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THE COST OF DISCONNECTION: QUANTIFYING URBAN ECOLOGICAL RESISTANCE BETWEEN HATIRJHEEL AND DHAKA'S REGIONAL WATER NETWORK

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Corresponding Author:	Joy Biswas, Bachelor of Urban and Regional Planning Sheltech Pvt. Ltd. BANGLADESH
Corresponding Author E-Mail:	joybuetbiswas@gmail.com
Corresponding Author Secondary Information:	
Corresponding Author's Institution:	Sheltech Pvt. Ltd.
Corresponding Author's Secondary Institution:	
First Author:	Joy Biswas, Bachelor of Urban and Regional Planning
First Author Secondary Information:	
Order of Authors:	Joy Biswas, Bachelor of Urban and Regional Planning
Order of Authors Secondary Information:	

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Joy Biswas Sheltech (Pvt.) Ltd., Dhaka, Bangladesh ORCID ID: <https://orcid.org/0009-0009-4056-4568> email: joybuetbiswas@gmail.com

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Abstract

Rapid and dense urban growth in the Dhaka Metropolitan Region (DMR) has broken up important green and blue spaces, isolating key ecological areas. This study uses **Geographic Information Systems (GIS)—a digital tool for mapping and analyzing locations—and the Least-Cost Path (LCP) modeling technique, which identifies the easiest route for ecological movement based on resistance**, to measure environmental resistance between the **Hatirjheel Special Area (HSA), an essential urban water feature, and the regional river network. A Resistance Surface—a spatial map showing how different land uses hinder movement—**was created using the **RAJUK Detailed Area Plan (DAP 2022-2035)**, assigning resistance costs (ranging from **1 to 150 units**) based on the difficulty of ecological flow passing through each area. The LCP model found a single best ecological corridor and calculated a **Total Accumulated Cost (TAC) of 776,104 Cost Units**, which measures the level of disconnection. This high number supports the idea that land uses like transport and commercial zones have created a significant barrier. The spatial map produced offers clear evidence of ecological disconnection and gives conservation planners specific guidance on where to focus restoration and mitigation efforts.

Keywords

Ecological Connectivity, Least-Cost Path (LCP), Green-Blue Infrastructure, Spatial Analyst, Resistance Surface, Dhaka Metropolitan Area (DMR), Hatirjheel Special Area, Urban Planning, GIS

Introduction

Urban ecosystems in megacities require the movement of matter, energy, and organisms between natural areas to support biodiversity and water system health. Rapid expansion fragments green and blue spaces, increasing isolation.

Dhaka faces ecosystem fragmentation due to high population density and complex water systems. The **Hatirjheel Special Area (HSA)** is critical for water storage and recreation, depending on connection to regional rivers. Urbanization threatens this connectivity despite the RAJUK Detailed Area Plan (DAP 2022-2035). Metrics for measuring **resistance** between HSA and the ecosystem are lacking. This study uses GIS-based **Least-Cost Path modeling to quantify the ecological cost and inform targeted solutions**.

This study quantifies how urban land uses impede Hatirjheel's ecological connection to the regional river network. It hypothesizes that a high Total Accumulated Cost confirms Hatirjheel's functional disconnection, mainly due to urban resistance.

Literature Review

Concepts of Ecological Connectivity: Ecological connectivity refers to how easily species and ecological processes move through a landscape, distinct from mere physical links that do not account for movement difficulties (Taylor et al., 1993). In urban planning, corridors like greenways or streams help reduce the "barrier effect" caused by infrastructure (Tischendorf & Fahrig, 2000; Tischendorf et al., 2000). It is important to assess how well these corridors' function, not just by measuring straight-line distance, but by examining the actual resistance encountered by animals and ecological processes (Adriaensen et al., 2003).

