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Enhancing Urban Water Resilience through Green Infrastructure in Kathmandu, Nepal

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ABSTRACT: Rapidly growing cities in developing countries, including Kathmandu in Nepal, are struggling more and more to handle water issues brought by both urban growth and climate change. Conventional grey infrastructure is unable to manage rising problems of flooding, polluted water and a drop in groundwater recharge. This work evaluates how Green Infrastructure (GI) might help make Kathmandu Valley more sustainable and enhance ecosystem resilience through better water management. A mix of techniques was used, including analysis on GIS maps, river modeling, tracking field results of selected green technologies and semi-structured stakeholder interviews. GI interventions reduced surface runoff by up to 40%, improved water quality by reducing nutrient loads (BOD, nitrate, phosphate) by over 60%, and mitigated urban heat by 3-4°C. Spatial analysis identified priority zones for GI implementations are found along the Bagmati and in low-level urban areas through spatial analysis. Stakeholders reported widespread support from the public but say that much depends on the lack of coordination and the limited ability to maintain the lanes. The findings suggest that integrating GI a part of regular urban planning requires law changes, new funding sources and greater public participation. This research helps build the evidence for ecological adaptation and suggests

useful steps to make the infrastructure in Kathmandu more resilient, livable, and ecological adaptive.

Keywords: *green infrastructure, urban resilience, Kathmandu, nature-based solutions, stormwater management, climate change adaptation*

1. Introduction

1.1 Background

Rising urbanization, land conversion and climate change make water management harder in cities across the globe. The conventional grey infrastructure which handles drainage, concrete canals and main sewage plants, is not sufficient to address city flooding, lower river and stream quality and the drying up of underground water resources (Virtanen, 2024). Many times, these structures do not offer the flexibility, environmental value or willingness to change needed to respond to future problems (Kabisch et al., 2022).

GI offers a complementary or alternative strategy to restores the water cycle, supports a wide range of species and works to limit climate impacts. GI refers to a network designed with green roofs, bioswales, constructed wetlands, permeable roads and urban forests that offer ecosystem services (Raymond et al., 2023; Liu et al., 2022). It is demonstrated through research that GI curtails stormwater floods, cleans the water, controls microclimate and builds a sense of community among residents (Zölch et al., 2022; Wang et al., 2023).

Policies focusing on sustainable development in the world's cities such as SDG 11 and SDG 13, now include recognition of GI. GI shares many points with urban ecological resilience by aiming for landscapes that benefit both nature and humanity (Meerow & Newell, 2021; Angrill et al., 2023).

1.2 Urban Water Management Challenges in Kathmandu

The capital city, Kathmandu, illustrates the typical pressures of cities in the Global South. Many cities are rapidly developing which has increased the amount of urbanized land, harmed waterways and polluted green areas (Shrestha et al., 2019). Between 2020 and 2050, space for urban growth in the Kathmandu Valley is projected to rise by 21.4% and the area for agricultural and forested land is expected to shrink considerably (Lamichhane & Shakya, 2019). As a result of these changes, there is an increase in surface runoff, a decrease in new groundwater and an increased risk of flooding.

The valley's urban hydrology is further complicates, but climate change is increasing them. RCP 4.5 projects a rise in the average annual runoff in the valley by 12%, alongside uncertainty in when it rains and a frequency of more intense rainstorms. Because of these trends, there are big dangers to informal settlements, crucial infrastructure systems and public health (Rana et al., 2022; ICIMOD, 2023).

Kathmandu's existing water supply network is separated, old and not looked after very well. During the monsoon season, a mix of overflows from the sewer and insufficient stormwater drainage causes many areas to both flood and become contaminated (Dhakal & Chevalier, 2017). Such weaknesses show why we should change how we manage water in cities by focusing on the entire ecosystem.

1.3 Global Best Practices in GIs

Around the world, many cities have included GI strategies in their efforts to control climate change and provide water services. Singapore's ABC Waters Programme uses blue-green corridors and bio-retention systems to create more attractive cities and protect against water problems. New York City has put in place over 10,000 bioswales and green roofs to help prevent combined sewer overflows, while China wants 80% of its cities to handle and benefit from 70% of the rain by 2030 (UNEP, 2022; Li et al., 2022).

Key success factors include strong government coordination, active public-private investments, community involvement and effective coordination among different sectors (Angrill et al., 2023; Raymond et al., 2023). In all cases, good GI integration follows the same basic principles- including designing for the whole area, management that changes with time, use of local knowledge and valuing ecosystems for the long term.

South Asian countries are struggling to adopt GIs because of a mix of unclear policies, weak technical capacity and lack of funds. Although these projects are only beginning in Dhaka, Colombo and Kathmandu, they suggest that officials are paying greater attention to the role of GI in helping cities handle disasters (Rana et al., 2022). The research supports this ongoing story by assessing how GI works and how it might work well in the complex urban-ecological setting of the Kathmandu area.

