Discover Sustainability

Research

Allergenic tree pollen in Johannesburg and Cape Town as a public health risk: towards a sustainable implementation framework for South African cities

Dorra Gharbi[1] · Frank H. Neumann[1,2] · Sarel Cilliers[1] · Selna Cornelius[1] · Jako Viviers[1] · Ernst Drewes[1] · Karen Puren[1] · Dilys Berman[3] · Nanike Esterhuizen[3] · Linus Ajikah[2] · Jonny Peter[3] · James Chakwizira[1]

Received: 12 May 2023 / Accepted: 26 July 2023
Published online: 03 August 2023

Abstract
South Africa's urban population is increasing, and in parallel, urban green infrastructure has shown an increase in alien tree species, e.g., mulberry (*Morus* sp.), oak (*Quercus* spp.) and plane trees (*Platanus* spp.) to name a few. This causes ecological problems since alien trees are often more water-demanding and competitive than indigenous trees, but they also increase the abundance of respiratory diseases often triggered by an allergic reaction towards the pollen of those alien taxa. In the current study, utilizing 7-day volumetric spore traps, we illustrate that the most abundant tree pollen in the two largest cities of South Africa, Cape Town and Johannesburg, is produced by alien trees with a high risk of allergenicity. This adds another aspect related to public health when evaluating plant species composition in urban forestry and urban ecology, which underlines the urgency of more intense monitoring. More importantly, this—for South Africa—newly emphasized risk for public health underlines the applicability of current directives [i.e., Spatial Development Frameworks (SDFs), localized Precinct Plans, Land Use Schemes (LUSs)] and implementation options in urban planning. Here, we present ideas that may be implemented in such a framework. From both a public health and an ecological perspective, it is recommended to plant indigenous trees like *Combretum erythrophyllum*, *Vachellia* and *Senegalia* spp. that have fewer ecosystem disservices, like a lower impact on public health due to lower allergenicity/lower pollen occurrence and providing more ecosystem services such as lower water needs.

Keywords South Africa · Allergenic pollen · Alien trees · Indigenous trees · Urban Green Infrastructure · Urban ecology · Urban forestry · Urban planning · Implementation framework

1 Introduction

A substantial increase in urban population is forecasted for developing countries in the Global South, with the fastest predicted rate in Africa, by tripling the current population of 1.26 billion by 2050 [1]. This will lead to the development of unsustainable trajectories in urban areas and the large-scale transformation of valuable natural areas, putting development pressure on the green spaces in and around urban areas [2]. Different concepts are used in sub-Saharan Africa to describe these urban green spaces [3]. The concept of urban forest is often used for tree-dominated (woodland)

✉ Dorra Gharbi, dorragharbi@yahoo.fr | [1]Unit for Environmental Sciences and Management, Faculty of Natural and Agricultural Science, North-West University, Potchefstroom, South Africa. [2]Evolutionary Studies Institute and School of Geosciences, University of the Witwatersrand, Johannesburg, South Africa. [3]Division of Allergology and Clinical Immunology, Department of Medicine, University of Cape Town, Cape Town, South Africa.

communities in cities [3]. According to Escobedo et al. [4] the urban forest includes individuals and groups of planted and remnant natural trees in public (e.g., streets and parks) and private (e.g., gardens) urban areas (Fig. 1). The discipline of urban forestry was developed in North America and Europe and involves the management of urban trees and their resources for their 'physiological, sociological, economic, aesthetic, and ecological benefits' [5, 6]. Although Shackleton [7] described a paucity of urban forestry research in South Africa, recent advances include, e.g., the importance of urban planning and management frameworks [8], role of plant nurseries [9] and phenological studies of urban forests [10]. Another concept used for urban green spaces, more recently for South Africa, is urban green infrastructure (UGI) (Fig. 1). UGI includes the urban forest but also non-woodland habitats such as natural grasslands and wetlands, as well as man-made habitats such as lawns, green roofs, green walls, bioswales and rain gardens [3]. UGI definitions focus on the interconnectedness of the different green spaces and the various benefits (ecosystem services) they provide [3, 11]. The rationale behind the inclusion of the concept of 'infrastructure', according to Pauleit et al. [12] is to align planning for UGI with the grey infrastructure (transport, communication, water supply and wastewater systems) in terms of their specific benefits, e.g., by planning rain gardens which help with the re-adsorption of runoff water [13]. The definition of UGI includes two core principles needed for its planning and development, namely multifunctionality and connectivity [3]. These two principles have a wide application in terms of social, economic, and ecological aspects, and UGI should be regarded as a part of the complex social-ecological system [14]. Other UGI principles include the integration between the green and the grey infrastructure, relevance on multiple scales over the long-term and social inclusion of all stakeholders, also addressing environmental injustice [3, 12, 15]. Globally, several disciplines are studying UGI, with urban ecology as the most prominent.

It is challenging to give one comprehensive definition of urban ecology due to various and still evolving perspectives. Most definitions describe it as an inter- and transdisciplinary science involving several disciplines from the natural and social sciences and other relevant urban stakeholders such as planners, managers, policymakers and the general public (citizen science) [16–18]. For Wu [19], urban ecology has become synonymous with urban landscape ecology and is an important part of sustainability science, therefore, he defines urban ecology broadly as 'the study of spatiotemporal patterns, environmental impacts, and sustainability of urbanisation with emphasis on biodiversity, ecosystem processes and ecosystem services'. Although Urban ecology has mainly developed with a focus on Global North realities, principles and frameworks, an immense body of urban ecological knowledge has been developed for the Global South over recent years [20]. These studies have shown the uniqueness of urban areas and approaches in studying the Global South and identify specific research needs for advancing urban ecology for the Global South. These needs include aspects such as addressing and integrating inequality and informality, disparities in terms of UGI provision, and specific links between UGI and human health [21]. Whether we use the concepts of urban forests or UGI, urban forestry or urban ecology, the provision and management of ecosystem services (ES) to make cities and human settlements; safe, resilient, and sustainable (see Sustainable Development Goal number 11) [22] is key.

Although ES is not a new concept, it gained prominence with the publication of the Millenium Ecosystem Assessment and refers to the direct and indirect benefits humans derive from ecosystem functions [23]. Urban ES are

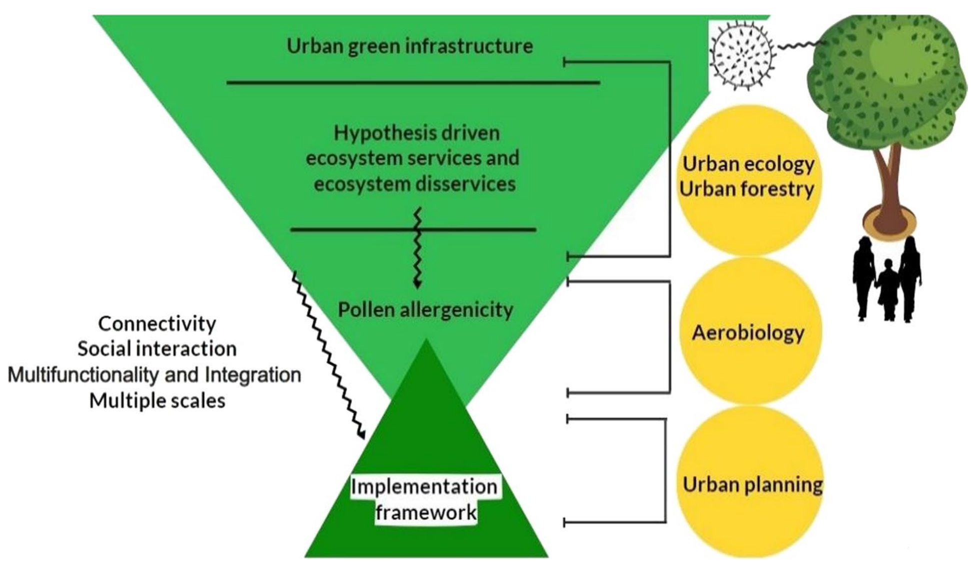

Fig. 1 Implementation of a sustainable urban framework for South African cities

generally divided into four classes, namely supporting (e.g., biodiversity), provisioning (e.g., food, medicine, water), regulating (e.g., climate and flood regulation, carbon sequestration, water purification) and cultural/socio-economic aspects (e.g., tourism, recreation, mental and physical health, spiritual experience, and sense of place) [24, 25]. Research on urban ES is more advanced in the Global North but see Shackleton [26] (provisioning ES), Escobedo [27] (urban regulating ES), and Dobbs et al. [28] (cultural urban ES) for summaries of the state of urban ES research in the Global South. Research on urban ES in sub-Saharan Africa focuses more on provisioning and regulating ES, and there is a significant prominence in South African studies [11]. Although UGI and urban ES are included in some policy-relevant frameworks in Global South cities, the same cannot be said for the various negative effects that humans experience from the UGI/urban forest, known as ecosystem disservices (EDS) [29, 30]. Davoren & Shackleton [31] grouped the urban EDS experienced in the Global South into six classes, namely aesthetic, ecological, economic, health, psychological and cultural impacts. Although there is a paucity of research on all these EDS in South Africa, the lack of information on health impacts and specifically pollen-related allergies associated with the UGI/urban forest is significant (Fig. 1). Determining the effect of this and other EDS on human health and well-being is 'essential for environmental-decision making since it indicates where management interventions are needed, by defining high-priority areas for control and determining the scale at which the UED should be managed' [31]. In UGI planning the management of EDS and improvement of ES would contribute to the development of healthy urban green spaces.

From an analytical point of view, even though tree planting might contribute to better respiratory health through the improvement of air quality and thermal comfort, certain studies list EDS produced by urban trees with respect to the suitability of planting specific tree species in cities [32], in which some tree species may also emit pollen aeroallergens [33] (Fig. 1). Pollen aeroallergens trigger symptoms of allergic diseases such as hay fever, conjunctivitis, itchy nose, wheezing, and asthma [34]. According to the World Allergy Organisation, between 10 and 30% of the global population shows allergic sensitisation to pollen and prevalence rates are increasing worldwide [35]. Studies on the effect of land cover on allergic and respiratory health are increasing. A study in England found that the presence of more tree cover, gardens, and green space in residential areas was associated with fewer asthma hospitalizations [36]. Another study, in Northern Belgium, documented that when exposure to airborne pollen or allergenic trees cannot be avoided during the pollen season, sensitized individuals may experience psychological stress [37]. Other studies in four European countries (Italy, France, Slovenia, and Poland) find that children living with more green space near their homes, where abundant endemic allergenic trees species such as *Alnus*, *Acer*, *Fraxinus*, and *Betula* were present, suffer more from wheezing and have an increased risk of allergic rhinitis [38] and asthma [39].

