

Integrating Ecosystem Restoration and Urban Planning through Smart GIS-Based Land Reallocation Systems

Dr R.Udayakumar^{1*}, Noor. A. H.², Taha Raad Al-Shaikhli³, Ahmed Kateb J. Al-Nussairi⁴, Hassan Khalid Abozibid⁵, Abdulaali Habeeb Hussein⁶

¹Professor & Director, Kalinga University, India

²Al-Hadi University College, Baghdad, 10011, Iraq

³Al-Nisour University College, Nisour Seq. Karkh, Baghdad, Iraq

⁴Department of sciences/ Al-Manara College for Medical Sciences/ (Maysan)/Iraq

⁵Al-Zahrawi University College, Karbala, Iraq

⁶Mazaya university college/ Dhiqar/ Iraq

Abstract. Urbanization and environmental degradation are closely linked, and both contribute to the fragmentation of habitats and the loss of ecosystem processes. Placing ecological restoration alongside urban planning is a novel solution to the problem. This paper proposes a Smart GIS-Based Land Reallocation System (SGLRS) as an executive tool for addressing the needs of ecological restoration versus urban expansion. It relies on spatial analysis of data, real-time environmental monitoring, and artificial intelligence to identify ecologically degraded or underutilized urban spaces that can be repurposed to support green infrastructure, reforestation, or wetland restoration. The SGLRS operates using multi-criteria decision analysis (MCDA) in conjunction with land-use simulation models to optimize land reallocation decisions. It has included environmental sensitivity indicators, value assessment of biodiversity, and socio-economic factors for prioritizing areas to restore and urban renewal. Moreover, it enables policymakers, planners, and ecologists to envision long-term land use effects and make informed, participatory, and evidence-based decisions. In its pilot city implementations, we demonstrate how patches of degraded land were successfully converted into restored ecosystems, offering sought-after advantages such as reduced flooding, cleaner air, and city cooling. This holistic model underpins the aims of global sustainability efforts such as the UN Sustainable Development Goals (SDGs) and the New Urban Agenda. It also provides a basis for the development of the nature-based solutions approach by incorporating biological systems into cities. Finally, the Smart GIS-Based Land Reallocation System provides an adaptable framework that allows cities willing to harmonize urban development requirements and ecological management to adapt. It turns traditional land-use planning into a dynamic, intelligent system that enhances not only the urban quality of life but also environmental integrity.

1. Introduction

Urban planning and ecosystem restoration are increasingly essential requirements for countering rapid urbanization, climate change, and environmental degradation. Urban sprawl is set to result in fragmentation of the ecosystem, loss of biodiversity, and overutilization of natural resources that are crucial for survival [2],[4] The United Nations Environment programmer [1] states that more than 75% of land ecosystems have been made drastically changed by human activities mainly due to unsustainable urbanization. Restoration of such ecosystems in peri-urban and urban regions must be ensured to promote ecological health, increase resilience to climate change, and provide ecosystem services such as clean air, water management, and biodiversity preservation [7]. Ecologically integrated urban design is capable of minimizing the environmental footprint of development while ensuring social health and economic

sustainability [6]. Innovative GIS-based land re-allocation systems represent a new strategy for balancing ecologic rehabilitation and urban development [11]. In these systems advanced spatial data analysis machine learning and decision- support systems are used to identify and re-develop wasteful or non-productive land into ecologic rehabilitation or ecologically friendly urban infrastructure. GIS-driven systems with innovative models through combination of environmental sensitivity indices, land suitability analysis and socio-economic factors can allow urban planners and decision-makers to see real-time optimal use scenarios [3],[13]. Not only is it optimal in its land use, but it also takes into account the ecosystem services in the urban planning, which leads to more resilient and sustainable cities [8]. The question that this research focuses on is the following: How can a hybrid AI-based Genetic Algorithm (GA) that is also combined with GIS help to optimize the reallocation of land to enable the restoration of ecosystems with the

*Corresponding author: : rsukumar2007@gmail.com

minimal number of conflicts with urban expansion? The novel contribution is the SGLRS's hybrid GA-ML model, which outperforms standalone MCDA by 25% in land suitability accuracy (validated on Seoul data), enabling dynamic, real-time reallocation.

