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**Review Article**

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# Air pollution over southern Africa: Impact on the regional environment and public health implication

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**ABSTRACT**

Air pollution is one of the problems in many countries posing serious challenges the world is facing today. This is a global public health and environmental issue with multiple facets; it affects all aspects -human health, development, economy, land use and the environment. Although industrial revolution has been a great advancement in human life in terms of technology, societal development, creation and provision of multiple services, it has also resulted in the production of large quantities of unpleasant substances the atmosphere. It is no doubt that worldwide urbanization and industrialization are escalating at a high rate and reaching unprecedented proportions in many countries. In this article, we revisit the state of air pollution over southern Africa and assess the extent to which this can impact on the regional environment. The study is qualitative but also employs a blend of quantitative and qualitative evidence on the status of Air Quality (AQ) over southern Africa. The subcontinent is now a significant source of atmospheric and environmental pollution, having transformed from a rural to one of the more developing regions in the world. There is an influx of particulate and gas pollution from both local and remote sources. Prominent hotspots can be observed on satellites for Nitrogen Oxide ($NO_x$), Particulate Matter (PM) and Biomass Burning (BB) emissions around active areas. Depending on the nature of pollutant generation and amount, there are often differing levels of exposure to certain toxic elements, some of which are more harmful to human life. Increase in seasonal/annual pollution, in accordance with continued human development and industrial revolution can have a dire effect on the region, especially considering the growing African population. Comprehensive long-term AQ management programs are therefore needed to ensure that tolerable pollution levels are not exceeded, and that population exposure is taken care of.

## Review

Air pollution is one of the leading environmental and health risks across the world today [1, 2]. It is now evident that the world at large is burdened with a significant amount of air pollution that negatively impacts on Air Quality (AQ) with an escalating potential consequence on human health, ecosystems, visibility, weather modification and changes in tropospheric chemistry [3, 4]. For a long time, this has been regarded as a problem

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associated mostly with developed and developing countries only [3, 5]. The problem is more critical in big cities [6, 7] where there are high population densities (in some cases very congested) and industrial activity that put people's lives at risk to pollution exposure [8]. However, air pollution is a worldwide problem which also becomes a concern when there are no legislative frameworks to regulate emissions [9].

The problem has also emerged in most developing countries mainly due to anthropogenic activities that lead to increased pollutants quantities [10]. The driving factors include socio-economic development and lifestyle changes, urbanization, better transportation, population growth [11] as well as rural-urban migration. Exposure to pollution is typically worse where there are high emissions collocated with high population density [12] and higher degree of urbanization [13]. This can negatively impact on human life and the environment, including ground water resources, atmospheric water, soil and air. As humans develop, new technological advancements emerge, results of which can negatively impact on the atmospheric and climatic composition through trace components. This can persist for as long as there is no political influence and not many people are knowledgeable about effects of pollution and its contribution to atmospheric dynamics, their health and sustainable environment management [4]. Several reports reveal direct relationship between air pollution and ill health as a result of poor AQ, increasing rate of morbidity and mortality manifested through cardiovascular and respiratory problems [10]. Many organizations and research studies [12, 14, 15] have also taken the mandate to study and/or monitor pollution across the world and assess AQ and human health impacts [2, 14]. The recent update on AQ guidelines [16] also emphasize on ways of monitoring air pollution in order to improve global AQ.

Southern Africa is therefore no exception to pollution that has reached high levels in many places. The subcontinent has developed from a rural to a more urbanized place [17] due to manufacturing, mining and construction, increasing automobile, congested busy roads and other human activities. However, the ever-increasing pollution could also be attributed to region-specific factors such as low vehicle standards and/or fuel quality, solid fuel usage in cooking and burning household waste [18]. This review focuses on the regional air pollution, for it poses a potential threat or serious problems to human health and their environment. Our main objective is to improve an understanding and high highlight where major gaps about air pollution impacts could still exist, including dose-response relationships, AQ guidelines, climate, and human well-being.

### *Data and method*

The primary data source for this review was electronic literature collection on the status of AQ over southern Africa. This was conducted by consulting various reports and articles encompassing research from several databases, peer reviewed scientific journals, conference/ workshop proceedings and other high-quality grey literature. The review exhibits both inclusion and exclusion criteria [19] in the publication distribution (Fig. 1). "Air pollution" and "air quality" and "human health" are some of the keywords used in our Science Direct search string, from which 8,130 articles were returned from the search query. We chose publications from the last three years (2021-2023) for bibliometric analysis, giving a total of 1,708 articles. A total of 477 articles were assessed for eligibility, with 407 published in English. Out of 120 articles between 2021-2023, 62 articles had more than 5 citations and were selected for the systematic review. We set the limit of 5 citations per article to narrow the scope of the research, including only significant articles. While all included documents are articles in English language, the excluded articles were those from engineering and other related fields. For content analysis 50 articles were selected based on their relevance to the research objective.