Therefore, because allergic rhinitis has become a major respiratory disease, continuous aerobiological monitoring of airborne pollen was conducted to highlight the major contribution of plants growing in UGI to the development of allergy symptoms in the local populations [40, 41]. Analysis of airborne pollen provides valuable information on biological air quality, different plant taxa and the distribution of local vegetation [42]. In addition, categorising pollen sources and quantifying their contribution to the overall pollen spectrum can enable a more efficient design of urban parks and gardens in terms of the choice of species and avoid allergy risk and can improve the management of UGI [43]. New methods for 3D simulation, mapping, and urban planning are now being used in urban aerobiological research to assess pollen exposure [44–46].

Allergenic tree species are a new challenge for urban planners, designers, and managers. The impact of allergic pollen on human health must be considered while choosing land cover vegetation, and non-allergenic pollen plants are the optimal options. Today, several studies focus on the potentially allergenic tree species in urban parks in the context of public health and allergenicity [47]. An index of urban green spaces to quantify the risk of tree pollen allergy has been developed in the Global North [46, 48]. This index is used for an assessment of the environmental health risk and an improvement in the planning and design of urban green spaces [49–51]. However, a large gap in our knowledge still exists regarding the state of the interactions between human exposure and the UGI for trends of high biodiversity across different biogeographical regions within the Global South, and more specifically for South Africa which is a major economic hub on the continent with a large degree of urbanization.

Numerous studies illustrate the high floristic diversity of UGI in South Africa, which stems from the introduction of ornamental species, both indigenous and alien [52, 53]. Species composition is determined based on local investigation of airborne allergenic pollen and baseline survey on vegetation. Furthermore, UGI are characterized by the abundance of allergenic alien species introduced from the northern hemisphere as ornamental trees, including cypresses (*Cupressus* spp.), plane trees (*Platanus* spp.), pines (*Pinus* spp.), olive trees (*Olea europaea* subsp. *europaea*), and oaks (*Quercus* spp.). The abundance of specific alien trees confirms the cause of pollinosis symptoms and their marked allergenicity, illustrating an important issue in the South African environment [54, 55]. Many allergenic pollen plants are centralized in urban areas, threatening human health, and the negative impact of allergenic pollen plants has not been considered during the species selection and collocation process of UGI. During the pollen season in spring (August-October for most taxa, in South Africa), the blooming of the alien tree species often simultaneously releases large amounts of often allergenic pollen into the atmosphere, considered among the most prevalent in the pollen spectrum in South African cities according to Berman [56]. An overview of the indigenous and alien allergens in South Africa documented that Johannesburg is the most heavily tree-planted city in South Africa, with alien trees (such as pines, oaks, planes, eucalyptus trees), but also acacias (*Senegalia/Vachellia* spp.) and other African trees including Combretaceae, consequently allergic reactions to tree pollen is common in Johannesburg, especially in spring [57]. Furthermore, plane and oak trees are the most common cause of short-lived allergy symptoms in the Western Cape, which occur each year in August and early September [58]. Also, in 2000 it was found that 15% of South African Olympic athletes were sensitive to plane tree pollen [55].

Pollen grain concentrations can be spatially and temporally highly heterogeneous depending on the proximity of sources but also on the urban topography of the environment. In recent research, which considered five northern hemisphere cities (Barcelona, Montreal, New York City, Paris, and Vancouver) with different urban forests and population densities, Sousa-Silva et al. [59] presented evidence on how tree pollen allergenicity datasets can shape the risk for pollen-allergy sufferers. However, the literature lacks studies from Global South cities, especially in Africa that focus on plant taxa and combine aerobiological datasets to explicitly explore the pattern of allergenic tree distribution in UGI.

As a response to this research gap, this paper builds an argument that the two study areas, Johannesburg and Cape Town, need to consider the abundance and distribution of allergenic tree species in their UGI as integral to their urban planning and design (Fig. 1). This consideration should consider the applicability of current directives in the form of SDFs, Precinct Plans, LUSs and other municipal planning policies as well as practical implementation options; all in attempting a sustainable implementation framework.

2 Materials and methods

For the purpose of this research, a multiple case study methodology [60], was employed as this enabled the researchers to "investigate a phenomenon in a specific setting" (allergenic pollen-producing trees within the context of the cities of Johannesburg and Cape Town), to "inform a wider inquiry" [60, 61] regarding the health risk for the South African population, as well as the management thereof in a sustainable implementation framework.

2.1 Study areas

The study was undertaken in the cities of Johannesburg and Cape Town, the two largest cities which are also centres for trade, industry, tourism, culture, and education, to allow comparisons between the representativeness of the vegetation in the UGI (Fig. 2). Located in the southwestern Cape of South Africa with a distinct winter rain climate, Cape Town (CPT) lies within a globally recognized biodiversity hotspot of the Fynbos biome with the characteristic plant families Proteaceae, Ericaceae and Restionaceae; the biome covers an area of 2460 km^2 [62, 63]. The topography is complex as Table Mountain rises steeply to a height of 1086 m from its position close to the port of Cape Town in Table Bay and there are two coastlines around the Cape Peninsula. These features give rise to different climatic conditions within a small area. The climate is Mediterranean with winter rainfall and warm, dry summers but rainfall varies from 350 mm on the western coast to > 2000 mm per year on the highest mountain summits [64]. The city's history of European colonization reaches back to 1652 when first alien plant species like oaks were introduced [65]. The natural vegetation is degraded and reduced due to urban development, with introduced species like *Platanus* spp., *Pinus* spp., *Quercus* spp. and Australian *Acacia* spp. being common [63, 66].

The second study site, the city of Johannesburg (JHB), is regarded as one of the most extensive man-made urban forests globally [67, 68]. The JHB urban forest is highly diverse, ranging from riverine forests along streams, alleys to parks, botanical gardens, and private green areas. Township areas are densely populated and with a low tree cover in comparison with more affluent areas [69]. The regional climate is warm-temperate and features a typical summer rainfall pattern with warm, wet summers and dry, cool winters. It is located within the temperate Grassland biome with patches of savanna in the summer rainfall region of South Africa but is also affected by anthropogenic impact due to urbanization processes [63]. Johannesburg's urban forest/UGI is regarded as an extraordinary urban ecological asset with 6.1% covered by trees, both remnant and planted indigenous and planted and naturalised alien species. Many North American and

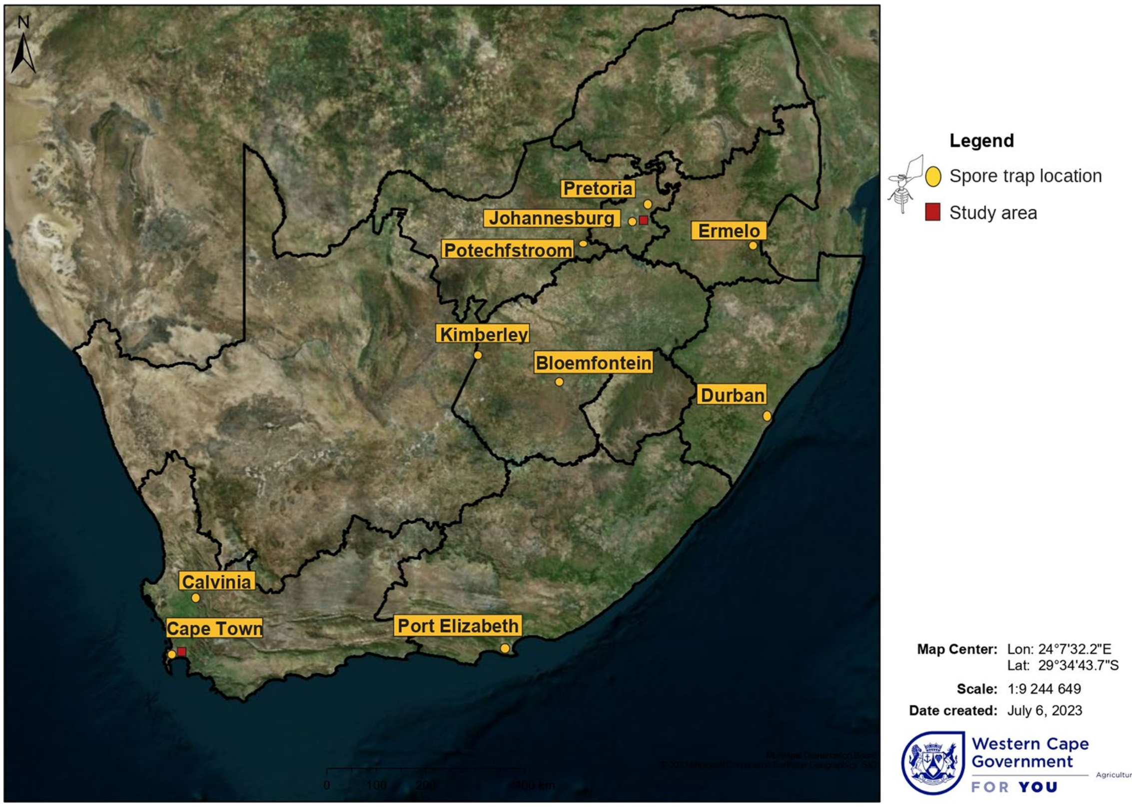

Fig. 2 A map of the ten aerobiological sampling stations which are run by SAPNET (South African Pollen Monitoring Network). Also shown are land use patterns in South Africa (https://gis.elsenburg.com/) (created date July 06, 2023)

Eurasian taxa, e.g., *Platanus* spp., *Morus* spp., *Betula* spp., *Fraxinus* spp., *Cupressus* spp. and *Quercus* spp. are also widely distributed as are southern hemisphere taxa like *Jacaranda mimosifolia* or *Eucalyptus* spp. [70].

2.2 Pollen data

Airborne pollen sampling was performed during 2019–2022, using a 7-day Hirst-type volumetric trap manufactured by Burkhard. The Cape Town sampler is situated 8 m above ground on a rooftop at the South African Astronomical Observatory. The Johannesburg spore trap is located on the roof of the Richard Ward Building at 12 m above ground, School of Chemical and Metallurgical Engineering, Braamfontein Campus East, University of the Witwatersrand (Fig. 2). Both samplers are calibrated to continuously suck air at a rate of 10 l/min. Pollen grains were trapped on a Melinex tape fixed on a rotating drum coated with Vaseline jelly, which was then cut into seven daily segments and mounted on the slides with a glycerol jelly media. The count of pollen grains was made with the aid of an optical light microscope (CX 23) with × 400 magnification along three full lengthwise traverses following the South African Pollen Network methodology (SAPNET). Pollen concentrations were expressed as daily mean pollen concentrations (p.g/m^3). The average of daily mean concentrations of pollen types during the years studied was calculated using the Microsoft Excel® software 2022. The annual sum of daily pollen concentrations (annual pollen index—API) for each aerobiological station is used in the inventory development process. The pollen types considered in this study were pollen of trees listed by the SAPNET such as species of *Cupressus*, *Platanus*, *Quercus*, *Pinus, Morus, Betula*, and the families Oleaceae, and Myrtaceae, which are allergenic pollen producers according to the South African Pollen Network [71]. Other trees which do not produce large amounts of allergenic pollen recorded in the atmosphere of sampling stations were included in the analysis.

