Community gardens for well-being

Exploring the link between Community Gardens and Well-being at the neighborhood scale Overijssel province, the Netherlands

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July 2025

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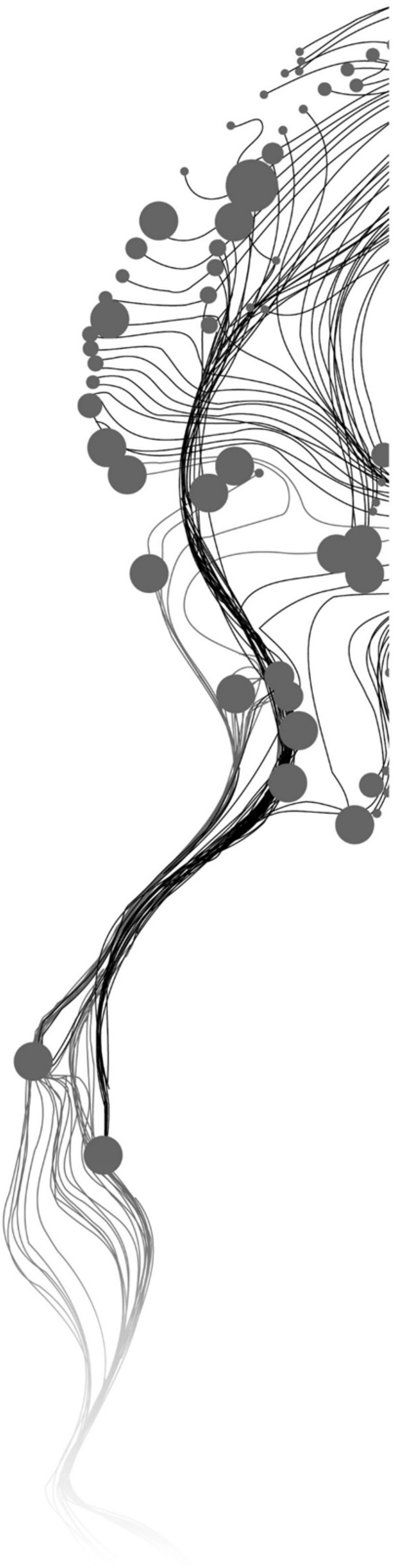

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ABSTRACT:

Community gardens offer numerous benefits, including improved health, social cohesion, and urban sustainability. While previous research has largely emphasized individual-level outcomes and user experiences, little is known about how these gardens relate to neighborhood-scale well-being indicators and whether their spatial distribution serves communities with the potential need. To address this gap, this study explores the spatial associations between community gardens and neighborhood-level well-being in Overijssel, the Netherlands.

Three primary objectives structured the research. First, spatial characteristics reflecting gardens' social and ecological functions were selected based on a literature review and available spatial data. Garden size, size per capita, vegetation health (NDVI), public transport accessibility, walking and cycling accessibility, and garden location are the selected qualities. Patterns were mapped using kernel density and spatial autocorrelation analyses, revealing that gardens are predominantly situated in rural neighborhoods and densely populated municipalities, particularly Zwolle and Steenwijkerland.

Second, neighborhood-level well-being indicators were compiled from reliable statistical sources, resulting in 27 measurable variables, to operationalize the Statistics Netherlands well-being framework. Hotspot analyses and comparative statistics highlighted significant urban-rural differences, with rural areas consistently displaying better overall well-being. Further statistical analysis found rural neighborhoods with community gardens exhibit notably higher resilience, social cohesion, and physical activity levels than those without. This spatial distribution of gardens suggests that they tend to be located in areas already characterized by higher well-being, indicating that neighborhoods with potentially greater needs and lower well-being indicators may be underserved by existing community gardens.

Third, associations between garden qualities and neighborhood well-being were examined using Kendall's rank correlation and Local Bivariate Relationship analysis in urban neighborhoods. Results indicated some statistically significant relationships, for instance, larger garden sizes per capita correlated positively with neighborhood resilience and social cohesion and negatively with stress. Spatial visualization showed that these associations were often spatially uneven. Additionally, low well-being neighborhoods that host low-quality community gardens were identified. Benchmarks and past literature were used to give suggestions on how to improve these gardens' qualities, to potentially improve the neighborhoods' well-being.

While causal relationships could not be established from this research, the study provides a replicable framework for integrating spatial and statistical methods to inform equitable community garden placement and design. It also highlights important avenues for future research, emphasizing the need for detailed qualitative data, individual-level information, and longitudinal studies.

Keywords: Community garden, Neighborhood well-being, Spatial analysis, Spatial equity

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1. INTRODUCTION

1.1 Community Garden concept and its importance

Urbanization has generated a series of environmental problems that encompass major challenges and threats to human health and environmental sustainability (Verma & Raghubanshi, 2018). Community gardens, as a unique type of Urban Green Spaces, have the potential to offer numerous benefits. This broad and clear definition of community gardens by Guitart et al. (2012) is what will be considered for this study: 'community gardens' are generally understood as 'open spaces which are often managed and operated by members of the local community in which food or flowers are cultivated' (p. 364). This contrasts with private gardens managed by a single family or individual plots (Guitart et al., 2012). They are recognized as important features in the urban landscape, providing a range of ecosystem services (ES), like Cultural services that are often the most highly valued, and include recreation, relaxation, nature experience, learning, social cohesion, and place-making (Camps-Calvet et al., 2016; Langemeyer et al., 2018). They contribute greatly to physical and psychological well-being (Thompson et al., 2007). Lambert et al. (2021), performing a systematic literature review, conclude that many studies indicate that community gardeners experience improved life satisfaction, happiness, general health, mental well-being, and social cohesion compared to non-gardeners (Lampert et al., 2021). Community gardens also provide Provisioning services, mostly including food production (Camps-Calvet et al., 2016). However, food production is not necessarily the primary purpose or motivation for all gardeners (Breuste & Artmann, 2015) They desire to connect with nature, have a quiet retreat, engage in physical activity, and enjoy the taste and freshness of self-grown produce (Breuste & Artmann, 2015). Community gardens also provide Regulation services, which mainly include air purification, local climate regulation, pollination, and maintenance of soil fertility (Camps-Calvet et al., 2016). They enhance community resilience to climate change and mitigate urban heat islands by providing urban green spaces (Nursey-Bray et al., 2014). These gardens can encourage pro-environmental behavior change, particularly towards reducing urban foodprints, which leads to low-carbon food consumption, through experiential and social learning (Kim, J. E, 2017). In short, community gardens provide many benefits, including fostering urban food production, creating social gathering spaces, and time devoted to beneficial leisure, all of which contribute to improved mental health and community well-being. Community gardens also align closely with the United Nations Sustainable Development Goals (SDGs), particularly SDG 3, Good Health and Well-being, SDG 11, Sustainable Cities and Communities, SDG 12, Responsible Consumption and Production, SDG 13, Climate Action, and SDG 15, Life on Land.

It is important to note that even though many related terms like "allotment garden", "civic garden", or "urban garden" exist, they often refer to areas with similar functions and benefits to community gardens (Camps-Calvet et al., 2016; Langemeyer et al., 2018) and are therefore considered the same for this research.

1.2 Problem statement

Despite the extensive studies on the social benefits of community gardens, they often focus on personal experiences, such as enhanced well-being, happiness, and social cohesion among gardeners (Lampert et al., 2021; Thompson et al., 2007) rather than spatial patterns. What remains unexplored is how the community garden characteristics are associated with community well-being on a city-wide or neighborhood scale. Exploring the spatial distribution and the quality of community gardens could reveal additional insights. Previous research has shown that community gardens can serve as tools for enhancing social equity by providing inclusive spaces for diverse communities and improving access to green spaces and healthy food (Ghose & Pettygrove, 2014; Poulsen et al., 2017). They also contribute to neighborhood quality of life by increasing social interaction, enhancing environmental aesthetics, and supporting urban resilience

(Armstrong, 2000; 'Yotti' Kingsley & Townsend, 2006). Understanding these patterns could highlight areas where new community gardens would be most impactful for promoting well-being and environmental benefits citywide, and where certain existing gardens can still be improved to increase well-being. Thus, the outcome of this research could help to address urban planning goals, such as increasing social equity and neighborhood quality of life.

In addition, while community gardens are known to provide diverse social and ecological benefits, many existing planning approaches do not systematically integrate multiple dimensions, such as social equity and environmental benefits, into a single, comprehensive structure. Smith et al. (2021) tried to address this gap by introducing a stakeholder-informed Multicriteria Decision Analysis (MCDA) framework that combines social and physical criteria to identify optimal locations for new community gardens (Smith et al., 2021). However, their framework still leaves room for incorporating additional ecological aspects, such as vegetation health or microclimate regulation, like urban heat mitigation, which are less explicitly represented.

This study aims to fill these gaps by identifying the different functions of community gardens and representing them spatially. In addition, it explores the link between community gardens and well-being by examining how various functions of these gardens are associated with different aspects of well-being and the overall quality of life of urban residents.

1.3 Research objectives and questions

The main aim of the research is to explore how various functions of community gardens are associated with different aspects of people's well-being in Overijssel province, the Netherlands. By analysing these relationships, the study aims to understand how community gardens can benefit residents' quality of life.

This main aim is divided into three objectives and corresponding research questions:

Objective 1: To identify different functions of community gardens.

a) What are the key spatial characteristics that capture the social and ecological functions of urban community gardens?
b) What is the spatial variation of these community gardens' characteristics?

Objective 2: To identify patterns of different well-being aspects in neighbourhoods with community gardens.

a) What are the key characteristics of neighbourhood well-being?
b) What is spatial variation in neighbourhood well-being?

Objective 3: To explore the spatial association between community garden qualities and well-being aspects in neighbourhoods.

a) What are the spatial associations between garden characteristics and well-being aspects?
b) How can improving community gardens' qualities enhance well-being in underserved neighbourhoods?

1.4 Structure of the thesis

The research is conducted in six chapters. This first chapter provided a primary background and justification for the research problem and reviewed research objectives and questions. The second chapter reviews the literature regarding the key concepts of the study. Chapter 3 first presents the study area and then describes the methodology of the study, and all the data used in this project. The study's findings and results are presented in Chapter 4 based on research objectives and questions. Finally, Chapter 5 discusses the findings and limitations of the research, and Chapter 6 provides a brief conclusion to bring the study to a close.

2. LITERATURE REVIEW

This chapter reviews the concepts associated with the study. It starts with introducing Urban Green Spaces and their functions and qualities. Community gardens, as part of this broad definition, are also later introduced in the section, and their functions and qualities are presented based on past literature. Well-being, as an important aspect of this study, is also presented in this section, based on the Statistics Netherlands (Centraal Bureau voor de Statistiek-CBS) structure. The literature reviewed in this section guided the choices made for this study.

2.1 Functions and qualities of Urban Green Spaces

Multiple definitions of Urban Green Spaces (UGS) exist in the literature, particularly regarding ownership and accessibility. Some represent UGS as "publicly owned and accessible open spaces within urban and peri-urban areas that are wholly or partly covered by considerable amounts of vegetation" (Farahani & Maller, 2018), p. 2). However, this definition might exclude semi-public spaces like some community gardens, which are frequently managed by local communities (Guitart et al., 2012). Therefore, for the purpose of this thesis, UGS also encompasses community gardens that are not always publicly owned. Urban green spaces provide numerous environmental, economic, aesthetic, social, and psychological benefits. They mitigate urban heat island effects, control different kinds of urban pollution, connect urban areas to the natural world, reduce the energy costs of cooling buildings, increase the value of properties around them, serve as a natural resource for relaxation and stress level reduction, and many more (Haq, 2011).

The quality characteristics of urban green spaces play a critical role in their use and their potential benefits. Higher-quality urban green spaces are associated with increased physical activity, lower obesity, and greater use by residents (Knobel et al., 2021). This research, that has been conducted in Barcelona, Spain, assessed the association between 10 different quality dimensions of UGS and physical activity, overweight/obesity, and their usage. These 10 quality dimensions were: quality of the surroundings, Access, Facilities of the area, Amenities of the area, Aesthetics and attractions quality, Incivilities, Safety, Area's potential usage, Animal biodiversity, and Birds biodiversity (Knobel et al., 2021). This study tried to understand the role of these qualities in promoting health and well-being. Their key findings were that higher [overall] quality of urban green spaces (located in a 300m radius of users' homes) was associated with more frequent use of them, increased physical activity, and lower risk of obesity among users. The qualities that were more strongly linked to these benefits were Bird diversity and Amenities. The absence of incivilities and surrounding quality was strongly associated with higher physical activity. Access, aesthetics, and safety were also linked to higher UGS use. An interesting observation that they had was that the mean quality of surrounding UGS was more important than just having one high-quality UGS nearby, which suggests the fact that having multiple moderately good green spaces is better than a single perfect one.

Another study in Brussels, Belgium, tried to emphasize the quality of urban green spaces and how these different qualities influence public satisfaction and use (Stessens et al., 2020). Thus, their goal was to develop a model that links objective green space characteristics to how people perceive them. The qualities they worked with were naturalness, quietness, spaciousness, cleanliness, safety, historical value, and cultural value. They developed a GIS-based model and used spatial indicators to show user-perceived qualities of urban green spaces. For example, layers of land cover, biological value, vegetation cover (NDVI), shape metrics, and noise levels. They reported different outcomes from their project. For example, Naturalness was well-predicted using GIS indicators like biological value, tree cover, and water presence, while Spaciousness depended on area, shape, and tree cover density, and Quietness was harder to model. They reported that Cleanliness, quietness, and safety were the most valued green space qualities for users and that large parks and peri-urban green spaces tended to have higher perceived naturalness and spaciousness (Stessens et al., 2020). Their novel view emphasizes how the user's perception is more important than just objective qualities because people don't always value what planners assume is important.

Lee et al. (2015) conclude that urban green spaces do not automatically provide well-being benefits just because they exist, and it is their actual use and function that determine their impact (Lee et al., 2015). Thus, it's important to consider when, why, and how people use these green spaces; In other words, not everyone benefits from UGS the same.

2.2 Well-being and quality of life and the role of Community Gardens

The concepts of well-being have been widely studied across different disciplines, and they generally refer to an individual's or community's overall state of health, happiness, and prosperity, encompassing both subjective and objective dimensions (Martinez et al., 2021). This is a crucial distinction in well-being research. As Martinez et al. (2021) cite Cummins et al. (1997), subjective well-being considers individuals' perceptions and emotional experiences, whereas objective well-being assesses measurable life conditions such as access to healthcare, education, and public services (Martinez et al., 2021). These dimensions often intersect, forming a multidimensional approach to assessing quality of life.

Several theoretical frameworks and structures categorize well-being differently. One influential perspective links well-being and sustainability. The United Nations Sustainable Development Goals (SDGs) emphasize that achieving well-being requires economic, social, and environmental balance (Martinez et al., 2021). This approach usually considers urban green spaces, including community gardens, as part of a broader sustainability effort and highlights how they contribute to sustainability through green spaces, food security, and economic resilience.

Another perspective focuses on community-based well-being. This approach emphasizes that community well-being extends beyond individual happiness. According to Kee, Lee, and Phillips (2019), community well-being consists of physical environment, like access to green spaces, social environment, like neighborhood interactions, economic resilience, and participatory decision-making governance (Kee et al., 2019). This perspective highlights the place-based nature of well-being, arguing that urban planning and community development/conditions play essential roles in shaping the quality of life. Based on this perspective, urban gardens serve as a tool to build trust, community identity, and civic engagement (Phillips & Wong, 2017).

In summary, well-being is a multidimensional and interdisciplinary concept, and various frameworks offer different ways to understand and measure this term. Understanding these different perspectives is crucial for assessing the role of community/urban gardens in enhancing both individual and collective well-being.

2.3 Well-being aspects in the Netherlands

Well-being is a broad concept that can vary greatly depending on cultural, social, and other contextual factors. In the Dutch context, Statistics Netherlands (Centraal Bureau voor de Statistiek, CBS) definition of well-being is used and will be used in this project as well. Statistics Netherlands is a Dutch governmental institution that gathers statistical data about the Netherlands, and their mission is to publish reliable and consistent information. Based on the definitions used by this institution, well-being refers to the quality of life here and now and the extent to which it is or is not achieved at the expense of the well-being of future generations and/or people elsewhere in the world (Centraal Bureau voor de Statistiek., 2022b). Well-being concerns people's freedom of choice, the choices they actually make here and now to make their lives worthwhile, the results of these choices, and the effects of their choices on others, in the future and elsewhere. Well-being 'here and now' concerns people currently living in the Netherlands. It includes their personal characteristics and the quality of the environment in which they live. This is the part that this project will focus on.

According to CBS, people shape their well-being through the use of various forms of capital, such as financial resources, social networks, natural surroundings, and knowledge or skills. These resources enable individuals to make meaningful life choices, support their personal development, and enhance their quality of life. Some of these resources are personally owned or shared within families and communities, such as savings, friendships, or neighborhood support. Others are collectively provided through institutions, governments, and society at large, including education, public safety, and access to green infrastructure. In addition, there are shared resources that benefit everyone but are not directly managed by individuals or institutions, such as clean air, biodiversity, or cultural values. Together, these different capitals contribute to both personal and societal well-being (Centraal Bureau voor de Statistiek., 2022b).

CBS monitors well-being on the basis of eight themes: subjective well-being, material well-being, health, labor and leisure time, housing, society, safety, and the environment, with each having various indicators (Centraal Bureau voor de Statistiek., 2022b). The CBS approach to well-being is not only nationally significant but also embedded within broader international frameworks for sustainable development. CBS aligns its monitoring system with the Conference of European Statisticians (CES) Recommendations on Measuring Sustainable Development (Centraal Bureau voor de Statistiek., 2022a), and actively contributes to efforts by the United Nations, OECD, and Eurostat to harmonize well-being statistics across countries. In this context, the Sustainable Development Goals (SDGs) provide a globally recognized structure for understanding and evaluating ecological, social, and economic aspects of well-being. CBS integrates the SDGs into its well-being reporting by using them to organize themes relevant to Dutch policy and society. Well-being is considered the overarching concept, with the SDGs representing a set of internationally agreed targets that support its realization. CBS categorizes SDG indicators into four types, resources and opportunities, use, outcomes, and subjective assessment, to present a balanced, systematic view of development trends. This integrated framework allows CBS to track not only whether goals are being met, but also how people perceive and experience progress.

As mentioned before in section 2.2, the concept of well-being and quality of life covers objective and subjective components, though it can sometimes be debated where the borderline between the two is exactly located. Objective indicators are measures informing about a situation (e.g., the size of the house someone lives in), whereas subjective indicators are about an evaluation of that situation (e.g., how satisfied one is with the housing space available) (Boelhouwer & Noll, 2014). This distinction can also be reflected in the type of indicators that CBS uses.

Table 1 shows the well-being themes and indicators as they are presented by CBS and reflects the type of indicators, whether they are objective or subjective.

Table 1: Well-being Theme and Indicators presented by CBS (Netherlands, n.d.)

Theme	Indicator	Type of indicator
Subjective well-being	Satisfaction with life	Subjective
	Feeling in control of life	Subjective
Material well-being	Median disposable income	Objective
	Individual consumption	Objective
Health	Healthy life expectancy	Subjective
	Overweight population	Objective
Labor and leisure time	Long-term unemployment	Objective

	Net labor participation	Objective
	Higher educated population	Objective
	Satisfaction with leisure time	Subjective
	Time lost due to traffic	Objective
	Satisfaction with work	Subjective
Housing	Housing costs	Objective
	Satisfaction with housing	Subjective
Society	Contact with family, friends, or neighbors	Subjective
	Voice and accountability	Subjective / Objective
	Trust in institutions	Subjective
	Trust in other people	Subjective
	Changes in values and norms	Subjective
	Voluntary work	Objective
Safety	Feeling unsafe in the neighborhood	Subjective
	Victims of crime	Objective
Environment	Managed natural assets	Objective
	Quality of inland bathing waters	Objective
	Nitrogen deposition & terrestrial nature areas	Objective
	Urban exposure to particulate matter	Objective
	Environmental problems	Subjective

The CBS definition of well-being will be used as a guiding framework, but it's important to note that the data will be gathered from other resources, especially since the CBS well-being data is only available at the municipality level, and this research aims to study the neighborhood scale. The research will maintain the structure and concept of well-being as outlined by CBS, and alternative objective and subjective indicators that are directly or potentially linked to community gardens will be chosen for the analysis.

2.4 Functions of Community Gardens: How, When, Where, and Who do community gardens benefit?

Community gardens can offer a range of improvements to residents' well-being. However, not all benefits are experienced equally by everyone. Community gardens vary in their structure and accessibility, which in turn shapes who benefits from them and how. As noted by Raneng et al. (2023), these gardens may include a combination of individual and shared plots, along with communal areas for socializing and the shared use of tools, food, and other resources (Algert et al., 2016; Raneng et al., 2023). Their governance models also differ; some are open to all, while others restrict access to specific groups, such as schools, hospitals, or community organizations (Guitart et al., 2012). Some gardens charge membership fees, while others are free but exclusive (Dolley, 2020). Many are supported, either directly or indirectly, by local governments through land provision or funding for set-up and maintenance. This diversity shapes the fact that some benefits are experienced mainly by garden users, while others can extend to the broader neighborhood, even to non-participants. And in some cases, the wider community may engage with the garden through events or visits; in others, they may benefit simply by living near a vegetated and managed green space. In this section, the examples of benefits are listed, following the wellbeing themes in Table 1 in section 2.3.

- Direct benefits for community garden users

Subjective Well-Being

Several studies have demonstrated the positive impact of community gardens on subjective well-being and life satisfaction. Blair et al. (1991) reported that gardeners experienced significantly higher life satisfaction and more positive life events compared to non-gardeners (Blair et al., 1991). Van den Berg et al. (2010) found that gardening positively influenced well-being, life satisfaction, and reduced loneliness (Van Den Berg et al., 2010). Mourão et al. (2019) highlighted that gardeners who visited gardens frequently considered themselves happier (Mourão et al., 2019). Similarly, Koay and Dillon (2020) observed that community gardeners reported higher levels of subjective well-being and optimism than those engaged in individual or domestic gardening (Koay & Dillon, 2020).

