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Monitoring Nature-Based Engineering Projects in Mountainous Region Incorporating Spatial Imaging: Case Study of a Hydroelectric Project in Nepal

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1 ABSTRACT

Infrastructure projects pose complex management challenges and require comprehensive solutions for diverse needs, including the monitoring of purpose-built nature-based components at regional scale. Our paper demonstrates the capability of spatial imagery in monitoring the health of a micro-hydro renewable energy generation plant in the mountainous region on the outskirts of Kathmandu, Nepal.

Our modelled results utilising the Normalised Difference Water Index (NDWI) from the longitudinal satellite data between between 1988-2020 show the spatial profiles of the hotspots for potential nature-based infrastructure interventions. This is typically an administrative challenge for wider implementation of such interventions in low/middle income countries such as Nepal. We recommend policy measures for enhancing nature-based local livelihoods can be one way for encouraging community-based local management of such initiatives. We also identify the need for regular data updation vital for providing ground-truthed decision making capability for such integrated infrastructures using an Artificial Intelligence platform.

Keywords: energy, spatial analysis, nature-based, infrastructure, monitoring

2 INTRODUCTION

Nepal's new Federal Constitution is creating higher, inclusive economic growth for the population of circa 31million. Increasing level of infrastructure projects are being proposed integrating blue-green (natural) alongside grey (built structures) components to increase sustainability across key sectors, including transport, energy, adventure sports and inner-city (aka "forest city") developments. The last decade has seen a push for integrated infrastructure projects in Nepal, combining nature-based components alongside built structures to meet the sustainable development (SDG 9 - Build resilient infrastructure). Typical projects include transport corridors, alternative energy installations, adventure sports facilities, etc., both in remote, naturally sensitive locations and in the urban hinterlands. However, there is still a lack of a comprehensive project management framework for ensuring effective delivery and post-delivery long-term monitoring of such nature-based engineering projects. Our study presents a case study demonstrating the role of remotely sensed satellite data in optimising infrastructure sustainability through targeted integration of purpose-built nature-based components at a hydroelectricty generation plant in Nepal.

3 METHODOLOGY

3.1 Case study description

The Kulekhani hydropower project (KHP-1) is a rock-fill dam on the Kulekhani River (also known as Indrasarobar), which was constructed in 1977; a 60 MW hydroelectric power station was later installed at the site in 1982. It is situated in the Bagmati River Basin of Makwanpur district of Nepal (between 27° 35′ 07″ N and 27° 37′ 43″ N latitudes; 85° 8′ 17″ E and 85° 9′ 56″ E longitudes) at an altitude of 1430 metres above sea level (Figure 1). The dam area is 7 km long and 114 m deep, with a total storage capacity of approx. 85 million m3 - 12 million m3 allocated to dead storage and 73 million m3 to live storage (Shrestha et al. 2014, Shrestha et al. 2021). This watershed extends from sub-tropical to temperate climate zone and has been facing the severe impact of climate change in the recent decades; daily precipitation level has decreased and temperature has increased in the past 30 years (Ghimire et al. 2019). The neighbouring region comprises of forested and cultivation areas which are aggressively being replaced by urban built-up areas,

