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Air quality in Africa from the telecoupled perspective: exploring interdisciplinary and transboundary scientific collaboration between Africa and the Global North

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Abstract

Non-Technical Summary. This article explores air pollution as a globally connected issue using the *telecoupling* lens, which links distant regions through environmental and human systems. It shows how pollution connects Africa and the Global North, demonstrating that actions in one place affect people and air quality elsewhere. Drawing on 90 research sources, it looks at how satellite data helps monitor air quality and finds that most studies focus on natural sciences, with limited input from social sciences and less frequently from African researchers. The authors highlight the need to close data gaps and call for more inclusive, cross-disciplinary, and international cooperation in air quality research. Overall, the study pushes for fairer, more connected approaches to understanding and tackling air pollution worldwide.

Technical Summary. Air quality (AQ) is a transboundary phenomenon resulting from globalized interactions between coupled human and natural systems. Drawing on the telecoupling framework, this article argues that pollution flows, socioeconomic systems, and policy responses interconnect Africa with the Global North and identifies important data gaps for better understanding these interconnections. Through a meta-synthesis of 90 academic and gray literature sources, we analyze the use of satellite data for air quality monitoring, with a particular focus on interdisciplinary collaboration and African scientific participation. Our findings highlight a strong reliance on natural science approaches, limited integration of social science perspectives, and ongoing marginalization of African voices in shaping research agendas. We argue for a transformative research agenda rooted in interdisciplinary integration, inter-regional collaboration, and data justice. By adopting a telecoupled lens and prioritizing inclusive development, this study provides new pathways to understand, measure, and address air pollution as a global issue with deeply local consequences.

Social Media Summary. Air pollution links Africa & the Global North–study urges data justice & inclusive, global cooperation.

1. Introduction

Derived from a concept of 'teleconnection,' which originated in climate science (Trenberth et al., 1998), telecoupling is a cross-disciplinary framework that captures the increasingly globalized interactions between coupled human and natural systems (J. Liu et al., 2013). These interactions – ranging from trade, migration, and species invasion to pollution transfer, information flows, and climate-induced phenomena – reflect the systemic interdependencies of the Anthropocene. The telecoupling framework enables a complex and interdisciplinary analysis by breaking global systems into manageable but interconnected analytical units: sending systems, receiving systems, and spillover systems. Moreover, each system comprises agents, causes, and effects, with connections forged through the exchange of information, material, energy, people, capital, and organisms (Jahn et al., 2022; J. Liu et al., 2013) (Figure 1).

In the growing body of research on telecoupling, air quality (AQ) has featured as a side effect or indirect outcome of other telecoupled processes, such as trade or industrial expansion, rather than as a primary subject within this analytical framework (Perrin & Bernauer, 2010; Wu et al., 2025). Traditional approaches to air quality management often focus on local sources and isolated policy responses. Air pollution, however, is not local but transboundary in nature, traveling from a neighboring household, industry, city, state, country, or even continent.

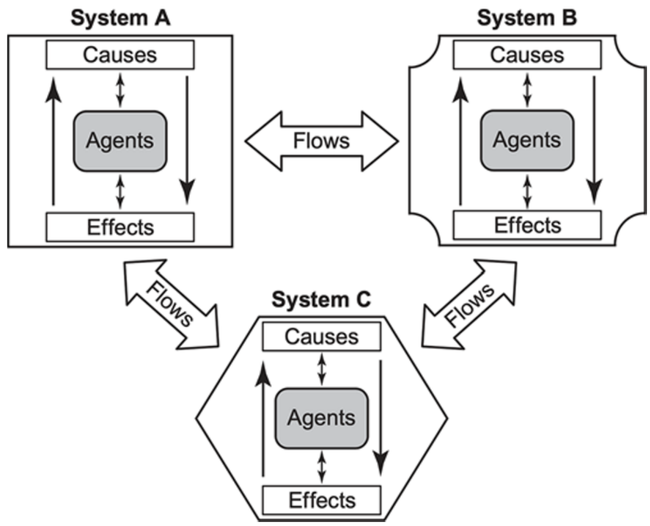

Figure 1. The telecoupling framework. Source: J. Liu, 2014.

It affects close and distant regions through a range of pathways. The pollutants involved have far-reaching and multifaceted impacts on health, the economy, climate, and the environment. Such intricate interplays between human and natural systems underscore the need to study air quality from a telecoupled perspective.

The concept of inclusive development, with its emphasis on socio-spatial distribution of well-being (Dekker, 2017) – including access to healthy air – provides an opportunity to examine these interplays from a telecoupled perspective. Vulnerable communities are disproportionately exposed to and affected by poor air quality, suffering greater health risks and economic disruptions. Moreover, urbanization, industrialization, and socioeconomic inequalities not only influence air quality but are also deeply shaped by it. This reciprocal relationship highlights that pollution is not merely a by-product of material flows, but is both driven by and affecting social systems through poverty, energy dependency, transportation needs, and global economic structures. Studying air pollution through this coupled socio-environmental lens thus enables a deeper understanding of how its drivers and impacts transcend borders.

The interconnectedness of air quality between Africa and the Global North illustrates the telecoupled nature of this socio-environmental issue. Pollutants such as Saharan dust can travel vast distances, affecting air quality, weather patterns, and climate conditions well beyond their points of origin (Dumont et al., 2023; Kok et al., 2021; Q. Liu et al., 2022; Pu & Jin, 2021; Rodríguez & López-Darias, 2024; Yu et al., 2015). Moreover, within Africa itself, wildfires – both natural and human-induced – as well as open burning and transportation emissions, are a significant source of air pollution (WHO, 2023b). While transboundary nature of air pollution is not unique to this region, though, it is a global phenomenon, the dynamics between Africa and the Global North are particularly significant due to both historical and contemporary emissions. Conversely, climate change exacerbated by emissions from industrialized regions, including Europe, can influence atmospheric conditions and air quality in Africa, increasing the frequency and intensity of wildfires as well as air pollution on the continent (Trisos et al., 2022; World Meteorological Organization, 2024). Moreover, as Europe and other industrialized regions pursue cleaner domestic environments, polluting industries are often relocated to less regulated regions including Africa (Newman et al., 2024). The continent also bears the environmental costs of extracting critical minerals essential for the global green energy transition, such as those used in batteries and renewable technologies (Kimeu, 2024; Martinez-Alonso et al., 2023). While this article focuses on Africa–Global North linkages, it is important to acknowledge that other major industrial powers – such as China and other rapidly developing economies – also significantly contribute to global air pollution and atmospheric transformations (Gamso, 2018), shaping the broader context in which African air quality is embedded. Despite the far-reaching implications of air pollution in Africa, its drivers, impacts, and transboundary telecoupled dynamics remain insufficiently understood.

Across much of the continent, efforts to understand and manage air quality in Africa are currently hindered by a limited measurement framework and persistent data gaps (Garland et al., 2023; Hsu et al., 2013). Most African countries lack consistent, high-resolution ground monitoring stations; consequently, pollution is frequently monitored using low-cost, ground-based monitoring networks. While the existing data are useful, it is often fragmented, of variable quality, and therefore insufficient for comprehensive analysis (Garland et al., 2023). This lack of reliable, locally generated data not only hampers evidence-based policy but also limits the development of African perspectives and expertise on air quality, raising critical questions about how narratives and solutions around air quality in Africa can be meaningfully shaped without the full participation of African scholars and the communities most affected on the ground.

