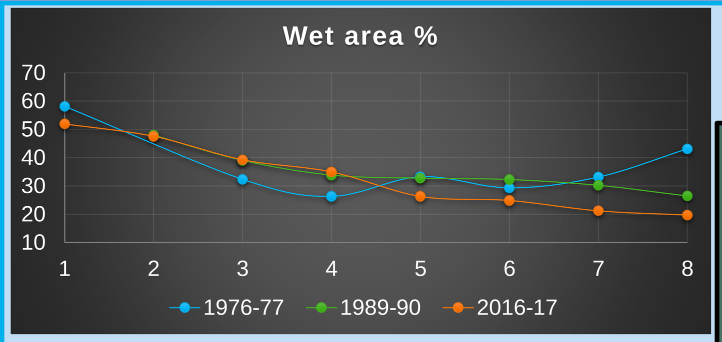


Fig. 5: The seasonal wet-area percent for different years. The year 1976-77 shows an unique characteristic where the wet area starts increasing. The year 2016-17 has a sharp decreasing trend while 1989-90 has a moderate trend. Numbers 1-8 corresponds to post-monsoon months Oct-May.

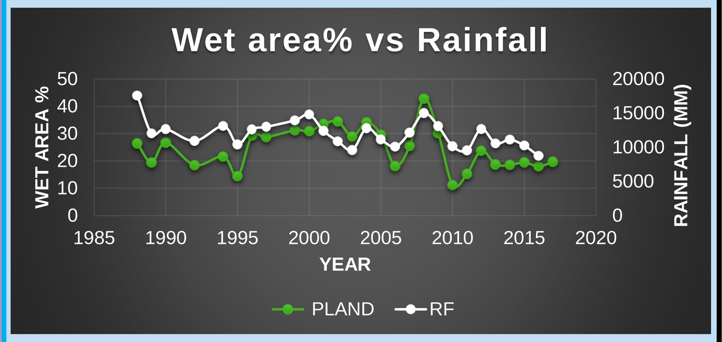


Fig. 6: The pre-monsoon wet areas for the year 1988 to 2017.

Wet area% = f(RF, x)
x is unknown. Could be satellite or RF data artefacts, anthropogenic interventions, flood-water inputs (e.g., 2008 Bashi embankment breach of river Burhi Gandak).

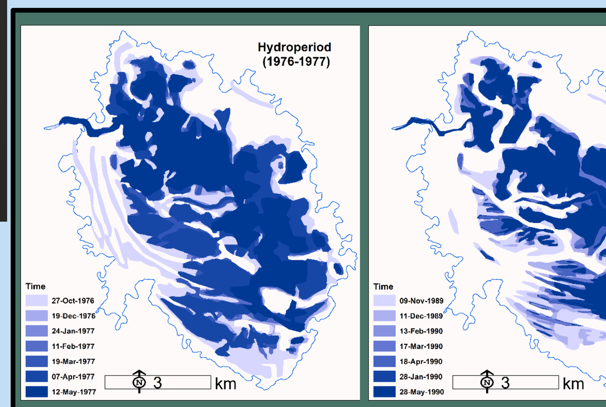


Fig. 3: Seasonal variation in the hydroperiods for different years. The increasing fragmentation in recent years is evident.

