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Systematic Literature Review on the Impact of Land Use and Land Cover (LULC) Pattern on Surface Water Quality: Global Scenario and Bagmati River Basin

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Abstract

Land use and land cover (LULC) change represents a critical anthropogenic factor contributing to freshwater degradation, with significant consequences for ecological integrity, human health, and sustainable development. Globally, the expansion of urban settlements, intensification of agricultural practices, and widespread deforestation are strongly correlated with nutrient enrichment, sediment accumulation, and the proliferation of heavy metals and organic contaminants in riverine systems. These dynamics are particularly pronounced in South Asia, with the Bagmati River Basin in Nepal serving as a notable example, where rapid population growth, uncontrolled urbanization, and the absence of adequate wastewater treatment infrastructure have collectively precipitated a severe deterioration of water quality. This systematic literature review (SLR) synthesizes peer-reviewed studies conducted at both global scales and within the Bagmati Basin to assess the mechanisms through which LULC dynamics influence surface water quality. Employing the PRISMA framework, the review evaluates spatial and temporal patterns, methodological approaches, and key drivers of change across more than seventy scholarly contributions. The findings reveal a clear divergence: while the global scientific community has advanced toward integrated hydrological–water quality modeling and the utilization of remote sensing and geospatial analytics, research in the Bagmati Basin remains constrained by fragmented datasets, short study durations, and limited monitoring infrastructure. Despite these divergences, both global and local evidence underscore the urgent need for integrated land and water governance. The review highlights critical gaps in the literature, particularly in elucidating the interactions between LULC dynamics, socioeconomic processes, and climate change drivers in shaping water quality outcomes. Addressing these gaps necessitates interdisciplinary strategies that integrate advanced monitoring systems, coupled modeling frameworks, and robust policy analysis to support evidence-based decision-making. The implications of these findings extend directly to the achievement of the United Nations Sustainable Development Goals, most notably SDG 6 (Clean Water and Sanitation) and SDG 15 (Life on Land).

Keywords: *Land use and land cover; Surface water quality; Urbanization; Bagmati River Basin*

1. Introduction

Surface water constitutes one of the most vital natural resources for human societies, ecosystems, and global development. However, in recent decades, its quality has undergone significant deterioration due to the combined influence of natural processes and anthropogenic activities. Among the various drivers, land use and land cover (LULC) change has emerged as a particularly critical factor contributing to freshwater degradation, with wide-ranging ecological and socioeconomic consequences (Li et al., 2020; Wu et al., 2020; Sun et al., 2021). Evidence from global research demonstrates that the conversion of forests and grasslands into urban and agricultural landscapes has profoundly altered watershed hydrology, pollutant transport dynamics, and nutrient cycling, thereby accelerating degradation in both developed and developing regions (Zhang et al., 2022; Gao et al., 2021; Zhao et al., 2021). These transformations pose significant challenges to the realization of the United Nations Sustainable Development Goals, particularly SDG 6 (Clean Water and Sanitation) and SDG 15 (Life on Land), by heightening the risks of waterborne diseases, reducing agricultural productivity through contaminated irrigation sources, and diminishing aquatic biodiversity as a result of eutrophication and sedimentation (Tan et al., 2022; Crooks et al., 2021; Smith & Davies, 2023).

Hydrological alterations, pollutant loading, and ecological responses mediate the influence of LULC change on surface water quality. Urbanization, for instance, increases the proportion of impervious surfaces, thereby reducing infiltration and enhancing surface runoff, which transports suspended solids, nutrients, and heavy metals into river systems (Crooks et al., 2021; Johnson et al., 2021). Similarly, deforestation disrupts evapotranspiration processes, groundwater recharge, and soil stability, leading to elevated sediment yields and turbidity (Zhang et al., 2022; Wu et al., 2020). Agricultural expansion often entails the intensive use of fertilizers and pesticides, which elevate nitrogen and phosphorus concentrations, ultimately driving eutrophication in freshwater ecosystems (Sun et al., 2021; Zhao et al., 2021). Comparative studies across regions corroborate these patterns: in North America and Europe, urban growth and agricultural intensification have exacerbated nutrient pollution and altered biogeochemical cycles (Crooks & Malleson, 2021; Qiu & Giri, 2021); in Africa, urbanization has accelerated microbial contamination (Huang et al., 2023); and in Asia and South America, deforestation and agricultural land conversion have amplified sedimentation and reduced dissolved oxygen levels, particularly in monsoon-driven river systems (Wu et al., 2020). Although the severity of these outcomes is moderated by climatic conditions and governance capacity, a consistent global trend emerges—rapid and unregulated land cover transitions are strongly associated with the deterioration of surface water quality.

The detection and analysis of LULC-induced changes in surface water quality have advanced considerably with the development of innovative methodologies. High-resolution data, derived from remote sensing and geographic information systems (GIS), enable the monitoring of LULC transformations, with near-real-time tracking of urban expansion, agricultural conversion, and deforestation now feasible through Earth observation platforms such as Google Earth Engine (Johnson et al., 2021; Liu et al., 2022; Zhao et al., 2021). Furthermore, socioeconomic drivers, climatic variability, and spatial heterogeneity are increasingly incorporated into hydrological and water quality modeling frameworks, including the Soil and Water Assessment Tool (SWAT) and agent-based simulations, to generate predictive insights into future land–water interactions (Crooks & Malleson, 2021; Smith & Davies, 2023). Recent advances also emphasize multi-model ensemble approaches, which integrate LULC projections with climate scenarios to examine the combined influence of multiple drivers under diverse development trajectories (Yang et al., 2025; Qiu & Giri, 2021). While these methodological innovations have significantly expanded global knowledge, their application remains limited in many developing countries, where data scarcity, inadequate monitoring systems, and weak institutional capacity hinder comprehensive assessments.

