Annals of GIS

ISSN: 1947-5683 (Print) 1947-5691 (Online) Journal homepage: www.tandfonline.com/journals/tagi20

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To cite this article: Tinashe P. Kanosvamhira, Tatenda Musasa & Oshneck Mupepi (2025) The potential for urban agriculture (UA) in Cape Town, South Africa: a suitability analysis, Annals of GIS, 31:1, 107-122, DOI: 10.1080/19475683.2025.2455430

To link to this article: https://doi.org/10.1080/19475683.2025.2455430

Published online: 26 Jan 2025.

ANNALS OF GIS
2025, VOL. 31, NO. 1, 107–122
https://doi.org/10.1080/19475683.2025.2455430

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The potential for urban agriculture (UA) in Cape Town, South Africa: a suitability analysis

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ABSTRACT
Urban agriculture plays a pivotal role in enhancing human well-being by contributing to food security, economic prosperity, and environmental sustainability. Despite its significance, many cities lack accurate inventories to identify suitable sites for such initiatives. This study examines the potential for urban agriculture in Cape Town using Multi-Criteria Decision Making techniques. Factors such as temperature, soil fertility, road accessibility, and precipitation were analysed using weighted overlay to determine the agricultural potential in Cape Town. Utilizing methodologies like the Analytic Hierarchy Process and Weighted Linear Combination, the agricultural potential was established. Findings indicate that there are highly suitable areas for agriculture whose potential has not yet been fully exploited. Currently, agricultural activities like vineyards, crop production, and cattle farming, though situated on good agricultural land, are not as prominent despite the availability of vast tracts of highly suitable land. Therefore, there is a need to raise awareness and promote urban agriculture to alleviate poverty-related food insecurities. The implementation of urban agriculture is anticipated to significantly improve food security, create economic opportunities, and enhance environmental sustainability within urban areas. The study recommends the need for longitudinal studies to gather essential information for informed decision-making, ensuring the sustainability of urban agriculture initiatives.

ARTICLE HISTORY
Received 24 April 2024
Accepted 2 January 2025

KEYWORDS
Analytic Hierarchy Process; urban food security; urban agriculture suitability analysis; urban land use; sustainable Development Goals

1. Introduction

Urban agriculture (UA refers to agricultural practices conducted within urban areas and their surrounding regions (peri-urban), encompassing horticulture, animal husbandry, aquaculture, and other practices for producing fresh food and agricultural products (Orsini et al. 2013). There are various approaches to urban agriculture, including ground-level farming, rooftop farming, hydroponics, greenhouses, and other innovative technologies. Urban agriculture has the potential to supply food for local consumption, particularly perishables and high-value horticultural crops (Kanosvamhira 2024a). Additionally, there is growing interest in the commercial-scale cultivation of non-food crops in urban areas, such as flowers, green walls, and similar products (Orsini et al. 2013). As the world's population continues to grow rapidly, it is projected that by 2025, two-thirds of the global population will reside in urban areas (Lederer 2016). This demographic shift underscores the importance of not only ensuring environmental quality and creating livable spaces but also addressing food security and developing resilient food systems .

UA plays a pivotal role in ensuring food security and is a hallmark of smart cities, which represent a phenomenon intricately entwined with urban economies, culture, science, and technology (Pearson, Pearson, and Pearson 2010). Its presence signifies a city's economic advancement to a higher echelon. In contrast to conventional agricultural practices, urban agriculture relies heavily on capital, infrastructure, technology, and labour (Ferreira et al. 2018). It embodies an industrialized, market-oriented approach to agriculture, leveraging the developed markets, information systems, and transportation networks of international cities to bolster agricultural productivity and facilitate interregional trade (Hallett, Hoagland, and Toner 2016).

UA has gained significant attention as a sustainable development strategy, offering potential solutions to critical urban challenges such as food security, poverty, and environmental sustainability. The United Nations Sustainable Development Goals (UNSDGs) provide a global blueprint for achieving a better and more sustainable future, and urban agriculture contributes directly to several of these goals. For instance,

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UA supports Goal 2 (Zero Hunger) by improving food security and nutrition, Goal 11 (Sustainable Cities and Communities) by promoting inclusive and sustainable urbanization, and Goal 12 (Responsible Consumption and Production) by fostering sustainable food systems.

Greenhouses were introduced decades ago primarily to shield plants from adverse weather conditions, initially utilized by rural farmers as an alternative means to safeguard their production. However, in recent years, greenhouses, encompassing plant factories and rooftop gardens, have proliferated within urban settings (Vardoulakis and Kinney 2019). A growing number of businesses and researchers have embraced urban farming, achieving sustainable production of fresh food and other commodities (Pearson, Pearson, and Pearson 2010; Salmond et al. 2016). Urban agriculture is increasingly recognized as an emerging business venture within urban areas (Orsini et al. 2013).

Urban agriculture within the urban public realm encounters numerous barriers and challenges that impede its establishment and sustained viability (Orsini et al. 2013). Among these impediments, aesthetics often play a significant role, with urban agriculture frequently lacking positive associations with its spatial presence and visual performance. Urbanization rates are escalating, leading to the rapid loss of agricultural land at a pace outstripping the preservation of productive land areas. This trend exacerbates the looming threat of climate change and the depletion of natural resources, which are projected to substantially diminish food production potential, particularly in the world's most food-insecure regions (Zhang et al. 2022).

The integration of urban agriculture into residential locales and built environments holds promise for delivering manifold benefits. As a form of green space, urban agriculture can mitigate carbon emissions associated with food transportation, reduce impervious surfaces, enhance microclimate control, promote ground aquifer recharge, and contribute to urban cooling efforts aimed at ameliorating the urban heat island effect and mitigating climate change impacts (Bedford 2022). Urban design and planning play pivotal roles in shaping human settlements, with urban agriculture offering avenues for enhancing public health, mental well-being, and fostering socially networked, food-resilient communities (Safdar et al. 2022). By addressing these multifaceted challenges and leveraging the potential of urban agriculture, cities can strive towards more sustainable, equitable, and resilient urban futures.

Growing food has long been a visible common practice in many cities and towns worldwide. Literature shows that current urban designs and architectural practices are already integrating productive landscapes within new and existing developments. The integration of urban agriculture in cities is shaped by available productive spaces on the ground, vertical surfaces, and rooftops, and is influenced by urban morphologies, socio-economic conditions, government and private initiatives, and people's perceptions and awareness (Orsini et al. 2013). Orsini et al. (2013) outlined the dimensions of urban agriculture as scale, products, destination, economic activities, location, and areas. Scale links to the physical characteristics of productive spaces; products relate to the types of produce such as vegetables, fruits, and herbs; and destination defines the 'farm to plate' distance that the produce travels to reach the consumer (Orsini et al. 2013; Russo et al. 2017).

In the realm of promoting green infrastructure, several studies have focused on the concept of edible green infrastructure (Russo et al. 2017). However, despite its manifold benefits, edible green infrastructure remains largely overlooked in cities across the global South. This knowledge gap within the literature presents a significant challenge in harnessing the potential of such green infrastructure to foster sustainable urban development. Land emerges as a critical component in this context, as its utilization must align with principles of sustainable development (Kanosvamhira and Shade 2025). With escalating demand and development pressures encroaching upon agricultural lands and wetlands in the immediate vicinity of urban centres, the environment faces increasing threats. This trend has not only resulted in the loss of agricultural lands but has also led to the degradation of investment in agricultural infrastructure, the destruction of natural landscapes, and the unsustainable exploitation of groundwater resources.