3 Results

3.1 Total and seasonal distribution of pollen production by trees

The continuous aerobiological monitoring of the air recorded at the two sites was compared to determine whether there are possible differences in the airborne pollen of the particular trees. The pollen of relevant tree species and families recorded during the period 2019–2022 was considered, e.g., *Cupressus* (cypress), *Platanus* (plane), *Pinus* (pine), *Olea* (olive), *Morus* (mulberry), *Betula* (birch), *Quercus* (oak), Myrtaceae (gum), *Fraxinus* (ash), *Podocarpus* (yellow wood), *Searsia* (karree), *Populus* (poplar), Combretaceae (bushwillow), *Ulmus* (elm), *Casuarina* (she-oak), *Acacia* type (Australian Acacias), and Tiliaceae (linden family) (compare Fig. 3, Table 1). Most dominant species were of Northern Hemisphere origin (*Cupressus*, *Platanus*, *Pinus*, *Olea*, *Morus*, *Betula*, *Quercus, Populus, Ulmus*) or Australian (most Myrtaceae (*Eucalyptus*), *Casuarina,* some *Acacia*-type pollen). Those taxa are well represented in both cities. Only Combretaceae are exclusively indigenous trees (typical savanna-woodland trees, namely *Combretum* spp. (bush willows). The diversity of taxa found at the two sites was similar. Comparisons of the API of the trees in both study sites are shown in Table 1. Johannesburg city has a higher annual pollen index with mean values of 6847 p.g/m^3 in comparison to Cape Town with mean values of 5059 p.g/m^3 during the studied years. A total of eight tree taxa largely exceeded an average of 100 p.g/m^{3}in JHB, as well as *Morus*, *Betula*, *Quercus*, *Pinus*, and *Fraxinus*, in comparison to six taxa that occurred in CPT where *Olea* and Myrtaceae have distinctly higher values. The main dominant pollen type in JHB was *Platanus* with a mean value of 3353 p.g/m^3. However, a considerable API of 2777 p.g/m^3 of *Cupressus* was identified in CPT. The pollen types with the lowest concentrations in JHB were *Casuarina*, Tiliaceae, and *Acacia*-type (including indigenous *Vachellia* spp. and *Senegalia* spp. as well as Australian *Acacia* spp., respectively), *Fraxinus*, *Populus*, and Combretaceae in CPT.

The general trend of the average daily mean concentrations of dominant tree pollen types for both localities is presented in Fig. 3. A pronounced difference in seasonality is evident. There were apparent differences in the pollen season dynamics between the stations of CPT and JHB. The average of pollen concentrations for each site evidenced that higher levels were registered in CPT, except *Platanus*, *Morus, Quercus,* and *Betula* pollen which reached higher concentrations in JHB.

4 Discussion

4.1 Tree pollen aeroallergens in South African cities.

Aerobiological research aims to identify sources of airborne pollen concentrations and quantify their contribution to overall pollen levels. This enables specific recommendations to be made regarding the most suitable ornamental species and is thus an essential step in ensuring a more efficient design of urban parks and gardens [72]. This study shows important information about the abundant allergenic pollen types and their respective aerobiological patterns in the studied cities. Keeping in mind that light microscopy is the standard method for identifying pollen in air samples [73]. Pollen of all species of the families Myrtaceae and Fabaceae (*Acacia* family) belongs to the same palynomorphological type and is not easily distinguishable even down to the genus level during routine aerobiological analysis with × 400 magnification [74]. Based on that, the terminology of Myrtaceae and *Acacia* pollen types were considered and reflected the presence of Eucalyptus and both Australian Acacia and African taxa previously known as Acacia.

In relation to pollen index and peaks, cypress, plane, pine, olive, mulberry, birch, oak, and ash tree pollen types are most abundant which is reflected in the spore traps revealing the urban landscape composition within JHB and CPT (Fig. 3). Thus, the most frequent pollen types detected in the spore traps include species native to Europe and, secondarily, North America. This group included some of the main causative agents of pollen allergy in the Mediterranean area, such as *Cupressus* (*C. sempervirens*, *C. arizonica* [75], *Platanus* [76, 77], and *Olea* [78] with values of potential allergenicity and others with a lower degree of allergenicity such as *Pinus* [79] and *Quercus* [80]. Other species such as *Betula* [81] and *Fraxinus* [82] are a cause of pollen allergy in Europe. All of them share an anemophilous character, high pollen production, an extensive flowering period (Fig. 3), and allergenic pollen grains, which led us to consider them as major allergens in the UGI of Cape Town and Johannesburg.

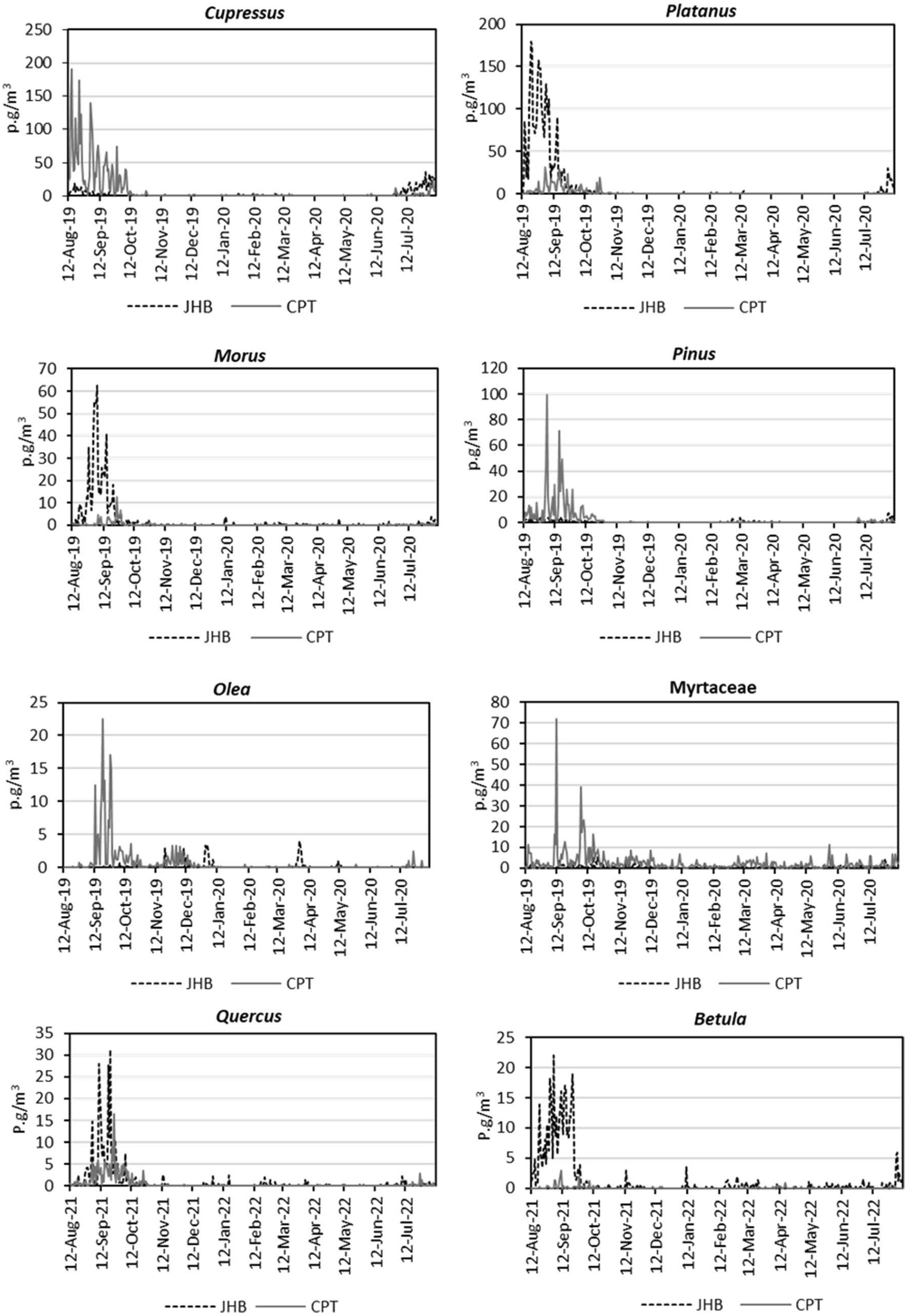

Fig. 3 Average seasonal dynamics of dominant pollen trees (pg/m^3) detected in the cities of Cape Town (CPT) and Johannesburg (JHB) (2019–2022)

Table 1 Tree pollen types, annual pollen index (API), max API, and average API recorded in the cities studied (2019–2022)

Pollen types	Common name of trees	Cape Town						Johannesburg						Average API 2019–2022	
		2019–2020		2020–2021		2021–2022		2019–2020		2020–2021		2021–2022		CPT	JHB
		API	Max	API	Max	API	Max	API	Max	API	Max	API	Max		
Cupressus[a]	Cypress	2692	483	1269	148	4370	383	752	49	874	49	865	48	2777	830
Platanus[a]	Plane	397	65	618	56	21	4	3220	371	3594	207	3245	276	345	3353
Pinus[a]	Pine	1084	287	66	12	523	51	134	17	245	16	255	12	558	211
Olea[a,b]	Olive	264	56	47	6	1408	209	58	10	61	12	32	9	573	51
Morus[a]	Mulberry	101	14	22	3	0	0	144	36	1380	140	835	75	41	786
Betula[a]	Birch	26	6	8	1	28	1	166	22	734	54	554	36	21	485
Quercus[a]	Oak	195	14	132	12	62	7	46	8	708	84	284	14	130	346
Myrtaceae[a,b]	Gum trees and other members of the myrtle family	250	21	683	26	384	47	215	14	247	12	128	9	439	197
Fraxinus[a]	Ash	6	4	1	1	5	1	12	1	176	30	411	23	4	200
Podocarpus[b]	Yellowwood	0	0	11	6	21	4	50	10	148	24	45	6	11	81
Searsia[b]	Karree	14	3	127	7	1	1	46	5	148	50	39	6	47	78
Populus[a]	Poplar	0	1	18	25	6	4	3	1	171	12	44	5	8	73
Combretaceae[b]	Bushwillow	0	0	0	0	0	0	17	6	94	5	59	6	0	56
Ulmus[a]	Elm tree	55	9	85	13	31	4	2	1	20	4	114	12	57	45
Casuarina[a]	She-oak	8	1	24	5	19	4	10	2	47	9	37	7	17	31
Acacia[a,b]	Australian acacias, indigenous acacias	4	1	1	1	6	1	7	4	21	2	12	1	4	13
Tiliaceae[b]	Linden family	5	1	2	1	73	15	7	3	18	4	9	2	27	11
Total	–	5101	984	3114	334	6958	1041	4889	569	8686	714	6968	547	5059	6847

[a]Alien trees

[b]Indigenous trees

4.2 Towards an implementation framework

UGI in South Africa may, from an urban planning perspective, be implemented by considering different approaches (i.e., on a strategic planning, land use management and implementation level), especially as Retief et al. [83] underscore megatrends evolving from a single predictable solution towards open and multi-purpose approaches.