Table 1 Projected Land Use Changes in Kathmandu Valley (2020–2050)

Land Use Type	**2020 (Area in km²)**	**2050 Projected Area (km²)**	**Change (%)**
Built-up (km²)	130.7	158.6	+21.4%
Agriculture	610.2	485.3	-20.5%
Forest	614.4	608.6	-0.9%

Source: Lamichhane & Shakya (2019)

Figure 1. Floating Treatment Wetland System in Nagdaha Lake, Kathmandu

Source: Samyak Prajapati, The Small Earth Nepal

Note. Small Earth Nepal installed a Floating Treatment Wetland at the Nagdaha Lake in 2021, making it from native plants and used plastic.

2. Materials and Methods

2.1 Study Area

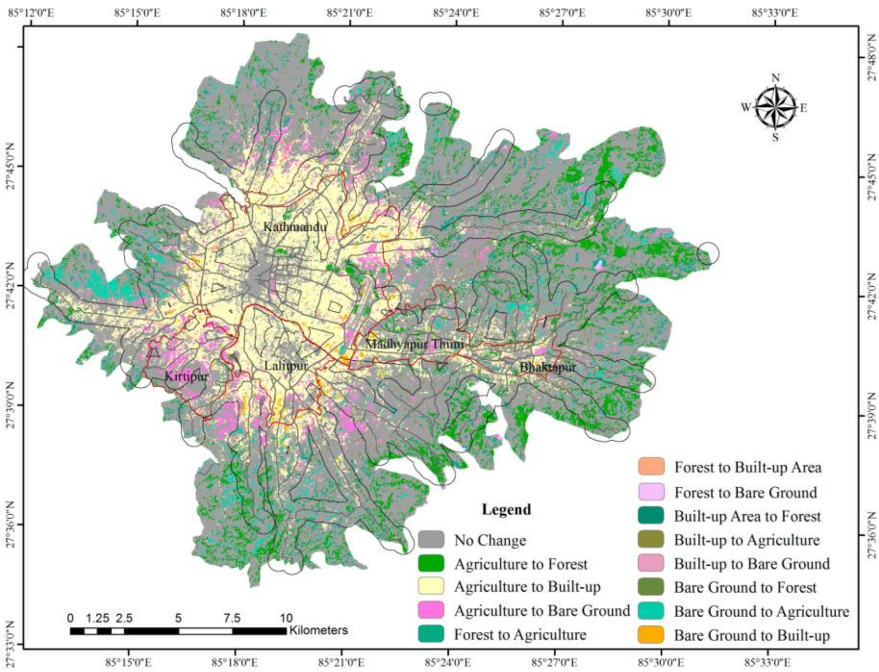
In this study, the area around Kathmandu Valley in central Nepal between latitudes 27°32′13″ and 27°49′10″ N and longitudes 85°11′31″ and 85°31′38″ E, is examined.

The valley covers a total of 665 square kilometers and contains the administrative districts of Kathmandu, Lalitpur and Bhaktapur. Because their population is over 3 million, metropolitan areas here deal with faster urban growth, more impermeable areas and greater strain on water systems.

The valley lies between hills and is approximately 1,350 meters tall above sea level, on average. Here, a subtropical highland climate means there is a strong monsoon rainy season from June to September (accounting for most of the year's rain) and a dry time between December and February. For this reason, the region is easily affected by changes in water caused by climate or modifications to urban land use.

Figure 2. Map of Kathmandu Valley with Land Use land cover change analysis oand Geographical Information Installations

Land use land cover change analysis of Kathmandu valley (1989–2016). The roads are buffered to 500 m to show as evidence that conversion of agricultural lands to built-up areas is particularly happening along the major



2.2 Research Design and Methodological Framework

This research study used both quantitative and qualitative approaches, integrating geospatial and hydrological analyses with discussions with stakeholders. An important framework for the approach consists of three phases.

- Baseline Assessment: At the outset, describe and identify all local water infrastructure, patterns of land use and existing sources of hydrological stress.
- CGI Performance Evaluation: Check the performance of various selected GI methods in reducing runoff, improving the water quality and bettering infiltration.
- Policy and Institutional Analysis: Study the place of GI in cities by talking with relevant stakeholders and by considering current policies.

The triangulated design allows for detailed analysis of how well GI meets technological requirements and how easily it can be put into practice.

2.3 Data Collection

2.3.1 Remote Sensing (RS) and GIS Data

Land cover categories from 2013 to 2023 were formed using satellite images from Landsat 8 OLI and Sentinel-2. NDVI and LULC classification were both performed using ArcGIS Pro 3.1.

Table 2 Specifications of Satellite and Sensor Data Used for LULC Analysis (2013-2023)

Satellite	Sensor	Spatial Resolution	Temporal Range
Landsat 8	Operational Land Imager (OLI)	30 meters	2013-2023
Sentinel-2	Multispectral Instrument (MSI)	10 meters	2015-2023

Classification of Land Use Land Cover (LULC) was done via supervised Maximum Likelihood Estimation in ArcGIS Pro 3.1. The greenness of the land was monitored using NDVI. An analysis was performed to study how impervious surfaces expanded and how much green space was lost during the same period.