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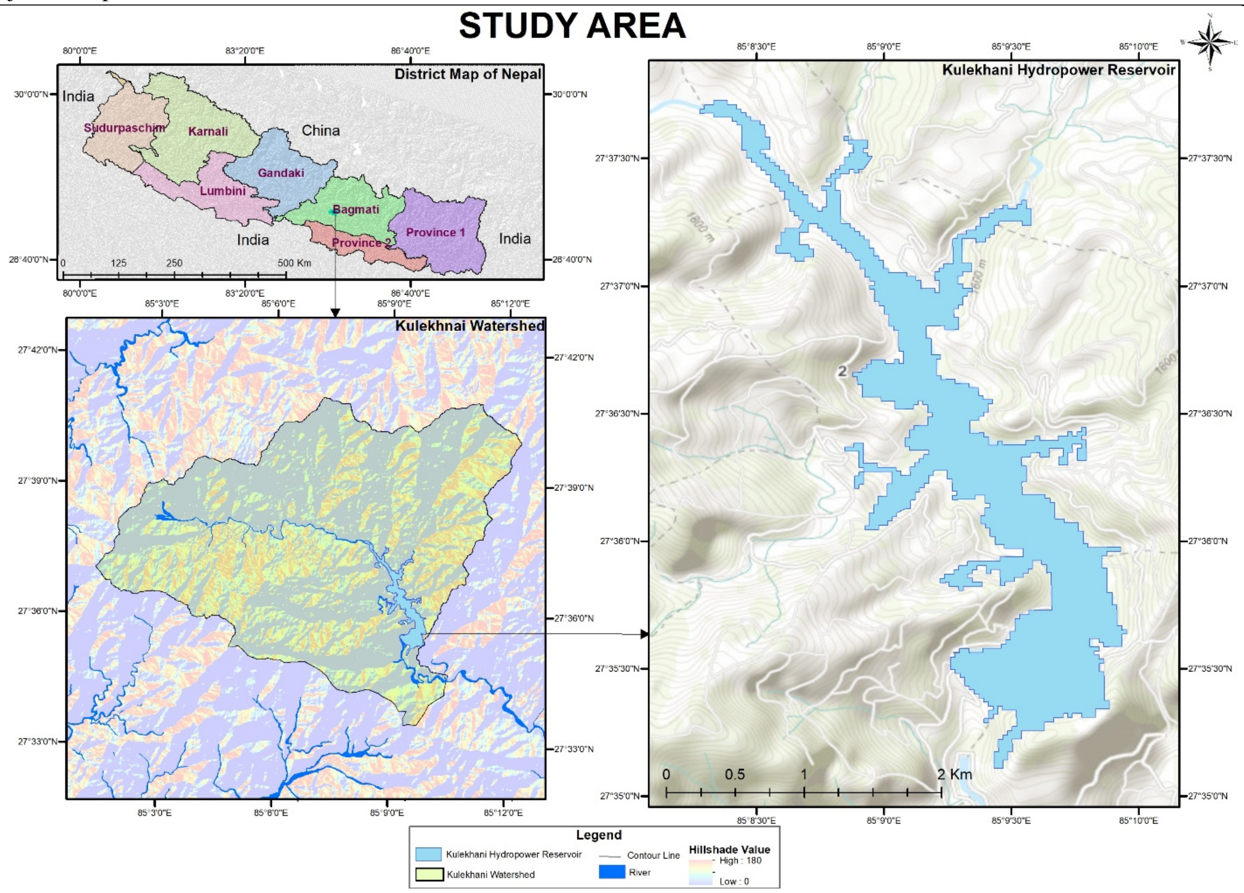

Figure 1: Location map of the study area (the span of the dam area shown in the inset in the right panel).

3.2 Data acquisition

In this study we have collected freely available Landsat Level 2 images 1988-2020 (Landsat 5 Thematic Mapper, TM; Landsat 7 Enhanced Thematic Mapper Plus, ETM+; Landsat 8 Operational Land Imager, OLI) from the United States Geological Survey (USGS), Table 1. All images were verified and analysis was conducted in ENVI v5.3 environment.

Year	1988	1990	1992	1994	1996	1998	2000	2002	2004	2006	2008	2010	2014	2016	2018	2020
Months	29-Nov	4-Feb	23-Oct	13-Oct	18-Oct	8-Oct	22-Nov	27-Oct	9-Nov	30-Oct	20-Nov	25-Oct	23-Dec	25-Oct	31-Oct	22-Jan
Sensor	TM	TM	TM	TM	TM	TM	ETM+	ETM+	TM	TM	TM	TM	OLI	OLI	OLI	OLI

Table 1: Time series Landsat 5, 7 and 8 imagery applied (Path/Row 142/040).