4.2.1 Strategic planning

As is often the stance, spatial planning directives (policy, law, and guidelines) in South Africa are not necessarily prone to purposefully advocate UGI, resulting in urban planners treating it too generally, as an all-embracing archetype within the diverse disciplines of urban planning [84]. In contrast, Brundtland [85] qualifies the coexistence of development (urban) and the environment, feasible once the responsibility of making the "ecosphere the first priority", is accepted. Failing in contemplating UGI from the onset, and also on a strategic level, will continuously prevent it from finding its way into urban planning. Inadequate emphasis on UGI by municipalities during strategic planning may result in inadequate reflection thereof in land use management instruments and by-laws. This conundrum may be amplified at the municipal level, where the value of UGI is often neither prioritized nor understood, especially since municipalities are confronted with seemingly more pressing socio-economic challenges resulting in trade-offs between other development needs and UGI [86].

Early planning directives (the National Environmental Management Act (NEMA) [87], provided for Strategic Environmental Assessments, although not compulsory [88] to, inter alia, inform SDFs. More recently the Spatial Planning and Land Use Management Act (SPLUMA), [89] has, nonetheless, seen references to the exceedingly diverse concepts of the "sustainable development of land" and the principle of "spatial sustainability" in its norms and standards (although neglecting to offer their implementation in practical ways). The lamentations of Farthing [90] endorse that planning research ever so often fails in meeting the needs of practitioners and should provide evidence, directives, and practice. Although the SPLUMA encouragingly permits the inclusion of environmental opportunities, typically UGI, in forward planning instruments i.e., the municipal SDFs or in more detailed "local plans" (SPLUMA, [89]), also known as Precinct Plans [91], municipalities are reinvigorated to place more emphasis on the SPLUMA imperative that a Land Use Schemes (LUS) must promote minimal impact on public health, the environment, and natural resources. While mostly leaving the incorporation of spatial sustainability in these documents open to the interpretation of urban planners, strategic planning is perceived as the first necessary advent in designing healthy urban green spaces in South Africa. Healthy urban green spaces are additionally promoted by the Sustainable Development Goals (e.g., Goal 11.6) inter alia, emphasizing improved air quality in cities [92]. Augmenting the linkages between relevant Sustainable Development Goals and UGI may be significant in further improving strategic planning. This may further facilitate the improved management of the potential allergenicity of tree species, commonly used as ornamentals in urban green spaces, through land use management measures.

4.2.2 Land use management

Departing from strategic planning, the SPLUMA, similarly provides for the preparation of new and integrated Land Use Schemes (LUS) by municipalities in, inter alia diverting from spatially distorted settlement patterns, by also taking cognisance of "environmental management instruments" [89]. As the SPLUMA resorts under national authority, municipalities had to prepare their own unique By-Laws, inter alia facilitating the preparation of LUS, within the context of the SPLUMA. Through this vehicle, municipalities are provided with the opportunity to prepare land use management measures for improving the incorporation of UGI in the development and management of their jurisdictional areas; either through their "land use management" by-law or any other newly prepared by-law. The facilitation of UGI and the design of healthy urban green spaces in South Africa are, therefore, duly established by this arrangement. However, since directives do not necessarily guide or enforce the practical implementation of sustainability on an urban scale, other than its mere mentioning, municipalities are left with a predicament, evidently seeing UGI low on the development agenda and impeding implementation options as meaningful disciplinary logic in the applied [93] and real-world [94].

4.2.3 Implementation

While the attainment of UGI, and subsequently the design of healthy urban green spaces in South Africa are to be accepted into strategic planning and land use management, its practical implementation evidently leaves urban planners despondent. UGI is internationally regarded as a "solution to complex urban problems" but not yet realized and successfully implemented in South Africa, according to Cilliers [95]. Although the South African Council for Scientific and Industrial Research (CSIR) [96] accentuates healthy ecosystems and climate-safe facilities in the design of urban open spaces, it falls short of addressing the design of healthy urban green spaces in a practical and achievable way. Research in this article is perceived as a pertinent keel in the chopping sea of UGI as it attempts to offer implementable and scientifically sound solutions within the built environment, in designing of healthy urban green spaces in South Africa. The built environment already presents functional and practical building blocks, offering opportunities for UGI, culminating in the design of healthy urban green spaces. In this instance, and originating from the work of Girling and Kellet [97], these building blocks are represented in the form of "fabrics" and "networks" in shades of green and grey (Table 2), where (i) networks refer to spatial corridors through which people and organisms flow, (ii) fabrics to spaces distributed between and served by networks, while both fabrics and networks are (iii) grey, if serving the built and urban environment and (iv) green, if serving ES, (v) all in a complex and interwoven relationship. It is a construct illustrating that practical and mutually supportive building blocks, all within which introducing non-allergenic, indigenous species to urban landscapes, may well be conducive to designing healthy urban green spaces in South Africa. The building block approach relates well to specific UGI principles i.e., connectivity and multifunctionality in terms of the provision of various ES, the integration of green and grey infrastructure and relevance on multiple scales [3, 12, 14].

A fifth component, not captured in the building blocks of Girling and Kellet, but traversing all four components, is the social component or community that daily utilises urban networks and fabrics. Social inclusion is also an important principle of UGI planning and is often neglected in urban areas of the Global South [3]. In this regard, implementing community-based participatory planning is admittedly inevitable to obtain meaningful solutions and insight from the residents, informing decision-making in designing healthy urban green spaces in South Africa [97, 98]. Cilliers and Cilliers [99], nonetheless, caution urban planners that the benefits of ecosystems are often subservient to socio-economic pressures in South African communities, thereby accentuating the need for participatory planning. Involving residents in the decision-making processes and the co-production of solutions [100], especially in addressing the allergenicity of the tree species commonly used as ornamentals in South African cities, may contribute to the sustainability of the proposed solutions [101]. In facilitating effective participatory planning and co-production of solutions, the attainment thereof will be determined by the awareness amongst the participants (the community and city actors) regarding the potential allergenicity of tree species. Creating awareness concerning the adverse impacts (EDS) of certain tree species and the dissemination of information on the effects of allergens on health and wellbeing, are subsequently integral to the successful implementation of UGI. Efforts to attain green urbanism in this manner will, in all probability, be accepted and maintained by a well-informed, continuously involved and concerned community.

Table 2 A framework for the practical introduction of non or low-allergenicity trees in cities

Green networks	Protecting, restoring, and interconnecting the urban ecological structure
Grey networks	Accessible, connective, and walkable, tree-lined street networks
Grey fabrics	Mixed land uses within walking distance
Green fabrics	Preserved remnant forests, tree-lined streets, and tree-covered spaces

Source: Girling and Kellett [97]

4.3 Sustainable urban forestry

For cultural and historical reasons, the presence of these species with allergenic pollen cannot be readily reduced. An exception is the management of declared invader species according to legislation, for example, *Acacia, Morus, Eucalyptus* and *Populus* [102]. Wind-pollinated *Morus* (Mulberry tree) was planted to provide multiple ES (shade, hedge, windbreak, fruit tree) in South Africa, but easily escaped from cultivation, now spreading into woodlands, within cities and along rivers often out-competing native species due to its fast growth and tolerance for droughts, different climatic conditions, and infertile soils in comparison with indigenous taxa (category 3 invader) [102, 103]. *Morus* is much more widespread in Johannesburg than in Cape Town (Fig. 3), in both cities, it can be seen along streets and streams or as a ruderal plant. Since it is both used as a fruit tree and releases a massive amount of pollen, it is of special importance that the tree can cause both food and pollen allergies [102, 104]. Some genera, like *Eucalyptus* and *Pinus*, include species which are both invasive and have a high-water demand and are therefore actively removed from the landscape [105, 106]. *Pinus* pollen has moderate allergenicity [107] but is a common pollen grain detected in Cape Town due to the fact that especially Mediterranean pines are well-adapted to seasonal droughts and poor soil conditions and are often successful competitors of the indigenous vegetation (Fig. 3). Myrtaceae pollen comprises *Eucalyptus* with some species such as *Eucalyptus camaldulensis*., *Eucalyptus cladocalyx*, *Eucalyptus diversicolor,* declared invaders in South Africa [108] and was recognized as important allergens for children with asthma in Australia [109]. *Eucalyptus* deserves attention since the pollen counts for Cape Town are -for short durations- alarmingly high (Fig. 3). *Acacia*-type pollen, both representing indigenous *Vachellia* and *Senegalia* species but also declared invaders such as the Australian Acacias [108], are underrepresented both in Cape Town and Johannesburg and of lesser concern for public health as is e.g., *Populus* (Fig. 3). *Casuarina* pollen, with low allergy potential, including *Casuarina cunninghamiana* and *C. equisetifolia*, are also declared invasive species from Australia and are listed are invasive aliens in the Western Cape, similar to *Searsia succedanea* which is indigenous to eastern Asia [108]. *Platanus* pollen was found in much higher concentrations in the city of Johannesburg than in Cape Town. Plane trees are widespread as alley trees in Johannesburg because they are tolerant towards high levels of air pollution which is common in the city [110]. Abutaleb et al. [111] underline the abundance of London plane (*Platanus* × *acerifolia*) trees in Johannesburg using remote sensing data, and its pollen is one of the main causes of pollen-related diseases in South Africa [112]. According to several atmospheric pollen studies, plane trees have intense and short blooming periods [113–116]. The allergenic importance of *Platanus* is caused by the abundance of pollen grains released by many individual trees along streets and in parks [42]. Pollen appears abruptly in the air, and peak counts are usually recorded only a week after the start of the pollen season with an average of 36 days, a pattern reported in Madrid, Barcelona, and Córdoba [117, 118]. For this reason, special attention must be given when considering the planting of plane trees in the future design and management of South African UGI.

