

Contextualizing a decade of air pollution and population vulnerability in Ecuador

Contextualizando una década de contaminación aérea y vulnerabilidad poblacional en Ecuador

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ABSTRACT

Analyses of remote sensing data can help identify areas facing environmental challenges that put local populations at risk. However, these sometimes lack sufficient context in terms of the socioeconomic and political processes associated with environmental injustice. In this article, we present the findings of our qualitatively contextualized study of spatial air pollution patterns in Ecuador, using an online self-reporting tool that documents environmental injustice globally: The Environmental Justice Atlas. Our findings supported previous work on the polluting role of industries such as oil refining and mining, as well as the greater exposure of at-risk populations, such as Indigenous peoples, compared to other demographic groups. Our findings also suggested a lack of follow-up on the part of polluting industries in the repair of the social and ecological damage caused. Application of the Environmental Justice Atlas as a means to contextualize geospatial environmental findings can be used to perform rapid-environmental assessments that take into account local socioeconomic and political processes.

Keywords: *Environmental justice, Global South, air pollution, environmental conflict*

RESUMEN

Los análisis de datos geoespaciales permiten identificar áreas cuyas condiciones ambientales ponen en riesgo a poblaciones locales. Sin embargo, estos a veces no tienen suficiente contexto respecto a los procesos socioeconómicos y políticos asociados con las injusticias ambientales. En este manuscrito presentamos nuestros resultados tras contextualizar cualitativamente patrones de contaminación aérea en el Ecuador. Para esto utilizamos una herramienta de reporte por usuario que permite documentar injusticias ambientales a nivel global: el Atlas de Justicia Ambiental («Environmental Justice Atlas», por su nombre en inglés). Nuestros resultados concuerdan con el cuerpo de literatura científica que demuestra la contaminación causada por industrias extractivas como la minería y la refinación del petróleo. Nuestros resultados también demuestran que los niveles de contaminación, en cuanto a su distribución geoespacial, están más asociados con grupos demográficos de alto riesgo, como las comunidades indígenas. Por último, nuestros resultados sugieren una falta de seguimiento por parte de las industrias extractivas en cuanto a la reparación social y ecológica causada por la contaminación. Utilizar el Atlas de Justicia Ambiental como medio para la contextualización de patrones geográficos permite llevar a cabo evaluaciones ambientales rápidas que toman en consideración los procesos socioeconómicos y políticos asociados a ellos.

Palabras clave: *justicia ambiental, sur global, contaminación aérea, conflicto ambiental*



Introduction

Latin America is one of today's most urbanized regions. As of 2020, eighty percent of Latin Americans lived in an urban area (AALA Center, 2020). By the year 2050, this number is expected to rise to ninety percent (AALA Center, 2020). Rapid and exacerbated urbanization comes with ecological degradation and global climate change (Solecki, Seto and Marcotullio, 2013).

Extreme degradation of natural environments is the cause of over 150,000 deaths per year globally (Sheffield and Landrigan, 2011). In response, environmental justice efforts have attempted to alleviate the burden that the most vulnerable communities confront, in the face of today's most challenging environmental concerns (Martinez-Alier *et al.*, 2016). However, there remains much discussion as to whether human rights driven movements, such as the environmental justice movement, can be effective in the Global South (Álvarez and Coolsaet, 2020).

The environmental justice movement has been criticized for employing a narrow and reductionist western perspective on the challenges faced by the Global South (Álvarez and Coolsaet, 2020). It is capable of overlooking the location-specific political, economic and social structures that shape communities' experiences with surrounding environmental conditions (Ulloa, 2017). When this occurs, it is often a result of focusing too much on the maldistribution aspect of environmental justice, and not on the socioeconomic and political processes associated with such challenges (Álvarez and Coolsaet, 2020). At the same time, scholars also argue that race and ethnicity, and their role in maldistribution, are inherently part of environmental injustice in Latin America and should not be ignored (Sundberg, 2008).

The contextualizing of spatial patterns allows us to understand the implications of geospatial findings in social and ecological systems (Rucks-Ahidiana and Bierbaum, 2015; Yeager and Steiger, 2013). In the context of environmental justice, qualitatively exploring spatial patterns contributes to the generating of geospatial research that can be leveraged by groups supporting local causes (Frickel, 2004; Haklay and Francis, 2018). In the context of the world's first nations, consideration of environmental injustice findings (including those from spatial assessments) in the context of local socioeconomic and political processes and community experiences, serves to contextualize environmental «misbehavior» occurring with the consent of local authorities (Álvarez and Coolsaet, 2020).

In this article, we discuss the findings of spatial analysis of the associations between air pollution and vulnerable populations in a South American country. Variables were evaluated for spatial correlations at the level of the smallest administrative boundary, and summarized by province. Specifically, we contextualized

findings for environmentally challenged communities in the country, including residents living in poverty and those from non-mestizo racial/ethnic groups (according to past efforts at documenting environmental injustice locally —see Latorre, Farrell and Martínez-Alier, 2015; and Martínez-Alier *et al.*, 2016), in order to identify the socioeconomic and/or political processes behind existing disparities. We addressed the following questions: Are there significant associations between the distribution of vulnerable populations and air pollutant content? What environmental challenges drive extreme pollutant-exposure nationally? We addressed these questions for the country of Ecuador and found the most vulnerable to be those populations of Indigenous and Afro-descendant, as well as those living in poverty. We hypothesized that the most extreme exposure to air pollution could be explained by urbanization and population growth patterns and assumed a null hypothesis in relation to population-based differences.

Materials and methods

Study site

With a land area of 283,560 km², Ecuador is one of the smallest countries in South America. Ecuador is divided into twenty-four provinces that encompass the four regions of the country (Figure 1), one of which is the insular region where the Galápagos Islands are located and three of which are found on the mainland («*costa*», or the coastal region; «*sierra*», or the highland region; and «*oriente*», or the eastern region). The smallest political delimitation in Ecuador is the parish, of which there are a total of 1,499 (Figure 1). Forestland comprises fifteen percent of Ecuador's total land area, having decreased substantially due to oil exploration, logging and urban development (Mosandl *et al.*, 2008). Activities associated with oil extraction and mining comprise the Ecuadorian economy's principal economic sectors, contributing thirty-three percent of Gross Domestic Product (GDP). The other major economic sectors are the service sector and agriculture, which contribute sixty percent and seven percent of GDP, respectively (Trade Office of Ecuador in the United Kingdom, 2019).

