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Substantial increase in population exposure to multiple environmental burden in sub-Saharan Africa (2000-2019)

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Long Abstract

Environmental uncertainties have increased worldwide. Unprecedented episodes of heat waves, droughts, and floods have been striking different regions in recent decades[1]. Half of the global population is exposed to increasing fine particulate matter ($PM_{2.5}$) air pollution[2]. Approximately 420 million hectares of forest loss has been reported due to conversions to other land uses since 1990[3]. Surging extreme weather events and pollution levels can pose negative consequences for health and well-being. In 2016, up to 24% of all deaths worldwide were due to adverse environmental conditions[4]. However, these challenges are far from uniform, varying significantly in magnitude and impact at international, national, and subnational scales.

Sub-Saharan Africa remains at higher risk due to intensifying environmental challenges[5]. The literature suggests rising temperature levels[6–8], deteriorating air quality[9], recurring droughts[10,11], and rampant land use/land cover change[12], among others, as key environmental challenges posing adverse impacts on the health and well-being of over a billion people. The adversities aggregate, as much of its population remains under the poverty line, i.e., representing around two-thirds of the global extreme poor population in 2018[13]. Additionally, many of the countries of the subcontinent are marked by large inequalities and little social protection[14], meaning that much of their population is likely to be unable to absorb the shocks related to a changing environment. Moreover, the lack of sufficient and timely environmental monitoring on the ground is another issue. For instance, the World Air Quality Report-2022[15] captures data from over 30,000 air quality monitoring stations, of which only 156 stations are located in Africa. Another study[16] highlights only 1 ground-level air quality monitor per 15.9 million people in sub-Saharan Africa. These conditions limit the power of national or international indicators in explaining spatially varying environmental conditions. In light of these limitations, the role of publicly accessible spatial data on the environment is immense, allowing temporally and spatially efficient environmental monitoring and informing targeted adaptation strategies.

Environmental exposure studies[6,8,17–19] have demonstrated the wide applicability of remote sensing and geospatial data to link specific environmental indicators with demographic and health indicators. However, it is imperative to recognize that different environmental challenges often coexist in the same geographical location, compounding risks for the populations residing there[20].

In the context of this study, we focus on hazardous levels of $PM_{2.5}$, temperature increase and prolonged drought severity, and green deficit as key environmental risk factors. We report the simultaneous presence of more than one of these risk factors as 'multiple environmental burden' (MEB). We quantify the population exposed to each of these key environmental risk factors and to MEB in sub-Saharan Africa at the finest spatial resolution (1 km grid cell) for 2000 and 2019 and analyse the changes in exposure over this period. We also ask: what is the contribution of population change, environmental change, and their interaction to the change in exposure to specific environmental risk factors and MEB? The findings are then aggregated at national, regional, and subcontinental levels, providing a comprehensive understanding of the population exposed to environmental burden in sub-Saharan Africa.

Data and methods

To derive population and environmental indicators, we employed publicly available raster data (geospatial pixelated data where each pixel presents the value of the indicator, see Table 1). These data were spatially processed (clipped, reprojected, rescaled, and aggregated using zonal statistics) using QGIS. The years 2000 and 2019 were selected to capture long-term changes and to avoid the temporary impact of COVID-19 restrictions on environmental parameters.

Indicator	Source	Spatial resolution and time
Population in pixel	WorldPop project[21]	~1 km 2000, 2019
Fine particulate matter ($PM_{2.5}$)	Atmospheric Composition Analysis Group[22]	~1 km 2000, 2019
Temperature	TerraClimate dataset[23], Climatology lab	~4 km 1980, 2000, 2019
Palmer Drought Severity Index (PDSI)		~4 km 1999, 2000, 2018, 2019
Fraction of Vegetation Cover (FCover)	Copernicus Global Land Service[24]	~1 km 1999, 2000, 2018, 2019

Table 1 Data used in the study.

Environmental burden and population exposure

We have selected four major measurable indicators to partially account for global environmental challenges as air pollution (with $PM_{2.5}$), climate change (with temperature increase), extreme events (with prolonged severe drought), and land cover change (FCover vegetation index). We set thresholds to define the environmental risk factors as:

(a) Hazardous $PM_{2.5}$ levels: pixels with values above 20µg/m^3 (annual average).

(b) Extreme temperature increase: pixels with a 1°C increase or more, in average annual temperature compared to twenty years before (1980 is the reference year for 2000, and 2000 for 2019).

(c) Prolonged severe drought: pixels with PDSI ≤ -3 for at least four months during the year and/or in the previous year (1999-2000 are the reference years for 2000, and 2018-2019 for 2019).

(d) Green deficit: pixels with an average FCover value of less than 0.3, that is where less than 30% of the 1 km grid cell holds vegetation (forest canopy cover).

In the paper we justify the choice of these thresholds.

These four criteria-specific raster data were resampled and rescaled at ~1km resolution, and were superimposed to create raster layers of MEB. The exposed population data were aggregated to country borders using zonal statistics.