For the family Cupressaceae, the API reflects significant differences between the sampling sites, being higher in CPT. *Cupressus* species are popular alien, ornamental trees frequently grown in South African parks and gardens as ornamentals, shade trees, windbreaks and hedges, and shelter belts [119]. The dominant species are native to the Mediterranean basin (*Cupressus sempervirens*)*,* California (*C. macrocarpa*)*,* Arizona (*C. arizonica*)*,* Mexico (*C. lusitanica*)*,* and Himalaya-South China (*C. torulosa*). Only three Cupressaceae species are indigenous to South Africa, as part of the African cedar genus *Widdringtonia* (W. *cedarbergensis*, W. *schwartzii*, and *W. nodiflora*). The previous two species only naturally exist in a relatively small number of locations, but *W. nodiflora* has a distribution that stretches from the southwest of the Western Cape Province northward into Malawi [120], but none of these species are commonly planted in CPT. In practical allergenicity terms, a study by Ordman [121] showed that fourteen cases of winter-spring hay fever and allergic conjunctivitis have been investigated and found to be associated with cypress-pollen sensitivity. On the other hand, the allergenicity of cypress pollen extracts may depend on where they have been collected. Bar-Dayan et al. [122] described a cross-reactivity between cypress allergens and allergens from *Podocarpus gracilor* and *Callitris verrucosa* and, both species, have been put forward as surrogates for controlling cypress allergy. Among other common northern hemisphere trees with the greatest allergenic potential, *Betula*, *Quercus*, and *Fraxinus* are associated with an abundance of pollen concentrations and make a significant contribution to the city of JHB where they are more common than in CPT. Different stakeholder views on the ES (especially recreation and aesthetics) and EDS provided by trees could lead to conflict if certain invasive species are removed. To address these conflicts in CPT, a management framework was developed based on stakeholder perceptions that distinguished between invasive species that can be tolerated, actively managed, or totally removed [123]. This framework could be expanded to include tree species with specific EDS such as those producing allergenic pollen. It is essential to not only manage but also to avoid the increase of the numbers of these species in newly developed UGI, in order not to aggravate their impact on allergy sufferers. The main reason why a greater effort should be made to limit the presence of alien species is that they are known to trigger symptoms in sensitive residents [48] and others have also other EDS like high water demands [124].

In a future framework that may be used to guide city actors (Fig. 4), it is recommended to point out those taxa which are of public health concern in the major cities of South Africa, CPT and JHB. Pollen grains of the predominantly Mediterranean genera *Cupressus*, *Pinus* and *Olea* are abundant in CPT within the Mediterranean Fynbos biome whereas pollen grains of temperate broad-leafed forest tree taxa *Platanus*, *Morus*, and *Betula* are the three most prominent pollen types in JHB which lies within the temperate Grassland biome. In contrast to the widespread alien trees, most of the indigenous tree species are animal pollinated and have colourful, large flowers with sticky, ornamented and relatively heavy pollen which are not widely dispersed and are produced in much lower quantities. Since those trees provide many ES, have a low water demand and are less risky in terms of allergenicity, they are better suited for an urban environment than their alien counterparts. The indigenous coral tree (*Erythrina* spp.) is recommended as is the River bushwillow (*Combretum erythrophyllum*), which is widespread in Johannesburg and with its pollen also reflected in relatively low quantities in the spore trap findings. *Combretum erythrophyllum* grows well in urban environments, provides shade, adds ornamental value, has no negative impact on water balance and does not release allergenic pollen. Other recommended indigenous tree species often planted in Johannesburg include *Searsia lancea, S. pendulina, Celtis africana, Olea europaea* subsp. *africana, Harpephyllum caffrum, Kiggelaria africana* and *Schotia brachypetala* [69]. Indigenous acacias (e.g., *Vachellia karroo*, *V. sieberiana* var. *woodii* and *Senegalia galpinii*) also have a high ornamental value, are water-wise, and have attractive flowers which are insect pollinated and release only few pollens into the atmosphere. All these indigenous tree species can be easily identified except for

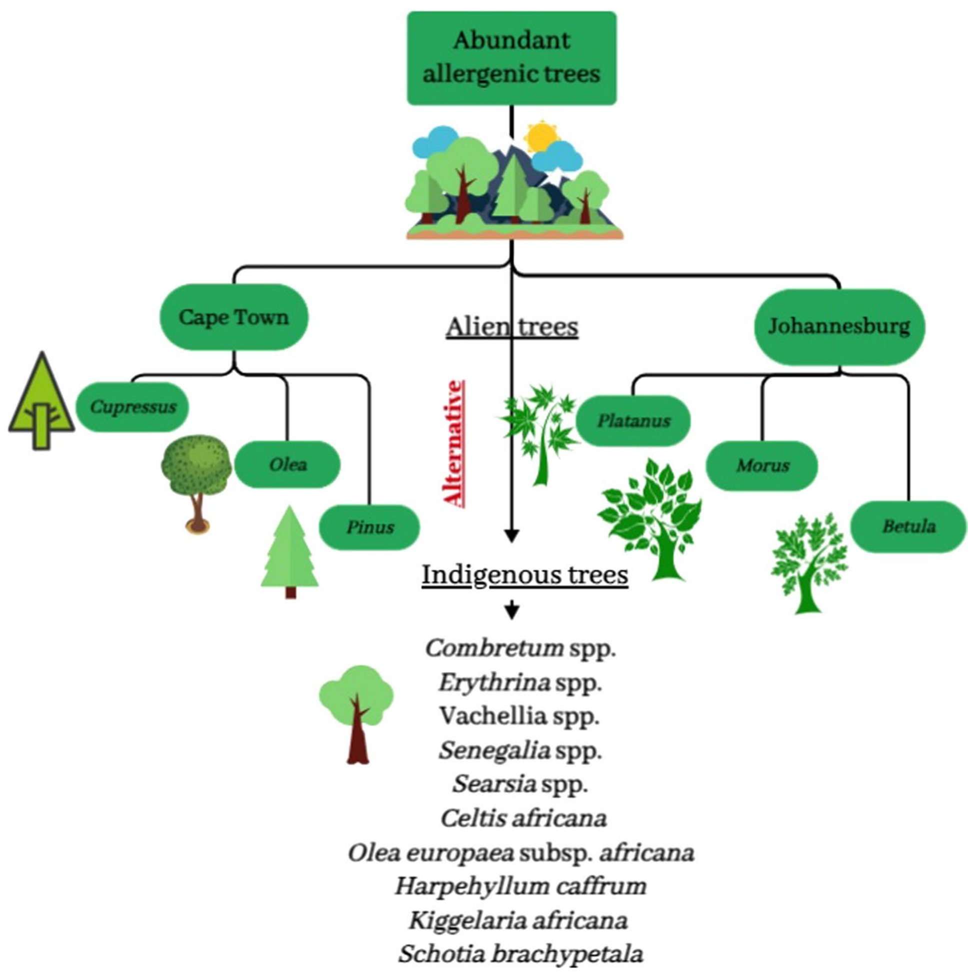

Fig. 4 Future framework for an alternative of allergenic trees in urban green infrastructure in Cape Town and Johannesburg (Van Staden and Stoffberg [69])

Celtis africana that could be confused with the alien species, *Celtis sinensis* which is often naturalised in urban areas and is recently flagged as a potential invasive species [125].

5 Conclusions

Pollen grains emitted in urban areas constitute a source of allergy. This study revealed the abundance of allergenic wind-pollinated alien trees throughout the UGI in two large South African cities. An urgent need exists to screen ornamental trees for allergenicity in South Africa before introducing them into urban green spaces, to improve the quality of the urban environment and protect pollen-allergy sufferers. Aerobiological criteria should be considered when planning urban green spaces for aesthetics and recreation. Valid strategies (Fig. 4) include using insect-pollinated, preferably indigenous (also often less water-demanding), species, which tend to produce less pollen and less aerodynamic pollen, than wind-pollinated species and ensuring the predominance of female plants in the case of dioecious species. It is also important to promote greater species diversity by focusing on indigenous species when designing new gardens, parks, and alleys. This measurement will prevent the excessive use of monospecific profiles, which can prompt a sharp increase in airborne pollen counts, but also increase ecological diversity and available ecological niches.

Current directives discussed in this article, such as implementing UGI principles (e.g., multifunctionality, connectivity, integration of grey and green infrastructure, multiple scale relevance and social inclusion) and the suggested framework (Fig. 4), are deemed largely sufficient to serve as a sustainable implementation framework for UGI. It is also questioned whether it is necessary to formulate additional directives for attaining healthy urban green spaces. Rather, the challenge seems to be how knowledge regarding allergenicity could be conveyed to city actors and to enhance their willingness in establishing healthy urban green spaces in SA cities. SPLUMA requires each municipality to include an Implementation Plan (section 21) in the compilation or revision of an SDF, which is the appropriate vehicle to include a *localised interpretation* of the abovementioned framework. The application of current directives (SDFs, LUSs and precinct plans, and SPLUMA) in collaboration with practical implementation options, are already steps in the right direction to ensure that healthy urban green spaces are developed in SA cities.

Acknowledgements We thank the following colleagues at the University of the Witwatersrand, Evolutionary Studies Institute and School of Geosciences, for their help and support regarding the JHB spore trap (in alphabetic order): Prosper Bande, Marion Bamford, Angela Effiom, Kevwe Eweto, Moteng Moseri, Nikiwe Ndlovu. We also acknowledge the help and support of Noejfah Jardien, Sarah Pedretti, Siyavuya Sidla and Wisahl Wallace from the University of Cape Town Lung Institute, as well as member of the South African Astronomical Observatory, for enabling the successful operation of the CPT spore trap. The Real Pollen Count initiative was sponsored by Clicks, Dr Reddy's, Thermofisher, Novartis, Glenmark, SA Natural Products, and Twinsaver.

Author contributions DG: Conceptualisation, Investigation, Visualisation, Writing—Original Draft Preparation, Writing—Review and Editing. FHN: Conceptualisation, Investigation, Data curation, Writing—Original Draft Preparation, Writing—Review and Editing. SC: Investigation, Writing—Original Draft Preparation, Writing—Review and Editing. SC: Original Draft Preparation, Writing—Review and Editing. JV: Writing—Review and Editing. ED: Writing—Review and Editing. Karen Puren: Writing—Review and Editing. DB: Investigation, Data curation, Writing—Review and Editing. NE: Investigation, Data curation, Writing—Review and Editing. LA: Writing—Review and Editing. JP: Writing—Review and Editing. JC: Writing—Review and Editing.