3.3 Evaluation of Kulekhani Dam area

We evaluated the water content and its further reduction/expansion in the dam area between 1988 and 2020 utilising the Normalised Difference Water Index (NDWI) from satellite images following the literature (Zhao et al. 2018, Acharya et al. 2019, Zhang et al. 2019, Li et al. 2020). The positive NDWI threshold value of 0 to 1 were applied for the extraction of the water value for all the years (Zhang et al. 2019, Yan et al. 2020). For the extraction of water value the following equations were applied (McFeeters 1996).

$$NDWI^{OLI} = \frac{Green\ (Band\ 3) - NIR\ (Band\ 5)}{Green\ (Band\ 3) + NIR\ (Band\ 5)}$$ Equation 1

$$NDWI^{TM}\ \&\ NDWI^{ETM+} = \frac{Green\ (Band\ 2) - NIR\ (Band\ 4)}{Green\ (Band\ 2) + NIR\ (Band4)}$$ Equation 2

RESULT

The NDWI estimates were used as the proxy for surface water level of the Dam area. Based on the results, the surface water of Kulekhani dam appears to have expanded significantly over the assessment period, represented by the NDWIs respectively of 0.182 in 1988 and 0.405 in 2020 (Figure 2). In the early part (1990-1994), the NDWI values remained low, however they have increased rapidly beyond 1994, indicating incremental part of the submerged area due to the dam.

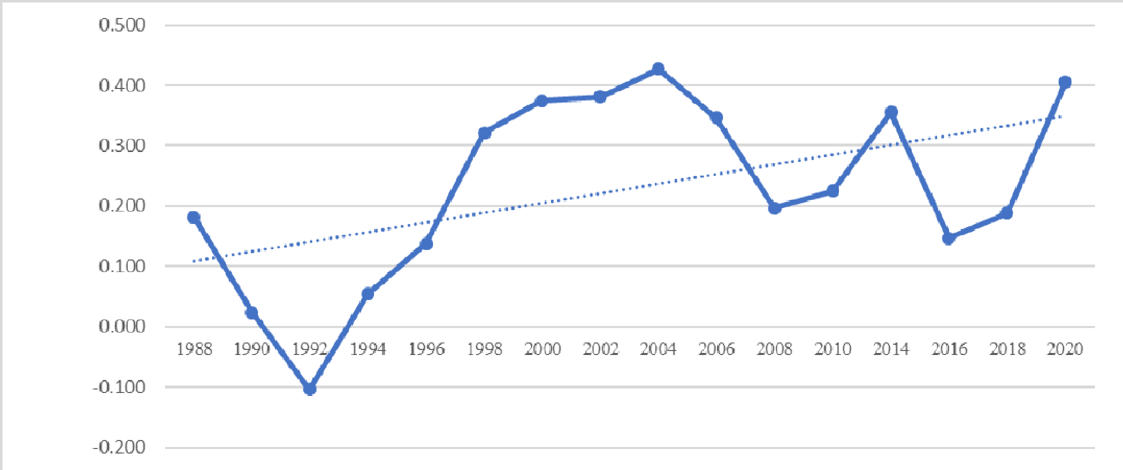

Figure 2. Time-series graph for the NDWI mean pixel values from 1988-2020.

The spatial distribution of the colour-coded NDWI values in the Dam area are plotted in Figure 3, clearly showing the increase in NDWI within the immediate reservoir boundary between 1988-2020. However, the NDWI in the neighbourhood areas of the dam in the corresponding years have been reducing. This could be attributed to multiple factors, such as - climate change impact, variance of precipitation, earthquake, sediment deposition.

