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Spatiotemporal Dynamics of the Harpan Khola and Its Hydro-ecological Impacts on Phewa Lake, Pokhara, Nepal

Rajeev Upadhyay[1*] and Debendra Bahadur Lamichhane[2]
Department of Geography, Prithvi Narayan Campus, Pokhara
Professor of Geography, Tribhuvan University
[*]Corresponding E-mail: rajeev@pncampus.edu.np

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Abstract

The Harpan Khola, a principal feeder stream of Phewa Lake in Gandaki Province, Nepal, plays an important role in upholding the hydro-ecological integrity of the lake and river. For many years, the Harpan Khola system has experienced crucial morphological changes because of many human activities, climate variability, and land use changes. This study provides a spatiotemporal analysis of the course alterations of the Harpan Khola in recent years 1979, 2014, and 2024 using remote sensing and GIS tools. The Khola's morphology has been substantially transformed with the increase of meander, sediment deposition, and channel migration, which have led to severe sedimentation in Phewa Lake. Such transformation has reduced about 24% water storage capacity together with the decline of aquatic biodiversity. The study also emphasizes increasing pollution loads, with the increase of Total Nitrogen (TN) and Total Phosphorous (TP) from agricultural runoff and crude urban waste. Even the tourism and local livelihoods are suffering from the lake's degradation. This research highlights the necessity of integrated watershed management and conservation planning.

Keywords: *Biodiversity, Channel shift, Eutrophication, GIS, Harpan Khola, Lake degradation, Land use, Morphology*

Background

The natural freshwater lake named Phewa, locating in Pokhara Metropolitan City of Nepal, is serving as a key environmental, economic, and cultural asset of the country. The lake, which attracts over half a million tourists every year, got the opportunity to be listed as Ramsar site in 2016. The global shift towards greener

economies, while essential for sustainable development, has raised growing concerns about involuntary negative impacts on freshwater biodiversity (UNEP, 2011; Gasparatos et al., 2017; Marttila et al., 2020). Rapid land-use changes and the expansion of urban areas to meet the demands of rapidly increasing population have emerged as key contributors to the ongoing degradation of freshwater ecosystems (Carpenter et al. 2011; Van Meter et al., 2016). Such pre-urban streams are susceptible to change owing to overlapping hydro-morphological pressures and water quality issues.

The fragmented nature of surrounding landscape, comprising a mosaic of urban, agricultural, and natural areas, contributes varying degrees of environmental stress. Considering such impacts needs the integration of biological indictors across multiple trophic levels, supported by hydromorphological, physicochemical, and chemical parameters (Birk et l., 2012; European Commission, 2019). Among the primary sources of inflow, the Harpan Khola plays a crucial role in sustaining Phewa Lake's hydrological balance and nutrient dynamics. While certain areas in the Lake's westernmost region are experiencing advanced stages of dystrophication, the central and main body of the lake has revealed characteristics indicative of a mature oligotrophic state (Lamichhane, 2000; Lamichhane, 2005).

Over the past five decades, the Harpan Khola and its tributaries have been severely impacted by deforestation, unplanned settlement, agricultural expansion, and increased climatic variability. These pressures have altered the Khola's hydrodynamics, increased sediment transport, and degraded the water quality of Phewa Lake. Reports indicate that since 1980, the lake has lost approximately 24% of its storage capacity due to sediment accumulation, primarily from the Harpan catchment (Gurung et al., 2018). More recent work by Gurung et al. (2018) measured the lake's volume loss due to sedimentation and emphasized the contribution of the Harpan Khola. Dahal et al. (2021) highlighted the impacts of nutrient loading from agricultural and urban sources on water quality, particularly the rise in Total nitrogen and Total Phosphorus levels, which have triggered frequent algal blooms and the spread of invasive aquatic plants like water hyacinth.

Karki et al. (2022) and Bhatt et al. (2023) utilized the remote sensing to study the geomorphological changes in river-lake systems and emphasized the role of GIS in watershed management. However, comprehensive examinations have not been made on the spatiotemporal morpho-dynamics of the Harpan Khola and its impacts on the lake ecology and hydrology over a long-term period. Several studies have examined the environmental changes affecting the Phewa Lake watershed. Lamichhane (2000, 2005) provided some of the earliest documentation of

sedimentation, water quality decline, and land use changes in the Harpan catchment. These studies warned of the consequences of continued urban encroachment, deforestation, and lack of policy enforcement.

The degradation of Phewa Lake has widespread impacts on local livelihood, biodiversity, and the tourism sector. Apart from this, there is also a gap in comprehensive, long-term, and spatiotemporal assessments of the Harpan Khola System. Efforts have been made in this study to address such a gap through the assessment of a) the spatiotemporal changes in the Harpan Khola's course between 1979, 2014, and 2023 using GIS and remote sensing techniques; b) the river's impact of sedimentation, water quality, and biodiversity in Phewa Lake; and c) integrated watershed management strategies to support the sustainable conservation of the lake's ecological integrity.