In recent years, air quality measurement infrastructure and data availability have improved in many places across the continent. However, this infrastructure still contrasts sharply with regions such as Europe, the USA, and China, where extensive monitoring networks provide detailed air quality information. For example, in sub-Saharan Africa, there is one monitor per 28 million people, in contrast to one monitor per 370,000 people in high-income countries (Health Effects Institute, 2022; World Bank, 2021). Satellite-based remote sensing offers a promising solution to this data scarcity by providing extensive open-access spatial and temporal coverage that can complement ground-based measurements. This potential is exemplified by air quality data from the OMI instrument, which played a pivotal role in raising awareness and informing air quality regulations in China by clearly revealing trends in pollutants such as NO_2 and SO_2 (Levelt et al., 2018; Van Der A et al., 2017). Building on this success, similar applications of satellite data in Africa could support public awareness and policy development to curb growing air pollution challenges. Moreover, leveraging these data within a telecoupling framework – treating air pollution not just as a localized issue but as part of a globally interconnected system – can open new avenues for interdisciplinary research and foster cross-regional collaboration.

This article will explore the intricate interplay between natural, social, and spillover systems, as well as assess the level of interdisciplinary and transboundary scientific collaboration between Africa and the Global North. To do so, we first set the scene on air quality in Africa, review the legal and policy frameworks that shape air quality governance, and examine the ways that AQ can be measured. We then conduct a meta-synthesis of both academic and grey literature on the use of satellite data for air quality monitoring across the continent. This approach is particularly useful given the scarcity of ground-based measurements in Africa, which makes satellite data one of the few consistent sources for tracking air pollution. Our review pays special attention to links between

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Table 1. Key air pollutants and their characteristics

Pollutant	Source(s)	Impacts	Notes
PM (Particulate Matter)	Natural (e.g. dust) & anthropogenic (e.g. combustion)	Affects human health, air quality, and climate change	Can form from precursor gases like NO_2 and SO_2
NO*x* (Nitrogen Oxides)	Fossil fuel combustion (transport, industry)	Precursor to ozone; harms health and vegetation; proxy for fossil fuel use	Includes NO and NO_2; linked to greenhouse gas emissions
(Ground level) Ozone (O_3)	Secondary pollutant from NO*x* + Volatile organic compounds (VOCs) (burning, combustion)	Harms human health, vegetation, and agriculture; component of urban smog	Tropospheric ozone is a key air quality indicator
NO_2 (Nitrogen Dioxide)	Combustion-related human activities	Direct health, agricultural, and ecosystem impacts	Also contributes to PM and ozone formation
SO_2 (Sulphur Dioxide)	Combustion of sulfur-containing fuels (e.g. coal, oil)	Impacts health and ecosystems; precursor to secondary PM	Often emitted from industrial sources and power plants
Black Carbon (BC)	Incomplete combustion of fossil fuels and biomass	Harms health, contributes to climate change through SLCP	Absorbs sunlight, warming the atmosphere
Short-Lived Climate Pollutants (SLCPs)	Includes black carbon, ozone, and PM	Major contributors to near-term climate change	Account for ~ 45% of global warming after CO_2

Source: (Hsu et al., 2013; Prunet et al., 2020; Zaelke, 2013).

air quality and diverse socioeconomic and spatial linkages, as well as the degree of interdisciplinarity and cross-geographical collaboration in the literature. The former will therefore encompass the diversity of disciplines represented in the research as well as in authorship teams, with particular focus on collaboration between African and non-African scholars and institutions. Finally, by integrating these dimensions into a structured analysis, the paper will highlight current gaps and opportunities for future (collaborative) research and action.

2. Understanding air quality in Africa

2.1. Status of air quality in Africa

Air pollution is caused by both natural and anthropogenic sources. In Africa, the natural sources include desert dust particles and intense dry season savanna and woodland fires, while the anthropogenic sources of air pollution on the continent include fossil fuel burning in activities such as power generation and road transportation and other types of fires, such as domestic burning of coal and wood, burning crop residue, and waste burning at landfills (Marais et al., 2019). In terms of biomass burning, Africa accounts for about 72% of the total global burned area, 52% of the primary combustion aerosol global emissions (Andreae, 2019; Bond et al., 2013; Brown et al., 2021; Isaxon et al., 2022) and about 52% of the total carbon emissions. The latter includes 44% of CO global emissions, 36% of CH_4 global emissions (Van Der Werf et al., 2010), and 60% of the total black carbon (BC) global emissions, which is twice the global average (Bond et al., 2013). Nevertheless, on a per capita basis, Africa has the lowest emissions of all continents with an average of 1 ton of CO_2 emitted annually by each individual (AJLabs, 2023). Table 1 summarizes information about key air pollutants and their characteristics.

Air pollution has been identified as the single largest environmental risk to public health globally, yet the burden and costs of air pollution are unequally distributed across distances, providing evidence of ecologically unequal and unjust exchange on multiple levels (Moran et al., 2013; Rice, 2007). Globally, there is substantial empirical evidence of the imbalanced flows of emissions between and within developed countries and developing countries. The research confirms that more affluent people and economies can shift the environmental costs of their consumption to distant places, usually with weaker regulatory frameworks and monitoring capabilities (Martinez-Alonso et al., 2023; Newman et al., 2024; WHO, 2021). In these places, air quality is degraded due to the production of global commodities (Kimeu, 2024; Martinez-Alonso et al., 2023), increased carbon emissions (Xiong et al., 2018) or deforestation (Jorgenson, 2006). These processes have significant negative impacts on society at large and socioeconomically disadvantaged and disempowered social groups in particular (Boillat et al., 2020; Borras et al., 2011; Peluso & Lund, 2011).

On the continental and regional level, local pollution, especially in urban and peri-urban areas, amplifies regional and transcontinental flows of air pollutants, including dust, aerosols, and combustion-related emissions (Atmosphere Monitoring Service, 2022, 2024; Duncan et al., 2008; Kallos et al., 1998; Yan et al., 2021). Rising local pollution levels are a result of Africa's current rapid demographic change, urbanization, and economic development, including industrialization (Avis & Bartington, 2020; Awe et al., 2022; Marais et al., 2019; World Bank and Institute for Health Metrics and Evaluation, 2016). Africa's cities are expanding at an unprecedented rate, often in the absence of adequate infrastructure, planning, and regulation (OECD/UN ECA/AfDB, 2022). Even with a limited air-quality monitoring network, the available literature indicates elevated levels of outdoor air pollution across the continent (Abera et al., 2020; Garland et al., 2023). The $PM_{2.5}$ concentrations at many measurement sites, although not always well-quantified, are alarmingly high, surpassing national limits and recommended guidelines in many areas (Health Effects Institute, 2022; WHO, 2023a).

Within countries, poorer and more marginalized communities, as well as other vulnerable groups in both urban and rural settings, are often disproportionately exposed to poor air quality and its negative effects (Ferguson et al., 2020). Recent statistics indicate that air pollution in Africa is the second leading cause of death on the continent, surpassed only by AIDS (Fisher et al., 2021). Such impacts have important implications for achieving inclusive development on the continent (Dekker, 2017; Woldai, 2020) and, subsequently, reaching the United Nations Sustainable Development Goals and Paris Agreements commitments or implementing suggestions made in the First Integrated Assessment of Air Pollution and Climate Change for Sustainable Development

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in Africa (United Nations Environment Programme, 2023a). In light of these transboundary and unequal dynamics, Africa can be considered as both a sending and receiving system for air pollution flows from the telecoupled perspective. It also becomes critical to examine how air quality is governed globally and within Africa, and to what extent existing policies and guidance frameworks are equipped to address both local challenges and global interconnections.