Given these challenges, there is a pressing need to identify suitable land for optimal agricultural practices. Several studies, such as those by Seyedmohammadi et al. (2018) and Ustaoglu, Sisman, and Aydınoglu (2021), have employed the Analytic Hierarchy Process (AHP) to evaluate the contribution of a wide range of agriculture suitability factors in non-urban areas. These studies analysed agriculture suitability in urban areas but could not quantify land available for agriculture vis-à-vis already used portions of that land, thus failing to clarify the availability of vacant land for agricultural activities, an aspect that warrants further attention (Weerakoon 2014). However, it is important to note the consensus among studies on factors that determine agricultural suitability, especially precipitation, soil type, temperature, proximity to roads and settlements, as well as terrain factors (Kheybari, Rezaie, and Farazmand 2020; Seyedmohammadi et al. 2018, 2019; Ustaoglu, Sisman, and Aydınoglu 2021; Zaki et al. 2023). This indicates the availability of criteria and methods for determining agricultural suitability, although with limited application in urban areas, particularly from a food security perspective. Expanding the application of these criteria and methodologies to urban contexts could significantly enhance our understanding of how urban agriculture can contribute to sustainable food systems and the overall resilience of urban areas.

Previous studies have explored various aspects of urban agriculture in Cape Town and other South Africa more generally. For instance, several studies have examined the socio-economic impacts of urban agriculture in Cape Town, highlighting its potential and hindrances to improve food security and provide livelihood opportunities (Battersby and Marshak 2013; Reuther and Dewar 2006). In South Africa cities, research has identified the benefits of UA in enhancing community resilience and promoting environmental sustainability including economic empowerment, social inclusion, and to a lesser extent ecological benefits (Kanosvamhira 2024b). Despite the growing body of literature in South Africa, there remains a gap in comprehensive suitability analyses of high-resolution spatial data to identify optimal locations for urban agriculture.

Against this backdrop, the present study employs Weighted Linear Combination calculations, map algebra techniques, and the Analytic Hierarchy Process to discern land parcels suitable for urban agriculture. By doing so, it aims to furnish a comprehensive guideline for determining the suitability of various areas within the study area for different types of urban agricultural activities. The main objectives of this study revolve around assessing the suitability of different regions within Cape Town for urban agriculture while employing Multi-Criteria Decision Making (MCDM) techniques.

By analysing factors such as temperature, soil composition, slope, proximity to streams, accessibility by road, and land use type, the study aims to provide a comprehensive evaluation of each area's potential for agricultural development. The research seeks to integrate diverse criteria and prioritize key factors influencing urban agriculture suitability. The ultimate goal is to generate insights that can inform urban planning strategies and agricultural development initiatives in Cape Town, aiding policymakers, land managers, and stakeholders in making informed decisions regarding land use, resource allocation, and sustainable development practices. Through this comprehensive analysis, the study endeavours to contribute to the promotion of food security, environmental sustainability, and socio-economic development within the urban landscape of Cape Town. These efforts align with the goals of achieving 'The Africa We Want' as outlined in Agenda 2063 for Africa and Sustainable Development Goals 1, 2, and 11, which focus on poverty reduction, hunger reduction, and sustainable cities and communities.

2. Materials and methods

2.1. Study area

South Africa has approximately 65% of its population residing in urban areas. This rapid urbanization has been characterized by various challenges, including land degradation and increased rates of unemployment (Cilliers et al. 2020). For instance, recent statistics show that more than half the population lives in poverty (2019). Additionally, food nutrition security is a major problem across South Africa. Despite the country being food secure nationally, food insecurity persists, especially in cities. Food security is an issue of financial and geographical access (Kroll 2016). Hence, it is no surprise that food insecurity prevails in urban households due to their reliance on income to purchase food. However, such drivers of food insecurity are largely ignored.

The Western Cape Province has a warm Mediterranean climate with cold winters and hot, dry summers. Cape Town's highest rainfall occurs in June, July, and August, while the driest months are January, February, November, and December, with annual rainfall between 500 and 700 mm (WCG 2005). While the average annual temperature in Cape Town is 17°C, the average high temperature is around 21°C which has the potential to affect urban agricultural activities. The region is drought-prone, as observed in the 2015–2018 drought, but water conservation and rainfall averted a crisis. Cape Town benefits from rich underground water reserves in the Table Mountain Group aquifer, which supplements the municipal water supply. The city is subject to harsh southerly winds in summer and north-westerly winds in winter and is a major tourist destination with landmarks like Cape Point and Table Mountain. Part of the Cape Floral Kingdom, a World Heritage Site, it features endemic plants such as the King Protea and the Silver Tree. The study site in the Cape Flats has sandy and calcareous soils, generally low in nutrients with high pH values, posing challenges for food crop cultivation.

The province of the Western Cape, with Cape Town as its capital (see figure 1), faces challenges in its food system despite its relative prosperity. Food insecurity is prevalent, particularly among households lacking access to sufficient food, which puts many children at risk of malnourishment (Frayne et al. 2014). The townships in the Cape Flats, such as Khayelitsha, Gugulethu, and Nyanga, face unique challenges related to food and

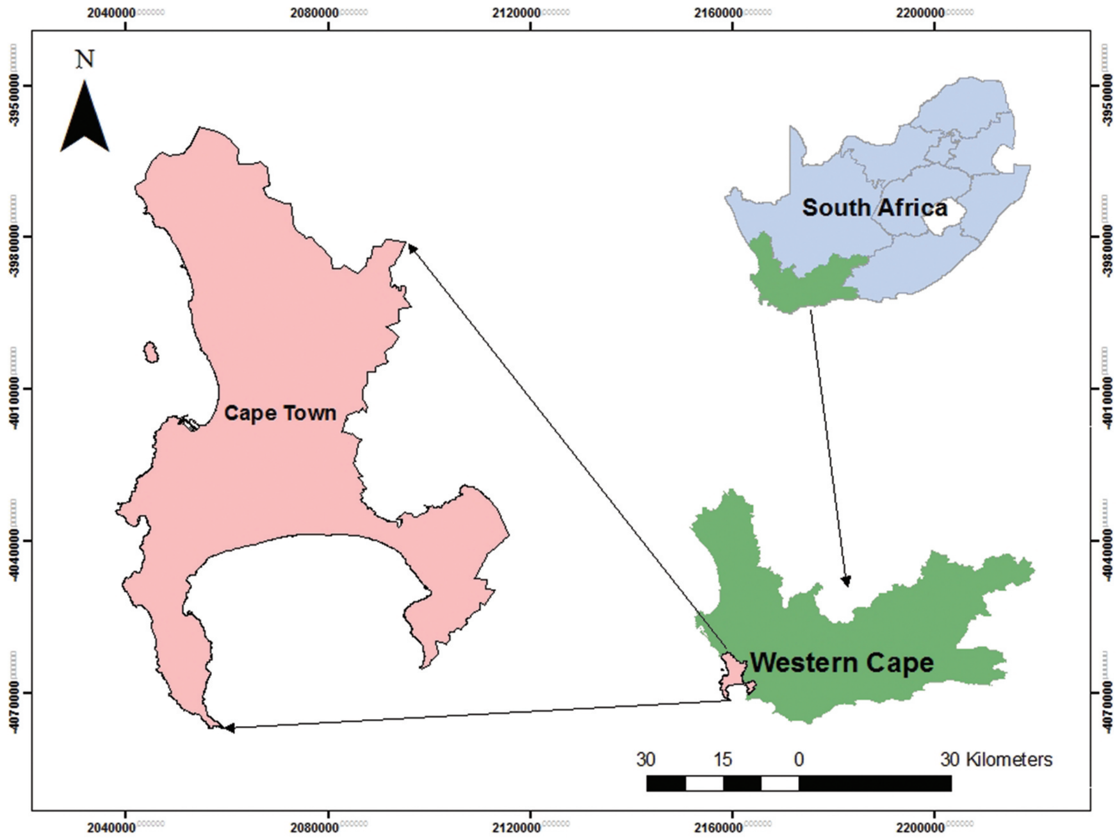

Figure 1. Location of Cape Town in South Africa.

nutrition security, including a scarcity of affordable, healthy food choices due to the predominance of supermarkets offering high-calorie options. Limited recreational and social amenities, as well as industrial and commercial centres, further compound these challenges, highlighting the urgent need for comprehensive strategies to address food insecurity and promote healthier food environments in these areas.

