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Where Nature and Poverty Meet: Developing a Multidimensional Environment-Poverty Measure

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ABSTRACT *Despite the intrinsic relationships between the natural environment, poverty and human wellbeing, measures of poverty do not adequately account for environmental dimensions of wellbeing. This paper furthers theoretical debates about environment-poverty relationships by developing environmental dimensions and indicators for integration into multidimensional poverty indices. We demonstrate that this integration is practically possible using public datasets that are part of regular data collection efforts. Using Brazil as a case study, we develop an environmentally-adjusted multidimensional poverty measure that combines data on proximity to natural land, floods, droughts and landslide risks with information on health, education and living standards. Our results show that the integration of environmental dimensions into a poverty measure can provide different estimates of the incidence and distribution of poverty in a country, shifting attention to new target areas for poverty reduction strategies. Our measure provides a complementary and broader understanding of poverty than traditional poverty indices and could be used to track changes over time. Our measure therefore provides a potentially useful avenue to assess progress towards achieving multiple Sustainable Development Goals, while also accounting for environmental change.*

KEYWORDS: Sustainability; environment; degradation; wellbeing; natural hazards

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1. Introduction

Improving human wellbeing and eradicating poverty are central to the international development agenda. The Sustainable Development Goals (SDGs) provide a re-articulation of these commitments and emphasise the interconnected social, environmental and economic pillars of development. The tight and diverse links between the natural environment, poverty and human wellbeing have been widely recognised in the environmental, sustainability and development literatures (e.g. Cheng et al., 2024; Duraiappah, 2004; Narayan, Chambers, Shah, & Petesch, 2000).

There are numerous frameworks for conceptualising and measuring poverty and human wellbeing that are underpinned by different philosophical theories (i.e. hedonism, desire satisfaction and objective list theories; e.g. Sen, 1985; Nussbaum, 1992; Deaton, 2001). Empirical and conceptual work suggests that the natural environment is a central, constitutive element of human wellbeing in different cultures and worldviews (Cloutier & Pfeiffer, 2015; Díaz et al., 2018; Møller, Cocks, & Vetter, 2023; Sterling et al., 2017; Woodhouse et al., 2015). Scholars have developed several approaches for considering environmental aspects when assessing wellbeing. At national levels, for example, green national accounts attribute monetary values to nature through natural capital accounting procedures (Managi et al., 2019; UN, 2021). Similarly, the Organisation for Economic Cooperation and Development (OECD) has adopted an indicator dashboard as part of their wellbeing framework with separate socio-economic and environmental indicators (OECD, 2020) and Eurostat (2003) considers five dimensions of non-monetary deprivations, including environmental issues such as noise and pollution. At the level of individuals, Nussbaum (2000) and Alkire (2002) have listed key constituents of human wellbeing based on Amartya Sen's Capabilities Approach (Sen, 1999) that refer explicitly to the natural environment.

Despite these developments as well as conceptual and empirical shifts to understand poverty as a multidimensional issue (Alkire & Foster, 2011), the diverse links between human wellbeing and the natural environment continue to be inadequately integrated into development policies and measures of poverty and wellbeing (Coulthard, Johnson, & McGregor, 2011; Prout, 2012; Schleicher, Schaafsma, Burgess, et al., 2018; Thiry, Alkire, & Schleicher, 2018). This lack of integration poses a challenge for identifying individuals or regions that are poor, which is essential for designing effective poverty alleviation strategies. The well-established Human Development Index (HDI, UNDP 2019) and Multidimensional Poverty Index (MPI; Alkire & Santos, 2010) focus on three wellbeing dimensions: (1) health, (2) education; and (3) living standards or income. However, the lack of environmental dimensions fails to account for the direct benefits that humans derive from the natural environment, such as the impacts of ecosystem conditions on human health (e.g. Bauch et al., 2015), and also for less tangible elements of wellbeing related to nature, including sense of security and self-realisation (Cooper et al., 2019; Prout, 2012). This omission exists even though Goal 1 of the SDGs aims to 'end poverty in all its forms everywhere' (UN, 2015, p.17). Furthermore, targets associated with SDG 1 explicitly highlight the need to 'build the resilience of the poor and those in vulnerable situations and reduce their exposure and vulnerability to climate-related extreme events and other economic, social and environmental shocks and disasters'. Nevertheless, environmental dimensions continue to be absent from international poverty indicators for measuring societal progress towards the SDGs.

Incorporating environmental considerations into multidimensional poverty measures thus continues to be a priority for devising more adequate measures of development and poverty (Alkire, 2018). Progress towards integrating environmental aspects into measures of poverty is hindered by at least three mutually reinforcing issues: (1) disciplinary and epistemic boundaries that separate poverty and environmental research and practitioner communities (e.g. Milner-Gulland et al., 2014; Ruggeri-Laderchi, Saith & Stewart, 2003); (2) technical and practical challenges of developing environmental indicators that complement internationally comparable poverty indices (Thiry, Alkire & Schleicher, 2018); and (3) lack of integration of existing social and environmental datasets needed to produce more holistic measures of poverty and wellbeing. For example, environmental aspects, such as the use of natural resources, are still inadequately reflected in most national censuses and representative household surveys that provide data for national poverty estimates. In addition, existing environmental datasets are typically not collected or held by the same institutions that collect or hold social data, posing a barrier for integrating environmental aspects within measures of poverty. Furthermore, it is often difficult to combine social and environmental datasets because they are frequently collected at different spatial and temporal resolutions (Oldekop et al., 2020). This lack of progress on integration has potentially far-reaching consequences because existing poverty alleviation strategies may inadequately address drivers of deprivations and might even provide perverse incentives that could encourage environmental degradation and maladaptation to global environmental change (Barbier & Hochard, 2018; Dyngeland, Oldekop & Evans, 2020). Identifying and integrating environmental aspects that are critical for the wellbeing of the poor can instead foster synergies and facilitate policy coordination between environmental and anti-poverty programmes. This is because addressing the relevant environmental aspects can be conducive to both reducing poverty and improving environmental sustainability.

Using Brazil as a case study, we demonstrate how environmental factors can be integrated into a municipal-level multidimensional poverty measure to inform poverty alleviation and environmental change strategies. Our analysis is facilitated by the increasing availability of global and national-level secondary environmental and social datasets (e.g. Joppa et al., 2016). We provide conceptual insights and empirical analysis of the impacts of such integration on the incidence and distribution of poverty. We develop a methodology, demonstrate its application with secondary environmental and socioeconomic secondary datasets in Brazil, and identify global datasets that allow the replication of this approach in other countries and regions. We then use these data to address the following questions: First, does the distribution and intensity of multidimensional poverty change in Brazil when environmental aspects of poverty are considered jointly with other deprivations (health, education, living standards), and if so, how? Second, do multidimensional poverty levels change in Brazil over time, once environmental aspects are considered, and how have these changes varied between different dimensions of poverty? We discuss the implications of our results for national level policies and strategies to reduce poverty, and for monitoring and achieving the SDGs.