2.2. Air quality policy and guidance

Given that air quality outcomes are shaped by interactions across distant but connected social and ecological systems, it is essential to examine the policies that govern these dynamics across multiple scales. Understanding how air quality is managed, through legal and regulatory frameworks at the global, continental, regional, and local levels is particularly important in regions where local monitoring and enforcement capacities are limited.

Regulating air quality is complex, as air pollution results from a wide range of social, political, and economic behaviors, combined with geographical, environmental, and population conditions (Andres et al., 2023; Scotford et al., 2021). For instance, AQ policies should regulate diverse sources of emissions (industry, private vehicles, public transport, power generation, ships, etc.) and diverse behaviors that generate air pollution (through urban planning, control of individual pollution incidents, or other means (Abera et al., 2020)). Unlike climate change, which is governed by global agreements such as the Kyoto or Paris Agreement, or the ozone layer – regulated by the Montreal protocol – air quality regulation lacks a comprehensive international framework (Levelt, 2012). This absence is particularly concerning given that certain air pollutants, notably methane, particulate matter, and tropospheric ozone, have significant global impacts due to their roles as Short-Lived Climate Pollutants (SLCPs). Globally, despite a number of initiatives, there is still no binding commitment in public international law to a specific level of ambient air quality that is compatible with human health and the natural environment (Scotford et al., 2021). Air pollution is therefore regulated through policies and frameworks (which are not always enforced) on the continental, regional, and national level.

2.2.1. Continental level

The key priority under the African Union Agenda 2063 goal of promoting environmentally sustainable and climate resilient economies and communities is to 'develop/facilitate the implementation of Africa Quality Standards for air and other forms of pollution.' The importance of improved air quality assessment across the continent has been reaffirmed by African policymakers multiple times. At the 15th session of African Ministerial Conference on Environment (AMCEN) in 2015, in Cairo, Egypt, ministers called for enhanced air quality monitoring and modelling and the need to develop an Africa-wide air quality framework agreement on air quality management in their declaration. This issue was addressed again at the 16th session of AMCEN (2017), Libreville, Gabon, where ministers acknowledged the region was facing increasing levels of air pollution, which has a negative effect on the environment and social and economic development in the region, as well as on human health and the well-being of the African population. The 2019 17th AMCEN Session in Durban, South Africa, concluded with Decision 17/2, which acknowledges the importance of SLCPs and the 'need for an assessment of the linkage between policies to address air pollution and policies to address climate change'. Finally, the AMCEN Decision 18/4 (2022) "urge[s] African countries to support further development and implementation of the 37 recommended measures as a continent-wide Africa Clean Air Program, coordinated by strong country-led initiatives, cascaded to the Regional Economic Communities and higher levels of policy" (CCAC secretariat, 2021).

In terms of initiatives on the continental level, the Clean Air Initiative in Sub-Saharan Africa (CAI-SSA) and the Air Pollution Information Network for Africa (APINA) were launched by the World Bank and the Stockholm Environment Institute, respectively, in the late 1990s, in response to the deteriorating air quality situation in the region (CCAC secretariat, 2021). More recently, Clean Air for Africa: Partnership Forum for Integrated Action on Air Pollution and Climate Change was launched in (2023), following the publication of the first Integrated Assessment of Air Pollution and Climate Change for Sustainable Development in Africa (United Nations Environment Programme, 2023a). The publication demonstrates that significant improvements in air quality are achievable without altering the economic or population growth trajectories of African countries. The purpose of the Partnership Forum is therefore to create awareness, partnerships, and develop a road map for the implementation of the 37 measures identified across five key areas: transport, residential energy use, energy generation and industry, agriculture and food systems, and waste management to combat climate change, prevent air pollution, and protect human health and the environment simultaneously. The expected outcome of the Forum became the outline for developing the Africa Clean Air Program.

2.2.2. Regional level

There has been significant regional progress in developing treaties and agreements concerning air quality in Africa, motivated by shared transboundary air pollution problems. Four key regional agreements call for cooperation on the harmonization of air quality standards, monitoring procedures, and data management: the North African Framework Agreement on Air Pollution (2011), the Eastern Africa Regional Framework Agreement on Air Pollution (2008 Nairobi Agreement), the Southern African Development Community (SADC) Regional Policy Framework on Air Pollution (2008 Lusaka Agreement), and the West and Central Africa Regional Framework Agreement on Air Pollution (2009 Abidjan Convention). All four enhance stakeholder participation in air quality management (Scotford et al., 2021). An Air Pollution Information Network for Africa (APINA) played a leading role in the development and promulgation of regional framework agreements on air pollution. The short description of relevant agreements can be found in the Table 2 below. However, these agreements are yet to translate into comprehensive actions and policies in many signatory countries. While APINA is no longer operational, the African Group on Atmospheric Sciences (ANGA) working group has been established and operates on its basis.

2.2.3. National level

Air quality laws and regulations have been identified as one of the key policy actions for significantly improving air quality. Yet, in Africa, such regulations are still in the early stages of development and are often inadequate or absent (Scotford et al., 2021). In fact, the majority of countries lacking legislative instruments that set ambient air quality standards are in Africa (Figure 2) (Scotford et al., 2021). Legal and constitutional structures vary across the continent, which can determine how air quality laws

Table 2. Regional agreements on air pollution in Africa

Declaration/ Resolutions/Agreements	Region/regional economic communities	Focus	Status
The Libreville Declaration 2008	Continental	Health and environment in Africa with a policy statement that provides a cohesive and integrated framework to address human health and environment links on the continent.	Signed by ministers of health and the environment from 52 African countries.
North African Framework Agreement on Air Pollution 2011	North Africa	Unknown	Unclear*
Lusaka Agreement 2008	SADC	Regional policy framework on air pollution outlining multilateral cooperation for action on air pollution from transport, industry, open burning, household air pollution, national environmental governance, public awareness, education, development, and capacity building.	Adopted by 14 SADC countries, representing governments, industry, NGOs, civil society, international organizations, and academia.
Nairobi Agreement 2008	EAC	Eastern Africa Regional Framework Agreement on Air Pollution developed actionable targets to address air pollution in the following key areas: transport; industry and mining; energy; waste; vegetation fires; household air pollution; urban planning and management; and regional and national environmental governance.	Signed by seven countries.
Dakar Declaration 2002	Sub-Saharan countries ECOWAS	Elimination of leaded fuel in sub-Saharan Africa	Agreed by participants from 25 sub-Saharan countries; including representatives of government, industry, and civil society, as well as from international organizations. Achieved in 2021.
Abidjan Agreement 2009	ECOWAS and ECCAS	Actionable targets to address air pollution issues in the following key areas: transport; industry and mining; household pollution; waste disposal; bush fires; uncontrolled burning and deforestation; urban planning and management; and national and regional environmental governance.	Signed by 13 countries.

**The Agreement is referred to in official documents of the United Nations Environmental Programme and NEPAD. Details about the focus and the status of this agreement were not found.*
Source: (United Nations Environment Programme, 2023b).

Figure 2. Countries with legislative instruments setting ambient air quality standards (2021). Source: Scotford et al., 2021.