In response to these issues, urban agriculture has been embraced as a food security strategy by the municipality and provincial government (Battersby and Marshak 2013; Battersby et al. 2014; Kanosvamhira 2019; Paganini and Lemke 2020). Urban cultivation initiatives, with approximately 6,000 operators in the Cape Flats alone, have emerged, with some forming cultivation groups on school and municipal land. Both governmental and non-governmental entities provide support to these initiatives, offering assistance in skill development, inputs, and marketing support for harvests (Haysom, Crush, and Caesar 2017; Kanosvamhira 2019).

Despite the support provided, urban agriculture in the region faces challenges that limit its effectiveness in addressing food security and income concerns. Research indicates that constraints such as insecure land tenure, inadequate market connections, and subpar soil quality within the city hinder the profitability and impact of urban cultivation efforts (Haysom and Battersby 2016; Paganini et al. 2021). Interestingly, the Philippi Horticultural Area (PHA) plays a significant role in supplying the city with vegetables, yet many urban poor residents, including those in informal settlements near the PHA, increasingly rely on supermarkets offering highly processed, energy-dense foods lacking in nutrition and dietary diversity (Peyton, Moseley, and Battersby 2015). This reliance exacerbates existing disparities in access to healthy food options between impoverished neighbourhoods and affluent areas in Cape Town (Battersby and Peyton 2014; Battersby-Lennard and Haysom 2012).

Beyond the issue of food security, numerous studies in Cape Town have underscored the multifaceted benefits of urban cultivation, extending beyond mere economic considerations. Indeed, urban agriculture holds the potential to catalyse positive social outcomes, particularly within distressed communities. Socially, urban cultivation initiatives have been shown to foster community cohesion, social inclusion, and empowerment, providing opportunities for individuals to actively engage in meaningful activities and connect with their neighbours (Kanosvamhira and Tevera 2020).

Moreover, by promoting local food production and distribution networks, urban agriculture can enhance food sovereignty and access to fresh, nutritious produce, thereby addressing issues of food justice and equity.

2.2. Study design and data collection

In this research, a mixed-methods research design was adopted, combining both quantitative and qualitative techniques of data collection to complement and expand research findings (Creswell 2017. The study necessitated a multipronged paradigm for decision-making based on six factors that determine urban agriculture suitability. This approach was comprehended through field observations and three interviews with key experts in urban agriculture. Face-to-face interviews were conducted with two Provincial Department of Agricultural Extension Officers and a representative from the City of Cape Town to seek their input regarding the ranking of factors of urban agriculture based on their importance. Each expert was asked to comment on the challenges related to urban agriculture and the difficulties in finding suitable land. This enabled the researchers to be well-equipped to rank factors of urban agriculture, consulting experts to augment their existing knowledge, like other studies (Weerakoon 2014; Zaki et al. 2023). The number of experts consulted was deemed adequate, as literature suggests a range of 1 to 20 experts is sufficient, depending on the context (Chou, Pham, and Wang 2013; Darko et al. 2019). In this case, two agricultural extension officers from the Department of Agriculture and a representative from the City of Cape Town were crucial in providing the necessary expert information.

Quantitative techniques, using Weighted Linear Combination calculations and map algebra, were then reinforced by descriptive statistics for easier interpretation of results. This methodology was a two-step approach that fused and triangulated both methods. The first approach was the Analytic Hierarchy Process (AHP), which facilitated multi-criteria decision-making based on six factors of urban agriculture suitability: precipitation, temperature, slope, proximity to streams, accessibility by road, and soil type. This comprehensive methodology ensured a robust and nuanced analysis of urban agriculture suitability within the study area.

The Analytic Hierarchy Process (AHP) is a structured technique for dealing with complex decisions, illustrated in Figure 2. A pairwise comparison technique was employed to derive the priorities for the criteria based on their importance in achieving the intended research outcomes. The initial step involved defining the problem and expanding the objectives by considering all factors influencing suitability for urban agriculture. The decision elements were organized into a hierarchical structure of interrelated components, including the goal, criteria, sub-criteria, and alternatives. At the topmost position of the hierarchy is the overall goal, followed by criteria that contribute to achieving this goal. The lowest level comprised alternative decisions from which the researchers would select (Figure 2).

The next step involved ranking for each of the criteria and alternatives using a pairwise comparison technique. This also included the rating scale of relative importance of factors under consideration. The number of comparisons for the decision elements (that is, criteria or alternatives) in a particular level was derived using (Number of comparisons = n (n – 1)/2) (Saaty 1987). Each comparison (for example, Criteria 1 *versus* Criteria 2 or Alternative 1 *versus* Alternative 2) was rated using the 9-point scale developed by Saaty (1980) for a pairwise comparison technique (Table 1).

The intensity of importance was allocated to criteria i against criteria j, where reciprocal value was assigned to criteria j as intensity of importance. For example, from the above matrix, i (soil type) = 9 while j (proximity to road) = 1/9. After comparison between all possible criteria pairs is complete, the weight (w) of criteria i is calculated based on equation 1 (Dai, Li, and Rocha 2016).

$$Wi = \left(\frac{\sum^{P} ij}{\sum_{i=1}^{n} \sum_{j=1}^{n} Pij} \right)$$

where P*ij* = relative importance in pairwise comparison of criterion i compared to criterion j

n = number of factors
i & j = criterion
W = priority weight

The relative importance of the criteria and the relative importance of the alternatives with respect to the criteria were determined after a pairwise comparison matrix for the criteria and alternatives has been prepared (Table 2). This was done by: (i) calculating the normalized values for each criterion and alternative; and (ii) determining the normalized principal eigenvectors or priority vectors (herein also referred to as relative weights). In calculating the normalized values for each criterion and alternative in their respective matrices, the value for each cell was divided by its column total. This process produced a column total of 1 for each matrix. The resulting values gave the relative weights of the criteria with respect to the goal, and the relative weights of the alternatives with respect to the criteria.