2. Material and methods

2.1. Study area

Our study focuses on Brazil due to its diverse ecosystems, its biological and cultural richness, the prevalence of income poverty in parts of the country, and the availability of numerous social and environmental datasets (Hofstede et al., 2010; Lima et al., 2016).

During the first decade of the millennium, Brazil implemented comprehensive social protection programs under the country's flagship *Fome Zero* strategy (meaning 'Zero Hunger'; Da Silva, Grossi & Franca, 2011). These programs provided policy instruments to alleviate income poverty, and improve access to food, education and health care (Da Silva et al., 2011). Given the well-established link between poverty and food security (Sen, 1982), *Fome Zero* is considered a key mechanism through which Brazil was able to meet the Millennium Development Goal of halving extreme poverty and hunger by 2015 (Castaneda, 2012).

In contrast to the country's strides in economic development, the vast and diverse ecosystems of Brazil continue to be under great stress, especially from logging, agriculture and mining activities (Mercure et al., 2019; Overbeck et al., 2015; Sonter et al., 2017). Environmental degradation in the country has led to conflicts over human rights and negative health impacts (Bauch et al., 2015; Castro et al., 2019; Mercure et al., 2019) reflecting how environmental aspects are closely linked to livelihoods and wellbeing in Brazil (Andrade & Romeiro, 2013; Chiarini, 2006; Gomes et al., 2015; Martins, 2002). However, the disconnect between the environment and poverty agendas in national development strategies in Brazil has been notable and long standing, especially during the period of colonisation and settlement of the Amazon beginning in the 1960s (Steward, 2007). These agendas have become somewhat more aligned in the last two decades (Pinho et al., 2014), primarily through policies tackling climate change and sustainable development, such as *Bolsa Verde* (Mercure et al., 2019). Closer examination of simultaneous environmental and poverty trajectories over the last twenty years could therefore offer deep insights about how social development and environmental agendas overlap (or not). Given Brazil's multiple political shifts in recent years are likely to have noticeable social and environmental impacts (Doniec, Alba & King, 2018; Nature Sustainability Editorial, 2018) such analyses are even more timely.

2.2. Data selection and analysis

To integrate environmental factors within a multidimensional poverty measure, we considered: (1) the availability of social and economic indicators and data, including existing multidimensional poverty measures; (2) the availability of environmental indicators and data; and (3) how to best integrate the social, economic and environmental indicators and datasets.

We based our decisions of which indicators and data to use and how to integrate them on a review of the relevant Brazilian and global literature on poverty-environment links, a series of discussion meetings among the author team, and two in-country workshops. We convened the workshops in Rio de Janeiro, Brazil, with researchers and policy makers from governmental and non-governmental organisations (NGOs) working on poverty and/or environmental issues. These workshops allowed to discuss the methodological approach and obtain country-specific insights into the most relevant measures and datasets for the Brazilian context. The first workshop was held in July 2017 over two days with 28 participants (15 researchers, 10 NGO representatives, and three policy makers) and served to discuss and validate the approach, while the second one-day workshop with 23 participants (15 researchers, four NGO representatives, and two policy makers) held in May 2018 was used to present a preliminary analysis and discuss potential adjustments to the methodology and datasets. We selected participants based on their experience with poverty statistics, in particular the MPI and HDI, with relevant indicators or datasets (e.g. social, economic, environmental, health, and natural disaster data) and/or with data processing in Brazil. Details of the data selection process and analyses are outlined in the following sections.

2.2.1. Social and economic data selection and analysis. A number of relevant multidimensional poverty and social indices have been used in Brazil. In particular, the MPI and HDI have been calculated in Brazil at federal, state and municipal levels (Fahel & Teles, 2018; UNDP, IPEA & FJP, 2016; Ximenes et al., 2016) as well as in other countries. This makes the MPI and HDI especially appropriate for this study, allowing our approach to be more easily replicable in other countries. They complement a number of other multidimensional social indices that have been developed and/or used in Brazil, such as a personal wellbeing index (Moura & Sarriera, 2019) and a multidimensional poverty measure using Fuzzy set theory (Ottonelli & Mariano, 2014).

Compared to more traditional income-based measures, the indicators of the MPI are advantageous because of their ability to directly assess people's access to basic services that are key for their quality of life (Alkire & Santos, 2010). Comparisons of MPI and income-based poverty profiles indicate that the two can deviate (Alkire et al., 2015). The global MPI has been adopted as the national poverty measure in various countries (e.g. Afghanistan, Nepal, Maldives, and Sierra Leone) and comprises ten indicators across three equally-weighted dimensions of health, education and living standards (Alkire & Foster, 2011). Other countries have developed national MPIs, retaining the MPI methodology, but adapting the indicators, dimensions and/or relative weights to their national context (e.g. Angola, Bhutan, Dominican Republic, Ghana, Rwanda and Seychelles). The Oxford Poverty and Human Development Initiative (OPHI) recognises that the global MPI has missing dimensions, such as physical safety, social connectedness and psychological wellbeing. Additional survey modules have been developed for some of these missing dimensions, but environmental dimensions continue to be excluded.

Here, we used the Brazilian multidimensional poverty measure (MPM) developed by Dyngeland et al., (2020) because it adapted the indicators of the global MPI to the Brazilian context (see Table S1) and is available for all Brazilian municipalities. It is based on national household census data from 2000 and 2010, carried out by the national Brazilian Institute of Geography and Statistics (IBGE, 2011; see Supplementary Information for further details). The MPM uses the dimensions of the MPI (equally weighted dimensions on health, education and living standards based on the recommendations of Alkire and Foster (2011)) with the statistical methodology used to calculate Brazil's official Municipal Human Development Index (Atlas Brazil, 2013), which uses the geometric mean to generate a combined poverty measure as it produces a ranking that is invariant to the scale at which each variable is measured (Klugman, Rodríguez & Choi, 2011). This approach differs from the household-level estimate calculated by the Alkire-Foster MPI methodology but provides the only way to combine multiple poverty dimensions because household-level data are not made public in the microdata published by IBGE (UNDP, IPEA & FJP, 2016). Our municipal-level approach is further justified because the environmental risks factors we have included do not operate at the household level but over larger geographical scales, and because municipalities in Brazil have substantial policy decision-making powers.

