Investigating the Factors that Influence the Allocation of Nature-Based Solutions in Italy

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Abstract. Nature-based Solutions (NbS), including artificial wetlands, raingardens, and reforestation, provide an effective strategy for enhancing living circumstances in rapidly expanding metropolitan areas. Nonetheless, empirical evidence suggests that the decision-making processes related to projects, especially in informal settlement improvement programs, are not favourable to the NbS incorporation. This study investigates the meta-functional relationships among the principal parameters influencing the concentration of Nature-based Solutions (NbS) in multidimensional regions. The methodology begin with a thorough examination of active NbS projects in Italy. The primary component starts to identify the key variables affecting NbS concentration. The principal driving forces are associated with the sustainable performance achievable through NbS implementation, alongside the luxury effect, which pertains to a city's productive prosperity. These factors can support a green transition plan for sustainable and equitable urban expansion by eco-system approach-design and programming public actions.

Keywords: NbS · Allocation study · Factorial analysis

1 Introduction

Nature-based solutions (NbS) including rain gardens, green roofs, and green pathways are increasingly preferred for bolstering urban resilience to climate change effects. These programs focus on the preservation, sustainable management, and restoration of modified or natural ecosystems. Cohen-Shacham et al. (2019) contend that they must adeptly and adaptively tackle societal challenges while concurrently improving public health and biodiversity [1]. These solutions improve living conditions in quickly growing cities because to their adaptability, offering a possible approach for advancing policy and ameliorating informal settlements [2].

Megacities globally accommodate significant proportions of their people in unregulated housing developments that pose a challenge for governments dedicated to enhancing the living conditions of residents in burgeoning cities [3]. Informal communities

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frequently emerge beyond planning regulations and provide restricted access to public services. The provision of inexpensive, climate-resilient, and sustainable choices is currently a critical priority for authorities at governmental level, especially in Africa and South Asia, where the majority of the global population living in informal settlements is located. This is particularly pertinent in light of the ongoing climate crisis.

To attain these aims, governments, international institutions, and scholars are increasingly advocating for the implementation of Nature-based Solutions (NbS) to support the lives of historically marginalized populations [4]. The implementation of these solutions is expected to enhance climate resilience and provide vital ecosystem services, including improved water quality, reduced flood risk, and mitigation of urban heat islands [5]. E.g., the restoration of mangroves, implementation of wetlands, and construction of interconnected gardens are framed as a promising strategy to deliver social, cultural, economic, and ecological benefits to historically marginalized communities [6].

European funding for NbS originates from various EU initiatives that promote sustainability, environmental preservation, and climate change adaptation. The Research and Innovation Programme (2021–2027) supports projects addressing climate change, biodiversity, and ecological resilience. The LIFE Programme advocates for nature conservation and climate action, particularly through Nature-Based Solutions for ecosystem preservation and climate adaptation. The EU Mission on Climate-Neutral and Smart Cities allocates resources for sustainable solutions in climate-neutral urban environments, including nature-based approaches for water management and urban renaturation. These offer extensive opportunities to finance nature-based initiatives focused on environmental sustainability and climate change adaptation. In 2015, the EU launched the Resilient Europe program, which selected 15 communities to test NbS measures like artificial wetlands, urban parks, and water front space to improve urban eco-environment [7].

Despite the increasing prevalence of Nature-based Solutions (NbS) in urban settings, substantial deficiencies persist in our understanding of their integration in a manner that aligns with existing policies [8]. This often results in pronounced disparities among the local population, fostering economic and social inequality within a singular territory. The allocation of NbS assets in a territory is influenced by essential multidimensional driving forces (economic, environmental, and social), which in turn dictate the significance of the NbS program relative to the territory's purpose. This poses a challenge of effective resource allocation for optimal territorial development, influenced by primary factors that affect territorial ecological transition [9].

The research seeks to examine the primary meta-forces that could affect the distribution of Nature-based Solutions (NbS) in urban areas addressing their ecological transition. The identification of the driving forces influencing investment allocation in natural projects anticipates equitable decision-making frameworks grounded in principles of environmental, social, and economic justice. This meta-analytical study focusses on Italian cities through the application of Principal Component Analysis (PCA), and the initial findings of this ongoing research are intended for dissemination.