Verification was done to determine the consistency of the evaluation by calculating the consistency ratio before the decision was made. The researchers

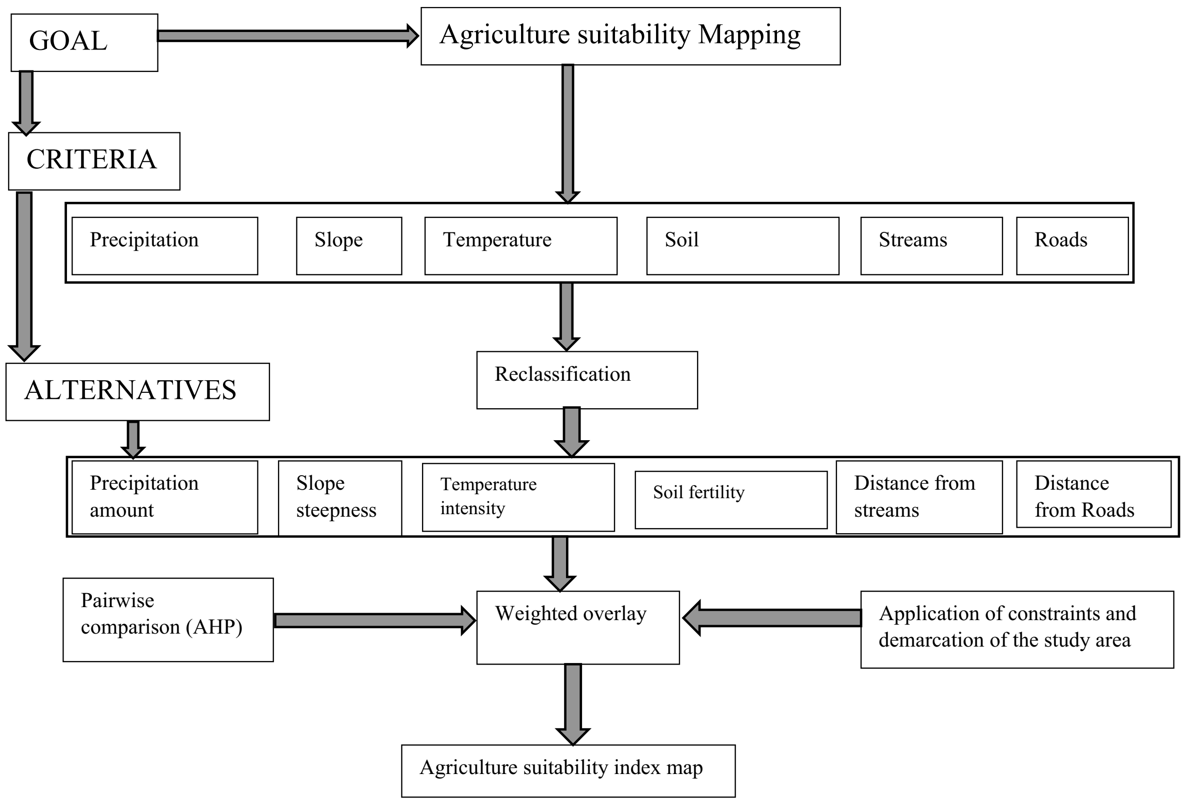

Figure 2. The AHP methodology structure.

Table 1. Nine-point intensity of importance scale (source: Estoque 2012).

Intensity of importance	Definition	Description
1	Equally important	Two factors contribute equally to the objective
3	Moderately more important	Experience and judgement slightly favour one over the other
5	Strongly more important	Experience and judgement strongly favour one over the other
7	Very strong more important	Experience and judgement very strongly favour one over the other. Its importance is demonstrated in practice.
9	Extremely more important	The evidence favouring one over the other is of the highest possible validity
2,4,6,8	Intermediate values	When compromise is needed
Reciprocals of above	If an element i has one of the above numbers assigned to it when compared with element j, then j has the reciprocal value when compared with i.	–
Ratios (1.1–1.9)	If the activities(elements) are very close	May be difficult to assign the best value, but when compared with other contrasting activities(elements), the size of the small numbers would not be too noticeable, yet they can still indicate the relative importance of the activities(elements)

Source: Estoque (2012).

Table 2. Ranking of agriculture suitability criteria to obtain the pairwise comparison matrix.

	Soil	Slope	Roads	Streams	Precipitation	Temperature
Soil	1	5	9	3	5	6
Slope	1/5	1	3	1/3	2	2
Roads	1/9	1/3	1	1/5	1/7	1/7
Streams	1/3	3	5	1	2	3
Precipitation	1/5	1/2	7	½	1	5
Temperature	1/6	1/2	½	1/3	1/5	1

performed calculations to find the maximum eigenvalue, consistency index, consistency ratio, and normalized values for each criteria/alternative. Saaty (1980) suggested that if the ratio exceeds 0.1, the set of judgements may be too inconsistent to be reliable. Thus, a CR below 0.1% or 10% is acceptable. When the evaluation is inconsistent, the procedure is repeated until the CR is within the desired range.

To determine consistency, the Lampda maximum value (ʎmax) was determined by dividing the weighted sum value by the criteria weights for each row followed by averaging all resulting values (Table 3). The next procedure was to calculate the Consistency Index (CI). This was done by subtracting the number of criteria (which in this case is 6) from (ʎmax) followed by dividing the result by the value obtained after subtracting 1 from the criteria value (CI = (ʎmax-n)/n-1). The final procedure was calculating the Consistency Ratio (CR) which was done by dividing the Consistent Index by the Random Index obtained using the random index table by T. L. Saaty (1980) (Table 4).

As proposed by T. L. Saaty (1980), the RI used depends on the number of criteria. This study had six (6) criteria hence RI used was 1.24 (Table 4).

This translated the consistency ratio to 0.06 which is below standard 0.1 as expected.

After determining the weight, there was the need to combine all the weighted criteria to obtain a suitability map by performing a weighted overlay analysis in ArcMap 10.5. According to Rafiee et al. (2011), there are multiple ways of combining the criteria and calculating the suitability index. Among these methods of criteria combination, the most common include Weighted Sum, Fuzzy Overlay, Boolean Intersection (BI), Weighted Linear Combination (WLC), and Ordered Weighting Average (OWA). In this study, the WLC method, which is based on a weighted average/mean that can easily be implemented in a raster GIS environment, was adopted and applied to produce an agriculture suitability index map. To corroborate quantitative data, field observations were conducted for ground truthing of the training sites that developed. Utilizing the AHP was found robust from a social perspective as the best knowledge and ranking came from agricultural experts who took part in the pairwise comparison and weighting of the factors. This differs from other automated methods like Analytic Network Process and TOPSIS methods though they are regarded highly accurate (Kheybari, Rezaie, and Farazmand 2020; Seyedmohammadi et al. 2018). These methods limit expert input which constitutes ground truthed decision making.

In this research, land use data was essential to determine areas that are already in use versus those that are not yet in use and suitable for agriculture in Cape Town. In this instance, data on land use that is what the area is being used for, whether it is residential, industry, natural, agriculture among others was obtained from the City of Cape Town and open street map. The City of Cape Town's Development Managment Department was the relevant department since they spearhead urban development and delineation of areas for potential agriculture and development. This data was essential since it provided an insight of the various land uses that were prevalent in the area, a situation that was essential in assisting to achieve the intended objectives. It was also essential to obtain data on slopes since this determines viability of agriculture. In this case, the slope was derived from the ASTER Digital Elevation Model (DEM) with a spatial resolution of 15 × 15 m thus allowing for detailed visualization of slope. The soil dataset was downloaded from the Soil and Terrain Database for Southern Africa (SOTERSAF) online to determine soil types and their associated potential for agriculture, especially based on fertility.

Data sets for roads and rivers or streams was derived from DIVAGIS and online platform which provides essential data to enable detection such features. In this case it was essential to demarcate areas close to rivers/surface water resources to reduce agriculture activities close to these resources for soil and water conservation purposes as enshrined within the Conservation of Agricultural Resources Act (CARA) 43 of 1983 in South Africa. To add on, data on roads was essential to determine the proximity of the areas to the road since access to modes of communication influences agricultural activities in urban areas. Precipitation and temperature data was

Table 3. Normalization and weight determination of criteria contributing to urban agriculture suitability.