Geospatial analysis

To represent a decade of air pollution in Ecuador, we used 2009 and 2019 Global Annual PM_{2.5} Grids from MODIS, MISR and SeaWiFS Aerosol Optical Depth (v4.03) (Hammer *et al.*, 2022) summarized at the parish level. At this parish level, we calculated the percentage of change between 2009 and 2019 and identified outliers in our data using the ArcGIS Pro (2.8.2) optimized outlier analysis tool (Esri, 2022). We then evaluated potential associations between past and current air pollutant content and the 2009-2019 percentage of change and local demographics, through Spearman's rank correlations, using R Statistical Software (4.1.1) (R Core Team, 2021), addressing these for

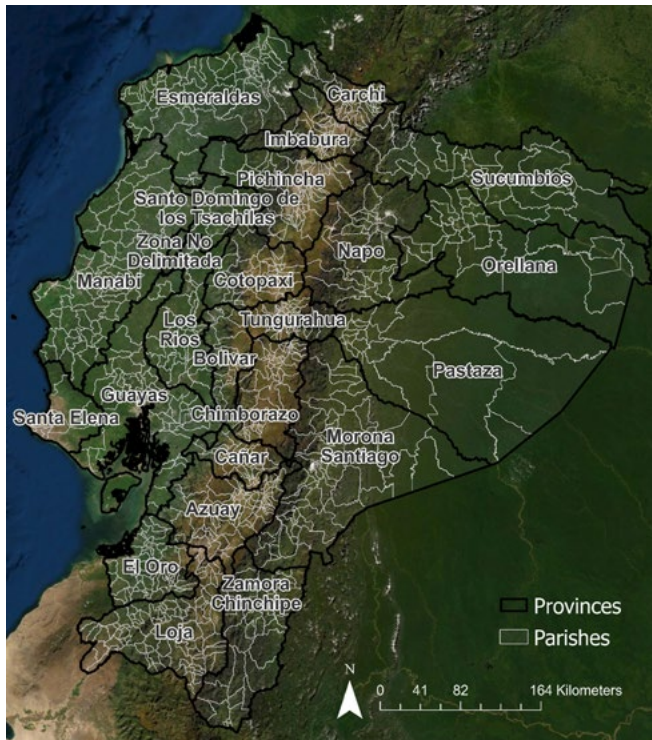


Figure 1. Study site. Map shows Ecuador's largest (provinces) and smallest (parishes) political boundaries.

each province. In this correlation analysis, we included two additional variables for reference: percentage of built-up area and total population (Florczyk *et al.*, 2019; JRC - European Commission and CIESIN - Columbia University, 2021). For our demographic data, we used population data from Ecuador's 2010 national census, which is publicly available, via the Instituto Nacional de Estadística y Censos (INEC) database. At the parish level, we extracted the total population of residents that identify as Indigenous or Afro-Ecuadorian, as well as the total population living in poverty. INEC administrative boundaries were downloaded from the Humanitarian Data Exchange (v1.60.3) (<https://data.humdata.org/>) (OCHA Latin America and the Caribbean, 2020).

Contextualization

We placed our qualitative findings relating to (a) high PM_{2.5} content in 2009 and 2019, (b) drastic increases in PM_{2.5} content from 2009 to 2019, and (c) outliers in local patterns of PM_{2.5} change from 2009 to 2019 within Ecuador's social, political and economic activities. Specifically, we characterized our findings qualitatively using records from the Environmental Justice Atlas (<https://ejatlas.org/country/ecuador>) (Ejatlas, 2022) from within the parishes and provinces being examined, for one or more of the three abovementioned items. The Environmental Justice Atlas is an online database that

records entries (from community members, scientists and others) related to environmental injustice throughout the globe (Temper, del Bene and Martinez-Alier, 2015). Sometimes described as a counter mapping tool (Kollektiv Orangotango, n. d.), the atlas currently contains more than 3,609 global entries on environmental injustice, of which sixty-five are located in Ecuador. Out of these sixty-five cases found in Ecuador (as of 2022), we identified conflicts relating to either «Fossil Fuels and Climate Justice/Energy» or «Mineral Ores and Building Materials Extraction», as well as those within any other conflict type that included the term «air pollution» as an entry for associated environmental impacts —numerous studies have documented the role of fossil fuel extraction and mining (including mining metallurgical sources) in air pollution (Matinde, Simate and Ndlovu, 2018; O'Rourke and Connolly, 2003). We then further categorized this subset of entries based on their relevance in explaining patterns relating to PM_{2.5}. Each was categorized as either «relevant» (i.e., the entry's description demonstrated an environmental conflict that has immediate relevance to past or present air pollution), «partially relevant» (i.e., the entry's description does not demonstrate an immediate relevance to past or current air pollution, but could relate to future patterns of air pollution through drivers such as deforestation, fire risk or other), or «not relevant» (i.e., the entry's description does not demonstrate an immediate relevance to past, current or future patterns of air pollution). Additionally, those classified as «relevant», but which contradicted our findings, were specified as such.

Results

A decade of air pollution

Generally, the proportion of PM_{2.5} content from 2009 to 2019 was maintained; that is, those parishes with the highest content in 2009 (generally located in northern parts of the country) continued to be the most polluted in 2019 (Figure 2a-b). Overall, PM_{2.5}, which was not found to correlate with percentage of built-up area, but did correlate with population (Figure 4), increased throughout the country, with the exception of a few parishes (Guayas, Los Ríos and El Oro) (Figure 2c). Those parishes with lower amounts of PM_{2.5} were located in southern parts of the country. Outliers were identified in terms of surrounding spatial trends occurring in relation to change in PM_{2.5} (whether increasing or decreasing from 2009 to 2019) (Figure 3). For example, at least five provinces (Cañar, Azuay, Morona Santiago, Manabí and southern Chimborazo) contained outlier parishes where PM_{2.5} increased, while surrounding parishes recorded decreases (Figure 3). Meanwhile, at least three provinces (Tungurahua, Orellana and northern Chimborazo) contained outlier parishes with decreases in PM_{2.5}, while surrounding parishes recorded increases (Figure 3).