Material Well-Being

Community gardens in the United States often serve different functions depending on the communities in which they are located. As Butterfield (2020) shows, gardens are more frequently found in both low-income, ethnically diverse neighborhoods, where they often emerge as a grassroots response to disinvestment and food insecurity, and in predominantly white, highly educated areas, where they are typically framed as tools for sustainability and food system reform (Butterfield, 2020). Importantly, the demographic and policy context of this study in New York City, USA, differs substantially from the Dutch context. Nonetheless, it highlights the potential for community gardens to reflect, and possibly reinforce, socio-spatial inequalities.

Algert et al. (2016) demonstrated that community gardens can improve nutrition and food security among low-income groups (Algert et al., 2016). Their study reported an average monthly cost saving of $84 for gardeners, which significantly supplemented their diet and alleviated financial struggles.

Health

Community gardens contribute positively to health outcomes. Van den Berg et al. (2010) noted that older gardeners (62+ years) scored better on health and well-being measures compared to non-gardening peers, though such differences were not observed among younger groups (Van Den Berg et al., 2010). Soga et al. (2017) found that community gardeners reported better general health, fewer somatic complaints, improved mental health, and stronger social cohesion (Soga et al., 2017).

Community gardens also promote healthy food production, encourage dietary changes, and increase physical activity, as noted by Mourão et al. (2019) (Mourão et al., 2019). These aspects collectively support healthier lifestyles and combat overweight populations.

Society

Community gardens can play a vital role in strengthening social ties, fostering emotional well-being, and promoting community-based environmental stewardship. In a study of 27 urban gardens in Barcelona, Langemeyer et al. (2018) found that gardens provided a wide range of ecosystem services (ES), including social cohesion and place-making. These gardens were not only spaces for food production but also hubs of family and social interaction, where individuals could spend time with loved ones, build friendships, and feel part of a community. Gardening promotes community engagement (Langemeyer et al., 2018). Blair et al. (1991) found that gardeners participated more actively in community projects compared to their neighbors (Blair et al., 1991).

Gardening activities foster social connections and trust. Gerber et al. (2017) reported greater social support among gardeners, while Booth et al. (2018) observed a stronger sense of community (Gerber et al., 2017). Cummings et al. (2008) demonstrated that community gardens created belonging and trust among African refugee participants (Cummings et al., 2008).

- Benefits for the wider community beyond the garden users

While much of the literature emphasizes the experiences of community garden users, there is growing evidence that gardens can contribute to neighborhood well-being more broadly and benefit the wider community beyond garden users.

Housing

Community gardens influence housing costs and property values. McCabe (2014) highlighted that community gardens attract new residents, stabilize neighborhoods, and generate economic benefits (McCabe, 2014). Voicu and Been (2008) found that community gardens significantly increased nearby property values, especially in poorer neighborhoods, by as much as 9.4% within five years of a garden establishment (Voicu & Been, 2008).

On the other hand, satisfaction with housing involves various factors, including living environment quality, air quality, and noise levels (Centraal Bureau voor de Statistiek., 2023). Jeong et al. (2018) indicated that residents valued community gardens for their provision of shade, relaxation, and social interaction spaces (Jeong et al., 2018). These are the qualities that can enhance the surrounding area, even for those who do not directly participate in community gardening. Truong et al. (2022) emphasized the role of gardens in enhancing green infrastructure and placemaking, which improves residents' satisfaction with their living environments (Truong et al., 2022). Similarly, Hong et al. (2020) found that community gardens positively influenced satisfaction with living environments and fostered community spirit (Hong et al., 2020).

Safety

Community gardens provide safe havens in low-income areas, offering a sense of nature, community, and security, as noted by Schmelzkopf (1995) (Schmelzkopf, 1995). McCabe (2014) further suggested that these spaces can reduce urban youth crime and stabilize neighborhoods (McCabe, 2014).

Environment

Community gardens contribute to urban biodiversity by serving as habitats for various flora and fauna, thereby enhancing urban ecosystems (Clarke et al., 2015; Dubová & Macháč, 2019). These contributions occur not only within the boundaries of the gardens but also through broader ecological functions in the surrounding urban area, for example, by supporting pollinators, improving soil health, and enhancing ecological connectivity.

Community gardens can also enhance environmental well-being by improving soil quality and supporting nutrient retention. Zhao et al. (2024) found that soils within raised beds in community gardens in Perth, Australia, exhibited significantly better soil health than adjacent urban soils. Raised bed soils, compared to surrounding bare ground, had lower bulk density, higher levels of total carbon and nitrogen, and improved cation exchange capacity, which are indicators of enhanced soil structure and fertility (Duddigan et al., 2020; Zhao et al., 2024). In addition, Junior et al. (2022) emphasized that urban green spaces, like botanical gardens, reduce particulate matter concentration compared to less vegetated areas (Junior et al., 2022).

By dividing the benefits into those that directly affect garden users and those that benefit the broader community, we can gain a clearer understanding of the multifaceted role that community gardens play in residents' well-being. Who is actually benefiting from existing gardens? This question is central to understanding the true impact of community gardens. While some benefits, such as increased property values or improved environmental quality, extend to all residents in a neighborhood, others, such as social interactions, volunteer engagement, and mental health improvements, are primarily experienced by those who actively participate in gardening. This distinction is a crucial step in the analysis. Table 2 summarizes the mentioned benefits based on this distinction.

Table 2: Community gardens' benefits to users and the wider community beyond their users

Benefits to users	Benefits to the wider community
Better subjective well-being and higher satisfaction with Life	Attract new residents and generate economic benefits
More positive life events and a higher level of optimism	Increase nearby property values
Reduced loneliness	Increase residents' satisfaction with their living environment
Consider themselves happier	Providing safe havens in low-income areas and offering a sense of security.
Food security for low-income neighborhoods	Increasing urban biodiversity
Sustainable food systems in high-income neighborhoods	Better soil health compared to urban soils (higher carbon and nitrogen)
Monthly cost savings for supplementing their diet from the garden for low-income groups	Reduce particulate matter concentration compared to less vegetated areas.
Better general health for older gardeners	Improving residents' satisfaction with their living environment.
Better reported perceived health	
Improved mental health	
Stronger social cohesion and place-making	
Increase physical activity and lower weight	
Healthier diet	
Provide a sense of belonging and trust, and feeling part of a community	
Promote community engagement and create hubs for social interactions	

2.5 From community garden benefits to their characteristics

While the previous section, 2.4, focused on how community gardens contribute to various aspects of well-being, this section examines the specific qualities and characteristics of gardens that may underlie those benefits. Existing literature offers valuable insights through studies that propose criteria for planning, siting, and evaluating community gardens. As said, most of these criteria are designed to guide where gardens should be located, rather than understanding how the qualities of existing gardens relate to different well-being aspects. This research will later bridge that gap by reviewing and adapting site selection criteria from the literature and reframing them as indicators of garden characteristics.

Caneva et al. (2020) propose a dual-level framework for understanding and evaluating urban community gardens with Italian cities as the case studies. Based on empirical analysis of case studies in cities such as Rome, Milan, Bologna, and Turin, the authors first identify twelve key descriptive variables, including garden size, morphology, management type, user profiles, and degree of urban integration, to map the diversity of existing community gardens. Building on this foundation, the study then introduces a preliminary set of qualitative sustainability indicators structured around six thematic areas of governance, design and management, environmental aspects, social and educational aspects, economic aspects, and urban integration and landscape. These indicators are designed to support participatory evaluation and improvement of urban community garden initiatives, to address goals such as food security, environmental restoration, social inclusion, and cultural reconnection (Caneva et al., 2020).

Sonneveld et al., (2021), also had the same goal (Sonneveld et al., 2021). They aimed to develop a decision-support tool that helps policymakers identify suitable areas for urban allotment gardens based on various criteria. They treat urban allotment gardens specifically as a subset of urban agriculture. Their main goal was to address the information gaps on selection criteria that have led to little political will to support urban agriculture as a solution to reduce poverty and food insecurity. The authors used ten key criteria to determine land suitability for urban agriculture, based on expert assessments and spatial data. The site-selection tool developed in this article can also be used for allotment gardens as a specific form of urban agriculture within the larger context and is mentioned to be dynamic, flexible, and can adapt to different scenarios or policy interventions over time.

In the same year, Smith et al. (2021) presented a systematic, stakeholder-driven approach using Multi-Criteria Decision Analysis to identify the best locations for urban community gardens. The authors argue that community gardens can generate multiple social, environmental, and economic benefits, but these vary based on garden characteristics and local contexts. Therefore, location and design must be guided by a strategic planning approach. The final goal of the study was to overcome biases related to decisions made ad hoc or by community requests that may reinforce existing unequal patterns of urban investment and increase economic disparities, and to optimize social and environmental objectives that deserve greater attention in site selection approaches. As a result, they developed two siting indices (Social characteristics and Physical setting) that incorporate stakeholder-weighted criteria related to physical and sociodemographic factors and applied these indices to identify suitable parcels within the urban core. Thus, the turning point of this research was considering social aspects alongside the physical ones. (Smith et al., 2021).

Ahmad Zaki et al., (2023) also tried to determine suitable locations for urban gardening using GIS tools combined with a Multi-Criteria Decision-Makingmethod (Ahmad Zaki et al., 2023). Their main aim was to overcome various challenges that urban farmers face in Malaysia, like limited and suitable land access, water availability, and many others. The authors use various criteria to assess land suitability, which are validated by experts through interviews. The Analytic Hierarchy Process is used to structure and prioritize the various criteria and sub-criteria involved in the decision-making process. They clearly mention that they considered spatial criteria in their analysis but also incorporated expert input to validate and refine the criteria. Thus, while the main criteria are physical, the expert feedback adds a qualitative layer to the analysis, ensuring that the physical criteria reflect practical and relevant considerations for urban gardening. Even though they didn't consider any separate social factors for their methodology, the variable of proximity to settlement areas can be categorized as an important social rather than a physical factor.

One relevant example of urban agriculture as a tool for community engagement and integration is presented by Pálsdóttir et al. (2021), who investigated the role of the Botildenborg project in Malmö, Sweden (Pálsdóttir et al., 2021). The study focused on how nature-based and urban farming activities could support a sense of belonging among migrants, particularly women with refugee backgrounds. Using semi-structured interviews, the authors explored participants' experiences and perceptions related to inclusion, trust, and social connection. The project emphasized not only food production but also interpersonal interaction, language learning, and skill-building as benefits of urban agriculture. Attributes of urban agriculture highlighted in the study included accessibility, social safety, aesthetic and sensory values of the garden, and opportunities for active participation. The outcomes pointed to improved social integration, strengthened personal identity, and increased emotional well-being among participants, suggesting that urban agriculture can play a significant role in enhancing both individual and community-level resilience.

Nearly all reviewed studies prioritize physical criteria, emphasizing the importance of selecting sites that are physically accessible and environmentally viable. Social factors are increasingly recognized as essential in community garden siting decisions. These criteria support community gardens' role in addressing urban inequalities and promoting health. And as a common approach, they all try to promote community gardens as sustainable urban developments. Table 3 summarizes the presented qualities across these studies, with the benefits they address.

Table 3: Summary of community garden qualities that have been addressed in past literature

Source	The main aim of the research	Study area	Community garden qualities	Benefits addressed
(Caneva et al., 2020)	To define evaluation indicators for urban community gardens.	Italy: Rome, Milan, Bologna, Turin	Size, Morphology (Slope), Soil, Sunlight, Water supply, Biodiversity value, Local pollution, Accessibility, School presence, Community center, presence, Distance to green areas	Savings (economic support) and productivity, Food security, Environmental restoration (and ecosystem functions), Environmental education, Sociability, Cultural value
(Sonneveld et al., 2021)	To develop and apply a spatial optimization model to determine the most effective locations for new urban allotment gardens to maximize social and environmental benefits.	Benin: Abomey-Calavi, Cotonou, Porto-Novo	Cadaster availability, Soil suitability, Road accessibility, Land-use suitability, Groundwater depth, Safety for women, Geological suitability, Surface water availability, Soil & groundwater pollution, Distance to market	Food security, Poverty reduction, Reducing the effect of heat islands, Urban waste into compost (improving soil quality)
(Smith et al., 2021)	To prioritize potential sites for community gardens using multicriteria spatial analysis.	US: Phoenix Metropolitan Area	Food deserts Community health, Low-income neighborhoods, Park-poor neighborhoods, Community space proximity, Minority neighborhoods, Residential proximity, Population density, Commercial proximity, Bikeability, Mass transit accessibility, Bare ground cover, Heat vulnerable Neighborhoods, Extreme temperature areas, Stormwater runoff, Shrub vegetated Groundcover, Mesic groundcover	Community health and nutrition improvement, Food security, Access to open green space, Improve community life, Foster cultural identity, Cooling benefits, Improved social cohesion, Reduced stress, Prevent stormwater runoff
(Ahmad Zaki et al., 2023)	To determine the suitability of land and the optimal location for the development of community gardens.	Malaysia: Shah Alam	Slope, Elevation, Land use, Proximity to settlement areas, Road accessibility, Proximity to water access	Food security, Promotion of physical activity and overall health, Foster social connections, Provide valuable educational opportunities, Enhance property values, Reduce crime rates, Enhance biodiversity, Contribute to overall environmental improvement
(Pálsdóttir et al., 2021)	Investigating the role of Urban agriculture and migrants' sense of belonging	Sweden: Malmö	Accessibility, Social safety, Aesthetic and sensory values of the garden, Opportunities for active participation	Improved social integration, Strengthened personal identity, Increased emotional well-being among participants, A safe meeting place, Opportunities to learn

In exploring the relationship between community gardens and urban well-being, this research faces a challenge due to the limited focus in existing literature on the characteristics of community gardens themselves. Previous literature mainly concentrated on criteria that are used for identifying suitable locations for them and have contributed greatly to this subject; however, we know little about how community gardens have contributed to a community's well-being and through what characteristics; quantifying this relationship could help us to know more nuanced improvement for community gardens besides having the perfect location. To address this gap, the criteria derived from past literature will be refined as criteria to assess the quality of community gardens. Thus, this research will develop a set of indicators that fit the specific approach and the goal of this study.

3. METHODOLOGY

This chapter is structured according to the research objectives and corresponding research questions introduced in section 1.3. Each part of the methods aligns with one of the three research objectives and addresses specific questions related to that objective. This approach provides a clear framework to describe the data sources, processing steps, and analytical methods used in the study. Before addressing the specific objectives, the study area is first presented to provide a geographical and contextual background.

3.1 Study area

The Overijssel Province in the Netherlands is the area where the research will be carried out. The province is located in the eastern part of the country and is bordered by Germany. With a population of about 1,184,000 as of January 2023 (Centraal Bureau voor de Statistiek., 2023). It has a total area of 3,421 km2 (Allecijfers, 2023). Overijssel is divided into 25 municipalities, and its capital is Zwolle.

Overijssel is one of the provinces in the Netherlands with the highest proportion of the population that consider themselves satisfied with their life (87.2%), satisfied with their free time (78.6%), satisfied with their living environment (87.3%) and the highest rank in contact with family, friends and society indicator (73.4%) (Centraal Bureau voor de Statistiek., 2022b). This province also reported very high experienced health among other provinces. These factors make Overijssel a compelling case for this research, and exploring what specific aspects of community gardens are linked to these positive experiences of well-being.

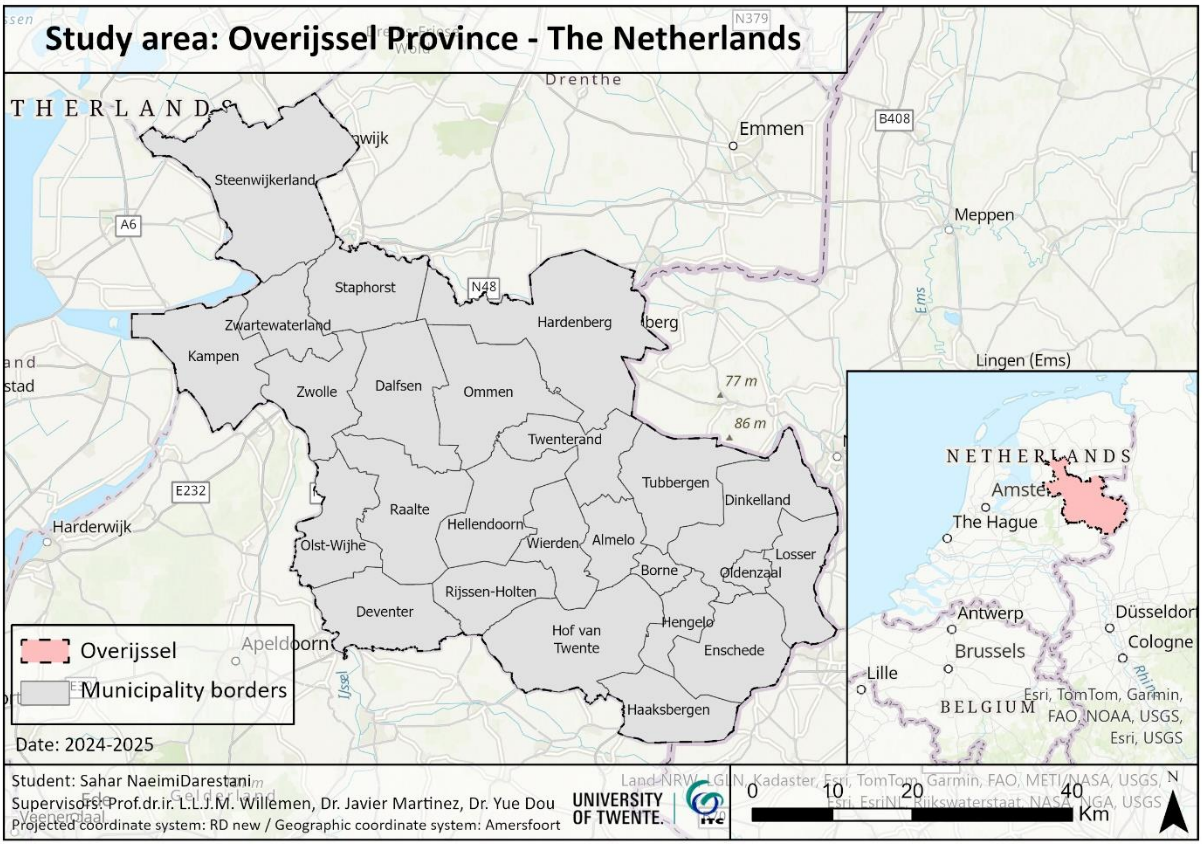


Figure 1: Study area: The Overijssel province, The Netherlands- Data source: CBS (2024), Basemap: Esri, World Topographic Map.

3.2 Identifying different functions of community gardens.

The first objective aims to examine how community gardens in Overijssel differ in their spatial characteristics and to identify patterns that reflect their potential social and ecological functions. This analysis supports the broader goal of understanding how garden characteristics may relate to aspects of well-being in the province. To begin this process, it was necessary to identify a set of spatial qualities that represent the functions of community gardens. For example, garden size may reflect ecological capacity and social accessibility, while proximity to public transport may influence those who can benefit from the garden.

Most existing literature focuses on siting criteria for future gardens, often aiming to maximize environmental or social benefits in urban planning contexts. While these studies offer useful indicators, they are not designed to describe existing gardens or their current functions. Therefore, this study builds on previous research by reviewing and reframing these siting-related qualities as descriptive spatial indicators of community gardens. These indicators were then used to explore the spatial variation of garden characteristics in the study area.

Each indicator will be presented in the following sections, along with its data source and explanation of how it relates to the social or ecological functions described in the literature. The two research questions under this objective guide this process:

3.2.1 Key spatial characteristics that capture the social and ecological functions of urban community gardens

To answer this research question, it was first necessary to identify spatial characteristics of community gardens that reflect their social and ecological functions. These characteristics were selected based on recurring indicators found in the past literature in section 2.5, where most studies focused on garden planning and site selection. Although these studies had different goals, they consistently emphasized certain qualities such as size and access. This research adapts and reframes such qualities to describe existing gardens in Overijssel. By refining the selection to a limited number of indicators, the analysis prioritizes depth and enables more focused interpretation. The selected indicators are location of the garden, size, size per capita, public transport accessibility, walking and biking access, and vegetation health.

Each indicator is explained below, along with its relevance, supporting literature, and the method used to obtain and process the corresponding spatial data:

Location of the community gardens

The location of a community garden is a foundational characteristic that influences who benefits from it and how. Previous studies show that community gardens can positively affect a range of well-being aspects, including housing satisfaction, safety, environmental quality, and neighborhood-level health outcomes (Clarke et al., 2015; Hong et al., 2020; Jeong et al., 2018; McCabe, 2014; Truong et al., 2022). However, the impact of these benefits often depends on where gardens are located. Therefore, understanding the spatial distribution of community gardens in the study area is essential to identifying where such benefits may occur and whether certain neighborhoods are underserved.

To map the location of community gardens in Overijssel, a combination of data sources was used. First, OpenStreetMap (OSM) data was downloaded using an ArcGIS plugin, which provided initial polygons tagged as “allotments” or “community gardens.” These locations were then verified and supplemented using Google Maps through manual inspection. Additional gardens were identified and cross-checked using a land use map of the study area to ensure higher accuracy and completeness. This process resulted in a final dataset of community garden locations, which was used in further spatial analysis.

Size of the community garden

The size of a community garden directly influences its capacity to support diverse activities, accommodate more users, and provide ecological benefits. Larger gardens are often associated with greater biodiversity, enhanced carbon sequestration, and more opportunities for community engagement (Caneva et al., 2020). As such, garden size can be seen as a spatial reflection of both ecological and social functions.

To obtain this indicator, the area of each garden polygon identified in the previous step was calculated using the "Calculate Geometry" tool in ArcGIS Pro. The result provides a standardized measure of garden size in square meters for each location.