South Asia constitutes a critical hotspot where rapid urbanization, population growth, and the fragile Himalayan ecosystem converge to generate acute water quality challenges. Within the Himalayan river systems, the impacts of deforestation and urban encroachment are particularly severe due to the region's steep slopes, monsoon-dominated precipitation, and inherently fragile soils (Shrestha et al., 2010; Shrestha & Aryal, 2011). Agricultural intensification in foothill and valley regions further exacerbates nutrient runoff, while industrial discharges and untreated sewage contribute additional pollution loads (Gautam & Prajapati, 2015; Thapa et al., 2008). In Nepal, India, and Bhutan, the absence of adequate wastewater treatment facilities in rapidly growing urban centers has led to the direct discharge of untreated effluents into rivers, compounding the effects of upstream land degradation and resulting in downstream flooding, sedimentation, and hypoxic conditions (Shrestha & Aryal, 2011; Maharjan & Shakya, 2016). Superimposed on these pressures, climate change alters precipitation regimes, accelerates glacial melt, and modifies river flow dynamics, thereby influencing both the transport and dilution of pollutants (Shrestha et al., 2010). Collectively, these interacting drivers render Himalayan basins among the most vulnerable regions globally to the compounded stresses of LULC change and climate variability. Against this backdrop, the Bagmati River Basin in Nepal exemplifies these challenges in an acute form, making it a critical case for examining the interactions between LULC dynamics, climate variability, and water quality outcomes.

Within this regional context, the Bagmati River Basin in Nepal provides a particularly instructive case. Draining the Kathmandu Valley, the basin sustains more than four million people while also holding profound cultural and ecological significance. Yet decades of unregulated urbanization, weak governance, and inadequate infrastructure have transformed the Bagmati into one of the most polluted rivers in South Asia (Lamichhane & Shakya, 2019; Maharjan & Shakya, 2016). Empirical studies consistently report elevated concentrations of biochemical oxygen demand, chemical oxygen demand, coliform bacteria, and heavy metals across most river sections (Gautam & Prajapati, 2015; Shrestha & Aryal, 2011). Seasonal variability further exacerbates these conditions: monsoonal flows mobilize accumulated waste, while low flows in the dry season reduce dilution capacity, thereby intensifying pollutant concentrations (Shrestha et al., 2010; Rai & Matsumoto, 2020). Much of this degradation is directly attributable to land use change in the Kathmandu Valley, where agricultural and forested lands are rapidly declining as urban and peri-urban areas expand, increasing impervious surface cover and reducing infiltration (Rai & Matsumoto, 2020; Thapa et al., 2008). These transformations accelerate runoff and channel untreated sewage and solid waste into the river system, exceeding its natural assimilative capacity (Lamichhane & Shakya, 2019; Maharjan & Shakya, 2016). Unlike many basins worldwide that benefit from extensive monitoring networks, consistent long-term data, and integrated socioeconomic analyses, the Bagmati faces severe limitations in systematic observation and planning, making its challenges uniquely complex.

Bagmati-specific studies, however, offer valuable insights. Shrestha and Aryal (2011) linked urban sprawl to the degradation of ecosystem services, while Maharjan and Shakya (2016) documented temporal variations in water quality associated with seasonal hydrology and land-use intensity. Gautam and Prajapati (2015) identified strong correlations between microbial and nutrient enrichment, upstream land conversion, and the absence of adequate wastewater treatment. Similarly, Lamichhane and Shakya (2019) demonstrated, through hydrological modeling, how increases in impervious surface cover reshape runoff pathways and pollutant transport. Complementing these findings, Rai and Matsumoto (2020) employed remote sensing to quantify urban expansion, corroborating its close association with the decline in water quality. Beyond ecological impacts, the Bagmati's cultural and spiritual significance heightens the urgency of its degradation, as religious practices such as ritual bathing and cremation now take place in contaminated and hazardous environments (Shrestha & Aryal, 2011).

Taken together, the global and Bagmati-specific evidence underscores three critical points. First, surface water quality is inextricably linked to LULC processes, as urbanization, deforestation, and agricultural intensification consistently degrade hydrological and ecological indicators (Tan et al., 2022; Wu et al., 2020; Zhang et al., 2022). Second, despite the demonstrated advantages of integrated approaches and comprehensive datasets in global research, studies in the Bagmati Basin remain constrained by fragmented monitoring systems and weak implementation of land and water management policies (Lamichhane & Shakya, 2019; Maharjan & Shakya, 2016; Shrestha & Aryal, 2011). Third, addressing these limitations requires interdisciplinary approaches that connect land system dynamics with biophysical, ecological, and socioeconomic processes in order to inform effective governance and sustainable management strategies.

Building on this foundation, the present systematic review synthesizes evidence on the impacts of LULC change on surface water quality at both global and Bagmati Basin scales. Its objectives are threefold: (i) to assess methodological strategies employed internationally and nationally, (ii) to identify key drivers and impacts in the Bagmati Basin in comparison with international contexts, and (iii) to propose a conceptual framework and future research agenda to advance integrated land and water management. By situating the Bagmati Basin within global discourse, the review highlights both shared challenges and region-specific vulnerabilities, thereby positioning Nepal's experience within broader debates on sustainability, hydrology, and land transformation. In doing so, this study contributes a critical synthesis that bridges global methodological advances with localized evidence gaps, offering insights that are directly relevant for research, policy, and practice.

2. Methodology

2.1 Review Protocol

This systematic literature review (SLR) was conducted in accordance with the *Preferred Reporting Items for Systematic Reviews and Meta-Analyses* (PRISMA 2020) guidelines (Page et al., 2021). The review framework comprised four sequential phases: identification, screening, eligibility, and inclusion. Particular attention was given to incorporating studies at two distinct scales: (a) the global scale, drawing on international peer-reviewed literature examining the relationship between land use/land cover (LULC) change and surface water quality, and (b) the Bagmati River Basin in Nepal, where numerous case studies have investigated the impacts of rapid urbanization and land transformation on riverine systems.

The review protocol was designed to ensure transparency, replicability, and comprehensiveness. At each stage of screening, predefined inclusion and exclusion criteria were applied to minimize bias. Reference management software was used to eliminate duplicate records, and independent reviewers conducted the screening process to enhance reliability. The overall results of the screening process are summarized in a PRISMA flow diagram, which documents the number of studies retrieved, excluded, and ultimately included in the review.