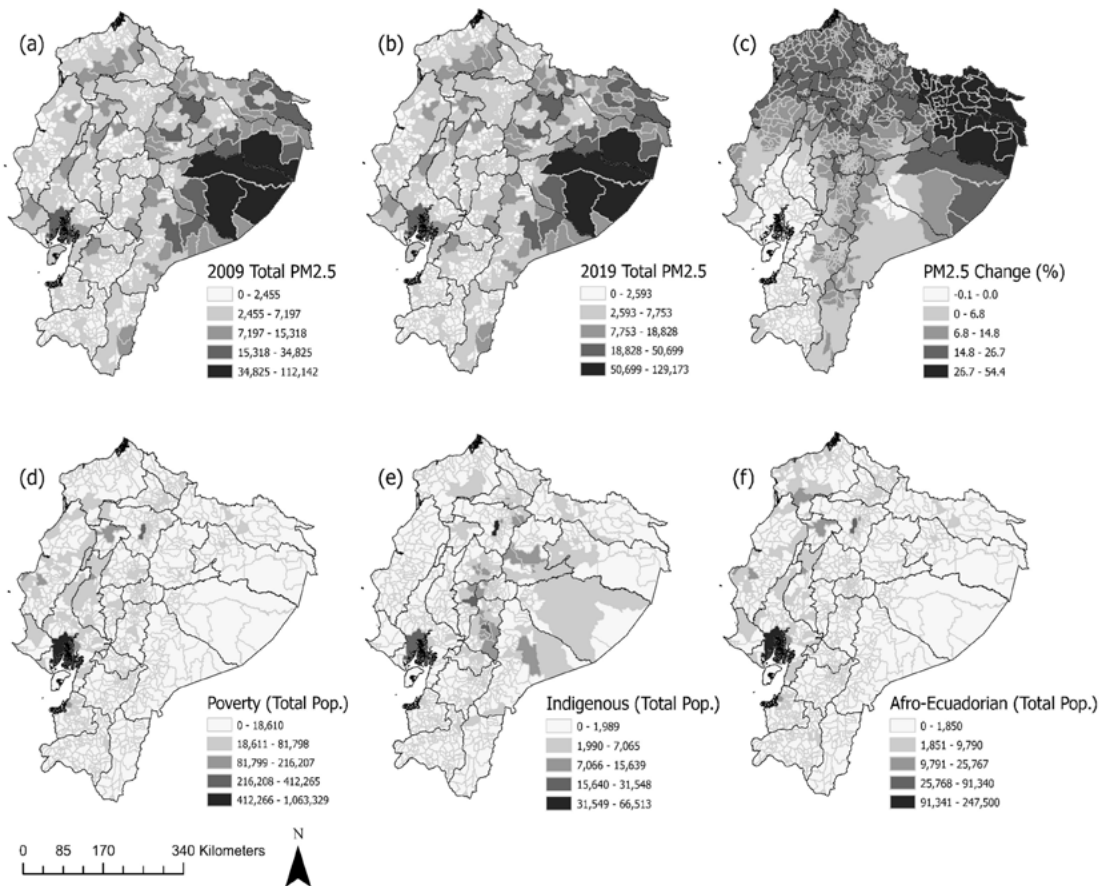


Figure 2. PM2.5 and demographics. Maps indicate PM2.5 content for the years 2009 and 2019, as well as the percentage of change between those years. Demographic variables evaluated for associations with PM2.5 are represented (i.e., Indigenous and Afro-Ecuadorian populations, and individuals living in poverty).

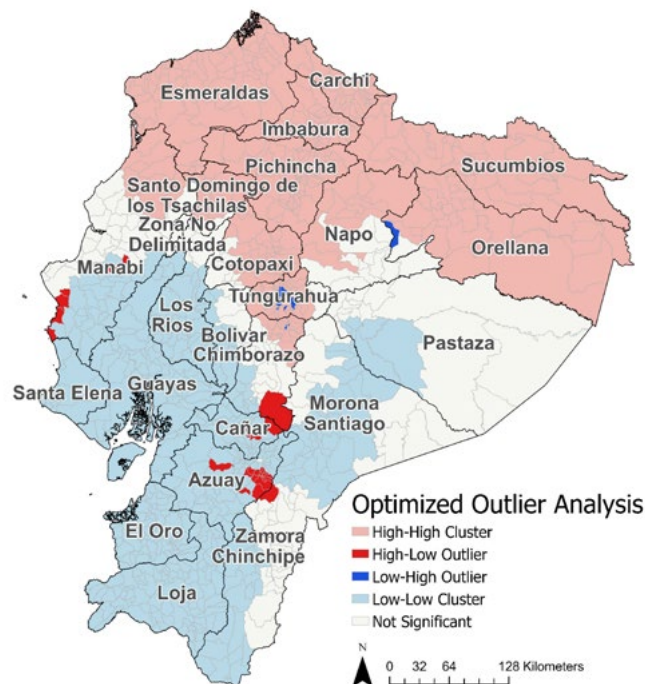


Figure 3. Optimized outlier analysis. Map shows clustering, using the percentage of change in PM2.5 between 2009 and 2019 and the optimized outlier ArcGIS Pro (2.8.2) analysis tool. Dark shaded areas represent outliers. High-low outliers (dark red) are parishes with increased PM2.5 in regions that primarily decreased from 2009 to 2019 (low-low clusters in light blue), and low-high outliers (dark blue) are parishes with decreased PM2.5 in regions that primarily increased (high-high clusters in light red).

