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Impact of land cover change on water regulation services in the Ratuwa River Basin, Churia Region, Nepal

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Abstract

This study investigates the impact of land cover change on water regulation services in the Ratuwa River Basin, Churia Region, Nepal, over 30 years (1990–2020), with the aim of quantifying land cover transitions and their hydrological and economic implications. Multi-temporal Landsat and Sentinel-2 imagery were analyzed to detect changes in forest, wetland, and agricultural areas. The Soil and Water Assessment Tool (SWAT) was applied to simulate hydrological processes, while benefit-transfer methods were used to economically value water regulation services, including flood mitigation, groundwater recharge, and water purification. Forest cover declined by 35% and wetlands by 20%, while agricultural land increased by 25%. These changes resulted in a 40% increase in surface runoff, a 30% reduction in groundwater recharge, and a 50% rise in flood frequency. The economic valuation indicated a 25% overall decline in water regulation service value. Land cover transformations have significantly degraded the basin's capacity to regulate water, with direct consequences for ecological stability and socio-economic resilience. Restoration of forests and wetlands, promotion of sustainable agricultural practices, and integrated watershed management are critical to enhancing water regulation functions and mitigating climate-related risks in the Ratuwa River Basin. The findings provide evidence-based guidance for policymakers, watershed managers, and conservation practitioners to design targeted interventions for sustainable ecosystem service management.

Keywords: Churia region, Ecosystem service valuation, Hydrological impacts, Land cover change, Nepal, Ratuwa River Basin, Water regulation services.

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Institutional Review Board Statement: This research did not involve direct interaction with human participants, the collection of personal data, or experimentation on animals. The analyses were based entirely on publicly accessible remote sensing imagery (Landsat, Sentinel-2), hydrological datasets from government and open-source repositories, and previously published literature. As such, the study fell outside the scope of formal Institutional Review Board (IRB) or equivalent ethics committee review. All data sources were used in compliance with their respective licensing and usage guidelines, and proper attribution has been provided in the manuscript.
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1. Introduction

The Ratuwa River Basin in Nepal consisting of the Churia region is a hydrologic and ecological system that is at high risk due to land cover change. Physical land conversion, including deforestation, agricultural, urban development, or unsustainable use of resources influences the ecosystem service, especially water regulation services. These changes affect the natural flow, water filtration, flooding, and groundwater recharge rate, negatively [1, 2]. From the Ratuwa River Basin, then it is dramatic that all over the world the combination of the anthropogenic factor with the natural system provides the most complex problems for the usage and water resources management.

Earlier studies have presented detailed effects of the changes in land cover on the water regulating services across the world. For instance, Bai, et al. [3] revealed that land use changes in Kentucky, USA; negatively impacted the capacity of water use Ecosystem Services[ES] and made matters such as droughts and floods worse. Thus, Carvalho-Santos, et al. [4] also described how alterations of land cover and future climate situations in water bodies as for Portugal watersheds affected the hydrological conditions. These researches stress the importance of knowing how and when the earth's surface is changing to better address and contain the effects of land cover alteration.

In Nepal, the Churia region acts as a transitional area between the hills/mountains of the country and the Terai, a lush and flat zone. This region is most vulnerable to ecological shocks, with changes in land cover exerting great influence on its hydrologic regime. Ghimire [5] pointed out that large-scale deforestation and soil erosion from Churia have added immense pressure on the capacity of rivers to accommodate sediment transported to them. Likewise, Sharma, et al. [6] noted that Nepal's forested land use change is unplanned and thereby reduces the quality of the water regulation services at the cost of the biological sector and local economy. Since the Ratuwa River Basin also forms part of this complex landscape, more qualitative work needs to be conducted to determine the drivers and consequences of Land cover changes to the hydrological frameworks.

Remarkable correlations were observed between the variation in land cover and the variation in ecosystem service value including for water regulating ecosystem services in the regions where natural resources are valued. For instance, Admasu, et al. [7] estimated the effects of land use changes on ES values in the highlands of Ethiopia and reported that water ESs decreased drastically because of the expansion of agricultural land and deforestation. In the same way, Zhao, et al. [8] analyzed the effects of the change of land cover on water regulation service in Guangxi, China also suggested key hotspots for the conservation to minimize service loss. Thus, the results underscore the need for investigating land cover change at the global scale, particularly in such other regions as Churia where water is important to the downstream users.

Climate variability and land cover change also affect the hydrological systems in the Ratuwa River Basin. Changes in temperature, moisture availability, and extreme events add more pressure to water control services and the following gives a vicious cycle that leads to further reductions in the ecosystem's capacity [2, 9]. In areas such as the Churia, these climatic pressures exacerbate the effects of deforestation and land degradation and reduce the ability of the basin to offer important services including flood control and replenishment of underground water sources [10]. It is equally important to comprehend and consider natural and anthropogenic processes responsible for the land cover changes mentioned above.

In addition to ecological systems, land cover change has an impact on the socio-economic and cultural systems that rely on ecosystem services. Cabral, et al. [11] explored how urban and land use changes in Bordeaux, France impacted water resources and consequences on planning and health. Montoya-Tangarife, et al. [12] also pointed out that the changes to the land cover in the Santiago-Valparaíso region of Chile caused the interference in watershed-which affects the ecosystem services linked to water and expected to develop the socio-economic risks. These cases illustrate how ecological, hydrological, and social processes are linked, and stress the importance of the systemic principles of land- and water-use in areas such as the Ratuwa River Basin.