Size per capita

Population density is an important factor in community garden planning, as it helps determine how many people can benefit from it (Lovell, 2010; Taylor & Lovell, 2014). A larger population can also provide a stronger base of active gardeners to support and maintain the space (McClintock & Cooper, 2010). Rather than using population density alone, this study uses garden size per capita to better represent the balance between available green space and the number of potential users in each neighborhood. This indicator reflects the social function of accessibility and equitable use.

To calculate this indicator, population data for each neighborhood were obtained from the Netherlands Statistics (Centraal Bureau voor de Statistiek, 2024). Garden size values were then divided by the number of residents in the corresponding neighborhood using ArcGIS Pro. The result provides a relative measure of garden space available per person/potential user.

Public transport accessibility

Access to public transport ensures that community gardens are reachable by a broader population, particularly those without access to private vehicles. This aspect of accessibility has been highlighted in several studies, including Smith et al. (2021), as a key factor for promoting inclusivity and equitable use of green spaces (Smith et al., 2021). As such, proximity to public transport reflects the garden's potential to function as a well-connected urban amenity serving diverse users.

To assess this indicator, public transport station data were obtained from two sources, train station locations provided by ProRail (2024) and bus station data from the Central Stop File (CHB), published by the NDOV management organization (2023). Using the Near analysis tool in ArcGIS Pro, the shortest distance between each community garden and the nearest public transport station was calculated. The distance was measured from the garden's boundary to the nearest bus or train stop. This method resulted in a continuous variable representing each garden's accessibility.

Walking and biking access

Proximity to community gardens is a critical determinant of their use. Gardens that are reachable on foot or by bicycle support more frequent visits and promote healthy, low-emission mobility. Smith et al. (2021) emphasize that walking and cycling access is essential for maximizing the public value of urban green spaces (Smith et al., 2021). This indicator reflects the potential of gardens to support both social inclusion and active lifestyles.

To evaluate walking and biking accessibility, a network-based service area analysis was conducted in ArcGIS Pro using the "Network Analyst" toolbox. The input road network was derived from the Core Network Cycling dataset (Movares Consultants and Engineers, 2021), which includes bicycle lanes that are commonly paired with pedestrian infrastructure in the Netherlands. Community gardens were set as "facilities", and service areas were generated for three distance thresholds: 300 meters, 1250 meters, and 3750 meters.

The 300-meter threshold follows the Accessible Natural Green Space Standard (ANGSt), which recommends access to green space within 300 meters of one's residence (Zulian et al., 2024). The 1250-meter and 3750-meter distances represent approximately 15-minute walking and cycling distances, as promoted in the "15-Minute City" urban planning model (Moreno et al., 2021).

The resulting service areas were clipped to the neighborhood boundaries in which the gardens are located. This allowed for the calculation of the proportion of each neighborhood that falls within each distance buffer, providing a spatially explicit measure of how accessible the gardens are by walking or biking.

Vegetation health

Vegetation health is a core ecological characteristic of community gardens, supporting biodiversity, regulating microclimates, and contributing to air purification. Remote sensing tools provide efficient and standardized ways to assess vegetation health, with the Normalized Difference Vegetation Index (NDVI) being one of the most widely used indicators (Caneva et al., 2020). NDVI is a spectral index calculated using the red and near-infrared (NIR) bands of satellite imagery, with the formula:

$$NDVI= (NIR+Red)/(NIR-Red)$$

NDVI values range from -1 to +1, with higher values indicating healthier, denser vegetation. In addition to vegetation conditions, NDVI can also be linked to other environmental factors such as soil fertility and water quality. For instance, changes in NDVI have been shown to correlate with soil organic matter and total nitrogen content (Qi-guo, 2013), and with water quality indicators in nearby streams (Griffith et al., 2002).

To assess vegetation health in the study area, 3-meter resolution and 8-band satellite imagery were obtained from Planet Scope. Image selection was a critical step due to the weather conditions in 2024. Although vegetation in the Netherlands typically peaks from May to mid-July, according to reports, heavy rainfall led to flooding in various parts of the country, including the eastern region of Twente in Overijssel in May 2024[1]. This weather condition potentially delays typical growth patterns. Based on these weather records and the availability of cloud-free images, imagery from 30 July 2024 was selected to ensure that vegetation had recovered and reached a stable, healthy condition.

NDVI was calculated using ArcGIS Pro by applying the index formula with the "Raster calculation" toolbox to the Planet Scope imagery. Since satellite data are in raster format, and each community garden is a vector polygon consisting of many pixels, the "Zonal Statistics as Table" tool in ArcGIS Pro was used to derive a single representative NDVI value per garden. The 90th percentile value was selected to reduce the effect of extreme values, such as bare patches of soil or single trees with high NDVI. This approach focuses on the upper-end distribution of NDVI values, representing the healthier vegetation areas within each garden while excluding potential outliers.

Table 4 summarizes the resources used to gather these garden qualities:

Table 4: Spatial data sources used to map community garden characteristics

Layer	Source	Restrictions	Year
Community gardens	OpenStreetMap Google maps	Open source	2024
Roads	National Roads Database (NWB)	Open space No usage restrictions	2024
Public transport stops (Train)	Train stations data by ProRail	Open space Not allowed in National Georegister	2024

[1] https://www.newsflare.com/video/664429/netherlands-severe-flooding-hits-eastern-twente-region-after-heavy-rainfall?a=on&utm

Public transport stops (Bus)	Central Stop File (CHB), published by the NDOV management organization	Open space No usage restrictions	2023
Cycling path	Core Network Cycling by Movares Consultants and Engineers	Open space Not allowed in National Georegister	2021
Vegetation Health (NDVI)	Planet data satellite images 30-July-2024	Restricted: Access granted through a student account under the Planet's Education and Research Program. Usage is subject to Planet's terms and cannot be freely redistributed.	2024
Statistical data at the regional level of neighborhoods in the Netherlands	Centraal Bureau voor de Statistiek, published by Overijssel geoportal	Open space No usage restrictions	2024

Appendix A also presents the data management plan for this study.

3.2.2 Spatial variation of these community garden characteristics

To explore the spatial variation of community garden characteristics across the study area, two approaches were applied. First, Kernel density was used to produce a continuous visual representation of garden concentration and identify spatial clusters. Second, because well-being data used in later stages of this research is available at the neighborhood level, all community garden indicators were aggregated accordingly to generate a single value per neighborhood for each variable.

Kernel density is a spatial analysis technique used to create a smooth surface that highlights areas with higher concentrations of a specific feature, in this case, community gardens (Silverman, 2018). The Kernel density tool in ArcGIS calculates the density of garden polygons within a specified radius, helping to identify hotspots where gardens are more densely distributed. This visualization provides an intuitive understanding of spatial trends and garden distribution patterns in Overijssel.

To align the analysis with neighborhood-level well-being data, all garden-level indicators were aggregated by neighborhood using an intersect spatial join. This method assigned each garden to the neighborhood it intersects with, ensuring that gardens spanning multiple boundaries were included appropriately. The aggregation method varied based on the nature of each indicator. For example, for the garden size, the total area of all community gardens within a neighborhood was summed up. For NDVI, public transport accessibility, and garden size per capita, the average value of all gardens in the neighborhood was used. And for walking and biking accessibility, it was more complicated. To avoid double-counting overlapping service areas, the buffer polygons of all gardens were first dissolved. Then, the total area covered by these dissolved buffers was calculated within each neighborhood and expressed as a percentage of the neighborhood's total area.

To further understand the spatial structure of these aggregated indicators, Global Moran's I was applied to each variable. Moran's I is a measure of spatial autocorrelation, which tests whether high or low values of a variable tend to cluster together geographically. This analysis helps determine whether the observed spatial patterns are random, clustered, or dispersed, and supports a more robust interpretation of spatial variation across neighborhoods.

3.3 Identifying patterns of different well-being aspects in neighborhoods with community gardens.

The second objective focuses on identifying and analyzing neighborhood-level well-being patterns in Overijssel, with attention to areas with community gardens. As mentioned in section 2.3, CBS defines well-being through eight broad themes, such as subjective well-being, material well-being, health, and environment, and the data are only available at the municipality level. To adapt the analysis to the neighborhood scale, the first research question aims to identify alternative indicators that reflect similar aspects of well-being. These were selected based on their conceptual alignment with the CBS indicators and their availability at the neighborhood level.

After identifying suitable alternative indicators, the second research question investigates the spatial variation of these well-being characteristics across the study area. This step allows for a more detailed spatial analysis of neighborhood conditions and sets the foundation for exploring their relationship with community garden characteristics in the next phase of the study.

3.3.1 Key characteristics of neighbourhood wellbeing

This part of the study aims to identify a set of well-being indicators available at the neighborhood level, as a substitute for the municipality-level well-being values provided by CBS (2022). The goal is to build a multi-dimensional picture of neighborhood well-being in Overijssel.

These alternative indicators were selected based on three criteria, conceptual similarity to the original CBS indicators, spatial resolution at the neighborhood level, and public availability and accessibility from reliable national datasets. The main data sources used include the Health Monitor for Adults and the Elderly (2022), CBS neighborhood statistics (2022), and the Livability Barometer (2022) provided by the Ministry of the Interior and Kingdom Relations. For example, to reflect the CBS indicator "Satisfaction with life" under the theme of subjective well-being, this study uses "Very much stress" and "High resilience" from the Health Monitor. Similarly, for the theme of health, variables such as perceived general health, weekly physical activity, and overweight prevalence were selected. For material well-being, several income-related variables from CBS datasets were used, including average disposable income and difficulty making ends meet. Social indicators were drawn from both the Health Monitor and the Livability Barometer, covering aspects such as social loneliness, emotional support, and neighborhood cohesion.

These alternative indicators help to identify the well-being pattern over the study area and at the neighborhood level, in the next question.

3.3.2 Spatial variation in neighbourhood well-being

To explore the spatial distribution of neighborhood well-being in Overijssel, a combination of visual and statistical methods was applied. The analysis focused on understanding how various well-being indicators are distributed across the entire study area, and whether specific patterns emerge in neighborhoods with community gardens.

First, the full set of alternative well-being indicators, as defined by the CBS framework (e.g., health, society), was analyzed across all neighborhoods in the Overijssel province. This step aimed to provide a comprehensive spatial overview of well-being, beyond neighborhoods with community gardens. Using the Hot Spot Analysis (Getis-Ord Gi) toolbox in ArcGIS Pro, statistically significant spatial clusters of high (hot spots) and low (cold spots) values were identified for each indicator. Thus, for each indicator, hotspot maps were created to visualize its spatial pattern. These maps helped identify areas of higher or lower well-being and revealed possible clustering or regional differences. The maps also served as a foundation for understanding spatial inequality in well-being and identifying potential areas of need. For example, clusters of low values in health-related indicators, like perceived health, may reflect areas where there are real health problems, like not having good access to health services, while hot spots in social loneliness or lack of emotional support could signal weaker social connections. By revealing such patterns, this step provided critical context for evaluating how the spatial distribution of community gardens aligns, or fails to align, with neighborhoods facing well-being challenges. In doing so, it helped answer the broader research question of whether gardens are located in areas that would most benefit from their potential social and ecological functions.

In addition to the maps, histograms were used to examine the statistical distribution of each well-being indicator. This approach allowed for a straightforward comparison of data spread, skewness, and central tendencies. In the context of this study, indicators with a wider spread or higher standard deviation may suggest greater inequality in well-being across neighborhoods. These histograms were further divided by urbanization level, revealing clear differences between rural and urban neighborhoods. To avoid misinterpreting such differences as the effect of community gardens, the next step compared the distribution of well-being indicators between all neighborhoods and those that contain community gardens. The comparison showed that neighborhoods with gardens followed the overall spatial well-being pattern of the province.

To control the effect of urbanization level, the dataset was then divided into two groups of urban neighborhoods (urbanization levels 1–4) and rural neighborhoods (urbanization level 5). Within each group, neighborhoods with and without community gardens were compared using the Mann–Whitney U test (Wilcoxon rank-sum test) in R. This non-parametric test was used to assess whether differences in well-being indicators between neighborhoods with gardens and those without were statistically significant. To visually support these results, violin plots were created for each indicator in R. These plots show both the distribution and density of the data across the two groups and allow a clearer understanding of the variation in well-being scores between neighborhoods with and without gardens.

This analysis not only highlights spatial patterns of well-being but also ensures that any observed relationships with community gardens are interpreted within the correct urban and rural context, and while no causal claims are made at this stage, this method helps guide the selection of relevant well-being variables for further exploration.

The Mann–Whitney U test and Violin plots code from R are presented in Appendix B.

3.4 Exploring the patterns in the spatial association between community gardens and well-being aspects in neighborhoods.

While earlier analysis explored whether neighborhoods with community gardens differ in well-being compared to those without, this last objective aims to investigate how the specific characteristics of community gardens are related/linked to well-being indicators, particularly within urban areas. The focus shifts from the presence of a garden to its spatial and ecological qualities, and how these may reflect patterns in residents' well-being at the neighborhood scale.

3.4.1 Spatial associations between garden characteristics and wellbeing aspects

To explore the relationship between specific community garden characteristics and neighborhood well-being, this analysis focused exclusively on urban neighborhoods (urbanization levels 1 to 4) that contain at least one community garden. The number of neighborhoods that have these conditions and are studied in this section is 112. In dense urban environments, where green space is more limited, the specific qualities of community gardens may have greater relevance than their existence and may meaningfully relate to patterns in local well-being outcomes. Unlike the previous objective, which examined the general presence of gardens, this step shifts the focus to their qualitative attributes, such as size, vegetation health (NDVI), and accessibility.

To assess these associations, a non-parametric correlation analysis was applied using Kendall's rank correlation coefficient (τ) between neighborhood-level garden characteristics and well-being indicators in R. This test was chosen due to the small sample size and the non-normal distribution of the variables, both of which limit the applicability of parametric tests like Pearson's correlation. Kendall's τ is particularly appropriate for evaluating monotonic relationships between two continuous or ordinal variables when ties and non-linearities may be present. Kendall's rank correlation measures the strength and direction of association between two variables based on the ranking of data rather than their actual values. The coefficient ranges from -1 to +1, where positive values indicate that higher values of one variable are generally associated with higher values of the other, and negative values suggest an inverse relationship. The accompanying p-value assesses whether the observed association is statistically significant.

To remain open to emergent spatial patterns, all combinations of garden qualities and well-being indicators were tested without pre-filtering. This allowed a more comprehensive exploration of potential disparities, especially in the absence of causal assumptions. This is particularly important given the contextual nature of urban green space and well-being relationships, which can vary across different urban environments, and also considering the available data and the goals of this study, which is to uncover patterns, not to test any pre-defined hypothesis.

After investigating these associations in R, at the global level (the whole province), ArcGIS Pro was also used for spatial visual outcome, but mainly at the local level. Therefore, Local Bivariate Relationships were conducted to show how those relationships vary over geographic space.

Kendall's rank correlation coefficient (τ) codes in R are presented in Appendix D.

3.4.2 Improving community gardens' qualities to enhance well-being in underserved neighbourhoods

The final research question builds on past analyses and the literature review on community gardens and well-being. While the positive impacts of community gardens on individual and community well-being have been broadly acknowledged in the literature (such as Lampert et al., 2021; Pálsson et al., 2021), this part of the study shifts focus toward practical implications.

To address this question, the first step was to identify urban neighborhoods of potential need. These were defined as neighborhoods that met two criteria:

- Relatively low well-being scores, based on selected indicators of perceived health, resilience, stress, social loneliness, volunteer work, risk of anxiety, mental complaints, and social cohesion, assessed against the median values across the urban neighborhoods with community gardens.
- The presence of a low-quality community garden, where they were evaluated based on the same qualities used earlier in the study, size, garden size per capita, vegetation health (NDVI), proximity to public transport, and walking/biking accessibility/service area.

To identify the urban neighborhoods with low well-being values, the "Select by Attribute" tool in ArcGIS Pro was used. SQL expressions were written to select urban neighborhoods with at least one community garden that performed below the median across all mentioned well-being indicators simultaneously, and these were categorized as "low well-being neighborhoods." Similarly, urban community gardens falling below the median on the mentioned qualities were categorized as "low-quality gardens." This data-driven filtering approach ensured that selected areas represented consistently low performance across all the studied dimensions. Once the two groups were identified, they were overlapped with each other to find the areas that met both criteria, i.e., low well-being urban neighborhoods with low-quality community gardens.

Neighborhoods with both conditions were considered to have both social needs and spatial limitations in their current garden infrastructure. These locations were then further explored in order to understand how their garden qualities could be improved.

The second step involved drawing on two sources of evidence to inform potential improvements:

a. High-quality gardens: Best performing/high-quality gardens within the study area, which are used as practical benchmarks. They were also selected based on the same qualities and whether they performed above the median across all of them. Once identified, each selected garden was investigated using Google Earth with high resolution satellite images credited to Airbus and [in some cases] their available websites, allowing for the visual examination of additional spatial features of greenhouses and covered gardening beds, which potentially indicate active use during cold seasons, and gathering spaces which indicate occurrence of community events and social activities beyond gardening.
b. Academic literature: Relevant academic literature, mentioned in sections 2.4 and 2.5, that identifies some garden qualities, as important factors in maximizing their functions and benefits.

Rather than proposing a universal solution, this step aimed to outline context-sensitive recommendations for how the garden in each underserved neighborhood might be strengthened in ways that align with both spatial limitations and well-being considerations. These recommendations are meant to demonstrate the practical utility of the study's spatial analyses and to serve as a basis for further site-specific investigations.

4. RESULTS

This chapter is also structured according to the research objectives and corresponding research questions introduced in section 1.4. Each part of the results aligns with one of the three research objectives and presents findings that directly address the specific questions associated with each objective. By following the same structure used in the methods chapter, this approach ensures a clear and consistent presentation of the outcomes of the spatial and statistical analyses.

4.1 Functions of community gardens

4.1.1 Key spatial characteristics that capture the social and ecological functions of urban community gardens

To answer the first research question, six spatial qualities/characteristics were selected based on their relevance to the social and ecological functions of community gardens, as identified in the literature. Each quality was derived using spatial datasets and processed in ArcGIS Pro to reflect conditions in Overijssel. These qualities include location, size, size per capita, public transport accessibility, walking and biking access, and vegetation health. Together, they provide a multi-dimensional view of the spatial characteristics of community gardens and form the basis for the analysis in the next section.

The following maps visualize these qualities across Overijssel and help illustrate variation between neighborhoods. For example, the maps of total garden size and garden size per capita shown in Figures 2 and 3 highlight the fact that neighborhoods with large gardens are not always those with the highest garden area per resident. This distinction supports the decision to include both indicators, as they capture complementary aspects of gardens. Figures 4 and 5 illustrate the accessibility of the community gardens, first by proximity to public transport stations and then by showing their service area within a 15-minute walk. Figure 6 also shows the NDVI value of the whole province, on 30 July 2024. As mentioned before, they were later clipped and aggregated to show a single value per neighborhood, to make comparisons possible. These values are shown in Figure 7.

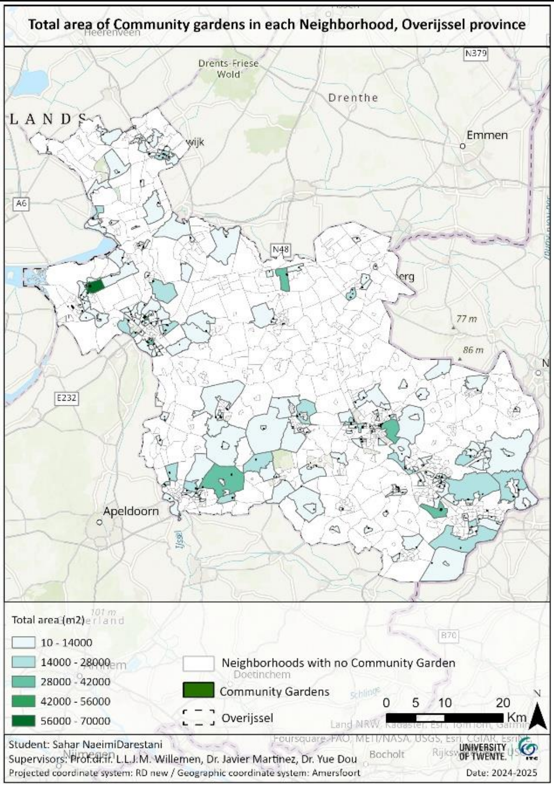


Figure 2: Total area (m2)- Data source: CBS (2024), OpenStreetMap (2024), Google Maps (2024), Basemap: Esri, World Topographic Map.

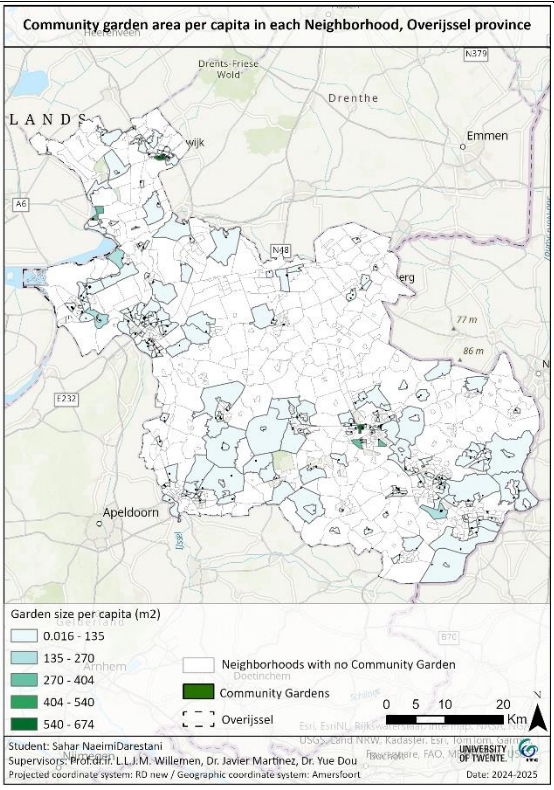


Figure 3: Area per capita (m2)- Data source: CBS (2024), OpenStreetMap (2024), Google Maps (2024), Basemap: Esri, World Topographic Map.