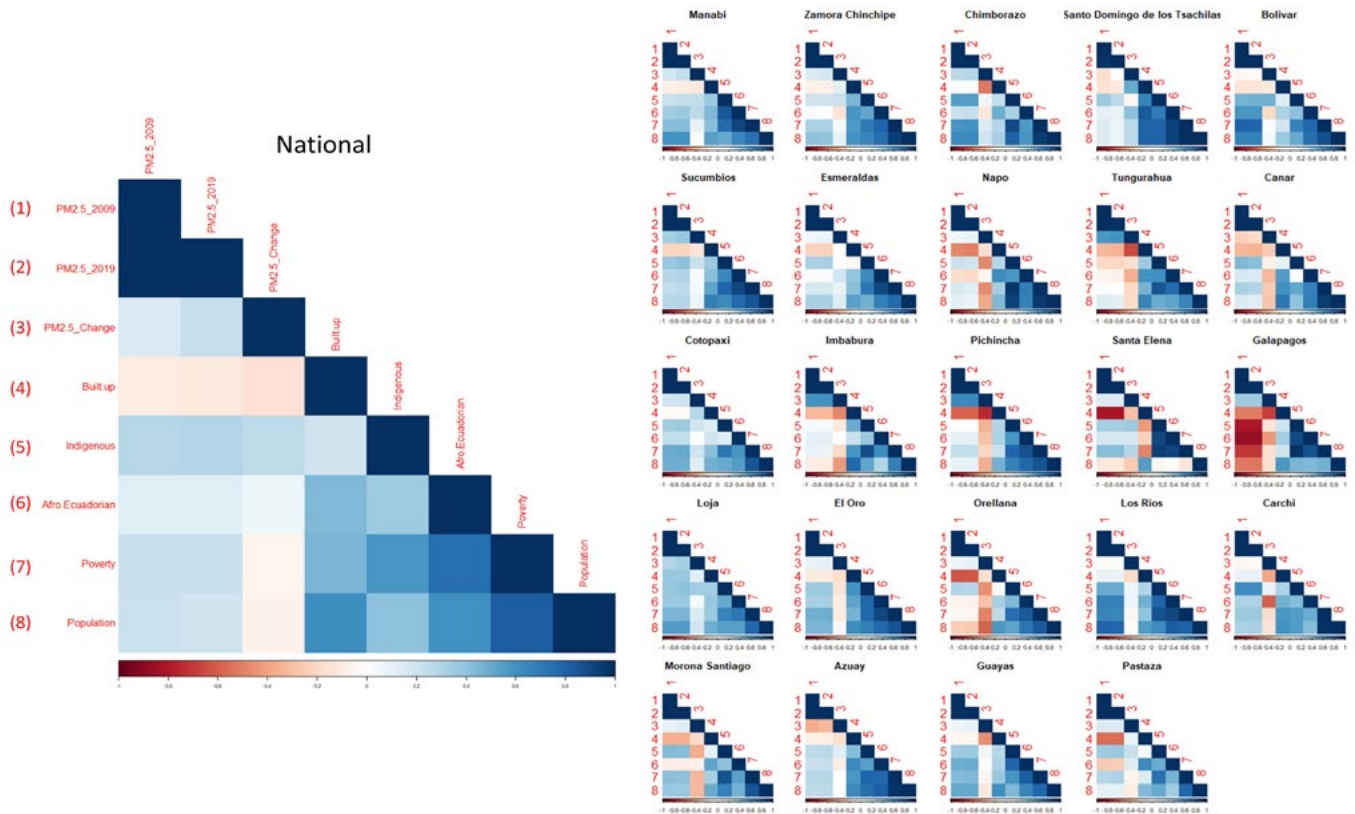


Figure 4. Correlations between PM2.5 variables and the demographics of interest. Large correlation matrix indicates correlations between PM2.5 content in years 2009 and 2019, the percentage of change between these, and the total population of Indigenous people, Afro-Ecuadorians and those living in poverty. Built-up area percentage and total population were included as references.

At-risk populations

Generally, total population is positively correlated with PM2.5, and, at the national level, PM2.5 correlates positively to the greatest degree with Indigenous people (Figure 4). In areas where the presence of Indigenous people is lowest (Figure 2e), this pattern is not present, and instead poverty is identified as the demographic characteristic most positively associated with high levels of PM2.5. Los Ríos and Guayas are the only two provinces where high PM2.5 levels are linked primarily to Afro-Ecuadorians. Nationally, areas with the greatest increases in PM2.5 content from 2009 to 2019 overlap the most with Indigenous populations (Figure 4).

Environmental conflicts behind air pollution

Out of the sixty-five Environmental Justice Atlas entries for Ecuador (see <https://ejatlas.org/country/ecuador>) (Ejatlas, 2022), a total of thirty-three were classified as conflicts relating to «Fossil Fuels and Climate Justice/Energy» or «Mineral Ores and Building Materials Extraction», and an additional nine registered air pollution as a potential environmental impact (Tables 1-2). Eight provinces made mention of environmental conflicts occurring primarily in Indigenous territories

(Orellanas, Pastaza, Morona Santiago, Zamora Chinchipe, Napo, Esmeraldas, Sucumbios and Carchi) (Tables 1-2). Three provinces made mention of environmental conflicts occurring primarily in impoverished and in Afro-Ecuadorian communities (Sucumbios, Esmeraldas, Carchi) (Table 2). Additionally, some entries, specifically one for Esmeraldas and another for the combined area of Sucumbios, Esmeraldas and Carchi, mentioned a lack of follow-up on social or economic compensation and ecological restoration to address the sequences of polluting industries in communities and local landscapes (Ejatlas, 2014; Ejatlas, 2016).

Out of the total of forty-two entries classified as either «Fossil Fuels and Climate Justice/Energy» or «Mineral Ores and Building Materials Extraction», twenty-four were found to have immediate relevance in supporting the patterns observed in our spatial analyses (Tables 1-2). Specifically, those provinces with the highest PM2.5 content in 2009 and 2019, which were Orellanas and Pastaza (Figure 2a-b), had eleven entries on oil extraction and related refinery activities (Table 1). Meanwhile, oil extraction, along with pollutant exposure from local landfills, was recorded for Sucumbios (Tables 1-2), which was one of the top two provinces (the other being

Orellanas) with rapid increases in PM2.5 from 2009 to 2019 (Figure 2c). The remaining provinces that followed an increasing trend (high-high cluster in Figure 3), recorded the presence of refinery activity and/or mining activities (Esmeraldas and Imbabura). Additionally, Pichincha, which was among those remaining provinces, also had issues relating to open landfills (Table 2). Lastly, lower PM2.5 levels in southern parts of the country, despite a few outliers, were found to align with entries indicating the conclusion of some mining projects (for example, in Zamora Chinchipe) (Table 2, Figures 2-3).

