

Review

Climate Change, Air Pollution, and Human Health in the Kruger to Canyons Biosphere Region, South Africa, and Amazonas, Brazil: A Narrative Review

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Abstract: There is a 50% possibility that global temperatures will have risen by more than 5 °C by the year 2100. As demands on Earth's systems grow more unsustainable, human security is clearly at stake. This narrative review provides an overview and synthesis of findings in relation to climate change, air pollution, and human health within the Global South context, focusing on case study geographic locations in South Africa and Brazil. Two case study regions—the Kruger to Canyons Biosphere region of South Africa and the Amazon region of Brazil—were the subjects of PubMed literature searches. Technical reports, policy briefs, and grey literature were also narratively synthesized. The burning of wood for fuel, as witnessed in Agincourt, and forest fires, such as those seen in the Amazon rainforest, release air pollutants such as methane and black carbon, which are strong short-lived climate pollutants (SLCPs) which fuel climate change and adversely affect human health. SLCPs have a brief lifetime in the atmosphere, but they frequently have a far larger potential for global warming than carbon dioxide (CO₂). Most air pollution in geographic case study areas, that are home to human settlements, is due to the burning of wood and other biomasses that are pollutants. These areas are seen to be important for climate and health responses, and if constructive action is taken to switch to other modes of electricity generation (such as solar power) and the prevention of deforestation, the worst of the impacts may still be mitigated in these regions. Authorities should also establish a monitoring strategy for air quality, as well as enforce air quality regulations that safeguard public health.

Keywords: climate change; air pollution; human health; Kruger to Canyons Biosphere; Amazon; South Africa; Brazil; Global South



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1. Introduction

Air pollution is thought to be the most serious threat to public health globally, causing an estimated 7 million premature deaths annually. Since all major pollutants have an effect on the climate and are similar to greenhouse gases, air pollution and climate change are also closely related. Despite being a worldwide problem, air pollution disproportionately affects more vulnerable populations such as women, children, and the elderly, as well as those who live in underdeveloped countries. Strokes, heart disease, lung disease, lower respiratory illnesses like pneumonia, and cancer are the deadliest diseases linked to particle pollution from fine particles (PM_{2.5}) [1]. PM_{2.5} refers to particulate matter that is 2.5 μm or smaller in diameter. These particles are small enough to penetrate deep into the lungs when inhaled, and even enter the bloodstream, posing various health risks. In addition to causing mental disease and impairing cognitive development, high amounts of PM_{2.5} can also induce diabetes. Furthermore, exposure to air pollution is thought to be a contributing factor in 20% of neonatal deaths globally. In addition, food security is threatened, cities and human settlements become unhealthy, and air pollution adds exponentially to climate change [2,3].

The primary cause for concern regarding climate change presently is the remarkably rapid rise in the average worldwide temperature, which is occurring fifteen to sixty times faster than the natural rate observed by humans since the dawn of civilization [4]. Paleoclimate records indicate that an additional 1 °C of warming will surpass the average global temperature during the past million years. An increase of 2 to 3 °C will have a profound impact on Earth as we know it. This temperature threshold has not been reached since three million years ago, when the sea level was 25 to 35 m higher than it is today [5]. Numerous climate experts caution that if humanity does not move to lower or halt the current high levels of emissions, we will soon find ourselves in a dangerous situation with disastrous outcomes. To prevent the worst-case scenarios of climate change, the rise in the global mean temperature must be kept below the lower bound of the predicted range and not exceed 2 °C. The likelihood of mankind averting a rise in the global average temperature of more than 2 °C is 80%, making it improbable or extremely unlikely if atmospheric carbon dioxide equivalent concentrations surpass 550 parts per million [6].

Human settlements in places which illustrate well the effects of economic globalization are the Kruger to Canyons Biosphere Region in South Africa and the Amazonas state in Brazil. In these two biomes, natural disasters such as droughts, air pollution related to deforestation and the burning of wood, economic and geopolitical strains, inequality in healthcare access and the economy, and climate change all converge, undermining the coping strategies usually employed to handle catastrophic occurrences, including pandemics. Many of the already-existing economic and social issues in South Africa and Brazil are also becoming worse as a consequence of the COVID-19 pandemic. This article synthesizes and discusses the main study outcomes in the two biomes in relation to climate change, air pollution, and human health.