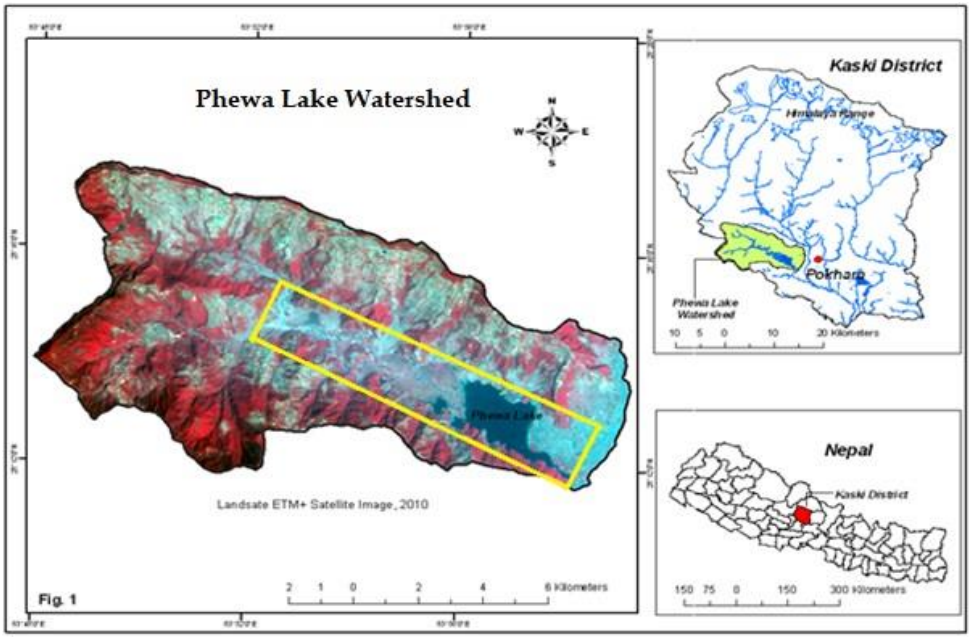
Methods and Materials

The study focuses on the Harpan Khola catchment in the southwestern part of Kaski District, Gandaki Province, Nepal, covering an area of 32.75 km². It spans five wards of Pokhara Metropolitan City (wards 6, 18, 22, 23, and 24) at an average elevation of 800 meters (Subedi & Poudel, 2013). The Khola flows eastward into Phewa Lake, with the study area extending approximately 8.7 km and lying between 28°13' to 28°10' N latitude and 83°51' to 83°57' E longitude (Figure 1).

Data sources included topographic maps (1:25,000 and 1:50,000) from the Department of Survey, high-resolution imagery from Google Earth Pro (2024), digital boundary maps (2016), and thematic maps from the Ministry of Forests and Environment (2019). Peer-reviewed literature also supported the analysis. ArcGIS 10.8 was used for spatial and temporal analysis of the Khola's morphology. Key features such as meanders, point bars, and oxbow lakes were digitized. Khola length, sinuosity, and sediment deposition were measured for 1979, 2014, and 2023. Land use changes in the catchment were assessed using map overlay techniques to evaluate human-induced transformations. This methodology enabled a comprehensive understanding of the Harpan Khola's morpho-dynamics and their impacts on Phewa Lake (Figure 2, 3 and 4).

Figure 1

The Study Area



Result and Discussion

Analysis of the morphology of the Harpan Khola in the years 1979, 2014, and 2023 reveals notable changes in both Khola length and water-covered area (Table 1). The lengths of the Khola were measured as 8.7 km in 1979, 8.326 km in 2014, and 10.358 km in 2023. The measured water and sandy areas were about 7,35,456 m^2 in 1979 and 7,08,111 m^2 in 2023. This increase in Khola length is reflected in the spatial extent of the Khola system, as shown in Figures 2, 3, and 4.

The 2023 data showed extensive sediment accumulation zones, especially in low-gradient areas. These sediments are a mixture of fine silt and sand, primarily eroded from deforested slopes and agricultural fields upstream. Features such as point bars and meander scrolls became more prominent, indicting a shift from stable to unstable channel conditions.

Table 1

Length and Water Area of the Harpan Khola.

Year	*Length of Khola (Km)*	*Area (Sandy & Water)*
1979	*8.7*	*735456*
2014	*8.326*	*540514*
2023	*10.358*	*708111*

Source: ArcGIS 10.8, Analysis according to the Map.