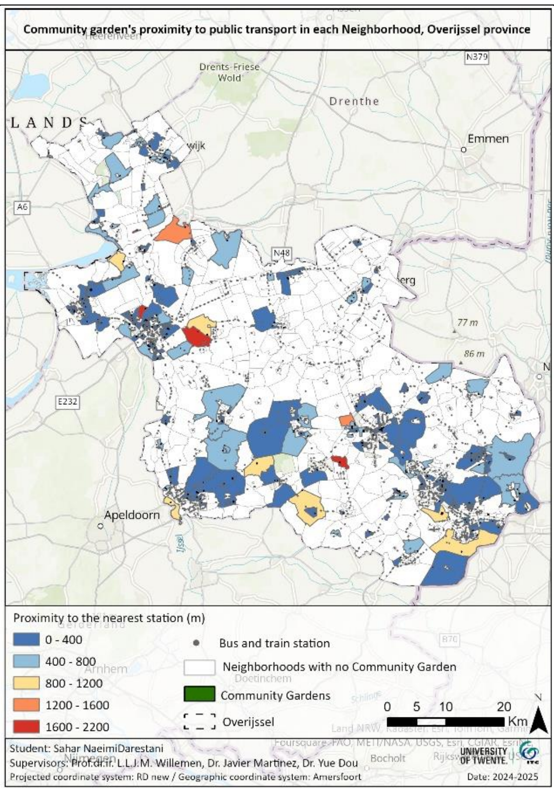


Figure 4: Proximity to public transport stations (m2)- Data source: ProRail (2024), NDOV (2023), OpenStreetMap (2024), Google Maps (2024), Basemap: Esri, World Topographic Map.

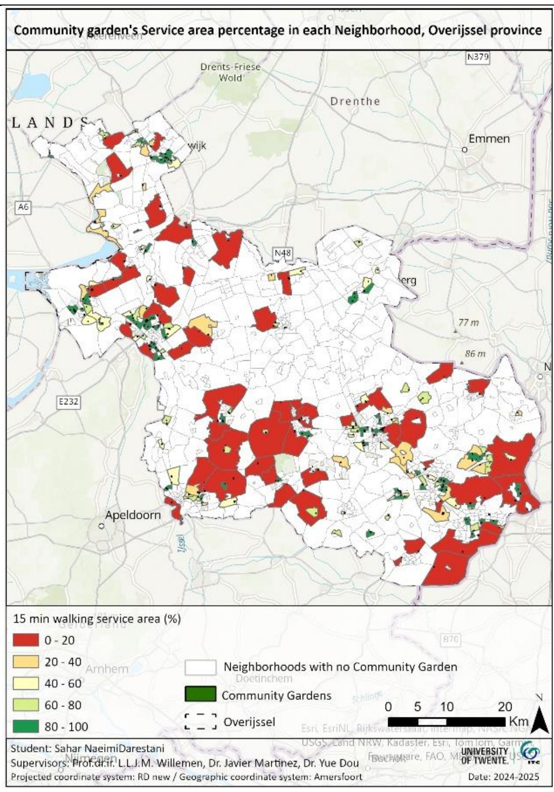


Figure 5: Walking service area percentage- Data source: Movares (2021), OpenStreetMap (2024), Google Maps (2024), Basemap: Esri, World Topographic Map.

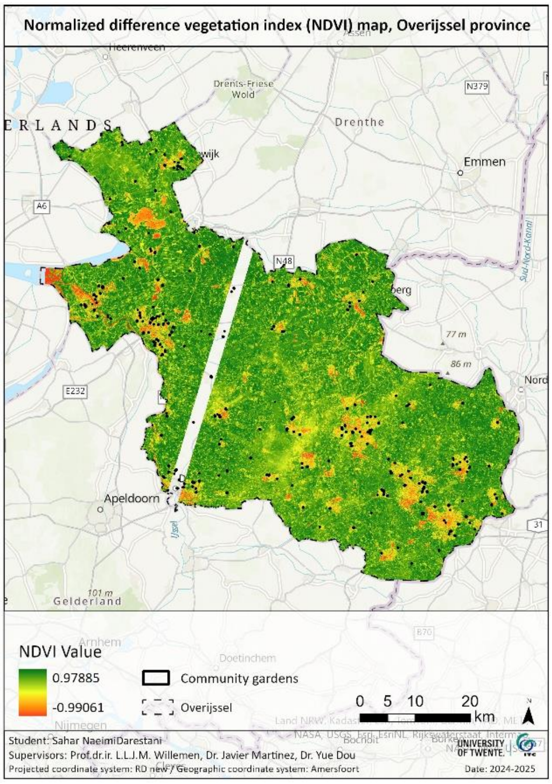


Figure 6: NDVI value on 30 July 2024- Data source: Planet scope (2024), Basemap: Esri, World Topographic Map.

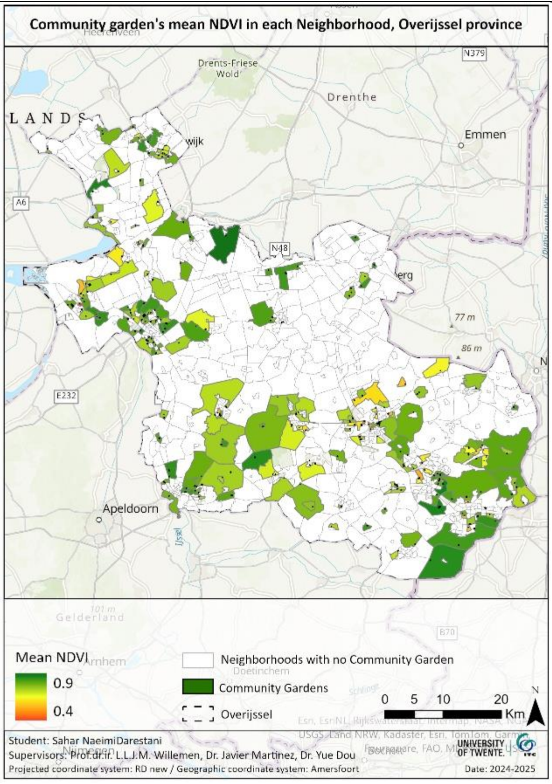


Figure 7: Mean of aggregated NDVI of the neighborhood's community gardens on 30 July 2024- Data source: CBS (2024), Planet scope (2024), OpenStreetMap (2024), Google Maps (2024), Basemap: Esri, World Topographic Map.

3-meter resolution, Plante Scope satellite image, 30 July 2024

4.1.2 Spatial variation of these community gardens' characteristics

This section presents the spatial variation of the selected garden characteristics across the province of Overijssel. Results include maps showing the distribution and concentration of garden qualities aggregated to the neighborhood level to align with well-being datasets. Where relevant, spatial clustering patterns are also discussed based on the results of Global Moran's I.

As mentioned before, kernel density analysis was performed to identify areas with higher concentrations of community gardens across Overijssel. The resulting map of garden locations in Figure 8, illustrated with the help of Kernel density, shows that community gardens are primarily concentrated in and around the province's larger cities, including Enschede, Hengelo, Almelo, Zwolle, Deventer, and Steenwijk. These urban areas show higher spatial densities of garden presence, which might reflect the concentration of population in these areas. Figures 9 and 10 also show the number of community gardens per Municipality, followed by their area (as hectares) in the table. Based on all this information, Zwolle (with 46 gardens) and Steenwijk (with 40 gardens) have the highest number of community gardens in Overijssel province.

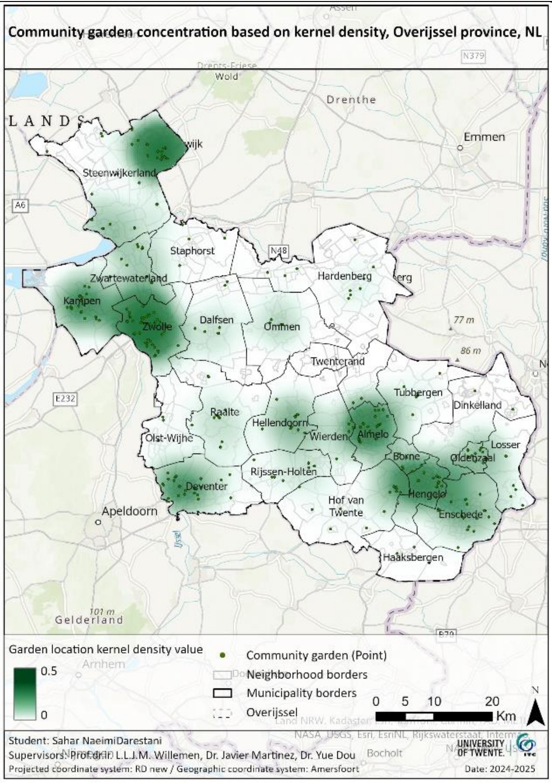


Figure 8: Garden location kernel density- Data source: CBS (2024), OpenStreetMap (2024), Google Maps (2024), Basemap: Esri, World Topographic Map.

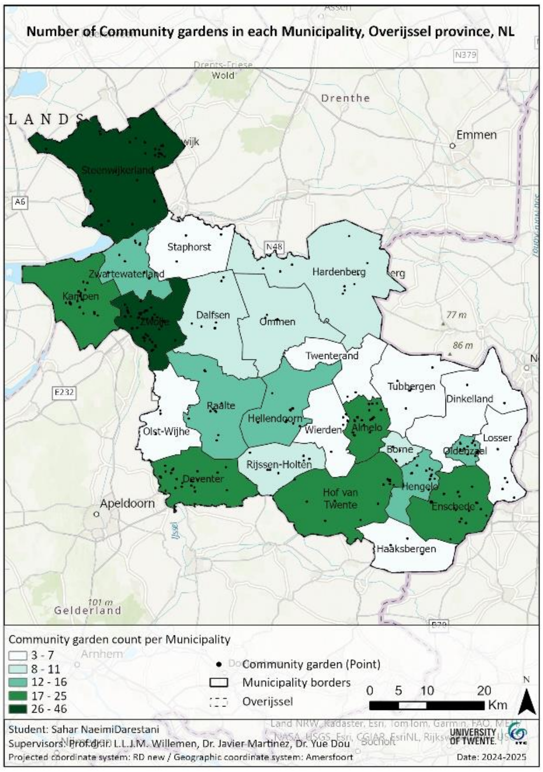


Figure 9: Garden count per Municipality- Data source: CBS (2024), OpenStreetMap (2024), Google Maps (2024), Basemap: Esri, World Topographic Map.

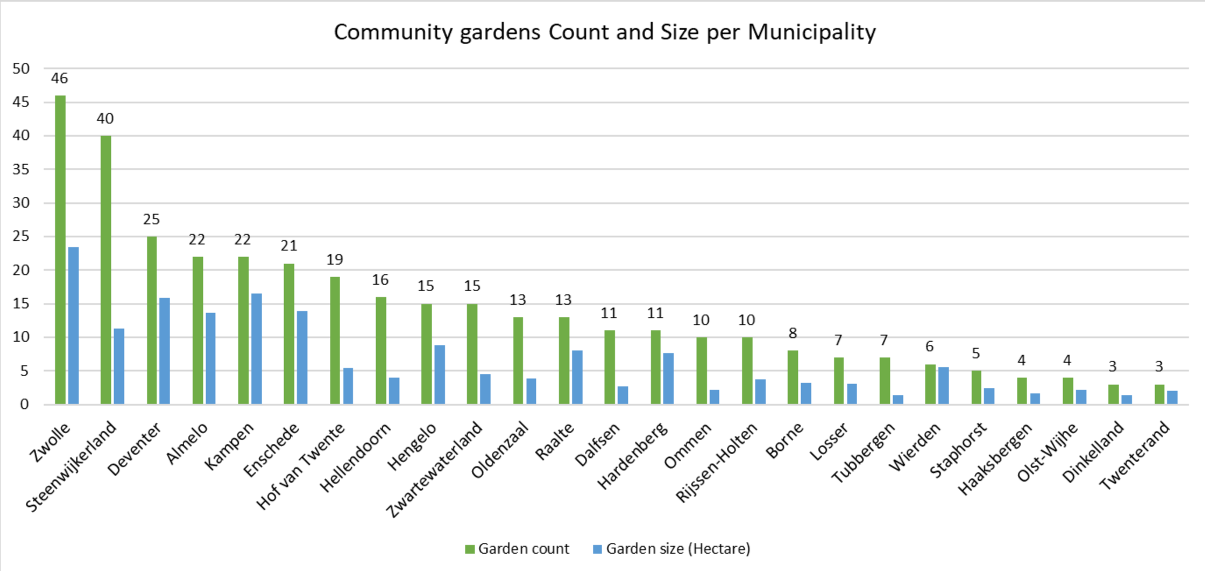


Figure 10: Community gardens count and size per Municipality

To further explore how specific garden characteristics are distributed spatially, weighted kernel density maps were produced using selected qualities, such as NDVI and garden size, as input weights. These maps highlight not just the number of gardens in an area, but the relative intensity of the selected quality. For example, the NDVI-weighted kernel density in Figure 11 indicates higher vegetation health values around the cities of Zwolle and Steenwijk, compared to other urban centers. This suggests that these areas not only have the highest number of gardens, but they also tend to exhibit better vegetation health. However, it should be considered that all weighted kernel density outputs remain influenced by the underlying distribution of garden locations. Therefore, these maps are best interpreted as a combination of both spatial density and attribute intensity.

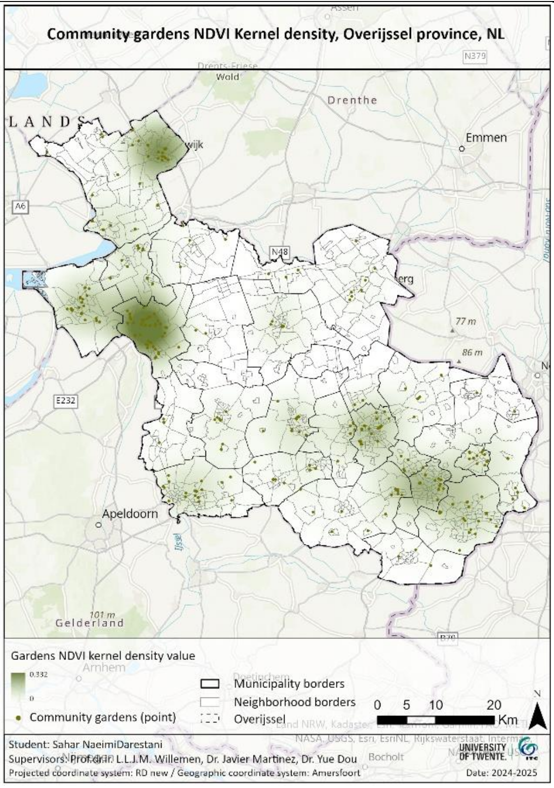


Figure 11: Garden NDVI kernel density- Data source: CBS (2024), Planet scope (2024), OpenStreetMap (2024), Google Maps (2024), Basemap: Esri, World Topographic Map

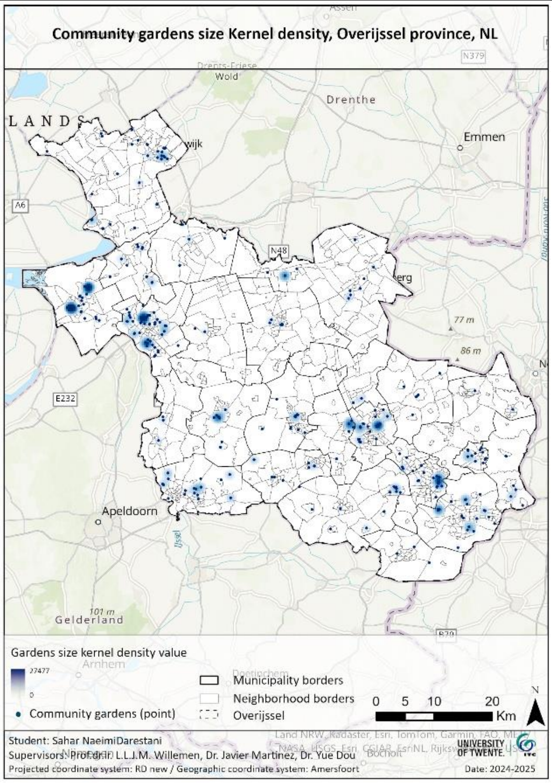


Figure 12: Garden Size kernel density- Data source: CBS (2024), OpenStreetMap (2024), Google Maps (2024), Basemap: Esri, World Topographic Map

To formally assess whether these patterns were clustered or randomly distributed, a Global Moran's I analysis was conducted for each indicator. Moran's I is a statistical measure of spatial autocorrelation that indicates whether similar values (either high or low) tend to cluster together. The index ranges from –1 to +1, where values near 0 suggest spatial randomness, and values closer to –1 or +1 indicate dispersion or clustering, respectively. The z-score and p-value provide additional context for statistical significance. The results are summarized in Table 5.

Table 5: Spatial autocorrelation of different garden qualities, based on Global Moran's I index

Quality	Moran's Index	z-score	p-value
Garden size	0.079	2.584	< 0.05
Garden size per capita	-0.0045	0.01	0.991
NDVI	0.306	9.485	< 0.005
Access to public transport	0.323	10.157	< 0.005
Service area via cycling (3750 m)	0.364	11.218	< 0.005

The results indicate a strong spatial clustering pattern for access to public transport, bicycle accessibility, and NDVI. This is expected, as transport-related characteristics are directly linked to shared infrastructure, and vegetation patterns may reflect underlying land use and ecological conditions that cluster geographically. Garden size and garden size per capita showed very weak or no spatial autocorrelation, suggesting these characteristics are more evenly or randomly distributed across the province and are not concentrated in specific zones.

Given the high Global Moran's I value for NDVI, a Local Moran's I analysis was also conducted to identify specific clusters. The resulting map in Figure 13 highlights areas where neighborhoods with high or low NDVI values are surrounded by similar values. This visualization provides additional insight into the spatial distribution of ecological quality among community gardens. For example, around Zwolle, high and low NDVI values are located near each other, while gardens with high NDVI values are clustered together in Deventer.

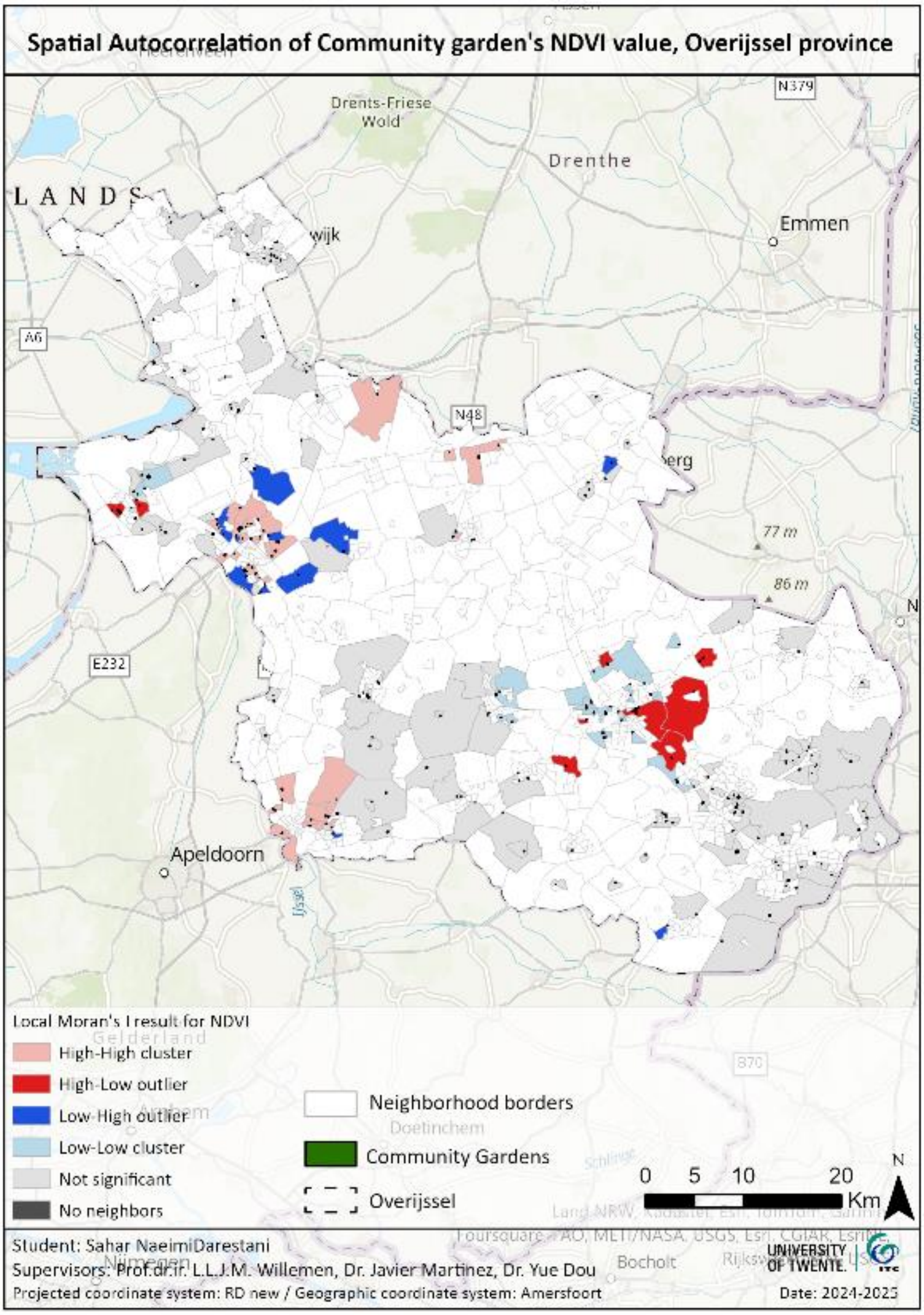


Figure 13: Spatial autocorrelation of the community garden's NDVI- Data source: CBS (2024), Planet scope (2024), OpenStreetMap (2024), Google Maps (2024), Basemap: Esri, World Topographic Map

4.2 Patterns of different well-being aspects in neighborhoods with community gardens.

4.2.1 Key characteristics of neighbourhood wellbeing

As mentioned in the methods 3.3 section, a set of alternative indicators was selected to represent neighborhood-level well-being, based on their alignment with the CBS well-being framework and their availability at the neighborhood scale. The full mapping between CBS themes and the selected alternative indicators is presented in Table 6. This approach enables a more detailed and spatially refined analysis of well-being patterns across Overijssel.