Application of Least-Cost Path Analysis: The LCP model, based on graph theory, is now a key tool for measuring functional connectivity in GIS (Gómez et al., 2018). It converts a land-use map into a Friction Surface, assigning movement costs to each area. The model finds the path with the lowest total cost between two points. This method is beneficial for planning in complex cities where traditional approaches fall short (Egan et al., 2017). Studies show this approach effectively finds functional corridors in urban areas (Balbi et al., 2019; Balbi et al., 2021). While Dhaka's RAJUK Detailed Area Plan (DAP 2022-2035) highlights the value of water bodies and open spaces (Chisty & Aktar, 2022), its push for high-density mixed-use zoning often increases landscape friction (Dhaka Planning Authority, 2021; More chaos feared as revised DAP allows mixed land use, 2020). Previous studies noted significant fragmentation in Dhaka's natural features but did not provide a quantifiable resistance metric for the HSA. Research in other Asian cities underscores the value of specialized resistance maps for urban green networks (Bae et al., 2020; Zhou et al., 2020).

Study Area and Data Sources

The study focuses on the **Dhaka Metropolitan Development Plan (DMDP)** area. Geospatial modeling is based on specifying the source, destination, and resistance matrix, as shown in Table 1.

Table 1: Geospatial Data Layers Used in the Least-Cost Path Analysis

Data Layer	Source	Role in Analysis
Resistance Matrix	RAJUK Detailed Area Plan (DAP 2022-2035)	Used to define land-use resistance costs.
Source	Hatirjheel Special Area (HSA)	The starting point of the ecological path.
Destination	Extracted Water Body features from Land Use	The endpoint (regional river network).

GIS Modeling and Tool Sequence

The analysis used **ArcGIS 10.8 Spatial Analyst Extension** and **Python scripting** to make sure data processing was strong and repeatable, following the standard LCP workflow:

- **Resistance Surface Creation:** Land-use data were labeled with an integer field, *Friction_Cost*, ranging from 1 (Water/Open Space) to 150 (Transport). *Friction_Cost* assigns a numeric value to each land type based on how much it impedes ecological movement (higher values indicate greater resistance). This step used **ArcGIS's Field Calculator (with Python scripting)** to assign each value based on the literature on land impermeability and disturbance (Akbulut et al., 2018; Akbulut et al., 2018). The data were then converted to a 30-meter raster (a grid in which each square represents 30 by 30 meters) to create the **Resistance Surface** (see Figure 1).
- **Source and Destination Raster:** The HSA and the extracted water bodies were converted to raster at an exact 30m resolution.
- **Cost Distance Analysis:** The **Cost Distance** tool generated the Accumulation Raster (a map showing the total movement cost from the source for each location). The Cost Back Link tool generated the directional raster (showing the direction of least resistance back to the source).
- **Least-Cost Path Generation:** The **Cost Path** tool traced the line of minimum cumulative resistance (the least-cost path) from the destination back to the source, yielding the **Optimal Ecological Corridor** (see Figures 2 and 3). The Optimal Ecological Corridor is the route with the lowest ecological resistance connecting two key points.
- **Quantification:** The **Total Accumulated Cost (TAC)**—the sum of all resistance values along the least-cost path—was extracted from the cumulative resistance surface at the path's endpoint. TAC provides a single number that indicates how difficult it is for ecological flow to move between the HSA and the regional water bodies.

Results and Data Presentation

Figure 1: The Resistance Surface of Ecological Cost

This **Resistance Surface map** displays the spatial cost based on the DAP 2022-2035 land-use. Areas are color-coded to show how much they resist ecological flow. The highest-cost zones (150, 75, and 35 friction units) highlight the main urban barriers.