An analysis of land use changes within the Harpan catchment from 1979 to 2023 reveals significant transformations driven primarily by anthropogenic activities (figure 2, 3 and 4). Over this period, the catchment has experienced a notable 25% loss in forest cover due to unplanned urban expansion, road construction, and agricultural intensification along the riverbanks. These changes have replaced natural vegetative buffers that previously played a critical role in stabilizing soil and regulating hydrological flow. The removal of vegetation has directly contributed to increased surface runoff, soil erosion, and sediment transport into the Harpan Khola, ultimately affecting the hydro-ecological integrity of Phewa Lake.

The expansion of settlements and farmlands has fragmented the watershed landscape, reducing its capacity to absorb and filter stormwater, thereby accelerating the processes of channel migration and sediment deposition. The degradation of upstream land cover has led to the expansion of sandy bars, increased Khola sinuosity, and the formation of unstable channel features such as point bars and meander scrolls (Shrestha et al., 2020; Gurung et al., 2018). These morphological changes, in turn, have contributed to the sedimentation of Phewa Lake, which has lost about 24% of its water storage capacity since 1980 (Gurung et al., 2018).

Figure 2

Course of the Harpan Khola, 1979

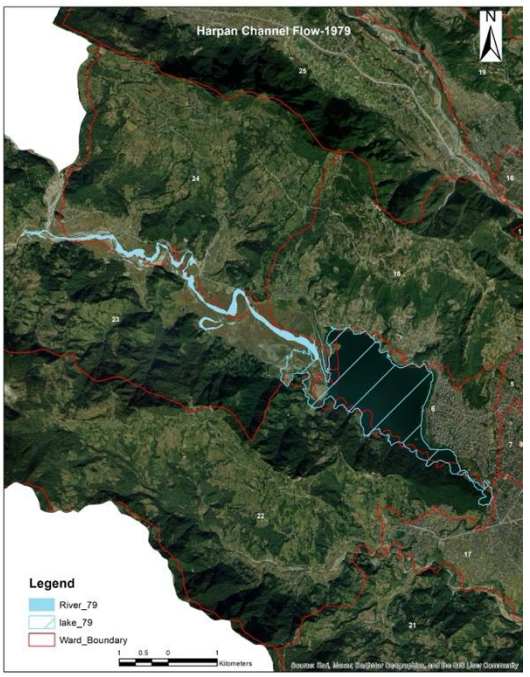
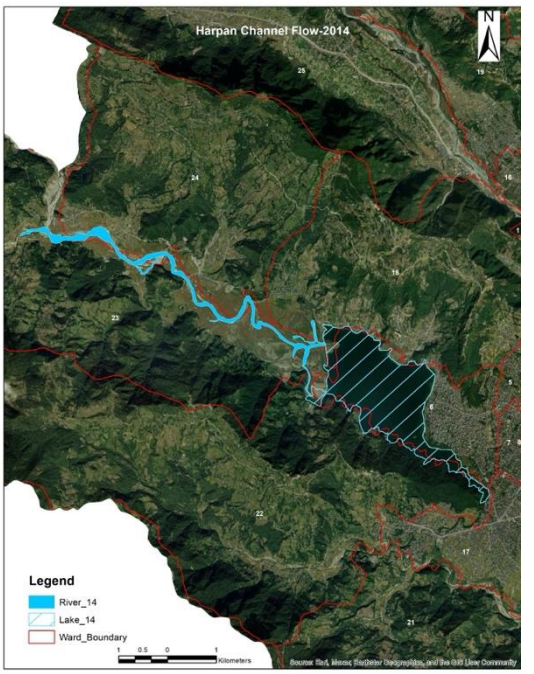


Figure 3

Course of the Harpan Khola, 2014



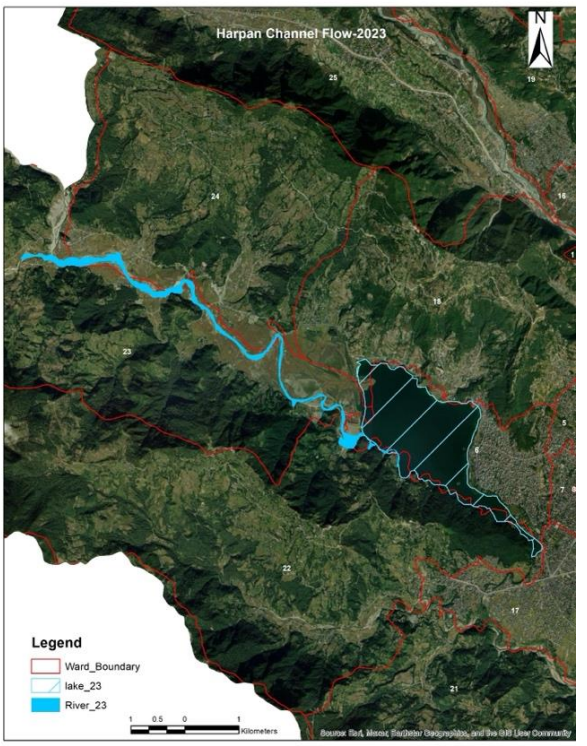
Furthermore, agricultural intensification has resulted in increased nutrient loading into the Khola system, particularly Total Nitrogen (TN) and Total Phosphorus (TP), which are responsible for the eutrophication of Phewa Lake and the spread of invasive species like water hyacinth (Dahal et al., 2021). These combined effects have not only deteriorated the water quality but also disrupted the lake's aquatic biodiversity and ecosystem functioning. Thus, land use changes within the Harpan catchment have directly influenced the morpho-dynamic behavior of the Khola system and played a critical role in shaping the ecological trajectory of Phewa Lake.