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Table 3. Overview of key satellite instruments for air quality monitoring

Instrument	Platform	Measured pollutants	Key features
MODIS (Moderate Resolution Imaging Spectroradiometer)	NASA Terra & Aqua	AOD (PM proxy)	Long-term AOD record, moderate resolution
MISR (Multi-angle Imaging Spectroradiometer)	NASA Terra	AOD, aerosol type	Multi-angle view improves aerosol characterization
OMI (Ozone Monitoring Instrument)	NASA Aura	NO_2, O_3, SO_2	Coarse resolution, predecessor to TROPOMI
S − 5P/TROPOMI (TROPOspheric Monitoring Instrument)	Copernicus Sentinel − 5P	NO_2, CO, CH_4, O_3, AOD	High spatial resolution, wide spectral range
IASI (Infrared Atmospheric Sounding Interferometer)	EUMETSAT MetOp-A, B, C	CO, CH_4, O_3, N_2O	High spectral resolution; supports both weather forecasting and climate monitoring
CrIS (Cross-track Infrared Sounder)	Suomi NPP, NOAA − 20 and NOAA − 21 satellites	CO, CO_2, CH_4, O_3, N_2O, HNO_3, and SO_2	Hyperspectral infrared sounder; detect the concentration of greenhouse gases in the atmosphere for improved weather and climate predictions

Source: own elaboration based on Blumstein et al., 2004; Diner et al., 1998; Gambacorta & Barnet, 2013; Justice et al., 1998; Levelt et al., 2006; Mcelroy, 2021; Veefkind et al., 2012).

are devised and implemented. Even where legal standards exist, the enforcement and compliance of these laws is highly variable.

While policy frameworks and guidance documents provide the structural foundation for addressing air pollution, their effectiveness ultimately depends on the availability and quality of air pollution data, as well as on the ability to make meaningful use of available data, through appropriate interpretation, analysis, and integration into decision-making processes. However, data access and capacity among government officials remain major barriers preventing policymakers in Africa from making informed, data-driven decisions to improve policies and their outcomes (Donback, 2020). As such, understanding the methods currently employed to measure air quality is essential.

2.3. Assessing air quality in Africa

A number of methods of air quality monitoring are utilized to assess levels of air pollution, including ground-level monitoring (reference or regulatory grade monitoring stations and increasingly lower-cost, sensor-based technology), satellite-based remote sensing, visibility as a proxy and a 'citizen science' bottom-up approach. Depending on the types of pollutant, different assessment methods are used and, often a combination of measurement methods is applied (Vélez-Guerrero et al., 2023). Air quality assessment methods vary widely in scale, precision, and accessibility. Ground-level monitoring, using either high-accuracy reference stations or increasingly accessible low-cost sensors, offers detailed, localized data but is often limited in spatial coverage, especially in under-resourced regions. In contrast, satellite-based remote sensing provides broader spatial and temporal insights. Citizen science bridges the gap between scientific research and local communities, allowing lived experiences and grassroots insights to inform data collection and interpretation (see Pope et al., 2024). Both proxy measures, such as visibility and citizen science approaches contribute valuable, though often less standardized, and sometimes creative, bottom-up data that can complement formal monitoring systems.

Satellite-based remote sensing, the main focus of this paper, offers a vital tool for monitoring air quality, especially in regions where ground-based measurements are sparse. Satellite sensors measure interference in the light energy reflected or emitted from the Earth, which is used to calculate concentrations of air pollutants such as PM, nitrogen dioxide, carbon monoxide, and ozone. In the case of particles, the satellite sensors measure the Aerosol Optical Depth (AOD) – the degree to which light has been absorbed or scattered by particles in the atmosphere. Using geophysical models and statistical calibration, scientists refine how to relate the satellite-based AOD observations to the surface concentration of $PM_{2.5}$ (Avis & Bartington, 2020). Public platforms like Google Earth Engine (GEE) and the Copernicus Sentinel-5P Mapping Portal (S5P-PAL) have made this data increasingly accessible, even in low-resource settings.

Among the instruments that have long supported air quality research, we should mention the Ozone Monitoring Instrument (OMI) (Levelt et al., 2006), the Moderate Resolution Imaging Spectroradiometer (MODIS) (Justice et al., 1998), Multiangle Imaging Spectroradiometer (MISR) (Diner et al., 1998), Infrared Atmospheric Sounding Interferometer (IASI) (Blumstein et al., 2004) and Cross-track Infrared Sounder (CrIS) (Gambacorta & Barnet, 2013). Today, the more advanced TROPOspheric Monitoring Instrument (TROPOMI) (Veefkind et al., 2012) has set a new standard in spatial resolution and precision (Mcelroy, 2021). TROPOMI enables detailed attribution of emissions from both natural and anthropogenic sources – including industrial facilities, power plants, and biomass burning, and supports the mapping of climate-relevant gases like methane and ozone. Carbon dioxide emissions can also be calculated for point sources and regions, based on the detailed mapping of nitrogen dioxide (NO_2) (Zheng et al., 2020). Table 3 provides a more detailed overview of key satellite instruments for AQ monitoring. Although these tools have influenced policy in high-income countries and were widely used to assess air quality changes during COVID-19 lockdowns (Cooper et al., 2022; Levelt et al., 2022; Prunet et al., 2020; Serrano-Calvo et al., 2023; Zheng et al., 2020), their application in Africa remains limited (see Figure 3 as one of a very few examples) (Dasgupta et al., 2020; El-Nadry et al., 2019; Hu et al., 2018; Marais et al., 2019; Shikwambana et al., 2020).

Satellite-derived estimates are critical for filling data gaps in areas without ground monitoring (De Sherbinin et al., 2014). While countries such as Egypt, Morocco, South Africa, Senegal, Ghana, Uganda, and Rwanda have begun developing real-time monitoring networks (Katoto et al., 2019; Okello et al., 2023), most of the continent still lacks reliable infrastructure for air quality management. The use of satellite data is increasingly recognized as an essential tool for decision-making (Woldai, 2020); nevertheless, persistent barriers hamper broader uptake of satellite data

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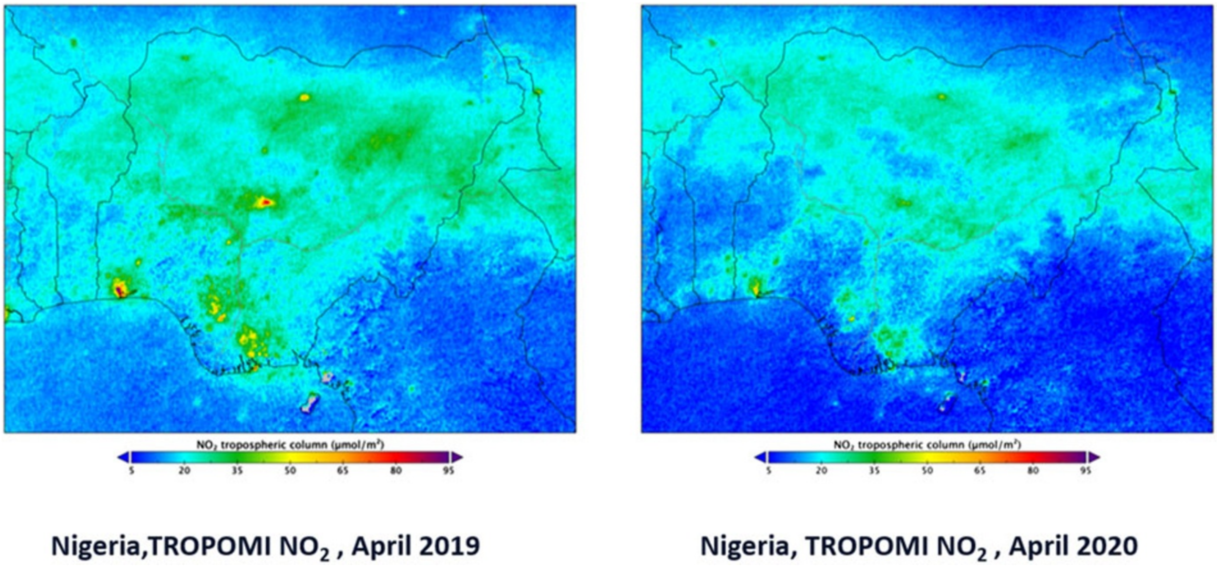