Funding Open access funding provided by North-West University. The financial assistance of Clicks, Dr. Reddy's, Thermofisher, Novartis, Glenmark, SA Natural Products, and Twinsaver toward the Real Pollen Count initiative is hereby acknowledged.

Data availability The full dataset in an Excel file is available from the corresponding author on request.

Declarations

Competing interests The authors declare no competing interests.

References

1. UN-Habitat 2014. State of African cities 2014: Re-imagining sustainable urban transitions. (Nairobi: United Nations Human Settlements Programme) 273 p. www.un-ilibrary.org/content/books/9789210575614. Accessed 19 Apr 2023.
2. Cilliers SS, Du Toit MJ, Cilliers J, Drewes JE, Retief F. Sustainable urban landscapes: South African perspectives on transdisciplinary possibilities. Landsc Urban Plan. 2014;125:260–70. https://doi.org/10.1016/j.landurbplan.2014.02.009.
3. Pauleit S, Vasquéz A, Maruthaveeran S, Liu L, Cilliers SS. Urban green infrastructure in the Global South. In: Shackleton CM, Cilliers SS, Davoren E, du Toit MJ, editors. Urban ecology in the Global South. Springer: Cham; 2021. p. 107–43.
4. Escobedo FJ, Giannico V, Jim CY, Sanesi G, Lafortezza R. Urban forests, ecosystem services, green infrastructure and nature-based solutions: nexus or evolving metaphors? Urban For Urban Green. 2019;37:3–12. https://doi.org/10.1016/j.ufug.2018.02.011.
5. Konijnendijk CC, Ricard RM, Kenney A, Randrup TB. Defining urban forestry—a comparative perspective of North America and Europe. Urban For Urban Green. 2006;4:93–103. https://doi.org/10.1016/j.ufug.2005.11.003.
6. Shackleton CM. Urban forestry South Africa—a Cinderella science? S Afr For J. 2006;208:1–4. https://doi.org/10.2989/10295920609505255.
7. Shackleton CM. Is there no urban forestry in the developing world? Sci Res Essays. 2012;7:3329–35. https://doi.org/10.5897/SRE11.1117.
8. Chishaleshale M, Shackleton CM, Gambiza J, Gumbo D. The prevalence of planning and management frameworks for trees and green spaces in urban areas of South Africa. Urban For Urban Green. 2015;14:817–25. https://doi.org/10.1016/j.ufug.2015.09.012.
9. Arnoldi M, Shackleton CM. The potential influence of commercial plant nurseries in shaping the urban forest in South Africa. Urban For Urban Green. 2021;64:127254. https://doi.org/10.1016/j.ufug.2021.127254.
10. Fitchett JM, Raik K. Phenological advance of blossoming over the past century in one of the world's largest urban forests, Gauteng City-Region, South Africa. Urban For Urban Green. 2021;63:127238. https://doi.org/10.1016/j.ufug.2021.127238.
11. du Toit MJ, Cilliers SS, Dallimer M, Goddard M, Guenat S, Cornelius SF. Urban green infrastructure and ecosystem services in sub-Saharan Africa. Landsc Urb Plan. 2018;180:249–61. https://doi.org/10.1016/j.landurbplan.2018.06.001.
12. Pauleit S, Liu L, Ahern J, Kazmierczak A. Multifunctional green infrastructure planning to promote ecological services in the city. In: Niemelä J, editor. Handbook of urban ecology. Oxford University Press: Oxford; 2011. p. 272–85.
13. Dunnett N, Clayden A. Rain gardens. In: Managing water sustainably in the garden and designed landscape. Timber Press, USA; 2007.
14. Andersson E, Langemeyer J, Borgström S, McPhearson T, Haase D, Kronenberg J, Barton DN, Davis M, Naumann S, Röschel L, Baró F. Enabling green and blue infrastructure to improve contributions to human well-being and equity in urban systems. Bioscience. 2019;69:566–74. https://doi.org/10.1093/biosci/biz058.
15. Hansen R, Rall E, Chapman E, Rolf W, Pauleit S. Urban green infrastructure planning: a guide for practitioners. GREEN SURGE Deliverable. 2017. http://greensurge.eu/working-packages/wp5. Accessed 22 Mar 2020.
16. McDonnell MJ. The history of urban ecology: an ecologlist's perspective. In: Niemelä J, Breuste JH, Guntenspergen G, McIntyre NE, Elmqvist T, James P, editors. Urban ecology: patterns, processes, and applications. New York: Oxford University Press; 2011. p. 5–13.
17. Childers DL, Cadenasso ML, Grove JM, Marshall V, McGrath B, Pickett ST. An ecology for cities: a transformational nexus of design and ecology to advance climate change resilience and urban sustainability. Sustain. 2021;7:3774–91. https://doi.org/10.3390/su7043774.
18. Mc Phearson T, Pickett STA, Grimm N, Niemelä J, Alberti M, Elmqvist T, Weber C, Breuste J, Haase D, Qureshi S. Advancing urban ecology towards a science of cities. Bioscience. 2016;66:198–212. https://doi.org/10.1093/biosci/biw002.
19. Wu J. Urban ecology and sustainability: the state-of-the-science and future directions. Landsc Urban Plann. 2014;125:209–21. https://doi.org/10.1016/j.landurbplan.2014.01.018.
20. Shackleton CM, Cilliers SS, du Toit MJ, Davoren E. The need for an urban ecology of the Global South. Urban ecology in the Global South. In: Shackleton CM, Cilliers SS, Davoren E, du Toit MJ, editors. Urban Ecology in the Global South. Cities and Nature. Springer, Cham; 2021. pp. 1–26. https://doi.org/10.1007/978-3-030-67650-6_17.
21. du Toit MJ, Shackleton CM, Cilliers SS, Davoren E. Advancing Urban Ecology in the Global South: Emerging Themes and Future Research Directions. In: Shackleton CM, Cilliers SS, Davoren E, du Toit MJ, editors. Urban Ecology in the Global South. Cities and Nature. Springer, Cham. 2021. https://doi.org/10.1007/978-3-030-67650-6_17.
22. United Nations 2015. Transforming our world: the 2030 Agenda for Sustainable Development. https://sdgs.un.org/2030agenda. Accessed 4 Apr 2023.
23. Millenium Ecosystem Assessment. Ecosystems and human well-being: a framework for assessment. Washington DC: Island Press; 2003.
24. Millenium Ecosystem Assessment. Millenium ecosystem assessment synthesis report. Washington DC: Island Press; 2005.
25. TEEB 2011. The economics of ecosystems and biodiversity: TEEB Manual for Cities—Ecosystem services in urban management. Available at: www.teebweb.org. Access 01 Mar 2023.
26. Shackleton CM. Provisioning services in Global South cities. In: Shackleton CM, Cilliers SS, Davoren E, du Toit MJ, editors. Urban ecology in the Global South. Springer: Cham; 2021. p. 203–26.
27. Escobedo FJ. Understanding urban regulating ecosystem services in the Global South. In: Shackleton CM, Cilliers SS, Davoren E, du Toit MJ, editors. Urban ecology in the Global South. Springer: Cham; 2021. p. 227–44.
28. Dobbs C, Vasquez A, Olave P, Olave M. Cultural urban ecosystem services. In: Shackleton CM, Cilliers SS, Davoren E, du Toit MJ, editors. Urban ecology in the Global South. Springer: Cham; 2021. p. 245–64.
29. Lyytimäki J, Sipilä M. Hopping on one leg—the challenge of ecosystem disservices for urban green management. Urban For Urban Green. 2009;8:309–15. https://doi.org/10.1016/j.ufug.2009.09.003.
30. von Döhren P, Haase D. Ecosystem disservices research: a review of the state of the art with a focus on cities. Ecol Indic. 2015;52:490–7. https://doi.org/10.1016/j.ecolind.2014.12.027.
31. Davoren E, Shackleton CM. Urban ecosystem disservices in the Global South. In: Shackleton CM, Cilliers SS, Davoren E, du Toit MJ, editors. Urban ecology in the Global South. Springer: Cham; 2021. p. 265–92.
32. Speak A, Escobedo JF, Russo A, Zerbe S. An ecosystem service-disservice ratio: using composite indicators to assess the net benefits of urban trees. Ecol Indic. 2018;95:544–53. https://doi.org/10.1016/j.ecolind.2018.07.048.