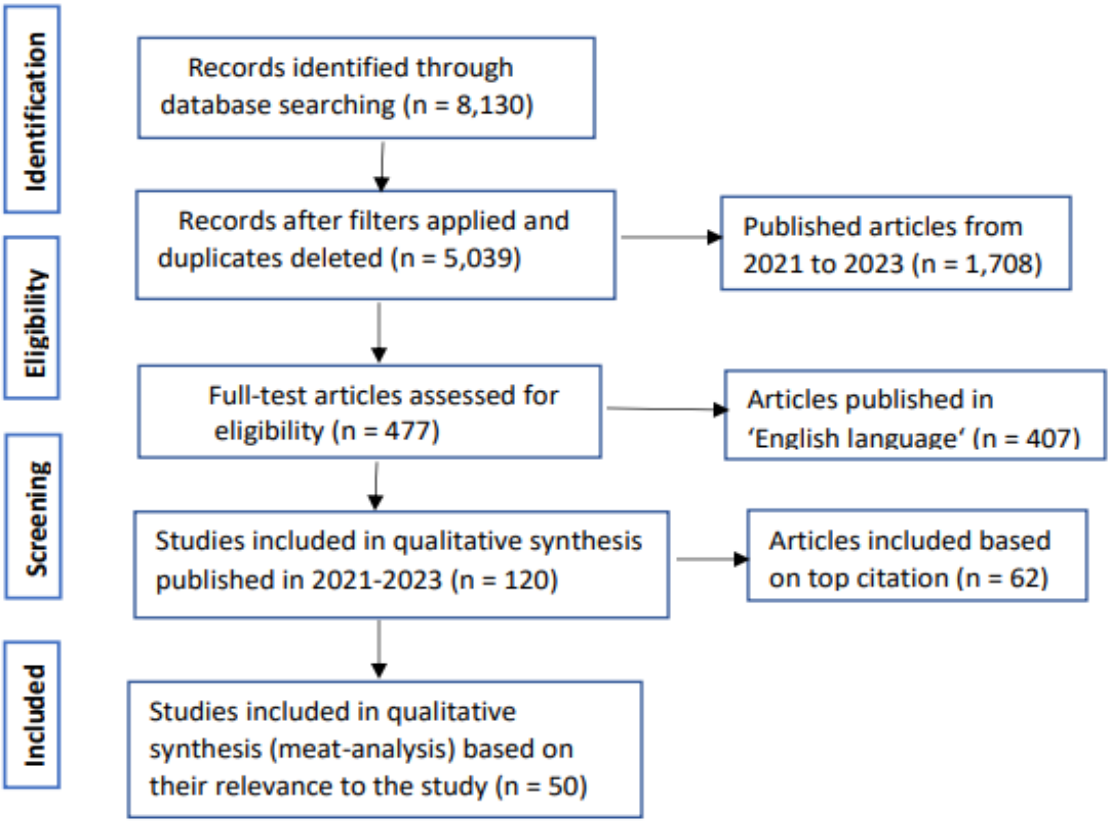


Fig. 1. PRISMA flow diagram [19]

## *Results*

Worldwide urbanization and industrialization are advancing at a high rate, reaching unpresented proportions and dire consequences in many countries. Consequently, southern Africa is one of the regions experiencing a significant amount of pollution. The sub-continent has transformed from a rural to a developing region and is now burdened with an influx of particulate and trace gas pollution. Prominent hotspots can be observed on satellite maps and model predictions for Nitrogen Oxide ($NO_x$), Particulate Matter (PM) and Miomass Murning (BB) emissions mainly around active areas.

### *Air pollution*

#### *Defining the problem*

Air pollution occurs due to introduction of harmful substances or products in undesirable or excessive amounts in atmosphere such that they can cause harm to humans and result in premature deaths and environmental damage [20, 21]. This can deteriorate AQ and the ecosystem. Exposure to air pollution (either long- or short-term) can have detrimental and/or toxic impacts on humans, depending on the type of pollutant species (e.g. respiratory problems, cardiovascular diseases, neuropsychiatric complications, eye irritation, skin diseases and long-term chronic illness such as cancer) [1, 10, 11, 22]. Pollutants can be solid, liquid or gaseous species -both primary (emitted directly from their sources in their natural/ chemical state [e.g. Carbon monoxide (CO), $NO_x$, Volatile Organic Compounds (VOCs) and other particulates such as dust and black carbon (BC)] and secondary (those forming in the atmosphere from primary pollutants' interactions and transformations [e.g. Ozone ($O_3$), Carbon dioxide ($CO_2$) and other forms of PM]).