Figure 3. TROPOMI nitrogen dioxide (NO_2) measurements over Nigeria: (a) yearly mean April 2019 (pre-Covid year) (b) monthly mean over 2020 (Covid-year). The reduction in the NO_2 tropospheric column in the Covid year is clearly visible from space. Source: Dr. Henk Eskes, KNMI.

in Africa (but also worldwide). These include technical challenges like cloud cover interference, discrepancies between satellite measurements and policy-relevant indicators, and insufficient collaboration across scientific and policy communities (Engel-Cox et al., 2013; Hsu et al., 2013; National Research Council, 2007). Moreover, perceptions of data usability continue to limit integration into air quality governance – a problem echoed in other regions around the world. Enhancing the use of satellite-based measurements, particularly through accessible platforms, interdisciplinary collaboration, and cross-sectoral partnerships, represents a promising pathway toward better understanding and informing environmental, socioeconomic, and public health policymaking in Africa (Agbo et al., 2021; Tang et al., Forthcoming). In light of this potential, the following section takes stock of the current landscape of international and interdisciplinary collaborations, focusing on the intersection between natural and social science disciplines and partnerships between African researchers and those based in the Global North that have used satellite measurements of atmospheric composition.

3. Methodology

In the context of the identified persistent data gaps and to better understand the telecoupled nature of air quality (i.e., links between social and environmental systems over distance), the authors conducted a meta-synthesis of the existing academic and grey literature focused on the use of satellite data for air quality monitoring in Africa and its use in combination with socioeconomic, environmental, and health data. Meta-synthesis is a qualitative research method used to systematically review and integrate findings from multiple studies. It goes beyond simply summarizing existing literature; instead, it interprets and synthesizes findings to generate new conceptual understandings or theoretical insights (Hoon, 2013; Jensen & Allen, 1996). This method is particularly useful when dealing with diverse, fragmented, or interdisciplinary bodies of literature, such as the one on air quality in Africa. The present study followed the following steps to organize the meta-synthesis (Hoon, 2013).

Step 1: Locating relevant research and selection criteria
This review employed a convenient sampling technique, which involves selecting available literature sources based on their accessibility, ease of retrieval, and relevance to the research topic. The focus was on readily accessible sources, such as academic journal articles, books, online databases, and reputable websites. The sources were identified by using search engines, academic databases, and citation networks to locate key literature and using a combination of key words, such as "satellite data," "remote sensing," "TROPOMI," "MODIS," "OMI," "vulnerability," "health," "socioeconomic impact," "air quality," "air pollution," and "Africa" (among others). The years 2000–2024 (January) were chosen as a cut-off date for the search. The authors recognize that the convenient sampling approach may not provide an exhaustive overview of the entire literature on the topic; however, it yields valuable insights and serves as a starting point for further exploration.

Step 2: Classification and comparison of main findings
The second stage of the meta-synthesis approach focused on exploring, analyzing, and compiling the descriptive analysis findings from the identified literature. Evidence from the studies under synthesis was categorized according to country/region, detailed location (if available), pollutant measured by the study, the remote sensors used to collect data, key conclusions, link to a socioeconomic/environmental/health impact, approach (siloed or interdisciplinary), and the science domain. A detailed table summarizing the publications can be found in the Supplementary material section (Figure S1).

Step 3: Synthesis
During the third stage, analyzed studies were synthesised. The synthesis of the findings was guided by a recurring emphasis on interdisciplinarity and cross-geographical knowledge exchange with Africa.

To capture the interconnected socioeconomic, environmental, and health dimensions of air quality impacts, this study employs the umbrella concept of inclusive development, which

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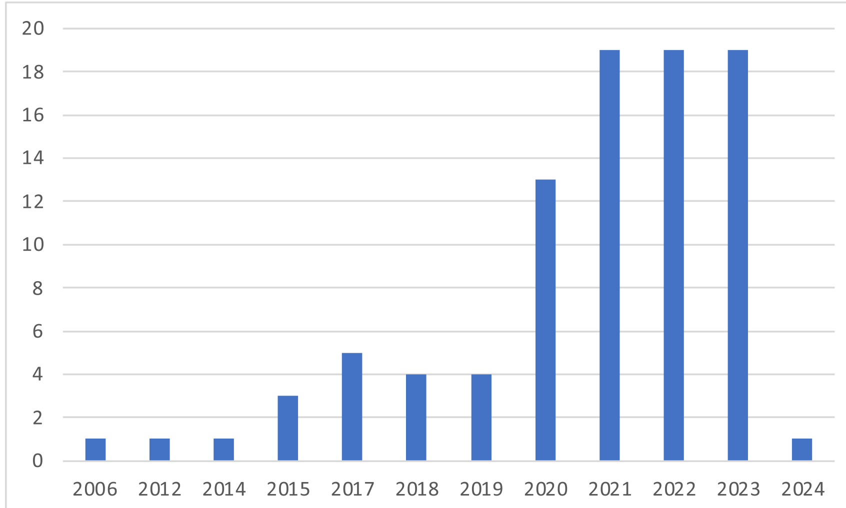

Figure 4. Number of reviewed publications by year. Source: Own calculations.

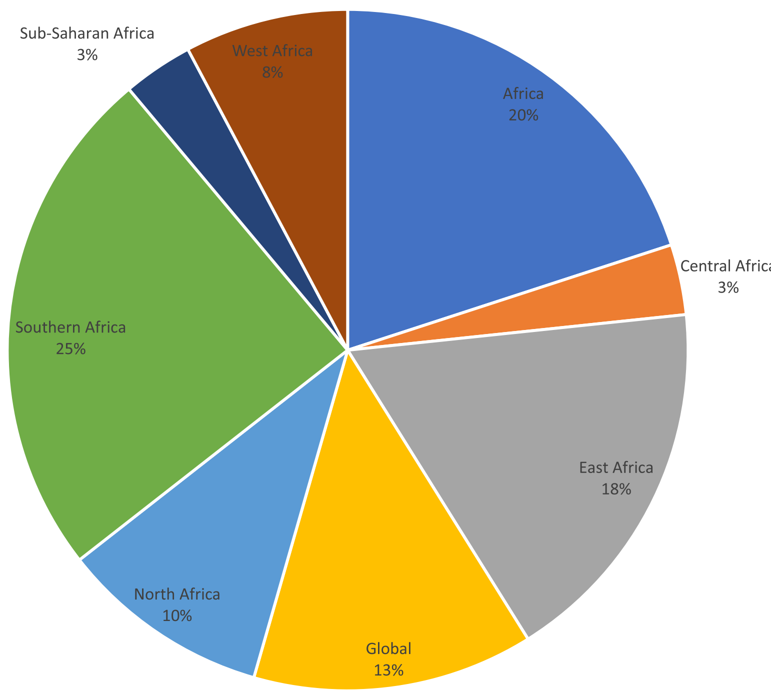

Figure 5. Regional distribution within the reviewed publications. Source: Own calculations.

encompasses these interrelated aspects within a unified analytical framework (Dekker, 2017). It is used deliberately to also capture the issues related to marginalization and environmental (in)justice /(in)equality within existing debates.

To further uncover how African perspectives are (or are not) represented in the literature, the institutional affiliations of the first and last authors of the reviewed studies were analyzed. Affiliations were taken directly from the publications and categorized based on the location of the authors' institutions into five groups: (i) non-African first author and non-African last author; (ii) African first and last author; (iii) African single author; (iv) African first author; non-African last author; and (v) non-African first author, African last author. No further "career tracking" of the authors was undertaken to assess their actual affiliation. It is important to note that there is high mobility among some of the scholars involved, which may have led to small inaccuracies regarding their actual origins and current home institutions. The key findings of the meta-synthesis are discussed in the following section.