Out of the forty-two entries on conflicts that could be linked to PM2.5, three entries were classified as only partially relevant to observed high or rapidly increasing PM2.5 in some provinces (Tables 1-2). One of these entries was for Carchi and indicated a conflict that also impacted Esmeraldas and Sucumbios until 2016, relating to the war against drug trafficking (aggressive aerial spraying of coca fields by the Colombian government) (Table 2). The remainder of these entries were for Napo, most relating to local refineries, and only covered some of the parishes with PM2.5 increases (Tables 1-2). No entries relevant in explaining PM2.5 levels were found for Santo Domingo de Tsáchilas and northern Manabí (Tables 1-2).

Although five cases were found to contradict findings from our spatial assessment (Tables 1-2), we were also able to explain some of the outliers in trends observed in PM2.5. For example, the persistence of mining in southernmost Ecuador, despite the culmination of a few conflicts (as in the case of Zamora Chinchipe), was evidenced by existing outliers such as several parishes in Azuay (which have high PM2.5 compared to the relative lower content in other nearby parishes) and entries for the province (Table 1, Figure 3). Mining also overlapped with outliers in Morona Santiago, where refinery activities were present (Figure 3, Table 1). Although the Chimborazo and Manabí outliers could not be explained with entries from the Environmental Justice Atlas, outliers in Cañar may have been partially associated with cane factories relying on combustion processes (Figure 3, Table 2).

A final notable finding was that some provinces were at risk of deforestation and potential fires (Table 2). The latter, which has occurred in the past, is the result of pine trees (which are not native to Ecuador) being planted by foreign companies in the provinces of Imbabura, Pichincha, Cañar and Azuay, in order to offset carbon on the other side of the globe.

Table 1. Environmental conflicts in Ecuador as of 2022, as recorded in the Environmental Justice Atlas (<https://ejatlas.org/country/ecuador>) (Ejatlas, 2022), associated with «Fossil Fuels and Climate Justice/Energy» or «Mineral Ores and Building Materials Extraction».

PROVINCE	EXACT LOCATION	CONFLICT NAME	URL	TYPE OF CONFLICT	REPORTED STATUS	RELEVANCE
Azuay	The parishes of Victoria del Portete, Tarqui, San Gerardo and Chumbn.	Iamgold and INV Metals in Kimsacocha, Azuay, Ecuador	https://ejatlas.org/conflict/iamgold-in-quimsacocha-ecuador	Mineral ores and building materials extraction	Not determined in entry, but an agreement was reached in 2019	relevant
Azuay	Molleturo	International Minerals Corporation (IMC) in Molleturo, Ecuador	https://ejatlas.org/conflict/international-minerals-corporation-imc-in-molleturo-ecuador	Mineral ores and building materials extraction	Ongoing, as of 2017	relevant
Azuay	Molleturo	Rio Tinto Zinc in Molleturo, Ecuador	https://ejatlas.org/conflict/rio-tinto-zinc-in-molleturo-ecuador	Mineral ores and building materials extraction	Concluded, but another began immediately afterwards	relevant
Azuay	Molleturo, Cochapampa, Rio Blanco, San Pedro de Yumate	Rio Blanco, Molleturo, Azuay, Ecuador	https://ejatlas.org/conflict/rio-blanco-molleturo-azuay-ecuador	Mineral ores and building materials extraction	Stopped, as of 2019	relevant
Azuay	Shaglli, Santa Isabel canton	Habitantes de Shaglli contra proyecto minero Shyri, Ecuador	https://ejatlas.org/conflict/habitantes-de-shaglli-contra-proyecto-minero-shyri-ecuador	Mineral ores and building materials extraction	Stopped, as of 2016, but a different company is now present	relevant
Bolivar	Las Naves canton	Curipamba Sur, Bolivar, Ecuador	https://ejatlas.org/conflict/curipamba-sur-bolivar-ecuador	Mineral ores and building materials extraction	Ongoing, as of 2017	relevant (but contradicts findings)
Ecuadorian Amazon	Provinces of Orellana, Sucumbios	Chevron-Texaco oil extraction and legal dispute	https://ejatlas.org/conflict/chevron-texaco-ecuador	Fossil fuels and climate justice/energy	Stopped, as of 2014	relevant

