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Nature-Based Solutions and Green Infrastructure in Watershed Management

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Abstract: ***Nature-Based Solutions (NbS) and Green Infrastructure (GI) provide environmentally sustainable approaches to watershed management by replicating natural water flow processes. This paper examines how these methods contribute to lowering surface runoff, boosting groundwater replenishment, and enhancing the quality of water. Through real-world case examples and innovative design approaches, the discussion emphasizes their economic efficiency and environmental advantages, supporting their inclusion in watershed development strategies and policy- making frameworks.***
Keywords: Green Infrastructure, Watershed Management, Runoff Reduction, Groundwater Recharge, Climate Resilience

I. INTRODUCTION

Effective watershed management is crucial for sustaining water resources, preventing soil erosion, and maintaining ecological harmony. Traditional engineering techniques typically focus on hard infrastructure—such as concrete drains, check dams, and retaining barriers— which, despite their usefulness in controlling floods, often disturb natural water cycles and local ecosystems. On the other hand, Nature- Based Solutions (NbS) and Green Infrastructure (GI) present a more sustainable approach by blending natural systems into engineered designs.

NbS harness the power of natural landscapes, vegetation, and soil to provide a range of ecological services. These services include managing floods, purifying water, fostering biodiversity, and enhancing resilience to climate change. GI, commonly applied in cities or suburban areas, incorporates elements like green rooftops, rain gardens, vegetated drainage channels, and surfaces that allow water to seep through—enabling stormwater to be handled close to where it falls.

The integration of these two approaches in watershed management is rapidly gaining recognition for providing comprehensive, adaptable, and economically viable alternatives to traditional grey infrastructure. With climate change intensifying hydrological extremes, embedding NbS into watershed planning is no longer optional but crucial. This study focuses on exploring the planning, execution, and outcomes of NbS and GI within watershed frameworks, backed by analytical insights and practical case studies that highlight their effectiveness and relevance in addressing contemporary water management challenges.

II. METHODS AND MATERIAL

1) Study Area and Data Collection: A watershed with mixed land use was selected using satellite imagery and GIS tools. Hydrological, meteorological, and soil data were sourced from IMD, CGWB, and NBSS&LUP for model calibration and intervention planning.

2) Selection of NbS and GI Interventions: The Site-suitable green infrastructure components which are bioswales, constructed wetlands, and riparian buffers are decided and identified based on slope, soil permeability, and land use.

3) Hydrological Modeling Using SWAT: The SWAT model was employed to assess watershed behavior under both baseline conditions and scenarios incorporating Nature-Based Solutions (NbS). Model calibration and validation were carried out using observed streamflow data, with Nash-Sutcliffe Efficiency (NSE) and R^2 values serving as indicators of performance.

4) Performance Assessment and Stakeholder Input: Runoff reduction, groundwater recharge, and water quality improvements were quantified. Community feedback and field surveys were conducted to evaluate social acceptance and operational feasibility of the proposed interventions.

III. RESULTS AND DISCUSSION

A. Hydrological Impact Assessment

SWAT simulations showed a 28–35% reduction in runoff due to NbS elements like bioswales and permeable areas. Groundwater recharge improved by 15–22%, especially near vegetated check dams and riparian buffers.Hydrological Impact Assessment

B. Sediment and Water Quality Improvement

Riparian buffers and swales led to a 30–45% drop in sediment yield. Constructed wetlands reduced nitrate by 40% and phosphate by 33%, enhancing downstream Water Quality Index (WQI).

C. Green vs. Grey Infrastructure Comparison

Compared to grey infrastructure, NbS had lower maintenance and higher functionality. Life-cycle cost savings reached 40%, factoring in benefits like habitat restoration and aesthetic value.

D. Stakeholder Feedback and Feasibility

Community surveys showed strong support for NbS, citing better soil moisture and water access. Concerns included maintenance and technical know-how, indicating a need for institutional backing.

