Integrating Spatial Data and Indigenous Knowledge Systems for Resilient Urban Planning: Lessons from South Africa

Thembani Moyo, Vuyiswa N Letsoko, Mhalisi G Mndzebele, Siphiwe G Mbatha, Nompumelelo P Mzobe, Trynos Gumbo

(Dr Thembani Moyo, Department of Urban and Regional Planning, University of Johannesburg. Cnr Siemert & Beit Streets, Doornfontein 0184 Johannesburg, South Africa, tmoyo@uj.ac.za)
(Dr Vuyiswa N Letsoko, Department of Urban and Regional Planning, University of Johannesburg. Cnr Siemert & Beit Streets, Doornfontein 0184 Johannesburg, South Africa, vuyisway@uj.ac.za)
(Dr Mhalisi G Mndzebele, Department of Urban and Regional Planning, University of Johannesburg. Cnr Siemert & Beit Streets, Doornfontein 0184 Johannesburg, South Africa, mhlalisim@uj.ac.za)
(Dr Siphiwe G Mbatha, Department of Urban and Regional Planning, University of Johannesburg. Cnr Siemert & Beit Streets, Doornfontein 0184 Johannesburg, South Africa, gmbatha@uj.ac.za)
(Nompumelelo P Mzobe, Department of Urban and Regional Planning, University of Johannesburg. Cnr Siemert & Beit Streets, Doornfontein 0184 Johannesburg, South Africa, nmzobe@uj.ac.za)
(Prof Trynos Gumbo, Department of Urban and Regional Planning, University of Johannesburg. Cnr Siemert & Beit Streets, Doornfontein 0184 Johannesburg, South Africa, tgumbo@uj.ac.za)

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1 ABSTRACT

Johannesburg's marginalised settlements are among the most dynamic urban environments globally. These locations have limited infrastructure resources, which have negatively impacted household livelihoods. There is a critical need for developing planning support systems to improve the quality of life in these communities. As part of the city's transformation strategy, urban agriculture has emerged as a critical approach to enhancing food security and economic empowerment, particularly in marginalized areas. However, effective planning for urban agriculture necessitates spatial intelligence and community engagement. This study employs a mixed-method approach, combining indigenous knowledge systems with spatial data to assess land suitability. The findings present a land suitability index to inform spatial planning, demonstrating how integrating GIS and citizen science strengthens urban resilience through adaptive land use, improved local food systems, and climate change mitigation.

Keywords: Geographic Information Systems, food security, citizen science, urban resilience, spatial planning

2 INTRODUCTION

In urban areas, there are often multiple competing activities for limited land. The combined effects of climate change and anthropogenic forces are altering urban ecosystems. These adjustments lead to ecosystem tipping points and, subsequently, shifting ecosystems, and are believed to negatively affect communities with ecosystem-dependent livelihoods. Ostensibly, in developing countries, little to no attention has been given to marginalised communities, particularly amid the growing pressure from climate change and human activities.

This, therefore, makes the study of marginalised populations very urgent in these parts of the world because these populations still rely on food obtained directly from these sources. Moreover, studies have shown that the attainment of many sustainable development goals (SDGs) is directly and indirectly linked to the quality, quantity, or availability of agricultural land, which influences the direct or indirect benefits that humans derive from land. In particular, ecosystem services can help achieve SDGs related to the environment.

The literature there is growing scientific evidence indicating that Geographic Information Systems (GIS) can provide essential tools for mapping land suitability, analyzing spatial patterns, and integrating urban agriculture into broader urban planning frameworks. Recently, citizen science has complemented GIS by actively involving local communities in data collection, monitoring, and decision-making, ensuring that urban agriculture initiatives align with local needs and priorities. In respect of SDGs 1 and 2, which stand for no poverty and zero hunger, respectively, ecosystem services provide resources and livelihoods for millions of people, especially for rural and marginalized communities.

In developing countries such as South Africa, little research has been conducted on combining indigenous knowledge (IK) systems with spatial data to assess land suitability, particularly for marginalised communities. The structure and functioning of marginalised communities in urban settings are characterised by precarious livelihoods. For this reason, it is expected that deploying GIS and citizen science could alleviate the negative developmental changes and support these communities.