2. Methods

The Kruger to Canyons Biosphere Region in South Africa and the Amazonas state in Brazil are examined in this narrative review as comparative geographic case studies with respect to climate change, air pollution, and human health. These two sites were selected as greenhouse gas (GHG) emissions are expected to rise in these areas in the future, causing extensive deterioration in both biomes, which are thought to be significant [7]. The two biomes have also been selected because of their significance to tourism, the environment, and international relations. In addition, there are persistent sustainability-related problems in both regions that are linked to poverty and the general vulnerability of the corresponding indigenous communities, as well as their ensuing equal access to healthcare. In addition, I have travelled across the two biomes and countries (in 2015, 2018, and 2021). I also presently work and live part-time on the periphery of the Kruger to Canyons Biosphere Region, located immediately south of the Sabie River. The demographic, climate change, air pollution, and healthcare infrastructure dynamics on the Kruger to Canyons Biosphere Region, South Africa, are covered in the first half of the Results section of the paper. The second half of the Results covers a similar synthesis with reference to the state of Amazonas in Brazil. The aim of this article is to synthesis and discuss the main study outcomes in the two biomes in relation to climate change, air pollution, and human health (including health systems).

A PubMed literature search was undertaken on the 16 February 2024 and again on the 23 April 2024, using the following MeSH codes: (“air pollution” [All Fields] AND “climate change” [All Fields] AND “human health” [All Fields] AND “Kruger to Canyons Biosphere” [All Fields]) OR “Agincourt” [All Fields] OR “South Africa” [All Fields] AND “Amazonas” [All Fields] OR “Brazil” [All Fields], which, in terms of modeling studies, narrative and systematic reviews, case studies, case series, or qualitative research pertaining to integrated outputs related to climate change, air pollution, and human health in these two biomes specifically, have not provided any synthesized focal area outputs as of yet. Although data on climate change, air pollution, and human health in isolation are, therefore, dispersed and fragmented throughout these two regions and nations, it has been possible

to locate and compile more localized information (including academic articles, technical reports, and grey literature) on these topics and their effects on health in the two biomes and regions. Such information has been thematically analyzed to identify common themes, patterns, and relationships across studies, and subsequently synthesized in the form of this narrative review.

3. Results

3.1. Case Study: Climate Change, Air Pollution, and Human Health Kruger to Canyons Biosphere Region, South Africa, and Amazonas, Brazil

The use of wood as fuel, forest fires, and wildfires—which are frequently observed in the Amazon rainforest, for example—is known to have a negative influence on the environment, including air pollution. They also have an impact on the climate as they release significant amounts of greenhouse gases, such as carbon dioxide, into the atmosphere. Not much research has been conducted on how fires affect the quality of the air and human health [8]. Moreover, the SARS-CoV-2 (COVID-19) pandemic expanded swiftly across the globe in 2020 and 2021, with new strains mostly emerging in South Africa, Brazil, and the United Kingdom. Following the devastating Spanish flu of 1918–1920, this pandemic has been the worst [9]. Nowadays, it is common knowledge that a significant number of recently emerging infectious diseases—possibly even the novel COVID-19 virus—have animal origins. Thus, the destruction of ecosystems such as rainforests, which is made worse by climate change and driven by economic development, creates an ideal backdrop for the emergence of new diseases [10,11]. Researchers remain in the early stages of molecular research into the virus’s environmental sensitivity, and climate is not yet known to be a driver of COVID-19. However, there are phases during the zoonotic spillover process when climate forcing can be reasonably expected. Zoonotic spillover is the multilayered process by which diseases (including COVID-19, Ebola, human immunodeficiency virus (HIV), and avian influenza viruses) can spread to different animal species and pass through several naturally existing barriers before being established. Thus, the environment should be seen as a significant but not sufficient factor that affects the origin of diseases [12]. Additionally, limited research conducted in South Africa and Brazil reveals that the respective health systems are largely unprepared for the increasing strain that climate change would bring [13,14].