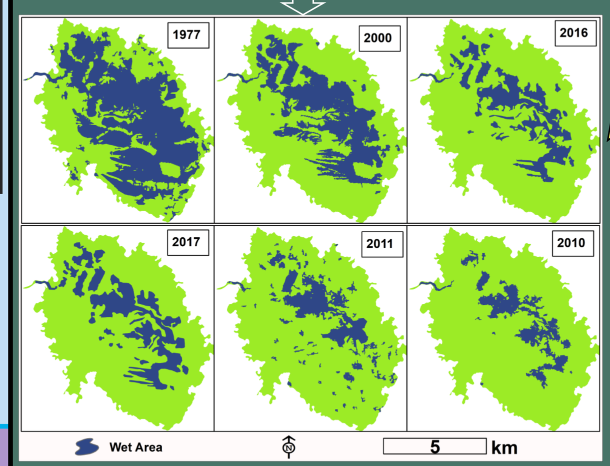
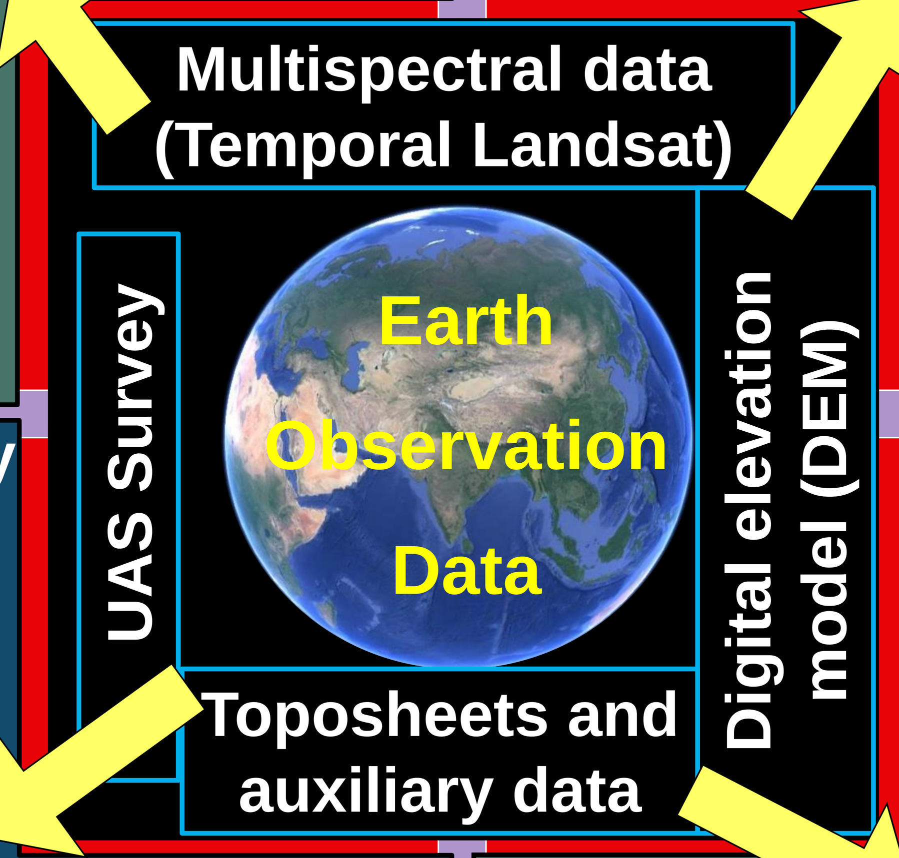


Fig. 4: Pre-monsoon wet areas for different years. The disconnection of northern patches from the central patch is noticeable phenomenon. The central patch forms the core area of KT in pre-monsoon times.

Active/inactive wetland areas



3.2. Hydrological Connectivity

Catchment-wetland connectivity

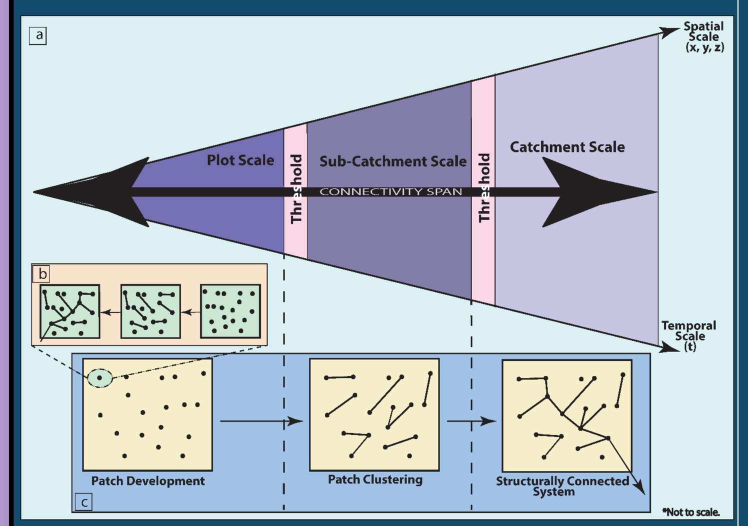


Figure 7: (a) Concept of connectivity is applicable at every spatio-temporal scale. Connectivity brings continuity among different scales. Spatial scale and temporal scale increases together. (b) The formation of CRU patches by CRU elements. (c) Connected CRUs form a cluster and their interconnection results into a connected system.

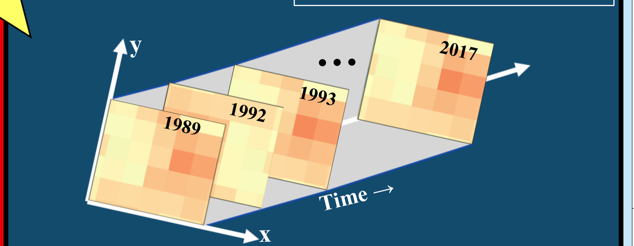


Fig. 8: A space-time cube of individual ICs. Each cell is a CRU element.