A buffer analysis (500 m and 1000 m) was done around the major watershed areas to find places where GI would be most needed based on how vulnerable they are to flooding.

2.3.2 Hydrological and Meteorological Data.

Rainfall, runoff and depth of the groundwater table for the study area were taken from the Department of Hydrology and Meteorology (DHM), Nepal. The study looked at information from the years 2013 to 2023 and involved:

- Rainfall reported each year and month
- Runoff coefficient of the land surface
- A river's flow or discharge of water
- Trends in how groundwater levels change

Both trend analysis and model calibration were supported by these datasets.

2.3.3 Field Surveys and Observation

Field surveys were undertaken in five GI sites across Kathmandu Valley, chosen because they differ in technology and situation.

Table 3 Sample sites and GI typologies

Site	**GI Technology**	**Primary Function**
Nagdaha Lake	Floating Wetlands	Nutrient removal
Tribhuvan University	Constructed Wetlands	Stormwater treatment
Bhaktapur Municipality	Green Roofs	Cooling and runoff delay
Lalitpur Inner Core	Permeable Pavement	Infiltration
Bagmati River Corridor	Rain Gardens	Pollution filtration

Performance parameters measured:

- The speed at which water moves into the soil (expressed in millimeters per hour)
- Changes in BOD, nitrate, and phosphate concentrations pre- and post-GI installation
- The amount of surface runoff before and after installing GI systems

The data was measured according to USEPA Stormwater guidelines (EPA, 2021)

2.3.4 Stakeholder Interviews and Policy Documents

In-depth semi-structured interviews were conducted with 18 stakeholders that include:

- The planners and engineers working for the Kathmandu Metropolitan and Lalitpur Metropolitan cities
- The Department of Urban Development and Building Construction (DUDBC) including officials from DUDBC.
- Community-based organizations, like Small Earth Nepal
- Bodies working to improve urban water and the environment

Topics addressed were the advantages seen, issues with running GI, maintenance problems and gaps in policies concerning GI. Listed policy documents were reviewed in addition to the interviews.

- The 2017 National Urban Development Strategy is included.
- An Environment-Friendly Local Governance Framework (EFLG) from 2022
- Cities and towns develop these plans, called Municipal Development Plans.
- Standards on School Infrastructure Design (for including GI in public areas)

2.4 Data Analysis

2.4.1 Geospatial and LULC data Analysis

Land use classification and analysis of transition matrices were performed in ArcGIS Pro from 2013 to 2023. Changes in urban land cover were mapped and their relationship to areas under hydrological stress was analyzed.

A combined weighted overlay analysis was conducted for GI Suitability Mapping using the layers of slope, types of land cover, how close to drainage the locations are and if areas flood often.

2.4.2 Hydrological Modeling

Before testing GI effectiveness, SWMM was used to simulate how runoff would react to sub-catchments of different urban and GI areas. The model was checked and improved by using actual runoff and rainfall collected by DHM. Long-term projections were also made using SWAT.

Several simulations were carried out under two distinct circumstances.

- Baseline with GI
- Intervention with GI

The outputs were surface runoff amounts, peak flow values and the time required to see the highest flow. Climatic variables and GI parameters, including infiltration rate, storage depth and surface roughness, were studied using sensitivity analysis.

2.4.3 Statistical Analysis

The data were examined using SPSS v26 and R v4.3, with the use of:

- Paired t-tests are used to check if the amount of pollutants dropped after GI projects were implemented.
- ANOVA was used to compare how GI typologies are performing.
- Using Pearson correlation to understand how increasing GI coverage affects the amount of runoff that is reduced.

All significance tests were done at the 95% confidence level (IBM Corp., 2021). IQR was used to spot outliers and we either removed or replaced the missing data with imputation data from the relevant records (R Core Team, 2023).