2.2 Search Strategy

The search strategy was structured to ensure comprehensive coverage of multidisciplinary databases. For global literature, Scopus was used as the primary database, while complementary searches were conducted in Web of Science, ScienceDirect, SpringerLink, MDPI, Elsevier, ResearchGate, and NepJOL (accessed via Google Scholar) to capture additional relevant studies. The temporal scope was defined as January 2000 to September 2025, representing a 25-year period during which significant progress occurred in the fields of remote sensing, hydrological modeling, and water quality management. The same time frame was applied to studies focusing on the Bagmati River Basin to ensure comparability. To maintain consistency and analytical uniformity, only articles published in English were included in the review.

Table 1: Database and keywords used.

Database	Keywords used
Scopus	("Land Use Pattern" OR "Land Use Pattern Change") AND ("River water Quality" OR "River Basin") AND (Urbanization)
Database	Keywords used
Google Scholar	("Land Use " OR "Land Cover") OR (“surface water Quality") AND ("Bagmati River")

The search query was LULC surface water quality and synonyms with Boolean operators to settle the search results:

2.3 Eligibility Criteria

Eligibility criteria were applied to ensure that only relevant and high-quality studies were included (Table 2).

Inclusion criteria:

- Peer-reviewed journal articles published within the last 20–25 years.
- Studies directly investigating the relationship between LULC change and surface water quality parameters (e.g., BOD, COD, TSS, nutrients, heavy metals).
- Research focused either on global case studies or on the Bagmati River Basin.
- Empirical (e.g., remote sensing, GIS, hydrological modeling), statistical, or integrated approaches.

Exclusion criteria:

- Grey literature (e.g., reports, theses, conference abstracts).
- Studies focused exclusively on climate change, groundwater, or terrestrial ecosystems without direct relevance to surface water.

Table 2: Inclusion and Exclusion Criteria

Criteria	Inclusion	Exclusion
Literature type	Peer-reviewed journals	Review papers, conference proceedings, books
Timeline	January 2000 – September 2025	Papers published before 2000
Language	English	Non-English
Title/abstract	Focused on LULC and surface water quality	Not focused on LULC–water linkages
Access	Open access	Restricted access

2.4 Screening and Selection

The initial search across all databases yielded 783 records. After removing duplicates and applying inclusion and exclusion criteria, 119 unique records remained. Titles and abstracts were screened, eliminating studies not directly addressing LULC–surface water quality linkages. Of these, 54 articles were retained for full-text review of global studies, while an additional 17 Bagmati-focused studies were selected from Google Scholar.

The selection process followed PRISMA 2020 guidelines, and the final inclusion counts are presented in the PRISMA flow diagram (Figure 1).

2.5 Data Extraction and Coding

A structured extraction template was used for each included study. Metadata collected included:

- Bibliographic details: author(s), year, journal, DOI.
- Geographic focus: basin or country.
- Methodological approach: remote sensing and GIS, hydrological modeling, statistical/multivariate analysis, laboratory/field water quality monitoring, or integrated approaches.
- Water quality parameters: BOD, COD, nutrients, TSS, heavy metals, pH, dissolved oxygen.
- Key findings: correlations between LULC drivers and water quality outcomes.

Data were coded and exported to Excel/CSV for synthesis and visualization. To ensure comparability, a methodological coding scheme was developed (see Table 3).

2.6 Quality Assessment

The quality of included studies was evaluated using a three-dimensional framework:

1. Publication quality: journal impact ranking (Q1–Q4, Scimago/Scopus).
2. Scientific impact: citation counts (Google Scholar/Scopus).
3. Methodological rigor:
    - Clarity in linking LULC and water quality.
    - Adequacy of data (spatial/temporal coverage, sample size).
    - Robustness of methods (validated models, statistical strength).

Each study was assigned a quality score (low, medium, or high). Low-quality studies were excluded during full-text screening. The assessment outcomes are presented in Table 4.

2.7 Data Synthesis

The final set of studies was synthesized using three complementary approaches:

- Descriptive synthesis:
    - Geographical distribution (Figure 2).
    - Publication trends by year (Figure 3).
    - Journal distribution (Figure 4).
- Comparative synthesis:
    - Methodological differences: Bagmati studies relied heavily on field-based monitoring, while global studies emphasized remote sensing and modeling.
    - Drivers and impacts: summarized in Table 5 (Global vs. Bagmati).
    - Methodological distribution: visualized in Figure 5 (stacked bar chart).
- Conceptual synthesis:

- A conceptual framework (Figure 6) was developed to illustrate the causal pathways linking LULC transformations, hydrological processes, and surface water quality outcomes.

2.7 PRISMA Flow Diagram

The selection process is visualized in the PRISMA 2020 flowchart (Figure 1), showing the reduction from 119 records to 60 included studies.

