

A GIS-based Method for Prioritising Brownfields Transformation into Multifunctional Urban Green Infrastructure: The Case of Rouen Metropolis

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Abstract

The spatial expansion of cities results in the loss of natural resources. It is therefore crucial to maintain ecological performance by balancing the land used for human purposes with efforts to restore or protect natural habitats. Here, we investigate how to transform brownfields into multifunctional urban green infrastructure. We use a GIS-based multi-criteria evaluation model to prioritise the brownfields in Rouen metropolis. We show that (1) the integration of site suitability and urban ecological demand is required, (2) Coupling Coordination Degree serves as an appropriate model for determining the interaction and coordination of site suitability and urban ecological demand.

Keywords Brownfield, Urban Green Infrastructure, Site Suitability Analysis, Multifunctionality, Spatial Planning

1. Introduction

Promoting reasonable land development while reducing land use challenges is a fundamental component of sustainable development (Wei & Ewing, 2018). The EU declared its policy of No Net Land Take by 2050, which France adopted in its national law with the policy “Zéro Artificialisation Nette” to encourage the reuse of developed lands (Science for Environment Policy, 2016). To follow these policies, the brownfields need to be redeveloped and given new life (Loures, 2015). It is recognised that brownfield redevelopment could bring a range of environmental, economic and social benefits (Wang et al., 2011). The integration of green infrastructure in brownfields, presents an attractive nature-based solution for addressing environmental concerns at brownfields (Hou et al., 2023). But is there a practical tool to prioritise brownfields for transformation into multifunctional urban green infrastructure? This question becomes crucial as costs involved in brownfield redevelopment can be significant (Bacot & O’Dell, 2006) and to avoid random allocation. We therefore investigated a GIS-based multi-criteria model to calculate the coupling coordination degree between site suitability and urban ecological demands. We demonstrated that 15 high priority brownfields exhibited a significant coupling coordinate degree and matching relationship to develop green infrastructure. This approach can be used as part of a spatial planning process, applicable to any city that faces similar problems. It provides support to identify suitable areas for green infrastructure expansion.

2. Methodology

The Green infrastructure decision-support tool derived from (Feng et al., 2023) is implemented in three phases. During the first phase, site suitability analysis of each brownfield assessed with seven criteria. In the second phase urban ecological demands was considered that could be addressed through green infrastructure planning. Finally, the coupling coordination model is used followed by an analysis of their matching degree through quadrant division.

The study is conducted in the Rouen metropolis, Normandie region, France, which covers approximately 663.8 km² and includes 71 municipalities (*Figure 1*). Located in the south of the Seine-Maritime department, the area had a total population of 496,629 inhabitants at the end of 2020. The distribution of brownfields within the metropolis aligns with the location of the rivers and valleys, with a few brownfields existing in the plateaus. Specifically, the municipalities situated on the left bank of the Seine, such as Oissel, Rouen (left bank), and Petite and Grand Quevilly, contain a large number

of brownfields, while several brownfields are also present in the municipalities surrounding the Cailly river. In the latest Cartofriches dataset, within the Rouen metropolis, a total of 416 sites have been identified as brownfields.