	Soil type	Slope	Roads	Streams	Precipitation	Temperature	Criteria weight	Weighted sum value	% weight
Soil	0.498	0.484	0.435	0.563	0.484	0.350	0.469	3.208	46.880
Slope	0.100	0.097	0.145	0.056	0.193	0.117	0.118	0.859	11.794
Roads	0.055	0.032	0.048	0.038	0.014	0.008	0.032	0.187	3.237
Streams	0.164	0.290	0.010	0.188	0.193	0.175	0.170	1.278	17.005
Precipitation	0.100	0.048	0.338	0.094	0.097	0.292	0.161	0.823	16.138
Temperature	0.085	0.048	0.024	0.062	0.019	0.058	0.049	0.291	4.946
Totals	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**6.000**	**100.000**

Table 4. Random index (RI) used to compute consistency ratios (CR).

n	1	2	3	4	5	6	7	8	9	10
RI	0	0	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49

also essential in this research. This data was obtained from Google earth Engine database whereby MODIS sensor was used to derive the temperature whilst CHIRPS data was used to derive rainfall data. From these, the emerging themes/patterns, that is, factors influencing agriculture viability, were grouped as text to corroborate the data. This method summarizes rather than reporting all the details about a message set. Weighted overlay analysis was done in ArcMap 10.8 software to finalize spatial analysis of the multi-criteria decision on agricultural suitability based on the aforementioned datasets. Field observations enabled ground truthing of areas that were deemed suitable or unsuitable for urban agriculture.

3. Statistical analysis of data

The research delved into the intricate dynamics shaping the suitability of urban agriculture in various regions of Cape Town, uncovering substantial variations in key factors influencing agricultural productivity. Temperature emerged as a pivotal determinant, delineating contrasting conditions between coastal and inland areas (Figure 3). Coastal regions, characterized by lower temperatures, posed challenges for crop cultivation due to suboptimal growing conditions. In stark contrast, areas situated in the north, northeast, and east registered higher temperatures, fostering an environment conducive to robust crop growth and development. These temperature differentials underscore the nuanced microclimatic variations within Cape Town, influencing agricultural viability and highlighting the importance of localized assessments in urban agriculture planning and management strategies.

The research findings highlight the significant relationship between soil composition and agricultural potential in various regions of Cape Town. Specifically, areas in the southwest and southeast, characterized by soil types such as Haplic Podzols, Rhodic Acrisols, and Lithic Leptosols, demonstrated limited suitability for agriculture. Conversely, the northern parts of Cape Town, where Gleyic Planosols and Rhodic Lixisols predominate, exhibited a more moderate potential for agricultural activities (Figure 3). However, it was the central and northern parts of Cape Town, characterized by Albic Arenosols and Haplic Luvisols, that showed the highest agricultural potential, particularly conducive to successful crop production.

Regarding slope, the study identified a distinct pattern across Cape Town. Areas with steep slopes, particularly in the southwest, were deemed unsuitable for crop

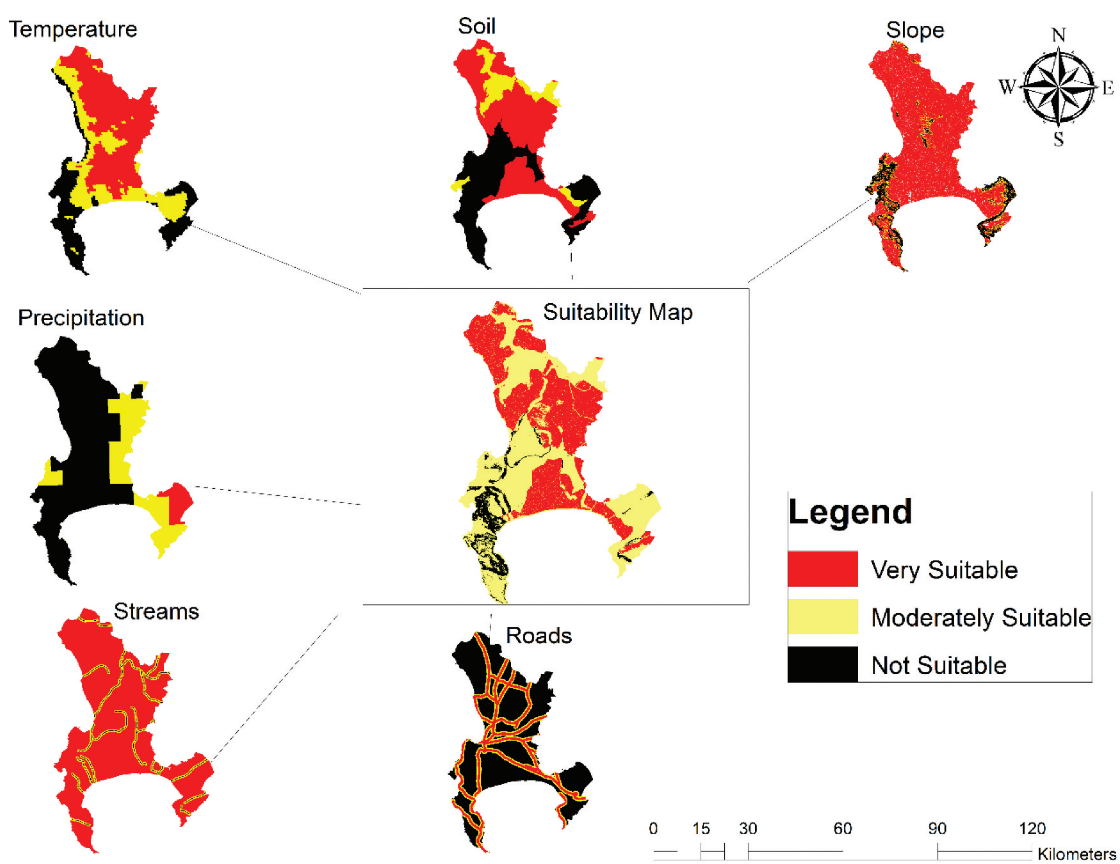

Figure 3. The spatial distribution of agriculture suitability criteria with respect to all considered factors.

production due to challenges such as soil erosion and water runoff, which can adversely affect soil fertility and crop growth. In contrast, regions with gentler slopes, particularly in the central and northern parts of Cape Town, provide more favourable conditions for agriculture. The gradual gradients in these areas facilitate better water retention, reduce erosion risks, and support more efficient cultivation practices.

The variability in precipitation patterns across Cape Town also significantly influences agricultural suitability. In the southeast, where annual precipitation ranges from 800 to 1101 mm, conditions are highly favourable for agriculture, promoting robust crop growth and productivity. Conversely, areas in the central, northern, and southwestern parts of Cape Town receive lower annual precipitation levels (245–500 mm), making them less suitable for intensive agricultural activities. However, certain eastern regions experience moderate precipitation levels (650–800 mm annually), creating a more conducive environment for agriculture compared to the drier areas.

Moreover, activities like agriculture close to surface water resources threaten the integrity of these ecosystems. This was considered in this study which explains why areas very close to surface water resources like rivers, dams and pans were considered not suitable. Most of the areas are situated more than 50 metres away from rivers, which promotes conservation of surface water resources though some are too far which limits access to crucial water resources necessary for irrigation and agricultural practices. However, in this study areas closer to surface water resources were less suitable (Figure 3) since agricultural activities within the vicinity of surface water resources negatively affect the integrity of these resources through increasing pollution and siltation.