Discussion

The findings of this study reveal pronounced morpho-dynamic changes in the Harpan Khola system and their subsequent hydro-ecological impacts on Phewa Lake. Over the past four decades, increased anthropogenic activities such as deforestation, agricultural intensification, and unregulated urban expansion have drastically altered the watershed landscape. These alterations have transformed the Khola's morphology, increased sediment influx, and degraded water quality trends that align with earlier observations made by Lamichhane (2000, 2005), who had warned of sedimentation-driven shrinkage in lake volume and ecological health.

Figure 4

Course of the Harpan Khola, 2023



The spatiotemporal data from 1979, 2014, and 2023 show increasing Khola length and meandering, accompanied by rising sediment deposition, particularly in low-gradient areas. This supports Lamichhane's (2005) estimation that the sediment influx approximately 159,553 metric tons annually could potentially infill Phewa Lake entirely within the next 287 years. The Khola's shift from relatively stable conditions in 1979 to increasingly dynamic and sediment-laden conditions in 2023 reflects the combined impact of catchment degradation and altered hydrological flow patterns (Gurung et al., 2018).

Water quality deterioration is another major concern. Elevated levels of Total Nitrogen (TN) and Total Phosphorus (TP), especially near the Harpan Khola mouth, have led to eutrophication, fostering frequent algal blooms and the spread of invasive aquatic species such as water hyacinth (Dahal et al., 2021). These phenomena have reduced lake oxygenation, disrupted the native fish population by nearly 40%, and altered the lake's trophic status from oligotrophic to mesotrophic or even eutrophic in certain sections. Such biological changes signal a decline in the ecosystem's resilience and biodiversity.

These environmental degradations also carry significant socioeconomic implications. Pokhara's tourism sector, which heavily depends on the aesthetic and recreational appeal of Phewa Lake, faces growing threats. Diminished water clarity, foul odors from algal blooms, and visible sedimentation have discouraged boating and fishing activities, directly affecting the income of local households dependent on these sectors (Adhikari et al., 2020; NTB, 2023). Additionally, the reduction in arable land due to sediment deposition has undermined food security in the surrounding rural communities.

Although efforts such as the *Phewa Lake Watershed Conservation Action Plan* (MoFE, 2019) have proposed reforestation, check dam construction, and community-based monitoring, their impacts remain limited due to weak institutional coordination, inadequate policy enforcement, and insufficient local participation (Thapa et al., 2021). The fragmented implementation of such interventions has failed to address the systemic drivers of watershed degradation.

Therefore, there is a pressing need for adaptive, inclusive, and science-based watershed management**.** This includes establishing vegetative buffer zones along riverbanks, promoting eco-friendly agricultural practices to reduce nutrient runoff, and employing real-time Remote Sensing monitoring systems. In addition, engaging local communities, stakeholders, and institutions in participatory conservation planning will enhance accountability and sustainability. The degradation of the Harpan Khola system and its consequences for Phewa Lake highlight a complex interplay of environmental, economic, and institutional challenges. Addressing these issues requires an integrated watershed governance framework that not only prioritizes ecological restoration but also strengthens the livelihoods and cultural heritage tied to this vital ecosystem.

Conclusion

The spatiotemporal transformations of the Harpan Khola have hydrological and ecological impacts on Phewa Lake. All the effects of unregulated land use and climate variability have led to increased sedimentation, declining water quality, and reduced biodiversity. The findings highlight necessity of land use zoning and regulatory enforcement to mitigate environmental degradation of the Khola and the lake. It should be emphasized for the expansion of vegetative buffer zones, which can be helpful both for the ecotones and ecosystems. The construction and ongoing maintenance of check dams should be made in erosion-prone areas so as to control sedimentation. In addition, eco-friendly agricultural practices should be promoted to minimize the surface runoff and nutrient loading. Regular monitoring using Remote Sensing tools and participatory approaches are significant for the regulation of the Harpan Khola system and the lake. Thus, the adaptive and inclusive watershed management is inevitable in this area. If appropriate measures are not taken, the capacity of Phewa Lake will not be able to sustain biodiversity, tourism, and local livelihoods.

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