We normalised all indicators to take values between 0 and 1, and combined them by taking the geometric mean of the three dimensions within individual municipalities. The resulting number represents a poverty measure, where higher values indicate higher levels of multidimensional poverty. In contrast to the MPI, our approach does therefore not rely on defining a poverty cut-off. Because borders of some municipalities changed between 2000 and 2010, we adjusted them to those of 2000, combining municipalities where necessary. We excluded 45 municipalities from the analysis, where boundaries could not be reconciled. We expect the impact of this to be negligible as the excluded municipalities were not very populous in 2000 nor particularly poor (they were on average slightly better off, with a higher mean municipal HDI, than all municipalities combined). Our final sample for our analysis is 5504 municipalities (median size $= 418\,km^2$).

2.2.2. Environmental indicator development and data Selection: a stepwise approach. We adopted a stepwise approach to select the environmental indicators and data included in our analysis. We first developed a longlist of environmental factors potentially relevant to poverty in Brazil. We then refined our selection based on specific criteria: they had to be a constituent element of poverty and not already included as part of existing indicators in the MPM (see further details below). Where possible, we then matched the list of indicators with relevant existing datasets.

We identified potential indicators for our longlist from a review of the literature, discussions among the authors, and our two workshops in Brazil. To refine our list, environmental indicators had to meet two criteria. First, indicators had to play a constituent role in poverty concepts (Schleicher et al., 2018, Thiry, Alkire & Schleicher, 2018, Dasgupta, 2001). Although issues of endogeneity cannot be completely eliminated, included environmental aspects should primarily have a constituent, or internal, role for poverty if they are part of how poverty is defined. Other environmental aspects can play a purely instrumental role, meaning that they are external determinants influencing poverty (e.g. water quality affecting health). Second, environmental elements are excluded that directly or indirectly are already captured in the MPM through an existing indicator (e.g. access to safe drinking water is already included in the living standards dimension of the MPM and therefore not added in the environmental dimension).

In addition, data for environmental indicators had to be available: (1) at national extent for Brazil; (2) at an appropriate spatial scale (i.e. be available at least at municipality level) and temporal resolution; and (3) for a suitable time period to be used in conjunction with the social data, which were available for the years 2000 and 2010. However, as these criteria were not always met, we had to either adapt some of the indicators to the available data or omit the indicator. For example, the most relevant time period for some environmental indicators might be the time predating the social poverty data (i.e. pre-2000), but such data was not available for some of the indicators (e.g. on vulnerability to hazards; see Supplementary Information Table S2). Once we identified relevant indicators, we matched these, where possible, with open access national and/or global datasets to ensure that our approach could also be replicated in other country contexts. In cases where several relevant datasets were available for the same indicator, we reviewed their suitability and chose the dataset that we judged best fit for purpose (see Supplementary Information Table S2).

Through this stepwise process we selected two categories of environmental dimensions and datasets: experiencing nature and environmental risks (see below). We also considered the inclusion of access to natural resources because such access can provide timber, non-timber forest products (e.g. fuelwood, medicinal, ornamental and genetic resources, raw materials) and other non-cultivated natural resources (e.g. water), and we reviewed available datasets (e.g. MapBiomas, Global Forest Cover and datasets held by the FAO and by Brazilian institutions such as EPE and IBGE). However, we deemed access to natural resources to have primarily an instrumental role in poverty.

2.2.3. Experiencing nature. Experiencing nature captures a diverse set of human-nature relationships provided by the proximity and access to green or natural space and/or to ancestral lands. This indicator thus encompasses a sense of belonging to nature, as well as spiritual and cultural connections to nature. It encapsulates the role of nature as a source of human identity and context for meaning as well as for personal growth and healing (Borish et al., 2021; Knippenberg et al., 2018; MacKerron & Mourato, 2013). This relates to eudaimonic aspects of wellbeing in relationships with, and responsibilities towards, nature. The respect for nature may also translate into fear of nature or of particular species. We considered these aspects to be constituent elements of wellbeing.

There were several potential Brazilian datasets available for this aspect (see Supplementary Table S2). This includes the FUNAI map of indigenous lands as a potential dataset to determine access to ancestral lands and/or spiritual and cultural connections with nature. However, we chose not to include this dataset because: (1) field data would first be necessary to specify what such connections to wellbeing would entail and to which populations these connections would be relevant to; and (2) the dataset did not cover all indigenous and traditional communities (e.g. it excluded Quilombolas and other communities' ancestral lands). We also considered including the World Database on Protected Areas' (UNEP-WCMC & IUCN 2019) data on community-managed protected areas, but decided against it because: (1) areas can be protected for reasons other than factors relevant for our indicators (e.g. political reasons); (2) the data is incomplete; and (3) the recorded categorisation does not always reflect the actual governance on the ground.

We also excluded data on land access (e.g. from INCRA and IBGE) and land tenure (from Imaflora), because land registration is still incomplete in Brazil and a contested issue (Damasceno, Chiavari & Lopes, 2017). Furthermore, we considered that natural land cover could also provide habitat for crop raiding species but could not find any appropriate dataset. In addition, because nutrition is already included in the MPM, we excluded it and related indicators, such as soil quality and access to cultivated products, from our poverty measure to avoid double counting. Moreover, soil formation processes take a very long time, and the suitability of land for agricultural production includes more than just nutrient availability. Available soil data were also outdated and did not reflect erosion.

Instead, we included access to green or natural space approximated by the proximity of such space. One limitation of this approach is that it disregards differences in relative importance of different types of natural habitats for human wellbeing. This could suggest that natural areas can be substituted or converted from one type to another without wellbeing implications, which will not always be the case. It also does not encapsulate that the diversity of ecosystems may matter nor provides detail on the quality (level of degradation) of these ecosystems. In addition, proximity does not necessarily mean the natural space is accessible, as it might for example be located on private land (Soares-Filho et al., 2014). However, the measure 'proximity of natural/green space' was the best indicator with available data as we did not have data for a more specific or weighted appraisal. While we acknowledge that the measure does not capture the diversity of human-nature relationships mentioned here, it represents some key elements of these relationships and we therefore deemed its inclusion important.