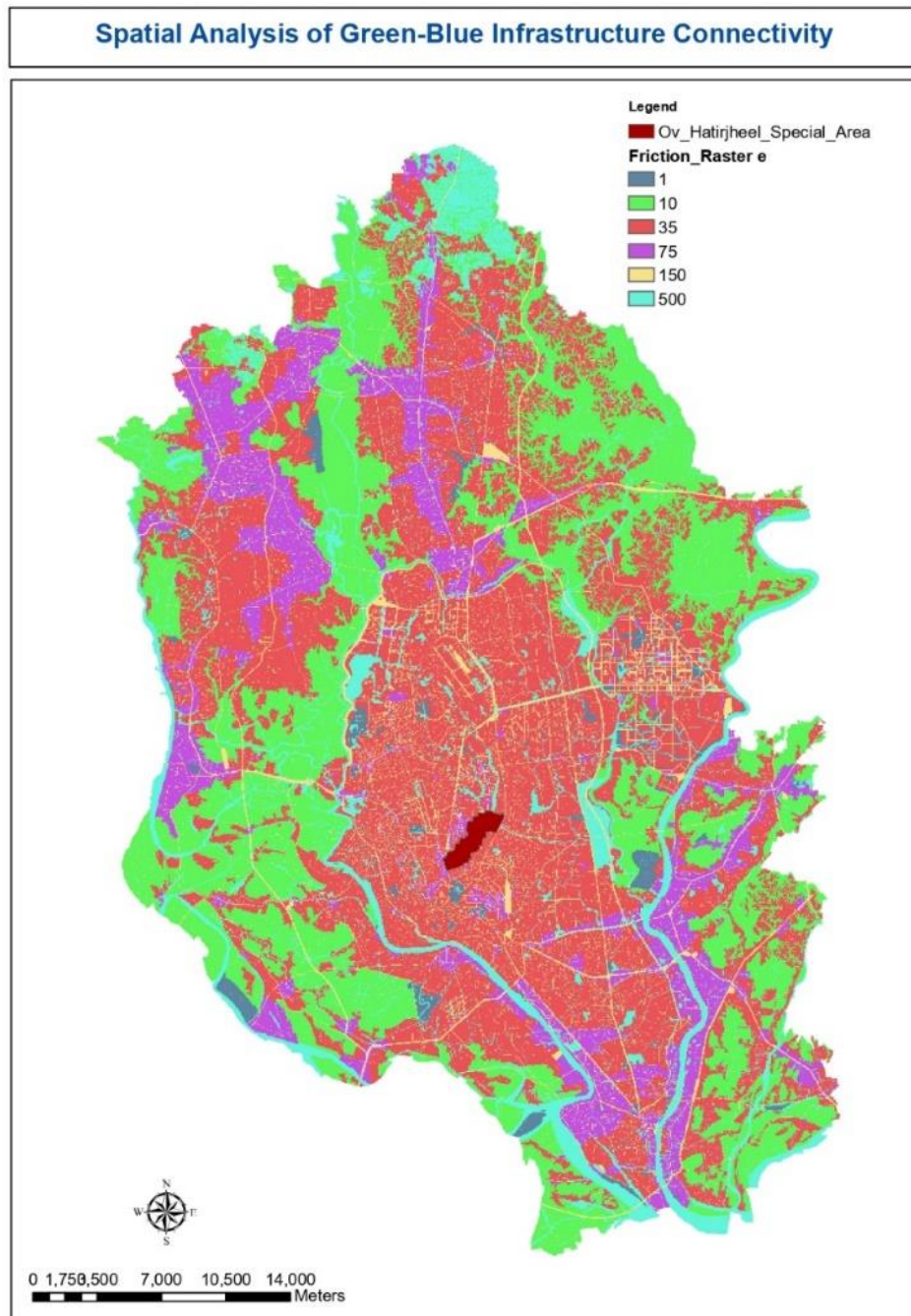


Figure 1: The Resistance Surface (Friction Raster) of the Dhaka Metropolitan Development Plan (DMDP) area.

