Uncovering Multiple Environmental Burdens in India: Vulnerable Population Exposures at High Spatial Resolution (2000-2019)

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Introduction

Environmental uncertainties are intensifying globally, with unprecedented episodes of heat waves, droughts, and floods affecting various regions over the past few decades. Nearly half of the global population is now exposed to rising levels of fine particulate matter (PM2.5) air pollution (Shaddick et al., 2020). Furthermore, approximately 420 million hectares of forest have been lost since 1990 due to land-use changes (UNEP & FAO, 2020), further stressing ecosystems. These escalating extreme weather events and pollution levels present substantial risks to human health and well-being. According to the World Health Organization, in 2016, up to 24% of global deaths were attributed to adverse environmental conditions (World Health Organization, 2018). However, these environmental challenges differ significantly across international, national, and subnational scales, emphasizing the need for region-specific strategies to address complex environmental risks. India's environmental challenges are particularly severe, given its status as the most populous country and one of the fastest-urbanizing nations. In 2019 alone, air pollution was responsible for an estimated 1.67 million premature deaths, representing 17.8% of the country's total deaths (Pandey et al., 2021). Additionally, over 25,000 deaths in 2022 were attributed to extreme heat (BBC News, 2024), further underscoring the vulnerability of the population to rising temperatures. Forest loss is another concern, as more than 3 lakh hectares of forest land have been diverted for industrial and infrastructure projects in the past two decades (India Today, 2023). In India, these challenges are further exacerbated by socio-economic disparities, extreme poverty, and insufficient health infrastructure. These factors can disproportionately impact vulnerable population groups, such as children, the older adults, and women of reproductive age.

Environmental exposure studies (Baker & Anttila-Hughes, 2020; Iyakaremye et al., 2021; Jones et al., 2015; Liu et al., 2017; Wu et al., 2023) have widely demonstrated the effectiveness of remote sensing and geospatial data in linking specific environmental indicators with demographic and health metrics. However, it is crucial to acknowledge that multiple environmental challenges often overlap within the same geographical area (Sikarwar & Golaz, 2024), exacerbating risks for the populations living in these regions (Feng et al., 2022). This convergence of environmental burdens can amplify health impacts, particularly for vulnerable groups.

Building on prior research conducted in Sub-Saharan Africa (Sikarwar & Golaz, 2024), this study focuses on four key environmental risk factors: hazardous PM2.5 levels, rising temperatures, prolonged droughts, and green deficits (scarcity of vegetation), which represent different dimensions of climate and environmental change. The simultaneous occurrence of two or more of these factors is referred to as 'multiple environmental burdens' (MEB). The analysis specifically targets exposure among vulnerable population groups, including children under 5 years of age, older adults aged 50 and above, and women of reproductive age (15-49 years). This study quantifies the exposure of these groups to each individual risk factor and to MEB across India, using high-resolution (1 km grid) data for the years 2000 and 2019, while assessing changes over time. Additionally, it examines the contributions of population dynamics, environmental changes, and their interactions in driving these exposure shifts. The findings will be aggregated at village, district, and regional levels, to provide a comprehensive understanding of which populations are most affected by these environmental risks. Using open-access, high-resolution spatial data, this research is critical for informing policy decisions at local administrative levels by identifying regions and populations most at risk. Understanding these patterns of exposure will enable the development of targeted, localized strategies for climate adaptation and public health interventions.

Data (as listed in the table below)

Indicator	Source	Spatial resolution and time
Gridded population	WorldPop project(Stevens et al., 2015)	~1 km 2000, 2019
Fine particulate matter ($PM_{2.5}$)	Atmospheric Composition Analysis Group(Van Donkelaar et al., 2021)	~1 km 2000, 2019
Temperature	TerraClimate dataset(Abatzoglou et al., 2018), 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(Camacho et al., 2013)	~1 km 1999, 2000, 2018, 2019

Methodology

Figure 1 outlines the spatial data approach employed in this study (for visual understanding only). Strategic methodological steps include:

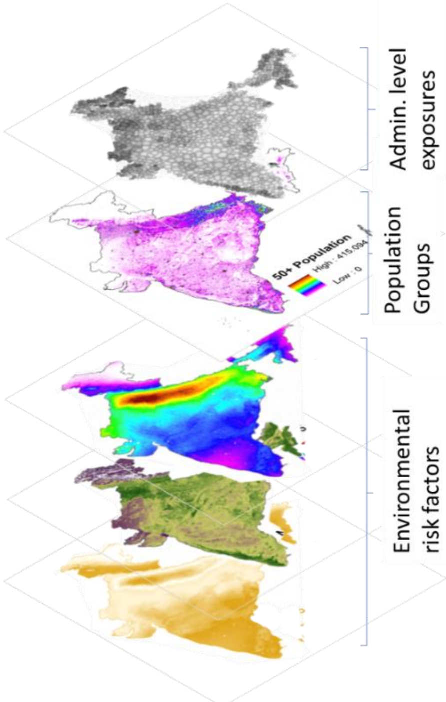

Figure 1 Spatial data approach employed in this study (for visual understanding only)

Environmental Burden and Population Exposure: This study will define four environmental risk factors: hazardous PM2.5 levels (above 20 µg/m³), extreme temperature increases (1°C or more over two decades), prolonged droughts (PDSI ≤ -3 for at least four months), and green deficits (FCover < 0.3). Each risk factor will be quantified using high-resolution (1 km) data for 2000 and 2019. WorldPop age group data will be integrated to identify vulnerable populations, specifically children under 5 years, older adults over 50, and women of reproductive age (15-49 years). To estimate Multiple Environmental Burdens (MEB), the four data layers will be superimposed, assigning each pixel a value from 0 to 4, indicating the number of coexisting risks. Raster layers will be created to identify areas experiencing at least two (2EB), three (3EB), or four (4EB) risk factors. Population exposure for these vulnerable groups will be calculated by multiplying the age-specific population data with the raster layers.

Environmental and Population Effects on Exposure: The total change in population exposure (ΔExp) will be decomposed into three components: the environmental effect, population effect, and interaction effect (Jones et al., 2015). Each effect will be expressed as a percentage of the total exposure change, providing insights into the contributions of each factor over time.

Aggregation of Results at Subnational Levels: To inform localized policy decisions, the results will be aggregated at subnational levels, including village and district levels. This step will enable the identification of specific regions where MEB and population exposure are most severe, offering actionable insights for targeted interventions.

Preliminary results from analysis on Older Adults

Figure 2 presents preliminary results from a partial analysis using bivariate maps to highlight district-level spatial patterns of environmental risks and the proportion of older adults (50 years and above). The analysis aggregates gridded population data and defines environmental risk factors based on air pollution (PM2.5), greenness scarcity, and temperature levels. In northern and central India, districts with high air pollution levels are marked by a relatively lower proportion of older adults, while southern districts exhibit both lower pollution levels and a larger older population. Central and northern India shows high levels of greenness scarcity, particularly in districts with a moderate to high proportion of older adults, indicating potential vulnerability. Similarly, high-temperature areas in southern and central India coincide with districts having a large older population. These patterns suggest areas where environmental risks and vulnerable populations overlap, identifying regions that may require targeted interventions to address potential environmental and health challenges.