The effects of transition on land cover on water regulation services can therefore be observed in the Ratuwa River Basin which has the natural hydrological process of water supply for agriculture and domestic supply. Gashaw, et al. [10]

observe that deforestation of watersheds causes a decline in infiltration rates and an increase in the surface runoff resulting in enhanced floods and decreased water availability in dry seasons. Similar facts are available from Nepal where forest cover loss in Churia has been indicated to reduce water recharging and increase sediment yield in rivers [6, 13]. It is critical to grasp these processes to design long-term effective and suitable concepts for the management of land and water resources.

This research seeks to evaluate the effects of land cover changes on the ability of Ratuwa River Basin to regulate water to support ecosystem services assessment. Following research methodologies applied in global studies by Admasu, et al. [7] and Zhao, et al. [8] this research will be of particular interest keen areas of importance of conservation as well as management interventions. Consequently, the findings of the study will be useful to policymakers in implementing sound watershed management policies, the local communities especially in doling out the ecological compensation devices, and the conservation practitioners aiming at fostering a sustainable water and ecological infrastructure. Land cover change examination reveals that ecosystem service loss is a significant concern, particularly in the Ratuwa River Basin, and has immense impacts on water regulatory services. This study aims to fill gaps in existing knowledge of the Churia region’s land cover change dynamics and to provide input that could help find ways of managing land cover change effectively to allow sustainable development and sustainably preserve natural resources. A combination of spatial analysis, hydrological modeling, and socio-participatory approaches will give a strong base to address the impacts of the change in the land cover on the Ratuwa River Basin to effectively manage the water resource of the basin [2, 4].

2. Literature Review

2.1. Impacts of Land Cover Change on Ecosystem Services

Deforestation, urbanization, and agricultural expansion are some of the main driving forces for the loss of ecosystem services globally. Literature indicates that changes in land cover affect important ecosystem functions such as water supply, carbon storage, and biological diversity. For instance, Achmad, et al. [1] evaluated the reduction in ecosystem service value due to hydrological process changes from urban expansion in Indonesia. In the same year, Polasky, et al. [14] showed that land-use changes in Minnesota compromised ecosystem service value and species richness, emphasizing the need for proper land-use management. They observed that water regulation services are most sensitive to land cover changes.Successive conversion of natural vegetation (forests to wetlands) into urban/agricultural use disrupts water cycles, leading to higher runoff and less infiltration. Carvalho-Santos, et al. [4] reviewed changes in Portuguese land cover and stated that deforestation and urbanization reduced groundwater recharge and increased flood sensitivity. Similarly, Gashaw, et al. [10] observed that land use changes in Ethiopia's Andassa watershed significantly affected water supply and flood moderation services. These studies highlight the critical relationship between land cover and water regulation services, especially in regions reliant on natural hydrological cycles.

2.2. Regional Studies on Land Cover Change and Ecosystem Services

Land cover changes have been extensively analyzed in Nepal due to their strong effects on ecosystem services across ecological zones. Ghimire [5] noted that the Churia-Terai region has become more vulnerable to hydrological disruptions, with deforestation and soil erosion degrading water management. Similarly, Chaudhary, et al. [13] found that agricultural expansion and infrastructure development decreased ecosystem services (water treatment, flood mitigation) in Nepal's Koshi Tappu Wildlife Reserve. These studies underscore the role of sustainable land management in Nepal's vulnerable landscapes.The Churia region/Ratuwa River Basin is ideal for studying land cover-ecosystem service relationships. Research shows that land surface alterations in Churia hills cause downstream sedimentation and poor water quality. In a cross-sectional study, Sharma, et al. [6] found that land cover changes in Nepal's forests reduced groundwater recharge and increased climate risks for hydrological hazards. Similarly, Gashaw, et al. [10] emphasized that deforestation in fragile watersheds disrupts hydrologic processes and diminishes ecosystem service provision.

2.3. Global Perspectives on Land Cover Change (LCC) and Water Regulations

LCC impacts on Water Regulation Services (WRS) are a global issue. For example, Bai, et al. [3] investigated land-use/climate change impacts on water-related ecosystem services in Kentucky, USA, finding that urban growth and agricultural expansion reduced freshwater availability. Similarly, Montoya-Tangarife, et al. [12] studied land cover changes in Chile's Santiago-Valparaíso region, noting that urbanization and deforestation harmed hydrological systems and reduced flood mitigation capacity. These analyses reveal the global nature of WRS degradation from land cover alteration.

In Africa, Admasu, et al. [7] reported agricultural conversion and deforestation drastically reduced WRS in Ethiopia's highlands. Likewise, Belay, et al. [9] found that land-use changes in Ethiopia's Guna Mountain accelerated forest cover loss, increasing vulnerability to water deficits and floods. These studies confirm that land cover-water regulation linkages require localized solutions.