4. Main findings

The literature scoping conducted for the purpose of this paper identified a total of 90 separate articles that use satellite data to assess air quality (and its potential impacts) in Africa. A clear increase in the number of reviewed publications has been observed since 2020 (Figure 4). Most of the publications analyze the situation in the Southern African region (mostly in South Africa itself) and East Africa (Kenya and Uganda). A growing trend is observed in West Africa, in particular publications from and about Nigeria (Figure 5). Data retrieved from MODIS were used most frequently, although a positive trend is also observed in terms of the use of data derived from OMI and TROPOMI. Increasingly,

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remote-sensing retrievals of aerosol optical depth (AOD) are being combined with atmospheric chemistry models to produce accurate and fairly resolved estimates of ground-level concentrations of $PM_{2.5}$ (hence the popularity of data derived from MODIS). The following sections explore the intricate interplay between natural, social, and spillover systems through a lens of inclusive development. They also assess the level of interdisciplinary and transboundary scientific collaboration between Africa and the Global North.

4.1. Satellite air quality data and inclusive development linkages

Population in low- and middle-income countries is disproportionately affected by polluted air. Constraints in terms of the accessibility, availability, and quality of healthcare provision further increase air-pollution-related mortality in developing countries (Lelieveld et al., 2020). Globally, approximately one in ten people exposed to unsafe levels of air pollution live in extreme poverty (Rentschler & Leonova, 2022). In sub-Saharan Africa, 405 million (or 57%) are directly exposed to unsafe $PM_{2.5}$ concentrations (Figure 6). On an individual level, poverty may increase individual susceptibility to air pollution due to: poor health status and access to healthcare; unaffordable nutrient-rich foods; and the increased likelihood of living in proximity to polluting industries, biomass burning, and unpaved roads, or dependence on jobs that require outdoor physical labour (Katoto et al., 2019).

Although the adoption of satellite-based measures of air quality in health studies in Africa is in its infancy, research in this area is growing. In recent years, there is an observable increase in understanding air pollution trends and their associated health and environmental impacts in sub-Saharan Africa using available satellite data. Consequently, the satellite data in the reviewed articles are mostly used to assess the impact of poor air quality on population health (Bachwenkizi et al., 2021, 2022; Etchie et al., 2018; Fisher et al., 2021; Fleischer et al., 2014; Heft-Neal et al., 2018; Kalisa et al., 2023; Larson et al., 2022; Lelieveld et al., 2015; Lin, Guo, Di, et al., 2017; Lin, Guo, Kowal, et al., 2017; Marais et al., 2019; Owili et al., 2017). A number of studies indicate that PM concentrations in urban centers are considerably higher than the WHO guidelines and were found to vary considerably temporarily and spatially. Among the vulnerable groups often referred to, newborn children, young mothers, and the elderly are mentioned most often.

Some reviewed studies have important health- and climate-policy-related recommendations. For instance, using satellite estimations of air pollution and pollutant-mortality risk models, Lelieveld et al. (2015) estimated the numbers of premature deaths attributable to air pollution globally (Figure 7). The authors suggest that ambient $PM_{2.5}$ from commercial and domestic energy generation, agriculture, and traffic sources contribute the most to premature deaths worldwide. They calculated that premature mortality could be reduced by 4.54 million annually by mitigating both ambient and household air pollution, mainly through changes in commercial and domestic energy use, especially in Africa where domestic energy mostly relies on solid fuels. Without concrete and appropriate mitigation plans and policies, the authors expect a doubling of mortality from air pollution by 2050 considering the projected rates of increase in population and air pollution levels.

Within the reviewed articles, links are also made between: socioeconomic development and air pollution (Hickman et al., 2021); air pollution and poverty (Rentschler & Leonova, 2022); agricultural activities and air pollution (Shikwambana et al., 2022); identifying areas facing both high social vulnerability and air pollution levels (Clarke et al., 2022); and assessing air quality trends with the climate factors, socioeconomic indicators, and terrain characteristics (Martinez-Alonso et al., 2023; Ouma et al., 2024). Furthermore, urbanization not only increases the number of people exposed to outdoor air pollution but also raises air pollution levels, which inevitably translates into new interactions between social and natural systems. Despite the fact that socioeconomic marginalization increases people's exposure and vulnerability to air pollution—and aside from the substantial evidence of this fact for the US—little evidence exists documenting the global or continental scale of poor people's exposure to harmful air pollution, especially in Africa.

Overall, despite a clear link between the air quality and inclusive development, the articles linking satellite air quality data to socioeconomic dimensions of well-being and related policy dialogues/interventions are sparse. Moreover, important limitations of the reviewed studies must be mentioned. The absence of long-term

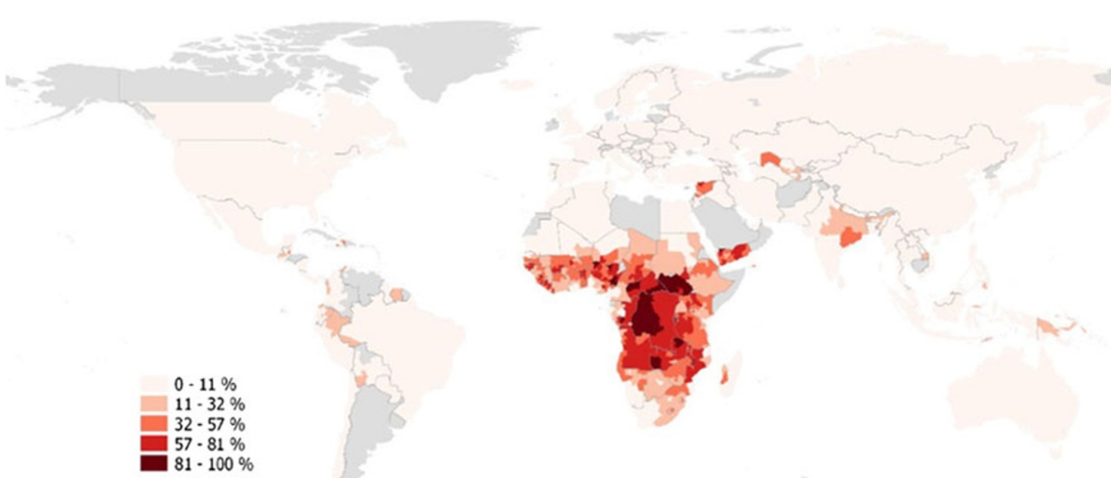

Figure 6. Share of population exposed to unsafe PM2.5 levels and living in poverty at $1.90/day. Source: Rentschler & Leonova, 2022.