El Oro	Portovelo/Zaruma	Artisanal and small-scale gold mining in Portovelo-Zaruma, Ecuador	https://ejatlas.org/conflict/artisanal-and-small-scale-gold-mining	Mineral ores and building materials extraction	Ongoing, as of 2017	relevant (but contradicts findings)
Esmeraldas	Esmeraldas	Esmeraldas refinery, Ecuador	https://ejatlas.org/conflict/esmeraldas-refinery-ecuador	Fossil fuels and climate justice/energy	Ongoing, as of 2014	relevant
Esmeraldas	Eloy Alfaro and San Lorenzo	Artisanal mining in Esmeraldas, Ecuador	https://ejatlas.org/conflict/mining-in-esmeraldas	Mineral ores and building materials extraction	Ongoing, as of 2017	relevant
Imbabura	Selva Alegre	Contamination by cement company in Selva Alegre, Ecuador	https://ejatlas.org/conflict/contaminacion-por-empresa-de-cementos-en-selva-alegre-ecuador	Mineral ores and building materials extraction	Ongoing, as of 2018	relevant
Imbabura	Cotacachi	Mining projects in Intag, Junin, Ecuador	https://ejatlas.org/conflict/intag-mining-junin-ecuador	Mineral ores and building materials extraction	Stopped, as of 2021	relevant
Manabí	Agua Blanca	Community of Agua Blanca against the oil pipeline, Ecuador.	https://ejatlas.org/conflict/comuna-of-agua-blanca-against-the-poly-oil-pipe-ecuador	Fossil fuels and climate justice/energy	Ongoing, as of 2014	not relevant
Morona Santiago	Territory of Shuar Arutam people, Cordillera del Cóndor, between the Zamora, Coangos and Santiago rivers, on the Amazon basin frontier between Peru and Ecuador.	Warintza de Solaris Resource Inc. mining project Ecuador	https://ejatlas.org/conflict/la-lucha-del-pueblo-shuar-arutam-psha-contra-solaris-resources	Mineral ores and building materials extraction	Stopped, as of 2021	relevant
Morona Santiago	San Juan Bosco	Panantza - San Carlos, Ecuador	https://ejatlas.org/conflict/panantza-san-carlos-ecuador	Mineral ores and building materials extraction	Ongoing, as of 2017	relevant
Morona Santiago	Macas	Jimbitono against mining and hydropower projects, Ecuador	https://ejatlas.org/conflict/jimbitono-against-mining-and-hydropower-projects-ecuador	Water management	Ongoing, as of 2014	relevant
Napo	Archidona, Tena, Carlos Arosemena	Pungarayacu oilfield, Ecuador	https://ejatlas.org/conflict/pungarayacu-oil-block-ecuador	Fossil fuels and climate justice/energy	Ongoing, as of 2014	relevant (but only parts overlap with parishes that increased in PM2.5)
Orellana	San Luis Armenia	Perenco guilty of environmental liability, Ecuador	https://ejatlas.org/conflict/perenco-guilty-for-environmental-liabilities-ecuador	Fossil fuels and climate justice/energy	Ongoing, as of 2014	relevant
Orellana	Dayuma	Dayuma oil extraction, Ecuador	https://ejatlas.org/conflict/dayuma-oil-extraction-ecuador	Fossil fuels and climate justice/energy	Ongoing, as of 2014	relevant
Orellana	Orellana	Armadillo case: indigenous people in voluntary isolation, Ecuador	https://ejatlas.org/conflict/armadillo-case-indigenous-in-voluntary-isolation-ecuador	Fossil fuels and climate justice/energy	Ongoing, as of 2014	relevant
Orellana	Ines Arango	Petroecuador guilty of environmental damage, Orellana, Ecuador	https://ejatlas.org/conflict/petroecuador-guilty-of-environmental-damage-orellana-ecuador	Fossil fuels and climate justice/energy	Ongoing, as of 2014	relevant
Orellana and Pastaza	Ishpingo-Tiputini-Tambococha oil fields	Yasuni National Park - ITT oil extraction, Ecuador	https://ejatlas.org/conflict/yasuni-national-park-itt-oil-extraction-ecuador	Fossil fuels and climate justice/energy	Ongoing, as of 2015	relevant



Orellana y Napo	Cut through to the southwest by the city of Francisco de Orellana.	Oil exploration in Lots 7 and 21, Ecuador	https://ejatlas.org/conflict/bloques-7-y-21	Fossil fuels and climate justice/energy	Ongoing, as of 2016	relevant
Pastaza	Amazon rainforest	Andes Petroleum Oil Proposal in Sápara Indigenous Territory in Amazon Rainforest, Ecuador	https://ejatlas.org/conflict/andes-petroleum-oil-proposal-in-sapara-indigenous-territory-in-amazon-rainforest-ecuador	Fossil fuels and climate justice/energy	Stopped, as of 2020	relevant
Pastaza	Pastaza	Sarayaku - Oil extraction in Block 23, Ecuador	https://ejatlas.org/conflict/sarayaku-oil-extraction-in-block-23-ecuador	Fossil fuels and climate justice/energy	Stopped, as of 2016	relevant
Pastaza, Morona Santiago, Zamora Chinchipe and Napo	Southeastern Amazon basin of Ecuador	Opposition from indigenous communities to the XI Ronda Petrolera, Ecuador	https://ejatlas.org/conflict/oposicion-de-comunidades-indigenas-a-la-xi-ronda-petrolera	Fossil fuels and climate justice/energy	Ongoing, as of 2016	relevant
Provinces of Napo, Pastaza and Orellana	Municipalities of Archidona, Tena, Juan Carlos Arosemena Tola, Santa Clara, Arajuno, Loreto	Ecuador's prior consultation in oilfields 20 and 29, Ecuador	https://ejatlas.org/conflict/ecuadors-prior-consult-in-the-oil-blocks-20-and-29-ecuador	Fossil fuels and climate justice/energy	Stopped, as of 2014	partially relevant (stopped)
Provinces of Pastaza and Morona Santiago	Municipalities of Taisha and Pastaza	Achuar and Shuar against oil extraction, Ecuador	https://ejatlas.org/conflict/achuar-and-shuar-against-oil-extraction-ecuador	Fossil fuels and climate justice/energy	Ongoing, as of 2014	relevant
Provinces of Pichincha, Sucumbios, Napo, and Esmeraldas	Lago Agrio, Esmeraldas and Calderon (Quito)	OCP-Heavy Crude Oil Pipeline, Ecuador	https://ejatlas.org/conflict/ocp-heavy-crude-oil-pipeline-ecuador	Fossil fuels and climate justice/energy	Ongoing, as of 2016	relevant
Sucumbios Province	Pacayacu County	Oil exploitation in Campo del Libertador, Ecuador	https://ejatlas.org/conflict/oil-exploitation-in-campo-del-libertador-ecuador	Fossil fuels and climate justice/energy	Ongoing, as of 2014	relevant
Zamora Chinchipe	Zamora Chinchipe	Podocarpus National Park and mining, Ecuador	https://ejatlas.org/conflict/podocarpus-national-park-and-mining-ecuador	Mineral ores and building materials extraction	Stopped, as of 2014	relevant
Zamora Chinchipe	Los Encuentros	Fruta del Norte, Ecuador	https://ejatlas.org/conflict/fruta-del-norte-ecuador	Mineral ores and building materials extraction	Stopped (company decided to not continue), as of 2017	relevant
Zamora Chinchipe	El Panguí	Mirador, Cordillera del Condor, Ecuador	https://ejatlas.org/conflict/mirador-cordillera-del-condor-ecuador	Mineral ores and building materials extraction	Ongoing, as of 2017	relevant (but contradicts findings)

Table 2. Environmental conflicts in Ecuador as of 2022, as recorded in the Environmental Justice Atlas (<https://ejatlas.org/country/ecuador>) (Ejatlas, 2022), that do not concern «Fossil Fuels and Climate Justice/Energy» or «Mineral Ores and Building Materials Extraction», but instead indicated «air pollution» as the associated environmental impact.