The Multi-Criteria Decision Making approach, employing the Analytic Hierarchy Process (AHP), has facilitated the identification of areas highly suitable for agriculture across Cape Town (Figure 4). Among these, strategic regions such as Durbanville in the northern parts of Cape Town have been classified as ‘very suitable’. These areas boast favourable temperature ranges and conducive soil compositions, creating optimal conditions for robust crop growth and agricultural productivity. Similarly, regions extending southwards to Philippi have also been identified as highly suitable for agriculture, benefiting from favourable climatic conditions and soil characteristics that support successful crop cultivation.

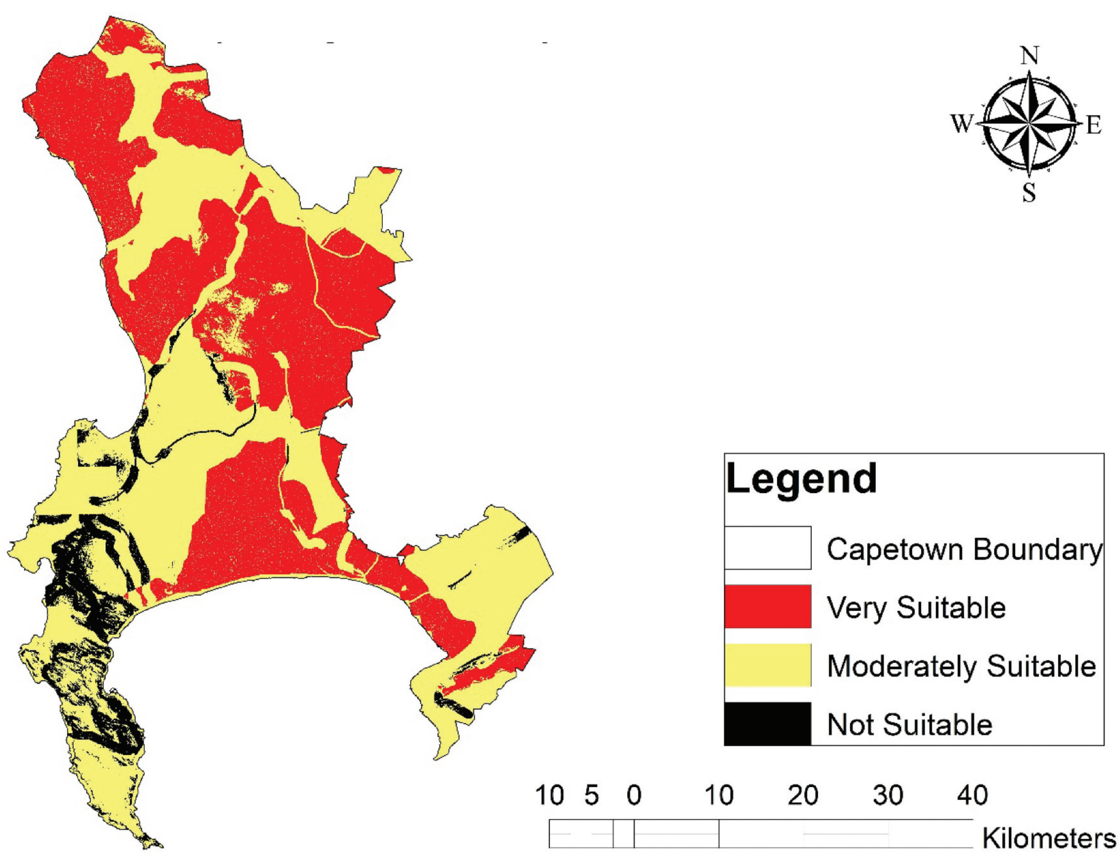

Figure 4. Suitability map of the Cape Town area based on AHP.

Table 5. Agricultural suitability statistics for Cape Town.

Suitability	Hectares	Percentage cover
Suitability/unsuitability of land when including already used land in Cape Town		
Very suitable	100474.6	41.2
Moderately suitable	125245.5	51.4
Not suitable	18096.03	7.4
Total	243816.1	100
Suitable/unsuitable land when excluding already used land in Cape Town		
Very suitable	79966.03	39.0
Moderately suitable	107834	52.6
Not suitable	17096.03	8.3
Total	204896	100

Source: Authors.

Conversely, the study has delineated areas classified as moderately suitable for agriculture (Table 5). These regions exhibit a spectrum of conditions that offer viable but less optimal environments for agricultural activities. The degree of suitability varies across these areas, influenced by factors such as temperature variations, soil composition diversity, and proximity to essential resources like water sources and transportation networks. While not as ideal as the 'very suitable' areas, these regions still hold potential for agricultural development. However, they may require targeted interventions and effective resource management strategies to maximize productivity and ensure sustainability over time.

The analysis of land use in Cape Town unveils a diverse landscape of urban development and utilization, with various sectors contributing to the overall land usage. Among the key findings, it is revealed that a total of 38,920.1 hectares, representing approximately 15.96% of Cape Town's land area, is currently utilized for different purposes. This breakdown further highlights the distribution of land usage across different sectors: 'Others' encompassing 20,301.8 hectares (8.33%), agriculture covering 13,508.6 hectares (5.54%), commercial activities occupying 364.9 hectares (0.15%), and industrial operations utilizing 4,744.8 hectares (1.95%).

Of particular significance is the proportion of land dedicated to urban agriculture, which accounts for 5.5% of Cape Town's total land area. This sector plays a crucial role in contributing to food security, community empowerment, and environmental sustainability within urban environments. Notably, urban agriculture activities are primarily concentrated in areas identified as highly suitable for such endeavours. These regions, characterized by favourable climatic conditions, soil quality, and accessibility, provide an ideal environment for successful crop cultivation and agricultural productivity.

However, despite the existing utilization of land for urban agriculture, the analysis also highlights the presence of vacant areas with untapped agricultural potential across Cape Town. These vacant spaces, particularly prominent around certain regions with high agricultural suitability, represent opportunities for further expansion and diversification of urban agriculture initiatives. Areas identified as very suitable or moderately suitable for agriculture present viable prospects for the establishment of new agricultural ventures, offering ample room for cultivation and agricultural development to meet the evolving needs of the city's population.

The analysis of land use in Cape Town reveals that a significant portion, accounting for 15.96% of the total land area, is currently utilized for various purposes (Figure 5). The breakdown of land usage highlights the diverse activities and sectors contributing to urban development and infrastructure within the city. Among the categories, 'Others' stands out as the largest contributor, encompassing residential areas, educational institutions, recreational facilities, and other miscellaneous land uses, totalling 20,301.8 hectares or 8.33% of the land area. Agricultural activities also play a notable role in land utilization, with 13,508.6 hectares (5.54%) dedicated to agriculture-related purposes. This category encompasses a range of agricultural practices, including vineyards, orchards, farmlands, and cattle production. These agricultural endeavours not only contribute to the city's economy but also serve as vital components of Cape Town's cultural heritage and environmental sustainability. Commercial developments, comprising shops, businesses, and other commercial establishments, utilize 364.9 hectares (0.15%) of the land area, reflecting the importance of commerce and trade in Cape Town's urban landscape. Additionally, industrial activities occupy 4,744.8 hectares (1.95%) of the land, underscoring the role of manufacturing, processing, and industrial sectors in driving economic growth and employment opportunities within the city.

4. Discussion

The research aimed to assess the feasibility of urban agriculture across various regions of Cape Town, focusing on identifying significant disparities in factors influencing agricultural productivity. Results reveal distinct variations in the suitability for urban agriculture, highlighting untapped potential influenced by factors such as temperature, slope, road networks, and precipitation patterns. These findings resonate with the insights of Kazemi and Hosseinpour (2022), who emphasize the intricate interplay of diverse factors in determining land use suitability, a complexity mirrored within Cape Town's context.