To calculate proximity to natural land, we used annual land use data from MapBiomas. This high resolution (30 metre) remotely sensed dataset includes 27 land cover classes. We chose this data source because we deemed it the most appropriate dataset for our purposes and because high resolution remote sensing based land use data is also often already available for other countries, making our approach transferable to other places. We aggregated these data to the common 1 km resolution used in our analysis, applying a majority resampling. We then aggregated land cover categories into four classes: natural forest, other natural habitat (e.g. grasslands), human-modified natural habitat (e.g. agriculture or pasture) and non-vegetated land (e.g. water bodies, urban areas; see Supplementary Table S3). Proximity to natural land was then calculated using a 3x3 focal filter on the natural forest and other natural land classes.

2.2.4. Environmental risks. Poverty aspects linked to environmental risks relate to mortality risks with associated mental wellbeing impacts. We chose to only include natural hazards (drought, flood and landslide risks – Supplementary Information Table S3) with high mortality risks for three main reasons. First, we considered that 'natural hazards' are perceived differently from 'man-made disasters' (e.g. economic crises and civil unrests), as individuals or communities cannot reduce the occurrence probability of natural hazards (Adger, 2006), even if the root causes of such events may be human-induced (Chmutina, Meding & Bosher, 2019). Such hazards are associated with negative impacts on mental health, including stress, loss of bodily integrity, complete loss of livelihoods, disruption and displacement, and can result in cumulative health impacts from repeated exposure to natural hazards (Fritze et al., 2008). Second, we assume that low levels of environmental risk are most likely risks that people are accustomed to and therefore do not relate to significantly lower levels of wellbeing. Third, for low level mortality risks of natural hazards, existing MPI and MPM indicators already capture the impacts of droughts and floods (e.g. on crop production through nutrition), whereas for high mortality risks, the existing health indicators in the MPI and MPM (e.g. life expectancy and child mortality) consider a range of potential causes including major disasters with high death tolls but are unlikely to reflect the associated stresses associated with anticipating future environmental risks.

Datasets in Brazil are currently being developed for a range of environmental risks, covering disaster occurrences, risks and management. We were able to identify suitable datasets for floods, droughts and landslides. Flood and landslide risk data are available at the pixel level (1 km) and can thus vary throughout a municipality. Drought occurrence data were only available at the municipality level and therefore assumes all people in that municipality are affected by drought if it occurs. It is worth mentioning that the years 2000 and 2010 were la Niña and el Niño years, which influences the pluviosity in Brazil, especially in the northern and north eastern regions. These events could, therefore, have affected our drought data, which was based on drought occurrence events (CEPED, 2013).

We could not identify suitable datasets for storms (including tornados, hurricanes) and fires. While a NASA MODIS state-level fire occurrence dataset is available from INPE, these data lack information on fire intensity, which would impact the level of risk to one's life. Moreover, the links between fire risk and wellbeing need further exploration before being potentially included in a poverty index because fires in some places can have positive effects (e.g. some tree species need canopy fires to regenerate). People also use fire to increase the fertility of soils, kill pests and diseases, to burn charcoal and to clear land. Such low intensity fires can be beneficial. Currently, only short-term fire forecasts exist (e.g. the fire danger forecast module of the Global Wildfire Information System) and there are no data for long-term severe fire risks.

We also excluded variability in precipitation because this effect would already be captured in nutrition through crop production as well as through droughts and floods. We also excluded air and water pollution because: (1) their effects were likely to be instrumental; (2) they were also captured through health issues; and (3) pollution can have many origins other than natural sources. Finally, we excluded vector-borne diseases such as malaria because these were assumed to be included by the existing health dimension in the MPI and MPM.

A limitation of our analysis is that we do not capture the effect of green and natural spaces in the reduction of certain risks, such as the presence of mangroves to reduce coastal flood risk, or the presence of trees on slopes to reduce the impacts of floods or landslides.

2.2.5. Developing an environmentally-adjusted multidimensional poverty measure: GIS and statistical analysis. We combined our environmental (land cover and drought, flood and landslide risks) and social (health, education and living standards) datasets to develop an environmentally-adjusted multidimensional poverty measure. For each of the selected environmental indicators and datasets, we decided on deprivation cut-off levels, which we considered to be critical for people's lives. We based these levels on the literature (see Supplementary Information for details). For drought and landslide risks, we used data on extreme droughts and high and very high landslide susceptibility, respectively. For floods, we used data on flood risk for a 100-year return period and a flood depth above 1 metre as a deprivation cut-off. Such floods represent a significant flood event, which will likely significantly impact people living in these areas directly and indirectly. Flood events with lower return periods (e.g. 10 years) are relatively frequent and can therefore be classed as recurring floods, which can have negative impacts, but may also be part of natural cycles (e.g. in the Amazon) and be critical in sustaining ecosystems and/or local livelihoods (de Oliveira et al., 2014). Flood depth, together with velocity, determine whether people can keep standing in a severe flood and we chose the value of 1 metre based on the literature describing flood impacts (Lekuthai & Vongvisessomjai, 2001; Priest et al., 2008). For proximity to natural land, we considered natural land to be proximate if located within a window of ~3x3 km, in line with recent studies (Chaplin-Kramer et al., 2023; Weiss et al., 2018; see Supplementary Information). We prepared all environmental datasets as binary raster data for Brazil and standardized at the lowest common resolution among the selected datasets (1 km). We carried out all spatial analyses using ArcGIS 10.3.

To assess the proportion of people affected by each environmental indicator within each municipality in 2000 and 2010, we used the global Landscan spatially distributed population datasets for 2000 and 2010 (Bright et al., 2011; Bright & Coleman, 2001) and extracted the relevant data for Brazil. These data come at ~1 km (30 arc second) resolution and represent population counts per pixel. We calculated the proportion of people affected by each environmental indicator within each municipality for the relevant year as follows: we multiplied each of the environmental raster data layers with the Landscan population datasets for the relevant year; then summed these values for each municipality to obtain the number of people within each municipality affected by each indicator; and divided this by the total number of people living in each municipality in the relevant year, extracted using zonal statistics from the Landscan datasets.

We weighted all social and environmental dimensions equally. Some scholars argue that equal weights are not value neutral and weights should be set by individuals or households themselves (Ravallion, 2011). However, we did not have any *a priori* reasons for an alternative approach to determine the relative importance of these different dimensions. Thus, we follow the equal weighting schemes applied for the rural MPI (FAO & OPHI, 2022), as well as in the Brazilian MPM used for this analysis (Dyngeland et al., 2020), although we are conscious that the relative importance of the environmental variables might vary between individuals and across regions in Brazil.