Table 6: CBS well-being aspects and alternative indicators

CBS well-being theme	CBS well-being aspect	Alternative indicator	Rationality
Subjective well-being	Satisfaction with life	Stress, Resilience from Health Monitor	Stress is inversely, and resilience is directly related to life satisfaction, and they provide insight into overall subjective well-being (W. Chopik, 2024; Ritu Rani, 2014; Cohn, 2009).
	Feeling in control of life	Resilience from Health Monitor	Resilience reflects an individual's perceived control over life circumstances (Dana Georgescu, 2019).
Material well-being	Median disposable income	Average standardized household income, Average income per income recipient, Average income per capita from CBS	These income measures provide detailed insights into material well-being at the neighborhood level.
	Individual consumption	Trouble making ends meet from Health Monitor	Financial strain indicators reflect consumption capacity and material living standards.
Health	Healthy life expectancy	perceived health; Weekly Sports Participants from Health Monitor	Self-reported health status and physical activity levels can be proxies for overall health conditions.
	Overweight population	Degree of overweight data from Health Monitor	Directly corresponds.
Labor & Leisure time	Long-term unemployment	Persons per type of benefit; WW from CBS	Unemployment benefit recipients can serve as an indicator of long-term unemployment rates.
	Net labor participation	Net labor participation from CBS	Directly corresponds.
	Higher educated population	High level of education from CBS	Directly corresponds.
	Satisfaction with leisure time	-	No alternative indicator available.
	Time lost due to traffic	-	No alternative indicator available.
	Satisfaction with work	-	No alternative indicator available.
Housing	Housing costs	Average WOZ value of homes from CBS	WOZ values can serve as a proxy for housing costs and affordability.
	Satisfaction with housing	-	No alternative indicator available.
Society	Contact with family, friends or neighbors	Socially Lonely; Lack of emotional support from Health Monitor	Indicators of social isolation and support networks reflect social connectivity.
	Voice and accountability	-	No alternative indicator available.
	Trust in institution	-	No alternative indicator available.
	Trust in other people	Social cohesion from Livability barometer	Social cohesion can measure the strength of social bonds and mutual trust within communities.
	Changes in values and norms	-	No alternative indicator available.
	Voluntary work	Volunteer work from Health Monitor	Directly corresponds.

Safety	Feeling unsafe in the neighborhood	Nuisance and insecurity from Livability barometer	Captures residents' perceptions of safety and neighborhood disturbances.
	Victims of crime	-	No alternative indicator available.
Environment	Managed natural assets	Physical Environment from Livability Barometer	Assesses the quality and management of natural and built environments.
	Quality of inland bathing waters	-	No alternative indicator available.
	Nitrogen deposition & terrestrial natural areas	-	No alternative indicator available.
	Urban exposure to particulate matter	-	No alternative indicator available.
	Environmental problems	Physical environment from Livability barometer	Evaluates environmental issues affecting residents' quality of life.

To provide clarity on the alternative data used in this analysis, Table 7 presents these indicators, along with a short description and data source for each. These indicators form the operational basis for measuring neighborhood well-being in this study.

Table 7: Alternative indicators' description

Indicator	**Description**	**Source**
Very good/good Perceived health	Percentage of people aged 18 years or older with the answer category "very good" and "good" to the question about their general health status.	Health Monitor for Adults and the Elderly, 2022
Weekly Sports Participants	Percentage of persons aged 18 years or older who exercise at least once a week.	
Overweight	Percentage of persons aged 18 years or older with a BMI of 25.0 kg/m2 or higher.	
Mental health complaints	Percentage of persons aged 18 years or older who indicate having mental health problems. This was measured with the Mental Health Inventory 5 (MHI-5).	
High resilience	Percentage of people who indicate that they have a (very) high resilience. Resilience was measured with 5 statements about how people felt over the past 4 weeks from the Dutch vitality meter VITA-16.	
High risk of anxiety or depression	Percentage of 18 years or older at high risk of anxiety disorder or depression.	
Socially Lonely	The percentage of people aged 18 and over who feel socially lonely.	
Volunteer work	Percentage of persons aged 18 years or older who answered 'yes' to the question "Do you do volunteer work?" This means work that is carried out unpaid in an organized context (e.g., sports club, church council, school).	
Lack of emotional support	Percentage of people who report missing emotional support. This was measured with an adapted version of the lack of emotional support subscale of the Social Support Inventory - Discrepancies (SSL-D).	
Very much stress	Percentage of people aged 18 years or older who have experienced (very) a lot of stress in the past 4 weeks.	
Trouble making ends meet	The percentage of people aged 18 years or older who have difficulty making ends meet.	
Walking/cycling to work/school	The percentage of people aged 18 to 65 who walk and/or cycle to school or work (partly) one or more days a week.	
The Livability Barometer	The Livability Barometer provides a prediction of the extent to which the characteristics of the living environment in an area are valued by residents.	The Liveability Barometer - the Ministry of the Interior and Kingdom Relations, 2022
Housing Stock	Refers to the characteristics of the residential environment, including housing types, density, availability, maintenance, energy efficiency, and ownership structures. It also considers elements like historical preservation (monuments) and affordability.	
Physical Environment	Covers the natural and built environment, including air and water quality, noise levels, green spaces, climate factors (e.g., heat stress), and risks like flooding or earthquakes. This dimension highlights the influence of infrastructure and environmental quality on health and well-being.	
Facilities	Focuses on access to amenities and services, such as education, healthcare, public transport, shopping, and leisure activities. It also evaluates the diversity and proximity of these facilities, affecting convenience and quality of life.	

Social Cohesion	Relates to the strength of social networks and relationships within communities. This includes the extent of mutual trust, neighborhood engagement, and the ability to foster inclusive environments despite diversity.	
Nuisance and Insecurity	Addresses factors that reduce perceived or actual safety and comfort in a neighborhood, such as crime, vandalism, and other disruptive activities. It assesses their impact on overall liveability.	
Average standardized household income	The disposable income is corrected for differences in size and composition of the household.	CBS - Key figures for districts and neighborhoods, 2023
Average income per income recipient	The arithmetic average personal income per person is based on persons with personal income who are part of private households.	
Average income per capita	The arithmetic average personal income per person is based on the total population in private households.	
Median private household wealth	The median is the middle number when all numbers are sorted from low to high. Wealth is the balance of assets and liabilities.	
Average WOZ value of homes	To determine the average WOZ value of homes, only BAG objects with a residential function for which a WOZ value is known and which are between 10 thousand and 5 million euros are used.	
High level of education	The number of persons who were between 15 and 75 years old who were registered in a Dutch municipality, whose highest educational level was higher education.	
Net labor participation	The share of the working population in the population (working and non-working population) ranges from 15 to 75 years old.	
Persons per type of benefit; WW	Persons receiving benefits under the Unemployment Act (WW).	
Degree of urbanization	Based on the environmental address density, each neighborhood, district, or municipality has been assigned an urbanity class. The following class division has been used: 1: very strongly urban >= 2,500 addresses per km^2 2: highly urban 1,500 - 2,500 addresses per km^2 3: moderately urban 1,000 - 1,500 addresses per km^2 4: little urban 500 - 1,000 addresses per km^2 5: non-urban < 500 addresses per km^2	

4.2.2 Spatial variation in neighbourhood well-being

The spatial analysis of neighborhood-level well-being indicators across Overijssel reveals a general trend that rural neighborhoods tend to perform better across many well-being aspects compared to more urbanized areas. This pattern is visible across several dimensions, for example, indicators such as mental complaints, stress, risk of anxiety or depression, and overweight tend to decrease in more rural areas. In contrast, perceived health, emotional support, volunteer work, resilience, liveability, and average income generally increase in these neighborhoods.

These observations are supported by both hotspot maps and divided histograms. The maps allow for a visual understanding of spatial distribution and clustering, while histograms grouped by degree of urbanization provide a clearer statistical view of how indicator values shift across different urban contexts. For instance, social cohesion and resilience show visibly stronger scores in rural areas, while higher rates of stress and mental health complaints are concentrated in more urban settings, such as Enschede and Zwolle. Not all indicators showed a distinct visual pattern; for example, income-related variables displayed less pronounced spatial variation. However, when examined alongside the urbanization gradient, even these indicators revealed underlying trends that align with broader socio-spatial patterns in the province.

A selection of hotspot analysis of well-being indicators is presented in Figures 14, 15, and 16 to illustrate the main findings. These examples are chosen to reflect both the positive trends observed in rural areas and the challenges more commonly found in urban neighborhoods.

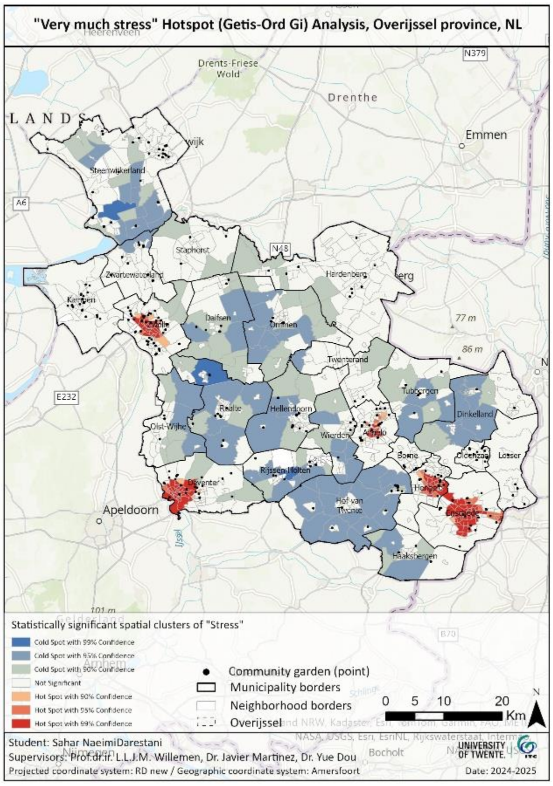


Figure 14: Hotspot analysis of Stress- Data source: CBS (2024), Health monitor (2022), OpenStreetMap (2024), Google Maps (2024), Basemap: Esri, World Topographic Map

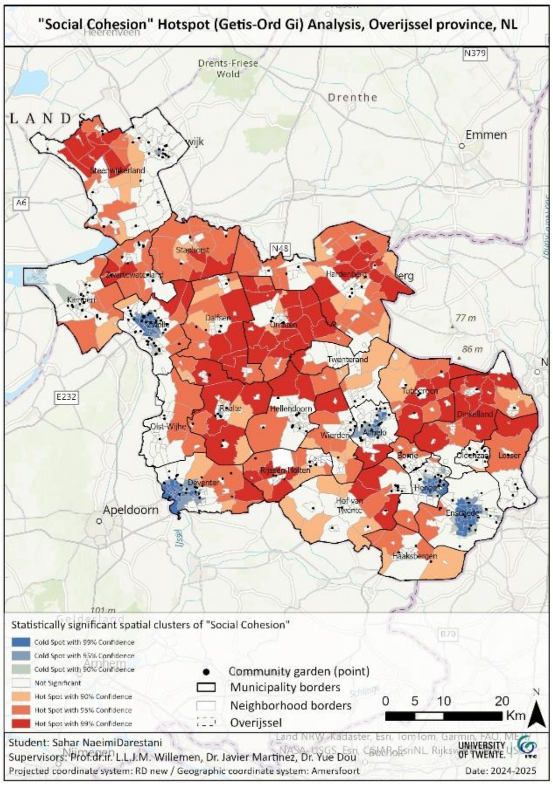


Figure 15: Hotspot analysis of Social cohesion- Data source: CBS (2024), Liveability Barometer (2022), OpenStreetMap (2024), Google Maps (2024), Basemap: Esri, World Topographic Map

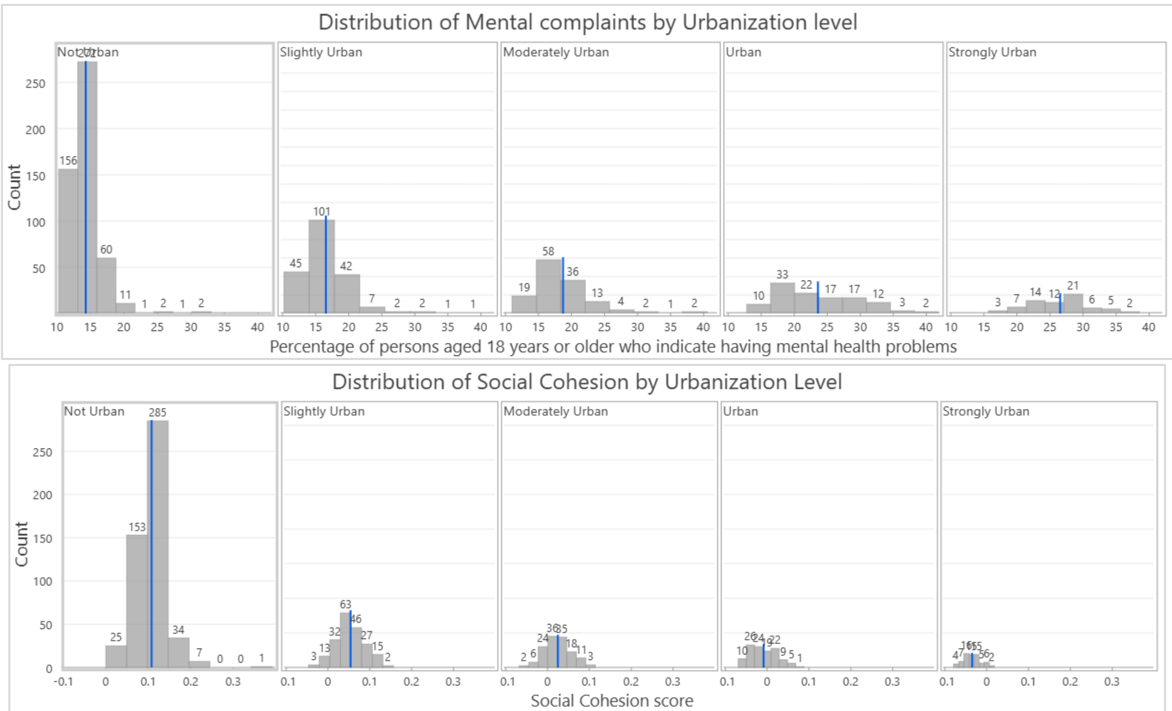
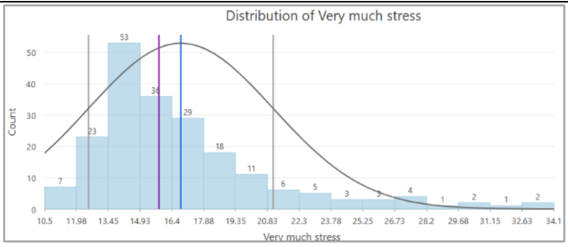


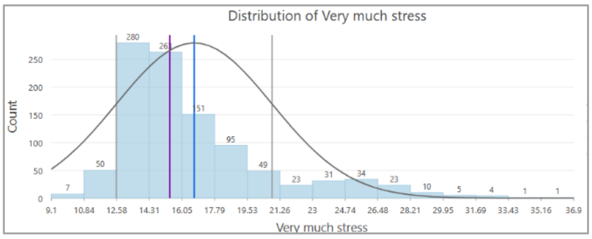
Figure 16: Distribution of Mental complaints and Social cohesion by Urbanization level

These findings suggest that the degree of urbanization is a key factor influencing neighborhood well-being in Overijssel. A clear distinction emerges between urban and rural neighborhoods, with most well-being indicators displaying consistent spatial trends. In general, rural neighborhoods show more favorable outcomes across a range of well-being aspects, highlighting the importance of contextualizing further analysis within this urban–rural gradient.

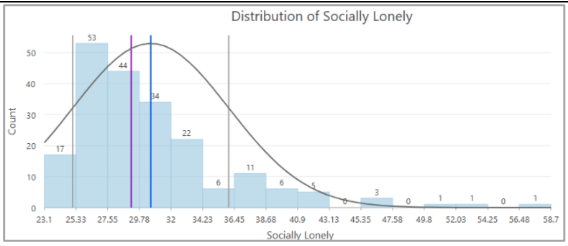
To assess whether neighborhoods with community gardens differ from others in terms of well-being, an initial comparison was conducted between all neighborhoods in Overijssel and the ones having community gardens. Histograms were used to compare the distributions of key well-being indicators between these two groups. The results showed a high degree of similarity in the distribution and central tendencies for most indicators. For instance, Figures 17 and 18 show that the median of stress and social loneliness levels was the same across both datasets, suggesting that neighborhoods with gardens reflect the broader well-being patterns of the province.



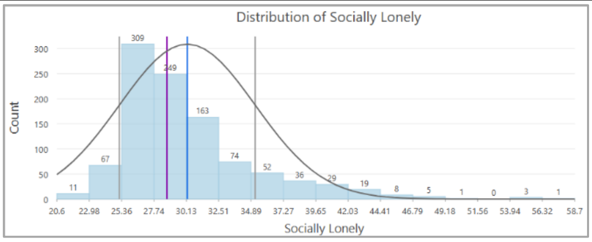
Median: 15.8



Median: 15.4



Median: 29.2



Median: 28.7

Figure 17: Histograms of "Stress" and "Socially lonely" indicators in neighborhoods with community gardens

Figure 18: Histograms of "Stress" and "Socially lonely" indicators in the Overijssel province

A closer look at the distribution of community gardens confirmed this finding. Out of all neighborhoods with community gardens, the vast majority are located in rural or moderately urbanized areas, while only a small number exist in strongly urban neighborhoods. Specifically, of the 198 neighborhoods with gardens, only 6 are classified as strongly urbanized. This spatial imbalance mirrors the overall pattern of the province, where rural neighborhoods are more numerous. One likely explanation is that rural areas offer more available space, making them more suitable for establishing community gardens. This was further supported by garden size data, shown in Figure 19, that rural neighborhoods often have gardens exceeding 10,000 m², while those in urban areas rarely exceed 6,000 m².

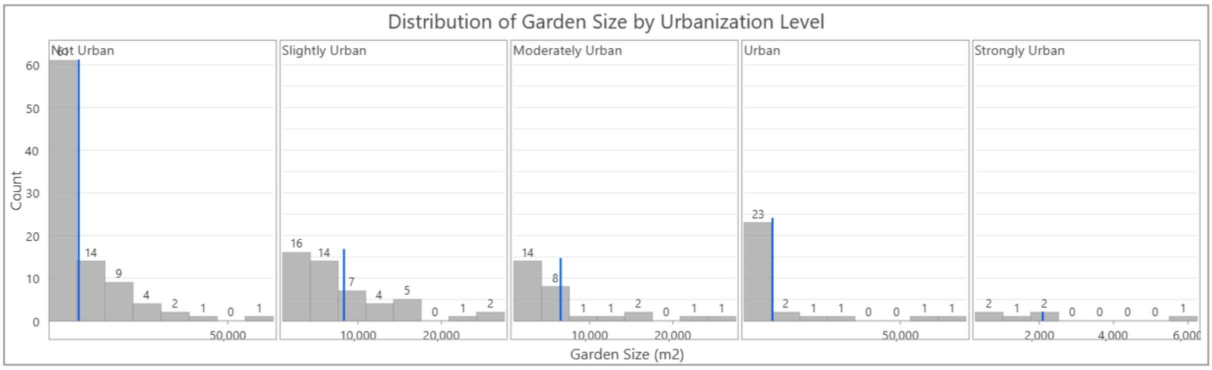


Figure 19: Histogram showing the distribution of community garden size at different urbanization levels

To more precisely evaluate whether community gardens are associated with differences in well-being, a second analysis was conducted within specific urbanization levels. Two subsets were created, first, highly urbanized neighborhoods (levels 1 to 4), and second, rural neighborhoods (level 5). Within each subset, neighborhoods with and without gardens were compared using the Mann–Whitney U test to assess whether the observed differences were statistically significant. Violin plots were later used to visualize the distribution and density of selected well-being indicators

In both urban settings, the Mann–Whitney U tests yielded high p-values across the majority of well-being indicators, indicating that the presence of a community garden was not significantly associated with better or worse well-being scores within the same urbanization level, and does not appear to shift well-being outcomes in a measurable way within the available data.

However, notable patterns emerged in the rural subset. Among rural neighborhoods, several well-being indicators showed significant positive differences in favor of areas with community gardens. Neighborhoods with gardens had higher values for weekly athletes, high resilience, cycling to work/school, and social cohesion. All Mann–Whitney U test results are provided in Appendix C.