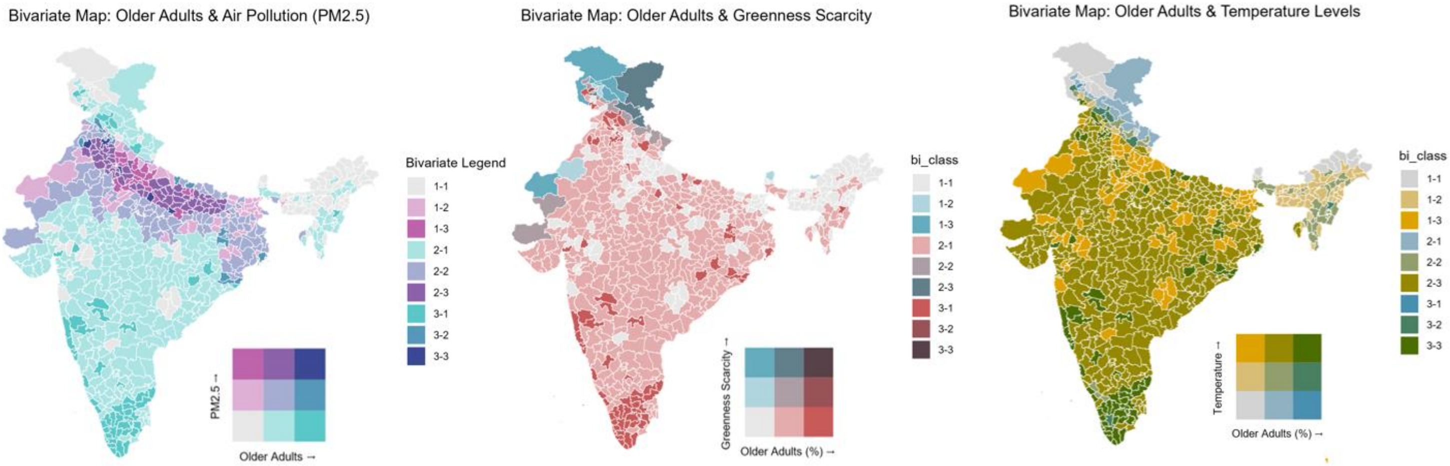

Figure 2 Preliminary District-Level Bivariate Maps of Environmental Risks and Proportion of Older Adults (50+ Years) in India

Expected Findings

This study anticipates several key outcomes regarding the population exposure to multiple environmental burdens (MEB) in India. First, it is expected that a significant portion of the population, particularly vulnerable groups such as children under 5 years, older adults over 50, and women of reproductive age, will be exposed to hazardous levels of PM2.5, extreme temperature increases, prolonged droughts, and green deficits. The analysis of the 2000 and 2019 data is likely to reveal an increase in overall exposure, driven by both population growth and environmental degradation, particularly in urbanized areas and regions experiencing rapid deforestation and infrastructure development. The spatial aggregation of results at village, district, and regional levels is expected to highlight hotspots of MEB where multiple environmental risks coexist. These hotspots are likely to be concentrated in densely populated regions, particularly those with high levels of industrialization and poor green cover. Additionally, rural areas dependent on agriculture may face increased vulnerability to droughts and temperature rises, exacerbating poverty and health disparities in these regions. The decomposition of exposure shifts will likely show that population growth and environmental degradation both significantly contribute to changing exposure levels. However, due to India's vast geographic and socio-economic diversity, these patterns are expected to vary across districts. The interaction effect of population growth and environmental risks may be more pronounced in densely populated, high-risk areas, while rural and urban districts may experience different drivers of exposure shifts.

Overall, the study will offer critical insights into the regions and populations most affected by MEB, providing a valuable basis for developing targeted and localized policies for climate adaptation and public health interventions. As India continues to grapple with the dual challenges of rapid development and escalating environmental risks, this research will serve as a crucial resource for policymakers seeking to build climate resilience and protect the health and well-being of all citizens, particularly those most vulnerable to environmental hazards.

References:

Abatzoglou, J. T. Dobrowski, S. Z. Parks, S. A. and Hegewisch, K. C. (2018). TerraClimate, a high-resolution global dataset of monthly climate and climatic water balance from 1958–2015. Scientific Data, 5(1), Article 1. https://doi.org/10.1038/sdata.2017.191

Baker, R. E. and Anttila-Hughes, J. (2020). Characterizing the contribution of high temperatures to child undernourishment in Sub-Saharan Africa. Scientific Reports, 10(1), 18796.

BBC News. (2024). India heat: Inside Delhi's first emergency room to tackle crisis. https://www.bbc.com/news/articles/cn00nkzdvkjo

Camacho, F. Cernicharo, J. Lacaze, R. Baret, F. and Weiss, M. (2013). GEOV1: LAI, FAPAR essential climate variables and FCOVER global time series capitalizing over existing products. Part 2: Validation and intercomparison with reference products. Remote Sensing of Environment, 137, 310–329.

