Review article

THE INTERSECTION BETWEEN AIR QUALITY AEROBIOLOGY AND ASTHMA IN SOUTH AFRICA – COULD GREEN SPACES HELP?

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ABSTRACT

Global and South African populations continue to increase exponentially, with large flows of persons into urban centres. Urban air quality and bioaerosol are therefore becoming an increasingly important consideration in the face of a growing burden of allergic respiratory diseases. More than 20% of South Africans have asthma, with morbidity being disproportionately high compared to high-income countries (HICs). Air pollutants (particularly particulate matter and ozone), pollen and fungal spores are known triggers and exacerbating factors in asthma and, alarmingly, the levels of air pollutants remain high in hotspot areas despite robust air-quality legislation in South Africa. The concern is that genetically and environmentally vulnerable children in low- and middle-income countries (LMICs) such as South Africa will have asthma triggered and exacerbated disproportionately by poor air quality. Urban green areas are increasingly being recognised by many stakeholders as important possible mitigation tools. However, multiple factors must be considered for having an optimal green space design. In this review, we bring together experts across the fields of health, air quality and aerobiology to outline the intersection between asthma and air quality and/or aerobiology in South Africa. We highlight the importance of careful multidisciplinary green space design as a possible healing tonic. We conclude that detailed studies combining air quality, pollen dispersal and health issues are needed to derive more precise exposure–response functions of the green spaces in South Africa and other LMICs.

Keywords: air quality, green spaces, respiratory health, aerosols

INTRODUCTION

By 2050, 1.26 billion people will be living in cities in the Global South and across Africa, which is triple the 400 million urban dwellers on the continent today.[1] Furthermore, urban areas are growing significantly in different parts of Africa and also in South Africa. In general, urban green infrastructures are considered to be the interconnected set of natural and man-made ecological systems, green areas and other landscape features. These infrastructures include alien and indigenous trees, wetlands, parks, green open spaces and original grassland and woodlands, in addition to street-level design or private residential spaces that incorporate vegetation. However, the ability of green infrastructure to compete with conventional alternatives is sometimes undervalued. In this article, we provide evidence of linking urban spaces to respiratory health issues such as asthma through a qualitative analysis of the urban environmental air quality.

EPIDEMIOLOGY OF ASTHMA IN SOUTH AFRICA

Characterised by a history of variable respiratory symptoms and demonstration of variable expiratory airflow limitation and reversibility, asthma is a non-communicable disease affecting people of all ages globally.[2] In Africa, asthma is the leading non-communicable disease in children and adolescents. Global studies of the prevalence of asthma show an increase in childhood and adolescent prevalence, particularly in low- and middle-income countries (LMICs), including South Africa, where the most recent reported prevalence is 21.7%.[3] In South Africa, asthma mortality is also high, with an estimated 18.5 deaths per

100 000 asthma cases and up to a 100-fold variation in age-adjusted rates when compared to countries with low mortality rates, for example, the Netherlands.[2]

Risk factors for asthma and severe disease are multifactorial and include socio-demographics, smoking, pet exposure, pollution exposure, informal housing and poor access to care or effective therapy.[2] Furthermore, in South African adolescents, environmental exposures, including outdoor air pollution, have been associated with both an increasing prevalence of asthma and severe disease.[4]

KNOWN KEY POLLUTANTS DRIVING ASTHMA DEVELOPMENT OR EXACERBATIONS IN LMICs

With more than 90% of the world's population breathing unclean air, air pollution has been considered a global health emergency, with health consequences across the life course.[5] While air quality has improved in many high-income countries (HICs), it continues to deteriorate in many LMICs.[6]

Air pollution is the contamination of the indoor or outdoor environment by any chemical, physical or biological agent that modifies the natural characteristics of the atmosphere.[7] The combustion of fossil fuels is the main contributor to air pollution, including indoor (eg, household activities and the use of unclean energy) and outdoor (eg, industry-, agriculture- and traffic-related) sources of combustion.[6] Natural sources such as desert dust and biomass burning (ie, forest fires and wildfires) also have an impact on many parts of Africa. While there are numerous air pollutants, the major health-damaging air pollutants include particulate matter ($PM_{2.5}$ and PM_{10}), ozone (O_3), nitrogen dioxide (NO_2), sulphur dioxide (SO_2), carbon monoxide (CO) and volatile organic compounds (VOCs).[6,8] Their ambient (ie, outdoor) levels are regulated by many countries due to the impact they have on health and they are often referred to as 'criteria pollutants'. The World Health Organization (WHO) has recently updated its recommended guidelines for many of these pollutants.[9]