Figures 20 to 23 illustrate these findings with the help of violin plots:

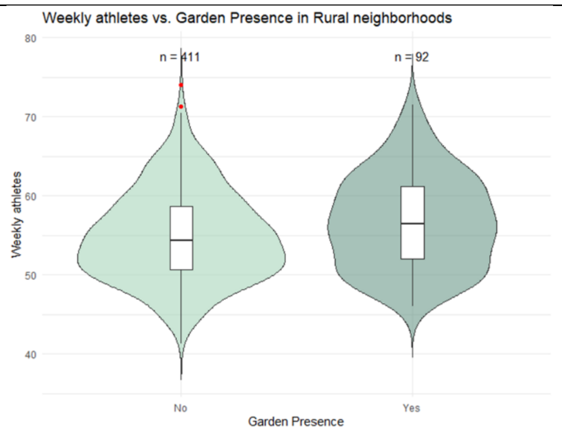


Figure 20: Violin plots showing distribution and density of Weekly Sports Participants in 2 groups of neighborhoods

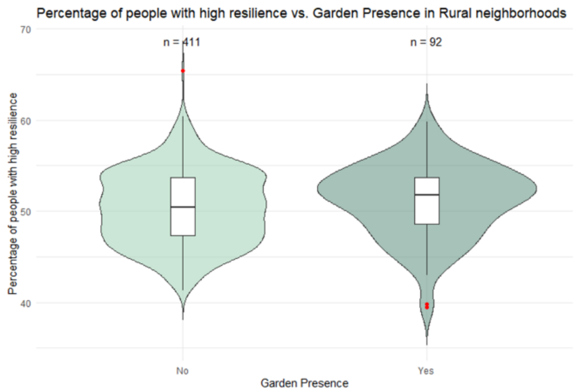


Figure 21: Violin plots showing distribution and density of people with High resilience in 2 groups of neighborhoods

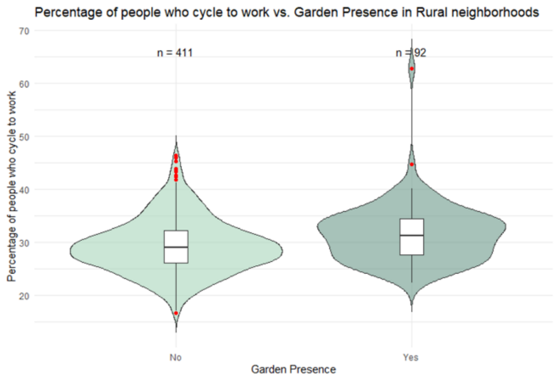


Figure 22: Violin plots showing the distribution and density of people who cycle to work in 2 groups of neighborhoods

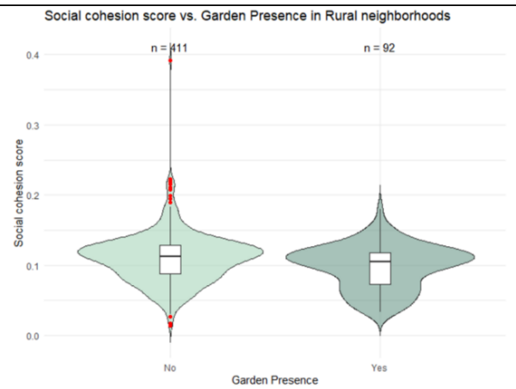


Figure 23: Violin plots showing distribution and density of Social cohesion in 2 groups of neighborhoods

In the case of urban neighborhoods, although no statistically significant differences were found in the well-being indicators, an interesting demographic pattern emerged. Urban neighborhoods with community gardens were located in more densely populated areas, and the difference in total population between garden and non-garden neighborhoods was statistically significant. Violin plots support this observation and illustrate a higher concentration of inhabitants in neighborhoods with gardens. Similar patterns were also observed in other demographic characteristics, such as higher numbers of both male and female residents, a larger proportion of youth (aged 15–25), and more elderly residents (65+), although these findings were not visualized in this section.

A comparable population pattern was also observed in the rural subset, where neighborhoods with community gardens also tended to have larger populations compared to those without.

This suggests that, regardless of urbanization level, community gardens in Overijssel are more likely to be located in more populated neighborhoods. This demographic pattern may indicate a strategic or organic tendency to place gardens in areas with greater numbers of potential users or social activities. Figures 24 and 25 illustrate these findings:

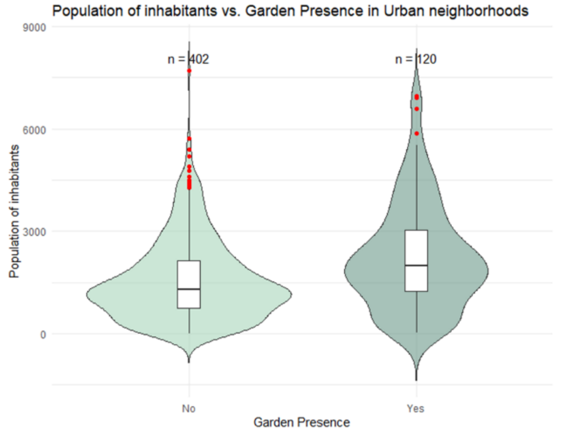


Figure 24: Violin plots showing the distribution and density of the population of inhabitants in 2 groups of urban neighborhoods

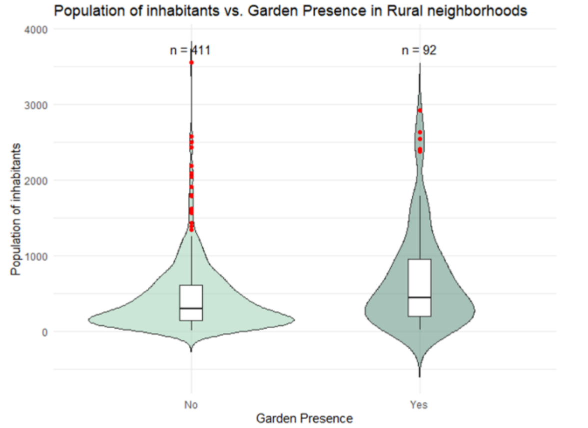


Figure 25: Violin plots showing the distribution and density of the population of inhabitants in 2 groups of rural neighborhoods

4.3 Patterns in the spatial association between community gardens and well-being aspects in neighborhoods.

In line with the methods described in section 3.4, this objective focuses on neighborhoods that contain community gardens, aiming to explore how different garden characteristics are associated with well-being indicators. The results of this correlation analysis provide insight into whether particular qualities of gardens may be linked to higher or lower levels of neighborhood well-being.

4.3.1 Spatial associations between garden characteristics and wellbeing aspects

To assess the relationship between community garden qualities and neighborhood well-being, Kendall's rank correlation was applied to urban neighborhoods containing at least one community garden. The results revealed several statistically significant associations, which are summarized and interpreted in this section. However, all the results are presented in Appendix E.

Total garden size

Community gardens that are larger in size are located in neighborhoods that reported lower stress and higher engagement in social activities, such as volunteer work, i.e., there was a positive association.

Garden size per capita

Results show that neighborhoods with a larger community garden area per capita is positively related to neighborhoods which are reported to have higher percentage of people with high resilience, volunteer work, and social cohesion, and a negative association with neighborhoods that reported higher percentage of people with very much stress, mental complaints, high risk of anxiety, and lack of emotional support. To summarize, neighborhoods that have a higher area per capita of community gardens are also the ones that reported better well-being outcomes.

Proximity to public transport

As mentioned before, this variable represents the distance from each community garden to the nearest public transportation stop. Therefore, a smaller value indicates better accessibility, while a larger value indicates poorer access. The results show that community gardens closer to public transport are not associated with better outcomes of well-being. Meaning that community gardens that have better access to public transport are located in neighborhoods that reported higher rates of social loneliness and lower levels of social cohesion.

Walking and biking access

Among the three service area distances (300 m, 1250 m, and 3750 m), the largest buffer (3750 m) showed more statistically significant relationships, which were a negative correlation with overweight, social loneliness, and a positive association with social cohesion. This suggests that neighborhoods with gardens accessible within a 15-minute cycling distance are associated with lower levels of overweight residents and higher social cohesion. However, no significant correlations were found for shorter distances (300 m or 1250 m) and other well-being indicators.

Vegetation health (NDVI)

The results show that community gardens with higher NDVI in urban neighborhoods are associated with neighborhoods that reported better perceived health, lower overweight individuals, and higher social cohesion. Table 8 presents Kendall's tau and p-values for the correlations between garden characteristics and neighbourhood well-being indicators.

Table 8: Kendall's tau results from R

	Size	Size per capita	Proximity to public transport	Walking/biking access	Vegetation health (NDVI)
Resilience		p= 0.0017 tau= 0.201			
Stress	p= 0.015 tau= -0.155	p= 0.0035 tau= -0.186			
Perceived health					p= 0.033 tau= 0.136
Socially lonely			p= 0.015 tau= -0.157	p= 0.064 tau= -0.118	
Volunteer work	p= 0.013 tau= 0.159	p= 0.024 tau= 0.144			
Social cohesion		p= 0.0002 tau= 0.233	p= 0.0003 tau= 0.229	p= 0.016 tau= 0.154	p= 0.074 tau= 0.114
WOZ value of houses			p= 0.038 tau= 0.131	p= 0.036 tau= 0.134	

The results of Kendall's rank correlation in the software tool R provided an overall understanding of the associations between garden characteristics and neighborhood well-being across all urban neighborhoods with community gardens. To further explore the spatial variation within these relationships, selected pairs were visualized using the Local Bivariate Relationship tool in ArcGIS Pro. This helped identify where significant associations were concentrated, and whether the global correlation observed through Kendall's τ reflected a consistent pattern or was spatially uneven at the local level.

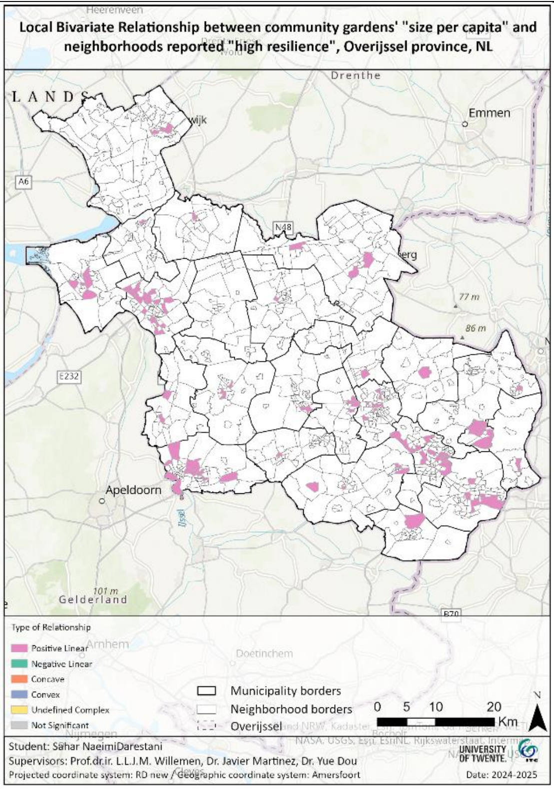


Figure 26: Local Bivariate Relationship: community gardens' "size per capita" and neighborhoods reported "high resilience"

Positive relationship: 100% of features

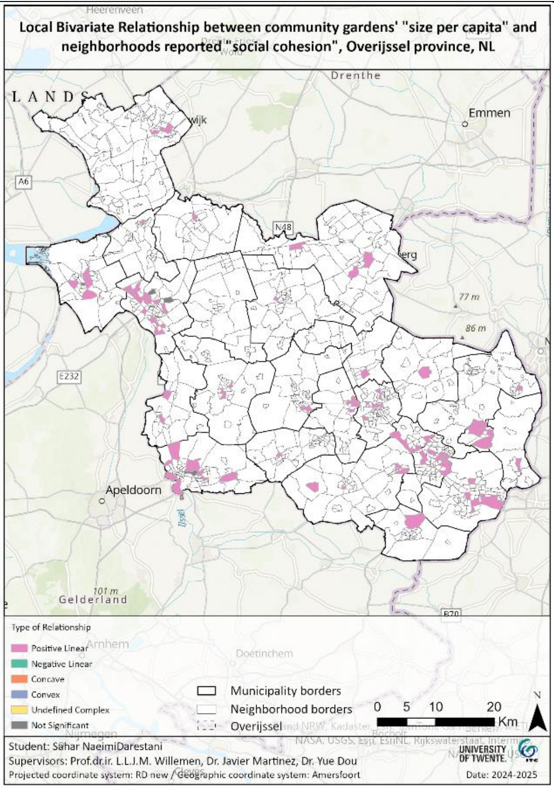


Figure 27: Local Bivariate Relationship: community gardens' "size per capita" and neighborhoods' reported "social cohesion"

Positive relationship: 96.43% of features
Not significant: 3.57% of features

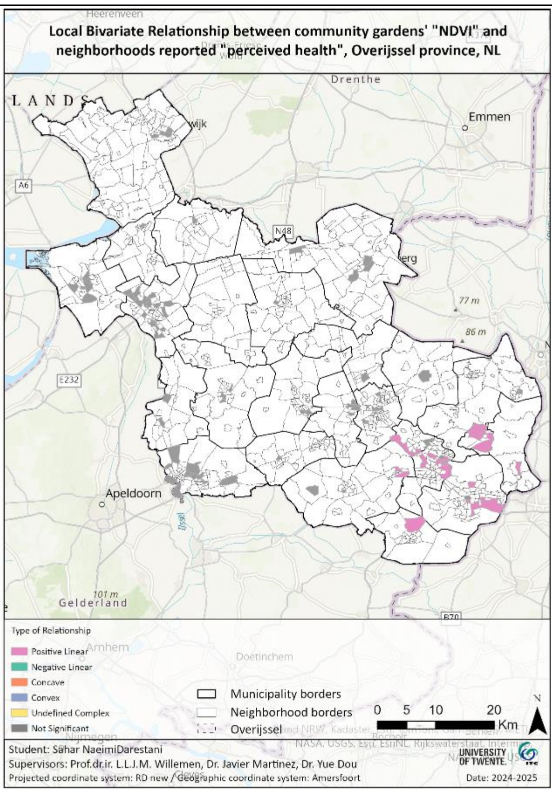


Figure 28: Local Bivariate Relationship: community gardens' "NDVI" and neighborhoods reported "perceived health"

Positive relationship: 32% of features
Not significant: 67% of features

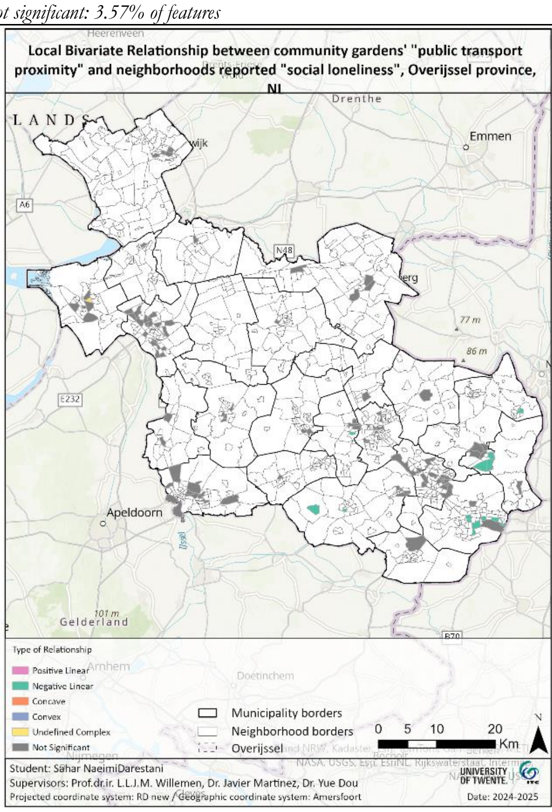


Figure 29: Local Bivariate Relationship: community gardens' "public transport proximity" and neighborhoods reported "social loneliness"

Negative relationship: 1.39% of features
Not significant: 85.71% of features
Complex relationship: 0.89% of features

Figure 26 to 29 data source: CBS (2024), Health monitor (2022), Liveability Barometer (2022), Planet scope (2024), ProRail (2024), NDOV (2023), OpenStreetMap (2024), Google Maps (2024), Basemap: Esri, World Topographic Map

Based on figures 26 to 29, the positive association between garden size per capita and high resilience was observed consistently across all the study areas, aligning well with the global Kendall's τ result. In contrast, for NDVI (vegetation health) and perceived health, although Kendall's τ indicated a positive association overall, the local spatial analysis revealed that this relationship was primarily concentrated in the southern part of the province, specifically in about 32% of neighborhoods, with the remaining areas showing no statistically significant correlation. Similarly, the negative relationship between public transport accessibility and social loneliness observed in the Kendall analysis was also spatially concentrated, but even more narrowly, only around 2% of the neighborhoods, located in the south, showed significant local negative correlations, while the rest exhibited weak or non-significant patterns.

These examples highlight how the global Kendall's τ statistic can sometimes be driven by localized spatial clusters and emphasize the importance of combining statistical correlation with spatial visualization when interpreting complex patterns.

4.3.2 Improving community gardens' qualities to enhance well-being in underserved neighbourhoods

To explore this question, first, low well-being neighborhoods and low-quality community gardens were identified. These two groups are visualized in Figure 30, which maps their locations across the neighborhoods of Overijssel.

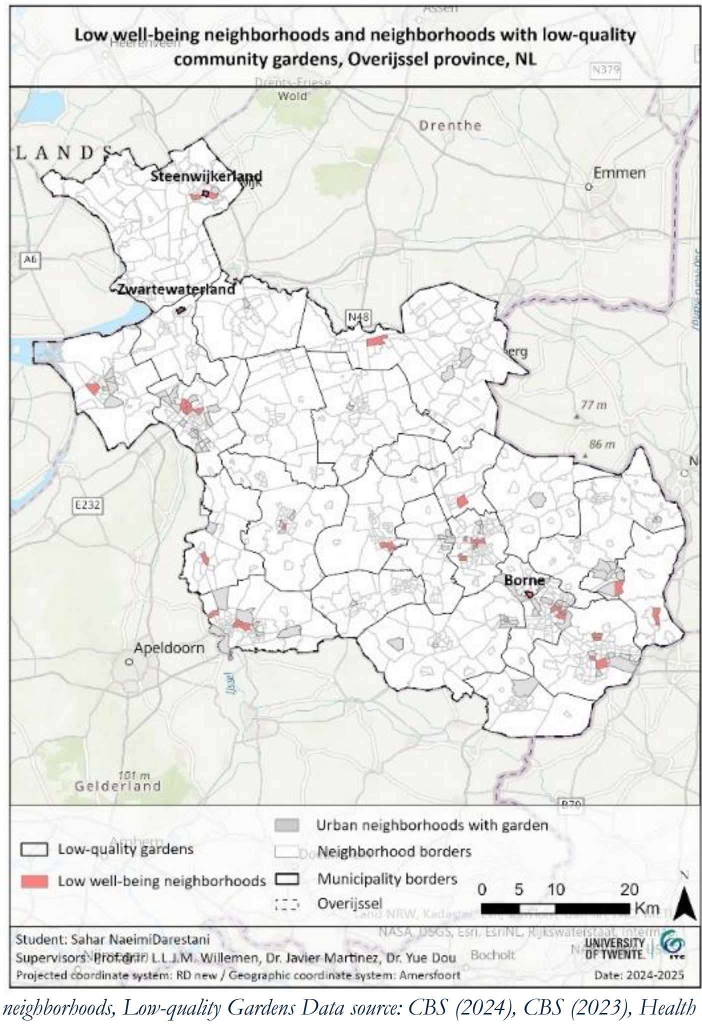


Figure 30: Low well-being neighborhoods, Low-quality Gardens Data source: CBS (2024), CBS (2023), Health monitor (2022), Liveability Barometer (2022), OpenStreetMap (2024), Google Maps (2024), Basemap: Esri, World Topographic Map

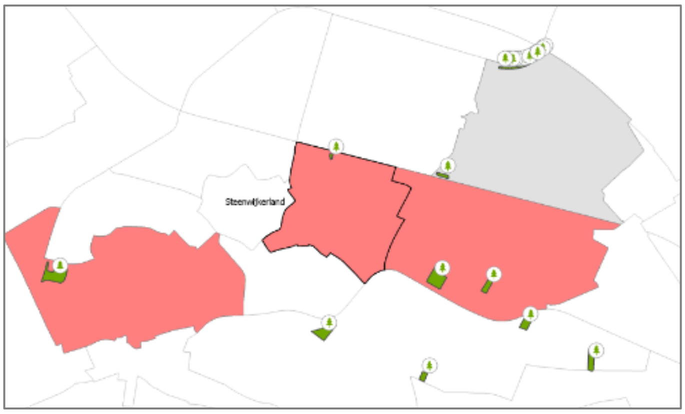


Figure 31: Neighborhood C with low-quality Garden 3 in Steenwijkerland

Figure 32: Neighborhood B with low-quality Garden 2 in Zwartewaterland

Figure 33: Neighborhood A with low-quality Garden 1 in Borne

Out of the urban neighborhoods with at least one community garden, a total of 3 neighborhoods were identified as simultaneously having below-median well-being values across all selected indicators and hosting below-median quality community gardens. Figures 31 to 33 illustrate these neighborhoods and their gardens that are located in 3 different cities. These identified neighborhoods represent locations of both social vulnerability and spatial limitations in existing garden infrastructure and areas of potential need where targeted improvement of garden qualities may support local well-being.

Following the classification of community gardens into high- and low-quality groups based on their qualities, descriptive statistics were calculated, and to complement these spatial indicators and further investigate the selected gardens, Google Earth imagery and, where available, garden websites, were used in the next step. This allowed for the identification of infrastructure, greenhouses, covered gardening beds, and gathering spaces, and using high-quality gardens as benchmarks, shown in Figures 34 to 36.

High-quality urban community gardens used as benchmarks:

Figure 34: High-quality community garden located in Kampen Municipality-Google Earth-Airbus-2024

Visible features from imagery:	Greenhouse, covered beds, and other structures for gathering spaces (like shelters or pergolas) are available.
Active website:	YES, https://onzetuinkampen.nl/ The site is used for planning and notifying users about events, and how to become a member. The active association board is responsible for the garden and its maintenance.