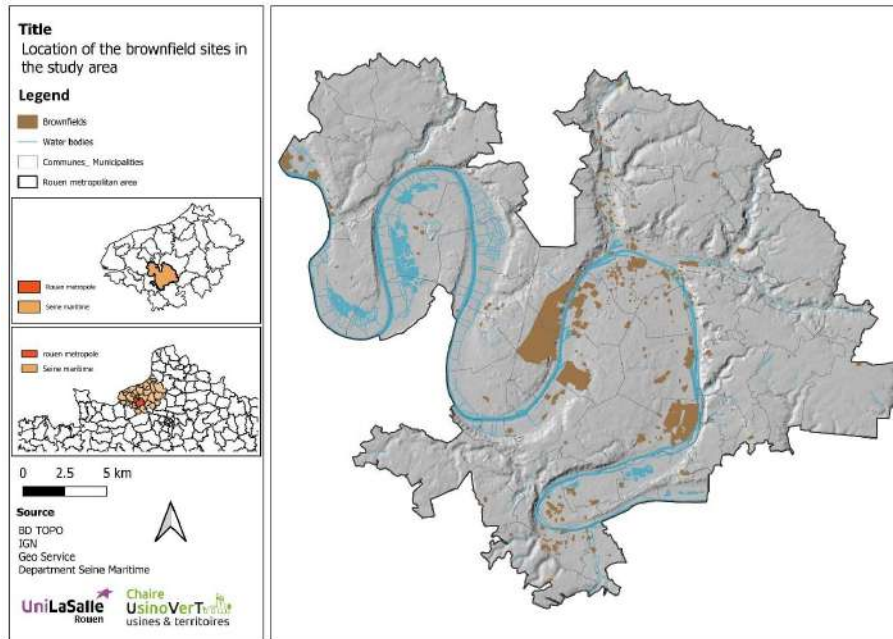


Figure 1: Map of the brownfields' location (Source: Done by the author)

For the site suitability analysis, we developed an index system with seven criteria comprising area, slope, NDVI, suitability of construction land, proximity to green area, proximity to settlement area, and soil contamination. Following this, we examined the attributes of each criteria based on literature and established a rating system. Then we determined the weights for each criteria through pairwise comparisons using the Analytic Hierarchy Process (AHP). For multifunctional green infrastructure planning, four indicators have been selected, including flooding risk, high land surface temperature, habitat fragmentation and air pollution. The urban demand values of brownfields were calculated by the zonal statistical tool in QGIS, which were then divided into five levels using the natural breakpoint method (Figure 2). Then, we calculated the weight of each index with AHP. To establish the coupling coordination degree model, the calculation was done with:

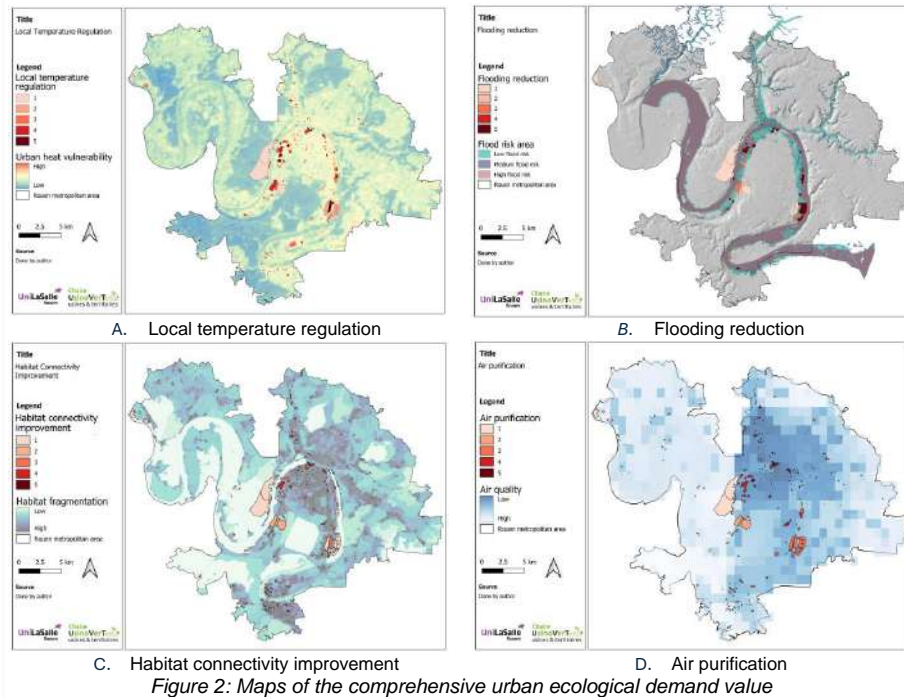
$$C = \frac{\sqrt{S \times D}}{(S + D)}$$

$$T = \alpha \times S + \beta \times D$$

$$CCD = \sqrt{C \times T}$$

S: Site suitability value
D: Comprehensive demand value
C: Coupling degree

T: Comprehensive coordination index
CCD: Coupling coordination degree
($\alpha = \beta = 0.5$)



Furthermore, quadrant division is being used to assess the position of points which represents site suitability and urban demands within a coordinate system. Lastly, we identified the brownfields with coupling coordination degree value greater than or equal to 0.85, and located in either quadrant “high demand–high suitability” or quadrant “high demand–low suitability”.