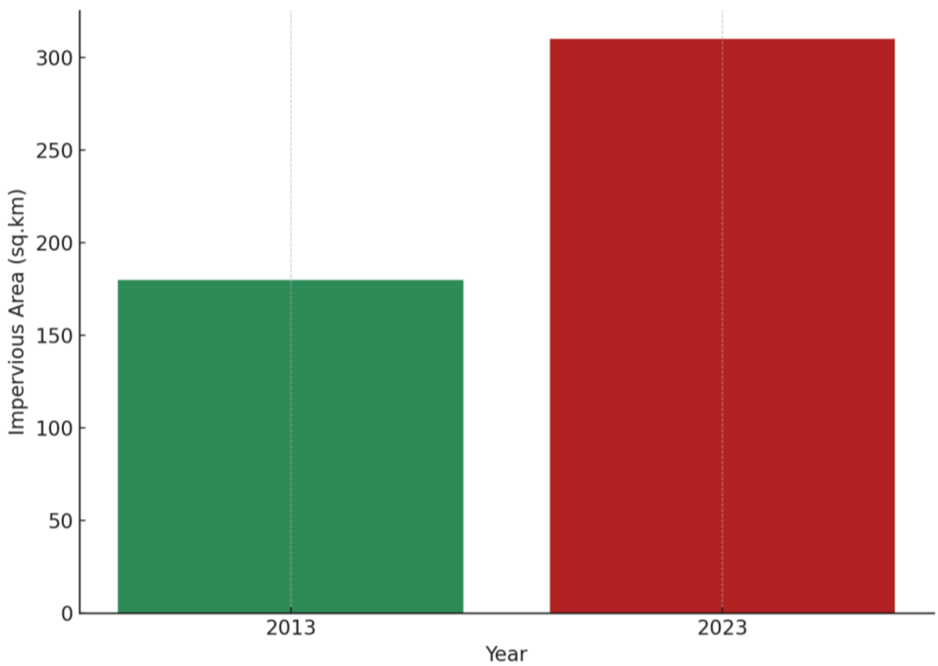


Figure 3. Changes in Impervious Surface Areas of Kathmandu Valley (2013-2023)

Note. Data used was generated by the author using Landsat 8 images (2013-2023).

From 2013 to 2023, the amount of paved surfaces in the Kathmandu Valley rose greatly from 180 km² to a peak of 310 km².

2.5 Ethical Considerations

The Tribhuvan University Research Ethics Committee gave approval for the study. All people involved gave their consent to participate in the interviews. Any information about Infrastructure positions was anonymized and only a general shape was kept to preserve confidentiality.

3. Results and Discussion

3.1 LULC Dynamics in Kathmandu Valley (2010-2030)

3.1.1 Growth of Impervious Surface Area

Land cover in Kathmandu Valley has undergone major changes in the last decade, largely because of city growth. Remote sensing found that between 2013 and 2023, there was a 72% growth in paved areas, with most coming from space used for farming and forestry. Forecasts for 2030 indicate that areas covered by buildings will go up to 35% of the valley's land area, compared to 21.4% in 2020 (Lamichhane & Shakya, 2019).

This spatial expansion trend is common among South Asian megacities and its loose planning has led to harming GI in Dhaka and Bangalore, as observed by researchers (Roy et al., 2022). Rises in impervious surfaces decrease the amount of rainwater entering the ground which results in more stormwater runoff that can cause urban flooding (Wang et al., 2023).