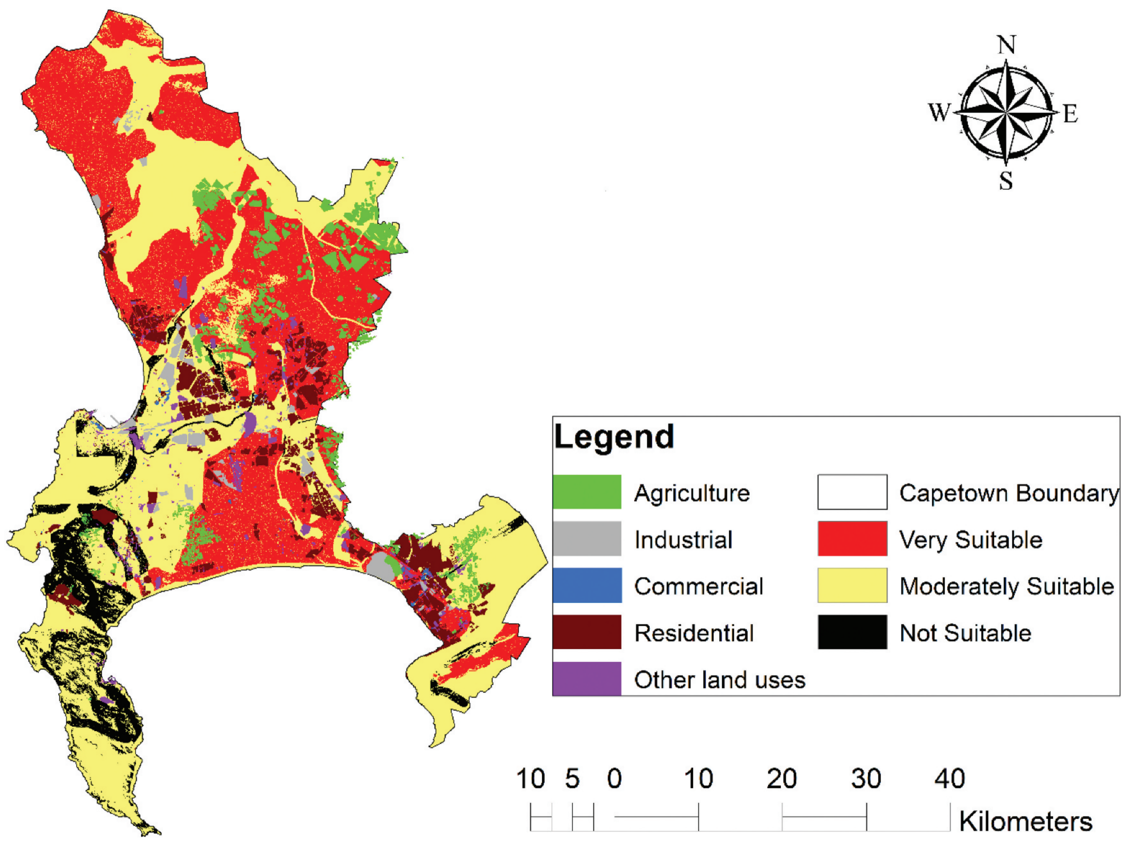

Figure 5. An overlay of current land uses and agricultural suitability index for Cape Town.

Temperature emerges as a critical factor shaping agricultural suitability, delineating conditions along coastal and inland regions. Coastal areas, characterized by lower temperatures, present challenges for crop cultivation due to suboptimal growing conditions. In contrast, regions in the north, northeast, and east of Cape Town experience higher temperatures, offering more favourable environments for agricultural activities. This temperature variability underscores the importance of localized assessments in urban agriculture planning and management strategies.

The study also highlights the correlation between soil fertility and agricultural potential across Cape Town's diverse regions. Areas with poor soil quality, such as those featuring Haplic Podzols, Rhodic Acrisols, and Lithic Leptosols, pose limitations to agricultural viability. Addressing these challenges requires targeted research efforts and funding allocations aimed at improving soil fertility through rigorous testing and appropriate interventions. Conversely, regions in northern Cape Town, characterized by Gleyic Planosols and Rhodic Lixisols, exhibit more moderate agricultural potential, aligning with findings reported by scholars like Diallo et al. (2016) and Beniston, Lal, and Mercer (2016).

Regarding slope, the research identifies significant trends across Cape Town. Areas with steep slopes, particularly in the southwest, are deemed unsuitable for crop production due to issues like soil erosion and water runoff. These conditions necessitate alternative land use strategies and conservation efforts to mitigate erosion and maintain soil integrity. Insights from Chapagain and Raizada (2017), focusing on smallholder farmers in Nepal, reinforce these findings, highlighting the challenges of terrace agriculture and proposing agronomic strategies to enhance productivity and sustainability.

Results also show that there were regions with more gentle slopes, particularly in the central and northern parts of Cape Town. These areas therefore presented more favourable conditions for agriculture. This could be attributed to the fact that gradual gradients in these areas facilitate better water retention, reduce erosion risks, and allow for more efficient cultivation practices. Therefore, farmers in these regions can capitalize on the relatively flat terrain to implement sustainable agricultural techniques, such as conservation agriculture which encourage contour farming and terracing, to optimize land use and maximize crop yields. By understanding the implications of slope variation on agricultural suitability, policymakers and land managers can make informed decisions to promote sustainable land use practices such as conservation agriculture and ensure the long-term resilience of Cape Town's agricultural landscapes.

Precipitation patterns across Cape Town exhibit significant variability, thereby impacting the suitability of different regions for agriculture. Certain areas, such as the south-eastern parts of Cape Town, receive high rainfall ranging from 800 to 1101 mm annually, creating favourable conditions for agriculture and fostering robust crop growth and productivity. Conversely, in regions with lower precipitation levels, such as the south-western parts where annual rainfall ranges from 245 to 500 mm, agricultural activities are hindered. The spatial distribution of surface water resources need to be cognized when determining agricultural suitability across Cape Town to ensure conservation of these fragile ecosystems. The research findings reveal that most areas in the region are situated more than 50 metres away from rivers, which makes most of the areas suitable for agriculture as agricultural activities will not impact aquatic ecosystems. The provisions of the Conservation of Agricultural Resources Act (CARA) 43 of 1983 in South Africa state that cultivation of the land must start from 10 m away from the stream/river which guarantees high levels of environmental conservation. In this study, the zone that stretches from this distance to 50 metres was considered less suitable due to risks of surface water resource contamination and high rates of erosion and associated siltation. This does not rule out the need to ensure water accessibility for activities like agriculture as water can still be drawn from 50 metres or more distances to satisfy water supply needs. These findings align with those of Alotaibi et al. (2023), who similarly underscore the significance of water availability in shaping agricultural suitability, thereby emphasizing the importance of strategic water management strategies for sustainable agricultural development in Saudi Arabia. Therefore this study advocates for the need to reduce agricultural activities within the vicinity of rivers, dams and other surface water resources while trying to enhance water access as a cushion to the climate change induced droughts that threaten food security.

Additionally, significant portions of agricultural land are situated at a distance from main roads, thereby presenting challenges for transportation and market access. While these factors play a crucial role in the overall suitability assessment, it is imperative to acknowledge the potential for infrastructure development to enhance accessibility and support agricultural activities in these areas. Strategic investments in road networks and irrigation systems can thus play a pivotal role in improving the viability of agriculture in regions previously considered less suitable, thereby fostering food security and economic development. Such initiatives have the potential to significantly contribute to urban agriculture, ultimately advancing strides towards poverty alleviation (Sheng et al. 2018).