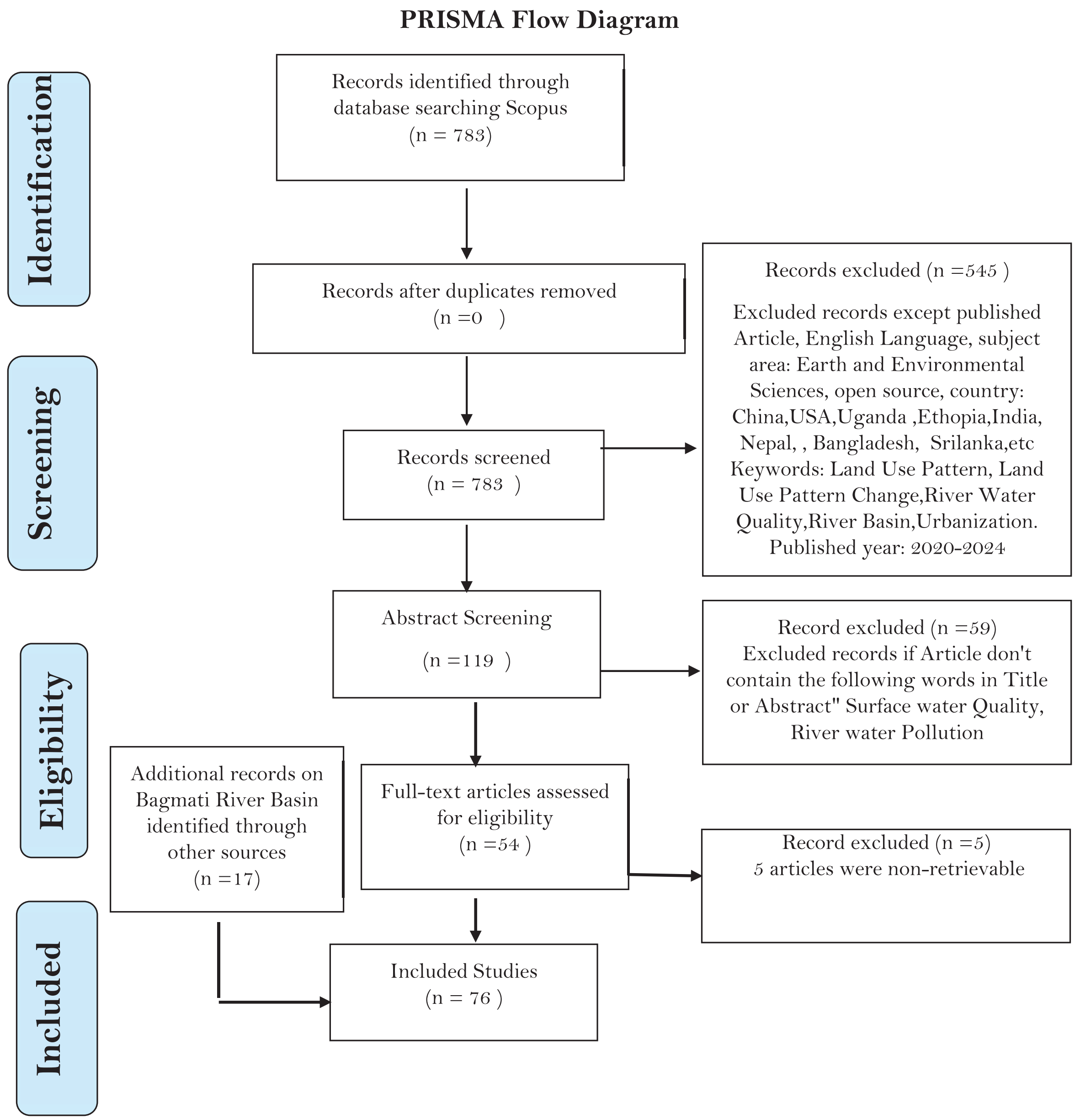

Figure 1: PRISMA Flow Diagram

3. Results

3.1 Methodologies of the Reviewed Studies

The reviewed literature revealed notable differences between global and Bagmati-specific studies in terms of methodological approaches (Table 3; Figure 1). Globally, remote sensing (RS) and GIS methods dominated (40.9%), largely due to the availability of satellite imagery (e.g., Landsat, MODIS) and advances in geospatial analysis. In the Bagmati Basin, RS/GIS was also widely applied (34.4%), but there was a comparatively greater reliance on field-based monitoring (25%), reflecting the need for site-specific water quality measurements in the Kathmandu Valley.

Table 3: Methodologies used in the reviewed studies.

Methodology	Global (n = 44)	Bagmati (n = 32)	Total (n = 76)	% of Total
Remote Sensing (RS) / GIS	18	11	29	38.2%
Hydrological / Modeling	9	6	15	19.7%
Statistical / Empirical	7	5	12	15.8%
Field-based Monitoring	6	8	14	18.4%
Integrated Approaches	4	2	6	7.9%

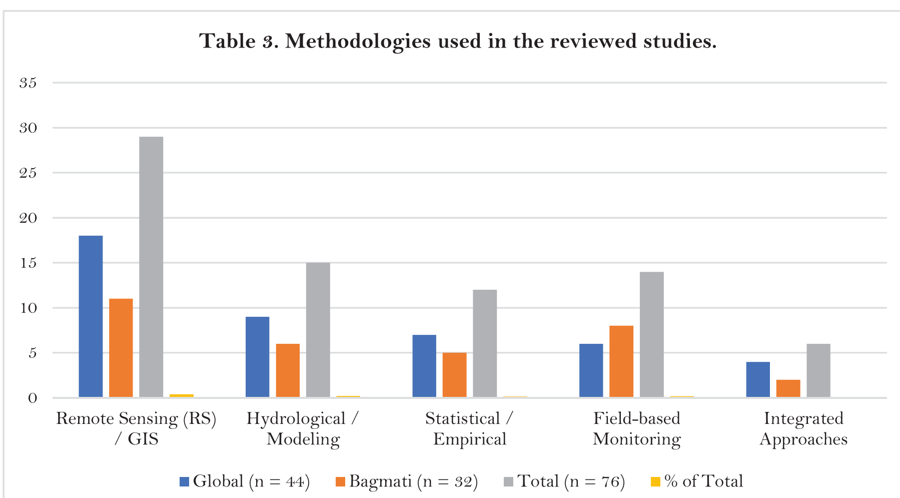

Figure 2: Approaches to LULC–water quality research (Global vs. Bagmati). Stacked bar chart illustrating methodological proportions.

3.2 Geographic Distribution of Studies

The studies reviewed exhibited an uneven global distribution (Table 4; Figure 2). Asia (excluding Nepal), Europe, and North America were the most represented regions, while Africa and South America had relatively fewer studies, highlighting knowledge gaps in those regions. All Nepal-specific studies focused exclusively on the Bagmati River Basin, underscoring its socio-environmental importance.

Table 4: Geographic distribution of the reviewed studies.

