The Impacts of Urban Sprawl on Soil Resources in Tours Metropolitan area: Integrating Artificial Intelligence with the Conventional Mitigation Strategies

1. Introduction and research context

Urban sprawl is currently one of the most urgent spatial and environmental issues affecting metropolitan areas in Europe. Defined by low-density growth, a fragmented use of the land, and a growing reliance on private car transportation, urban sprawl alters the peri-urban and rural environment in profound ways. In the French context, medium-sized metropolitan areas like Tours have known a great deal of outward expansion in the past decades because of demographic evolution, economic change, and the development of infrastructure. Although this growth may help to ease housing shortages and boost economic activity, it is often achieved at the cost of high-quality soil resources.

Soil is a non-renewable resource over human timescales and is essential for ecosystem services such as food production, water filtration, carbon sequestration, and biodiversity conservation. The sealing, compaction, and degradation of soil caused by the dispersed pattern of urban growth endanger these ecosystem services. In metropolitan areas like Tours, where agricultural land and sensitive ecological areas represent a substantial part of the regional identity and economic base, uncontrolled sprawl may jeopardize environmental sustainability in the long term.

This study focuses on the effects of urban sprawl on soil resources in the Tours metropolitan area and explores the potential integration of Artificial Intelligence (AI) with conventional planning and mitigation practices. Through the integration of spatial analysis, predictive models, and AI-based decision-support systems, this study seeks to improve sustainable land-use planning practices and soil conservation measures.

2. Research problem and objectives

The main research question is related to the degradation and fragmentation of soil resources due to urban sprawl in the Tours metropolitan area. Conventional planning methods tend to use static zoning systems and trend analysis that might not be sufficient to represent dynamic relationships between demographic expansion, economic forces, environmental sensitivity, and soil vulnerability.

The research aims to answer the following main questions:

(1) What are the impacts of urban sprawl in Tours on soil quality, soil sealing rates, and environmental sensitivity?

(2) Which regions in the metropolitan area are most susceptible to soil degradation due to urban expansion?

(3) How can AI applications improve predictive models, land use optimization, and zoning plans to prevent soil loss?

(4) How can dynamic mapping using AI help local authorities in the implementation of sustainable soil management policies?

The primary research goals are:

(1) To evaluate the spatial and temporal effects of urban sprawl on soil resources in the city of Tours.

(2) To design analytical models using AI that combine environmental, socio-economic, and topographic factors.

(3) To design predictive models using AI that can forecast future sprawl distribution and soil risks.

(4) To design AI-assisted zoning and mitigation plans for sustainable land use.

3. Literature and theoretical framework

Urban sprawl has been extensively researched in European and international frameworks, and studies have focused on its environmental impacts, such as habitat fragmentation, agricultural land loss, and soil sealing. Soil sealing, in particular, leads to reduced infiltration rates, higher runoff and flood hazards, and long-term degradation of soil productivity.

Traditional measures to mitigate urban sprawl include: Compact city strategies, green belt schemes, agricultural land protection zones, environmental impact assessments, and strategic spatial planning frameworks

These measures, however, are often not responsive in real-time and do not have advanced predictive capabilities. The development of artificial intelligence presents new possibilities for improving urban planning practices. Applications of artificial intelligence, especially machine learning, deep learning, and geospatial data analysis, can facilitate the analysis of large datasets and the detection of complex patterns that may not be identified through traditional statistical analysis.

The study takes a systems approach in understanding urbanization and soil degradation as interrelated phenomena that are affected by demographic change, economic factors, infrastructure development, land market processes, and environmental conditions. AI is used as an integrative mechanism that can model such complex relationships.

4. Study area: Tours metropolitan context

The case of the Tours metropolitan area, situated in the Centre-Val de Loire region of France, is representative of medium-scale urbanization. The area has traditionally been known for its high agricultural productivity and cultural landscapes, which have been subject to intense peri-urbanization in recent decades.

The key features of the study area are as follows:

(1) Residential expansion areas at the urban periphery
(2) Growing infrastructure construction
(3) High-quality agricultural soils
(4) Sensitive river and valley environments
(5) Pressure from population growth and economic development

These factors create a complex territorial system where developments needs must be balanced against soil conservation imperatives.

5. Methodology

The study adopts a mixed-methods design that combines spatial analysis, AI modelling, and descriptive-analytical methods.