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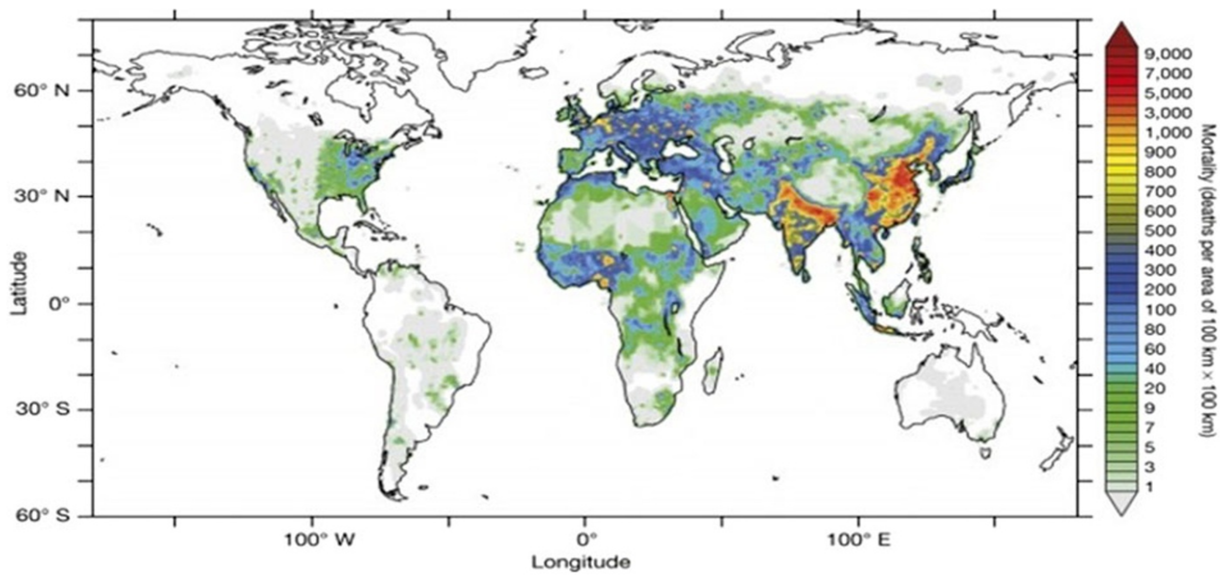

Figure 7. Mortality linked to outdoor air pollution in 2010. Source: (Lelieveld et al., 2015).

air quality data and a related monitoring network in most African countries make it difficult to develop a complete assessment of the magnitude of the air pollution problem (Pope et al., 2018; Singh et al., 2020, 2022). Furthermore, satellite information at the local level can be reliable only after calibration with referenced ground-level data, which are largely lacking on the continent. Some studies have explicitly shown that satellite data-modeled outputs (for $PM_{2.5}$) are not always consistent with ground-level monitoring observations over Africa (Awe et al., 2022). Consequently, there has been and remains very limited available (and reliable) data on African air quality to date, which translates into limited available interdisciplinary research.

4.2. Satellite air quality data in interdisciplinary and inter-geographical knowledge exchange with Africa

4.2.1. Interdisciplinarity of air quality research

Greater dialogue between disciplines and transdisciplinary research fosters cross-fertilization by integrating diverse perspectives, methodologies, and types of knowledge to address complex challenges, like air pollution, in more holistic and innovative ways. While analyzing the literature, it becomes clear that studies using air quality satellite data in Africa adopt a mono-disciplinary approach (76% of the reviewed articles). These publications are mainly derived from natural sciences. They often apply generic and non-contextualized models based on satellite and ground-level air quality data. The remaining 24% of the articles take, or attempts to take, an interdisciplinary approach combining air quality satellite data with other types of data or studies in order to test potential impact of air quality on, most frequently, health (Bachwenkizi et al., 2021, 2022; Etchie et al., 2018; Fisher et al., 2021; Fleischer et al., 2014; Heft-Neal et al., 2018; Kalisa et al., 2023; Larson et al., 2022; Lelieveld et al., 2015; Lin, Guo, Di, et al., 2017; Lin, Guo, Kowal, et al., 2017; Marais et al., 2019; Owili et al., 2017). A limited number of the reviewed studies link air quality to some elements of the inclusive development (i.e., disability (Lin, Guo, Di, et al., 2017), community and occupational exposure (Kwarteng et al., 2020; Martinez-Alonso et al., 2023); exposure of vulnerable residents to air pollution (Dasgupta et al., 2020); economic growth (United Nations Environment Programme, 2023b); urbanization (Wei et al., 2021); link between socioeconomic development and air pollution (Hickman et al., 2021); agriculture activities and air pollution (Shikwambana et al., 2022); identifying areas facing both high social vulnerability and air pollution levels (Clarke et al., 2022); and assessing air quality trends with the climate factors, socioeconomic indicators, and terrain characteristics (Ouma et al., 2024). These studies, though, still tend to adopt a siloed approach. While they often reference the potential inclusive development impacts, they rarely test them using methods from both disciplines.

Although beyond the scope of this review, an observation was made about a growing body of literature that links vulnerability and some inclusive development lenses to air pollution in Africa—yet without the use of satellite data to establish the links (among others: urban climate justice (Corburn et al., 2022; Flanagan et al., 2021); risk exposure (Becerra et al., 2020; Ngo et al, 2017); air quality and socioeconomic status (John & Das, 2012; Manshur et al., 2023; Mutahi et al., 2021; Ngo et al., 2019; Olaniyan et al., 2020; Rooney et al., 2012). The key methods of assessing air quality in the above-mentioned literature are either analysis of data derived from (lower-cost) ground-level sensors or engaged citizen science. Alternatively, the air quality data is retrieved from existing databases. This not only shows an increasing interest in establishing further evidence about the link between air quality and vulnerability, but it also indicates that the social science community is not aware, or not able to use, available air quality satellite data. These observations point to siloed approaches in both the natural as well as the social sciences. These silos result in and are the consequence of differences in access to and use of data, compounded by a lack of communication, co-creation, and cross learning around a common set of interdisciplinary data that can be used in both natural and social sciences.

4.2.2. Cross-geographical knowledge exchange

Regarding data, a number of global emission inventories have been published to date, and these have been used for air quality

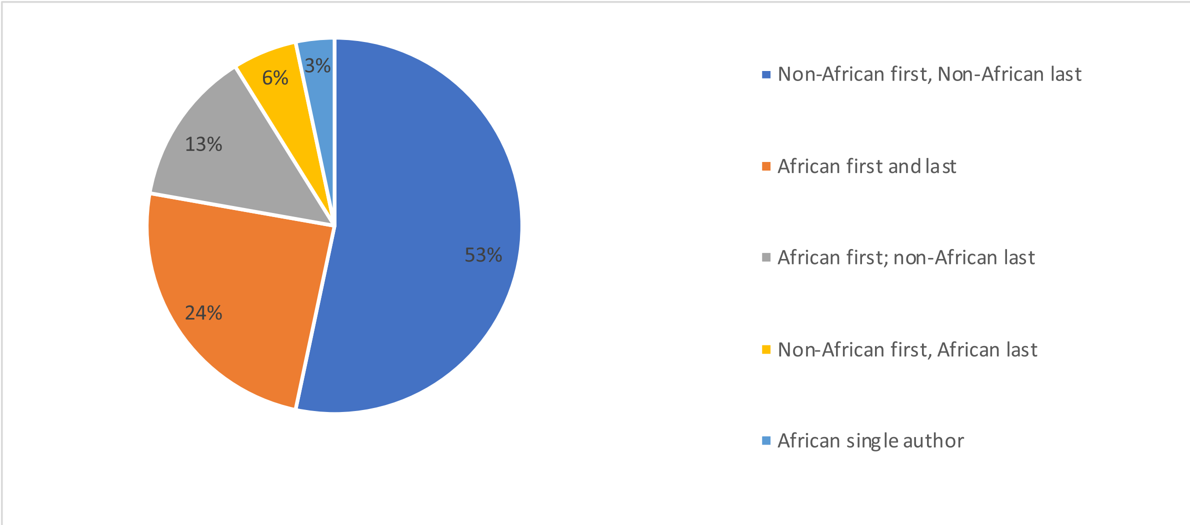

Figure 8. The affiliations of the reviewed articles' authors. Source: Own calculations.

and climate change modeling in Africa (i.e., Duncan et al., 2016; Fioletov et al., 2020). These works used detailed emissions available at the regional scale for North America, Europe, and Asia, but not for Africa, for which there is a general lack of detailed anthropogenic inventories at the continental and regional scales. This means that the models that are currently used for air quality and climate change in Africa rely on global inventories that are primarily collected from outside Africa and based on generalized assumptions. This inevitably creates a bias and higher uncertainty in the assessment of air quality and its impacts on the continent. Recently, a new community modeling infrastructure has enabled the study of atmospheric composition and chemistry over Africa: The Multi-Scale Infrastructure for Chemistry and Aerosols Version 0 (MUSICAv0). MUSICAv0 has been designed to simulate air quality and chemical transport across multiple spatial scales (Tang et al., 2023). The model developed for East Africa, however, suggests that the region exhibits the largest model–*in situ* observation discrepancies (Tang et al., 2023). This means that to enhance monitoring processes across the continent, Africa must significantly improve its emission maps and atmospheric modeling capabilities, as even the best models cannot perform well without accurate and reliable data.