The work is organised into the following sections: Sect. 2 (Materials and Method) presents a comprehensive review of the distribution principles for NbS according to pertinent literature, along with a description of the methodology employed for the meta-analytical analysis of the primary factors influencing the distribution of NbS in Italy; Sect. 3 delineates the case-study results accompanied by a succinct explanation, while Sect. 4 articulates the conclusions of the work.

2 Materials and Method

The World Bank originally proposed the idea of Nature-based Solutions (NbS) in its 2008 report titled "Biodiversity, Climate Change and Adaptation: Nature-based Solutions in World Bank Investments" [10]. As part of the framework for climate change and development strategies, NbS emphasizes how humans and nature can live in harmony through measures taken to preserve, manage, and restore ecosystems in a sustainable way [11]. Environmental restoration, ecological engineering, ecological infrastructure, and green infrastructure are all examples of NbS measures. However, these are not the only types of measures that should be considered. Ecological infrastructure is defined as the collection of conditions and the combination of actions that are required to preserve, improve, and increase the operation of ecosystem services [12].

From a pragmatic perspective, several Nature-based Solutions (NbS) can be strategically implemented to achieve similar objectives or anticipated outcomes [13]. NbS provide several functions, such as enhancing ecosystem services, creating habitable urban environments, and fostering social inclusion [14]. In urban ecology, NbS emphasises the ecological significance of urban green spaces. Its objective is to restore impaired urban ecosystems by establishing green infrastructure, hence facilitating enhanced solutions to ecological and environmental issues [15].

What socio-economic and environmental factors may affect the equitable distribution of nature-based investments? This question will be addressed by presenting a concise assessment of the primary functional correlations established from empirical evidence in sub-Sect. 2.2. The 2.3 provides an explanation of the principle component search algorithm.

2.1 Review of NbS Allocation Drivers

Aligning NbS with other policies for infrastructure provision and NbS development is key to ensuring that they are fair and connected with the needs and priorities of residents [16]. Little is known, however, about the decision-making processes and values that orient how key stakeholders perceive these systems within the realm of policy and practice of government-sponsored NbS projects [17]. The literature reveals that to ensure that greening projects are successful, cost-effective and fair, these solutions must be embedded in the local culture and decision-making processes [18]. For instance, proposing the use of these solutions within some of the largest megacities in the Global South requires the recognition that similar systems have been used for centuries for urban water management and agricultural irrigation systems in the Global South within specific governance models and aligned with traditional and knowledge systems [19].

Championing the use of NbS in urbanized, or not, settlements, several authors have delved into how nature is perceived and approached by residents and governmental officers in these contexts. Studies have shown that the relationships between residents and nature are site-specific and underpinned by social and economic factors [20]. Others have argued that accounting for the needs of local residents is key, since people value nature differently and their priorities may change over time depending on their life conditions [21]. The literature of values indicates that different perspectives of nature and preferences for specific types of NbS can lead to vastly different behaviors toward greening initiatives [22]. A prevalent observation is that prosperity and educational attainment are positively connected with increased abundance [23] and enhanced diversity of urban vegetation [24].

A range of complementing socio-technological theories has been suggested to clarify the robust correlation between socio-economic status and urban vegetation patterns. The relationship between urban landscapes and nature has been handled, anticipating various configurations of interactions like that shown in Fig. 1 below. It outlines the conflicts between the landscape environment and the socio-technical and innovative forces that can shape developmental pathways [25].

Considering this theoretical framework, the analytical procedure is formulated (Principal Component Analysis, PCA), as detailed in the subsequent Subsect. 2.3, for the identification of the primary factors influencing NbS allocation within the region.