3. Results

Site suitability analysis was carried out for brownfields. The suitability values ranged from 1.64 to 4.52, while these scores varied, the general trend indicated favorable suitability overall. The analysis revealed that 115 brownfields, 36.05% of the total, had suitability values greater than 3.5. There was no clear spatial pattern of site suitability values, but brownfields located near the Seine river, specifically close to the Rouen and Elbeuf cities, tended to be more suitable for green infrastructure development. For the comprehensive urban demand value, the brownfields with values between four and five comprise 31 sites, representing 9.7% of the total number of brownfields, and there are 71 brownfields with values between three and four, representing 22.2% of the total. The coupling coordination between site suitability and urban demand values range from 0.50 to 0.95, indicating an almost ideal coupling relationship between them. This spatial pattern indicates a harmonious trend between the suitability of brownfields and the ecological demands of the surrounding area. Considering matching relationship (Figure 3), quadrant “high demand- high suitability” consists of 82 brownfields, with 25.86% of the overall total. Quadrant “high demand- low suitability”, hosts 69

brownfields, constituting 21.76% of the total. When considering the high-demand regions, the total count reaches 151.

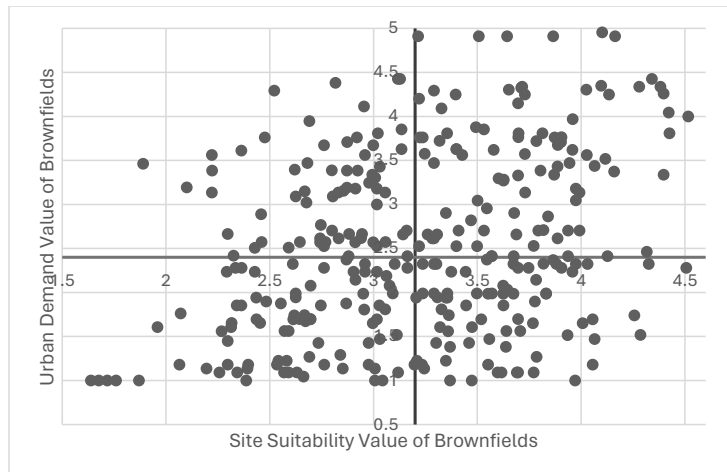


Figure 3: The matching relationship

The model shows 84 brownfields to be integrated into green infrastructure in Rouen metropolis. The brownfields with high site suitability and high urban demand values were categorized into three priority levels based on their coupling coordination degree. Specifically, 15 brownfields were identified as high-priority sites, having a CCD above 0.9. In addition, 28 sites fell into the medium priority category, with CCD values between 0.85 and 0.9, while 41 sites were classified as low priority, characterised by CCD values between 0.75 and 0.85. The spatial distribution of high priority brownfields interestingly shows an agglomeration of eight brownfields located in the Rouen city, in the industrial zone of the Rive gauche. The other priority sites do not show a clear trend but are all located within the alluvial terraces of the Seine and tributaries.