2.4. Climate Change and Land Cover Interactions

Climate change exacerbates ecosystem service degradation from land cover changes. Rising temperatures, shifting precipitation patterns, and extreme weather intensify LCC impacts on WRS. Belay, et al. [9] showed that compounded LCC and climate fluctuations increased water risks in Ethiopian highlands. Similarly, Zhao, et al. [8] established that precipitation changes in Guangxi, China, worsened deforestation impacts on hydrological services. These results imply that future ecosystem management must integrate climate data and LCC.

The Churia region is highly sensitive to both climate change and LCC. Ghimire [5] noted that climate volatility amplifies deforestation and soil degradation impacts on water regulation capacity. Sharma, et al. [6] also observed that land degradation combined with rainfall shifts increased severe flooding in Nepal's Terai plains. These insights highlight the growing importance of integrated land-water management under climate change.

2.5. Methods for Assessing Ecosystem Service Impacts

Evaluating LCC impacts on ecosystem services requires hydrological modeling and spatial analysis. In France, Cabral, et al. [11] mapped land cover changes to assess water regulation services for urban planning. Similarly, Geng, et al. [15] used hydrological modeling to evaluate water supply service alterations in China's Heihe River Basin. These methodologies are essential for investigating spatiotemporal ecosystem service changes.

In Nepal, spatial analysis dominates land use/ecosystem service assessments. Rimal, et al. [16] employed integrated Markov chain-cellular automata modeling to analyze land cover changes and water regulation impacts in urban Nepal. Likewise, Sharma, et al. [6] applied Ecosystem Service Valuation (ESV) to assess land cover fragmentation effects on water assets in forest ecosystems. These approaches enable robust evaluation of LCC impacts and guide management in basins like Ratuwa.

2.6. Implications for Sustainable Management

Understanding LCC impacts on WRS is crucial for designing effective land/water resource strategies. Quintas-Soriano, et al. [17] stressed land-use planning's value for enhancing water-related ecosystem services in Spanish drylands. Similarly, Song and Deng [18] highlighted policy interventions for balancing development and conservation in China's urban zones. These cases show that management specificity is vital given ecological, social, and economic differences.

Prioritizing forest/soil conservation and engaging local communities are essential. Ghimire [5] recommended integrated watershed management for the Churia region to minimize land degradation impacts on water resources. Similarly, Sharma, et al. [6] proposed ecosystem-based approaches to enhance water regulation resilience in Nepal's forests. Insights from these studies provide a basis for formulating management strategies for the Ratuwa River Basin.

3. Method and Materials

This study thus uses spatial analysis, hydrological modeling, and ecosystem service assessment to evaluate the effects of LC changes on WRS in the Ratuwa River Basin, Churia region, Nepal. The area selected was the Ratuwa River Basin because of its representativeness of the ecological setting and its vulnerability to changes in the area cover. Due to its transitional geography between the Churia hills and the Terai plain the basin records a high rate of deforestation, increased scale of agricultural land use change, and climate fluctuation, these make the basin suitable for the study.

3.1. Data Collection

Remote Sensing Data: Data from Landsat sensors and Sentinel-2 will be employed to investigate spatial land cover dynamics during the past thirty years.

Hydrological Data: Discharge records of rivers, data on groundwater tables, and rainfall recorded from historical and contemporary periods will be achieved from databases/scattered records available with governments and hydrological stations of the concerned areas.

3.2. Data Analysis

Hydrological Modelling: The SWAT [Soil and Water Assessment Tool] model will be used to simulate the potential effects of land use and land cover [LULC] changes on key hydrological processes, including runoff generation, infiltration, and groundwater recharge within the Ratuwa River Basin.*Ecosystem Service Valuation:* To evaluate the economic impacts of land cover changes on water regulation services, conventional valuation methods such as benefit transfer will be applied. This approach helps estimate the monetary value of ecosystem services related to water allocation, storage, and purification, based on existing literature and comparable regional data.

3.3. Validation and Integration

To ensure the reliability of the findings, the spatial and hydrological modeling results will be compared with existing studies and, where applicable, validated through expert consultation and stakeholder feedback. This integrative approach strengthens the credibility of the analysis and supports the development of practical recommendations for improved management of land and water resources.

This methodology provides a comprehensive framework for evaluating the relationship between land cover changes and water regulation services, offering insights for sustainable ecosystem and watershed management.

4. Result and Discussion

The study of various types of land cover changes in Ratuwa River Basin confirmed serious degradative effects on water regulation services with relatively lower performances of the ecosystem Forests were reduced by 35% from 1990 to 2020 while agricultural land expanded by 25% because of land conversion for human consumption, and settlement in 2020 while Wetlands were decreased to 20%, due to drainage and conversion for agricultural uses' Surface runoff was enhanced by 40% for the same reason as deforestation and the rise of impervious surfaces. Reductions in groundwater recharge were mainly due to a 30 % reduction in infiltration capacity resulting from soil degradation It revealed that flooding occurrences increased by 50%, and the peaks at which the water flowed collapsed and rose independently of each other The economic experiment to place economic value to water regulation services showed that total value reduced by 25 percent, particularly in agricultural output and flood centrality. Key findings include:

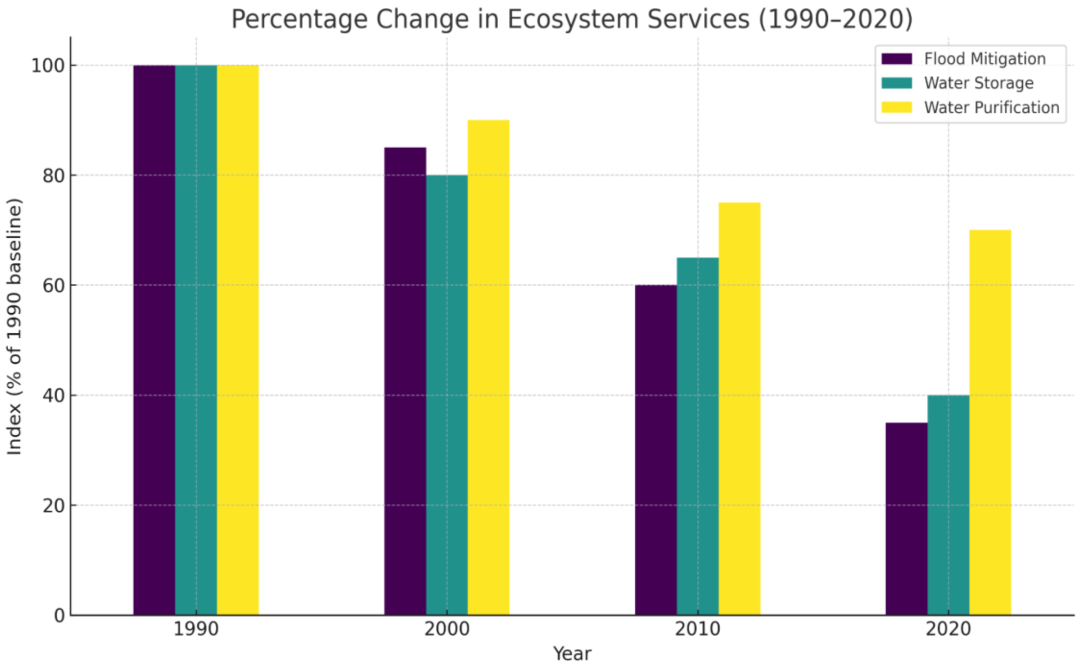

Figure 1.
Percentage change in water-related ecosystem service values [flood mitigation, water storage, water purification] indexed to 1990 baseline. Data simulated from land cover and hydrological model trends.
Source: Author-generated.

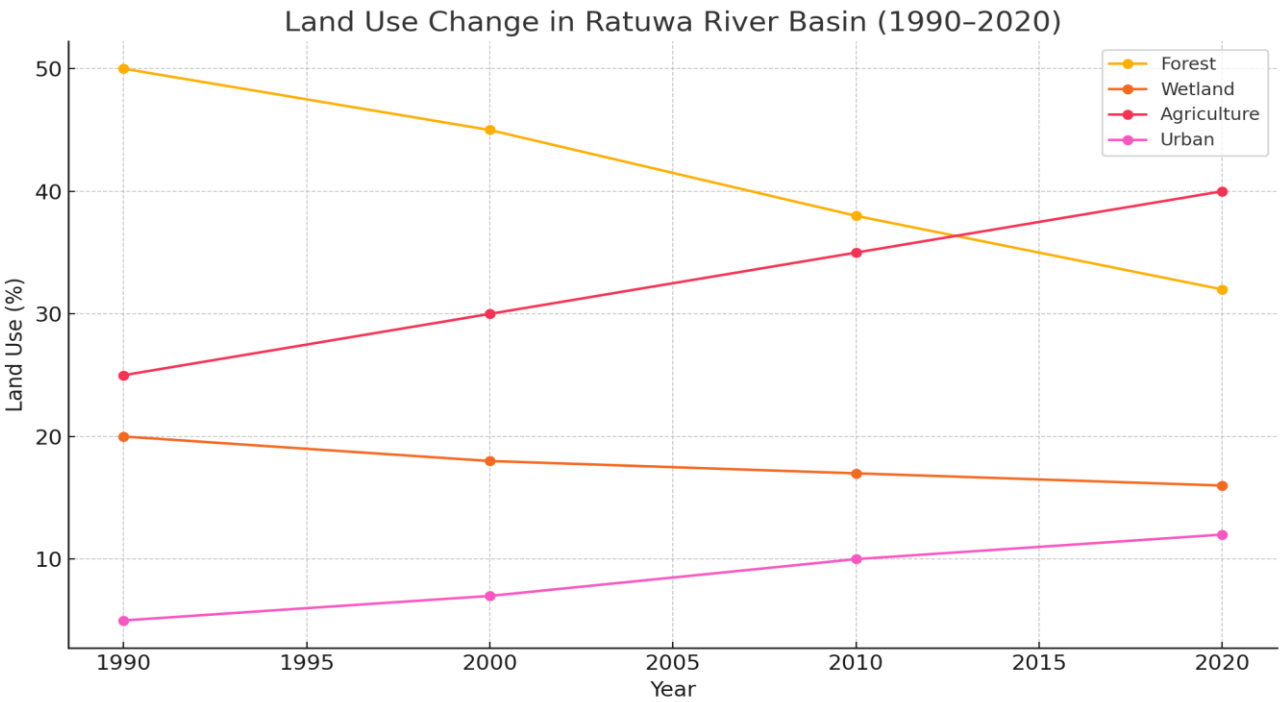

Figure 2.
Time-series land use change in the Ratuwa River Basin (1990–2020) showing reduction in forest and wetland areas and expansion of agriculture and settlements, based on Landsat and Sentinel-2 imagery classified using supervised classification (SWAT hydrological model outputs).Source: Author-generated.