### *Air pollutants*

Air borne substances are introduced and/or accumulate in the atmosphere and affected by existing atmospheric conditions such as wind and solar radiation. Also, meteorological parameters and land use can greatly affect pollutants' concentrations at any given time and location [21]. These substances occur from both natural/biogenic (e.g. volcanic eruption, wind-blown dust, pollen grain etc.) and anthropogenic activities (e.g. construction dust, industrial sprays and automobile emissions). Their impacts can be very diverse, depending on factors such as pollutant chemical or physical composition, exposure time and particle size. World Health Organization (WHO) and Environmental Protection Agency (EPA) [23] identify six "criteria" pollutants and regulate them by developing human health-based and/or environmental-based guidelines as permissible exposure levels. These include particulate matter, carbon monoxide, ozone, sulfur- and nitrogen oxides and lead. Databases compile data from field or ground measurements of pollutants concentrations for various gas and particles aimed at representing an average for site/location (e.g. city or town) or the country as a whole, rather than individual stations. WHO outlines the importance on health hazards in relation to air pollution; it also provides thresholds on different pollutants exposure and recommendations on AQ guidelines for global member states. While different countries could develop their own AQ standards, it is emphasized that WHO guidelines suit every person across the globe.

### *Particulate matter (PM)*

Particle pollution is usually formed from different chemical reactions and/or their transformations in the atmosphere. This comprises of all tiny (microscopic) solid substances or liquid droplets. Particles can span different orders of magnitude or size, and made up of thousands of different substances that enter the atmosphere either from anthropogenic or natural sources [24] and can vary greatly in their chemical as well as physical properties [25]. Some particles are emitted directly from the sources while others form in the atmosphere from primary species. PM is generally classified into two classes: particles with diameters of the order of 10 μm or less (referred to as $PM_{10}$), and extremely fine particles with diameters generally 2.5 μm or less ($PM_{2.5}$). Particle pollution can have serious effects on human health and AQ (e.g. coughing, shortness of breath, lung damage, premature death, poor AQ and visibility). Pollution sources can be affected by changes in precipitation patterns and climate [18]. Such changes would likely increase or influence windblown dust carried into cities [26] and/or residential sites. Figure 2 below illustrates interactions and interdependencies of particle pollution.

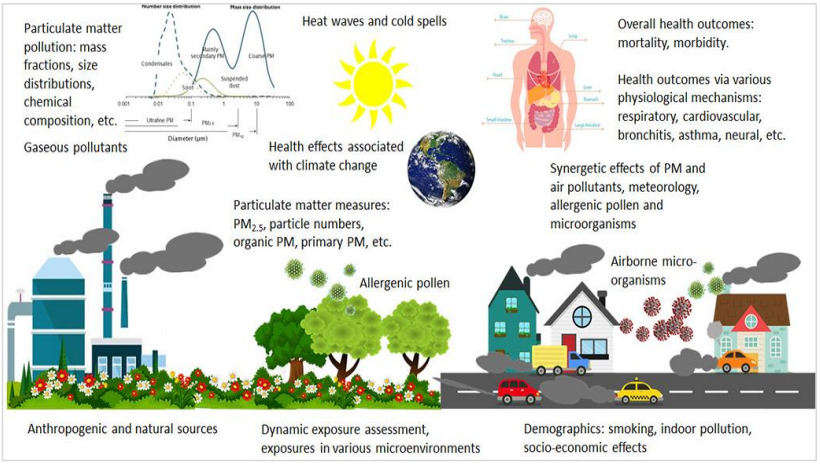


Fig. 2. A schematic illustration of particulate pollution showing the evolution in the atmosphere and health impacts [2]

### *Carbon monoxide (CO)*

Carbon monoxide is a primary pollutant gas produced mainly from incomplete combustion processes. CO levels are typically highest during cold weather; cold temperatures make combustion less complete and cause temperature inversions that trap pollutants close to the ground [27]. Serious or severe impacts are common in places where there is more exposure to high levels of prolonged gas emission [4, 27]. Common problems include headache, dizziness, weakness, nausea, vomiting and loss of consciousness -via inhalation. CO also react with hemoglobin and lead to Carboxyhaemoglobin (COHb), which reduces oxygen-carrying capacity in blood cells [27]. At high amounts, CO can also affect visibility.