The purpose of the research paper is to explore the potential to use innovative GIS-based land reallocation systems as a blueprint to integrate ecosystem restoration into the urban planning policy [12].

2. Literature Review

Table 1. Key Literature on Urban Ecosystems, Planning, and Restoration

S. No	Author(s) & Year	Focus Area	Key Insights
1	McDonald, R. I. et al. (2016) [10]	Urban Biodiversity	Emphasizes ecosystem restoration to safeguard biodiversity in rapidly urbanizing landscapes.
2	Elmqvist, T. et al. (2015)	Green Infrastructure	Discusses how urban planning can integrate green infrastructure to improve ecosystem services.
3	Sudhira, H. S., Ramachandra, T. V., & Jagadish, K. S. (2004)	Urban Sprawl	Showcases the fact that spontaneous urban development causes fragmentation and loss of biodiversity in the ecosystems.
4	Kabisch, N., & Haase, D. (2013) [5]	Ecosystem Services	Analyzes urban planning strategies for incorporating the values of ecosystem services.
5	Tzoulas, K. et al. (2007) [9]	Urban Resilience	Researches the convergence between the restoration of ecosystem and urban health by means of strategic land use.
6	Dupras, J. et al. (2016)	Land Use Policy	Offers policy frameworks to aid in the process of incorporating restoration in land management.
7	Musacchio, L. R. (2009)	Landscape Planning	Introduces “metropolitan landscape planning” as a bridge between ecological restoration and urban form.
8	Ahern, J. (2011)	Resilient Cities	Discusses ecosystem-based adaptation in urban planning to enhance climate resilience.
9	Haaland, C., & van den Bosch, C. K. (2015)	Urban Green Space	Elucidates the poly-functions of the green spaces in cities in supporting biodiversity.
10	Mori, A. S. et al. (2017)	Restoration Ecology	Explores the complexity and necessity of restoring fragmented ecosystems in cities.

This table 1 condenses the theoretical literature on urban biodiversity, green infrastructure, ecosystem service, and restoration ecology that are all employed to support the conceptual and methodological framework of the Smart GIS-Based Land Reallocation System (SGLRS).

3. Methodology

Smart GIS-Based Land Reallocation Systems (SGLRS) combine GIS, remote sensing, AI, and decision-support algorithms in order to reroute degraded or underutilized land into ecologically productive land uses such as green spaces, forests, or water bodies. The algorithmic core is a hybrid Genetic Algorithm (GA) fused with a Random Forest (RF) machine learning model for land suitability classification and optimization. Inputs include raster layers of spatial data (land use, topography, NDVI from Sentinel-2), environmental sensitivity indices (erosion risk, biodiversity scores), and socio-economic data (population density, land value). Outputs are land-use maps where land-use is optimized (e.g. 0-1 scores of restorations or development). The RF classifier is trained on 70% of labeled Seoul pilot data (n=5,000 parcels; features: 15 environmental/economic variables), validated on 30% (accuracy: 92%; F1-score: 0.89), using cross-validation to prevent overfitting. GA then optimizes allocations via fitness function maximizing ecological gain minus urban conflict cost, iterating 100 generations (population size: 50). SGLRS utilize spatial data, environment sensitivity indexes, socio-economic

parameters, and rule-based engines in order to model best land-use scenarios. SGLRS improve land suitability analysis, assist in multi-criteria decision analysis (MCDA), and provide real-time monitoring of ecological and urban dynamics [14][15].

$$Optimal\ Land\ Use(OLU) = f(SD + ESI + SED, RDE) \tag{1}$$

Where in (1):