3 LITERATURE REVIEW

Over the years, scholars have developed computer-based support systems that are either focused on user-friendliness or on planning qualities. Much of the research on planning support systems (PSS) implementation focuses on understanding and improving the user-friendliness of the instruments (Te Brömmelstroet 2013; Long et al. 2011). Pelzer (2016) defines PSS as digital tools that aim to facilitate planning strategies. Whilst Jiang et al. (2003, p. 1) describe PSS as "spatial decision making systems with particular application for planning, which involves a wide range of professionals with diverse backgrounds and the general public concerned." PSS can accordingly be described as planning tools that facilitate collaborative planning by focusing on specific steps of the planning process and by improving the strategic capacity of these plans (Pelzer 2016; TeBrömmelstroet 2016a, b).

Tools to enable the spatial targeting of urban agriculture must therefore be developed to provide scientific methods that enable urban planners to implement spatial transformation in South Africa and other cities in the Global South. The complexities of modern urban planning have led to the introduction of PSS, which seeks to assist planners in shaping their city's development and in making land-use decisions. Spatial planning for urban agriculture in cities of the developing world, such as Johannesburg, is made difficult by the lack of appropriate data. In most cases, informal land-use activities are discussed descriptively and statistically, leaving out their spatial characteristics. This makes the orderly planning very difficult if not impossible, especially given that the informal activities dominate the marginalised areas of most developing countries. In the absence of other spatial datasets, this unique PSS provides a handy way to reveal spatial locational trends among informal land-use activities and the preferred locational behaviour of informal urban agricultural activities in the city. In the South African context, developing a PSS to guide and inform urban agriculture requires a model that is user-friendly, interactive, and allows the end-user to easily modify and interpret the results. The introduction of geospatial analysis platforms in conjunction with planning policies (namely the Spatial Planning and Land Use Management Act 16 of 2013, SPLUMA) and the housing Atlas (Council for Scientific and Industrial Research 2008) has enhanced how PSS are formulated. Nonetheless, though the potential merits of implementing PSS are vast, most African cities have not yet integrated them into their daily practice, as they lack the required mechanisms to do so.

Within this theoretical tradition, resilience is not reducible to infrastructural robustness or technological optimisation. Rather, it is produced through diversity, redundancy, modularity, feedback sensitivity, and adaptive governance. Knowledge diversity is therefore not peripheral but central to resilience. Systems that rely on singular epistemologies risk brittleness, whereas epistemic pluralism enhances adaptive capacity by broadening interpretive and response repertoires. Despite this, urban planning institutions have historically privileged technocratic and positivist knowledge systems, often marginalising experiential and indigenous epistemologies (Nkosi et al, 2022). This epistemic hierarchy raises a critical tension: while resilience theory emphasises diversity and learning, planning practice frequently narrows legitimate knowledge to scientifically codified forms. It is within this contradiction that debates about the integration of IK and scientific knowledge must be situated.

Indigenous Knowledge can be conceptualised as a cumulative, place-based system of ecological understanding, embedded within social norms, cultural values, and livelihood practices. From a resilience perspective, IK contributes to what is often described as ecological memory the repository of practices and experiences that enable communities to respond to recurring environmental variability. In agrarian and peri-urban contexts, such knowledge includes seed selection, soil management, seasonal forecasting, and risk-spreading strategies that have evolved through iterative adaptation. Empirical studies consistently demonstrate that development initiatives that ignore IK often face resistance, limited uptake, or unsustainable outcomes (Chanza & Musakwa, 2022; Moyo-Nyoni, 2022; Kom et al., 2023). Within a resilience framework, this may be interpreted as a disruption of local feedback systems and social learning processes. When external technical interventions override embedded practices without participatory negotiation, they may erode social capital and undermine adaptive governance.

However, resilience theory also demands a critical interrogation of IK. While IK enhances diversity, it is not inherently adaptive under all conditions. Rapid urbanisation, climate change, and socio-economic transformation can render certain practices maladaptive. Scholars caution against romanticising IK as uniformly sustainable or universally applicable (Gómez-Baggethun, 2022; McGregor, 2023; Zurba & Papadopoulos, 2023). From a systems perspective, resilience includes the capacity for transformation, therefore, IK must be understood as dynamic and evolving rather than static and sacrosanct. The erosion of IK in urbanising contexts particularly in urban agriculture represents a loss of ecological memory that may reduce system redundancy and increase vulnerability (Swiderska et al., 2022; Ricart et al., 2023). Yet preservation alone is insufficient; resilience requires adaptive recombination of knowledge rather than mere conservation. Calls for integrating indigenous and scientific knowledge systems are widespread (Chirisa et al., 2021). International policy discourses similarly advocate aligning scientific innovation with local priorities to achieve sustainable natural resource management (Chanza & Musakwa, 2022). However, the concept of integration is frequently under-theorised and politically neutralised. Scientific knowledge is typically institutionalised, standardised, and validated through formal methodologies privileging abstraction, quantification, and replicability. IK, by contrast, is often tacit, relational, and embedded within cultural and moral frameworks. Efforts to process IK through scientific epistemic criteria risk epistemic reductionism, translating complex relational knowledge into decontextualised data points. Such practices may reproduce epistemic injustice, where indigenous systems are recognised only insofar as they conform to scientific standards.