We integrated the different dimensions to calculate the multidimensional poverty measures taking the geometric mean. We then mapped the resulting values for each municipality. We calculated multidimensional poverty measures for different combinations of dimensions: (1) including only the social indicators; (2) including all social and environmental indicators and dimensions; and (3) including all social indicators combined with separate environmental dimensions. Doing so allowed us to examine how our results vary with different combinations of dimensions and indicators. To analyse the impact of the choice of environmental indicator and cut-off values on the number of people considered environmentally poor, we performed sensitivity analyses exploring multiple combinations of datasets and cut-off values (see Supplementary Information).

3. Results

3.1. Environmental dimensions and proxy indicators

The final set of two environmental dimensions identified as being particularly relevant for poverty, with the associated datasets included in the study, are shown in Table 1. These indicators fell within the following dimensions: (1) experiencing nature, associated with the spiritual and cultural values of the environment, and (2) environmental risks of natural hazards. The first dimension captures proximity to natural space or to ancestral lands, people's sense of belonging to nature, and their spiritual connections with nature. This reflects the role of nature as a source of human identity and context for meaning as well as for personal growth and healing. The second dimension captures the environmental risks related to mortality risks due to severe natural hazards as well as the sense of insecurity and the mental wellbeing impacts associated with them.

To capture these two dimensions, we included four indicators in our analysis of the Brazilian MPM (see Table 1 and Table S1). As a proxy for experiencing the existence of nature, we included the proximity of natural habitat or land cover. As environmental risks we included risk of flood, occurrence of drought, and risk of landslides, to reflect the negative impacts of severe natural hazards.

In addition, we identified key gaps for large scale environmental datasets. This includes in particular (1) empirical data on the diverse values people attribute to the natural environment and the role they play for their wellbeing, especially relating to the cultural and spiritual values, (2) people's perceptions of different environmental risks, and (3) the realised, and differentiated, access to the natural environment rather than just the proximity of natural spaces.

3.2. Incidence, distribution and changes in environmentally-adjusted poverty

Between 2000 and 2010, the percentage of MPM-poor across Brazilian municipalities reduced considerably from 11.2 to 5.6% (Figure 1). This was primarily the result of improvements in living standards, although health and education indicators also improved.

Table 1. Key environmental dimensions identified in this study and the respective environmental indictors and datasets included in the analysis, where applicable

Environmental dimension	Environmental variables	Dataset	Global /Brazil	Spatial resolution	Temporal resolution	Data source
Experiencing nature	Proximity to natural land	Land use/land cover	Brazil	30 metre	2000-2016	MapBiomas annual land use land cover maps from 2000-2016.
Environmental risks and natural hazards	Flood risk	Flood return periods from 1-in-10 years to 1-in-500 years	Global	~1 km (30 sec)	Based on 1980-2013 period	JRC (Dottori et al., 2016, 102)
	Drought occurrence	Drought occurrence by municipality	Brazil	municipality	1991-2012	Atlas Brazil (CEPED, 2013)
	Landslide risk	Landslide risk	Global	1 km	Based on 2001-2016 period	(Stanley & Kirschbaum, 2017)

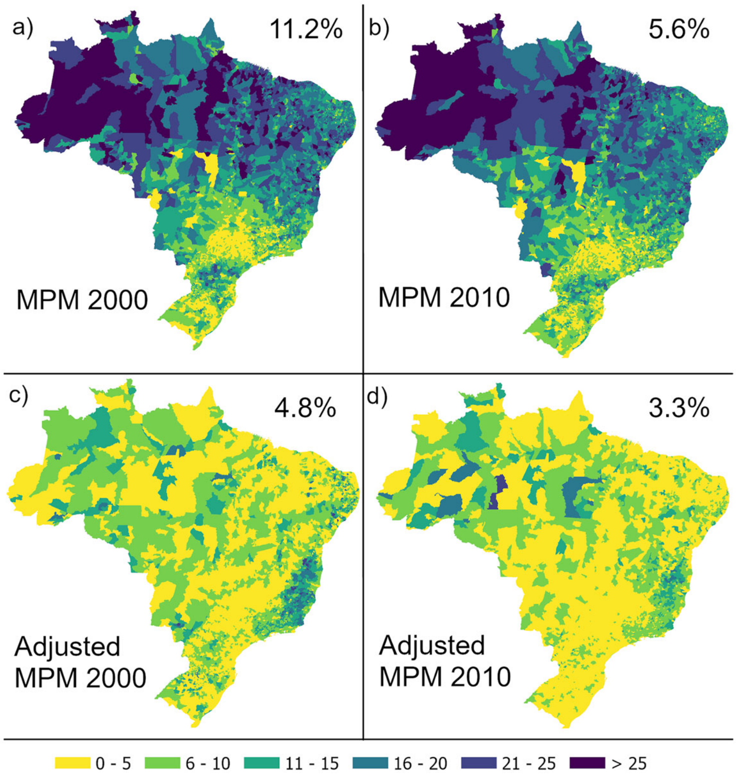

Figure 1. Multidimensional poverty measure (MPM) across Brazil for 2000 and 2010 (i) including dimensions on health, education and living standards (a-b) and (ii) adding environmental dimensions from Table 1 (c-d). Percentage values denote the mean value across all municipalities.

Adding environmental indicators to the Brazilian MPM decreased the overall incidence of poverty (in 2000 by 6.4%, and in 2010 by 2.3%) across Brazilian municipalities (Figure 1). However, the percentage of municipalities considered deprived in our environmental dimensions (comprising flood, drought and landslide risks, and proximity of natural land) only slightly decreased from 4.9% to 4.6% between 2000 and 2010 across the municipalities. This is partly due to land degradation (mainly loss of forest), which reduced the level of proximity to natural land. In 2000, on average 19% of people were not proximate to natural land while in 2010, on average 22% of people were not have proximate (Figure 3). In addition, more people were affected by severe drought in 2000 compared to 2010, increasing from 5.0% on average to 11.8% across all of Brazil (Figure 3). Our regional analysis showed an increase of 17.9% and 13.7% of people impacted by drought events from 2000 to 2010 in Brazil's north eastern and northern regions, respectively (Figure 4). The data on floods and landslide risks for Brazil did not change between the two time-periods; however, due to changes in population and population distribution, the number of people potentially affected did change, with an increase in number of people exposed to extreme floods from 3.6% to 3.8% (Figure 3), especially in the north region (Figure 4). The number of people exposed to landslides showed an overall decrease from 6.4% in 2000 to 5.8% in 2010, with the biggest percentage of affected people in the southeast region (Figures 3 and 4).