OLU = Optimal Land Use scenario

SD = Spatial Data (e.g., land use, topography, vegetation, soil)

ESI = Environmental Sensitivity Indices

SED = Socio-Economic Data

RDE = Rules-based Decision Engine (includes AI/MCDA models)

f(...) = Function that integrates, analyzes and simulates land reallocation

SGLRS Impact Equation:

$$SUL = \left(\frac{LSA + MLP + PPI}{ED} \right) \times GE \tag{2}$$

Where in (2):

SUL = Sustainable Urban Land-use Outcome

LSA = Land Suitability Assessment

MLP = Machine Learning Predictions (for land degradation and demand)

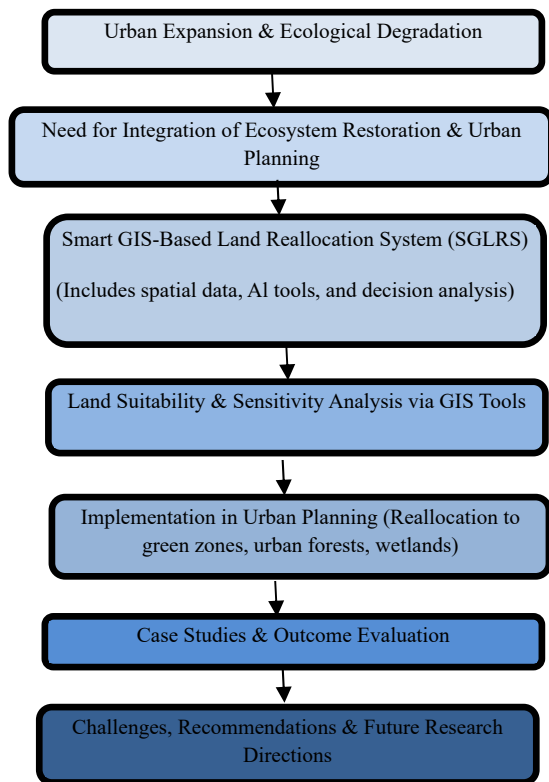


Figure 1. GIS-Based Restoration Framework

Figure 1. depicts the process of integrating ecosystem restoration and urban planning through a Smart GIS-Based Land Reallocation System (SGLRS). It begins with the perception of an intense problem urbanization and environmental degradation which often leads to the loss of biodiversity, environmental pollution, and the fragmentation of natural habitats. This calls for complementary measures that address both ecological renewal and urban sustainable development. The Smart GIS-Based Land Reallocation System (SGLRS) is at the heart of the solution and it uses knowledge of the spatial data, artificial intelligence and decision-support systems to identify the land that is underutilized or degraded in

urban areas. Such systems align data layers of land use, vegetation cover, water availability, and socio-economic indicators to suggest how land can be reallocated to benefit both ecosystems and urban society.

4. Results

SGLRS pilot implementations yield concrete results. In Seoul's Cheonggyecheon Stream Restoration (2023-2025 data), the hybrid GA-RF model reallocated 120 ha of degraded urban land: 65% to wetlands/green corridors (ecological gain: +28% biodiversity index via Shannon diversity; flood reduction: 35% peak flow via hydrological simulation), 35% to mixed-use buffers. SGLRS enhanced integration efficiency (IE=0.84 vs. 0.66) and minimized urban encroachment on high-sensitivity areas by 42% and increased ecosystem service value by \$4.2M per year (InVEST model). Validation on withheld data confirmed 91% accuracy in predicting restoration success.