Resilience scholarship has increasingly recognised that governance systems are shaped by power relations. Whose knowledge is legitimised within urban planning institutions is not merely a technical question but a political one. Adaptive co-management and knowledge co-production are frequently proposed as solutions; however, without explicit attention to power asymmetries, these frameworks risk becoming procedural formalities rather than transformative practices. Thus, the integration of IK and scientific knowledge must be reframed as epistemic negotiation rather than technical assimilation. This requires institutional reflexivity, participatory governance structures, and recognition of plural ontologies. In urban agriculture, for instance, combining indigenous soil fertility practices with agronomic research and climate modelling may enhance productivity and resilience but only if local actors participate meaningfully in defining problems, priorities, and success metrics. From a resilience perspective, the goal is not simply integration but transformative capacity, the ability of urban systems to reconfigure governance, institutions, and practices in response to structural pressures. The persistence of epistemic hierarchies within urban planning institutions may constrain such transformation. If IK is incorporated only instrumentally valued for its utility but excluded from decision-making authority, then resilience efforts may reinforce existing inequalities rather than address systemic vulnerability.

4 METHODOLOGY

Region G is situated approximately 36 km south of the Johannesburg, Central Business District. According to the Spatial Development Framework (SDF), communities in this region are among the most geographically isolated within the city. This peripheral location has resulted in limited access to economic opportunities, social amenities, and critical infrastructure (Fig. 1). Despite several public sector interventions, including housing developments and the provision of basic services, the area continues to face significant challenges. These include high concentrations of dense informal settlements, inadequate public infrastructure, and persistent spatial disconnection from social and economic opportunities, which together contribute to entrenched poverty and high unemployment levels. The quality of life of residents in Region G is further undermined by crime and safety concerns, with vulnerable groups disproportionately affected.

Spatial data were collected through systematic geographic mapping of both formal and informal land-use activities in Region G. Data collection focused on areas surrounding suburban shopping centres, industrial zones, transportation and communication nodes, residential areas, as well as open spaces and road networks. Land-use activities were recorded in situ using a Global Positioning System (GPS), resulting in the capture of 452 spatial points. Base maps were previously scanned and geo-referenced to establish a spatial framework, after which land-use features were identified and digitised. Density analysis was then applied to assess spatial patterns and quantify temporal changes, with results expressed in both absolute and percentage terms.

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5 FINDING AND DISCUSSION

Understanding the community of Region G's relationship with nature is crucial to the area's well-being and sustainable development in the face of climate change. The City of Johannesburg Climate Change Action Plan (2021) has identified Region G as highly vulnerable to the effects of Climate change. As such, Region G is susceptible to and unable to cope with the adverse effects of climate change, including climate variability and extremes. The communities in Region G depend on the area for survival, and the environment and surrounding areas determine whether sustainable development is to be achieved. Assessing the linkages among the environment, livelihoods, and climate change is essential for sustainable development. The key issues in the area are air pollution from uncontrolled burning, clearing the ridge for informal settlements, and littering around economic activity areas. There is a need for education campaigns to raise awareness of the adverse impacts and to also build capacity at key locations, such as community facilities.