Taking account of the environmental deprivations also affected the spatial distribution of Brazilian municipalities most affected by poverty (Figure 1). While municipalities in the north and north east of the country are considered poorest using the MPM metric, adding environmental indicators changes this pattern to a more even distribution throughout the country highlighting the more economically developed and densely populated areas along the east coast, especially in the southeast, where the availability of natural land is lowest (Figure 2).

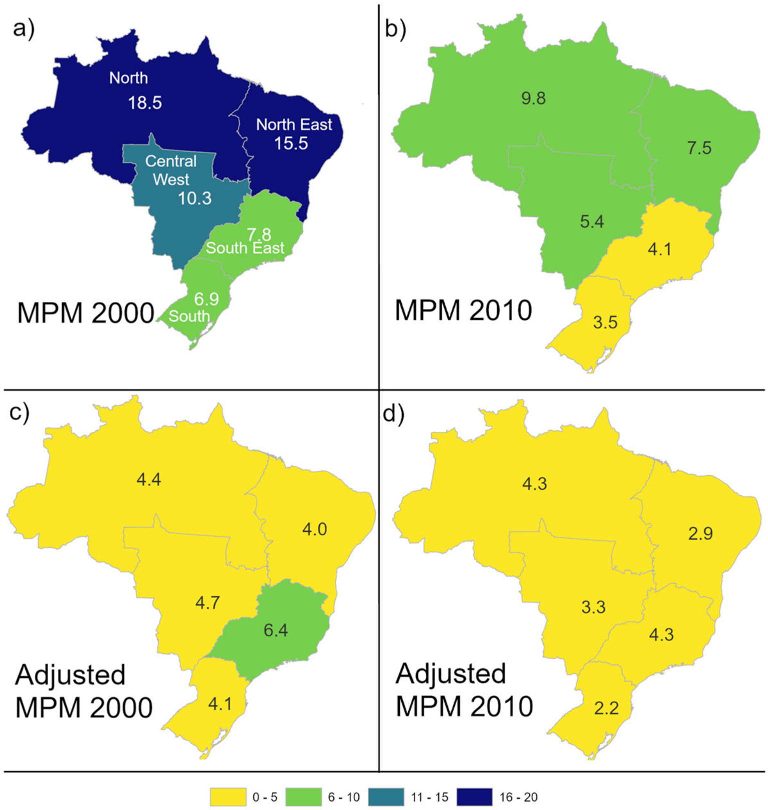

Figure 2. Multidimensional poverty measure (MPM) across Brazil by region for 2000 and 2010 (i) including dimensions on health, education and living standards (a-b) and (ii) adding environmental dimensions from Table 1 (c-d). Percentage values denote the mean value across all municipalities within each region.

Our analysis appears to be most sensitive to the use of different cut-off levels for the landslide risk data. Our main analysis included the high and very high risk of landslide categories only. However, including moderate risk of landslides in the sensitivity analysis increases the number of people who are poor in environmental dimensions across Brazil by around 4.5% for both years (Figure S1). This is mainly due to the much larger spatial areas affected by moderate landslide risks than high and very high categories. In contrast, using different return periods for floods had a very small impact on the results. Even though there is a considerable change in potential area flooded between the different return periods, many of these areas are less inhabited (i.e. north Amazon region) and thus overall changes in impacts are smaller. Only drought occurrence and landcover change data was available between the two time periods, while flood and landslide risk data were only available for one time period. Therefore, many of the changes between the two time periods can be attributed to changes in human population density and distribution included in the analysis.

4. Discussion

Our findings highlight that including environmental dimensions into a non-monetary multidimensional poverty measure can change the magnitude and distribution of poverty across Brazilian municipalities. Adding environmental dimensions attenuated overall levels of multidimensional poverty in both years, because taking environmental factors into account attenuated MPM-poverty for those people, such as indigenous peoples or rural communities, who have access to natural areas but are not exposed to natural hazards. The attenuation is much larger