3.1.1. Kruger to Canyons Biosphere Region, South Africa

Northeastern South Africa’s Kruger to Canyons Biosphere Region is shared by the provinces of Limpopo and Mpumalanga (Figure 1). The biosphere includes two of the most visited tourist locations in South Africa, the Blyde River Canyon and Kruger National Park, as well as the Wolkberg Region, one of the world’s top flower hotspots. The Letaba River in the north, the Sabie River in the south, the Blyde Escarpment in the west, and the border with Mozambique in the east currently mark the borders of the recognized Biosphere. This results in a total area of 2,474,700 Ha, of which 898,300 Ha is the core zone, 476,400 Ha is the buffer zone, and 1,100,000 Ha is the transition zone. The core zones of this region are home to about 1155 permanent residents, the buffer zones to 10,475, and the transition zones to 1,488,684 people. This vast geographic range combined with the high population density in the area result in a very dynamic and diverse landscape. Estimates place the proportion of black African residents at 99.35%. The vast majority of people living in the region are underprivileged, live in inadequate dwellings, have no or limited means of transportation, and lack access to private medical care [15].

The principal municipality in the region, Bushbuckridge (see Figure 2), is a prime illustration of a socio-ecological system. It is noteworthy for having a cultural environment where the interdependence of the community and the biophysical environment is apparent. Along with the arrival of Mozambican migrants in the 1990s who were fleeing the armed conflict in their homeland, the forced relocation of black Africans during the apartheid administration from the 1950s to the 1980s, which implied separate development and

a framework of social and economic inequality and depravity, has sustained a growing concentration of population in the area [16]. Numerous problems that affect the region are also common to all South Africa, such as a high HIV/AIDS rate, poverty, and an inadequate organizational governance framework [16,17].



Figure 1. The Kruger to Canyons Biosphere location in South Africa. Source: <https://kruger2canyons.org/kruger-to-canyons/>, accessed on the 2 April 2024.

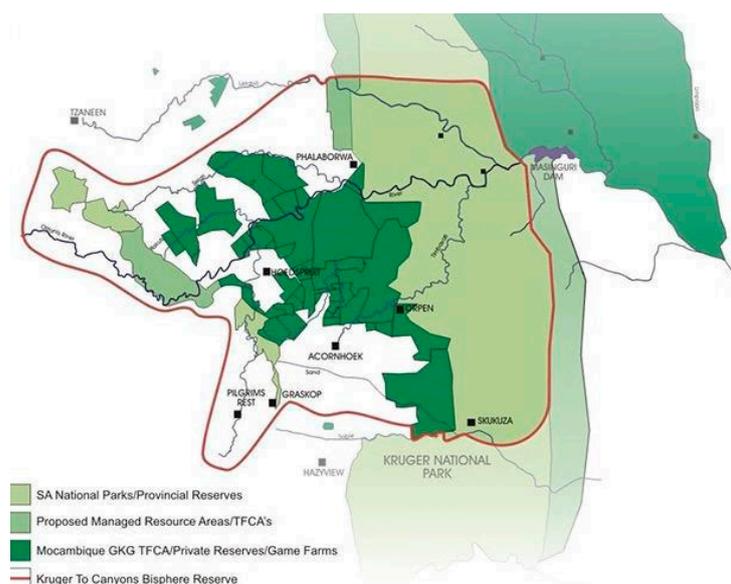


Figure 2. Kruger to Canyons Biosphere and Bushbuckridge Municipality. Source: <http://www.mpumalanga-info.co.za/provinces/article/181/kruger-national-park-biosphere-reserve>, accessed on the 2 April 2024.