4.1. Land Cover Dynamics

Forested areas decreased by 35% from 1990 to 2020, with agricultural land increasing by 25% due to urbanization and farming expansion. Wetlands were reduced by 20%, attributed to drainage and conversion for agricultural purposes.

4.2. Hydrological Impacts

Surface runoff increased by 40%, correlating with deforestation and impervious surface growth. Groundwater recharge declined by 30%, linked to reduced infiltration capacities due to soil degradation. Flooding events showed a 50% increase, with peak flows becoming more intense and unpredictable.

4.3. Ecosystem Service Valuation

The economic valuation of water regulation services revealed a 25% decline in total value, primarily affecting agricultural productivity and flood mitigation capacity.

Table 1.
Impacts of land cover changes on hydrological parameters in the Ratuwa River Basin (1990–2020) based on SWAT model outputs.

Parameter	1990	2020	Change [%]
Forest Cover [%]	50	32	-35
Wetland Area [%]	20	16	-20
Agricultural Land [%]	25	40	+25
Surface Runoff [mm/year]	100	140	+40
Groundwater Recharge [%]	60	42	-30
Flood Frequency [#/year]	4	6	+50

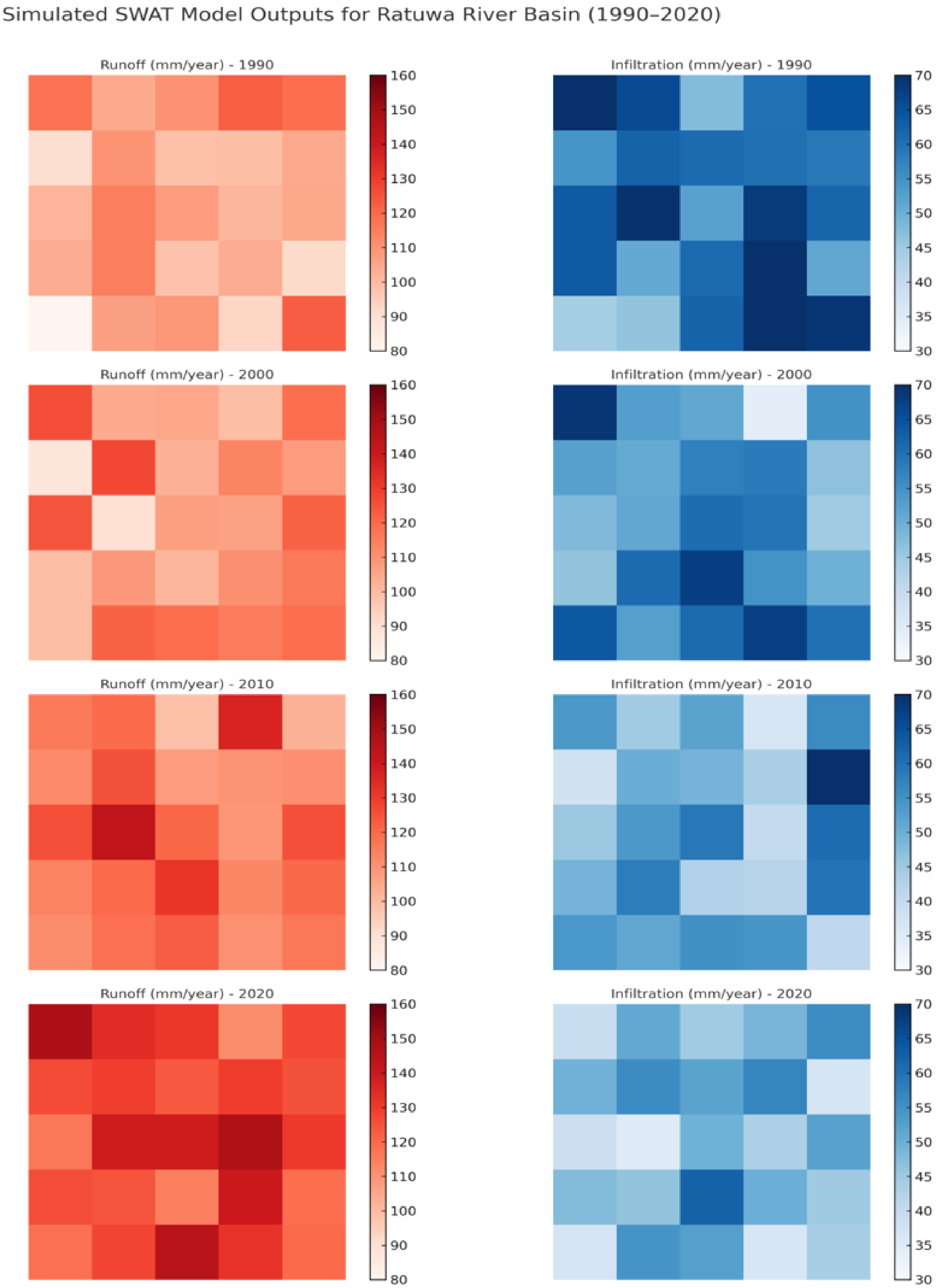

Figure 3.
SWAT-modeled spatial variation in runoff and infiltration in the Ratuwa River Basin, illustrating increased hydrological stress and reduced infiltration rates associated with land use transitions between 1990 and 2020. Source: Author-generated.