In South Africa, the ambient levels of pollutants are regulated through the National Ambient Air Quality Standards (NAAQS), which set the threshold levels for these pollutants. Air pollution levels are monitored in ~130 sites across South Africa. These are focused mainly in densely populated areas (urban and peri-urban), industrial areas and near large highways (see https://saaqis.environment.gov.za).[10,11,12] In general, the NAAQS are exceeded at many of these sites, which indicates that human health is at risk from poor air quality. These excessive levels are often driven by PM and O_3, though extreme SO_2 and NO_2 levels are in evidence closer to large sources. Pollution levels are often highest in low-income settlements, where the most vulnerable populations are then exposed to the highest pollution levels.[10] Despite having some of the most comprehensive air-quality legislation in Africa, the pollutant levels in South Africa have generally either not been improving at all or have been improving too slowly.[13]

Air pollution has been implicated in both the development of asthma and asthma exacerbations.[14] With increasing evidence that lung-health trajectories are set in early life,[15] growing evidence supports the role of prenatal and early-life exposure to air pollution in the development of asthma.[14,16] A large birth cohort study of close to 200 000 participants showed both pre-natal and post-natal exposure to air pollution and especially $PM_{2.5}$ was associated with the development of asthma later.[17] A South African birth cohort study also showed a gene–environment interaction, with infants with a genetic predisposition to asthma, there was an increased susceptibility to the adverse effects of prenatal exposure to indoor air pollution (PM_{10}) with the subsequent impact on lung function and longitudinal lung health.[18] An American Thoracic Society (ATS) report also concludes that sufficient evidence links long-term exposure to air pollution and the development of childhood asthma.[19]

The mechanisms by which key pollutants induce asthma or exacerbations are complex and probably multifactorial. For PM, it is thought that it is caused by both oxidative stress and enhanced airway inflammation which interacts with both innate and adaptive immune systems and an imbalance in Th1 and Th2 responses, which are clearly implicated in the development of allergic diseases.[14,20] NO_2 is a respiratory irritant and is thought to play a role in the enhanced sensitisation of inhaled allergens. Similarly, SO_2 is a highly irritating pollutant, especially for those prone to allergies and asthma.[10]

While there are limited African studies that assess the impact of air pollution exposure through direct measurements of health outcomes,[16] those that have measured air pollution and the impact it has on asthma have shown associations between NO_2 and $PM_{2.5}$ exposure on asthma exacerbations[17] and airway inflammation measured by means of lung-function testing.[18] Furthermore, CO exposure was associated with spirometric abnormalities in school-aged children.[19]

AIR POLLUTION, CLIMATE CHANGE AND ALLERGIC POLLENS – IMPLICATIONS FOR ASTHMA

There is another link between air pollution, climate change and biodiversity loss, the interplay of these factors compounding the effects on health.[21] Climate change, air pollution and allergenic pollens are closely interrelated and may have an impact on both the development and exacerbation of allergic diseases.[22] Climate change is driven primarily by emissions of CO_2 and enhanced by emissions of other greenhouse gases (GHG) and short-lived climate-forcing pollutants (SCLPs). Contributors to the rising GHG levels include burning fossil fuel, livestock farming, industrial activity and deforestation. Meteorology and climate also have an impact on air pollution levels. For example, higher temperatures can accelerate the production of O_3 from the precursors – VOCs, CO and nitrogen oxides. Concentrations of PM, polycyclic aromatic hydrocarbons (PAHs) and black carbon may rise in places due to changes in the temperature, the frequency of precipitation and forest fires, exacerbated by climate change. Changes in climate will also have an impact on the production of pollen. Annual cumulative increases in temperature over time have been associated with a significant increase in the pollen load and pollen season duration in most of the locations analysed.[22]