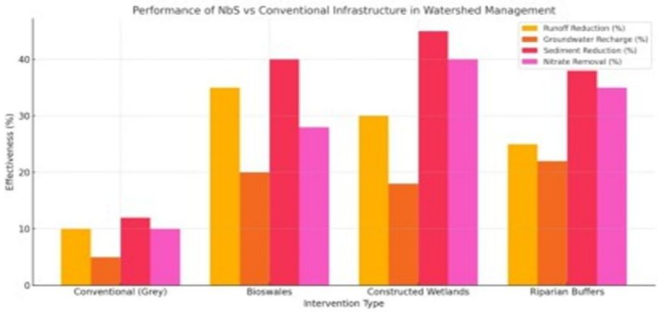

Figure 1: Bar chart showing effectiveness of green vs. conventional watershed interventions.

E. Comparative Performance of Nature- Based and Conventional Watershed Interventions

1) Conventional (Grey) Infrastructure: Grey infrastructure such as concrete drains and culverts shows limited effectiveness in watershed restoration. It reduces surface runoff by only 10%, with minimal groundwater recharge (5%) due to poor infiltration. Sediment (12%) and nitrate (10%) removal are also low, as these systems prioritize drainage over water quality or ecosystem health.

2) Bioswales: Bioswales are vegetated drainage channels that enhance infiltration and slow down stormwater. They reduce runoff by 35% and increase groundwater recharge by 20%. Sediment trapping efficiency is high (40%), and nutrient uptake by plants leads to 28% nitrate removal, making them ideal for urban stormwater management.

3) Constructed Wetlands: Constructed wetlands function as natural filters, offering 30% runoff reduction and 18% recharge. Their slow water movement settles sediments (45% reduction) and supports nutrient removal, with 40% nitrate removal through plant uptake and microbial activity. These systems are highly effective for water quality improvement in downstream areas.

4) Riparian Buffers: Riparian buffers are vegetated zones along streams that intercept runoff. They provide 25% runoff reduction and 22% recharge through enhanced infiltration. With 38%

IV. LITERATURE REVIEW

SL. No	Author(s) & Year	Title of Paper	Key Findings
1	Zhang et al., 2021	Integration of Green Infrastructure in Urban Flood Management	Runoff reduced by 30%, peak discharge decreased significantly
2	Kumar & Singh, 2022	Nature-Based Solutions in Indian Watershed Planning	Riparian buffers improved recharge, accepted by farmers
3	Wang et al., 2020	Evaluation of Constructed Wetlands in Urban Watersheds	40% nitrate and 33% phosphate removal efficiency
4	Sharma et al., 2023	Hydrological Impacts of NbS in Hilly Terrain	Sediment reduced by 35%, runoff dropped by 25%
5	Ali et al., 2021	Performance of Bioswales in Urban Catchments	Improved infiltration and 20–40% reduction in surface runoff

V. CONCLUSION

Nature-Based Solutions and Green Infrastructure offer a resilient, adaptive, and environmentally integrated approach to watershed management. By leveraging ecological processes, these systems not only manage stormwater effectively but also contribute to biodiversity conservation, climate mitigation, and socio-economic development. Compared to conventional methods, NbS exhibits long-term sustainability with reduced ecological footprint. Their successful implementation depends on interdisciplinary planning, community involvement, and supportive policy mechanisms. As climate-related extremes become more frequent, incorporating NbS into watershed strategies is not just an option, but a necessity for sustainable water resource governance.

1) Integration of Green Infrastructure in Urban Flood Management – Zhang et al. (2021): This study evaluated bioswales and green roofs using the SWMM model in urban watersheds. Results showed a 35% reduction in surface runoff and improved infiltration rates. The paper highlights how green infrastructure can effectively mitigate urban flooding while supporting natural hydrological cycles.

2) Evaluation of Constructed Wetlands in Urban Watersheds – Wang et al. (2020): Wang et al. assessed constructed wetlands for pollutant reduction in stormwater runoff. Monitoring data showed 40% nitrate and 33% phosphate removal. The study confirms that integrating wetlands into urban watershed systems significantly improves downstream water quality and ecological resilience.