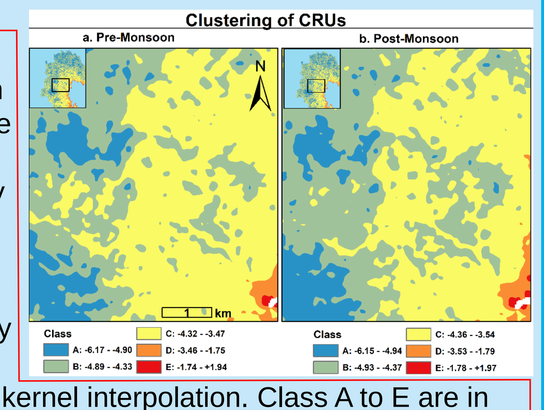


Fig.9: The comparison between the structural connectivity of pre- and post-monsoon seasons. By application of diffusion kernel interpolation. Class A to E are in decreasing order of connectivity potential.

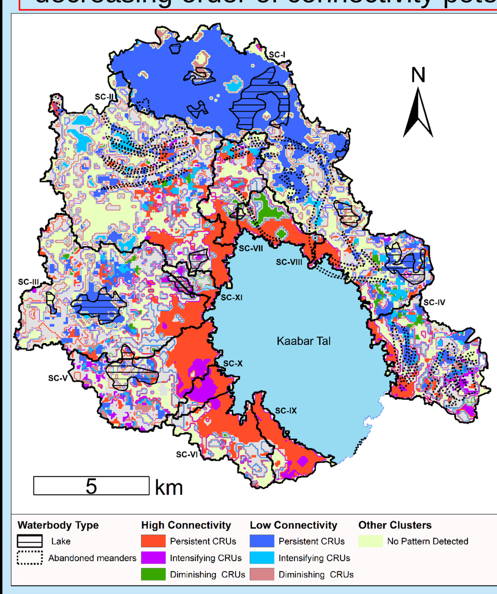


Fig. 10: Dynamic connectivity pattern of the catchment for the post-monsoon season. Intensifying and diminishing CRUs represents the dynamic connectivity patterns.

Table 2: Stats of different geomorphic features of KT.

Geomorphic Feature	Area (km^2)	Areal extent (%)	Elevation Range (m)	Average elevation (m)	Activity
Active Wetland	28.4	55.4	42-27	36	Active
Upland	10.0	19.5	64-33	38	Conditionally active
Dry margins	12.8	25.1	62-30	40	Conditionally active
Abandoned* Meanders	10.4	20.3	42-27	36	Active (July-March)
Seasonal Wetland	13.8	26.9	42-27	37	Active (July-February)
Perennial Wetland	7.3	14.2	38-25	35	Active (Throughout year)

*Some abandoned meanders are part of perennial wetland too.

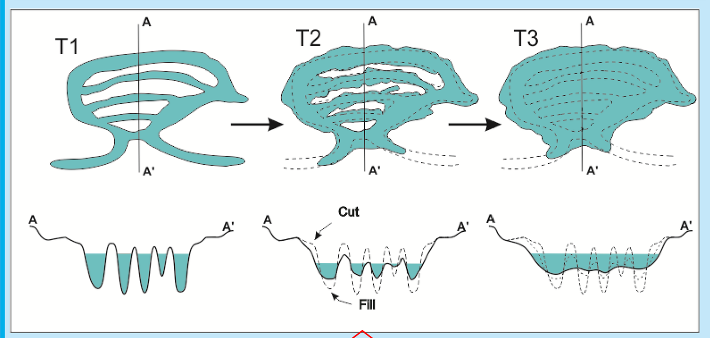


Fig. 13: The erosional-depositional (cut-fill) process acting on a fluvially formed ridge-swale topography. T1, T2, and T3 are time in increasing order since the channel abandonment. With time, whole system gets translated into a wetland system. This is the dominant process acting on the relict fluvio-geomorphic features left behind by avulsive river systems.