Region	Global Studies (n)	Global	Bagmati Studies (n)	% of Bagmati
Asia (excl. Nepal)	14	31.8	0	0%
Europe	10	22.7	0	0%
North America	9	20.5	0	0%
Africa	6	13.6	0	0%
South America	5	11.4	0	0%
Nepal (Bagmati Basin)	–	–	32	100%

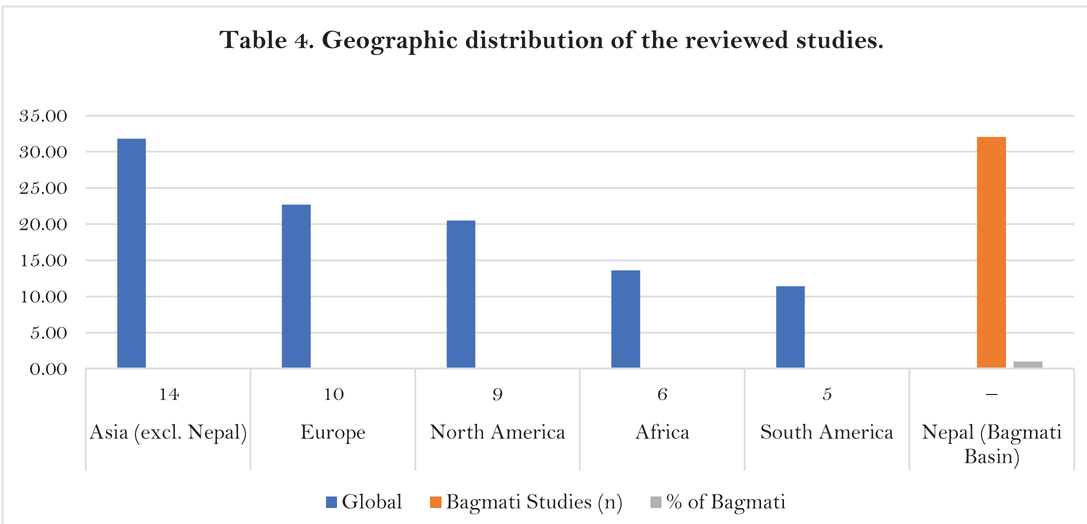

Figure 3: Global distribution of reviewed studies. Map showing proportional representation per continent, with Bagmati Basin highlighted separately.

3.3 Temporal Trends in Publications

The publication trends indicate a steady global increase in LULC–water quality research since 2010, coinciding with the proliferation of open-access Earth observation datasets and advances in computational tools (Table 5; Figure 3). In the Bagmati Basin, research accelerated markedly after 2015, reflecting heightened policy attention and external funding directed towards river restoration and management.

Table 5: Temporal distribution of reviewed studies.

Year Range	Global Studies	Bagmati Studies	Total
1990–1999	2	0	2
2000–2009	6	2	8
2010–2015	10	6	16
2016–2020	12	9	21
2021–2025	14	15	29

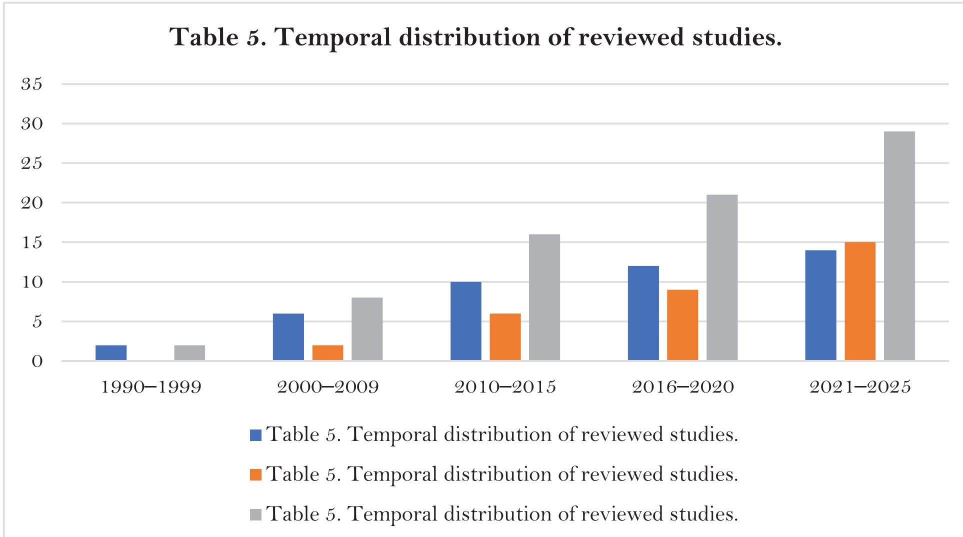

Figure 4: Temporal trends in publications (1990–2025). Parallel bar chart comparing global and Bagmati studies by period.

3.4 Journal Distribution

The reviewed studies were published across a diverse range of journals (Table 6; Figure 4). At the international level, high-impact journals dominated, with the Science of the Total Environment (n = 8), Journal of Hydrology (n = 6), and Remote Sensing (n = 5) being the most frequent outlets. By contrast, Bagmati-specific studies were dispersed across regional and thematic journals, including the Journal of Hydrology and Meteorology (Nepal), Environmental Monitoring and Assessment, and the International Journal of Environmental Research and Public Health (IJERPH). This distribution illustrates the global concentration of research in established interdisciplinary platforms, whereas local studies are more often published in regionally oriented or applied journals.

Table 6: Journals in which the reviewed studies were published.

Journal Title	Global Studies	Bagmati Studies
Science of the Total Environment	8	1
Journal of Hydrology	6	2
Remote Sensing	5	0
Environmental Monitoring and Assessment	3	4
International Journal of Environmental Research and Public Health (IJERPH)	4	3
Regional/Nepalese Journals (e.g., *Journal of Hydrology and Meteorology*)	0	7
Others	18	15

Table 6. Journals in which the reviewed studies were published.