PROVINCE	EXACT LOCATION	CONFLICT	URL	TYPE OF CONFLICT	REPORTED STATUS	RELEVANCE TO STUDY
Cañar	La Troncal	Sugar cane factory La Troncal, Ecuador	https://ejatlas.org/conflict/sugar-cane-factory-la-troncal-ecuador	Industrial and utilities conflicts	Ongoing, as of 2014	relevant (cane factory with combustion process)
Esmeraldas	Muisne	Shrimp farming in Muisne, Ecuador	https://ejatlas.org/conflict/shrimp-farming-in-muisne-ecuador	Biodiversity conservation conflicts	Ongoing, as of 2016	not relevant
Los Rios	Los Rios	Baba Dam Project - Los Rios, Ecuador	https://ejatlas.org/conflict/baba-dam-project-los-rios-ecuador	Water management	Ongoing, as of 2014	not relevant
Pichincha	Parroquia Cangahua, cantón Cayambe	Landfill waste disposal in Cayambe, Ecuador	https://ejatlas.org/conflict/vertedero-de-residuos-en-cayambe-ecuador	Waste management	Ongoing, as of 2016	partially relevant (landfill may expose dust particles)
Provinces of Imbabura, Pichincha, Cañar and Azuay	Provinces of Imbabura, Pichincha, Cañar and Azuay	FACE pine plantation, Profafor, Ecuador	https://ejatlas.org/conflict/face-pine-plantation-profafor-ecuador	Biomass and land conflicts (forests, agriculture, fisheries and livestock management)	Ongoing, as of 2019	partially relevant (could lead to future fires and, as a result, greater PM2.5)
Santo Domingo de los Tsáchilas	Santo Domingo	Contamination of the pork industry, PRONACA, in Tsáchilas, Ecuador	https://ejatlas.org/conflict/contaminacion-de-industria-porcicola-pronaca-en-tsachilas	Industrial and utilities conflicts	Ongoing, as of 2016	not relevant
Sucumbios	Puerto Rico area, Lago Agrio canton	Contamination through sanitary landfill in the community of Puerto Rico, Nueva Loja, Ecuador	https://ejatlas.org/conflict/contaminacion-por-releno-sanitario-en-comunidad-de-puerto-rico-ecuador	Waste management	Ongoing, as of 2016	partially relevant (dust from site might contribute, but likely not driver)
Sucumbíos, Esmeraldas, Carchi	Sucumbíos, Esmeraldas, Carchi	Aerial fumigation and Plan Colombia, Ecuador	https://ejatlas.org/conflict/aerial-fumigations-and-plan-colombia-ecuador	Biomass and land conflicts (forests, agriculture, fisheries and livestock management)	Stopped, as of 2016	partially relevant (stopped, but impacted impoverished Indigenous, Afro-Ecuadorians and mestizos)
Cross-border	Manta-Manaus Multimodal Corridor	Manta-Manaus Multimodal Corridor, Ecuador/Peru/Brazil	https://ejatlas.org/conflict/manta-manau-multimodal-corridor-ecuador-peru-brazil	Infrastructure and built environment	Temporarily stopped, as of 2016	not relevant



Discussion

Interpretation of findings

Analysis of remote sensing data can help identify areas facing environmental challenges that put local populations at risk (Weigand et al., 2019). Distributive assessments of this kind can still lack sufficient context for the socioeconomic and political processes associated with environmental injustice, which are crucial in contextualizing the role played by institutions with power, and which knowingly engage in environmental misconduct for monetary or political gain, or for other motives (Althor and Witt, 2020; Álvarez and Coolsaet, 2020; Bluhm et al., 2022). In this article, we have presented our findings from a qualitative contextualizing of air pollution patterns in a South American country. Our article offers a pathway to the systematic review of environmental conflicts, through use of an online self-reporting tool that documents environmental injustice globally.

Although superficial spatial analyses can often be reductionist, the incorporation of accounts from the Environmental Justice Atlas (<https://ejatlas.org/country/ecuador>) (EJAtlas, 2022) provided guidance for the contextualization of our findings in a way that considered past evidence, time-period relevance and spatial location, while retaining the less time-consuming nature of rapid spatial assessments (compared to in-depth reviews of scientific literature, policy briefs, technical reports, news articles, etc.) (Anderson, 2010). Our findings suggest that refinery and mining activities, rather than the extent of built-up area, are the likely driving factors behind national PM2.5 patterns in our study area, Ecuador's mainland, thereby contradicting the hypothesis that urbanization is the main driver (although urbanization-related activities such as vehicle CO2 emissions, industrial activities, etc. are significant contributors to air pollution in Ecuador's major cities —see Jurado and Southgate, 1999). Additionally, our results indicate that a major social consequence of polluting industries is the further exposure of vulnerable populations, including Indigenous communities, to environmental challenges. These findings mirror those of recent studies indicating the links between regional economic activity, air pollution and vulnerable populations (Bluhm et al., 2022). Lastly, we found evidence, through the Environmental Justice Atlas, suggesting that post-damage monetary compensation for affected communities (if enforced) is as far as some of the institutions behind environmental injustices go, stopping short of repairing the local landscape where environmental exploitation has taken place. This has also been observed in global assessments, which have observed that these institutions also often fail to acknowledge the health complications faced by community members exposed to pollution (Navas, D'Alisa and Martínez-Alier, 2022).