3.3. Geomorphology

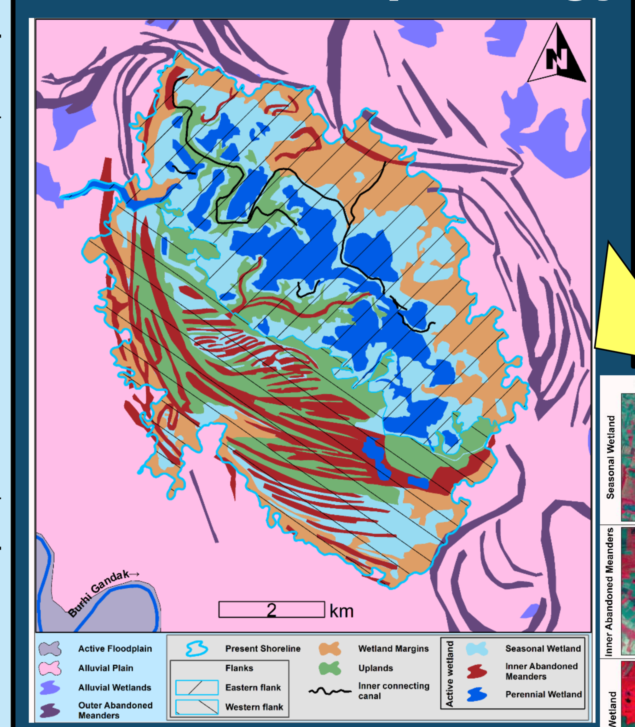


Fig. 11: Major geomorphic units and features in and around KT. This wetland is a fusion of many fluvio-geomorphic features. The abundance of abandoned meanders are indicating that in past, rivers have traversed through this area.

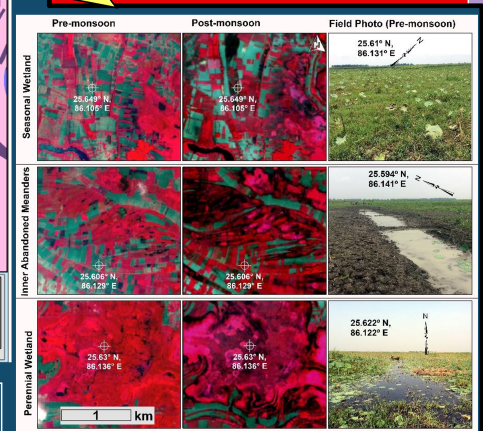
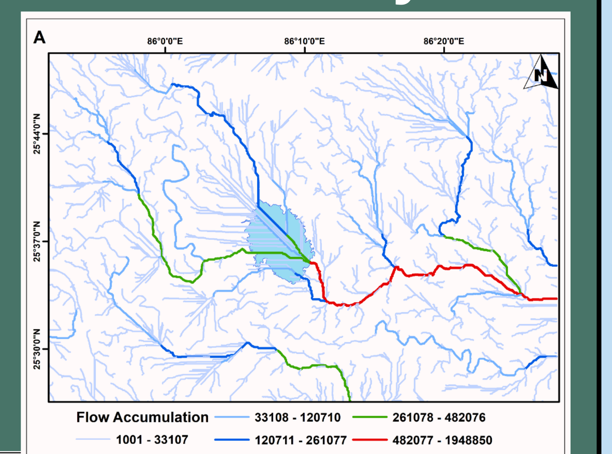


Fig. 12: Seasonal satellite imagery and field photos of the active wetland areas.

Fluvio-geomorphic signatures

3.4. Evolutionary Pathway



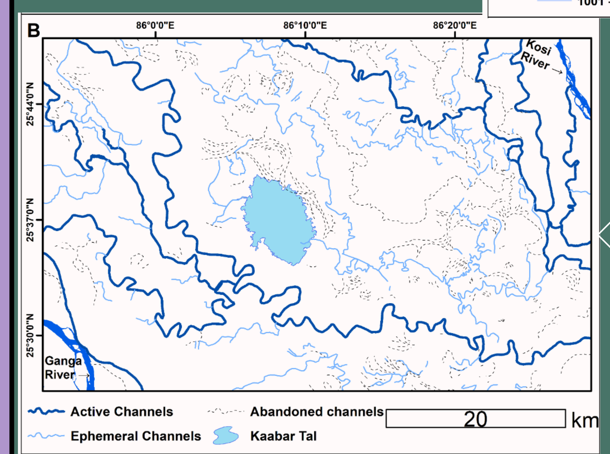


Fig. 14: (A) DEM derived flow-accumulation scenario and (B) the present stream configuration around KT.

In the past, KT was a confluence point for many streams.