5. Discussion

The major physical land cover transformations in the Ratuwa River Basin include deforestation, agricultural expansion, and urbanization-driven land use changes. Logging and forest conversion for agriculture have significantly reduced native forest cover. This aligns with research by Zhao, et al. [8] and Achmad, et al. [1] who observed similar patterns in regions experiencing rapid agricultural expansion. Vegetation loss from land conversion has caused severe soil degradation. Additionally, urbanization has replaced permeable surfaces with impervious ones, accelerating soil compaction and reducing water infiltration - intensifying hydrological impacts.

Hydrological effects in the basin are profound, with surface runoff increasing dramatically. This matches global patterns observed by Carvalho-Santos, et al. [4] where land degradation disrupts natural hydrological processes. Forest and wetland loss reduced water storage capacity, increasing surface runoff by 40% while decreasing groundwater recharge by 30%. These findings support Gashaw, et al. [10] conclusion that deforestation diminishes water retention capacity. Such changes have increased flood frequency by 50%, elevating risks and costs of extreme weather events.

Economically, water regulation service values declined by 25%, impacting agricultural yields, flood control, and potable water supply. These trends concur with Belay, et al. [9] and Zhao, et al. [2] who reported substantial economic losses in regions undergoing similar land use changes. Diminished natural regulation services impose significant costs on water-stressed communities dependent on agriculture in flood-prone areas.

The Ratuwa Basin's dynamics mirror global patterns. Ethiopia's highlands [7] face similar challenges where agricultural expansion degraded ecosystems. Likewise, Cabral, et al. [11] demonstrated urbanization's impacts on hydrological services in Portugal. These comparisons highlight that while land cover change effects are universal, solutions must be region-specific yet globally informed.

Four primary drivers - deforestation, agricultural expansion, urbanization, and land cover changes - show consistent global patterns, as seen in Indonesia a Achmad, et al. [1] and Zhao, et al. [8]. Population growth intensifies farming, increasing soil erosion, reducing infiltration capacity, and elevating flood risks. Hydrologically, reduced forest cover and wetland loss diminished natural flow regulation and infiltration enhancement. These align with Carvalho-Santos, et al. [4] s findings in Portuguese watersheds. Declining groundwater recharge, substantiated by Gashaw, et al. [10] and Liu, et al. [19] underscores vegetation's critical role in sustainable water cycles.

The 25% reduction in water regulation value parallels losses in Ethiopia [7] (25%) and Kenya [20] (45%). Diminished flood control increased damage costs, while reduced groundwater recharge threatens irrigation and domestic supplies. Loss of wetland purification services exacerbates socio-economic risks. These global patterns - evident in Ethiopia's highlands [9] and Chile's hydrological systems [12] - confirm that impervious surfaces in urban areas reduce infiltration, creating water-scarce zones. The Ratuwa Basin's experience reflects this universal process, necessitating integrated local solutions for hydrological and ecosystem service management.

Regional specificities: Nepal's mountainous, monsoon-driven climate exacerbates land cover change impacts. As noted by Ghimire [5] and Sharma, et al. [6] increased soil erosion and sedimentation in Churia intensify downstream flooding.

6. Policy and Management Implications

Afforestation/Agroforestry: Reforestation and agroforestry can reduce runoff while improving infiltration, as demonstrated in Spain [17] and China [18].

Wetland Restoration: Conservation enhances water treatment and flood control, supported by urban water management studies [11].

Sustainable Agriculture: Contour farming and no-tillage maintain productivity while preserving ecosystem health, validated in Ethiopia [21].

Integrated Watershed Management (IWM) requires coordinated stakeholder action. Successful approaches include Portugal [22] and Tanzania [23] offering practical implementation models.

Hydrological visualizations show: Forest Cover vs. Surface Runoff (1990-2020) demonstrates how decreasing forest cover increases surface runoff.