Table 2: Friction Cost Values Assigned to Land Use Categories in the Resistance Surface

Land Use Type	Friction Cost (Units)	Ecological Interpretation	Barrier Contribution
Transport/Communication	150	Absolute linear obstacle or highly impervious surface.	Absolute Linear Barrier
Commercial/Industrial	75	High density, high human activity, high area-wide imperviousness.	High Area-Wide Barrier
Residential/Institutional	35	Moderate density, paved surfaces, high fragmentation of small patches.	Significant Landscape Cost
Water/Open Space	1 - 10	Optimal habitat, high permeability, minimal resistance to flow.	Lowest Resistance

Table 2 shows the detailed **Ecological Resistance Cost Matrix**, which is central to the **LCP model**. This matrix assigns each land-use category a specific friction cost based on the RAJUK DAP 2022-2035 data layer. The **Ecological Corridor overlays the Resistance Matrix**.

Figure 2: The Optimal Ecological Corridor appears over the Resistance Surface and shows the most efficient route for ecological movement between regional water bodies and the HSA. The path’s winding shape shows it must bypass high-friction urban zones.

Figure 3: Functional Linkage to the Regional Water Network

These visual highlights the **Optimal Ecological Corridor** and its primary connection to the blue-lined regional Waterbody network. The map shows exactly where the path crosses high-resistance urban areas. These spots are good targets for intervention.