The analysis of land use in Cape Town reveals a diverse array of functions for which the land has been acquired and utilized. Various sectors contribute to the overall land usage, with approximately 38,920.1 hectares of Cape Town's land area currently allocated for different purposes. Specifically, agriculture, the primary focus of this study, encompasses 13,508.6 hectares (5.54%), while commercial activities occupy 364.9120872 hectares (0.15%), and industrial operations utilize 4,744.78 hectares (1.95%) respectively. Of particular significance is the proportion of land dedicated to urban agriculture, accounting for 5.5% of Cape Town's total land area. This sector could play a crucial role in contributing to food security, community empowerment, and environmental sustainability within urban environments. This explains why Battersby and Marshak (2013) called for the need to grow communities thus integrating the social and economic benefits of urban agriculture. This will address the local community needs as far as food availability within the same resource base is concerned.

Notably, urban agriculture activities are predominantly concentrated in areas identified as highly suitable for such endeavours. These regions exhibit favourable climatic conditions, soil quality, and accessibility. However, it is noteworthy that a considerable portion of land potentially suitable for agriculture is currently occupied by other land uses. This underscores the importance of intensive investigation and government support to ensure optimal utilization of these areas. By leveraging available land resources effectively and prioritizing agricultural development, policymakers can bolster food security, enhance community well-being, and foster environmental resilience in urban areas like Cape Town.

Overall, Cape Town hosts vast amounts of land suitable for agriculture (92.2%) which is currently open and underutilized. This indicates least priority that is being given to agriculture in urban areas despite significant potential being observed. This mimics a scenario found in Ardabil province, Northwest Iran where 90.24% of the land was found to be suitable for agriculture but being underutilized (Seyedmohammadi and Navidi 2022). However, in that study, the focus was on one crop which is wheat which allowed for informed preparation for wheat production. This needs to be done for a variety of crops especially fruits and vegetables among others that thrive in urban setups. Future research should be concentrated on furthering an understanding of specific crop production suitability since vast land exists from which to select. This aspect was lacking in this study as the focus was mainly on determining suitability for unspecified types of crops.

A number of studies have been conducted in Iran (Seyedmohammadi et al. 2018, 2019) to analyse land suitability for irrigated Maize and Soybean though these studies were not targeted in urban areas to bolster the relevant mechanisms required to enhance the concept so that it can yield desirable results. This calls for urban area studies that open avenues for improved food security through informed agriculture activities in urban areas. Some studies conducted using GIS and AHP in urban areas, such as those examining the Kaduwela Municipal Council Area (KMCA) in the Colombo District, Sri Lanka (Weerakoon 2014), have failed to clarify the percentage and location of suitable areas for crop production. This aspect is one of the main strengths of the present study. This makes the present study one of the few studies conducted to unveil available agriculture activities and more areas that can be used for agriculture though there is still need to improve on crop type suitability specification.

Ustaoglu, Sisman, and Aydınoglu (2021) conducted a similar study but in peri urban areas and found that very suitable areas were in rural communities. However, the focus should be shifted to urban areas where urban food insecurity is increasing but overlooked. Some studies emphasized on the need to improve fruit and vegetable production since shortage of these is affecting food availability and accessibility. Zaki et al. (2023) analysed suitability of urban gardening in Petaling District in Shah Alam which is known to locate highly urbanized areas in the Selangor State and found that over 60% of the land was not suitable. However, their study underscored the need to boost food security of urban communities through utilizing the existing land suitable for vegetable production. This therefore shows that if well managed and given the required focus, the concept of urban agriculture is crucial in enhancing efforts aimed at attaining Sustainable Development Goals, in this case SDG 1 and 2 on zero hunger and ending poverty. This will therefore provide solutions that are key towards sustainability of well properly monitored as present generations can benefit whilst at the same time preserving for the future generations.

5. Conclusion and recommendations

Based on the analysis conducted on the suitability of urban agriculture in various regions of Cape Town, this study has revealed insights into the complex dynamics influencing agricultural productivity. The findings highlight the critical role of temperature, soil composition, slope, precipitation patterns, and infrastructure accessibility in shaping the feasibility of urban agriculture within the city. The research underscores the nuanced microclimatic variations within Cape Town, emphasizing the importance of localized assessments in urban agriculture planning. It reveals that while coastal regions present challenges for crop cultivation due to suboptimal growing conditions, areas in the north, northeast, and east of Cape Town offer favourable environments conducive to robust crop growth and development. Furthermore, the study identifies soil composition as a key determinant of agricultural potential, with certain regions exhibiting limited suitability for agriculture due to deficient soil quality. This underscores the need for targeted interventions, such as soil amendments, to enhance soil fertility and improve agricultural productivity in these areas.

Moreover, the analysis highlights the impact of slope and precipitation patterns on agricultural suitability, with steep slopes and low precipitation levels posing challenges for agricultural activities. Strategic investments in infrastructure development, including road networks and irrigation systems, are identified as crucial for enhancing accessibility and supporting agricultural activities in these areas. The study also sheds light on the current distribution of land usage in Cape Town, emphasizing the contribution of urban agriculture to food security, community empowerment, and environmental sustainability. However, it is noted that a considerable portion of land potentially suitable for agriculture is currently occupied by other land uses, highlighting the need for optimal land utilization strategies. In conclusion, this research contributes valuable insights into the potential of urban agriculture as a sustainable solution to food security challenges in Cape Town. It underscores the importance of integrated planning approaches that consider climatic, environmental, and socio-economic factors to promote the viability and success of urban agriculture initiatives.

To ensure the sustainable development of urban areas like Cape Town, it is imperative to integrate urban agriculture into city planning and development strategies. By incorporating urban agriculture into urban planning frameworks, policymakers can optimize land use and enhance food security within the city. This integration can involve identifying suitable locations for agricultural activities, promoting mixed land-use zoning that incorporates agricultural spaces, and providing incentives for urban farming initiatives. Additionally, targeted soil improvement programs should be implemented to address soil quality issues in regions with deficient soil. Soil amendments and conservation practices can help enhance soil fertility and productivity, thereby supporting sustainable agricultural practices and increasing yields. Soil amendments and conservation agriculture practices, which usually result in the build-up of organic matter content, can help enhance soil fertility and productivity, thereby supporting sustainable agricultural practices and increasing yields.

Community engagement and participation are also essential aspects of promoting urban agriculture. By involving local communities in agricultural initiatives, policymakers can foster social cohesion, empower residents, and build community resilience. By adopting these measures, policymakers can create an enabling environment for urban agriculture to thrive, contributing to the overall sustainability and resilience of cities like Cape Town. Adopting a holistic approach that addresses the multidimensional challenges of urban agriculture, policymakers and stakeholders can realize the full potential of this sector in promoting sustainable development, resilience, and prosperity in Cape Town and beyond.

Acknowledgements

We would like to express our sincere gratitude to the reviewers for their constructive feedback and insightful comments, which significantly enhanced the quality of this manuscript.

Disclosure statement

No potential conflict of interest was reported by the author(s).

Funding

The authors declare that no financial support or funding was received for this research.

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Author contributions

T.K, T.M and O.S conceived and designed the study. All authors conducted the fieldwork and data collection. All authors performed the statistical analysis. All authors contributed to the manuscript writing and have read and approved the final version.

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