Our understanding of the role that polluting industries play in environmental degradation is not new. Numerous experts have evaluated case studies throughout Ecuador, examining the environmental and social impacts associated with oil extraction, mining, deforestation, industry and other activities (Barraza et al., 2020; Buchanan, 2013; Jurado and Southgate, 1999; Mosandl et al., 2008). However, the intensive work that such research involves, while rewarding, can also be time and resource consuming (Anderson, 2010). The advantage of remote sensing, particularly when relying on open data, is the ability to assess environmental patterns across large areas of territory quickly and effectively (Singh, 2019). This is particularly advantageous for the environmental justice movement, given that many of the issues examined are time-sensitive, and it is therefore of crucial importance that scientists move quickly to provide the research-based evidence required to support local activism (Stallworthy, 2009). However, a downside of remote sensing, for which it has been criticized heavily within the context of environmental justice studies, is its inability to incorporate local accounts other than superficial demographic-based analyses (Althor and Witt, 2020; Álvarez and Coolsaet, 2020; Mah, 2015; Singh, 2019). The Environmental Justice Atlas (<https://ejatlas.org/country/ecuador>) (EJAtlas, 2022) and similar tools provide an avenue for scientists to more quickly connect with local issues, taking advantage of all that our modern technologically driven world can contribute (Mah, 2015).

Both our national-level findings on PM2.5 spatial patterns and our review of environmental injustice entries relating to mining and oil extraction indicated that Indigenous communities are the most exposed to these issues (contradicting our null hypothesis). The relationship between environmental injustice and marginalized communities is now common knowledge (Anguelovski, 2013; Sundberg, 2008). The environmental justice movement was born out of the need to shift the focus to how historically marginalized communities were often the worst affected by environmental issues (Taylor, 2011). Over time, the movement has also suffered from over-simplification, in the form of studies that fail to go beyond the identification of demographic-based disparities (Althor and Witt, 2020). Moreover, when applied in the Global South, such studies frequently lack awareness regarding the numerous socioeconomic and political contexts responsible for the fact that local authorities, and in some cases the communities most affected, fail to stand up to the environmental misconduct of powerful institutions (Álvarez and Coolsaet, 2020). In Ecuador, the oil refining and mining industries are relied on for financial income (particularly in order to address issues associated with national debt) (Kuecker, 2007; Latorre, Farrell and Martínez-Alier, 2015; Lu and Silva, 2015; van Teijlingen, 2016), and derived products are exported (Russi et al., 2008). Due to their considerable

contribution to the national economy (thirty-three percent through the industrial sector —see Trade Office of Ecuador in the United Kingdom, 2019), the Ecuadorian government has mostly failed to implement regulations for such industries (Latorre, Farrell and Martínez-Alier, 2015; van Teijlingen, 2016). Even where regulations are implemented, the ambiguity of the government's position can lead to inadequate enforcement, as well as limited action when courts rule against industries accused of environmental injustice (Kauffman and Martin, 2017). Our review of environmental injustice entries found evidence of lack of follow-up with regard to compensation for communities, the payment of fines, or the restoring of local landscapes affected by environmental degradation, and these findings are comparable with those for other locations (Navas, D'Alisa and Martínez-Alier, 2022).

Our study focused only on linking entries from the Environmental Justice Atlas to air pollution patterns (including where high PM_{2.5} occurs, drastic changes and outliers), but application of the EJAtlas to numerous other approaches for the contextualizing of environmental injustice has been steadily growing (Latorre, Farrell and Martínez-Alier, 2015; Merino, Rosas-Casals and Gibert, 2016). For Ecuador, Latorre, Farrell and Martínez-Alier (2015) utilized the Environmental Justice Atlas to assess how resistance against ecological damage from extracting industries has shifted over time. For their part, Merino, Rosas-Casals and Gibert (2016) relied on its, at the time, sixty-four entries in order to identify key actors in environmental conflicts within the country. Our contribution has been to demonstrate how the Environmental Justice Atlas can be used in combination with remote sensing data to interpret spatial patterns of environmental variables (i.e., counter mapping for conservation and environmental science) (Harris and Hasen, 2005; Kidd, 2019). Although the capacity of its application for this purpose may be limited by the number of entries, our work suggests that the EJAtlas can be a valuable resource when assessing environmental justice for a given region, in the absence of the ability to conduct field data collection. The implications of this are varied, from serving as a potential resource in the classroom for learning about global environmental justice (Walter; Weber and Temper, 2020; Weber, Temper and Del Bene, 2021), to reflecting on the applications of counter-mapping for large-scale environmental evaluation (Harris and Hazen, 2005; Kidd, 2019).

Concluding thoughts

The aim of environmental justice is to alleviate the burden that the most susceptible communities face, in the context of today's most prevalent environmental challenges. However, the environmental justice movement

has been criticized for being reductionist when applied in the Global South. One way to combat this is to incorporate local knowledge, which can be achieved through community input. The critical nature of the need to address inequities relating to the environment and society calls for a rapid response. This article reflects on the application of a counter mapping tool, the Environmental Justice Atlas, in order to contextualize large-scale spatial findings associated with environmental variables (in this case, air pollution). Our results show that the Environmental Justice Atlas can be an effective tool for rapid assessments that reveal distributive injustices, while not overlooking significant local contexts. We believe the next step will be to evaluate the accuracy of this type of approach to geospatial environmental justice. There are numerous entries related to Ecuador in the Environmental Justice Atlas and these entries have been used by recognized researchers in order to thoroughly assess environmental conflict; we suggest establishing whether or not other rapid-assessment tools might be used in order to arrive at the same conclusions derived from these in-depth analyses. One potential avenue would be the application of automated content analysis to entries in the Environmental Justice Atlas. Regardless, as it stands our study can be used to support local efforts to achieve environmental justice, employing environmental data on PM_{2.5} content in those areas most exposed to polluting industries.

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Author contributions

The lead author conducted the geospatial analyses, produced the figures and wrote the text. The second author cleaned and prepared the data, created the tables and edited the text. Both authors contributed to the qualitative contextualization, and to the final interpretation of the findings.

Conflicts of interest

The authors have no conflicts of interest to declare.

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