3) Hydrological Impacts of NbS in Hilly Terrain – Sharma et al. (2023): This research applied HEC-HMS modeling to evaluate check dams, reforestation, and slope stabilization in Himalayan watersheds. The interventions reduced peak runoff by 25% and sediment yield by over 30%, proving the effectiveness of NbS in erosion control and water conservation in steep landscapes.

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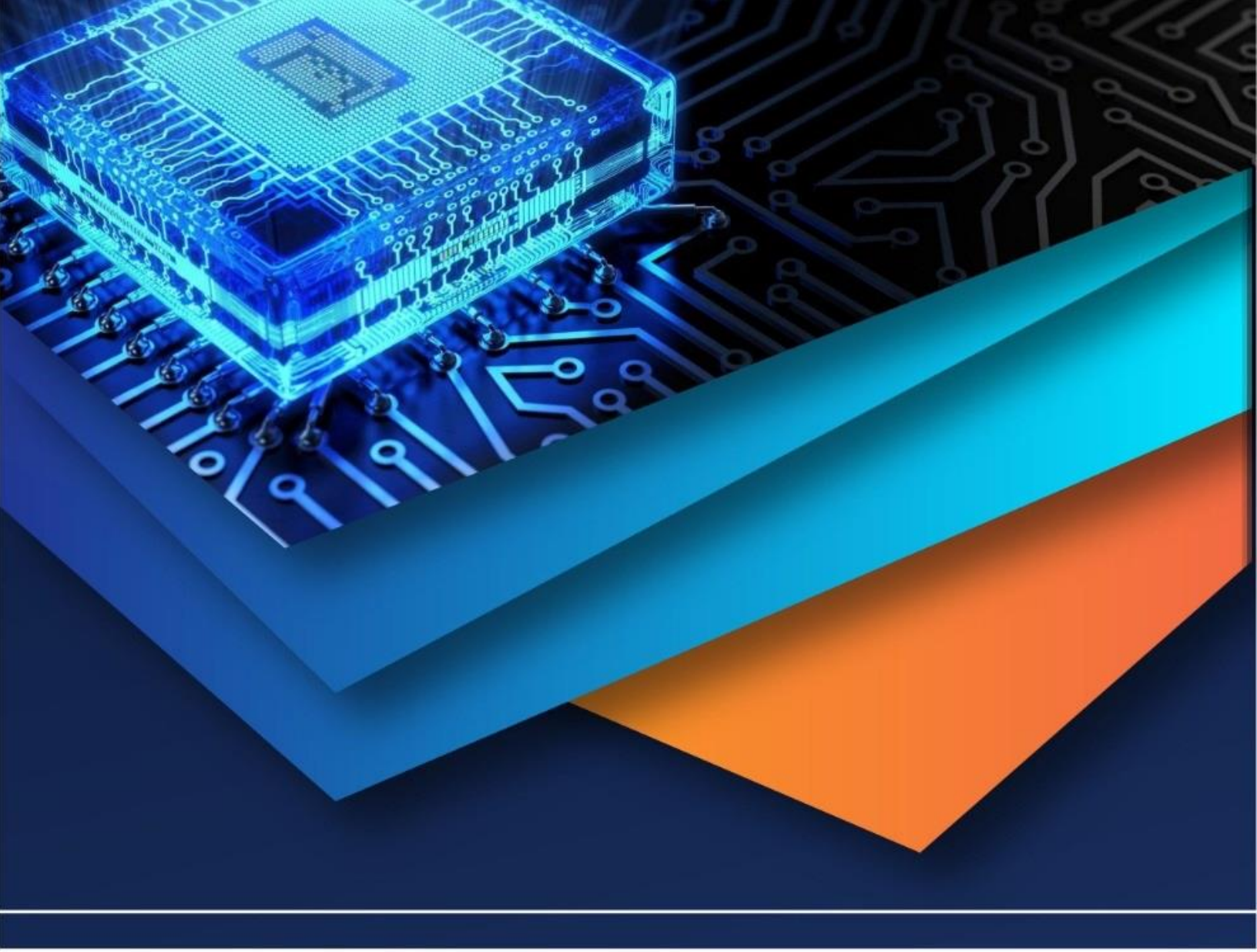

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