### *Nitrogen oxides ($NO_x$)*

One of the most common air polluting chemical species in the atmosphere is Nitrogen Oxide ($NO_x$) -a shorthand for Nitric Oxide (NO) and Nitrogen dioxide ($NO_2$). This is a primary gas pollutant and critical component of photochemical smog produced from the reaction of nitrogen and oxygen during combustion processes of fuels (e.g. hydrocarbons), BB, automobiles or car engines. Similarly, $NO_x$ gases are also produced naturally by lightning. The primary emitted gases are NO and $NO_2$, which later establish a rapid equilibrium state. Quite often NO is oxidized by ozone ($O_3$) to give $NO_2$, but the two gases are rapidly inter-converted during the day. Atmospheric chemical reactions of $NO_x$ with other species can also lead to production of secondary gas pollutants such as $CO_2$, whereas interaction with light (photolysis) can lead to $O_3$ formation. $NO_x$ is an irritant gas that can penetrate deep into the lungs, inducing respiratory complications (e.g. coughing, wheezing, dyspnea and bronchospasm) [20], and even pulmonary edema when inhaled at high concentrations. Several studies have been conducted to explore the relationship between $NO_2$ exposure and mortality rate, where for example, $NO_2$ daily exposure appear significantly associated with increased cardiovascular and respiratory mortality [11]. High $NO_2$ levels can also be deleterious to crops and vegetation [4].

### *Ozone ($O_3$)*

Ozone is a secondary pollutant gas produced from the reaction between dioxygen molecules ($O_2$) and a singlet O atom under high voltage [28], usually in the presence of a third body molecule to absorb the heat. $O_3$ is a secondary pollutant because it is not directly released into the atmosphere nor directly generated by human activities; it forms from the high temperature chain reactions of primary pollutants triggered by solar radiation. Examples of such reactions include those of $NO_x$ and VOCs. Since it's a gas specie, it can be carried by air masses remotely from its initial source [20] and accumulate in the air aloft. Tropospheric $O_3$ is formed from photochemical reactions of precursor compounds (e.g. $NO_x$, CO and VOCs). It can also be formed far downwind by oxidation of CO and methane ($CH_4$) during very high combustion gas concentrations and long lifetimes of very large smoke plumes.

Ground level ozone is generated mainly by humans from chemical reactions (e.g. $NO_x$, VOCs and automobile emissions) in the presence of sunlight emitted into the atmosphere [18]. In highly polluted regions, $O_3$ concentration is enhanced by its production [3] but can be depleted within the nocturnal boundary layer by NO and $NO_2$ because of its reactivity. Ozone concentrations are enhanced over southern Africa due to frequently high emissions from BB and intense solar energy [29, 30] which triggers the reaction. Its uptake into the human system occurs through inhalation. It can affect skin layers and tear ducts [31], depletes vitamins C and E and reduce growth and plant microflora [4].

### *Sulphur oxides ($SO_x$)*

Sulphur oxides are a group of highly reactive gases comprising of Sulfur dioxide ($SO_2$), Sulphate ($SO_3$) and solid sulphates. Particularly, $SO_2$ is the predominant and harmful form of $SO_x$ found in the lower atmosphere. It is a colorless gas formed mainly from combustion processes such as fossil fuel burning in industries and other coal-fired power plants [20]. Its major sources include dihydrogen Sulfide gas ($H_2S$) oxidation during organic matter decay and volcanic activity. It can affect humans, animals and plants and it is a sensory irritant that can penetrate into the human lungs and convert into bisulfite and interact with sensory receptors to cause bronchoconstriction [4]. Its adverse effects in humans include bronchitis, respiratory problems such as asthma [27], eye irritation, lung cancer etc. For example, $SO_2$, PM and mercury emissions caused more than 2000 deaths from respiratory diseases, stroke and heart attack in South Africa [32]. $SO_2$ also contributes to acidic rain which can have major effects on plant and animal life. It can wash away soil nutrients for plant growth and alters soil composition as well as respiratory problems in animals and humans. Similarly, $SO_2$ can lead to metal and paint corrosion and damage to buildings.