Agincourt is a town within the Bushbuckridge Local Municipality, which was formerly an informal settlement (or squatter camp) under the Apartheid regime. A total of 44% (70/159) of Agincourt households primarily use fuels other than electricity for cooking, and 67% (106/159) of Agincourt homes are situated on unpaved roads, which is linked to the production of dust and particulate matter. These findings highlight Agincourt's unfavorable housing conditions, which may have an impact on the severity or transmission of disease [18]. The quality of cooking and heating appliances, ventilation techniques, overcrowding, and the type of fuel used for cooking (or water/space heating) can all affect a household's exposure to indoor air pollution and the risk of developing a variety of respiratory and communicable diseases [19]. Wood and other biomass constitute

a significant contributor to household air pollution. These sources produce fine particles, or PM_{2.5}, which are especially dangerous for public health [20]. Public health is predicted to significantly improve with a change from residential biomass use to electricity (which could be generated by solar power) and other safer fuels [21]. However, there is a dearth of comprehensive data regarding housing problems in emerging nations, particularly in African contexts. Among the main causes of particulate matter exposure are probably the extensive use of liquid and solid fuels for cooking and space heating, a lack of municipal garbage collection services, which frequently results in the burning of solid waste in backyards, and unpaved roads. Similar to water supply, Agincourt is the site of the greatest health concerns with particulate matter exposure from biomass, as reports of somewhat extensive wood fuel use are supported by substantial monthly household wood expenditures [18].

Furthermore, the workforce assessment results of eight (out of ten) Agincourt health-care facilities revealed that the greatest need across the facilities related to adequate access to medical doctors and pharmacists, with three facilities entirely lacking such access. This study focused on climate change and healthcare sustainability in the Agincourt sub-district of the Kruger to Canyons Biosphere. Patients were forced to rely on the unauthorized taxi business as a means of transport because only three of the facilities had adequate road access, and none had patient transportation strategies in place [13]. Due to the past political discrimination caused by Apartheid, many of South Africa's impoverished people remain geographically isolated, making "transport poverty" an underestimated but very real issue [22]. Furthermore, one facility did not have working toilets or running water at the time of the study, which was extremely dangerous for people's health [13].

3.1.2. Amazonas, Brazil

Located in the northwest of the nation lies the Amazonas federal state of Brazil, which sources its name from the Amazon River (see Figure 3). It is the largest state by area in Brazil and the seventh largest national subdivision across the globe. Tropical rainforest covers most of the state, and cities and human settlements are concentrated along navigable canals that are only accessible by boat or aircraft [23]. Prior to the rubber boom of the 19th century, the state experienced little change. There are over 240 indigenous communities in the Amazonas, most of which are semi-nomadic and make their living by migratory farming, fishing, hunting, and gathering. The Amazon rainforest is believed to be the world's largest carbon dioxide sink, capturing 25% of global carbon dioxide emissions. Therefore, minimizing the effects of global warming depends heavily on the Amazon rainforest [24]. Additionally, there have been few research studies examining the effects of wildfires on air quality and health in the very fire-prone Amazonas region [8]. More than half a million square kilometers have been destroyed since 1985, when the government started keeping track of the Amazon's deforestation. Fires are usually the result of this deforestation since the vegetation left behind after important trees are cut down is burned, frequently without permission. In order to make way for agriculture, livestock grazing, or land speculation, fires burn in the Amazon year-round, but they often reach their height from July to October during the dry season. The air pollution caused by these fires is extremely dangerous to human health. Particularly at risk are young people, the elderly, expectant mothers, and those with pre-existing heart or lung conditions [25].

The Amazon Environmental Research Institute (Instituto de Pesquisa Ambiental da Amazônia, IPAM), Human Rights Watch, and the Institute for Health Policy Studies (Instituto de Estudos para Políticas de Saúde, IEPS) jointly assessed the health impact of fires caused by deforestation in the Brazilian Amazon in 2019 [26]. Using official data, IPAM analyzed the patterns in fires and deforestation for the year. Using official data on hospitalizations for respiratory illnesses and air pollution, IEPS performed a statistical analysis of the health effects of these trends (the statistical study is available). Human Rights Watch examined policy papers and spoke with representatives of the Brazilian Amazon's five states' health departments, medical professionals, and other interested parties. According to this report's results, public health in the Amazon region suffered significantly

in 2019 as a result of fires caused by deforestation. This includes 2195 hospitalizations for respiratory illnesses linked to the fires, per a statistical analysis carried out by IEPS in collaboration with Human Rights Watch and IPAM. Of these, 1080 hospitalizations (49%) involved individuals 60 years of age and older, while 467 hospitalizations (21%) involved infants aged 0 to 12 months. According to the report, individuals who were exposed to air pollution from fires in 2019 spent a total of 6698 days in the hospital [26].