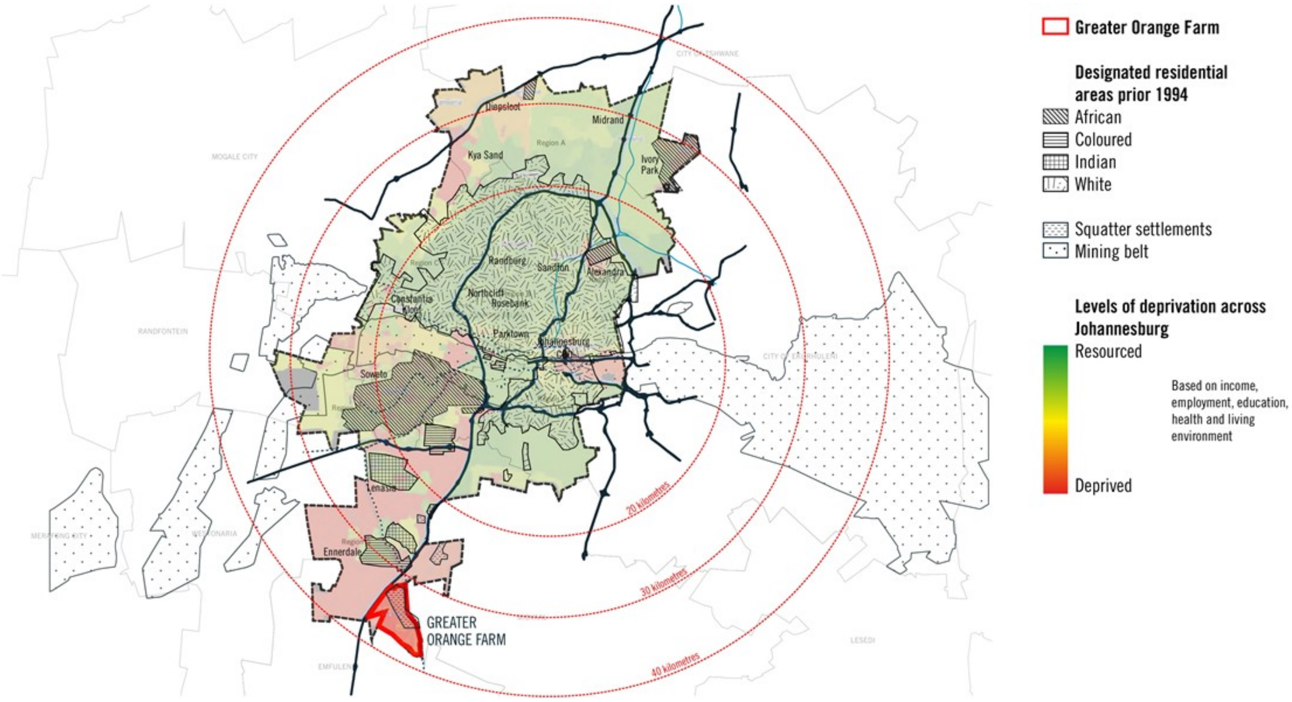

Fig. 1: Study area

Continued growth of informal urban agricultural activities in Region G will most likely lead to further densification and congestion, eventually hindering the promotion of sustainability and smart cities. The question, therefore, becomes, can more growth in these areas be sustained or should growth be channelled elsewhere? (Musakwa et al. 2017). Perhaps a serious paradigm shift is required that promotes integrated settlements, given the limited available land. Areas currently used for urban agricultural activities but unsuitable or poorly located for formalisation are located in the upper northern, southern, and eastern areas. These poorly located areas are mostly in wetlands, consistent with the weighted criterion, since dolomite had a greater influence. These areas are traditionally townships, mostly populated by low-income groups and far from economic opportunities. It is very difficult to develop on these unsuitable sites as the presence of dolomite increases construction costs and the risk of subsidence and damage to infrastructure. Interestingly, large populations inhabit these areas, and it is not necessarily smart given the risks, in the future, it is advisable for the city not to promote housing development for low-income families in dolomite areas due to the associated cost implications. However, if unavoidable, the rational design approach can be implemented.

From Fig. 2, it is clear that the moderately well-located land is mostly located adjacent to the well-located land. This shows that suitability gradually declines as one moves away from the well-located sites that almost form a concentric pattern. Likewise, the less well-located areas are farther from the very well-located areas. This is consistent in South African cities as a result of the apartheid segregation policies. What is more worrying is that, 25 years after independence, the same spatial pattern still broadly exists. This casts doubts on the smartness and the seriousness of the current planning system in reversing the apartheid planning.

Findings from interviews with stakeholders revealed the following formalised farming activities (see Fig 3), through communal gardens. While all the sites are within the highly suitable and moderately suitable ranks, they require maintenance and upkeep. The suitability ranking correctly designated the Urban Resilience hub as a strategically located site, and the debate remains whether the programs and services offered there are accessible to all residents. There is a need to roll out satellite offices of the Urban Resilience hub to other community facilities. The findings demonstrate that IK plays a critical role in shaping urban agricultural practices in the City of Johannesburg. Farmers rely on locally embedded, experience-based knowledge to respond to resource constraints, particularly water scarcity, limited land, and poor soil quality. These practices highlight the adaptive nature of IK within an urban socio-ecological context.