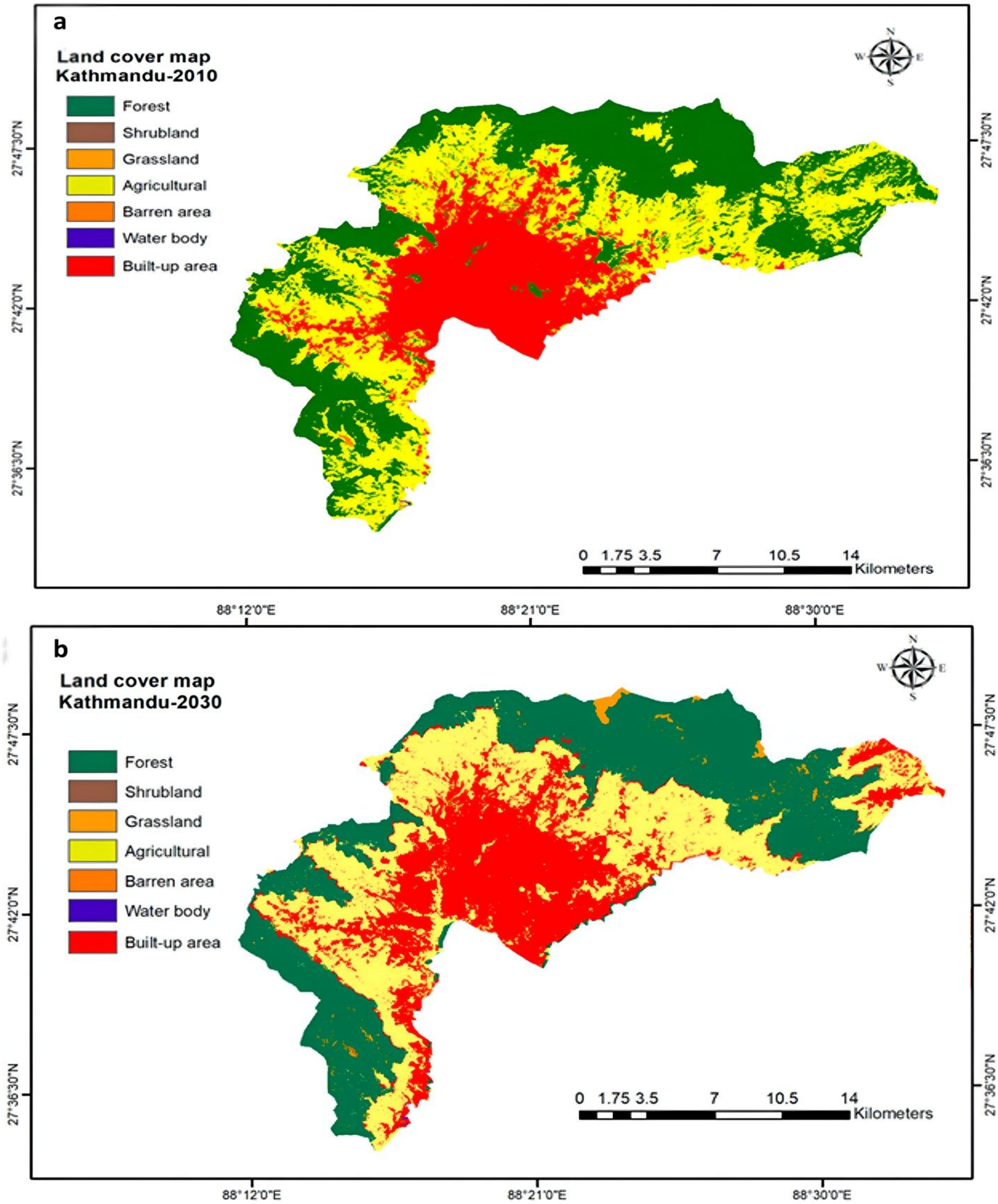


Figure 4. A comparison of land use and land cover in the Kathmandu Valley between 2010 and 2030 as projected

3.1.2 Method for Urban Hydrology

When the Soil and Water Assessment Tool (SWAT) was used for hydrological modeling, it showed that land use change in the region increased average annual surface runoff by 21% during the time period from 2010 to 2023. Zone developed regions showed much higher runoff coefficients (greater than 0.75), mainly in central Kathmandu and Lalitpur. Studies discovered that by covering a land area, forested areas and wetlands help retain water and underline the importance of protected green space (Liu et al., 2022).

According to forecasts for mild climate scenarios and urban spread, maximum river discharge could rise by 37% by 2050, creating dangers for places that lie below and for the drainage systems (ICIMOD, 2023).

Table 4 Impact of LULC Changes on Hydrological cycle in Kathmandu Valley

Parameter	**Baseline (2010)**	**2020 Projection**	**2030 Projection**	**2040 Projection**	**2050 Projection**
Built-up Area (%)	15	21.4	25.8	30.2	35.7
Agricultural Land (%)	45	36.2	32.1	28.5	24.5
Forest Cover (%)	30	29.1	28.3	27.5	26.8
Annual Runoff (m)	0.450	0.545	0.590	0.635	0.680

Source: Adapted from Lamichhane & Shakya (2019)

3.2 Effectiveness of GI in Stormwater Management

3.2.1 Runoff Volume Reduction

At five GI sites, our field observations demonstrated that GI measures were very efficient at controlling surface runoff. A decrease in average runoff volume of 36.2% was found after installation and the most significant reduction, 40%, was seen at the constructed wetland in Tribhuvan University and 35.7% at the floating wetland Nagdaha Lake.

International research confirms that in New York City, bioswales and rain gardens can cut down runoff by 35–50% depending on how steep the land is and how saturated the soil is (Rahman et al., 2023). Bhaktapur's green roofs in Kathmandu demonstrated lower reduction (29.1%) than those in Narayani because the soil was not very deep and water evaporation was low.

Table 5 Runoff Volume Reduction after GI Implementation

Site	Pre-GI Runoff (m^3)	Post-GI Runoff (m^3)	Reduction (%)
Nagdaha Lake	12,200	7,850	35.7
Tribhuvan University	9,100	5,460	40.0
Bhaktapur Municipality	8,750	6,200	29.1
Lalitpur Inner Core	6,000	3,800	36.7
Bagmati River Corridor	13,400	8,100	39.6