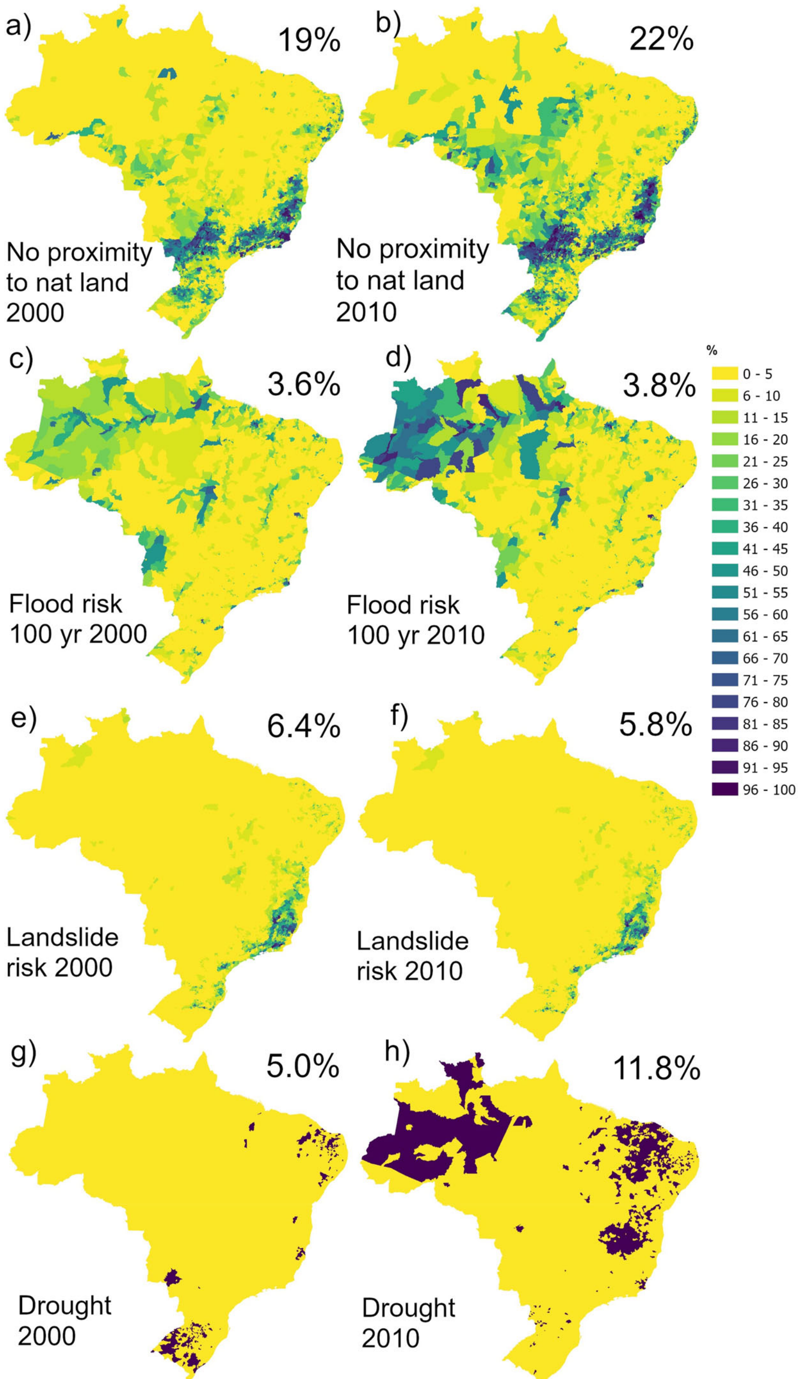

Figure 3. Percentage of people within municipality without proximity to natural land or experiencing natural hazard for all indicators included in the analysis for the years 2000 and 2010. Large percentage values are the mean values across all municipalities in Brazil. For environmental data sources, see Table 1.

for the year 2000. The reduction in MPM-poverty was offset by the loss of natural habitat and increase in natural hazards (Figure 2). The addition of environmental factors to poverty estimates therefore had a higher effect in 2000 than in 2010. This is because the decade saw

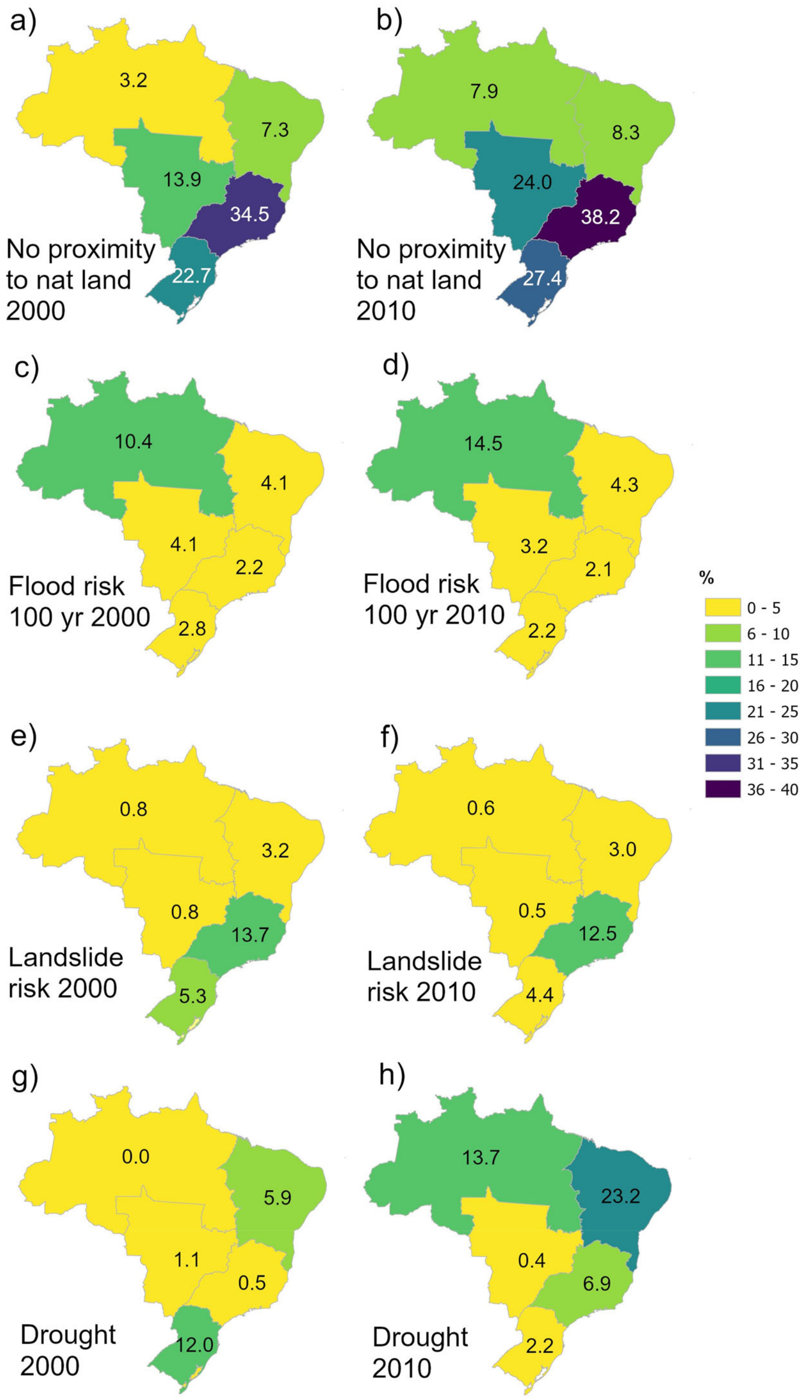

Figure 4. Percentage of people within regions without proximity to natural land or experiencing natural hazard for all indicators included in the analysis for the years 2000 and 2010. Percentage values denote the mean value across all municipalities within each region. For environmental data sources, see Table 1.

increases in environmental degradation that reduced people's proximity to natural land (in all regions) as well as increases in the occurrence of droughts mainly in the north and north east of the country.

A wide set of poverty alleviation and environmental policies were implemented in Brazil between 2000-2010 (Dyngeland et al., 2020; Garrett et al., 2021). However, studies suggest that existing social policies are insufficient to reduce poverty in all its dimensions (Bedran-Martins, Lemos & Philippi, 2018). In addition, stricter environmental policies alone will not necessarily address environmental degradation; for example, they may not reduce soy production – one of the largest drivers of deforestation in Brazil - as long as there is sufficient demand and technologies for intensification are available (e.g. Koch et al., 2019). Furthermore, many interventions are likely to result in trade-offs between social and environmental outcomes (Garrett et al., 2022). Our results show that such trade-offs (perceived or realised) between social and environmental goals need to be made explicit and addressed. This reemphasises the need to carefully consider environmental sustainability in the development agenda. Including environmental aspects, which are critical for the wellbeing of the poor, in poverty measures can therefore inform the design and targeting of policies to address poverty. Our results show for example that including environmental dimensions increased the level of poverty in 2010 in the south east region of Brazil (Figure 2), a region that also has a low proportion of recipients of the *Bolsa Família* programme, a flagship social welfare programme part of Fome Zero (Cargnin & Bandeira, 2015). Furthermore, inclusion of environmental indicators can foster policy coordination between environmental and anti-poverty agendas, and therefore encourage the mainstreaming of the natural environment into other aspects of the sustainable development pillars. Doing so is relevant in the context of the SDGs. While the goals and targets are better at integrating environmental considerations compared to the predecessor Millennium Development Goals, the SDG indicators themselves that measure progress towards the SDGs do not capture these links. Our results show that expanding such measures can be possible and can impact the spatial distribution of poverty and its different dimensions.