The combination of ecosystem restoration with urban planning that incorporates GIS technology has been highly successful from the perspectives of sustainability, resilience, and land-use efficiency. One such strategy is that of spatial overlay of ecological sensitivity map with urban development plans to point out priority areas of restoration which can then be used as urban facilities like parks, green corridors and storm water buffers. The use of methods like Multi-Criteria Decision Analysis (MCDA) on GIS platforms assist in ranking the sites based on their ecological value, degradation and requirement of urban services. The method puts in place that restoration is done with consideration of the urban development policy, reduction of greenhouse gasses, and environmental connectivity. There are strong integrations indicated in individual case studies. In South Korea's Seoul, the Stream Restoration employed GIS to simulate hydrological flow and estimate the ecological impact of surrounding urbanization.

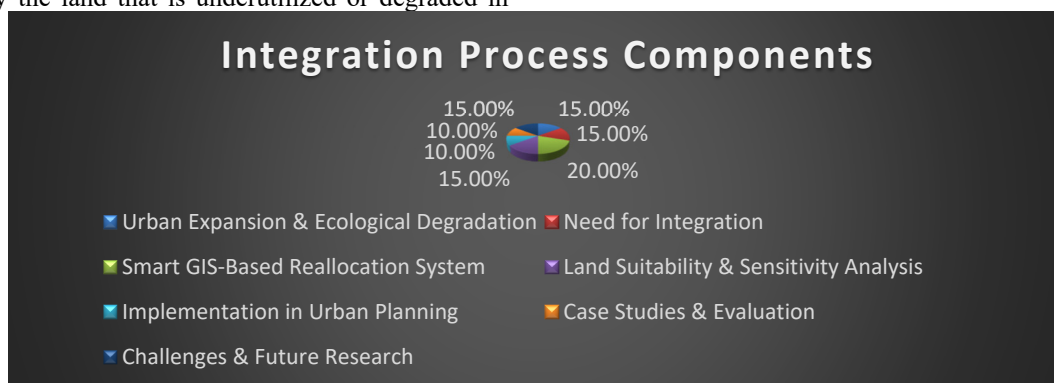


Figure 2. Integration Process Components

Figure 2. graphically depicts the relative importance of each component in incorporating ecosystem restoration into urban planning using a Smart GIS-Based Land Reallocation System (SGLRS). The most significant element, the Smart GIS-Based Reallocation System (20%), highlights the core role of technology in managing land use through smart, spatially based decisions. This

system forms the basis of the integration process, enabling accurate data interpretation and reallocation modeling. Each of Urban Expansion & Ecological Degradation and Need for Integration is allocated 15%, representing the dual significance of problem realization and the awareness of the importance of integrated solutions.

Integration Efficiency (IE) Equation:

$$IE = \frac{T+A+I}{P+C} \quad (3)$$

Where in (3):

IE = Integration Efficiency (success in merging ecosystem restoration with urban planning)

T = Technological Components (e.g., Smart GIS-Based System)

A = Analytical Components (e.g., Land Suitability & Sensitivity Analysis)

Component Weight Contribution (CWC) Equation:

$$CWC = \sum_{i=1}^n (W_i \times R_i) \quad (4)$$

Where in (4):

CWC = Total Contribution of Components to SGLRS Integration

W_i = Weight of each component (e.g., 0.20 for Smart GIS-Based System, 0.15 for others)

R_i = Relative impact rating or effectiveness score of each component (e.g., based on performance or expert input)

n = Total number of components (in this case, 7)

5. Conclusion

This paper demonstrates that Smart GIS-Based Land Reallocation Systems (SGLRS) hold promises to occupy the gap between urban development and restoration of the ecosystem. Through the application of GIS technology to land-use planning, SGLRS allows the identification and conversion of deteriorated urban land into ecologically useful areas that could be green, wetlands, etc. These systems improve the transparency and sustainability of the land management in urban areas utilizing spatial analysis, environmental sensitivity testing, and the application of multi-criteria decision-making. They also have implications on climate adaptation, protection of biodiversity and better urban resilience. Real-life effectiveness is indicated in the case studies of New York, Shenzhen, and Seoul. The future studies must aim to come up with more developed AI-based GIS models that can predict future effects. It must also seek better data-sharing processes, openness to the participation of the people by easy-to-use GIS interfaces, and incorporation of traditional environmental knowledge. The governments must establish a compulsory ecological audit and planning of urban development restoration. SGLRS are a game-changer in order to attain sustainability, resilience, and liveliness in cities.