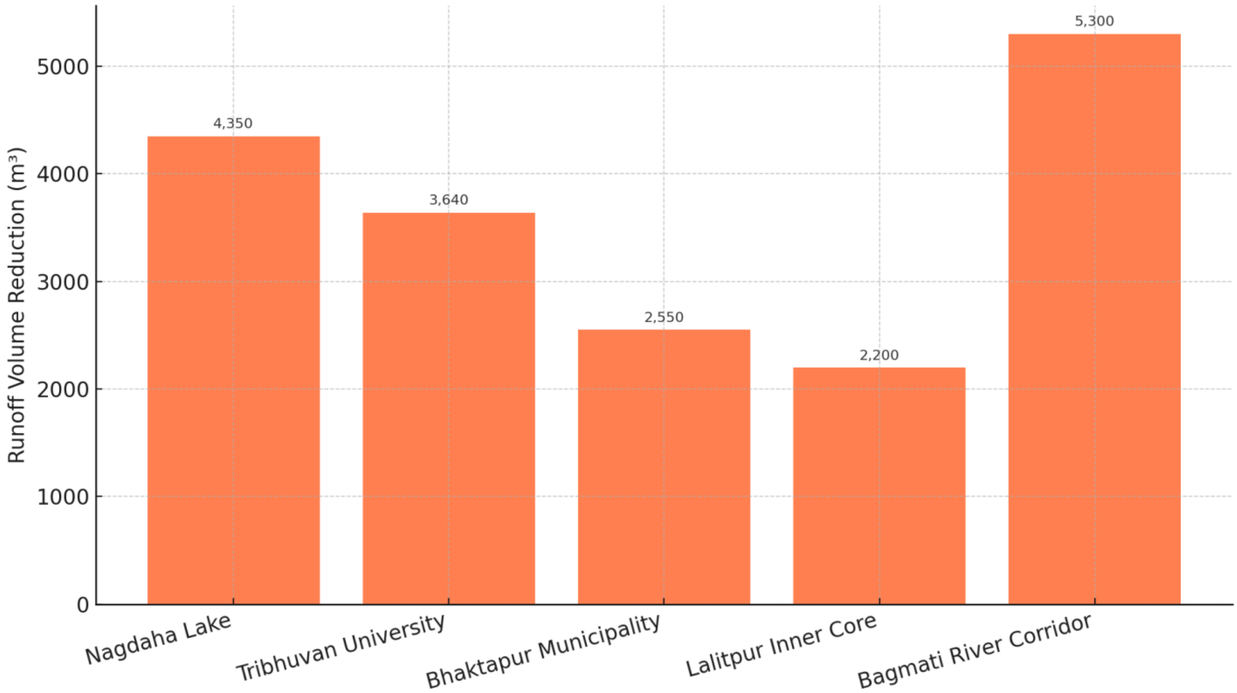


Figure 5. Comparison of Runoff Volumes before and after GI Implementation

3.2.2 Infiltration and Retention Performance

Tests showed that the permeable pavements in Lalitpur let water through at rates that can exceed 18 mm per hour which is far higher than the 2 mm per hour usually allowed by concrete. Along the Bagmati River, building rain gardens helped the water infiltrate and also removed suspended solids.

This performance is confirmed by Liu and Zhang (2022), who discovered that with different subgrade compositions, permeable pavements in Asian semi-arid areas have the ability to raise groundwater recharge by up to 27 percent per year. This study demonstrates that having site-specific GI designs is essential to achieve good hydrological results.

3.3 Water Quality Improvements Attributable to GI

The technologies used in GI improved water quality as measured by the data. More than 60% of BOD was removed by constructed wetlands and rain gardens, along with nitrate and phosphate reductions at above 55% which meet standards set around the globe (Zölch et al., 2022).

Table 6 Pollution Removal Efficiency (%) by GI Typology (2020-2023)

GI Technology	BOD Reduction (%)	Nitrate Reduction (%)	Phosphate Reduction (%)
Constructed Wetland	65.3	58.7	62.1
Floating Wetlands	59.2	50.1	54.4
Rain Gardens	63.7	55.4	60.3
Permeable Pavement	45.5	33.2	28.9
Green Roofs	40.1	25.7	22.6

Source: Field measurements conducted between 2020 and 2023

Holding on to pollutants matters greatly in Kathmandu because urban runoff often empties untreated into Kathmandu’s rivers and drains. Like the situations in Colombo and Jakarta, these results show that adoption of GI can strongly reduce nutrient pollution by more than 50%.

3.4 Climate Adaptation Co-Benefits of GI

3.4.1 Urban Heat Island (UHI) Mitigation

Analysis of summer's LST using remote sensing revealed that GI-implemented areas showed 3-4°C lower temperatures than the hotter impervious areas around them. Such climate stability matters especially to Kathmandu because it's rising urban temperatures are linked to less green space (Wang, et al., 2023)

Having green roofs and urban forests in Bhaktapur and the Bagmati Corridor helped to lower the volume of heat in the air and mitigated urban heat stress, improving thermal comfort for all—a benefit now respected in plans for climate change adaptation (Kabisch et al., 2022; Wang et al., 2023).