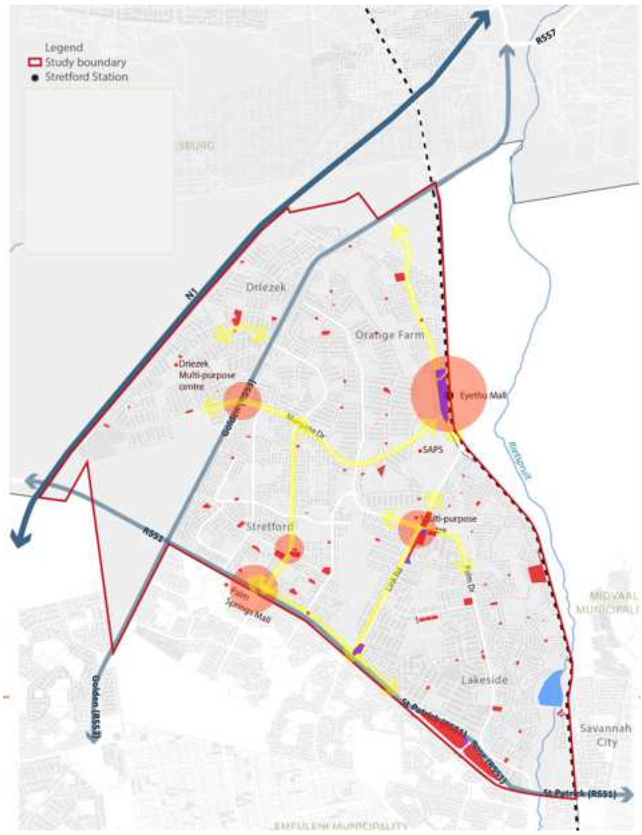

Fig. 2: Concentration of agricultural activities

Water conservation strategies, including rainwater harvesting, greywater reuse, and mulching, reflect practical responses to irregular water supply and seasonal variability. Similarly, composting and the use of plant-based bio-fertilisers are widely employed to restore soil fertility while reducing reliance on commercial inputs. Crop diversification and rotation enhance resilience by minimising pest risks and maintaining soil health, while natural pest control methods such as garlic, chilli, and neem-based solutions demonstrate an ecological understanding of pest dynamics. Knowledge exchange through community networks further strengthens adaptive capacity, enabling farmers to share seeds, techniques, and locally tested solutions. Overall, IK strategies contribute significantly to sustainable, low-input urban food production and represent an important knowledge system that can inform more inclusive urban agricultural policy and planning frameworks.

Participation in formal urban agriculture is low due to various factors. These are mainly due to a lack of adequate access to land for farming, poor access to the market because of limited and inconsistent supply of the produce, and lack of access to services such as water in areas where land is available. The farming activity noted in Region G is through communal and backyard gardens. The food resilience hub shares a space with the City of Johannesburg's skills centre and the Discovery Business Hub. There is a lack of integration among the three spaces, resulting in the loss of opportunities to train local farmers. There is also no programme to research innovative ways to improve urban agriculture and overcome some of the identified challenges. sSome farmers use the open spaces available near their houses. When speaking to a local farmer, who is currently working at the food Resilience Unit, he indicated that the local farmers are faced with the following challenges;

- Lack of farming tools to distribute to urban farmers

- Urban farmers require fencing material
- Lack of land to practise urban farming
- Lack of water supply
- Farmers are not equipped with enough skills to understand the difference between organic or chemical farming techniques, which then affects the final produce.
- Limited communal farming projects
- Lack of skills training to support farmers to be able to manipulate land to obtain maximum output (which crops/plants to grow together; crop rotation; and which crops grow better together etc).

Fig 3. Samples of formalised agricultural activities

6 CONCLUSION

Within the Southern African context, there remains a limited body of modelling-based research to inform policy on strategic land identification. In marginalised areas such as Region G, balancing the need to stimulate emerging local economies with the imperative to protect natural ecosystems is critical. This study demonstrated the application of a Planning Support System (PSS) tool to identify strategically located land suitable for urban agriculture. The growing emphasis on sustainable development in marginalised urban areas positions urban agriculture as a viable emerging economic activity with the potential to enhance livelihoods and overall quality of life. However, identifying appropriate land and empowering residents from informal settlements remains a persistent challenge in South African cities. The findings of this study contribute evidence to support more informed, spatially grounded policy interventions aimed at advancing inclusive and sustainable urban development.

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