Pollutants are able to increase pollen production and modify

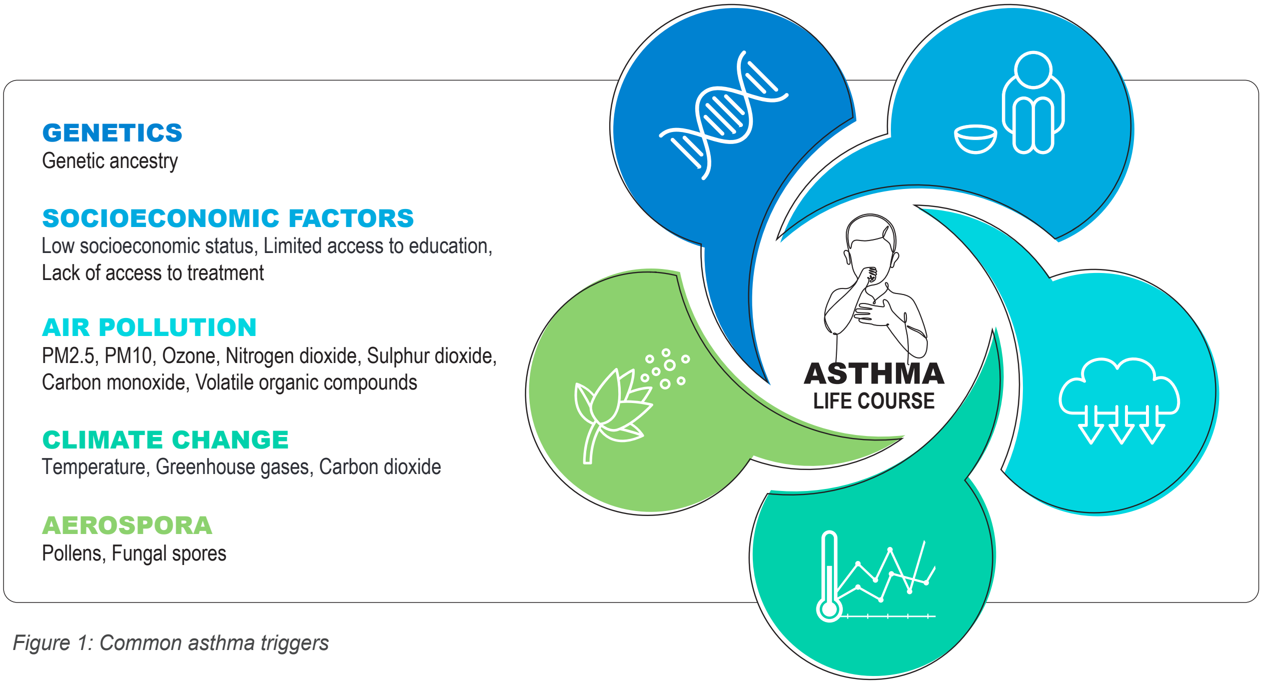

Figure 1: Common asthma triggers

pollen morphology and content and its chemotactic and immunomodulatory properties, altering their immunogenicity. Studies have shown that pollen grains can absorb heavy metals, nitrates and that sulphur oxidants such as O_3 and NO_2 can have an impact on the allergenicity of pollen.[23] In addition, particles can agglomerate on the surface of pollen grains. Pollen–particle interaction may modulate the allergen release and the absorption of pollen proteins to airborne particles, finally contributing to the increase in pollen allergies and asthma in highly polluted areas.[24]

The interplay between climatic factors, air pollution and allergic diseases is being studied increasingly. A large Chinese study aimed at quantifying the relative impact of meteorological factors and air pollutants on childhood allergic diseases found the prevalence of allergic rhinitis (AR) and asthma to be inversely associated with the daily mean temperature and positively associated with the daily air pressure, NO_2 and O_3. Whereas both climatic factors and air pollution played a role, the number of allergic diseases attributable to an interquartile range (IQR) change in meteorological factors also appeared to be greater than those attributable to an IQR change in air pollutants.[25]

The complex interplay of air pollution, climate change and aeroallergens on asthma causation and exacerbations requires novel approaches to be pursued to mitigate these effects (Figure 1). This is especially the case in settings such as South Africa, where communities live in diverse environments and face many socio-economic challenges.[26,27] The role of green spaces in mitigating these effects may be important.