Spatial Analysis of Green-Blue Infrastructure Connectivity

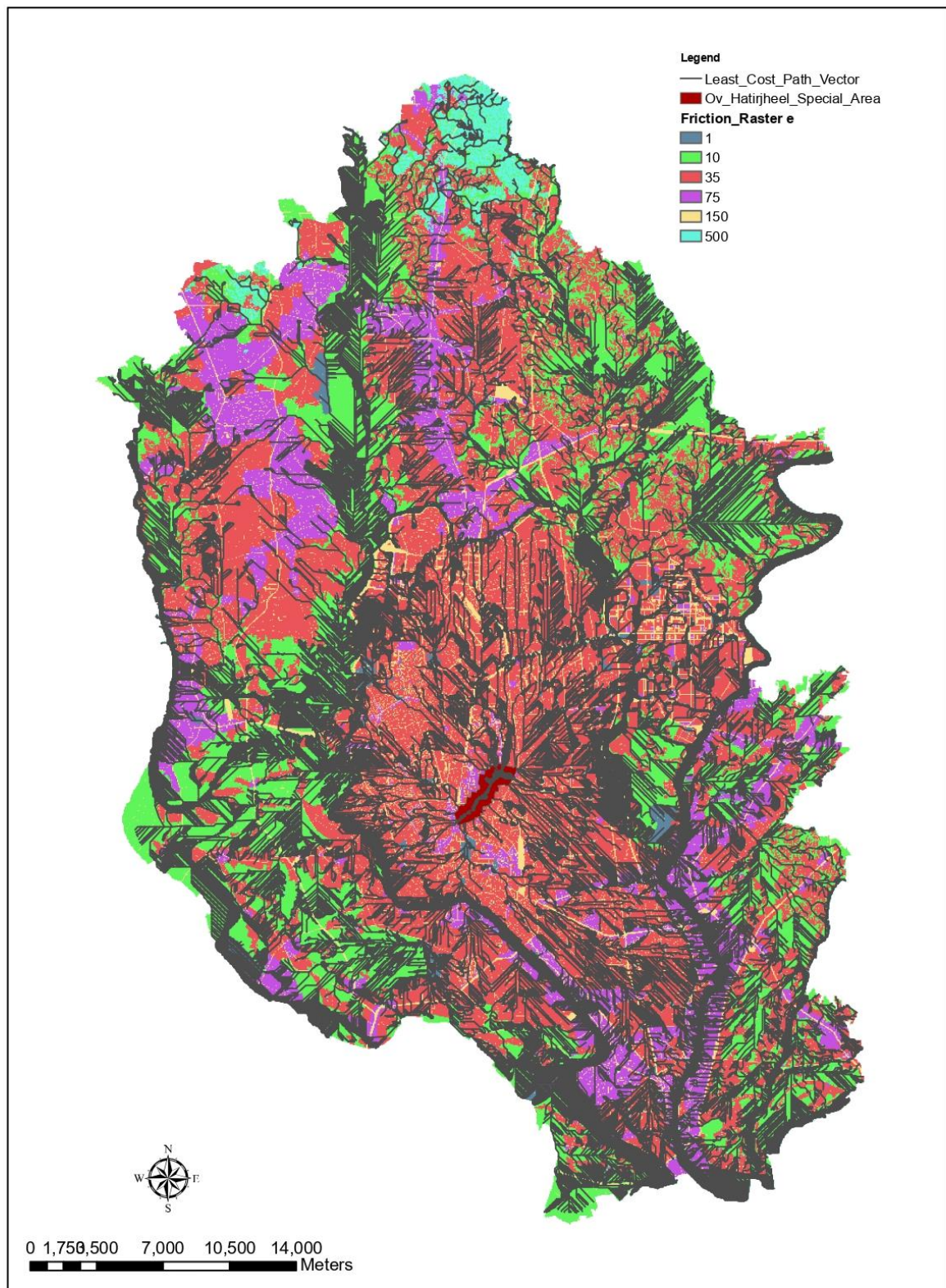


Figure 2. Optimal Ecological Corridor (Least-Cost Path Vector) overlaid on the Resistance Surface