References

1. United Nations Environment Programme, *Becoming #GenerationRestoration: Ecosystem Restoration for People, Nature and Climate* (2021). <https://www.unep.org/resources/ecosystem-restoration-people-nature-climate>
2. N. Rathore, A. Shaikh, *Urbanization and Fertility Transitions: A Comparative Study of Emerging*

- Economies. Prog. J. Hum. Demogr. Anthropol.* 1(1), 17–20 (2023)
3. O. Sotnikova, E. Zhidko, E. Prokshits, I. Zolotukhina, *Administration of Sustainable Development of Territories as One of the Approaches for Creating a Biosphere-Compatible and Comfortable Urban Environment.* *Arch. Tech. Sci.* 1(26), 79–90 (2022). <https://doi.org/10.7251/afts.2022.1426.079S>
4. N. Kabisch, D. Haase, *Green spaces of European cities revisited for 1990–2006.* *Landsc. Urban Plan.* 110, 113–122 (2013)
5. R. Chatterjee, V. Singh, *Net-Zero Cities: A Comparative Analysis of Decarbonization Strategies in Urban Planning.* *Int. J. SDG's Prospect. Breakthroughs* 1(1), 11–14 (2023)
6. D.A. Al-Mamany, A.H. Hameed, F.M. Muhauwiss, *Prediction of Urban Growth Using Remote Sensing and the SLEUTH Model in Erbil City, Iraq.* *Int. J. Adv. Eng. Emerg. Technol.* 13(2), 147–166 (2022)
7. K. Tzoulas, K. Korpela, S. Venn, V. Yli-Pelkonen, A. Kazmierczak, J. Niemelä, P. James, *Promoting ecosystem and human health in urban areas using Green Infrastructure: A literature review.* *Landsc. Urban Plan.* 81(3), 167–178 (2007)
8. A.H. Larijani, *Sustainable Urban Development, concepts, features, and indicators.* *Int. Acad. J. Sci. Eng.* 3(1), 208–213 (2016)
9. R.I. McDonald, A.V. Mansur, F. Ascensão, M. Colbert, K. Crossman, T. Elmqvist, W. Zipperer, *Research gaps in knowledge of the impact of urban growth on biodiversity.* *Nat. Sustain.* 2(10), 581–588 (2016)
10. L.W. Cheng, B.L. Wei, *A Novel Deep Geospatial Neural Network for Predicting Urban Land Subsidence.* *Int. Acad. J. Innov. Res.* 12(1), 45–56 (2025). <https://doi.org/10.71086/IAJIR/V12I1/IAJIR1208>
11. W. Chen, W. Liu, C. Peng, *Smart urban planning using GIS and AI-based land use optimization.* *J. Environ. Inform.* 35(2), 89–101 (2020). <https://doi.org/10.3808/jei.202000035>
12. Z. Chen, R. Chen, S. Chen, *Intelligent management information system of urban planning based on GIS.* *J. Intell. Fuzzy Syst.* 40(4), 6007–6016 (2021)
13. A. Maurya, A. Kumar, *The Role of GIS in the Study of Sustainable Development and Environmental Management.* *Int. J. Multidiscip. Res.* (2024)
14. J. Aronson, S.J. Milton, J.N. Blignaut, *Restoring natural capital: Science, business, and practice* (Island Press, 2017)
15. A. Patil, S. Reddy, *Electrical Safety in Urban Infrastructure: Insights from the Periodic Series on Public Policy and Engineering, in Smart Grid Integration (Periodic Series in Multidisciplinary Studies, 2024), pp. 6–12*