AEROBIOLOGY IN SOUTH AFRICA AND SAPNET

Some 20–30% of South Africans are subject to AR, with co-morbid asthma occurring in 20% of cases – highlighting sensitisation to pollen and house-dust mite (HDM) allergens as one of the main causes.[28]

In August 2019, a national pollen-monitoring project for South Africa was established under the direction of the Allergy and Immunology Unit at the University of Cape Town Lung Institute and the South African Pollen Monitoring Network (SAPNET). Prior to 2019, Cape Town was the only location where continuous aerobiological data were available. In 2019, seven-day volumetric Burkard spore traps were placed in seven major South African cities: Bloemfontein, Cape Town, Durban, Johannesburg, Kimberley, Port Elizabeth and Pretoria.[29] In 2023, additional spore traps in the cities of Calvinia, Ermelo and Potchefstroom were added to the network. These were aimed at obtaining information about the aerospora content (airborne pollen and fungal spore), the aerial concentrations and seasonal fluctuations. This new cycle of monitoring since 2019 covers the major population hotspots in South Africa and takes into consideration the growing and increasingly mobile population, climate and environmental changes and the expansion of aeroallergen-triggered allergic diseases. It helps pollen allergy sufferers to identify allergenic pollen levels by providing weekly reports on the website (see http://www.pollencount.co.za) and establishing regional pollen calendars.

GREEN SPACES IN SOUTH FRICA AND KEY CONSIDERATIONS FOR THE FUTURE

Green spaces are accessible open spaces in cities characterised by the presence of vegetation and they are considered to be of strategic importance to improving the quality of life (QoL).[30] These spaces include larger green spaces such as parks, gardens, forests and grassland or smaller private residential green spaces. Green spaces provide important ecosystem services that help with climate regulation and carbon sequestration, mitigate exposure to air pollution and enrich environmental biodiversity.[30–33] However, exposure to green spaces might have a negative impact on human health and well-being, defined as 'ecosystem disservices'.[34] For example, vegetation releases volatile organic compounds, which can react with NOx (a major traffic-based pollutant) to form O_3, exacerbating photochemical smog problems.[35] In addition, several plant species commonly used in urban green areas may pose health problems because they produce a huge amount of allergenic pollen that triggers the risk of asthma and allergic conditions for allergy sufferers.[36,37] Therefore, factors such as these should be assessed during the planning of green spaces.

In South Africa, in the context of urban green areas, Cilliers et al[38] reported the dominance of the occurrence of alien plant species in and around many South African cities. Therefore, results from aerobiological studies reflect the dominance of the pollen of trees such as cypresses, planes, pines, olives and oaks in the atmosphere of Cape Town and Johannesburg. The relevant tree species are among the several allergenic alien species that have been introduced from the northern hemisphere and are frequently used as ornamental trees in green spaces. The widespread use of specific alien plants, which produce a huge amount of pollen during the main pollen season, verifies the origin of pollinosis symptoms and their strong allergenicity, which is a significant concern in the environment of South Africa.[28,38] Therefore, it is clear that new approaches to the selection of appropriate tree species in South African green spaces should be considered. It would be valuable in the future for policymakers and urban planners to assess the implementation of concrete frameworks. These would take into account concerns about the pollution and allergenicity potential of urban spaces in South Africa and extending the use of indigenous tree species such as *Combretum erythrophyllum, Vachellia* and *Senegalia* spp, with low allergenic risk and low water demands.

FUTURE RESEARCH AND CALL TO CONTINUED ACTION

The continued population growth and urbanisation in LMICs means that urban indoor and outdoor pollutant exposures will increase in the coming decades. Carefully thought-out urban green spaces offer a real opportunity possibly to mitigate some of the many negatives of urban living. We think that bringing together physicians, aerobiologists, air-quality scientists and urban-planning actors may be a useful strategy to aid the optimal design for greenspace planning that will have maximal impact for the good of citizens. More studies related to the measurements of aerobiology and air quality are clearly needed to derive more precise exposure–response functions and determine the extent to which green spaces can mitigate these in South African and other LMICs.

Therefore, future research linked to air-quality and health issues needs to include technological innovations to monitor atmospheric composition more holistically (eg, biological, non-biological aerosols, trace gases), the including satellite remote sensing and automatic measurement of aerospora at high temporal resolutions. This could also create awareness and provide real-time updates for individual allergy sufferers and medical practitioners, as a result helping to ensure better diagnoses, treatment and development of new immunotherapies and medication. In addition, further research is needed to understand the linkages between pollen and air pollutants in a changing climate and their combined impact on health.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

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