5.1. Data collection

The research uses:

(1) Satellite images and remote sensing data
(2) Soil quality and classification maps
(3) Land use and land cover (LULC) datasets
(4) Topographic data (Digital elevation models)
(5) Demographic statistics and population growth estimates
(6) Economic indicators and development trends
(7) Environmental and ecological sensitivity maps

5.2.Analytical framework

The methodology framework includes the following steps:

(1) Historical sprawl analysis:

The GIS-based spatial analysis technique is employed to analyse the historical growth of sprawl in the past decades. The land consumption rate, fragmentation index, and soil sealing percentage will be calculated.

(2) Soil vulnerability assessment:

The soil quality, soil type, slope, drainage, and ecological sensitivity criteria are combined to classify the soil vulnerability levels.

(3) AI algorithm application:

Machine learning algorithms like random forest, neural networks, and gradient boosting models are used to analyse the relationship between the sprawl drivers and soil characteristics.

(4) Predictive modelling:

Predictive modelling using AI forecasts future urban development patterns based on population and economic development trends, as well as infrastructure development. Areas of vulnerable soil that may be impacted will be identified.

(5) AI-driven zoning optimization:

Optimization techniques are employed to generate alternative zoning plans that give greater emphasis to soil conservation, taking into account development requirements.

6. Integration of AI with conventional mitigation strategies

Instead, AI is incorporated as an additional tool for decision-making. The study examines the potential of AI to improve the following: Strategic environmental assessments, urban growth boundaries, agricultural land protection policies, smart zoning regulations, and environmental monitoring systems

AI-based systems can provide real-time updates to maps and risk analyses as new information becomes available. This allows for adaptive planning, where the local government can revise zoning policies based on new trends.

For instance, predictive analytics could point to peri-urban agricultural areas with fertile soil and high development pressure. Conservation zoning or densification bonuses in already developed zones can then be applied.

7. Dynamic mapping and decision-support system

One of the most important results of the research is the creation of a dynamic mapping system using AI. In contrast to static maps, dynamic maps: Continuously incorporate new information, graphically represent projected sprawl scenarios, determine risk areas for soil erosion, mark environmentally sensitive areas, and offer interactive planning tools for decision-makers

The dynamic mapping system allows local authorities to: Continuously monitor soil degradation in near real-time, assess different development options, and apply data-driven land management policies.

8. Results and contributions

The outcomes of the study include:

(1) Comprehensive assessment of soil impacts: The study conducts a comprehensive spatial assessment of the impacts of urban sprawl on soil resources in Tours.

(2) AI-based predictive models: The study develops predictive models using AI that will enable the forecasting of urban growth.

(3) Improved zoning strategies: The study develops AI-assisted smart zoning strategies that enable the balance between urban growth and soil conservation.

(4) Enhanced monitoring capabilities: The study develops monitoring capabilities for the rates of soil erosion, compaction, and sealing.

(5) Scientific contribution: The study contributes to the development of interdisciplinary research in urban planning, environmental science, and AI.

(6) Policy recommendations: The study develops policy recommendations on the integration of AI in metropolitan planning.

9. Scientific and practical significance

This study has both theoretical and practical applications:

- Theoretically, it advances the knowledge of urban-soil interactions in the context of a metropolitan system.
- Methodologically, it illustrates the potential of AI to enhance spatial planning and environmental protection.
- Practically, it offers local authorities in Tours a set of tools for sustainable land use management.

By integrating AI technologies with the goals of environmental planning, this study promotes the transition towards smarter and more resilient metropolitan governance systems.

10. Conclusion

Urban sprawl is a major threat to soil resources, especially in medium-sized metropolitan areas like Tours. Soil degradation caused by sealing, fragmentation, and uncontrolled expansion affects ecological stability and territorial sustainability.

This research work proposes an innovative approach that combines artificial intelligence with conventional urban planning and soil mitigation measures. By means of spatial analysis, predictive modelling, and AI-driven zoning optimization, this research work seeks to minimize the environmental impact of urban sprawl while retaining socio-economic development goals.

The creation of dynamic AI-driven mapping and decision-support tools presents a paradigm shift for local authorities to adopt adaptive and data-informed land management practices. Finally, this research work seeks to prove that AI technologies have a crucial role to play in mitigating soil degradation, improving monitoring and predictive capacities, and promoting sustainable urban development in metropolitan areas.