Figure 3. Amazonas state location. Source: Encyclopedia Britannica, <https://www.britannica.com/place/Amazonas-state-Brazil>, accessed on the 4 April 2024.

Furthermore, hospitalization data may not fully reflect the impact on health because many people in the Amazon have extremely limited access to medical facilities. Private institutions are not included in the data that are currently accessible, despite the fact that 25% of Brazilians have private insurance and frequently visit these places for services. Furthermore, they ignore the much greater proportion of individuals whose respiratory issues, albeit being severe, did not necessitate hospitalization [25]. In addition, the emergence of COVID-19 made the effects of fires on health in 2020 harsher. Health officials, medical professionals, and specialists worry that hospitals, already overburdened by the COVID-19 outbreak, found it difficult to treat fire victims, leading to a collapse of the health system in some areas of the Amazon. When people with respiratory conditions brought on by fires travel great distances to receive complicated care—as residents of the Amazon region frequently must—they run the added risk of catching the virus. Furthermore, the smoke made the virus’s symptoms worse, leading to more severe cases, and it may have increased the number of COVID-19-related deaths [25]. The capital and largest city of the state of Amazonas, Manaus (refer to Figure 4), was among the areas of the world most severely impacted by COVID-19 outbreaks in April and May of 2020. The city is known as the entry point to the Amazon jungle, and its main mode of transportation is via boat. Photographs and videos captured the aftermath of the Manaus healthcare system collapse, documenting Brazil’s coronavirus tragedy, which had mortality rates second only to the United States. About thirty public and private hospitals in Manaus serve many of the isolated indigenous and small settlements nearby. Nevertheless, the majority of approaches to the town must be made by river or by air due to the lack of road connections, making it difficult to reach there and equip such clinics and hospitals. Photographs and videos of thousands of recently excavated graves became emblematic of Brazil’s coronavirus crisis, with fatality rates second only to that of the United States, following the collapse of the healthcare system in Manaus. Frontline medical workers had to work chaotic 36 h hospital shifts as a result of COVID-19. Manaus’s cemeteries have also become even more packed. There are about thirty public and private hospitals in Manaus that provide healthcare to many remote indigenous settlements and small towns nearby. But reaching there and

outfitting those clinics and hospitals can be challenging logistically because there are not many road links; therefore, the majority of approaches to the town must be made by air or by water [27].



Figure 4. Manaus locality in Amazonas state. *Source:* Amazonas, v-brazil.com, <https://za.pinterest.com/pin/358388082817148277/> accessed on the 4 April 2024.

Moreover, official air quality data allow for at least the quantifying of how many individuals are exposed to the poisonous smoke. However, it is impossible to properly determine the overall number of persons whose health worsened due to smoke from the fires due to the lack of solid health data beyond hospitalizations. In August 2019, the World Health Organization (WHO) recommended a threshold for PM 2.5 exposure, which is dangerously high levels of fine particulate matter that can be hazardous to human health. This threshold was exceeded by approximately three million residents living in ninety municipalities inside the Amazon region. In September, the affected population in 168 municipalities climbed to 4.5 million. This pollution has been connected to respiratory and cardiovascular conditions, early mortality, and a high correlation with the frequency of fires in the Amazon. Indigenous people in the Amazon are particularly affected by the fires' effects on public health. Their livelihoods are impacted by the environmental damage, but so is their health. Indigenous lands are frequently the site of illegal clear-cutting and the fires that follow, which can occasionally destroy crops and reduce the availability of food, medicine, and game for hunting [25].

4. Discussion

Preserving human health and guaranteeing fair access to healthcare must be one of the top priorities in all attempts to reduce and adapt to climate change, global warming must be limited to 1.5 degrees Celsius, and a threshold of $-10.0 \mu\text{g}/\text{m}^3$ appears optimal for controlling negative PM2.5 data in public reporting [28]. Furthermore, the COVID-19 health crisis has adequately illustrated the importance of consulting with and considering the views of medical and health communities when making decisions related to strategic planning. It has also brought attention to the disparate impacts of the dangers within the Global South context. All governments must enact robust national climate pledges if they are to sustain a healthy and ecologically sustainable pandemic recovery [29]. The need for access to healthcare in the Global South will become more pressing as a result of the fact that impoverished populations—especially those living in human settlements—are more susceptible to the negative health consequences of climate change [13].