Excluding studies with a global scope, there are two major review articles on air quality issues in Africa: Simwela et al. (2018) and, more recently, Agbo et al. (2021). Although the evidence base in Agbo et al. (2021) has substantially grown in comparison to the Simwela et al. (2018) publication (which also looked at the air quality literature more broadly), both reviews highlight the very serious situation related to air quality in Africa, the lack of political responsiveness caused by limited data, and they also call for more research. Moreover, Okello et al. (2023) undertakes a scoping review of strategies developed and/or implemented in Africa for improving air quality and/or health outcomes, co-benefits of the strategies, potential collaborators, and pitfalls of current air quality management strategies in Africa. Neither of the reviews explicitly analyze the data source of the articles under review. An analysis of the references used in these review articles indicates that only a handful of publications have used satellite data, basing their analysis on mostly temporary ground measurements campaigns.

Regarding authorship, an increased number of articles authored by African scholars (as the first and the last author) has been noted in recent years. Although the publications written by non-African (first and last) authors still constitute over 50% of all the reviewed articles, the remaining 46% involved African scholars in either lead-authorship (40%, including solo publications) or as the final author (6%) (Figure 8). Among the articles first-authored by the scientists affiliated to an African institute (37 in total), only three of them published research on an African country other than the one in which their institution was based. This means that an important in-country expertise has been generated.

Most 'non-African authors' (first and last ones) were affiliated with institutions in North America (USA and Canada), Asia, and Europe. It should be noted that some of these authors do have links to Africa (i.e., they published while affiliated with a foreign institution during his or her (temporary) PhD contract but have since returned to their country of origin. Tracking the career paths of the authors was beyond the scope of this research). Despite this lack of precision, a small positive trend can be observed in increased capacity and interest in this climate-change-related topic among locally based scholars. This is an important observation, which would ideally lead to increased flow of research funding to African institutions, locally led research projects, an increase in African-led scientific publications, and finally, bringing local and contextual voices to the global discussion currently dominated by the 'northern' perspective (Overland & Sovacool, 2020).

To this end, the authors of this article would like to reflect on the disciplinary and geographic composition of their team. We acknowledge that, like much of the scholarship on air quality in Africa, this paper is authored predominantly by researchers based in institutions located in the Global North. This mirrors an ongoing structural imbalance in academic publishing. However, our team is intentionally interdisciplinary (social and natural science) and intergeographical, with contributors from African and non-African institutions, including the University of Pretoria and the African Studies Centre at Leiden University. We believe that collaboration with African scholars is not only ethical and necessary but also vital. Local expertise provides critical insights into the lived realities, behavioral dynamics, and socio-political contexts that shape both the causes of and responses to air pollution. The work of African scholars, often under-cited, plays a critical role in identifying contextually grounded, African-led, home-grown solutions that are not only scientifically sound but also politically and socially feasible. Our inclusion of key African references throughout the paper is a deliberate effort to highlight this contribution and to align scientific research with the realities and agency of African communities and policy processes.

5. Conclusions

This paper has argued that air quality in Africa should be analyzed through a telecoupling lens, as a transboundary, interdisciplinary challenge rather than a localized environmental concern. The application of this framework reveals a number of complexities stemming from different telecoupled systems in relation to the Africa–Global North AQ dynamics. Sending, receiving, and spillover systems are constantly intertwined through the exchange of air pollution, as well as through the on-the-ground activities that exacerbate both the pollution and its subsequent impacts. Our analysis also reveals the uneven distribution of monitoring infrastructure, as well as the marginalization of African voices in the global air quality agenda. These dynamics are shaped by deeply embedded patterns of epistemic and environmental injustice, where knowledge production, data access, and policy influence remain disproportionately concentrated in the Global North, despite the most acute burdens of air pollution falling on vulnerable populations across Africa.

This article argues that the risk exposure to air pollution is shaped by socio-political and natural processes across multiple scales. A lack of or insufficient air quality data hampers a better understanding of this telecoupled phenomenon. National and local governments in Africa often lack, or possess only partial knowledge of, pollutants' concentrations and trends, which makes it difficult to evaluate the effectiveness of the strategies and policies, select target values, and set priorities that are adapted to the local context (Okello et al., 2023). Moreover, numbers, graphs, and pollution maps only tell half the story. The multi-scalar and interdependent nature of air pollution presents a complex landscape for air quality studies.

To this end, our meta-synthesis of 90 studies shows that while satellite-derived data holds significant promise for bridging critical air quality data gaps, its use remains limited and predominantly led by natural scientists, with very limited complementary discussions from the social science perspective. The siloed nature of current research, where natural and social sciences often operate in isolation, hinders effective communication, co-creation, and interdisciplinary learning, preventing the utilization of a common set of data for holistic research and policy development. Consequently, understanding spatial heterogeneity in the prevalence of air pollution, its differential impacts on various population groups, and regional and global responses are areas that require further exploration.

Furthermore, African scholars and institutions, though increasingly present in the literature, continue to face structural barriers to leading or shaping the research agenda. These are, among others, the lack of emissions data, ground-level monitoring for concentration validation, weak or lack of political frameworks, context-specific air quality assessment models, and the (abovementioned) siloed approach within the research community. To address these challenges, it is crucial to prioritize awareness-building, contextualize progress, and highlight the unique challenges and solutions specific to monitoring air pollution in Africa. Satellite-based air quality data provides a promising source of information. Collaborative efforts involving multiple scientific disciplines from both the Global North and South are essential for creating sustainable and inclusive research and practice communities.

To address these challenges, we advocate for a transformative research agenda grounded in three pillars: interdisciplinary integration, inter-regional collaboration, and data justice. Central to this agenda is the concept of inclusive development, which we adopt as an umbrella framework encompassing the socioeconomic, environmental, and health dimensions of air quality impacts. By prioritizing locally relevant data generation, investing in capacity-building, and fostering reciprocal learning between disciplines and regions, it is possible to reposition air quality not only as a scientific or technical issue, but as a cornerstone of inclusive development and climate justice.

Ultimately, the telecoupling perspective offers a powerful analytical and practical tool to reframe the air pollution discussion in Africa. It encourages scholars, practitioners, and policymakers to move beyond fragmented, siloed approaches toward a more interconnected, equitable, and actionable understanding of how air quality links people, places, and policies across vast distances. Only by acknowledging and addressing these complex interdependencies can we hope to bridge disciplinary divides, promote interdisciplinary research between continents, and enhance our understanding of air pollution's socioeconomic impacts, ultimately contributing to more sustainable and inclusive development across the continent and beyond.

Supplementary material. The supplementary material for this article can be found at https://doi.org/10.1017/sus.2025.10019.

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Competing interests. None.

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