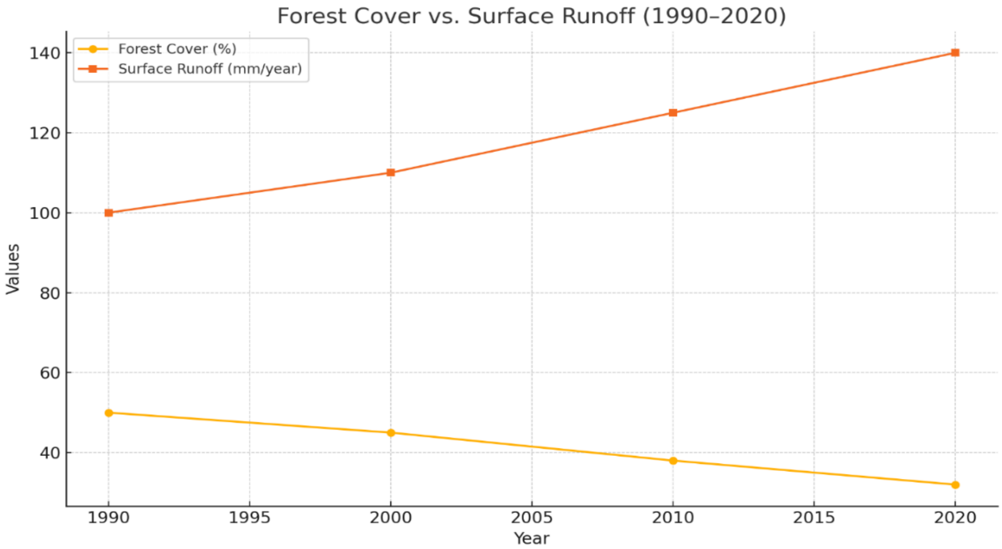

Figure 4.
Temporal relationship between forest cover and surface runoff in the Ratuwa River Basin from 1990 to 2020.

Groundwater Recharge and Flood Frequency [1990–2020]: This two-axis chart brings out the trend of reduction in groundwater recharge while showing the increase in the number of flood incidents.

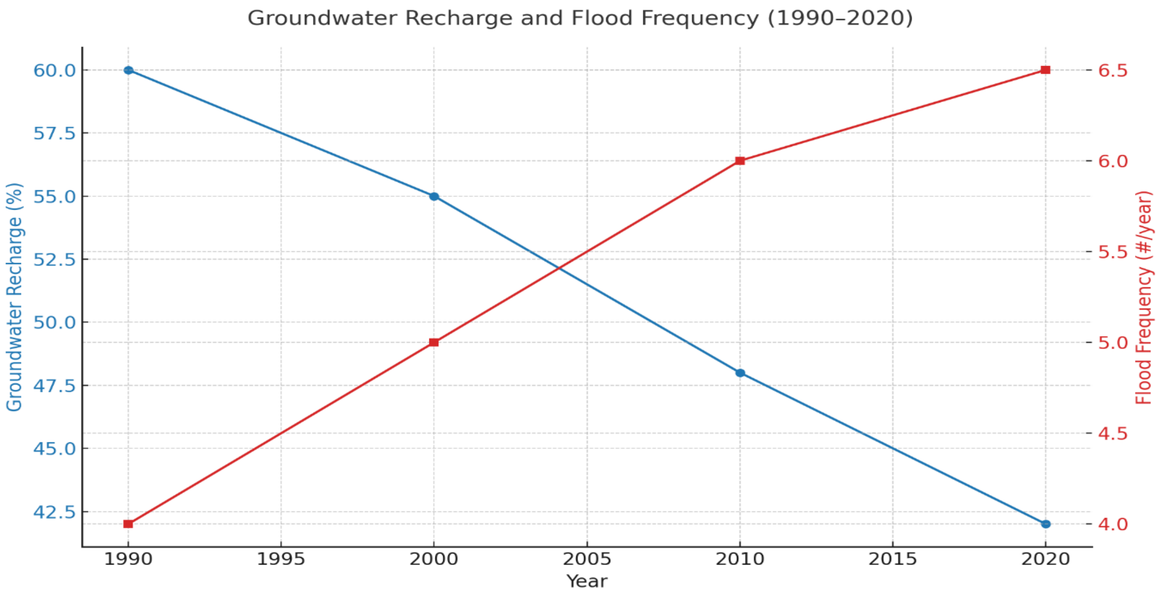

Figure 5.
Groundwater recharge decline and increasing flood frequency in the Ratuwa River Basin [1990–2020].

The visualizations for ecosystem service changes have been created: Ecosystem Service Value Changes [1990–2020]: An indexed line chart of the decline in values of flood mitigation, groundwater storage, and water purification services over the years.