### *Lead (Pb)*

Lead is a chemical element used in different industrial plant activities (e.g. car batteries, cable sheathing, radiation protection etc.). It is a naturally occurring heavy metal with many beneficial uses. Despite its beneficial uses, lead is an air pollutant and can be toxic to humans and animals alike. Lead as a pollutant is emitted from automobiles and other petrol-operated engines, including batteries, radiators and incinerators [33]. It is poisonous to human and animal health as well as the environment. It can cause several diseases and disorders (especially in young children), such as brain damage and nervous system, slowed development/growth, learning and behavioral problems that my lead to loss of IQ and/or ability to pay attention, anemia, and gastrointestinal effects [33]. Contact with Pb occurs through inhalation, ingestion and dermal absorption which exposes people at risk to the above effects. High dose of lead exposure (especially to expectant women) also affects the fetal nervous system and can lead to edema or brain damage [34].

### *Climate outlook and pollution status over southern Africa*

Southern Africa is characterized by a spatially varying arid climate in the west; semi-arid, temperate and sub-humid in the central, and semi-arid climate in the east [35, 36]. The climate becomes largely humid when approaching the Congo Basin towards the equator. The climate is mainly influenced by prevailing air masses within the regional scale that dominate the weather patterns [37, 38]. Over the interior of the mainland, the climate is often subject to seasonal changes. For example, the climate is characterized by seasonal and highly varying rainfall (inter-annual and intra-seasonally), frequent droughts and heat waves as well as flash floods. Circulation patterns over the highveld are often characterized by winter anticyclonic circulations and frequent easterly summer disturbances [39]. These systems can modify atmospheric conditions (e.g. reduce vertical mixing depth), and influence pollutant levels so that pollution can stay aloft for several days before exiting the landmass [37, 38, 40–42]. Vegetation comprises of various categories from which VOC emissions can be more significant [39], especially after the wet spells during summer.

The subcontinent has now transformed from a rural to a complex region, having made significant progress towards industrialisation, urbanisation and economic development [17]. Consequently, this transformation, also accompanied with population growth constitutes a threat, and together with

deforestation, negatively impact on the state of the environment over Africa [43]. The subcontinent now generates and experience high pollution (both particulate and gas pollutants) from combustion processes such as BB (e.g. firewood, waste burning, charcoal), fossil fuels (automobiles and industries) as well as aeolian dust. Similarly, construction, manufacturing and industrial processes also contribute significant amount of aerosol and gas emissions.

Various studies in literature [37-38, 42, 44-49] have discussed air pollution over the subcontinent. Most studies identify three major emission source categories, namely BB, aeolian dust and industrial emissions. BB is by far the most dominant emission source activity across Africa [50-51]. Consequently, Africa sub-Sahara burns more biomass than most other world regions annually [52]. Much of this occurs within tropical central and southern Africa. The temporal distribution involves activities such as open burning (agricultural and land management, bush clearing, charcoal production), domestic fires (cooking and energy supply) -especially during the dry season [50, 53], as well as traffic and industrial emissions and continuous wind-blown dust from the open land. High amount of pollutant species emitted into the tropical troposphere exerts a significant influence on the regional and/or global atmospheric composition, especially relatively pristine Southern Hemisphere (SH) and tropical Atlantic regions [54, 55]. On the other hand, industrial derived and construction aerosols are major constituents during summer. A significant amount of air pollutants also comes from vehicular emissions due to high densities of car fleets in some countries [17, 56, 57] and power generation [58].

### *Aerosol generation and pollution build-up*

The rate at which pollution accumulates and disperses in air depends entirely upon the atmospheric condition, particularly the earth's planetary boundary layer and dominant meteorological processes [59]. Once pollution is released into the atmosphere, meteorological processes control the build-up, dilution and/or dispersal. Pollution transport and dispersion is controlled by the meteorological patterns that strongly affect the mixing of pollutants [60] as well as their lifetimes. In the process, pollutant concentrations are driven by the interplay between the interacting planetary and synoptic scale features such as wind/air masses, species reactions and/or transformation in the atmosphere.

Southern Africa currently experiences a growing industrial sector (most of which is coal-powered) that releases high quantities of pollution into the atmosphere. For example, the most common trace emissions include $SO_x$, $NO_x$ and PM such as Black- and Organic Carbon (BC and OC) and other combustion products concentrated around the major source locations such as Mpumalanga industrial area (South Africa), Copperbelt Province (Zambia) [49] and some large-isolated point sources across subcontinent, including automobile emissions. There are several common air pollution scenarios across the region (e.g. open burning, desert dust and vehicular emissions) which also play a significant role in pollution status. Quite often, these are either not regulated or monitored and at times lead to high pollutants concentrations when not acted upon by the meteorology (e.g. dilution, dispersal and/or deposition). High-point emissions (e.g. $SO_2$) have also been reported in some areas at high concentrations exceeding health guidelines [8], thus affecting people nearby [17].