Figure 35: High-quality community garden located in Hengelo Municipality-Google Earth-Airbus-2022

Visible features from imagery:	Greenhouse and covered beds are available. No gathering space is visible from the image.
Active website:	NO

Figure 36: High-quality community garden located in Staphorst Municipality-Google Earth-Airbus-2024

Visible features from imagery:	Greenhouses, covered beds, and other structures for gathering spaces (like shelters) are available.
Active website:	NO

Low-quality urban community gardens, located in low well-being neighborhoods:

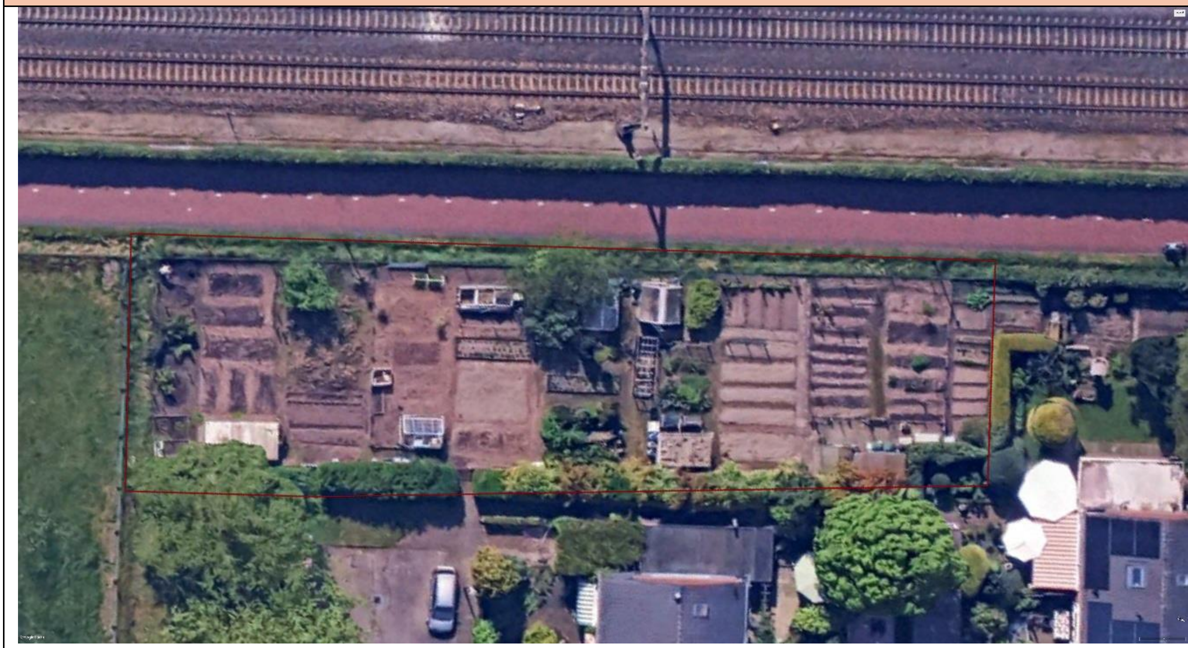


Figure 37: Low-quality community garden 1 located in Borne Municipality-Google Earth-Airbus-2024

Visible features from imagery:	Some small greenhouses are available.
Active website:	NO

Figure 38: Low-quality community garden 2 located in Zwartewaterland Municipality-Google Earth-Airbus-2022

Visible features from imagery:	Many covered beds are seen, but there is no available greenhouse.
Active website:	NO

Figure 39: Low-quality community garden 3 located in Steenwijkerland Municipality-Google Earth-Airbus-2022

Visible features from imagery:	There are no greenhouses, covered beds, or gathering spaces available.
Active website:	NO

These three urban neighborhoods that simultaneously exhibited low well-being indicators and hosted low-quality community gardens could benefit from targeted improvements in their garden infrastructure, and the two mentioned sources of evidence identified in section 3.4.2 will be used for this matter, these sources were high-quality community gardens and academic literature.

High-quality community gardens were not only above median values in all spatial quality indicators but also based on Google Earth imagery, consistently included greenhouses or covered gardening beds, and, in some cases, infrastructure such as a shelter or pergola that is used for social gatherings, events, or other activities.

One high-quality garden had an active website, used to organize events and communicate membership rules. In contrast, none of the low-quality gardens had a social gathering area, and only a minority featured greenhouses or covered beds.

The importance of improving garden qualities can also be supported by existing literature that links specific features of community gardens to well-being outcomes. For instance, many of the well-being indicators examined in this study, such as social cohesion and reduced loneliness (Langemeyer et al., 2018; Van Den Berg et al., 2010), are directly related to how gardens facilitate social interaction; suggesting that community gardens with gathering areas, such as pergolas or sheltered spaces, may enable more frequent and meaningful community interactions. The importance of accessibility is also highlighted by multiple sources. For example, Mourão et al. (2019) discussed how frequent use correlates with higher well-being, which implies that proximity to the garden, whether by walking/cycling or public transport, is critical to enabling access. Truong et al. (2022) and Jeong et al. (2018) also observed that living near a well-managed green space positively contributes to housing satisfaction, a dimension often intertwined with subjective well-being. Moreover, vegetation health is central to both the ecological and health-related functions of gardens.

- Neighborhood A, Low-quality community garden 1 located in Borne Municipality, Figure 37:

This neighborhood has the lowest percentage of people reporting high resilience and also a very low percentage of people with good perceived health. The low-quality community garden located in this neighborhood has the lowest NDVI (based on July 2024 images) among all the gardens and hard access (both via walking and public transport). According to literature, improving accessibility (like placing a bus stop near the garden), adding vegetation, and more year-round infrastructure like greenhouses could help support the resilience of residents in this neighborhood.

- Neighborhood B, Low-quality community garden 2 located in Zwartewaterland Municipality, Figure 38:

This neighborhood has the highest percentage of people having high levels of stress and its community garden has the worst access to public transportation. Based on literature that supports the role of nearby well-designed green spaces in improving subjective well-being, improving transit accessibility could help mitigate stress and improve this neighborhood's social outcomes.

- Neighborhood C, Low-quality community garden 3 located in Steenwijkerland Municipality, Figure 39:

This is the most socially vulnerable neighborhood with extremely low social cohesion, the highest percentage of people feeling socially lonely, and have a high risk of anxiety. The community garden located in this neighborhood also has the lowest size per capita, with no greenhouses, covered gardening beds, or gathering spaces. This garden would benefit from expansion, denser planting, and the introduction of a pergola/shelter to enable community-building events. These steps could particularly address the low well-being of the neighborhood.

In summary, each of the three identified neighborhoods presents a distinct well-being challenge. By aligning the observed well-being deficits with the spatial limitations of their local community gardens, this analysis proposed specific, modest interventions tailored to the local context of each neighborhood. Rather than prescribing generalized solutions, these recommendations demonstrate how spatial characteristics of community gardens can be adjusted in targeted ways to potentially support the particular well-being needs of underserved neighborhoods. This highlights the practical value of spatial analysis in designing more responsive green infrastructure.

5. DISCUSSION

This research explored the link between community gardens and neighborhood well-being, building on extensive literature that documents the benefits of community gardens for both direct users and the wider community. Community gardens have been shown to promote health, reduce stress, enhance social inclusion, and foster environmental awareness (Soga et al., 2017; 'Yotti' Kingsley & Townsend, 2006). These benefits extend beyond gardeners and include broader neighborhoods, such as improved aesthetics, informal meeting spaces, and strengthened local identity (Bell, 2016; Egerer et al., 2024).

With this background in mind, the overarching aim of the study was to assess whether community gardens in Overijssel are located in neighborhoods characterized by lower well-being scores and thereby to explore their spatial alignment with areas of greater need. As Jermé and Wakefield (2013) emphasize, without equity-focused policy frameworks, community gardens risk reinforcing rather than reducing spatial injustices. They should be tools to advance environmental justice, especially in under-resourced neighborhoods (Jermé & Wakefield, 2013).

In the context of Overijssel, the spatial distribution of community gardens revealed clear patterns. First of all, they were predominantly concentrated in more populous municipalities such as Enschede, Zwolle, Steenwijkerland, Deventer, and Almelo. Also, a substantial majority of gardens (141 out of 322) were located in rural neighborhoods, where they were also larger in size. Well-being indicators such as perceived resilience, perceived health, and social cohesion were consistently higher in rural areas compared to urban areas. This suggests that, on a broad scale, community gardens are not predominantly located in areas of potential need, as they tend to be situated in rural neighborhoods that already report higher well-being. Recognizing this contrast, the analysis proceeded by separating urban and rural areas to explore differences more precisely. Among urban neighborhoods, no statistically significant difference in well-being was found between neighborhoods with and without community gardens. However, in rural settings, neighborhoods with gardens reported notably higher levels of resilience, social cohesion, and physical activity. Interestingly, across both rural and urban classifications, community gardens tended to be located in neighborhoods with relatively higher population density. This supports the municipal-level trend observed earlier and suggests that population concentration may influence garden placement, regardless of well-being scores.

The analysis was further deepened by investigating how community garden qualities relate to well-being conditions in neighborhoods that may be underserved. Neighborhoods with both low well-being and low-quality community gardens were identified. Drawing from benchmarks set by high-quality gardens in the study area, as well as the academic literature, these neighborhoods were then examined in detail to understand whether specific improvements in garden qualities might support better well-being outcomes, and tailored suggestions were made for each selected garden. This approach provides practical insight into how spatial inequalities in garden infrastructure may correspond with well-being disparities, and how modest, context-sensitive improvements could potentially align community garden functions more closely with local social needs.

While this study provided valuable insights into the spatial distribution and qualities of community gardens in relation to neighborhood well-being, several limitations remain that point toward promising directions for future research. First, the well-being indicators used in this study were, at the smallest scale, available at the neighborhood level, which limited the ability to capture variation within neighborhoods or assess individual experiences. The data also represented a single year, 2022, which prevented any examination of how well-being may have changed before and after the construction of a community garden. Moreover, the dataset did not include information about garden users or surrounding residents, as Lawson (2004) and Firth et al. (2011) highlight that governance models, user participation, and social capital are equally central to a garden's impact (Firth et al., 2011; Lawson, 2004); all of which could influence both garden usage and well-being outcomes. Future studies would benefit from the inclusion of longitudinal well-being data, as well as individual-level surveys or interviews, to better understand the pathways through which gardens might contribute to local well-being and social outcomes.

In terms of the community gardens themselves, the study was limited to spatially measurable characteristics such as size, vegetation index (NDVI), and accessibility. As Jermé and Wakefield (2013) also underscore, the limitation of evaluating gardens solely by their physical qualities, given that social infrastructure plays a crucial role in enabling equitable impact (Jermé & Wakefield, 2013). In this study, many other important garden attributes were not available in existing datasets. These include the presence of active governance structures, rules for membership, the number and diversity of users, and the types of activities offered. These qualitative dimensions are likely to play a crucial role in shaping a garden's social and ecological functions and could not be incorporated into the current analysis. Additionally, physical features like fencing, available infrastructure, or maintenance practices were not assessed, although they may contribute to a garden's perception and use by the community.

The study was also constrained by neighborhood borders, which may be too coarse to detect localized effects. For instance, it is likely that community gardens have their strongest impact within a walkable radius rather than across an entire neighborhood unit. To address this, future studies could consider using buffer zones or service areas based on walking distance to more accurately model a garden's influence.

Finally, several findings from this study raise important questions that are worth further investigation. One recurring pattern was that community gardens in total and even high-quality gardens tend to be located in neighborhoods with higher well-being scores. It remains unclear whether this reflects proactive planning in already advantaged areas, greater community initiative, differences in funding and institutional support, or any other reason. Similarly, the consistent association between garden presence and higher population density, observed both at the municipal and neighborhood level, suggests a possible spatial logic behind garden placement, which deserves closer attention. These questions could be explored through a combination of field visits, stakeholder interviews, and participatory mapping approaches that complement spatial analysis with contextual understanding.

The spatial knowledge and analysis method used in this study is crucial for planners and local authorities seeking to identify suitable locations for future community gardens in a way that promotes spatial equity and supports residents' quality of life. As highlighted by Lawson (2004), community gardens have historically emerged as grassroots responses to urban social and environmental challenges, but their success and sustainability increasingly depend on institutional support and integration into urban planning frameworks (Lawson, 2004). The spatial analyses presented in this study allow planners to move beyond ad hoc placement and toward more data-informed decisions about where gardens are most needed. Moreover, as noted by Evers and Hodgson (2011), integrating food-growing spaces into urban strategies requires planners to recognize community gardens as multifunctional areas that support health, social cohesion, and sustainability (Evers & Hodgson, 2011). Urban planning decisions by Municipalities in Overijssel can be better aligned with both community needs and environmental justice.

While this research focused on the province of Overijssel, the methodological approach and spatial indicators used are adaptable to other contexts. In regions facing similar disparities in green space, or specifically, community garden access or well-being outcomes, this framework can support more equitable urban greening initiatives. Thus, the findings contribute not only to local planning in Overijssel but also to broader discussions on how spatial analysis can guide sustainable and just urban development in diverse settings.

This research was further enriched by the author's internship at Botildenborg, a socially oriented urban farm and community garden in Malmö, Sweden. The experience provided an applied perspective on many of the aspects explored in this study, particularly the relationship between garden qualities and community well-being. While the quantitative analysis in Overijssel relied on spatial indicators such as garden size, NDVI, and accessibility, the internship highlighted how additional qualitative attributes, such as social infrastructure and seasonal adaptability, also play an important role in shaping how gardens are used and by whom.

At Botildenborg, the gardening areas were relatively modest in scale. Yet, the garden offered multiple social functions beyond cultivation, like a shared pergola for gathering, small greenhouses that allowed year-round activity, and community events like shared cooking sessions. These elements expanded the scope of participation to include not only those engaged in cultivation but also residents and visitors involved in social, cultural, and educational activities. This aligns with the broader literature that defines community gardens not merely as spaces of production, but as socially constructed landscapes where health, inclusion, and cohesion are cultivated (Bell, 2016; Egerer et al., 2024).

The internship reinforced the idea that the design and management of community gardens, including their physical features and governance structure, significantly influence their inclusivity and overall social impact. These firsthand observations affirm the central argument of this thesis, that it is not just the presence of gardens, but their spatial and functional qualities, that shape their potential to enhance neighborhood well-being. Specifically, the social infrastructure observed at Botildenborg, such as gathering spaces and community events, can be linked to several well-being themes in the CBS framework. For example, they foster social cohesion and help reduce social loneliness by encouraging interaction among diverse groups. The involvement in gardening and food preparation also supports health through physical activity and nutritious food consumption. Furthermore, volunteer opportunities and participatory governance may enhance willingness to do volunteer work and a sense of resilience among participants. While no income was directly generated, the farm's operations contributed to material well-being indirectly by improving participants' skills and offering learning or integration opportunities, particularly for newcomers. These CBS-aligned insights underscore how thoughtfully designed gardens can contribute to multiple dimensions of well-being. Also, since the two areas differ in many aspects, like policy frameworks or socio-demographic composition, it should be noted that while the analytical framework may be transferable, its practical application must be adapted to local governance and cultural conditions. This comparison highlights the importance of context-sensitive planning, where spatial equity tools are informed by, but not rigidly copied from, other regions

6. CONCLUSION

Community gardens have been increasingly recognized for their contributions to social benefits, such as enhanced well-being, social cohesion, mental and physical health, and urban sustainability (Lampert et al., 2021; Thompson et al., 2007). However, they focus on personal experiences rather than spatial patterns. What remains unexplored and is recognized as the research gap by this study is how community gardens are associated with community well-being on a neighborhood scale. Are community gardens spatially distributed in an equitable way that serves residents with the greatest/potential need? This research aimed to address this gap by exploring the spatial associations between community gardens and neighborhood well-being across Overijssel, the Netherlands, asking not only where gardens are located, but also what qualities they possess and what relationships they hold with well-being patterns.

The overarching aim of the study was approached through three objectives:

The first objective of this study was addressed through two guiding questions. The first question aimed to identify which spatial qualities of community gardens best reflect their social and ecological functions. Drawing from past literature and adapting it to the available spatial data, six qualities were selected, garden location, size, size per capita, proximity to public transport, walking and biking service area, and vegetation health (NDVI). These qualities provided a structured basis for assessing the pattern of community gardens across the region.

The second question examined the spatial patterns of these qualities across Overijssel. Kernel density analysis was applied to map both the general distribution of gardens and the spatial concentration of their qualities based on their location. The results showed that gardens are not evenly distributed; rather, they are concentrated in more populated municipalities, with nearly 30% of all community gardens located solely within Zwolle and Steenwijkerland. To further explore spatial variation, spatial autocorrelation was assessed for each quality. Among them, proximity to public transport, walking service area, and NDVI exhibited spatial autocorrelation. This was expected, as transport-related characteristics are directly linked to shared infrastructure, and vegetation patterns may reflect underlying land use and ecological conditions that cluster geographically, but more localized patterns are worth examining in detail. Therefore, Local Moran's I was used to investigate NDVI clustering. The results showed clustering of gardens with both high and low NDVI in Zwolle, whereas Deventer exhibited a notable cluster of gardens with higher NDVI. In contrast, other qualities, such as overall size or garden size per capita, displayed no clear spatial clustering, indicating that these attributes are more randomly distributed across the province.

The second objective focused on uncovering the spatial patterns of neighborhood-level well-being across Overijssel. To do so, the first step/question involved identifying relevant well-being indicators at the neighborhood scale. Twenty-seven alternative indicators were selected based on their thematic alignment with the CBS well-being framework, their availability from reliable sources, and their level at the neighborhood scale.

To address the second research question under this objective, the spatial pattern of well-being, several analytical steps were carried out. Hotspot maps were first generated to visualize overall trends, revealing a clear distinction between rural and urban neighborhoods. Rural areas consistently exhibited better well-being scores across most indicators. This observation was further supported by divided histograms, which confirmed significant differences. The next step compared the well-being distributions in neighborhoods with community gardens against the province as a whole. These comparisons indicated that, in many cases, the patterns were general and not specific to garden neighborhoods. For example, the median stress level in garden neighborhoods closely mirrored that of the overall Overijssel, which also suggested that broader spatial dynamics, like the predominance of rural areas, were influencing the results.

Given this, rural and urban neighborhoods were analyzed separately to reduce bias. It was also noted that the majority of community gardens are located in rural areas, and they tend to be larger in size. Statistical comparison using the Mann–Whitney U test (Wilcoxon rank-sum test) showed that in urban neighborhoods, no significant differences were found between areas with and without gardens across well-being indicators. However, in rural settings, neighborhoods with gardens reported higher levels of resilience, stronger social cohesion, and more frequent weekly physical activity. An additional observation emerged across both urban and rural contexts; Community gardens tended to be located in neighborhoods with higher population density, reinforcing a consistent spatial association between garden presence and demographic concentration.

The third objective built upon the findings of the previous two by exploring the association between community garden characteristics and neighborhood well-being indicators. This stage of the research focused specifically on urban neighborhoods with community gardens, aiming to understand how different garden qualities may be linked to local well-being outcomes. The first question under this objective was addressed using Kendall's rank correlation (τ), a non-parametric test suitable for small sample sizes and non-normally distributed variables. This analysis was conducted in R, comparing each spatial garden quality to a wide range of well-being indicators. Several significant associations have emerged. The larger garden size was related to lower levels of stress and higher levels of volunteer work. Garden size per capita showed the strongest and most consistent associations; Neighborhoods with more garden space available per resident also reported higher resilience, stronger social cohesion, more volunteer work, and lower levels of stress, mental complaints, and anxiety risk. Proximity to public transport was negatively associated with well-being. Meaning that gardens closer to transit stops tended to be located in neighborhoods with higher levels of social loneliness and lower cohesion. Walking and biking accessibility, especially at the largest buffer of 3750 meters, was positively associated with social cohesion and negatively correlated with overweight prevalence and loneliness. Finally, NDVI (vegetation health) was positively associated with better perceived health, lower overweight rates, and higher social cohesion.

To further investigate the spatial consistency of these relationships, selected pairs were visualized using the Local Bivariate Relationship tool in ArcGIS Pro. These maps helped reveal whether the global correlation identified through Kendall's τ was evenly distributed or driven by local concentrations. For instance, the positive relationship between garden size per capita and high resilience was found consistently across the study area, reinforcing the global result. However, the relationship between NDVI and perceived health was spatially uneven. It was only statistically significant in about 32% of the neighborhoods, mostly located in the southern part of the province. Similarly, the negative correlation between public transport accessibility and social loneliness was only locally significant in about 2% of the neighborhoods. These examples underscore the importance of combining global correlation statistics with local spatial analysis to better interpret complex urban and ecological patterns.

The second question of this objective tried to explore how well-being in underserved neighborhoods can be improved with the help of improving the quality of their community gardens. To address this, low well-being neighborhoods hosting low-quality community gardens were identified using the Select by Attribute tool in ArcGIS Pro, based on whether they scored consistently below the median across all indicators/qualities. This selection helped narrow the focus to a smaller group of gardens for deeper investigation. These neighborhoods were then examined in detail to understand whether specific improvements in garden qualities might support better well-being for the neighborhood.

Additional qualitative insights from high-quality gardens were gathered through visual inspection using Google Earth, which allowed assessment of features not captured/available in the original dataset and as benchmarks. High-quality gardens consistently included greenhouses or covered beds, indicating their ability to function in colder seasons. At least one high-quality garden featured social infrastructure such as a pergola or shelter, enabling group gatherings and events. Furthermore, one garden maintained an active website, used for event planning and sharing membership guidelines, which is a sign of organizational capacity and community engagement. In contrast, none of the low-quality gardens had an online presence, and only a few displayed any form of greenhouse or seasonal infrastructure. Drawing from the high-quality gardens and past literature, tailored suggestions were made for how each selected garden could be enhanced. This layered analysis illustrates how combining spatial data with qualitative observation can provide a more nuanced understanding of garden functionality and local context.

Despite the valuable insights offered by this research, several limitations highlight directions for future studies. The well-being data used were at the neighborhood level and for a single year (2022), limiting both temporal and intra-neighborhood insights. Furthermore, the absence of individual-level data, such as garden users, restricted the ability to conclude any causal relationships. Similarly, the scope of garden characteristics was limited to spatially measurable attributes, excluding key qualitative factors such as governance structures, accessibility rules, user diversity, and activity types. These elements likely play a significant role in a garden's functionality and impact. Moreover, while this study relied on administrative boundaries, future research could benefit from analyzing walkable service areas to better capture the local influence of gardens. Finally, patterns observed, such as the tendency for high-quality gardens to be located in higher well-being neighborhoods or the clustering of gardens in denser areas, raise questions about planning priorities and support systems. These findings could be meaningfully extended through mixed-method approaches like stakeholder interviews, site visits, or participatory mapping, offering richer contextual understanding to complement the spatial analysis.

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APPENDIX

Appendix A: Data management plan

Primary data:

No primary data was collected or generated for this research.