In addition, our analysis of 2000 and 2010 data points towards a dynamic nature of the environment-poverty relationship. Our analysis showed changes in the spatial pattern (rather than the direction) of the multidimensional poverty measure with environmental indicators. This could call for different potential policy responses, such as targeting or specific programmes to enhance environmental protection, to develop drought and climate adaptation particularly relevant for the poor in Brazil (Kasecker et al., 2018), or to provide and support alternative livelihood options. Such policies should be aligned with local needs and contexts, whilst avoiding the clientelism and rent-seeking associated with past interventions (Bedran-Martins & Lemos, 2017). It is therefore beneficial to evaluate multidimensional poverty estimates that incorporate environmental dimensions repeatedly over time, in particular post-COVID-19, given the acute and differential impact COVID-19 had in Brazil, especially amongst the poor (Tavares & Betti, 2021, Sott et al., 2022). Other important analyses to further explore are how different regions compare to each other and whether changes over time differ between regions versus in the aggregate. Demographic changes, including due to migration, are important to consider in this context as they will be impacted by environmental factors (Black et al., 2011) and can influence poverty measures. It can therefore be insightful to analyse demographic shifts alongside temporal changes in poverty.

Our study has shown that it is possible to include relevant environmental indicators into multidimensional measures of poverty based on globally available open access datasets, and provides a methodology that could be applied to other contexts and countries beyond Brazil. Our multidimensional poverty measure provides a richer and complementary understanding of poverty, rather than claiming to draw a more 'accurate' picture. Our analysis does therefore not advocate that this specific environment-poverty measure should be adopted widely in diverse settings. We hope, instead, that our proof of concept will encourage debate locally, nationally and internationally for developing more holistic and inclusive measures of poverty and wellbeing in different contexts. When assessing poverty and wellbeing in any particular setting, we urge that institutions and practitioners consider the prevalent cultural context and worldviews that influence which environmental aspects matter and for whom (Deneulin & McGregor, 2010). Measures that reflect the diverse worldviews and values people hold, in particular concerning what environmental aspects are most relevant, need to also reflect priorities at different scales. Our proposed environmentally-adjusted poverty measure remains within a tradition of individualistic and anthropocentric wellbeing measurement for human development (Nussbaum, 2011). Developing measures based on other traditions, such as locally-developed biocultural approaches (Sterling et al., 2017), could be valuable and complementary.

The relationships between social and environmental dimensions in our analysis raise important questions about how outcome measures to evaluate 'development', 'poverty-wellbeing', 'progress' and 'shared prosperity' are defined, and whose voices and interests influence the underlying decisions. While we were able to include environmental dimensions using secondary datasets, the environmental aspects we could include were limited by data availability and suitability. Although there are many environmental secondary data available for Brazil, some of these are not available at a suitable spatial resolution or for relevant timescales that allow their integration with available social datasets. Other data were judged unsuitable for our purposes as national proxies for indicators of wellbeing or poverty, in particular as they primarily play an instrumental role or do not differentiate between man-made or natural events. Various environmental aspects potentially key to people's lives are not captured by existing datasets (e.g. spiritual values, ancestral connections with land). We resorted to an indicator for 'proximity of natural habitat', being aware that this presumes that the conversion of one nature type to another (e.g. from forest to grassland) does not have a bearing on wellbeing – an assumption that might not hold in some cases. Moreover, we relied on stipulation, literature and national level workshops for the selection of indicators (Gasper, 2005), but not on participatory or bottom-up processes (Sterling et al., 2017). We therefore cannot claim to have comprehensively captured socio-cultural relations between a good life and nature across communities in Brazil.

Many more intangible spiritual and cultural relationships with the natural environment are not easily amenable to large scale and/or quantitative assessments that are typically used to generate the types of datasets included in this study, and for reporting on current development indicators, such as for measuring progress against the SDGs. Many such aspects are best captured by in-depth local qualitative assessments. This suggests that there needs to be a broadening of the types of indicators used for national and international development reporting, including on poverty, wellbeing and the SDGs (Schleicher, Schaafsma & Vira, 2018). This also applies to other issues for which no suitable data were available, including on the actual and differentiated access to the natural environment, rather than just the proximity of natural spaces, and a sense of unsafety related to conflicts over natural resources. What aspects are most important is likely to vary between and within communities, making it difficult to define universally applicable indicators that capture the diversity of values that people attribute to the ways nature impacts their lives. The appropriate balance between locally legitimate versus universally applicable poverty indicators will likely need to be sought on a case-by-case basis, depending on the complexity and diversity of environment, poverty and their relationships, data availability and available funding for further assessment.

Our analysis highlights a number of important gaps linked to large scale datasets. This includes: (1) empirical data on the diverse values and relationships people attribute to the natural environment, including the cultural and spiritual values and the role these play for their wellbeing; (2) people's perspective on environmental risks; and (3) the realised (and differentiated) access to the natural environment. In many cases, addressing these gaps will require data collection through fieldwork. Further developments in remote sensing, citizen science and low-cost monitoring techniques may also help to increase the range of relevant available environmental data that can be included or improve the selected proxies. Besides emphasising specific data gaps where future efforts for data collection would be particularly valuable, the present approach needs to be complemented with empirical work and indicator development at the local level to define what matters to people in a particular context (Sterling et al., 2017; Woodhouse et al., 2015). Similarly, our municipality-level analysis can help to identify municipalities that are more or less deprived; however, as with any analysis conducted at a specific resolution, it cannot depict the heterogeneities that exist within these areas. Hence, it would be valuable to complement our study with analysis conducted at high resolution once such data becomes publicly available. Furthermore, for the ambitious goals articulated in the 2030 agenda to be realised, it is pivotal to integrate the diverse visions of development and various efforts taking place across scales from the local to the global. It is key to find ways for these to be reflected in our assessment of progress towards the goals (Schleicher, Schaafsma & Vira, 2018), including by more qualitative means.

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Data availability statement

The data used in this study are available under https://zenodo.org/records/14218877 (DOI: 10.5281/zenodo.14218877).

Disclosure statement

The authors report there are no competing interests to declare.

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