The highveld (in South Africa) is the largest industrial area in Africa and is among the top five $NO_2$ emission hotspots worldwide with significant source of $CO_2$, $SO_2$ and sulphate particles [61, 62]. Also, South Africa is among the world's leading mining and mineral-processing countries [63], with large deposits of mineral resources [64]. Consequently, the

country is one of the largest coal by-products emitting countries in the world and is among several developing countries likely to face globally imposed emissions constraints [65]. Needless to say, air pollution problem has always been unmonitored in most countries [66]. In many countries, ground-based pollution monitoring is sparse or non-existent; quality control and evaluation of monitoring stations is also inadequate [2]. It was just recently when very few countries started air pollution monitoring. Even where there are standards to control pollution, it becomes not be very useful if the laws and regulations are not enforced [67]. Although there might be no AQ alarming problems on record, several air pollution scenarios exist [68] where severe AQ problems are likely to persist. Therefore, air pollution is likely to continue to exacerbate, resulting in widespread emission exceedances, particularly in major regulated species such as PM, CO and $NO_x$.

### *Pollution transport patterns*

The semi-permanent South Atlantic Ocean anticyclone, continental anticyclone over southern Africa and the South Indian Ocean anticyclone have dominant effects on the regional transport of air pollution [69]. Pollutants are transported in stratified layers above the landmass [70, 71] and may interact with other atmospheric dynamics [12]. Previous studies indicate that vast amounts of particulates and trace gas pollutants generated within southern Africa re-circulate aloft and are deposited locally [37,72, 73]. For example, there is a circulation transport system, such that pollution recirculates back toward its point of origin over the subcontinent [42]. Trans-boundary pollution involves transport of pollutants over thousands of kilometers crossing geographical (country or continental) boundaries through the two main pathways -the 'Angolan route' into the Atlantic Ocean and the 'Natal plume' into the Indian Ocean [37]; (see also [3], Fig. 1). A typical example of pollution outflow is the so-called 'river of smoke' often observed from the mainland into the Indian Ocean [74, 75]. Despite their short atmospheric lifetimes, pollutants can be transported far away from the sources, depending on particle size and the prevailing atmospheric conditions. In some cases, wet- and dry deposition also take place and dump pollution over the local citizens.

### *Progressing towards the problem*

*Awareness, response and research initiatives*

Air pollution has since been one of the major worrisome issues pertaining to AQ degradation across the world. For example, there have some regional and international initiatives established, such as the National Aeronautics and Space Administration (NASA) funded campaign project called Southern Africa Fire-Atmosphere Regional Science Initiative (SAFARI). Several field campaigns were undertaken during the fund such as the SAFARI field campaigns of 1992 and 2000 [74-77]. Others include the International Global Atmospheric Chemistry Program/Biomass Burning Experiment project [IGAC/BIBEX], Southern Tropical Atlantic Region Experiment [STARE] [77], Southern Africa Atmosphere Research Initiative [SA'ARI] [78] and the Aerosol Recirculation and Rainfall Experiment [ARREX] [79]. Other research initiatives were also set up within the subcontinent, mostly focusing on Southern African Development Community (SADC) bloc. One example is the Air Pollution Information Network for Africa (APINA); this was mandated to 'drive the regional air pollution policy process as well as address air pollution related issues in Africa' and co-ordinate follow-up to the 1998 Harare Resolution on Prevention and Control of Regional Air Pollution over southern Africa and its likely transboundary effects [80]. One of the objectives was to identify some knowledge gaps on pollution issues in the region and

provide information, ensure that concerns are well articulated to policy makers, promote policy progress, as well as forming a strong link between the scientific community and policy makers on air pollution at national levels [80]. Also, the Regional Policy Framework on Air Pollution was developed by the United Nations Environment Program (UNDP) held in Zambia in March 2008 [81]. Upon its adoption, it was recognized that:

- Air pollution is the leading factor impacting on human health, environment and Africa's economy.

- More than half of total African trips are non-motorized, sometimes combined with inadequate public transport on poor roads (the world's most dangerous) and poor urban planning.

- There are high levels of pollutant emissions (e.g. $SO_2$, $NO_x$, PM and heavy metals) from the industry and power generation sectors.

- Agricultural emissions (especially ammonia) negatively impact human health.

- Open burning has a significant contribution to the environment and health status.

- Indoor air pollution (especially use of solid fuels in cooking) leads to high levels of PM exposure, especially to women and children.