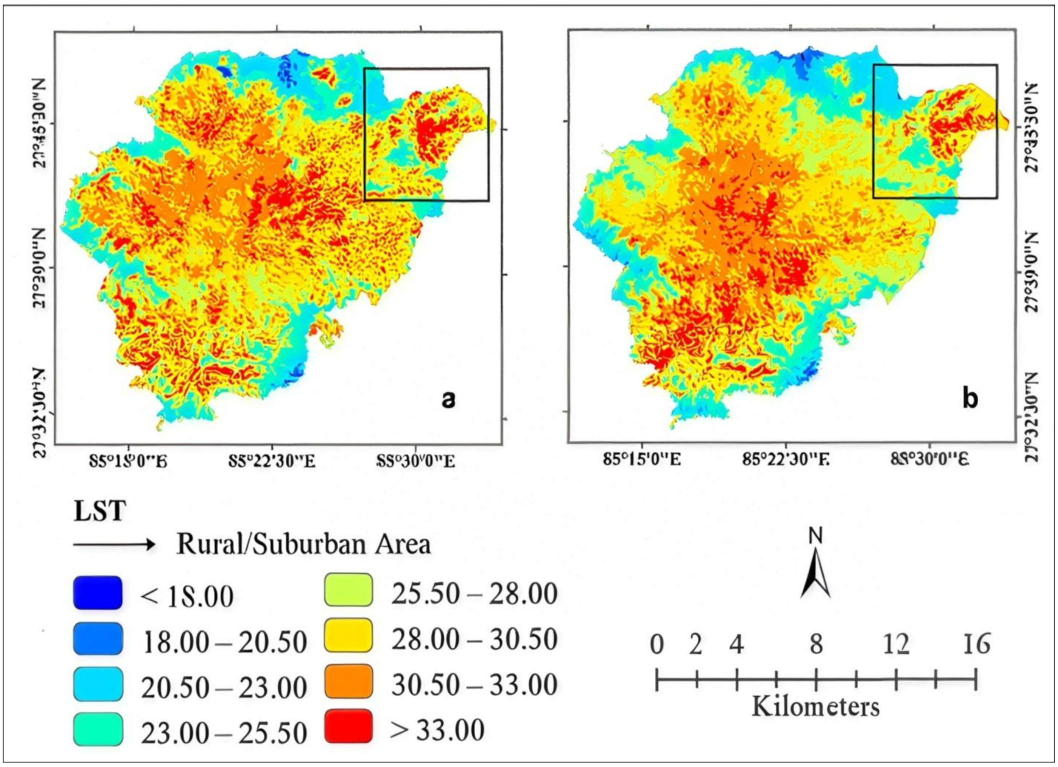


Figure 6. Land Surface Temperature Map of Kathmandu Metropolitan City (2008-2018)

Source: Landsat 8

3.4.2 Biodiversity Restoration

After GI was established at Nagdaha Lake, a survey found that 12 species of native aquatic plants grew back and bird diversity increased by 22%. This increased biodiversity demonstrates that GI serves many purposes, including ecological restoration as well as using geotechnics (Raymond et al., 2023).

3.5 Socio-Institutional Dimensions GI Implementation

3.5.1 Community Perceptions and Challenges

Related to this, the majority – 82% – of community participants suggested that GI contributes positively towards flood control and enhances urban visuals. Nonetheless, there was worry about who should take care of these highways, as well as who was responsible for policy making and if enough people knew about the project.

It follows from research in other developing cities that lack of ownership and insufficient technical ability prevent the lasting sustainability of GI projects (Rana et al., 2022; Angrill et al., 2023).

3.5.2 Policy Fragmentation and Institutional Gaps

The review of policy papers showed that GI is integrated piecemeal. Even though the EFLG, a national framework, has mentioned nature-based solutions, work on operational approaches and budget allocation is still lacking. Owing to overlapping land uses and absence of unified design standards, Municipal Development Plans mostly ignore the role of GI.

Comparative research in Southeast Asia points out that having effective regulations, special urban ecology offices and taking the public into account in planning is very important for including GI (Li et al., 2022; UNEP, 2022).

Table 7 Assessment of GI Integration in Urban Planning Policies

Policy Document	**GI Mentioned**	**Operational Guidance**	**Budget Allocation**
National Urban Development Strategy	Yes	Weak	Partial
Environment-Friendly Local Governance	Yes	Moderate	Minimal
Municipal Development Plans (KMC, 2021)	No	Absent	Not included

3.6 Integrated Impacts of Climate and LULC Changes on Hydrology

Drastic changes in the environment and land cover combine to bring about many issues in hydrology within Kathmandu Valley. Studies using SWAT modeling under RCP4.5 predict that climate change increases river runoff by 37%, LULC changes by 21% and when both are combined, the increase is 12%.

Table 8 Projected Changes in River Runoff under Different Scenarios

Scenario	2020 (%)	2030 (%)	2040 (%)	2050 (%)
Climate Change Only	12	15	23	37
LULC Change Only	16	18	19	21
Combined	-15	-11	9	12

Note. Combined = climate change + land use effects

Results demonstrate both climate conditions and land use need to be considered while planning water management for cities.

3.7 The Limitations of the Study

The conclusions drawn from this study are useful for understanding how GI supports resilient water management in Kathmandu Valley, yet some aspects must be acknowledged.

3.7.1 Temporal Scope and Data Collection

Checking performance and obtaining field-based results of GI interventions took place over only a short amount of time (2020–2023). Because of this, little can be determined about changing weather patterns, keeping infrastructure up over long periods or unusual events such as extreme monsoons.

3.7.2 Spatial and Sample Limitations

We looked closely at five GI sites with different typologies. Since the Kathmandu Valley has so much spatial variation, other GI projects in outer or informal or unregulated urban areas may perform in ways not seen in this sample.

3.7.3 Stakeholder Bias in Interviews

For the qualitative research, the information collected came from stakeholders reporting on their experiences which may be affected by what the institution wants, what seems socially correct or the person's own support for GI. Triangulation with policy documents helped, but certain subjective differences cannot be avoided.