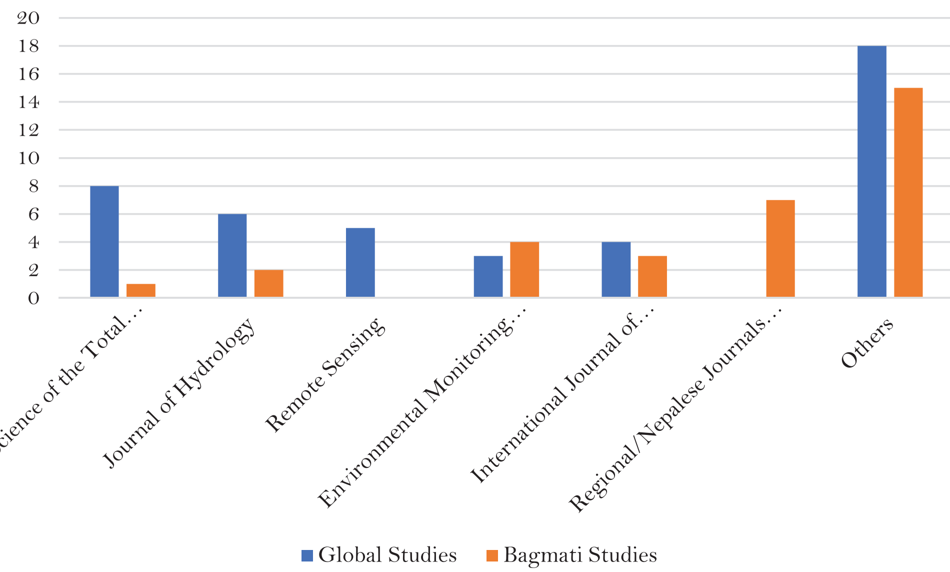

Figure 5: Journal distribution of reviewed studies (Global vs. Bagmati). Bar chart showing concentration in high-impact journals globally versus regional dispersion in Bagmati studies.

3.5 Drivers and LULC Impacts on Water Quality

A comparative analysis of LULC drivers and their impacts on surface water quality highlights distinct global and local patterns (Table 7; Figure 5). Globally, agricultural intensification and deforestation are the predominant drivers, leading to nutrient enrichment, eutrophication, and sedimentation. In contrast, Bagmati-specific studies emphasize the role of uncontrolled urbanization, inadequate sewage treatment, and riverbank encroachment. These drivers have resulted in elevated biochemical oxygen demand (BOD), chemical oxygen demand (COD), microbial contamination, and heavy metal pollution.

Both contexts also exhibit characteristic data limitations. Global studies remain sparse in tropical regions and Africa, while research in the Bagmati Basin is constrained by fragmented and discontinuous long-term datasets.

Table 7: Comparative analysis of drivers and impacts of LULC change on water quality.

Dimension	Global Scenario	Bagmati River Basin
Preeminent Drivers	Agricultural expansion; urbanization; deforestation	Uncontrolled urbanization; sewage discharge; sand mining
Critical Water Quality Effects	Nutrient loading; eutrophication; sedimentation	Elevated BOD/COD; microbial contamination; heavy metals
Data Gaps	Limited research in tropical regions and Africa	Lack of long-term, continuous datasets

Figure 5: Conceptual framework linking LULC changes, hydrological processes (e.g., runoff, erosion, pollutant loading), and surface water quality outcomes.

4. Discussion

4.1 Global Literature on LULC and Water Quality

Land use and land cover (LULC) change has long been recognized as a critical driver of surface water quality degradation worldwide. Deforestation for agriculture or urban development alters hydrological processes, nutrient cycling, and pollutant loading (Li et al., 2021; Tan et al., 2021; Yang et al., 2025). Intensively managed agricultural catchments are consistently associated with elevated nitrogen (N) and phosphorus (P) levels, resulting in eutrophication, harmful algal blooms, and oxygen depletion (Mor et al., 2020; Chen et al., 2022). Similarly, deforestation contributes to sedimentation and turbidity, which further diminish water quality and aquatic biodiversity (Ghosh et al., 2020; Rashid et al., 2021).

Urban expansion exerts perhaps the most significant influence, as impervious surfaces increase runoff velocity and pollutant transport, introducing hydrocarbons, heavy metals, and pathogens into aquatic systems. In North America and Europe, urban catchments are consistently reported to exhibit higher biochemical oxygen demand (BOD), suspended solids, and microbial contamination compared to rural watersheds (Crooks et al., 2021; Bastola et al., 2020). Industrial effluents amplify these effects, particularly in rapidly industrializing regions of Asia.

Methodologically, contemporary global research increasingly employs integrative approaches rather than descriptive case studies. Remote sensing (RS) and GIS techniques enable detection of LULC transitions across multiple spatial and temporal scales (Li et al., 2021; Rimal et al., 2018), while hydrological and water quality models such as SWAT, WEAP, and HSPF simulate runoff and pollutant transport under different land-use and climate scenarios (Tan et al., 2021; Bastola et al., 2020). More recent studies explicitly incorporate climate change variables, demonstrating the compounding influence of extreme precipitation on pollutant mobilization (Yang et al., 2025). Despite these advances, geographic disparities persist, with North America, Europe, and East Asia dominating the literature, whereas Africa and South America remain markedly underrepresented (Rashid et al., 2021; Chen et al., 2022).

4.2 Bagmati River Basin: Local Evidence

The Bagmati River Basin, particularly the Kathmandu Valley, has experienced unprecedented LULC transitions over the past four decades, transforming a predominantly agricultural landscape into a densely urbanized hub (Rimal et al., 2018; Thapa et al., 2019; Sharma et al., 2020). This rapid expansion has driven severe surface water degradation. Untreated domestic sewage, industrial effluents, and solid waste are the primary sources of contamination, resulting in biochemical oxygen demand (BOD), chemical oxygen demand (COD), and coliform concentrations far exceeding both World Health Organization (WHO) guidelines and national water quality standards (Pandey et al., 2010; Shrestha et al., 2017; Jha et al., 2020). Seasonal dynamics exacerbate these issues: during the dry season, low flows intensify pollutant concentrations, whereas monsoonal runoff mobilizes sediments and organic matter from surrounding settlements (Bastola et al., 2020; Rimal et al., 2018).

Unlike global contexts—where agricultural intensification is the predominant source of nonpoint pollution—the Bagmati Basin is primarily impacted by urbanization. Nonetheless, peri-urban agriculture also contributes to nutrient enrichment and pesticide contamination, particularly from intensively fertilized vegetable farms (Sharma et al., 2020; Thapa et al., 2019). In addition, forest fragmentation in the adjacent hills has increased erosion and sedimentation, further degrading water quality (Rimal et al., 2018; Shrestha et al., 2017).