### *Socio-economic impact*

While it is acknowledged that Africa is advancing economically, industrializing and infrastructural development [18, 82], the continent at large is undergoing a transition in environmental risks from traditional to modern pollution sources [82]. African cities are expanding, and economies are growing well beyond the continent's traditional dependence on commodity exports [83]. However, Africa is the least studied continent on earth with regard to pollution but most sensitive to climate change [84], yet the continent experience serious pollution scenario. For example, ambient air pollution has increased due to increased fossil fuel use and ambient air pollution-related mortality has risen from 26.13 per 100000 population in 1990 to 29.15 in 2019 [82]. Consequently, Africa is faced with multiple challenges such as high poverty rate, unstable governments, widespread corruption, violent conflicts, non-prioritizing and/or mitigating of some disturbing issues such as air pollution [18], an unfortunate scenario that is likely to persist into the long future. Particularly the subcontinent (southern Africa) is one of the regions in world with high aerosol loading, most of which are from anthropogenic sources [3].

Although there may be no evidenced fatalities known, it is very likely that as emissions continue to increase and/or not controlled, some ecosystems would be at risk in the future, including some highly diverse and unique ones [80]. It has been noted that air pollution levels in some parts of the subcontinent are above recommended national and WHO guidelines. This has resulted in some mortalities and financial implications. For example, a UNICEF report of 2017 indicated that deaths increased by 57% from 164 000 in 1990 to 258 000, due to outdoor air pollution in Africa within the last three decades. As a result, there was over $215bn annual loss in GDP which also cut short lives of children by 24 months [85]. According to Schwela [57], urban outdoor pollution accounts for about 49, 000 deaths (premature) per year in Africa, while indoor air pollution is responsible for eight times this value. The most affected region being sub-Saharan Africa. Again Fletcher [85] noted the Health Policy Watch reported that from the global total estimate of 7 million annual deaths, about 1.1 million African people died prematurely from air pollution-related diseases in 2019 alone.

WHO indicates that air pollution is one of the greatest environmental and health risks affecting people across the globe, be it in low- middle or high income countries [86]. There is great concern due to deteriorating AQ

across the world, which contributes to health problems -especially the young and elderly people and those already with respiratory complications [87]. The global standards (AQ guidelines) are set to help reduce air pollution impacts. Table 1 shows the revised WHO new AQ guidelines for some common air pollutants (i.e. 2021 thresholds compared to those in 2005). These threshold limits are set to quantify or estimate maximum average contaminants' concentrations to which people could be exposed to such pollutants in a given time without injury to their health [88-89]. Generally, they are an international reference on the adverse effects of human exposure to air pollution [11]. They are quite simple and clear, and fundamental to pollution management and provide a potential clue on exposure time between the source of emission (emitter) and the user or target (recipient)

Table 1. WHO Recommended air quality thresholds (2021 vs 2005). Annual and peak season for long-term exposure (24-h) and short-term exposure (8-h) [88]

| Pollutant | Averaging time | 2005 AQGs | 2021 AQGs |
|---|---|---|---|
| $PM_{2.5}$ $\mu g/m^3$ | Annual | 10 | 5 |
| | 24-h | 25 | 15 |
| $PM_{10}$ $\mu g/m^3$ | Annual | 20 | 15 |
| | 24-h | 50 | 45 |
| $O_3$ $\mu g/m^3$ | Peak season | - | 60 |
| | 8-h | 100 | 100 |
| $NO_2$ $\mu g/m^3$ | Annual | 40 | 10 |
| | 24-h | - | 25 |
| | 1-h | 200 | 200 |
| $SO_2$ $\mu g/m^3$ | 24-h | 20 | 40 |
| | 10 min | 500 | 500 |
| CO $mg/m^3$ | 24-h | - | 4 |
| | 8-h | - | 10 |
| | 1-h | - | 35 |

Notwithstanding however, most countries across the world have high annual mean $PM_{2.5}$ concentrations exceeding global recommended guideline of 10 μg/m³ [90]. According to WHO, about 99% of the world population live in areas with pollutant concentrations above the limits [91]. Globally, an estimated 93% of children live in environments where outdoor air pollution levels exceed WHO set AQ limits, and more than one in every four deaths of children below 5 years is directly or indirectly related to environmental risks [92–93]. This is a worrisome and unfortunate situation, for it already surpassed the pre-set WHO AQ target whereby "by the year 2000, air quality in all countries around the world should be improved to a point at which recognized air pollutants do not pose a threat to public health" [88].