Feng, S. Meng, Q. Guo, B. Guo, Y. Chen, G. Pan, Y. Zhou, J. Xu, J. Zeng, Q. and Wei, J. (2022). Joint exposure to air pollution, ambient temperature and residential greenness and their association with metabolic syndrome (MetS): A large population-based study among Chinese adults. Environmental Research, 214, 113699.

India Today. (2023). India's forests: A tale of growth, loss, and revival. India Today. https://www.indiatoday.in/diu/story/india-forests-a-tale-of-growth-loss-and-revival-2429324-2023-08-31

Iyakaremye, V. Zeng, G. Yang, X. Zhang, G. Ullah, I. Gahigi, A. Vuguziga, F. Asfaw, T. G. and Ayugi, B. (2021). Increased high-temperature extremes and associated population exposure in Africa by the mid-21st century. Science of The Total Environment, 790, 148162.

Jones, B. O'Neill, B. C. McDaniel, L. McGinnis, S. Mearns, L. O. and Tebaldi, C. (2015). Future population exposure to US heat extremes. Nature Climate Change, 5(7), Article 7. https://doi.org/10.1038/nclimate2631

Liu, Z. Anderson, B. Yan, K. Dong, W. Liao, H. and Shi, P. (2017). Global and regional changes in exposure to extreme heat and the relative contributions of climate and population change. Scientific Reports, 7(1), 43909.

Pandey, A. Brauer, M. Cropper, M. L. Balakrishnan, K. Mathur, P. Dey, S. Turkgulu, B. Kumar, G. A. Khare, M. Beig, G. Gupta, T. Krishnankutty, R. P. Causey, K. Cohen, A. J. Bhargava, S. Aggarwal, A. N. Agrawal, A. Awasthi, S. Bennitt, F. … Dandona, L. (2021). Health and economic impact of air pollution in the states of India: the Global Burden of Disease Study 2019. The Lancet Planetary Health, 5(1), e25–e38. https://doi.org/10.1016/S2542-5196(20)30298-9

Shaddick, G. Thomas, M. L. Mudu, P. Ruggeri, G. and Gumy, S. (2020). Half the world's population are exposed to increasing air pollution. Npj Climate and Atmospheric Science, 3(1), Article 1. https://doi.org/10.1038/s41612-020-0124-2

Sikarwar, A. and Chattopadhyay, A. (2020). Analyzing population and land use change: selected case studies of Indian metropolitan cities. Springer Nature.

Sikarwar, A. and Golaz, V. (2024). Substantial increase in population exposure to multiple environmental burdens in sub-Saharan Africa (2000-2019). Environmental Research Letters, 19(4), 044068. https://doi.org/10.1088/1748-9326/ad376b

Stevens, F. R. Gaughan, A. E. Linard, C. and Tatem, A. J. (2015). Disaggregating census data for population mapping using random forests with remotely-sensed and ancillary data. PloS One, 10(2), e0107042.

UNEP and FAO. (2020, May 21). The State of the World's Forests: Forests, Biodiversity and People. UNEP - UN Environment Programme. http://www.unep.org/resources/state-worlds-forests-forests-biodiversity-and-people

Van Donkelaar, A. Hammer, M. S. Bindle, L. Brauer, M. Brook, J. R. Garay, M. J. Hsu, N. C. Kalashnikova, O. V. Kahn, R. A. and Lee, C. (2021). Monthly global estimates of fine particulate matter and their uncertainty. Environmental Science & Technology, 55(22), 15287–15300.

World Health Organization. (2018). Preventing disease through healthy environments: a global assessment of the burden of disease from environmental risks. https://www.who.int/publications-detail-redirect/9789241565196

Wu, S. Chen, B. Webster, C. Xu, B. and Gong, P. (2023). Improved human greenspace exposure equality during 21st century urbanization. Nature Communications, 14(1), Article 1. https://doi.org/10.1038/s41467-023-41620-z