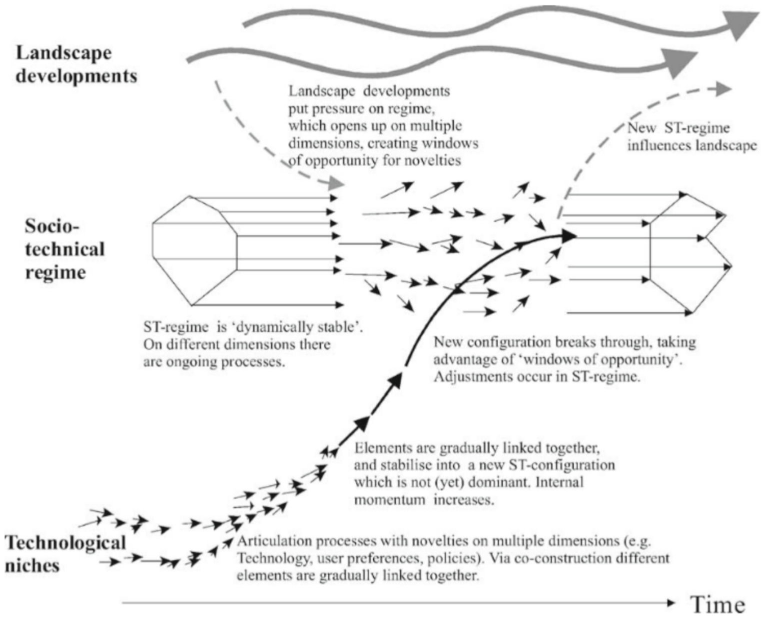

Fig. 1. Innovative system developments from a dynamic and multi-level perspective [25].

2.2 PCA for NbS Allocation

Principal Component Analysis (PCA) is a multivariate analysis technique that simplifies and synthesises a huge set of indicators into a smaller, more relevant subset, while minimising information loss.

According to Kendall's classification, these methods can be categorised into two groups: *a*) methods of dependency analysis; *b*) methods of interdependency analysis. The (a) encompasses variance and regression analysis; (b) encompasses various forms of correlation and contingency analysis. Kendall categorised PCA, which presupposes a linear relationship among *n* observed variables and *k* factors derivable a posteriori, as a multivariate analysis method.

The PCA model aims to synthesise *n* observed variables z_j (where $j = 1, 2, \ldots, n$) using *k* a posteriori defined variables (*factors*), with the condition that $k \leq n$ results.

The primary attribute of a posteriori-defined variables is their linear independence, which enhances their structural clarity. The factors synthesising the n observed variables can be categorised into two groups: a) common, if they are present in all or only in some of the observed variables; b) unique, if they are present in only one observed variable.

If we then denote $F_1, F_2, \ldots, F_m$ as the common factors and $U_1, U_2, \ldots, U_n$ as the unique factors, each observed variable z_j can be expressed in the form (with $j = 1,2, \ldots, n$):

$$z_j = a_{j1}F_1 + a_{j2}F_2 + \cdots + a_{jm}F_m + a_jU_j \quad (1)$$

Assuming the variable z_j can assume N values over N observations (with $i = 1, \ldots, n$), Eq. (1) can be articulated as:

$$z_{ji} = a_{j1}F_{1i} + a_{j2}F_{2i} + \cdots + a_{jm}F_{mi} + a_jU_{ji} \quad (2)$$

This is followed by the determination of the coefficients $a_{j1}, a_{j2}, \ldots, a_{jm}$ for each observed variable for the factors that were previously identified as common. Each coefficient denotes the relative significance of the individual analytical element.

To address (2), Thurstone's Centroid approach, that has been utilised in the proposed case study, can be employed to ascertain the matrix F, recognised as the matrix of factorial weights.

This is followed by Sect. 3 on the illustration of the case study analysed in order to rank the key parameters influencing the distribution of public investments in nature-based solutions in the Italian setting, specifically in a collection of cities where this type of project was discovered.

3 Case-Study

To identify the primary characteristics that, as of March 2025, have impacted the dispersion and subsequent concentration of Nature-based Solutions (NbS) in Italy, the quantity of NbS action programs executed in Italian cities was used as the dependent variable (z_i, where $i = 1, \ldots, 14$). The NbS programs are derived from the census conducted by the EU Repository of Nature-Based Solutions *Oppla*, which facilitated the survey of 54 NbS throughout 14 Italian cities (1. Reggio Calabria, 2. Bari, 3. Rome, 4. Siena, 5. Lucca, 6. Genoa, 7. Bologna, 8. Piacenza, 9. Ferrara, 10. Padua, 11. Mantua, 12. Trento; 13. Milan, 14. Turin) resulting in the identification of 14 NbS action programs.