33. Nowak DJ, Ogren LT. Variations in urban forest allergy potential among cities and land uses. Urban For Urban Greening. 2021;63:127224. https://doi.org/10.1016/j.ufug.2021.127224.
34. Averbeck M, Gebhardt C, Emmrich F, et al. Immunologic principles of allergic disease. J Dtsch Dermatol Ges. 2007;5:1015–28. https://doi.org/10.1111/j.1610-0387.2007.06538.x.
35. Pawankar R, Canonica, GW, Holgate ST, Lockey RF, Blaiss M. editors. World Allergy Organisation (WAO). White book on allergy. World Allergy Organisation, Wisconsin; 2013.
36. Alcock I, White M, Cherrie M, Wheeler B, Taylor J, McInnes R, Kampe EOI, Vardoulakis S, Sarran C, Soyiri I, Fleming L. Land cover and air pollution are associated with asthma hospitalisations: a cross-sectional study. Environ Int. 2017;109:29–41. https://doi.org/10.1016/j.envint.2017.08.009.
37. Aerts R, Bruffaerts N, Somers B, Demoury C, Plusquin M, Nawrot TS, Hendrickx M. Tree pollen allergy risks and changes across scenarios in urban green spaces in Brussels, Belgium. Landsc Urban Plan. 2021;207:104001. https://doi.org/10.1016/j.landurbplan.2020.104001.
38. Parmes E, Pesce G, Sabel CE, Baldacci S, Bono R, Brescianini S, D'Ippolito C, Hanke W, Milena H, Liedes H, Maio S, Marchetti P, Marcon A, Medda E, Molinier M, Panunzi S, JuhaPärkkä PK, Prudhomme J, Ricci P, Tratnik JS, Squillacioti G, Stazi MA, Cara Maesano N, Annesi-Maesano I. Influence of residential land cover on childhood allergic and respiratory symptoms and diseases: evidence from 9 European cohorts. Environ Res. 2020;183:108953. https://doi.org/10.1016/j.envres.2019.108953.
39. Tischer C, Gascon M, Fernández-Somoano A, Tardón A, Materola AL, Ibarluzea J, Ferrero A, Estarlich M, Cirach M, Vrijheid M, Fuertes E, Dalmau-Bueno A, Nieuwenhuijsen MJ, Antó JM, Sunyer J, Dadvand P. Urban green and grey space in relation to respiratory health in children. Eur Respir J. 2017;49:1502112. https://doi.org/10.1183/13993003.02112-2015.
40. Singh AB, Mathur C. An aerobiological perspective in allergy and asthma. Asia Pac Allergy. 2012;2(3):210–22. https://doi.org/10.5415/apallergy.2012.2.3.210.
41. Zemmer F, Ozkaragoz F. Aerobiology in the Clinics of Pollen Allergy. In Allergic Disease-New Developments in Diagnosis and Therapy. IntechOpen. 2022. https://doi.org/10.5772/intechopen.107311.
42. Agashe SN. Aerobiology for the clinician: basic and applied aspects, pollen sources, pollen calendars. In: Textbook of allergy for the clinician. CRC Press. 2nd Edn eBook. 2021. pp. 49–68.
43. Maya-Manzano JM, Tormo-Molina R, Fernández-Rodríguez S, Silva-Palacios I, Gonzalo-Garijo Á. Distribution of ornamental urban trees and their influence on airborne pollen in the SW of Iberian Peninsula. Landsc Urban Plan. 2017;157:434–46. https://doi.org/10.1016/j.landurbplan.2016.08.011.
44. Rachel NMC, Hemming D, Burgess P, Lyndsay D, Osborne NJ, Skjøth AC, Thomas S, Vardoulakis S. Mapping allergenic pollen vegetation in UK to study environmental exposure and human health. Sci Total Environ. 2017;599–600:483–99. https://doi.org/10.1016/j.scitotenv.2017.04.136.
45. Pecero-Casimiro R, Fernández-Rodríguez S, Tormo-Molina R, Monroy-Colín A, Silva-Palacios I, Cortés-Pérez JP, Gonzalo-Garijo Á, Maya-Manzano JM. Urban aerobiological risk mapping of ornamental trees using a new index based on LiDAR and Kriging: a case study of plane trees. Sci Total Environ. 2019;693:133576. https://doi.org/10.1016/j.scitotenv.2019.07.382.
46. Fernández-Alvarado JF, Fernández-Rodríguez S. Environmental risk assessment based on the allergenicity of urban green infrastructure: case study of an urban park. Sustain Cities Soc. 2023;94:2210–6707. https://doi.org/10.1016/j.scs.2023.104532.
47. Cariñanos P, Casares-Porcel M, Quesada-Rubio JM. Estimating the allergenic potential of urban green spaces, a case-study in Granada Spain. Landsc Urban Plan. 2014;123:134–44. https://doi.org/10.1016/j.landurbplan.2013.12.009.
48. Velasco-Jiménez MJ, Alcázar P, Cariñanos P, Galán C. Allergenicity of the urban green areas in the city of Córdoba (Spain). Urban For Urban Green. 2020;49:126600. https://doi.org/10.1016/j.ufug.2020.126600.
49. Cariñanos P, Casares-Porcel M. Urban green zones and related pollen allergy: a review. Some guidelines for designing spaces with low allergy impact. Landsc Urban Plan. 2011;101(3):205–14. https://doi.org/10.1016/j.landurbplan.2011.03.006.
50. Dujardin S, Stas M, Van Eupen C, Aerts R, Hendrickx M, Delcloo AW, Duchêne F, Hamdi R, Nawrot TS, Van Nieuwenhuyse A, Aerts JM, Orshoven JV, Somers B, Linard C, Dendoncker N. Mapping abundance distributions of allergenic tree species in urbanized landscapes: a nation-wide study for Belgium using forest inventory and citizen science data. Landsc Urban Plan. 2022;218:104286. https://doi.org/10.1016/j.landurbplan.2021.104286.
51. Magyar D, Páldy A, Szigeti T, Orlóci L. A regulation-oriented approach for allergenicity categorization of plants. Urban For Urban Green. 2022;70:127530. https://doi.org/10.1016/j.ufug.2022.127530.
52. Cimi PV, Campbell EE. Investigation of the plant species diversity, density, abundance and distribution in Grahamstown, South Africa. J Res For Wildl Environ. 2017;9:28–35.
53. Bux Q, Anderson P, O'Farrell PJ. Understanding the local biodiversity and open space strategies in two South African cities. Ecol Soc. 2021;26(3):4. https://doi.org/10.5751/ES-12498-260304.
54. Ordman D. Pollinosis in South Africa: a study of seasonal hay-fever. SAMJ. 1947;21(2):38–48.
55. Potter PC. Common indoor and outdoor aero-allergens in South Africa—identification of the allergen that is responsible for symptoms is the key to the management of the allergic patient. CME. 2010;28(9):426–32.
56. Berman D. Pollinosis and the aerobiology of Southern Africa. Allergy Clin Immunol Int World Allergy Organiz J. 2000;12(6):0258–61. https://doi.org/10.1027/0838-1925.12.6.258.
57. Potter P. An overview of the indigenous and alien allergens of Southern Africa. Current Allergy Clin Immunol. 2013;26(4):182–9.
58. Hawarden D, Baker S, Toerien A, Prescott R, Leaver R, Potter PC, Derman W, Katelaris CH. Aero-allergy in South African Olympic Athletes. S Afr Med J. 2002;92(5):355–6.
59. Sousa-Silva R, Smargiassi A, Kneeshaw D, Dupras J, Zinszer K, Paquette A. Strong variations in urban allergenicity riskscapes due to poor knowledge of tree pollen allergenic potential. Sci Rep. 2021;11:10196. https://doi.org/10.1038/s41598-021-89353-7.
60. Yin RK. Case study research and applications: design and methods. 6th ed. Thousand Oaks, California: Sage; 2018.
61. Mac cullum D, Babb C, Curtis C. Doing research in urban and regional planning: lessons in practical methods. New York: Routledge; 2019. https://doi.org/10.4324/9781315818894.
62. Holmes PM, Rebelo AG, Dorse C, Wood J. Can Cape Town's unique biodiversity be saved? Balancing conservation imperatives and development needs. Ecol Soc. 2012;17(2):28. https://doi.org/10.5751/ES-04552-170228.

63. Mucina L, Rutherford MC. The Vegetation of South Africa, Lesotho and Swaziland; Strelitzia 19. South African Biodiversity Institute, Pretoria. 2006, 807pp. ISBN-13: 978-1-919976-21-1.
64. Rebelo AG, Holmes PM, Dorse C, Wood J. Impacts of urbanization in a biodiversity hotspot: conservation challenges in Metropolitan Cape Town. S Afr J Bot. 2011;77:20–35. https://doi.org/10.1016/j.sajb.2010.04.006.
65. Pooley S. The long and entangled history of humans and invasive introduced plants on South Africa's Cape Peninsula. In: Histories of Bioinvasions in the Mediterranean. Cham: Springer International Publishing; 2018. p. 219–51.
66. Berman D. Variations in pollen and fungal air spora: an analysis of 30 years of monitoring for the clinical assessment of patients in the Western Cape [PhD thesis]. Cape Town: University of Cape Town; 2018.
67. Schäffler A, Swilling M. Valuing green infrastructure in an urban environment under pressure—the Johannesburg case. Ecol Econ. 2013;86:246–57. https://doi.org/10.1016/j.ecolecon.2012.05.008.
68. Symes CT, Roller K, Howes C, Lockwood G, van Rensburg BJ. Grassland to urban forest in 150 years: avifaunal response in an African metropolis. In: Ecology and conservation of birds in urban environments. Cham: Springer; 2017. p. 309–41.
69. Van Staden EM, Stoffberg GH. The Greening Soweto tree-planting project in South Africa—eliminating the "green divide" legacy of apartheid. Urban For and Urban Green. 2021;65:127371. https://doi.org/10.1016/j.ufug.2021.127371.
70. Glen H, van Wyk, B. 2016. Guide to Trees Introduced into Southern Africa. Struik Nature, Cape. ISBN 9781775841258.
71. Ajikah L, Neumann FH, Berman D, Peter J. Aerobiology in South Africa: a new hope! S Afr J Sci. 2020; 116(8). https://doi.org/10.17159/sajs.2020/8112.
72. Churkina G, Grote R, Butler TM, Lawrence M. Natural selection? Picking the right trees for urban greening. Environ Sci Policy. 2015;47:12–7. https://doi.org/10.1016/j.envsci.2014.10.014.
73. Galán C, Smith M, Thibaudon M, Frenguelli G, Oteros J, Gehrig R, Berger U, Clot B, Brandao R. Pollen monitoring: minimum requirements and reproducibility of analysis. Aerobiologia. 2014;30:385–95.
74. Trigo MM, Jato V, Fernandez D, Galán C. Atlas Aeropalinologico de España. Junta de Castilla y León. Consejería de Educación y Cultura, 2008.
75. De Linares C, Plaza MP, Valle AM, Alcázar P, Díaz de la Guardia C, Galán C. Airborne cupressaceae pollen and its major allergen, Cup a 1, in urban green areas of Southern Iberian Peninsula. Forests. 2021;12:254. https://doi.org/10.3390/f12020254.
76. Vrinceanu D, Berghi O, Cergan R, Dumitru M, Ciuluvica R, Giurcaneanu C, Neagos A. Urban allergy review: allergic rhinitis and asthma with plane tree sensitization (review). Exp Ther Med. 2021; 21(3). https://doi.org/10.3892/etm.2021.9706.
77. Fernández-González M, Ribeiro H, Pereira JRS, Rodríguez-Rajo FJ, Abreu I. Assessment between platanus pollen and Pla a 1 allergen in two cities of North-Western Iberian Peninsula. Aerobiologia. 2019;35:463–75. https://doi.org/10.1007/s10453-019-09576-0.
78. Brito FF, Gimeno MP, Carnés J, Martín R, Fernández-Caldas E, Lara P, López-Fidalgo J, Guerra F. Olea europaea pollen counts and aeroallergen levels predict clinical symptoms in patients allergic to olive pollen. Ann Allergy Asthma Immunol. 2011;106(2):146–52. https://doi.org/10.1016/j.anai.2010.11.003.
79. Marcos C, Rodriguez FJ, Luna I, Jato V, González R. Pinus pollen aerobiology and clinical sensitization in northwest Spain. Ann Allergy Asthma Immunol. 2011;87:39–42. https://doi.org/10.1016/S1081-1206(10)62320-4.
80. Prados M, Aragon R, Cranco MI, Martínez A, Martínez J. Assessment of sensitization to holm oak (Quercus ilex) pollen in the Mérida area (Spain). Allergy. 1995;50(5):456–9. https://doi.org/10.1111/j.1398-9995.1995.tb01178.x.
81. Biedermann T, Winther L, Till SJ, Panzner P, Knulst A, Valovirta E. Birch pollen allergy in Europe. Allergy. 2019;74(7):1237–48. https://doi.org/10.1111/all.13758.
82. Imhof K, Probst E, Seifert B, Regenass S, Grendelmeier S. Ash pollen allergy: reliable detection of sensitization on the basis of IgE to Ole e 1. Allergo J Int. 2014;23:78–83. https://doi.org/10.1007/s40629-014-0010-8.
83. Retief F, Bond A, Pope J, Morrison-Saunders A, King N. Global megatrends and their implications for environmental assessment practice. Environ Impact Assess Rev. 2016;61:52–60. https://doi.org/10.1016/j.eiar.2016.07.002.
84. Campbell DS. The Planner's triangle revisited: sustainability and the evolution of a planning ideal that can't stand still. J American Plan Assoc. 2016;82(4):388–97. https://doi.org/10.1080/01944363.2016.1214080.
85. Brundtland G. Report of the World Commission on environment and development: our common future. Oxford: Oxford University Press; 1987.
86. Pasquini L, Enqvist JP. Green Infrastructure in South African Cities. Report for Cities Support Programme, African Centre for Cities, May 2019. Available online: https://www.africancentreforcities.net/wp-content/uploads/2020/01/CSP_green-infrastructure_paper_LPasquini_JEnqvist_11.pdf. Date of Access: 10 July 2023.
87. National Environmental Management Act 107 of 1998. https://www.gov.za/documents/national-environmental-management-act. Date of Access: 10 July 2023.
88. Retief F, Rossouw N, Jones C, Jay S. Status of Strategic Environmental Assessment (SEA) Practice in South Africa. In Proceedings of the annual international conference of the International Association for Impact Assessment (IAIA). 2004; 24–30.
89. Spatial Planning and Land Use Management Act 16 of 2013. www.gov.za/sites/default/files/gcis_document/201409/367305-8act16of20.pdf. Access 01 Apr 2022.
90. Farthing SM. Research design in urban planning: a student's guide. London: SAGE; 2016. https://doi.org/10.4135/9781473921375.
91. Laubscher N, Hoffman L, Drewes E. Nysschen J. SPLUMA a Practical guide. 1st edn. Johannesburg: LexisNexis; 2016.
92. United Nations. Global indicator framework for the Sustainable Development Goals and targets of the 2030 Agenda for Sustainable Development. 2017. https://unstats.un.org/sdgs/indicators/indicators-list/ Accessed 9 May2023.
93. Thorne S. Interpretive description: qualitative research for applied practice. New York: Routledge; 2016. https://doi.org/10.4324/9781315545196.
94. Geneletti D, Cortinovis C, Zardo L, Adem Esmail B. Planning for ecosystem services in cities. Springer Briefs in Environmental Science, Springer Nature, Switzerland; 2020.
95. Cilliers EJ. Reflecting on green infrastructure and spatial planning in Africa: the complexities, perceptions, and way forward. Sustainability. 2019;11(2):455. https://doi.org/10.3390/su11020455.