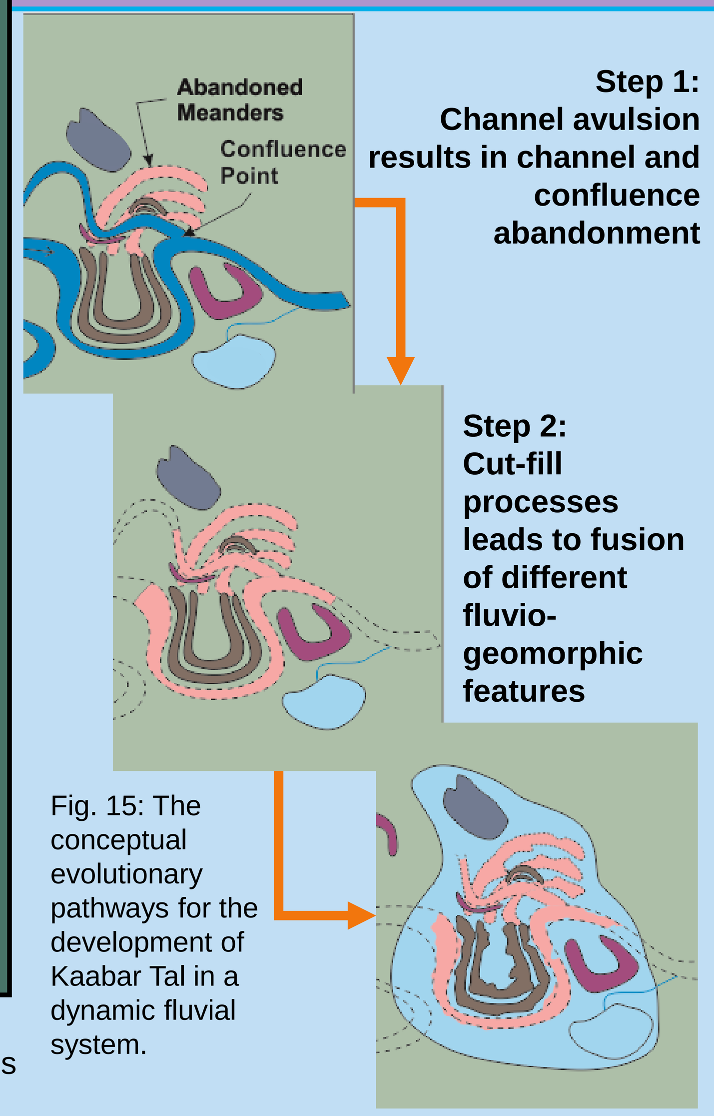


Fig. 15: The conceptual evolutionary pathways for the development of Kaabar Tal in a dynamic fluvial system.

Results from geomorphic mapping and flow-accumulation modeling are combined to assess the evolutionary pathways of KT.

4. Conclusions:

The fragmentation of the Kaabar Tal has been amplified and the hydroperiods have changed drastically in the recent times.

The wetland's dynamic connectivity with catchment is decreasing over the years with an exception in the proximal catchment areas where the connectivity is persistently high and increasing, subjecting the wetland to siltation from the surrounding agricultural lands.

In the past, this wetland was a confluence point for many streams. The wetland is a result of the fusion of different hydro-geomorphic units like scrolls, oxbows, abandoned meanders left by those streams.

Lowering hydrological connectivity, siltation from proximal catchment areas, and the uneven morphology of Kaabar Tal are the causal factors for its amplified fragmentation in the recent times.

The results show that this wetland is a heterogeneous and complex system, with a catchment undergoing severe LULC changes. Such factors should be considered in design and execution of management and restoration plan.

5. Acknowledgements:

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CRU calculation

One instance → Diffusion Kernel Interpolation → Spatial CRU clusters → Structural connectivity

Multi-temporal → Space-time cube → Getis-Ord Gi* statistic → Mann-Kendall statistic → Spatio-temporal CRUs → Dynamic connectivity

Landsat → NDVI → C-factor (W)

DEM → Slope (S) → IC

6. References:

Borselli, Lorenzo, Paola Cassi, and Dino Torri. "Prolegomena to sediment and flow connectivity in the landscape: a GIS and field numerical assessment." Catena 75, no. 3 (2008): 268-277.

Singh, Manudeo, Sampat K. Tandon, and Rajiv Sinha. "Assessment of connectivity in a water-stressed wetland (Kaabar Tal) of Kosi-Gandak interfan, north Bihar Plains, India." *Earth Surface Processes and Landforms* 42, no. 13 (2017): 1982-1996.

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