Secondary data:

The table 9 shows the sources of the acquired data, their collection date, and their unit of analysis. Data accuracy and reliability were ensured during the collection phase. There are no restrictions on most of the data, and they can be used as desired, if a statement of the source is included. The satellite images were downloaded from Planet Scope, and access was granted through the author's student account. The data was organized by date and source, with clear names that directly show what the files are.

The project did not need a review from the ITC Ethics Committee, as all the data that will be used was downloaded without restrictions.

Table 9: Secondary data collected

Layer	Source	Restrictions	Year
Community gardens	OpenStreetMap Google maps	Open source	2024
Roads	National Roads Database (NWB)	Open space No usage restrictions	2024
Public transport stops (Train)	Train stations data by ProRail	Open space Not allowed in National Georegister	2024
Public transport stops (Bus)	Central Stop File (CHB), published by the NDOV management organization	Open space No usage restrictions	2023
Cycling path	Core Network Cycling by Movares Consultants and Engineers	Open space Not allowed in National Georegister	2021
Vegetation Health (NDVI)	Planet data satellite images 30-July-2024	Restricted: Access granted through a student account under the Planet's Education and Research Program. Usage is subject to Planet's terms and cannot be freely redistributed.	2024
Statistical data at the regional level of neighborhoods in the Netherlands	Centraal Bureau voor de Statistiek, published by Overijssel geoportal	Open space No usage restrictions	2024

Indicator	Description	Source
Very good/good Perceived health	Percentage of people aged 18 years or older with the answer category "very good" and "good" to the question about their general health status.	Health Monitor for Adults and the Elderly, 2022
Weekly Sports Participants	Percentage of persons aged 18 years or older who exercise at least once a week.	
Overweight	Percentage of persons aged 18 years or older with a BMI of 25.0 kg/m2 or higher.	
Mental health complaints	Percentage of persons aged 18 years or older indicate having mental health problems. This was measured with the Mental Health Inventory 5 (MHI-5).	
High resilience	Percentage of people who indicate that they have a (very) high resilience. Resilience was measured with 5 statements about how people felt over the past 4 weeks from the Dutch vitality meter VITA-16.	

High risk of anxiety or depression	Percentage of 18 years or older at high risk of anxiety disorder or depression.	
Socially Lonely	The percentage of people aged 18 and over who feel socially lonely.	
Volunteer work	Percentage of persons aged 18 years or older who answered 'yes' to the question "Do you do volunteer work?" This means work that is carried out unpaid in an organized context (e.g. sports club, church council, school).	
Lack of emotional support	Percentage of people who report missing emotional support. This was measured with an adapted version of the lack of emotional support subscale of the Social Support Inventory - Discrepancies (SSL-D).	
Very much stress	Percentage of people aged 18 years or older who have experienced (very) a lot of stress in the past 4 weeks.	
Trouble making ends meet	The percentage of people aged 18 years or older who have difficulty making ends meet.	
Walking/cycling to work/school	The percentage of people aged 18 to 65 who walk and/or cycle to school or work (partly) one or more days a week.	
The Livability Barometer	The Livability Barometer provides a prediction of the extent to which the characteristics of the living environment in an area are valued by residents.	The Liveability Barometer - the Ministry of the Interior and Kingdom Relations, 2022
Housing Stock	Refers to the characteristics of the residential environment, including housing types, density, availability, maintenance, energy efficiency, and ownership structures. It also considers elements like historical preservation (monuments) and affordability.	
Physical Environment	Covers the natural and built environment, including air and water quality, noise levels, green spaces, climate factors (e.g., heat stress), and risks like flooding or earthquakes. This dimension highlights the influence of infrastructure and environmental quality on health and well-being.	
Facilities	Focuses on access to amenities and services, such as education, healthcare, public transport, shopping, and leisure activities. It also evaluates the diversity and proximity of these facilities, affecting convenience and quality of life.	
Social Cohesion	Relates to the strength of social networks and relationships within communities. This includes the extent of mutual trust, neighborhood engagement, and the ability to foster inclusive environments despite diversity.	
Nuisance and Insecurity	Addresses factors that reduce perceived or actual safety and comfort in a neighborhood, such as crime, vandalism, and other disruptive activities. It assesses their impact on overall liveability.	
Average standardized household income	The disposable income corrected for differences in size and composition of the household.	CBS - Key figures for districts and neighborhoods, 2023
Average income per income recipient	The arithmetic average personal income per person is based on persons with personal income who are part of private households.	
Average income per capita	The arithmetic average personal income per person is based on the total population in private households.	
Median private household wealth	The median is the middle number when all numbers are sorted from low to high. Wealth is the balance of assets and liabilities.	
Average WOZ value of homes	To determine the average WOZ value of homes, only BAG objects with a residential function for which a WOZ value is known and which is between 10 thousand and 5 million euros are used.	
High level of education	The number of persons who were between 15 and 75 years old that were registered in a Dutch municipality, whose highest educational level was higher education.	
Net labor participation	The share of the working population in the population (working and non-working population) ranges from 15 to 75 years old.	
Persons per type of benefit; WW	Persons receiving benefits under the Unemployment Act (WW).	
Degree of urbanization	Based on the environmental address density, each neighborhood, district or municipality has been assigned an urbanity class. The following class division has been used: 1: very strongly urban >= 2,500 addresses per km^2 2: highly urban 1,500 - 2,500 addresses per km^2 3: moderately urban 1,000 - 1,500 addresses per km^2 4: little urban 500 - 1,000 addresses per km^2 5: non-urban < 500 addresses per km^2	

Data Organizing and Documenting:

The folder structure that was used to organize the data was simple and understandable. The names of the folders represent the type of data contained in them. The year of acquisition will be written alongside the names of files, especially satellite Images.

Data Storage, Security, and Sharing:

All collected and generated research data were safely stored and protected to prevent unauthorized access, accidental disclosure, and loss. A copy of the GIS geodatabase was backed up in external storage. The document was also saved in the Teams environment to prevent loss.

Data Archived:

The secondary data is entirely open source, i.e., it can be downloaded again. Hence, it does not require a separate archive. However, additional steps will be taken to be able to analyze them. Therefore, the final geodatabase and the tables were archived.

Appendix B: R Studio codes - Mann–Whitney U test and Violin plots

This appendix provides the codes used in R Studio to calculate the Mann–Whitney U test (Wilcoxon rank-sum test) in Figure 40. This nonparametric test was used to assess whether differences in well-being indicators between neighborhoods with gardens and those without were statistically significant.

Violin plots were also created for each indicator. These plots show both the distribution and density of the data across the two groups and allow a clearer understanding of the variations.

```r
#Importing Urban neighborhoods data
dataurban <- read.csv("Level1234_TableToExcel.csv")

#Importing Rural neighborhood data
datarural <- read.csv("Neighborhoods_level5_TableToExcel.csv")

#Mann-Whitney U test (Wilcoxon Rank-Sum test) For Urban neighborhoods
dataurban$Have_garden <- factor(dataurban$Have_garden)
wilcox.test(dataurban$Social_cohesion~ dataurban$Have_garden, exact = FALSE)

#Mann-Whitney U test (Wilcoxon Rank-Sum test) For Rural neighborhoods
datarural$Have_garden <- factor(datarural$Have_garden)
wilcox.test(datarural$Social_cohesion~ datarural$Have_garden, exact = FALSE)

#Violin Plot
ggplot(dataurban, aes(x = Have_garden, y = Social_cohesion, fill = Have_garden)) +
  geom_violin(trim = FALSE, alpha = 0.6) +
  geom_boxplot(width = 0.1, fill = "white", outlier.color = "red") +
  geom_text(data = countsurban, aes(x = Have_garden, y = max(dataurban$Social_cohesion) * 1.05,
                                    label = paste0("n = ", n)),
            inherit.aes = FALSE, size = 4) +
  labs(title = "Social cohesion vs. Garden Presence in Urban neighborhoods",
       x = "Garden Presence", y = "Social cohesion") +
  scale_fill_manual(values = c("#A8D5BA", "#6C9A8B")) +
  theme_minimal() +
  theme(legend.position = "none")
```

Figure 40: R Studio code to calculate Mann–Whitney U test and Violin plots, Source: Author 2024-2025

Appendix C: Mann–Whitney U test results

This appendix provides the Mann–Whitney U test results from R in Table 10. The p-value (probability value) of less than 0.05 was considered to be statistically significant for this study, in which the null hypothesis should be rejected.

Table 10: Mann–Whitney U test results

Well-being indicator	**Mann–Whitney U test URBAN neighborhoods**	**Mann–Whitney U test RURAL neighborhoods**
Weekly Sports Participants	W = 25126 p-value = 0.4882	W = 15695 p-value = 0.01084
Overweight	W = 23168 p-value = 0.5114	W = 20240 p-value = 0.2901
High resilience	W = 24150 p-value = 0.984	W = 16352 p-value = 0.04269
Trouble making ends meet	W = 24055 p-value = 0.9642	W = 20267 p-value = 0.2803
Walking and cycling to work or school	W = 24311 p-value = 0.8957	W = 15464 p-value = 0.006321
Walking	W = 25308 p-value = 0.413	W = 17221 p-value = 0.1813
Cycling	W = 24228 p-value = 0.9409	W = 14276 p-value = 0.0002387
Good perceived health	W = 24489 p-value = 0.7996	W = 18698 p-value = 0.8692
Mental complaints	W = 24377 p-value = 0.8596	W = 18390 p-value = 0.6821
High risk of anxiety or depression	W = 24493 p-value = 0.7975	W = 19368 p-value = 0.7141
Socially lonely	W = 24044 p-value = 0.9585	W = 18920 p-value = 0.9918
Volunteer work	W = 23054 p-value = 0.4622	W = 18545 p-value = 0.7745
Lack of emotional support	W = 23808 p-value = 0.8296	W = 19034 p-value = 0.9196
Very much stress	W = 24324 p-value = 0.8884	W = 19734 p-value = 0.5113
Population of inhabitants	W = 17553 p-value = 5.935e-06	W = 14602 p-value = 0.0006367
Gender-men	W = 17601 p-value = 6.937e-06	W = 14630 p-value = 0.0006922
Gender-women	W = 17578 p-value = 6.427e-06	W = 14640 p-value = 0.0007103
Western migration background	W = 19354 p-value = 0.00101	W = 14518 p-value = 0.0004243
Non-Western migration background	W = 19642 p-value = 0.002006	W = 13963 p-value = 3.15e-05
Population density	W = 29120 p-value = 0.0005655	W = 18035 p-value = 0.4897
Average WOZ value of homes	W = 22890 p-value = 0.3965	W = 16727 p-value = 0.08375
Net labor participation	W = 23319 p-value = 0.5802	W = 17893 p-value = 0.4121
Average standardized household income	W = 22690 p-value = 0.324	W = 15794 p-value = 0.009806

Persons per type of social security benefit of WW	W = 20971 p-value = 0.02246	W = 16371 p-value = 0.006053
Age 15 to 25	W = 18514 p-value = 0.0001105	W = 14404 p-value = 0.0003501
Age 65 or older	W = 18972 p-value = 0.0003849	W = 14042 p-value = 0.0001122
Average income per income recipient	W = 23782 p-value = 0.8159	W = 16834 p-value = 0.0984
Average income per capita	W = 24532 p-value = 0.7765	W = 15826 p-value = 0.0143
Median private household wealth	W = 21897 p-value = 0.1251	W = 15769 p-value = 0.009365
Livability barometer	W = 23779 p-value = 0.8143	W = 17205 p-value = 0.1772
Physical environment	W = 23700 p-value = 0.7723	W = 17342 p-value = 0.2147
Nuisance and insecurity	W = 22896 p-value = 0.3988	W = 20933 p-value = 0.1078
Social cohesion	W = 23254 p-value = 0.5506	W = 22611 p-value = 0.003286
Facilities	W = 23923 p-value = 0.8922	W = 13176 p-value = 5.455e-06
Housing stock	W = 24425 p-value = 0.5929	W = 19690 p-value = 0.5341

Appendix D: R Studio codes - Kendall's rank correlation coefficient (τ)

This appendix provides the codes in R Studio used to calculate Kendall's rank correlation (τ) in Figure 41. This tool was used to assess the association between Urban neighborhoods' community garden qualities and their well-being indicators.

```r
#Importing Urban neighborhoods data with at least one community garden
dataurbangarden <- read.csv("Level1234_WithGarden_TableToExcel.csv")

# Kendall's Rank Correlation
with(dataurbangarden, cor.test(Good_percieved_health, SUM_GardenSize, method = "kendall"))
with(dataurbangarden, cor.test(Good_percieved_health, GardenSize_perCapita, method = "kendall"))
with(dataurbangarden, cor.test(Good_percieved_health, MEAN_NDVI_PCT90, method = "kendall"))
with(dataurbangarden, cor.test(Good_percieved_health, ServiceArea1250, method = "kendall"))
with(dataurbangarden, cor.test(Good_percieved_health, MEAN_Dist_near_station, method = "kendall"))
```

Figure 41: R Studio code to calculate Kendall's rank correlation coefficient (τ), Source: Author 2024-2025

Appendix E: Kendall's rank correlation coefficient (τ) results

This appendix provides the Kendall's rank correlation coefficient results from R in Table 11. The p-value (probability value) of less than 0.05 was considered to be statistically significant for this study, in which the null hypothesis should be rejected. The Tau value that shows the coefficient ranges from –1 to +1, where positive values indicate that higher values of one variable are generally associated with higher values of the other, and negative values suggest an inverse relationship.

Table 11: Kendall's rank correlation coefficient (τ) results

Urban neighborhoods with at least one garden (n=112)	**Service Area 3750**	**Service Area 1250**	**Service Area 300**	**NDVI**	**Proximity to public transport**	**SUM garden size**	**Garden size per capita**
Weekly Sports Participants	z = 1.4459 p-value = 0.1482	z = 0.61106 p-value = 0.5412	z = -0.4903 p-value = 0.6239	z = 1.8307 p-value = 0.06714 Tau= 0.1173627	z = 2.0973 p-value = 0.03597 Tau= 0.1344512	z = 0.23638 p-value = 0.8131	z = 1.295 p-value = 0.1953
Overweight	z = -2.1477 p-value = 0.03174 Tau= -0.1378316	z = -1.5341 p-value = 0.125	z = -1.1518 p-value = 0.2494	z = -2.0195 p-value = 0.04344 Tau= -0.1296526	z = -0.67147 p-value = 0.5019	z = 0.21377 p-value = 0.8307	z = -0.93049 p-value = 0.3521
High resilience	z = 1.1015 p-value = 0.2707	z = 0.080476 p-value = 0.9359	z = -1.3932 p-value = 0.1635	z = 0.28922 p-value = 0.7724	z = 3.5838 p-value = 0.000338 Tau= 0.2300808	z = 1.3354 p-value = 0.1817	z = 3.1386 p-value = 0.001698 Tau= 0.2014213
Trouble making ends meet	z = -1.1291 p-value = 0.2589	z = -0.62616 p-value = 0.5312	z = 0.33446 p-value = 0.738	z = -1.3077 p-value = 0.191	z = -1.9716 p-value = 0.04866 Tau= -0.1264314	z = -0.72425 p-value = 0.4689	z = -1.5918 p-value = 0.1114
Walking and cycling to work or school	z = -0.29673 p-value = 0.7667	z = -0.45264 p-value = 0.6508	z = 0.46773 p-value = 0.64	z = 0.27913 p-value = 0.7801	z = -3.5684 p-value = 0.00035 Tau= -0.2287789	z = -3.2213 p-value = 0.001276 Tau= -0.2065298	z = -2.8818 p-value = 0.003954 Tau= -0.1846901
walking	z = -1.0638 p-value = 0.2874	z = -0.51555 p-value = 0.6062	z = 0.91291 p-value = 0.3613	z = -1.2877 p-value = 0.1979	z = -3.4958 p-value = 0.0004727 Tau= -0.2245206	z = -3.4958 p-value = 0.00047 Tau= -0.07914756	z = -3.4958 p-value = 0.0004729 Tau= -0.0644228
cycling	z = 0.41745 p-value = 0.6763	z = 0.18609 p-value = 0.8524	z = 0.49289 p-value = 0.6221	z = 0.63625 p-value = 0.5246	z = -3.3422 p-value = 0.00083 Tau= -0.2144071	z = -3.5132 p-value = 0.000442 Tau= -0.2253776	z = -3.3647 p-value = 0.00076 Tau= -0.2157723
Good perceived health	z = 2.3161 p-value = 0.02055 Tau= 0.1485129	z = 1.5415 p-value = 0.1232	z = 0.037721 p-value = 0.9699	z = 2.1174 p-value = 0.03422 Tau= 0.1358286	z = 2.1074 p-value = 0.03508 Tau= 0.1351833	z = 0.42751 p-value = 0.669	z = 1.0839 p-value = 0.2784

Mental complaints	z = -1.1291 p-value = 0.2588	z = -0.4602 p-value = 0.6454	z = 0.61108 p-value = 0.5411	z = -0.4426 p-value = 0.6581	z = -2.721 p-value = 0.006508 Tau= -0.1745728	z = -1.6598 p-value = 0.09696	z = -2.5122 p-value = 0.012 Tau= -0.1611165
High risk of anxiety or depression	z = -1.1619 p-value = 0.2453	z = -0.44264 p-value = 0.658	z = 0.73941 p-value = 0.4597	z = -0.9481 p-value = 0.343	z = -2.427 p-value = 0.01522 Tau= -0.155986	z = -1.7228 p-value = 0.08493	z = -2.5301 p-value = 0.0114 Tau= -0.162548
Socially Lonely	z = -1.8485 p-value = 0.06453 Tau= -0.1187121	z = -1.2298 p-value = 0.2188	z = -0.17353 p-value = 0.8622	z = -1.1921 p-value = 0.2332	z = -2.4396 p-value = 0.01471 Tau= -0.1567307	z = -1.0664 p-value = 0.2863	z = -1.1292 p-value = 0.2588
Volunteer work	z = 1.0763 p-value = 0.2818 Tau= 0.06902133	z = 0.89022 p-value = 0.3733	z = 0.3068 p-value = 0.759	z = 1.436 p-value = 0.151	z = 2.6431 p-value = 0.008216 Tau= 0.1695575	z = 2.4871 p-value = 0.01288 Tau= 0.1595551	z = 2.2532 p-value = 0.02425 Tau= 0.1444932
Lack of emotional support	z = -1.0643 p-value = 0.2872	z = -0.43024 p-value = 0.667	z = 0.68184 p-value = 0.4953	z = -0.9837 p-value = 0.3252	z = -2.6846 p-value = 0.007261 Tau= -0.1733622	z = -1.4719 p-value = 0.1411	z = -2.0908 p-value = 0.03655 Tau= -0.1349635
Very much stress	z = -0.8551 p-value = 0.3925	z = -0.49294 p-value = 0.6221	z = 0.43258 p-value = 0.6653	z = 0.34959 p-value = 0.7266	z = -2.5125 p-value = 0.01199 Tau= -0.1614295	z = -2.422 p-value = 0.01544 Tau= -0.1556122	z = -2.9124 p-value = 0.003587 Tau= -0.1870472
Average WOZ value of homes	z = 2.0998 p-value = 0.03574 Tau= 0.1346452	z = 1.3303 p-value = 0.1834	z = -0.027662 p-value = 0.9779	z = 1.4888 p-value = 0.1365	z = 2.0621 p-value = 0.03919 Tau= 0.1322796	z = 0.75444 p-value = 0.4506	z = 1.4007 p-value = 0.1613
Net labor participation	z = 2.1081 p-value = 0.03502 Tau= 0.1373872	z = 1.8512 p-value = 0.06414 Tau= 0.1206447	z = 1.1006 p-value = 0.2711	z = 1.4407 p-value = 0.1497	z = 0.73545 p-value = 0.4621	z = -0.62463 p-value = 0.5322	z = -2.0023 p-value = 0.04525 Tau= -0.1304933
Livability barometer	z = 1.5992 p-value = 0.1098	z = 0.98568 p-value = 0.3243	z = 0.060347 p-value = 0.9519	z = 0.51548 p-value = 0.6062	z = 2.4014 p-value = 0.01633 Tau= 0.1536976	z = 0.50039 p-value = 0.6168	z = 1.6193 p-value = 0.1054
Physical environment	z = 1.3025 p-value = 0.1927	z = 2.2077 p-value = 0.02726 Tau= 0.1412484	z = 1.8155 p-value = 0.06945 Tau= 0.1161519	z = 0.50542 p-value = 0.6133	z = 0.037718 p-value = 0.9699	z = 0.20871 p-value = 0.8347	z = -1.4131 p-value = 0.1576
Nuisance and insecurity	z = 1.4785 p-value = 0.1393	z = 0.75434 p-value = 0.4506	z = -0.34197 p-value = 0.7324	z = 0.27911 p-value = 0.7802	z = 2.9194 p-value = 0.003507 Tau= 0.1868512	z = 2.0342 p-value = 0.04193 Tau= 0.1302004	z = 2.8162 p-value = 0.004859 Tau= 0.1801802

Social cohesion	z = 2.4038 p-value = 0.01622 Tau= 0.1537967	z = 1.4282 p-value = 0.1532	z = -0.63365 p-value = 0.5263	z = 1.7778 p-value = 0.07544 Tau= 0.1137845	z = 3.5933 p-value = 0.00032 Tau= 0.2299831	z = 1.471 p-value = 0.1413	z = 3.641 p-value = 0.000271 Tau= 0.2329472
Facilities	z = -1.5087 p-value = 0.1314	z = -1.3478 p-value = 0.1777	z = 0.040232 p-value = 0.9679	z = -0.63115 p-value = 0.5279	z = -2.7182 p-value = 0.00656 Tau= -0.173976	z = -2.0946 p-value = 0.03621 Tau= -0.1340629	z = -1.3779 p-value = 0.1682
Housing stock	z = 1.5163 p-value = 0.1294	z = 0.64474 p-value = 0.5191	z = -0.53771 p-value = 0.5908	z = 1.4679 p-value = 0.1421	z = 3.7513 p-value = 0.00017 Tau= 0.2412126	z = 1.5444 p-value = 0.1225	z = 3.6926 p-value = 0.000222 Tau= 0.2373464