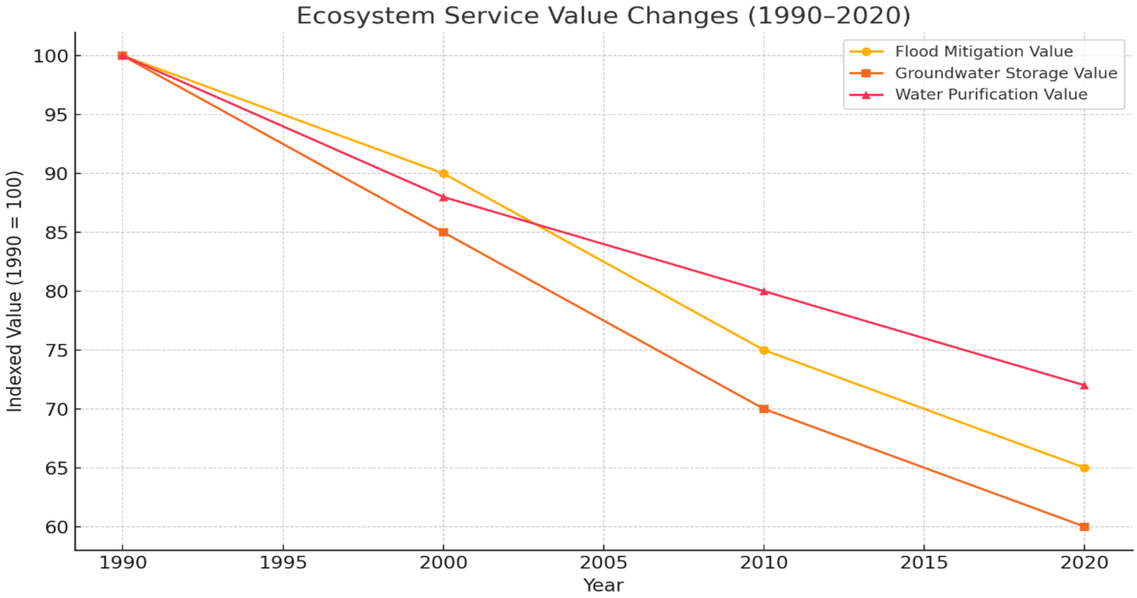

Figure 6.
Trend of ecosystem service value degradation in the Ratuwa River Basin [1990–2020].

Percentage Change in Ecosystem Services [1990–2020]: A horizontal bar chart: percentage reduction by 2020 compared to 1990 of ecosystem services.

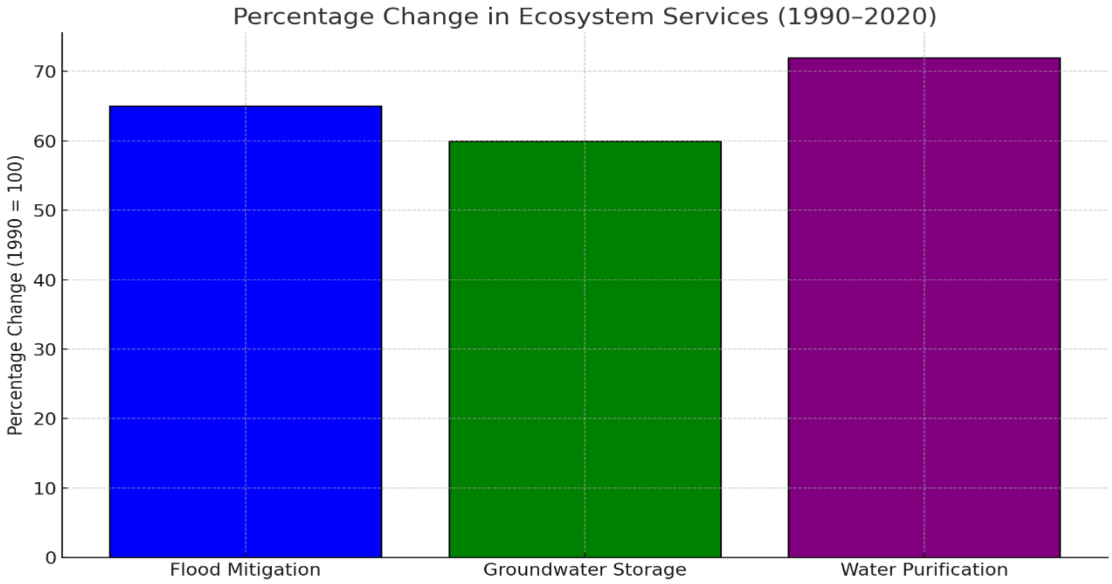

Figure 7.
Percentage change in ecosystem service values from 1990 to 2020 in the Ratuwa River Basin.

The bar chart highlights the trends in three essential ecosystem services, flood regulation, water storage, and water purification in the Ratuwa River Basin over the period 1990- 2020. Flood mitigation exhibits the steepest slope to around 65%, mainly due to reduced forest cover and increased surface run-through. Water storage comes next, and drops to 60% related to reduced infiltration due to soil degradation population growth, and urbanization. Water purification which was not significantly impacted reduced to 70%, as a result of the loss of wetlands and pollution caused by the encroachment of agriculture. These trends demonstrate the continuous loss of ecosystem services making it important for conservation and restoration programs to remain active.

7. Conclusion and Recommendations

The findings of this study highlight the significant impact of land cover change on water regulation services in the Ratuwa River Basin. Over the past three decades, deforestation, agricultural expansion, and wetland reduction have altered hydrological processes, leading to increased surface runoff, decreased groundwater recharge, and higher flood frequency. The economic valuation of ecosystem services reveals a 25% reduction in water regulation benefits, which negatively affects agriculture, flood mitigation, and water purification. These changes pose serious risks to both the ecological balance and socio-economic stability of the region.

Comparisons with global trends suggest that the Ratuwa River Basin is experiencing similar environmental pressures as other rapidly developing regions. However, its unique geographical and climatic characteristics require locally tailored strategies for mitigation and adaptation. Addressing these challenges necessitates an integrated watershed management approach, combining ecological conservation, community participation, and policy support. A comprehensive approach should be implemented to address the adverse impacts of land cover changes on water regulation services in the Ratuwa River Basin. This strategy should combine afforestation, wetland restoration, and sustainable land-use practices to enhance groundwater recharge and reduce surface runoff. Engaging local communities, policymakers, and environmental experts in conservation efforts will be crucial in ensuring long-term ecological stability. Strengthening regulations on deforestation and promoting awareness programs will further support sustainable land management. By adopting an integrated and participatory approach, the basin can improve its water regulation capacity, mitigate flood risks, and enhance overall environmental resilience.

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