In this study, the 14 NbS action program were valuated with several related metrics (z_j, whit $j = 1, \ldots, 7$), selected as control variables, including: Population Density (PopDen), URBanised area per-capita (URB), GDP, per-capita GDP (perGDP), per-capita

Green Area (GREEN), per-capita INCome (perINC), Sustainable Development Index (SDI). The SDI reflects the efficacy of the NbS program in attaining the SDG in relation to the development of the reference territory. The calculations were conducted based on the indicators gathered from the 14 cities where the NbS programs were evaluated, as provided by the OECD for review. The numbers for each indicator are determined for the period of time between 2022 and 2025, taking into account the most recent information that is available in OECD and *Il Sole24Ore* datasets.

Due to the absence of data on the relevant indicators for the 14 census cities on the *Oppla* website, the final collection of cities utilised in the principal component analysis comprises 7 cities: 1. Bari, 2. Roma, 3. Genoa, 4. Bologna, 5. Padua, 6. Milan, 7. Turin.

At follow, the Table 1 provides the matrix values of the variables z_j (PopDen, Urb, GDP, perGDP, GREEN, perINC, SDI) values and that of the dependent variable z_i (N° NbS). Table 2 presents NbS Italian initiatives that can be monitored within the *Oppla* case studies section. These are Nature-based Solutions (NbS) action programs mostly executed in urban settings and big metropolitan areas, focused chiefly on the defence against and mitigation of environmental hazards, including flood risk reduction.

Figure 2 depicts the geographical distribution of the interventions analysed by *Oppla* throughout the survey region of Italy.

Table 1. Values Matrix.

Cities	N° NbS [n.]	PopDen [ab/sqKm]	Urb [sqm/ab]	GDP [USD]	perGDP [USD/ab]	GREEN [sqm/ab]	perINC [€/ab]	SDI [n.]
1. Bari	2	643	155	19,604	29,993	63	22,419	44
2. Rome	6	697	162	196,135	57,107	90	27,206	52
3. Genoa	8	569	104	28,405	44,578	81	23,659	53
4. Bologna	1	387	139	39,193	53,599	98	27,626	56
5. Padua	2	872	258	22,105	45,379	127	27,936	44
6. Milan	10	1591	195	283,296	60,267	106	35,282	50
7. Turin	15	1005	153	67,728	45,367	58	25,224	46
Dev. St.	5	393	49	104,055	10,120	24	4,187	5
Max	15	1,591	258	283,296	60,267	127	35,282	56
Min	1	387	104	19,604	29,993	58	22,419	44
Avg	6	823	167	93,781	48,041	89	27,050	49

Table 2. NbS Italian projects.

Cities	NbS projects	Tot.
Bari	L. Braille Public Garden	2
	Lama Balice protected area	
Reggio Calabria	Bergamot production system	1
Rome	Let's Crop the Diversity (LCD)	6
	Greening Rome for human and ecosystem health	
	Transition Planning - Parco Agricolo	
	CES assessment through social media data in the urban parks of Rome (IT)	
	Participatory Reconversion Workshop	
	Reinventing the traditional use of rural commons through social and environmental innovation	
Siena	Co-Creation of an URBiNAT Healthy Corridor for Siena	1
Lucca	Improve hydraulic capacity of canal system	3
	Retention/sedimentation basin	
	Buffer strips along canals in the area of Lake Massaciuccoli	
Genoa	Green Façade Pilot Project, INPS	8
	Green Wall	
	Bioswale	
	Infiltration Basin	
	Rain Garden	
	Drought-resilient orchard	
	Slope afforestation	
	Tree groups and green areas	
Bologna	VEG-GAP Information Platform	1
Piacenza	Processed tomato supply chain	1
Ferrara	Green Infrastructure and Ecosystem Services for Urban Plan	2
	LIFE AGREE	
Padua	Biophysical analysis of public trees in Padova	2
	Uforest Case Study: WOWnature	
Mantua	Forest-habitat biodiversity payment scheme	1
Trento	Mapping and assessing ecosystem services to support urban planning in Trento	1