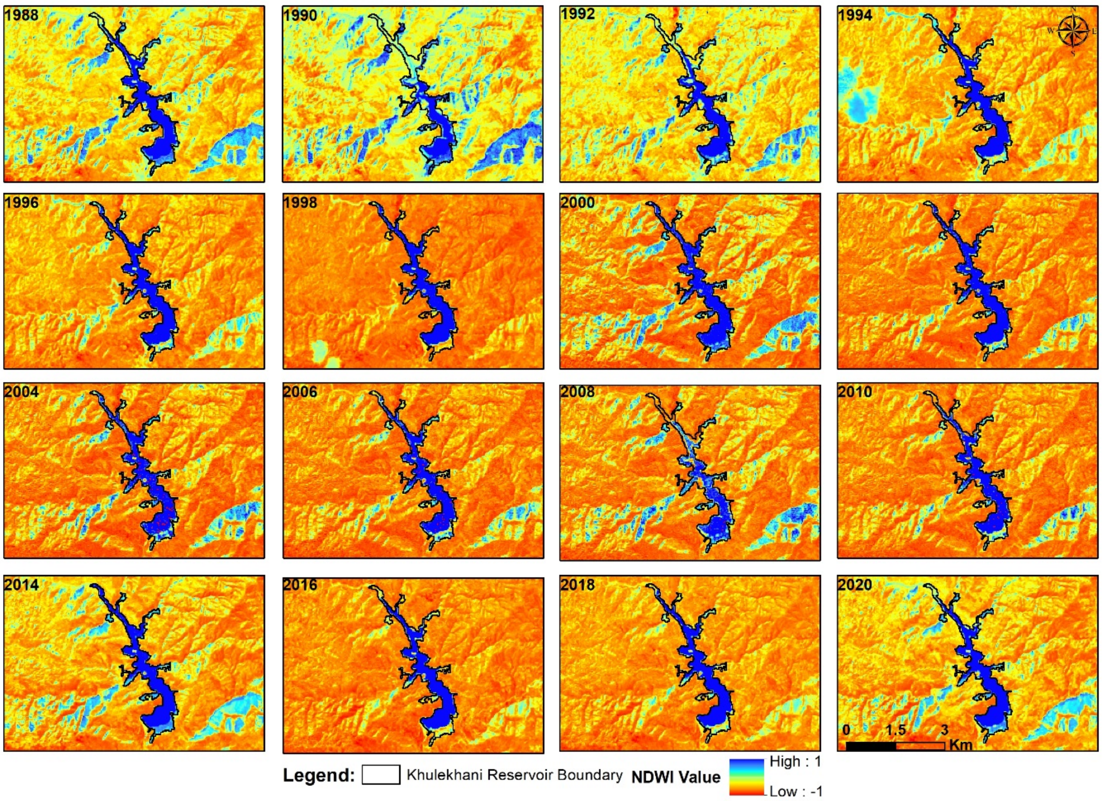

Figure 3: Contour maps of the NDWI profiles showing the reservoir and the neighbourhood areas between 1988 and 2020

4 DISCUSSION AND CONCLUSION

Our study reveals an interesting paradox in relation to the state of hydroelectric power station in mountainous regions - we estimated surface water level of the dam area in the specific case study location increased between 1988 and 2020 (an increase of 122% in the corresponding NDWI values within the reservoir boundary, estimated from satellite imagery from 0.182 to 0. 405). On contrary, the storage capacity

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of Kulekhani reservoir is reported to be reduced from 85 million m3 to 60 million m3 within the last 30 years (Hurford et al. 2014). Although we did not consider the reasons for this contradictory phenomenon within the scope of this study, previous studies have identified sedimentation deposition as one of the key factors leading to this paradox (Shrestha et al. 2014, Ghimire et al. 2019). Adverse anthropogenic encroachment activities have led to further deterioration of the reservoir storage capacity, with increased level of deforestation leading to gully erosion. We consider longitudinal satellite data as a vital tool in monitoring the overall role of nature-based intervention in mitigating such adverse impacts of reservoir capacity. Going forward, we recommend long-term monitoring using remotely sensed satellite data combined with artificial intelligence as essential for understanding the true scale of sediment collection and the potential role of nature-based intervention in mitigating such adverse impacts for infrastructure projects in hard-to-reach mountainous regions.

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