96. CSIR (South African Council for Scientific and Industrial Research). The neighbourhood planning and design guide: creating sustainable human settlements. Part 2. Pretoria: CSIR Building and Construction Technology; 2019.
97. Girling C, Kellett R. Skinny streets and green neighbourhoods: design for environment and community. Covelo, London, Washington: Island Press; 2005.
98. Kahn F. Public participation and environmental decisionmaking in South Africa—the Frankdale environmental health project. S Afr Geogr J. 1998;80(2):73–80. https://doi.org/10.1080/03736245.1998.9713648.
99. Cilliers EJ, Cilliers SS. Planning for green infrastructure: options for South African cities. 2016. https://www.sacities.net/publication/planning-for-green-infrastructure-options-for-south-african-cities/. Access 01 Apr 2023.
100. Watson V. Co-production and collaboration in planning—the difference. Plann Theory Pract. 2014;15:62–76. https://doi.org/10.1080/14649357.2013.866266.
101. RICS (Royal Institution of Chartered Surveyors). Governance of participatory planning for resilient communities. London: RICS Research Trust, 2021.
102. CARA. Conservation of Agricultural Resources ACT 43. Republic of South Africa. 1983. https://www.gov.za/sites/default/files/gcis_document/201504/act-43-1983.pdf. Access 23 Mar 2023.
103. CABI. Morus nigra in: Invasive Species Compendium. 2018. http://www.cabi.org/isc. Access 30 Mar 2023.
104. Papia F, Incorvaia C, Genovese L, Gangemi S, Minciullo PL. Allergic reactions to genus Morus plants: a review. Clin Mol Allergy. 2020;18:1–5. https://doi.org/10.1186/s12948-020-00116-7.
105. Dzikiti S, Schachtschneider K, Naiken V, Gush M, Le Maitre DC. Comparison of water use by alien invasive pine trees growing in riparian and non-riparian zones in the Western Cape. S Afr For Ecol Manage. 2013;293:92–102. https://doi.org/10.1016/j.foreco.2013.01.003.
106. Dzikiti S, Gush MB, LeMaitre DC, Maherry A, Ramoelo A, Jovanovic NZ. Quantifying potential water savings from clearing invasive alien Eucalyptus camaldulensis using in situ and high resolution remote sensing data in the Berg River Catchment, Western Cape, South Africa. For Ecol Manage J. 2016;361:69–80. https://doi.org/10.1016/j.foreco.2015.11.009.
107. Gastaminza G, Lombardero M, Bernaola G, Antepara I, Muñoz D, Gamboa PM, Audicana MT, Marcos C, Ansotegui IJ. Allergenicity and cross-reactivity of pine pollen. Clin Exp Allergy. 2009;39:1438–46. https://doi.org/10.1111/j.1365-2222.2009.03308.x.
108. National Environmental Management: Biodiversity ACT, 2004 (ACT NO. 10 OF 2004). Alien and Invasive Species Lists, 2020? https://www.dffe.gov.za/sites/default/files/gazetted_notices/nemba_invasivespecieslist_g43726gon1003.pdf. Access 08 July 2023.
109. Gibbs JEM. Eucalyptus pollen allergy and asthma in children: a cross-sectional study in South-East Queensland, Australia. PLoS ONE. 2015;10(5):e0126506. https://doi.org/10.1371/journal.pone.0126506.
110. Gregorová B, Karel C, Holub V, Strnadová V. Effects of climatic factors and air pollution on damage of London plane (*Platanus hispanica* Mill.). Hort Sci. 2010;37:109–17. https://doi.org/10.17221/47/2009-HORTSCI.
111. Abutaleb K, Freddy MM, Nkongolo NW, Newete S. Estimating urban greenness index using remote sensing data: a case study of an affluent vs poor suburbs in the city of Johannesburg. Egypt J Remote Sens Space Sci. 2021;24(3):343–51. https://doi.org/10.1016/j.ejrs.2020.07.002.
112. Derman D, Hawarden D, Schwellnus MP. Allergic rhinoconjunctivitis in athletes-mechanisms of impaired performance and implications for management. Curr Allergy Clin Immunol. 2010;23:2.
113. Alcázar P, García-Mozo H, Trigo MM, Ruiz L, González-Minero FJ, Hidalgo P, Díaz de la Guardia C, Galán C. Platanus pollen season in Andalusia (southern Spain): trends and modeling. J Environ Monit. 2011;13(9):2502–10. https://doi.org/10.1039/C1EM10355E.
114. Nowak M, Szymańska A, Grewling Ł. Allergic risk zones of plane tree pollen (Platanus sp.) in Poznan. Adv Dermatol Allergol/Postępy Dermatolo i Alergolo. 2012;29(3):156–60.
115. Lara B, Rojo J, Fernández-González F, González-García-Saavedra A, Serrano-Bravo MD, Pérez-Badia R. Impact of plane tree abundance on temporal and spatial variations in pollen concentration. Forests. 2020;11:817. https://doi.org/10.3390/f11080817.
116. Álvarez-López S, Fernández-González M, Sánchez Espinosa KC, Amigo R, Rodríguez-Rajo FJ. London plane tree pollen and Pla A 1 allergen concentrations assessment in urban environments. Forests. 2022;13:2089. https://doi.org/10.3390/f13122089.
117. Gabarra E, Belmonte J, Canela M. Aerobiological behaviour of *Platanus* L. pollen in Catalonia (North-East Spain). Aerobiologia. 2002;18:185–93. https://doi.org/10.1023/A:1021370724043.
118. Alcázar P, Cariñanos P, De Castro C, Guerra F, Moreno C, Dominguez-Vilches E, Galán C. Airborne plane-tree (*Platanus hispanica*) pollen distribution in the city of Córdoba, southwestern Spain, and possible implications on pollen allergy. J Investig Allergol Clin Immunol. 2004;14:238–43.
119. Kerfoot O. Distribution of the Coniferae: the Cupressaceae in Africa. Nature. 1966;212(5065):961.
120. Farjon A, Filer D. An atlas of the world's conifers: an analysis of their distribution, biogeography, diversity and conservation status. Boston: Brill; 2013.
121. Ordman D. Cypress pollinOSiS in South Africa. A study of seasonal hay-fever and allergic conjunctivitis occurring in the winter spring period. S Afr Med. 1945;19:142–53.
122. Bar-Dayan Y, Keynan N, Waisel Y, Pick AL, Tamir R. Podocarpus gracilor and Callitris verrucosa, newly identified allergens that cross-react with *Cupressus sempervirens*. Clin Exp Allergy. 1995;25:456–60. https://doi.org/10.1111/j.1365-2222.1995.tb01077.x.
123. Gaertner M, Larson BM, Irlich UM, Holmes PM, Stafford L, Van Wilgen BW, Richardson DM. Managing invasive species in cities: a framework from Cape Town. South Africa Landsc Urban Plan. 2016;93:184–93. https://doi.org/10.1016/j.landurbplan.2016.03.010.
124. Bromilow C. Problem plants and Alien Weeds of Southern Africa. Pretoria: Briza Publications; 2018.
125. Siebert SJ, Struwig M, Knoetze L, Komape DM. *Celtis sinensis* Pers. (Ulmaceae) naturalised in northern South Africa and keys to distinguish between Celtis species commonly cultivated in urban environments. Botahlia. 2018;48(1):a2288. https://doi.org/10.4102/abc.v48l.