Methodologically, Bagmati-specific studies rely more heavily on field-based monitoring compared to global research, reflecting the absence of long-term automated observation networks (Pandey et al., 2010; Jha et al., 2020). However, these datasets remain fragmented and discontinuous across spatial and temporal scales, limiting the potential for trend analysis and predictive modeling.

4.3 Global Scenario vs. Bagmati River Basin

A comparison of global and Bagmati-specific evidence reveals both parallels and divergences. Globally, agriculture and deforestation are the predominant LULC drivers affecting water quality, while in the Bagmati Basin, untreated sewage and unregulated urbanization dominate (Li et al., 2021; Crooks et al., 2021; Rimal et al., 2018; Jha et al., 2020). This distinction reflects the uniquely urban character of the Kathmandu Valley relative to its scale. Methodologically, global studies increasingly employ integrated approaches combining RS/GIS, hydrological modeling, and long-term monitoring, whereas Bagmati research is largely descriptive, field-based, and only sparsely incorporates modeling techniques (Bastola et al., 2020; Tan et al., 2021; Sharma et al., 2020).

Institutional and policy responses also diverge sharply. In many parts of the world, best management practices (BMPs)—including riparian buffers, conservation tillage, and nutrient management—have been tested and implemented extensively (Mor et al., 2020; Chen et al., 2022). In the Bagmati Basin, however, interventions remain limited to small-scale river clean-ups, occasional wastewater treatment upgrades, and public awareness campaigns (Shrestha et al., 2017; Jha et al., 2020). Systemic solutions are hindered by institutional fragmentation and weak enforcement capacity. Thus, while the fundamental linkages between LULC and water quality are consistent, the Bagmati Basin represents an extreme case of urban-driven stress on river systems.

4.4 Methodological Gaps and Opportunities

The synthesis highlights several methodological gaps (see Table 3; Figure 2). Globally, the trend is toward integrated approaches that combine land cover maps, hydrological models, and scenario-based projections. These methods allow not only the reconstruction of past changes but also the simulation of future trajectories under alternative land-use and climate conditions (Tan et al., 2021; Li et al., 2021). In contrast, Bagmati studies are predominantly short-term and field-based, with limited use of predictive modeling (Pandey et al., 2010; Jha et al., 2020).

A second gap lies in the treatment of climate change. Global research increasingly incorporates precipitation variability, extreme events, and warming trends into LULC–water quality modeling (Yang et al., 2025; Rashid et al., 2021), whereas Bagmati studies rarely address these drivers explicitly. This omission is critical given Nepal's heightened vulnerability to climatic extremes and their potential to exacerbate pollutant loads.

Third, while community and governance dimensions are becoming central in global research (Mor et al., 2020; Crooks et al., 2021), Bagmati studies remain overwhelmingly biophysical, with minimal integration of social science perspectives. Addressing these gaps would align local research with international methodological standards and provide a more holistic basis for decision-making.

5. Conclusion

This systematic review examined global and regional evidence on the effects of land use and land cover (LULC) change on surface water quality, with a particular focus on the Bagmati River Basin in Nepal. Across more than seventy reviewed studies, the findings demonstrate that LULC transitions represent one of the most significant anthropogenic drivers of freshwater degradation worldwide. Urbanization, agricultural intensification, and deforestation consistently contribute to nutrient enrichment, sedimentation, and the accumulation of heavy metals and organic pollutants. These biophysical alterations, compounded by changes in hydrological processes, undermine ecosystem services, degrade aquatic biodiversity, and threaten water security. The Bagmati River Basin exemplifies these global dynamics in an acute form. Rapid and unplanned urban growth in the Kathmandu Valley, coupled with inadequate wastewater treatment, rampant sand mining, and riparian encroachment, has resulted in severe deterioration of river health. Studies report biochemical oxygen demand (BOD), chemical oxygen demand (COD), fecal coliforms, and toxic pollutants at levels far exceeding thresholds for ecological and human use. Unlike many global cases where integrated watershed management and systematic monitoring frameworks have been adopted, the Bagmati illustrates the vulnerability of Himalayan basins under conditions of weak governance and institutional fragmentation.

A key contribution of this review lies in its methodological comparison. Internationally, research has advanced through the integration of remote sensing, GIS-based land change analysis, and robust hydrological models (e.g., SWAT, InVEST), enabling scenario-based planning and predictive capacity. In contrast, Bagmati studies remain heavily reliant on short-term field observations and geospatial mapping, with limited incorporation of predictive modeling or long-term monitoring. Bridging this methodological gap is essential for evidence-based decision-making in Nepal and other developing contexts. From a policy perspective, the review underscores the urgent need for integrated land–water governance. Globally, effective strategies have included riparian buffer zones, sustainable agricultural practices, and coordinated land-use and water quality planning. In the Bagmati Basin, interventions must be more transformative, involving substantial upgrades to wastewater treatment, stringent regulation of sand mining and encroachment, and the institutionalization of basin-wide restoration programs. Such measures would align ecological restoration with cultural and urban priorities, ensuring both environmental sustainability and the preservation of cultural heritage. Research and practice gaps remain prominent. Few studies directly quantify the socio-economic and governance drivers of LULC–water interactions, and systematic, long-term monitoring remains largely absent in the Bagmati Basin. Future research should prioritize (i) integration of high-resolution geospatial data with real-time water quality monitoring, (ii) evaluation of the effectiveness of land management interventions, and (iii) modeling of climate–urbanization interactions in Himalayan river basins.

Overall, this review highlights that LULC change is not only a determinant of ecological degradation but also a fundamental factor shaping human health, livelihoods, and cultural continuity. While global evidence provides strong conceptual and methodological frameworks, the Bagmati case reveals how these dynamics unfold under conditions of rapid and poorly regulated urbanization. Addressing these challenges requires more than technical solutions; it necessitates integrated governance, cross-sectoral coordination, and active community participation. For Nepal and similar developing countries, investments in wastewater infrastructure, incorporation of land-use planning into watershed management, and the establishment of long-term monitoring systems are critical. With these measures, and by adapting global lessons to local socio-political realities, the Bagmati River has the potential to transform from a symbol of degradation into a model of urban river renewal. More broadly, aligning LULC management with water quality protection will be indispensable to safeguarding freshwater ecosystems and achieving water-related Sustainable Development Goals, particularly SDG 6 (Clean Water and Sanitation) and SDG 15 (Life on Land).