Social justice and health also need to be given top priority in climate negotiations, according to the World Health Organization's COP26 Special Report on Climate Change and Health (2021) [30]. The mental health sector must be prioritized in climate change

initiatives, even though it is evident that there is a lack of scientific information regarding the impacts of climate change on health and health systems generally within the Global South context. Climate-related risks and air pollution may also contribute to mental health conditions like anxiety, depression, PTSD, and suicide, despite the paucity of empirical research in this field. Climate-related risks that result in negative outcomes like economic loss and displacement (due to, for example, droughts in rural areas or air pollution in human settlements) may increase the prevalence of mental health disorders [31]. Furthermore, those who already struggle with mental or physical health problems can be more vulnerable to these changes and helpless against them. Other mental problems that can become more common after a catastrophic or life-threatening event include trauma, post-traumatic stress disorder, anxiety and depression, chronic pain, and solastalgia [32].

The scant research conducted in Africa indicates that the health sector is largely unprepared for the heightened demands that climate change will inevitably bring about [13]. However, a perspective based on society and technology consistent with the fourth industrial revolution can help to strengthen the resilience of healthcare systems in the African context [22]. It has lately come to light that telemedicine and other comparable strategies can be successfully implemented in many sub-Saharan African countries, for example, providing otherwise absent mental health and medical professionals with access to vulnerable populations. This was particularly apparent when the COVID-19 outbreak was occurring [13,33]. However, successful telemedicine implementation requires such connections' technology, which is not often the case in rural areas [29]. Furthermore, switching from domestic biomass use to electricity (which could be solar generated) and other cleaner fuels is expected to greatly enhance community health in South Africa's human settlements [21].

There are also far-reaching effects of the degradation of the Brazilian Amazon outside of Brazil. Given that rainforests absorb and store carbon dioxide over time, they serve as natural storage locations for this key greenhouse gas that is responsible for climate change. In this sense, the Amazon is a remarkable barrier against climate change, storing over 100 billion tons of carbon, or ten years' worth of greenhouse gas emissions worldwide, and removing about 600 million tons annually from the atmosphere. On the other hand, fires and deforestation have the opposite effect, releasing massive volumes of carbon dioxide into the sky when a forest is burned and cut. The fires will continue to devastate the rainforest and contaminate the air that millions of Brazilians breathe until Brazil takes decisive action to stop deforestation [25].

5. Conclusions

In addition to endangering people's health and wellbeing, air pollution also plays a significant role in climate change, jeopardizes food security, and destabilizes human settlements. Local action is insufficient to address this situation. To combat the cause of bad air in a sustainable manner, regional collaboration is also necessary. Enhancing the quality of the air will help development, the environment, and human health. Despite being a worldwide issue, air pollution disproportionately affects people who live in developing countries, especially the most vulnerable, including women, children, and the elderly [3]. Additionally, COVID-19 has been a driving force behind the transformation of existing notions of sustainable development in general, and sustainable supply chains in the healthcare sector specifically, within the South African and Brazilian context.

Above all, by keeping its promises to lessen deforestation in the Amazon, the Brazilian government should work to stop the cause of the suffering. As part of the Paris Climate Agreement, Brazil committed to putting an end to illicit deforestation by 2030. Brazil pledged, under its legally enforceable National Policy on Climate Change, to bring Amazon deforestation down to less than 3925 square km a year by 2020. However, by the end of July 2020, 4700 square km had already been cleared of forest, even according to the official projection, which is the most conservative. This area is greater than the area that was cleared of trees during 2019, and it is already far beyond the limit that Brazil set for itself in its climate promises for 2020 [25].

According to their international commitments to uphold the rights to health and a healthy environment, South Africa and Brazil should both take more action to address this ongoing and avoidable public health crisis. This should include preventing fires, deforestation, and indoor air pollution to lessen their negative health effects. It is recommended that authorities establish a monitoring strategy for air quality that is both effective and responsive, and that they enforce air quality regulations that safeguard public health.

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