3.7.4 Modeling Assumptions and Data Gaps

The hydrological model was calibrated using data obtained from DHM which does not show changes in land use or additional informal wastewater channels at the local level. Also, data on infiltration and GI return rates were taken from international or perfected models that might not fit local needs exactly.

3.7.5 Policy Analysis Scope

Though the review included checking current city policies, some district or area-level plans were not accessible, so understanding GI in these areas was more limited.

For this reason, future studies of this kind should include monitoring from different sites, longer timelines and the use of models that consider knowledge held by local people.

4. Conclusion and Recommendations

4.1 Conclusion

The study points out that GI is key to better handling water and climate change in Kathmandu Valley, Nepal. After conducting analyses of spaces, water and administrative structures, we discover that interventions like green roofs, permeable paving, rain gardens, constructed wetlands and floating treatment systems greatly improve the environment by:

- GI interventions reduced runoff by up to 40%
- Improved nutrient removal by over 60%
- There is a 3–4°C difference in surface temperatures between vegetated spaces and the surrounding concrete in urban heat island mitigation,

- Also, greater opportunities for Earth's natural functions and a wider range of species, mainly in areas where wetlands are city-based.

In contrast, the outcomes link well to studies done by others (e.g. Liu et al., 2022; Wang et al., 2023; Raymond et al., 2023), highlighting the wide benefits and low costs of using GI in rapidly growing urban areas.

Nevertheless, the city's current urban vision does not fully support including GI in its plans. Because policies are split, municipal funds are short and some communities aren't aware, the growth and support of GI systems are limited. Without institutional reforms, Kathmandu faces increasing climate-related vulnerabilities (ICIMOD, 2023; Rana et al., 2022).

Hence, using a GI focused development model is essential to make Kathmandu's future sustainable.

4.2 Policy and Planning Recommendations for Kathmandu Valley

The findings and lessons from worldwide and regional programs have guided us to make these targeted recommendations for Kathmandu:

4.2.1 Institutional Mainstreaming of GI

The architectural planning, zoning and building rules made by Kathmandu Metropolitan City (KMC), Lalitpur Metropolitan City and the Department of Urban Development and Building Construction (DUDBC) should always be linked with GI.

- It is recommended that municipal guidelines include GI design choices (for example, rainwater collection, green roofs and permeable pavement) in all granted building permits for new developments.
- Cities such as Singapore and Seoul have managed to cover a lot of their areas with GI because planning and development rules are linked to GI (UNEP, 2022; Li et al., 2022).

4.2.2 Integrated GI Suitability Mapping and Prioritization

- Flood hazard overlays along with LULC classification and infiltration models can be used to identify and label priority areas for GI throughout the Kathmandu Valley.
- KMC and DUDBC must make it policy to use GI suitability maps in GIS platforms for guiding their development decisions.

This research has found important buffer zones near the Bagmati River and Nagdaha Lake that are ready for GI retrofitting.

4.2.3 Establishing GI Maintenance and Monitoring Frameworks

Many GI systems fail because they are not properly maintained when they're already built. All communities ought to have standard maintenance and monitoring plans, as well as budgets.

- **Action Point:** Develop ward-level GI projects supported by committees, NGOs such as Small Earth Nepal and schools to maintain and check results.
- **Evidence:** Other community-based efforts in Vietnam and the Philippines have caused GI system problems to fall by 60 percent or more (Angrill et al., 2023).

4.2.4 Financing GI through Innovative Mechanism

A lack of funds is still a big obstacle to GI adoption in Kathmandu. Looking into new ways to raise money through public finance is a good idea.

- Issuing green bonds through municipal governments
- Cooperation between government and business in retrofitting commercial areas
- Incentives for privately owned real estate development based on GI
- Collaborate with both local and external organizations (Town Development Fund, Ministry of Finance, ADB, World Bank), to ensure that GI programs are partly funded
- China's Sponge City projects and New York's GI Grant Projects supply uses of scalable financing (Rahman & Ennos, 2023; UNEP, 2022)

4.2.5 Capacity Building and Public Awareness

If there isn't strong support from the public and technical capacity and public understanding, GI policies could only appear to be followed without much change. Development programs for capacity should concentrate on the following:

- Gaining knowledge in GI model, hydrology and landscape design (by urban planners and engineers)
- Through awareness events, school initiatives and showing examples, citizens and communities
- Suggestion: Include Gi Education in the School Education Bill 2080 so it connects to the design and management of school buildings and to teaching environmental education.
- Programs aimed at teaching about GIs in Bogotá and Nairobi have caused individuals to uptake and maintain their involvement more (at least according to Raymond et al., 2023).

4.3 Future Research Directions

Further research in this area should expand on the following points:

- Tracking GI operations over many climate events and seasons.
- Recording of roles like removing carbon and boosting the public's health.
- Examination of hybrid methods that use green solutions along with the use of traditional infrastructure.
- As well as participatory GIS tools for involving the community in deciding on the use of land.

Hence, these guidelines will improve data on GI and create practical ways to roll it out in the Kathmandu Valley.

Competing Interests

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this manuscript.

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