(*continued*)

Table 2. (*continued*)

Cities	NbS projects	Tot.
Milan	Environmental recovery of a quarry ATEg20	10
	Parco Nord Milan	
	NbS for urban regeneration	
	Greening Milan: Innovating Urban Spaces Through Nature-based Solutions	
	Environmental recovery of a quarry ATEg32 - Gaggiano, Trezzano sul Naviglio, Zibido San Giacomo	
	Environmental recovery of a quarry ATEg30 Pero	
	Environmental recovery of a quarry ATEg15 Paderno Dugnano	
	Flood Retention Basins of Lura River	
	Constructed wetlands	
	Integrated valuation of a nature-based solution for water pollution control	
Turin	Valdocco Vivibile: NbS for liveable and climate-proof neighbourhoods	15
	Farfalle in ToUr	
	Green indoor and outdoor walls	
	"OrtoMobile" - micro gardens in boxes	
	Didactic box gardens in schools	
	New green roof at WOW	
	Pollinator friendly garden	
	New soil production in Sangone Park	
	Butterfly gardens for schools and disadvantaged people	
	Mirafiori Castle's ruins recovery and new planting	
	Gardens integrated within housing	
	Green corridor and local natural heritage enhancement	
	Mirafiori Sud Living Lab	
	Gardens in Cascina Piemonte	
	Aquaponics test system	

3.1 PCA Implementation

The identification of the primary factors for the *j*-th variables is executed using Thurstone's centroid approach, which addresses PCA scenarios. The aforementioned algorithm is predicated on a sequence of following steps:

a) Creation of the normalised value matrix (X) for the analysis variables of dimensions $[n \times N]$ utilising the expression:

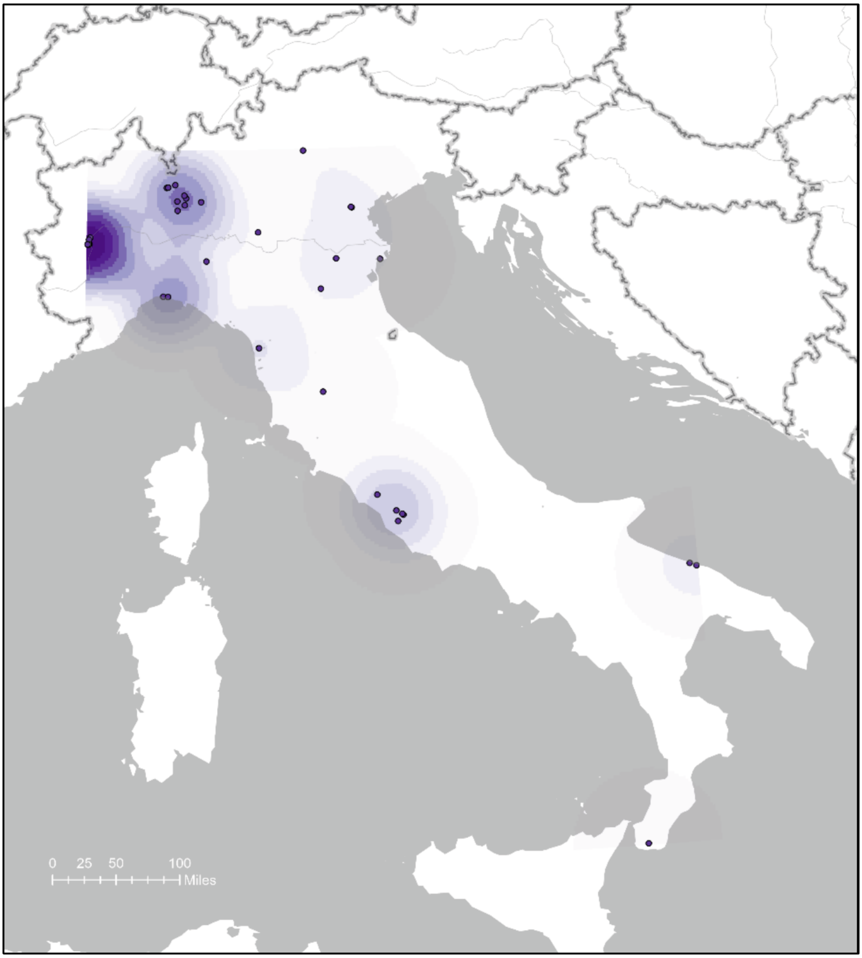

Fig. 2. Geographical-density distribution of NbS initiatives in Italy.

$$z_i = \frac{x_{ij} - \overline{x_j}}{\sigma_j} \tag{3}$$

where:

z_i = i-th NbS programme in Italian study cities (with $i = 1, \ldots, 7$);

x_{ij} = value of the j-th variable for the i-th programme NbS (with $i = 1, \ldots, 7$; $j = 1, \ldots, 7$);

$\overline{x_j}$ = avg value of the numerical series of the j-th analysis variable;

σ_j = standard deviation of the numerical series of the j-th variable.

b) construction of the factorial weight matrix (F) of dimension [1×7].

Subsequently, the matrix (X) of dimension [7×7] containing the variables' values normalised according to (3). Conversely, Table 3 displays the weights (f_j) of the analytical variables organised in the matrix (F) of dimensions [1 × 7].

$$X = \begin{bmatrix} 0.4587 & \cdots & 1.2015 \\ \vdots & \ddots & \vdots \\ 0.4616 & \cdots & 0.6037 \end{bmatrix}$$

Table 3. PCA outputs.

	PopDen	Urb	GDP	perGDP	GREEN	perINC	SDI
f_j	0.78	0.76	0.86	0.82	0.83	0.72	0.89

The Sustainable Development Index (SDI) emerges as the most significant factor ($f_{SDI} = 0.89$) influencing the concentration of Nature-based Solutions (NbS) in Italian cities, followed closely by the economic wealth indicator, GDP ($f_{GDP} = 0.86$). The latter indicates a correlation between the feasibility of implementing NbS and the economic resources available, relative to the cities' productive capacity. The variable exerting the minimal impact on the concentration of NbS is per capita income (perINC), with a f_{SDI} of 0.72. This suggests that Nature-based Solutions (NbS) must be rendered as available as feasible to the populace, irrespective of wealth disparities, to uphold the tenets of environmental, social, and economic justice.

4 Conclusions

Urban planners and politicians are increasingly interested in Nature-based Solutions (NbS), acknowledging it as a crucial tool for rejuvenating urban ecosystems and bolstering urban resilience. Despite the growing acknowledgement of NbS, there exists a paucity of research clarifying their contribution measures to urban policy and planning, with the majority of studies predominantly featuring qualitative analyses and comparative evaluations of specific examples. Thus, a difficulty arises in thoroughly elucidating the effects of NbS measures on urban growth [26].

The research not only shows the efficacy of Nature-based Solutions (NbS) measures but also proposed an investigative methodology that considers the NbS perspective based on principal driving factors. The findings indicated that NbS are crucial for enhancing urban sustainability. In alignment with [26], it is imperative to customise NbS to the unique characteristics and conditions of a city's production system. The results corroborate this perspective and may serve as a source of inspiration for the strategic implementation of NbS measures. This strategy will promote the creation of new spaces that are both of high quality and contextually pertinent, aligned with current economic and productive characteristics that meet public and private requirements.

The conducted analysis signifies a preliminary stage of continuous effort, and the described technique necessitates additional clarification to enhance the outcomes, for instance, by integrating a sensitivity analysis [27]. The next phase will entail a comprehensive examination of NbS concentration across several analytical scales, particularly within specific cities, employing the detailed cases of Turin and/or Milan. This seeks to clarify the elements that may affect the distribution of particular Nature-based Solutions, notably the developmental green-trajectories of a region [28].

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