Spatial Analysis of Green-Blue Infrastructure Connectivity

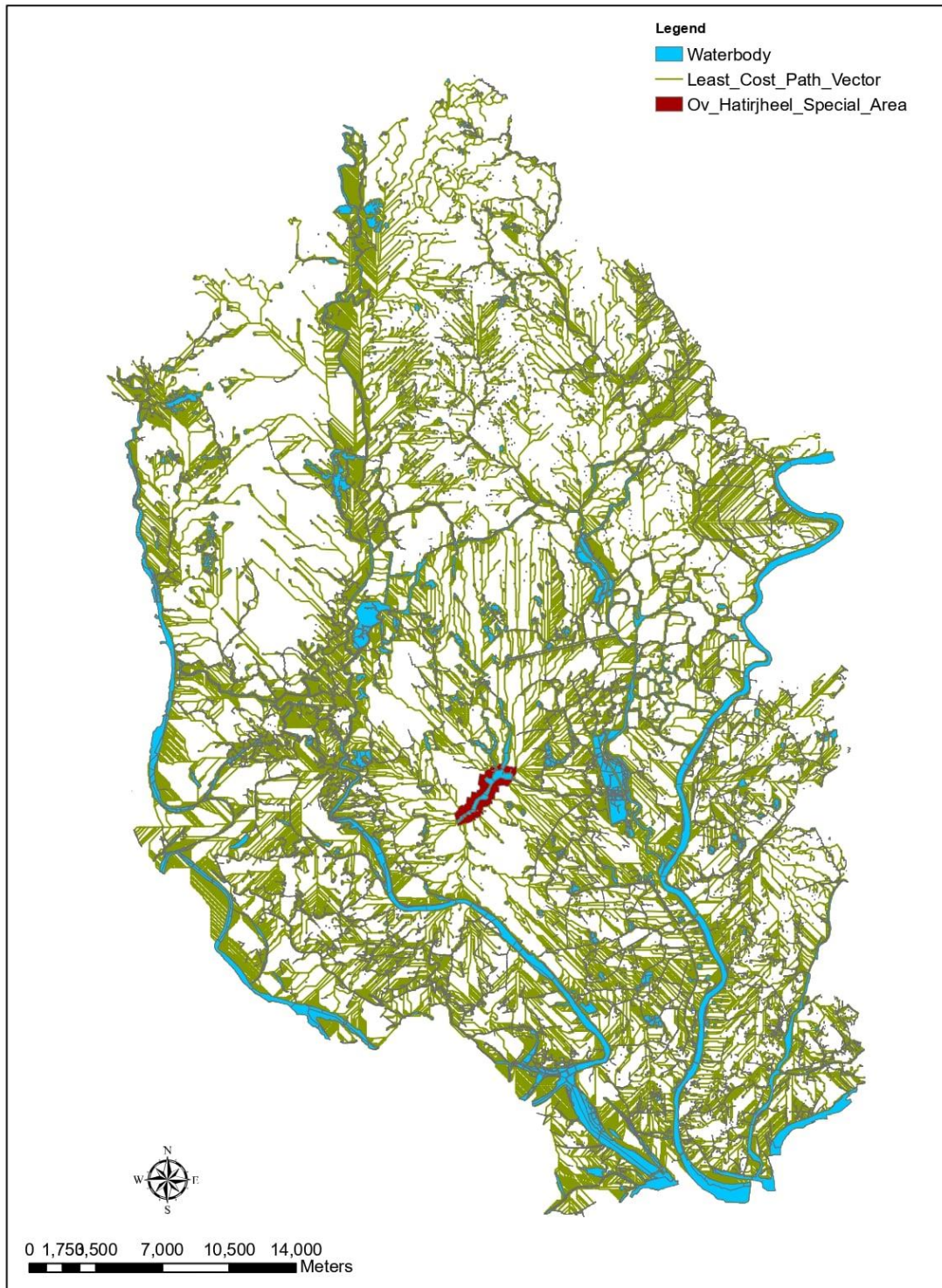


Figure 3. The Functional Linkage map showing the Optimal Ecological Corridor and Regional Water Bodies.

Key Finding: Total Accumulated Cost (TAC)

The quantitative output of the LCP model is the **Total Accumulated Cost (TAC)**:

Total Accumulated Cost (TAC) = 776,104 Cost Units

This high number supports the research hypothesis and indicates severe ecological disconnection caused by the high-resistance land use in the area.

Discussion

The total cost of **776,104 Cost Units** shows that the Hatirjheel Special Area is functionally cut off from the broader ecosystem. This result highlights low **landscape permeability, with** dense development acting as a significant barrier (Forman, 1995). The high TAC value serves as a measurable **Ecological Permeability Index** for this highly urbanized area.

Policy Recommendations for Corridor: The LCP output is a key tool that turns broad conservation goals into a clear, spatial policy plan and roadmap.

- **Prioritized Land Use Intervention:** Resources must focus on securing and restoring the land parcels intersected by the **Optimal Ecological Corridor** (Adriaensen et al., 2003).
- **Infrastructure Retrofitting:** Solutions such as **vegetated wildlife underpasses or eco-ducts** are necessary to reduce the localized resistance cost associated with transport infrastructure (Tischendorf & Fahrig, 2000). (Jacobson et al., 2016) (Tischendorf et al., 2000)
- **Zoning Policy Review and Enforcement:** Immediate review of zoning policies is required to prohibit the conversion of low-cost land uses to high-cost industrial/commercial uses (Dhaka Planning Authority, 2021). This aligns with integrating GIS into policy for sustainable urban management (Jiménez-Espada et al., 2023).
- **Mandatory LCP Assessment:** The TAC value should be adopted as the baseline **Ecological Permeability Index**. All future large-scale infrastructure projects should be mandated to conduct an LCP assessment to ensure they do not increase the existing TAC (Taylor et al., 1993). This proactive approach mirrors modern, GIS-based infrastructure planning in other large regions (DPIIT, 2025). (Taylor & B., 1993)

Conclusion

This study used advanced GIS techniques and Python scripting to measure the ecological isolation of the Hatirjheel Special Area in the Dhaka Metropolitan Area. The Total Accumulated Cost of 776,104 Cost Units supports the research hypothesis and shows the profound impact of current urban development on green and blue spaces. The resulting optimal ecological corridor map is a strong, evidence-based tool that helps planning authorities move from general conservation goals to specific, targeted actions for ecological restoration.

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