Environmental and population effects on exposure

The change in population exposure to an environmental risk factor can be caused by population change, change in the area undergoing this environmental risk factor, or by the interaction of these two elements over time. Following previous studies[8,18], we decomposed the total change in exposure from 2000 to 2019 (ΔExp) into three components: the environmental effect, defined by the product of the population from base year and the variation in the area under extreme environmental conditions ($P_{2000} \times \Delta Env$); the population effect, defined by the product of the population change over time and the area under extreme environmental conditions fixed at base year ($\Delta P \times Env_{2000}$); and the interaction effect, that can be derived from the previous terms (by subtracting the sum of population and environmental effects from total exposure).

Results

Similar analyses were led for all environmental risk factors in 2000 and 2019 and finally, for multiple environmental burden, looking at the addition in the same places of 2 risk factors (2EB), of 3 risk factors (3EB) or of 4 risk factors (4EB). We reported exposure by identifying the number of people living in each grid cell with multiple environmental burden (2EB, 3EB, and 4EB) for both years. Our results are mapped out (e.g. Fig. 5 here) and commented at country level, on the basis of summary tables and risk factor graphs. (not presented in this abstract)

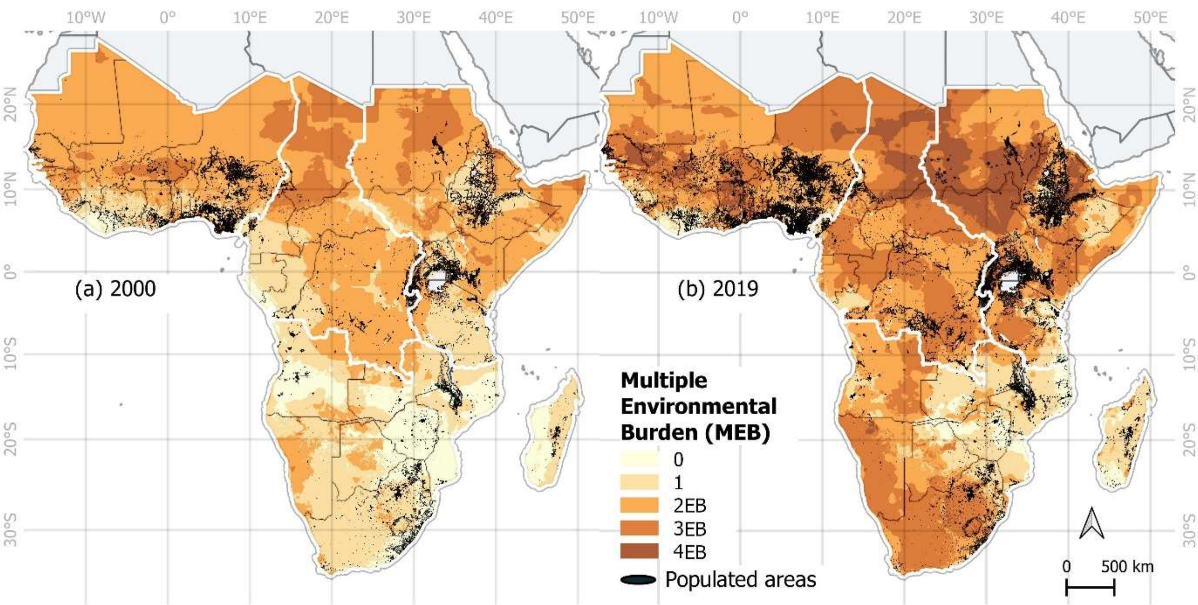

*Figure 1 **Multiple Environmental Burden (MEB) and population exposure.** (a) Spatial patterns of MEB (light to dark blue) and populated areas (black) in 2000; (b) spatial patterns of MEB and populated areas in 2019.*

We find that the population exposed to MEB experienced a remarkable increase over the study period: from approximately 300 million to about 465 million for 2EB, from around 47 million to approximately 292 million for 3EB, and from none to approximately 92 million for 4EB.

This change in exposure is due partly to population increase in places above the chosen thresholds, partly to environmental change per se, and in many cases to the interaction or co-presence of environmental degradation and population growth. We tested this for all risks factors as for Multiple environmental burden. Our results show the role played by environmental change vs population change, as here (Fig. 6), with PM2.5 – mostly related to population growth in exposed areas, and temperature increase – mostly related to the temperatures themselves.

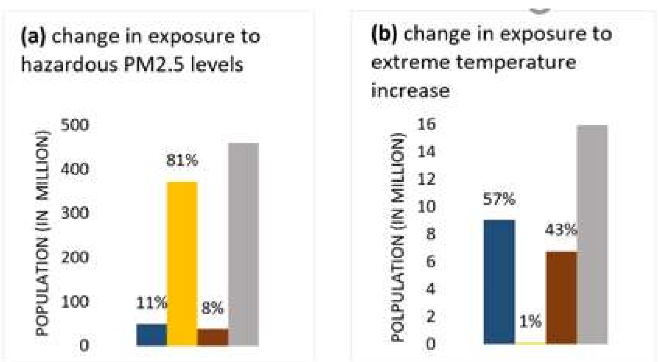

*Figure 2 **Contribution of environmental effect, population effect, and interaction effect** in the change in population exposure from 2000 to 2019 to (a) hazardous PM2.5 levels, (b) extreme temperature increase*

A discussion section and a conclusion follow the result presentation section. While our thresholds are critically defined to represent (multiple) environmental burden, we suggest objective-based modifications for linking these with health indicators.

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