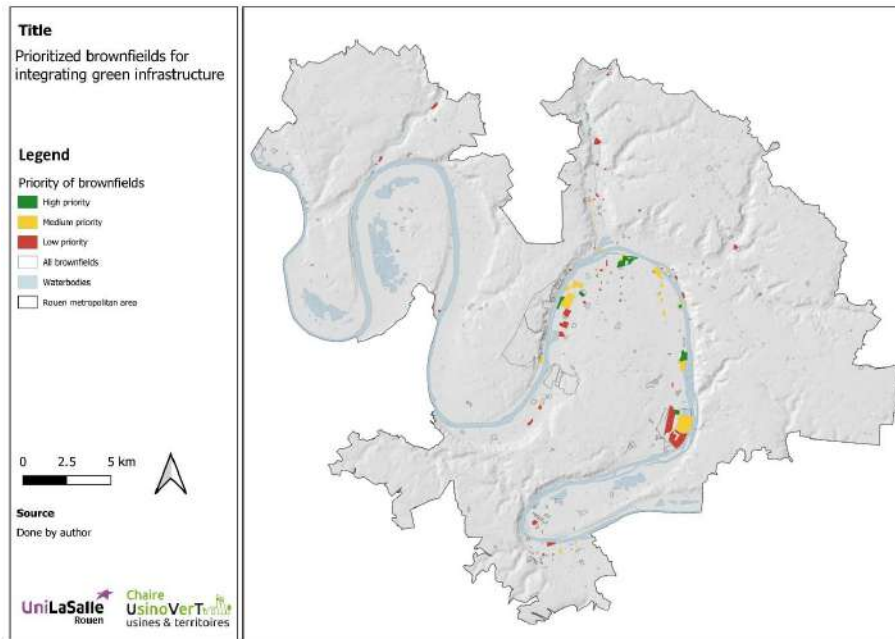


Figure 4: Map of the prioritized brownfields

4. Discussion

In the literature, previous studies have focused on either site suitability analysis or green infrastructure planning. However, the integrated outcomes present a unique perspective distinct from either the site suitability results or the findings on urban ecological demands when considered individually. Using this methodology, we can not only identify sites that are suitable for the implementation of green infrastructure based on a range of criteria such as area, slope, NDVI, etc., but also highlight sites that need intervention to meet multifunctional ecological demands of the area. The emphasis on multifunctionality represents a departure from the conventional approach observed in many previous studies, and potentially unlocks a wider range of benefits that green infrastructure can provide.

High priority brownfield sites are concentrated within the cities of Oissel, Saint-Étienne-du-Rouvray, Sotteville-lès-Rouen, Rouen (left bank), Le Petit-Quevilly, and Le Grand-Quevilly. Notably, all six municipalities out of a total of 71 are situated in close proximity to each other, south of one of the Seine river loops. While the medium and low-priority brownfields are more distributed, a significant portion of them are also concentrated in the same cities. Brownfields are all situated in close proximity to the rivers Le Seine, Le Cailly, and L'Austreberthe. They represent locations where green development is needed to complete the network of natural and semi-natural areas.

The Coupling Coordination Degree Model is a widely used method in environmental studies to determine the interaction and coordinated evolution of different systems, particularly in the Chinese literature. Numerous scientific papers have used the CCDM

to integrate complex systems across a range of disciplines, demonstrating its versatility and applicability (T. Li et al., 2022; Y. Li et al., 2012; Shi et al., 2020; Tang, 2015; Xing et al., 2019) . Despite its widespread use and high citation rate in the Chinese literature, this methodology has not penetrated the academic literature of other countries to any significant extent. Our study sheds light on the effectiveness of the CCDM by demonstrating its utility in analysing the complex relationship between site suitability and urban ecological demands.

This tool is a basis for decision-makers to explore and evaluate options and to conduct different scenarios that can easily be assessed by planners and developers at the beginning of the planning process.

On the one hand, there is a need to explore the application of the model in different regions, especially in different urban settings. On the other hand, it is necessary to collect socio-economic data in order to assess the sustainability of the interaction between brownfield regeneration and the development of multifunctional green infrastructure.

5. Conclusion

In this study, we propose a model to guide practitioners and researchers in identifying and prioritising brownfields suitable for transformation into green infrastructure. The proposed methodology has been developed by overlaying seven site attributes, with ecological demand considerations. Through the application of the coupling coordination degree model and quadrant division, the most suitable brownfields for transformation into green infrastructure have been identified. A total of 84 brownfields were selected for integration into green infrastructure within the Rouen metropolis. Among these, 15 brownfields were designated as high-priority sites, while 28 sites were categorized as medium priority, and 41 sites as low priority.

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