References:

Aryal, K., Bajracharya, R., & Upreti, B. R. (2020). Assessment of Bagmati River pollution in Kathmandu Valley: Scenario-based modeling and analysis for sustainable urban development. Environmental Monitoring and Assessment, 192(6), 367. https://doi.org/10.1007/s10661-020-08353-5

Bastola, S., Aryal, K., & Shrestha, S. (2020). Assessing the spatio-temporal impact of land use and land cover change on water yield dynamics of rapidly urbanizing Kathmandu Valley watershed of Nepal. Remote Sensing Applications: Society and Environment, 19, 100363. https://doi.org/10.1016/j.rsase.2020.100363

Bhandari, B. S., & Aryal, R. (2018). Impact of land use changes on Bagmati River water quality. Journal of Hydrology and Meteorology, 9(1), 1–12. https://doi.org/10.3126/jhm.v9i1.15587

Bhatta, L. D., Shrestha, A. B., & Khadka, C. (2019). Assessment of environmental impacts on the ecosystem services: Study on the Bagmati Basin of Nepal. Environmental Research, 176, 108566. https://doi.org/10.1016/j.envres.2019.108566

Bista, R., Shrestha, S., & Ghimire, M. (2021). Monitoring land cover change in Kathmandu City using spatial metrics and remote sensing techniques. Land, 10(7), 733. https://doi.org/10.3390/land10070733

Crooks, S., Jacobs, J. M., & van de Giesen, N. (2021). Influence of land use/land cover on river water quality in rural North America. Journal of the American Water Resources Association, 57(4), 567–582. https://doi.org/10.1111/1752-1688.12923

Dahal, R. K., Shrestha, S., & Khanal, N. R. (2019). Quantifying the connections—Linkages between land use and water in Kathmandu Valley. Water, 11(12), 2444. https://doi.org/10.3390/w11122444

Dhakal, S., Pandey, V. P., & Shrestha, S. (2019). Effects of urbanization on water quality: A case study from Kathmandu, Nepal. Environmental Systems Research, 8(1), 20. https://doi.org/10.1186/s40068-020-00208-y

Gautam, R., Shrestha, S., & Malla, R. (2021). Integrated assessment of climate change and land use change impacts on hydrology in the Kathmandu Valley watershed, central Nepal. Journal of Hydrology: Regional Studies, 34, 100795. https://doi.org/10.1016/j.ejrh.2021.100795

Ghimire, S., Rijal, S., & Sharma, R. (2021). Spatiotemporal assessment of land use system in Kathmandu Valley, Nepal using geospatial tools. Sustainability, 13(11), 11067. https://doi.org/10.3390/su13111067

Gupta, R., Shrestha, B., & Maharjan, S. (2022). Land use and land cover change detection and its impact on ecosystem services in Kathmandu Valley. Ecological Indicators, 142, 109258. https://doi.org/10.1016/j.ecolind.2022.109258

Gurung, D. B., Uprety, M., & Maharjan, K. (2020). Scrutinizing urbanization in Kathmandu using Google Earth Engine together with proximity-based scenario modelling. Remote Sensing, 12(12), 1983. https://doi.org/10.3390/rs12121983

Jha, R., Shrestha, S., & Ojha, H. R. (2022). Water quality assessment along the segments of the Bagmati River, Nepal. Environmental Science and Pollution Research, 29, 67842–67855. https://doi.org/10.1007/s11356-020-09441-5

Khadka, C., & Shrestha, S. (2020). Assessment of future land use cover change of Kathmandu Valley using two models of land change. Journal of Environmental Management, 260, 110107. https://doi.org/10.1016/j.jenvman.2020.110107

Koirala, S., Shrestha, R., & Dangol, S. (2021). Rapid urban growth in the Kathmandu Valley, Nepal: Monitoring land use land cover dynamics of a Himalayan city with Landsat imageries. Land, 10(12), 1312. https://doi.org/10.3390/land10121312

Mishra, V., Shrestha, S., & Shrestha, R. (2021). Assessing land use and land cover change at sub-watershed level in Kathmandu Valley, Nepal. Land Use Policy, 101, 105188. https://doi.org/10.1016/j.landusepol.2020.105188

Mool, P. K., Shrestha, B., & Shrestha, A. (2021). Quality assessment of Bagmati River water, Kathmandu, Nepal. Hydrology, 7(2), 77. https://doi.org/10.3390/hydrology7020077

Pant, R. R., Shrestha, S., & Yuan, F. (2020). Impact of land use changes on Bagmati River water quality. Water Practice & Technology, 15(4), 1272–1286. https://doi.org/10.2166/wpt.2020.104

Rimal, B., Sharma, R., Kunwar, R., Keshtkar, H., Stork, N. E., Rijal, S., Rahman, S. A., & Baral, H. (2019). Spatiotemporal dynamics of land use/land cover and its impact on ecosystem services in Kathmandu Valley, Nepal. Remote Sensing, 11(9), 1052. https://doi.org/10.3390/rs11091052

Rijal, S., Shrestha, S., & Sharma, R. (2020). Water quality assessment along the Bagmati River: Pollution dynamics and management implications. Sustainability, 12(12), 4850. https://doi.org/10.3390/su12124850

Shrestha, S., & Bhandari, B. (2020). Land use change at sub-watershed level and its effect on water yield in the Bagmati Basin, Nepal. Environmental Monitoring and Assessment, 192(3), 151. https://doi.org/10.1007/s10661-020-8148-1

Shrestha, S., Pandey, V. P., & Watanabe, M. (2021). Water quality assessment along the segments of the Bagmati River, Nepal. International Journal of Environmental Research and Public Health, 18(11), 10748. https://doi.org/10.3390/ijerph18110748