Particularly, human populations living in large or high-polluting places are the likely receptors of pollutant levels [64]. However, the true picture or exact number and exposure time remain unclear and there would likely be other variables depending on biological, behavioural and environmental factors [94]. Also, scientists stress that pollution concentrations (or exposure times) still under the new guidelines cannot be considered safe, because there is no specific level at which pollutants would not cause damage to the human body. Recent numerous emerging data also show that even at low pollution concentration levels, there are adverse health effects and no clear threshold values can be established for human health safety [11].

### *Development and economic context*

Africa's economic growth and development has been advancing rapidly within the past decades. The continent has been on track to more than triple its population while making enormous gains in health [95]. This rapid growth in population is also accompanied with more industrialization, motorization and urbanization, hence creating more dense urban centers [96]. There are high pollution scenarios mainly from large-scale human activities (e.g. industrial and manufacturing plants, power stations, combustion and engines etc.). Because of the growing human development and technological advancement, these are large-scale activities and are by far major pollution sources [4].

While ambient air pollution may be lower than in many other parts of the world, it is already contributing to an increasing number of deaths and related problems (pneumonia, heart disease, stroke, diabetes, chronic lung disease, and lung cancer) in Africa [92]. For example, an estimated 1.1 million deaths in 2019 as highlighted earlier; these included an estimated 697000 deaths (526 000–879 000) due to household air pollution, 383 000 deaths (289 000–491 000) attributable to ambient $PM_{2.5}$ pollution, and 11 300 deaths (4800–18 300) due to ambient $O_3$ pollution [97]. Air pollution is now the second largest cause of death in Africa, after AIDS. It must be acknowledged also that the continent is faced with challenges that come with development. Experience also shows that with developing countries' economic growth, large-scale migration of people between different places (especially rural to urban), their AQ deteriorates [98].

Pollution species' concentrations have increased considerably from pre-industrial period, especially due to human activities [99, 100], as human lives develop. High quantities are generated in urban areas. Particularly, high anthropogenic emissions are thought to have risen above their environmental levels since the 21st century [99]. Most developing and populated countries suffer severely from indoor air pollution arising primarily from biomass and other fossil fuel use as well as outdoor pollution from industrial and transport [101]. As humankind move away from traditional biomass fuels (e.g. wood and charcoal) to liquefied petroleum gas and non-polluting renewables (e.g. wind and solar), household air pollution could be expected to decline. But at the same

time, industrialization and economic growth means ambient air pollution is increasing. Although it is widely recognized that developing countries suffer more from outdoor air pollution [82, 101], indoor air pollution is also at an alarming rate. For example, it was reported that an estimated 49,000 premature deaths occur annually due to outdoor air pollution, while from indoor air pollution (especially using solid fuels) the number is eight times this value, the most affected countries being within Sub-Saharan Africa [57].

## Conclusion

Air pollution is a public health emergency with a big environmental risk carrying a global responsibility [102]. This can have diverse and/or deleterious impacts on humankind and other ecosystems. For example, it can trigger and induce many diseases and cause high mortalities as well as impacting development in many parts of the world. Although industrial revolution has been a great success in human development and technological advancement, societal development, provision of multiple services (e.g. infrastructure, energy, transport etc.), it has also introduced the production of unwanted pollutant species into the atmosphere. Consequently, social, economic, health and wellness habits are all connected and affected by this problem [4]. By virtue of the growing African population and development, this suggests that:

- Air pollution levels are likely to be high in many places and will pose a serious threat.

- Air pollution is worldwide problem and should be one of the top priority lists to many governments, policy makers, legislators and related stakeholders alike.

- African governments need to increase support on pollution management and control in order to respond to the magnitude of the threat to human health and their economy.

Concerning southern Africa, an understanding of key pollution concepts is critical, especially that the region continues to experience increasing pollution. But it is important to note that responding to pollution is a challenge that entails concerted efforts from all parties to save lives and unlock economic opportunity through action at all levels (local, national, regional and global). This requires concerted effort and cooperation, working towards attaining a safer environment to reduce pollution. Also, if most countries are reluctant to implement mitigation strategies, pollution will continue to increase. Without deliberate intervention, the problem can persist into the future and hinder economic productivity, deplete human capital and development.

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## Author's contributions

M. Wiston: conceptualization, formulation, writing -original draft of the manuscript, writing-review and editing. L.D. Sebitla, N.C. Mbangiwa, G. Ramaphane: reading, review and editing. All authors read and approved the final manuscript.

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## Ethical considerations

"Ethical issues (Including plagiarism, informed consent, misconduct, data fabrication and/

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